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Static design of steel-concrete lining for traffic tunnels

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Abstract. Article summarizes the results of research focused on the structural design of traffic tunnel linings that have been achieved in the framework of a research project TE01020168 that supports The Technology Agency of Czech Republic. This research aim is to find and develop a process for design structure parameters of tunnel linings. These are now mostly build up by a shotcrete technology. The shotcrete is commonly endorsed either with steel girders or steel fibres. Since the installation a lining structure is loaded while strength and deformational parameters of shotcrete start to rise till the setting time elapses. That´s reason why conventional approaches of reinforced concrete are not suitable. As well as there are other circumstances to step in shown in this article. Problem is solved by 3D analysis using numerical model that takes into account all the significant features of a tunnel lining construction process inclusive the interaction between lining structure with rock massive. Analysis output is a view into development of stress-strain state in respective construction parts of tunnel lining the whole structure around, including impact on stability of rock massive. The proposed method comprises all features involved in tunnel fabrication including geotechnics and construction technologies.

1. Introduction

Contemporary tunnel lining of subterranean works build by New Austrian Tunneling Method (NATM) is double wall system. It consists of two particular structures an outer primary lining and the inner secondary lining. The both are separated by a thin insulating layer of a plastic membrane which prevents groundwater to permeate into the inner lining.

The both lining are essential in stabilizing rock ground. The first one starts stabilizing rock ground around excavation and provides safe space for execution all of tunnel compounds, inclusive of the secondary lining installation. The secondary lining steps in operation later after the primary lining loses bearing capacity due not being protected against aggressive groundwater.

Static response of the primary lining built from shotcrete and steel frame structure is marked by variable working diagram consequently in accord with setting time of shotcrete. Initially it is in operation the steel frame structure only and instant stiffness of the lining is not high. Then lining stiffness grows and eventually settles as shotcrete becomes solid with time. This quality is welcomed because it allows rock ground relaxation that is indispensable to achieve the lowest rock ground load on a lining structure. Installation of the insulating layer and a followed construction of the secondary lining structure built from reinforced concrete require more time. The both can be performed only for steady rock ground excavation which is achieved by assistance of a primary lining.

Interaction of primary and secondary lining is only a temporary act limited to an initial period of lining operation after it's completion. The primary lining is not protected against the impact of the aggressive groundwater which limits the life time of a primary lining. The necessary response to stabilize the rock ground is gradually transposed from primary to secondary lining. So the bearing capacity of a secondary lining must be sufficient to avoid a the next rock ground deformation when the transfer is accomplished and the secondary lining must hold the excavation space steady forever. Construction period of the primary lining is a decisive event for stabilizing of the rock ground. The rigid working diagram of a primary lining implies a higher value of stabilization response. A design intention of the primary lining is to achieve a minimum response.

2. Design approaches

Design procedures for lining of subterranean works are not explicitly included in the current legislation of the Czech Republic. Eurocode EC7 [1] that focuses the design of geotechnical structures does not include construction of tunnel lining. Eurocode EC2 [2] which addresses the design of concrete building structures, can be used for the design of the secondary lining structure on condition that this is made from concrete or reinforced concrete.

The EC2 takes not notice of a primary lining structure built from shotcrete and steel frame arch inclusive of rock ground interaction. Static activity the primary lining structure, however, is crucial for the steadiness of the rock ground and the amount of the permanent load put on the secondary lining.

Design and evaluation of the lining of subterranean works made from concrete and steel elements are analyzed in the manual by Bartak, Horejsi and Zapletal [3]. In the manual proposed method uses partial coefficients modifying the input calculation parameters, especially those ones that implement phenomena inherent in rock ground. An other contribution to the solution of lining presents a work by Zapletal [4].This author assumes a design of the lining as a composite steel and concrete structures. The evaluation of a variable elastic modulus of steel shotcrete cross-section of lining investigates work by Rott [5].

Most contemporary structural designs of subterranean work linings is performed on available commercially distributed computer programs. These programs are based on theories of mechanics of continuous materials (Midas NX, Plaxis) or discontinuous materials (UDEC). These programs provide respective elements to stand for rock ground as well as lining structure. There are several options and elements to represent a lining structure.

Authors of this contribution are developing design method to set up lining parameters systematically for more than twenty years. They designed the original method of homogenizing heterogeneous cross-section of the lining structures assembled from steel girder combined with layers of shotcrete. Lining solution is based on the theory of cooperating rings and homogenizing a heterogeneous steel shotcrete cross-section of the lining [6]. Unlike the evaluation of a variable elastic modulus of steel shotcrete cross-section at work [5] this time the homogenization algorithm is based on an analytical model for calculation of stress strain state in a multi-layer circular ring, which was formulated by Bulytschev [7]. This analytic model uses the theory of analytic functions of complex variables based on Kolosov's functions for complex potentials. Next development in solution was implementing the analytical model of lining cross-section with a numerical model standing for rock ground [8]. This option extends the static analysis of a lining structure for possibility to take better off an account on geomechanical circumstances and to carry out calculations for alternative excavation scheme, construction technology and mechanical parameters of lining. It depicts an interaction of rock ground and lining on an interface plane that they met on. It is apt to relate dependency of rock ground stress-strain behavior on lining parameters and vice versa. The final stress-strain state on the interface plane makes the load secondary lining.

Last proposal of design of subterranean work lining parameter animates 3D numerical model. This enables to integrate rock ground constitutive structures, primary stress-strain in rock ground, mechanical properties of the rocks, lining construction phases, i.e. geometric conditions and material properties that describe lining construction .

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3. Numerical 3D design

The following example documents a solution by 3D numerical model of a simple primary lining structure of oval shape that supports a rock ground excavation. This computes the internal forces in the primary lining constituents concrete shell and steel girders. The computation sets the necessary primary lining response to maintain the rock ground around it in steady conditions not to collapse. The necessary lining response provides initially only the primary composite lining. Due not being protected against ground water this lining dilapidates and the response is transposed to the secondary lining made from reinforced concrete lining. Design and assessment of reinforced concrete lining structure is carried out separately from the 3D model according to structural mechanics for known discreet load specified with 3D model. The design conditions also allowable deformation of secondary lining that has not to go beyond regulated value. Calculation of the primary tunnel lining were made by Midas MX.

Figures 1 and 2 show a 3D computational model of rock ground and primary lining and a close up view of the steel shotcrete cross-section modelling of the primary lining.

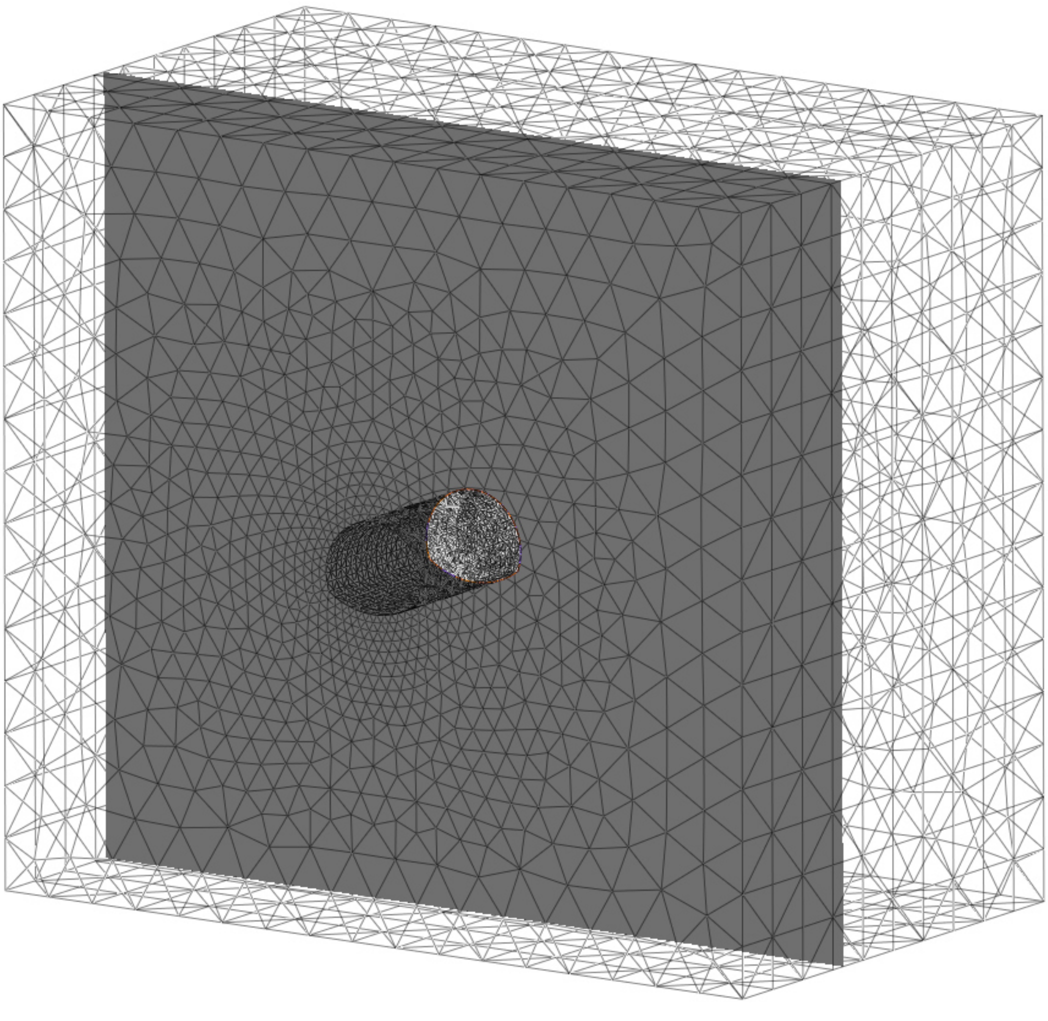

Figure 1. Calculation 3D model of primary lining.

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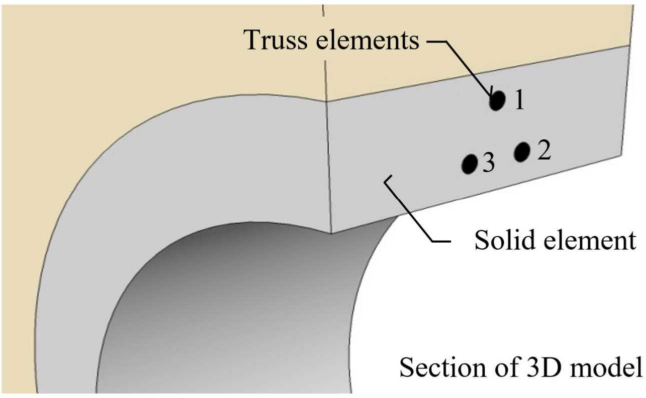

Figure 2. The modelling of a steel shotcrete cross-section.

Figure 3 shows calculated values of stresses along the primary lining perimeter in the steel elements.

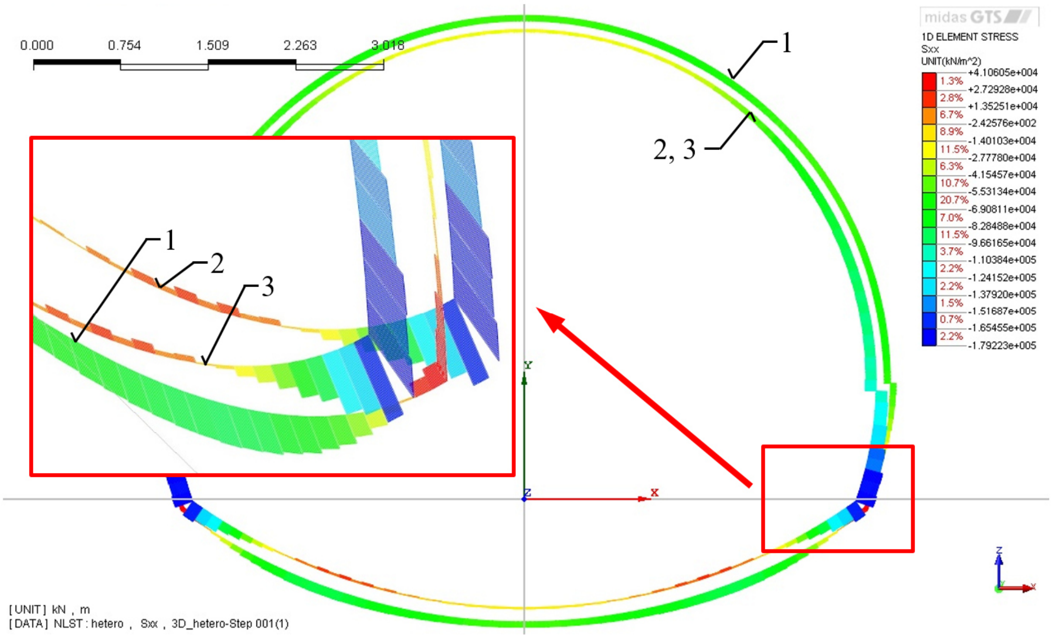

Figure 3. Depiction of stresses along a perimeter the primary lining in steel elements.

Figure 4 shows mean stress in the rock ground around the excavation and a curve of the mean stress development along perimeter of a lining on the interface plane with rock ground.

4. Conclusions

Structural analysis of tunnel lining by mathematical 3D model allows comprehensive inclusion of all relevant circumstances come in on tunnel construction. These include rock ground constitutive structures, primary stress strain in rock ground, mechanical properties of the rocks, lining construction phases, mechanical parameters and working diagram.

Significant feature of 3D numerical model is that it deals the interaction of both rock ground and lining structure through constitutive tress-strain relations that other contemporary approaches miss.

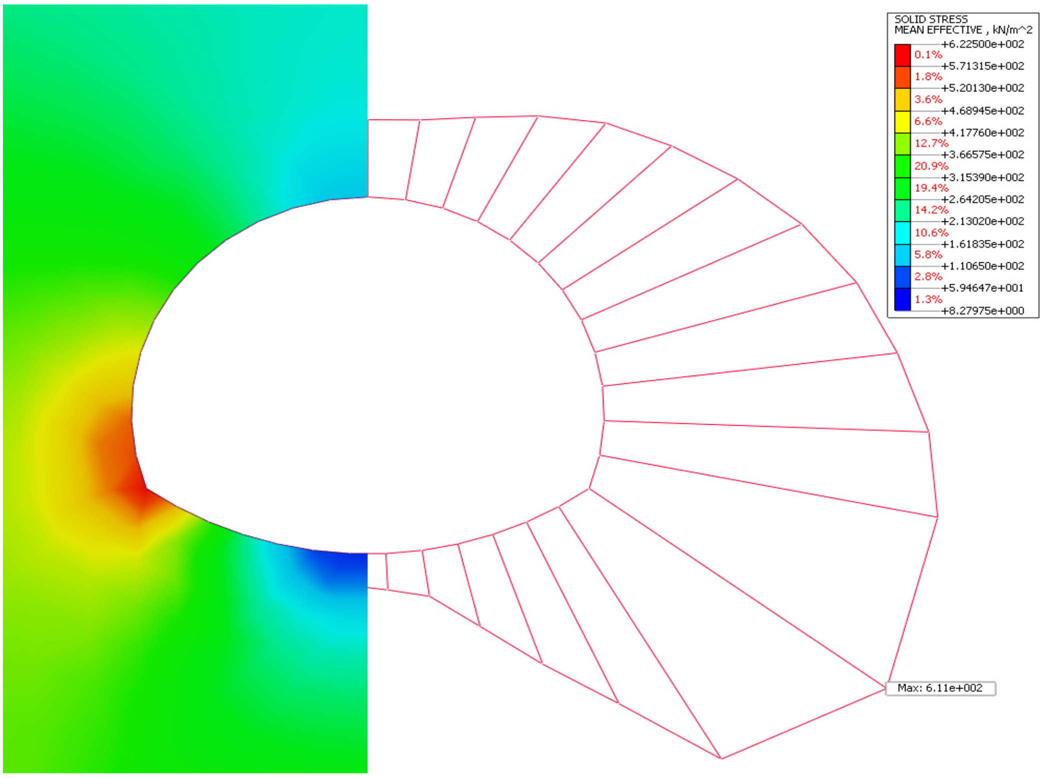

Figure 4. The curve of the mean stress along perimeter of a lining on the interface plane with rock ground.

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