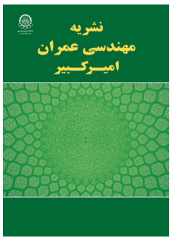

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Numerical Study of the Effects of Segmental Joints and Grouting Pressure on the Behavior of Tunnel Segmental Lining

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ABSTRACT: Tunnel Boring Machine (TBM) is used widely to bore long tunnels in hard rocks. If you choose shield TBMs, precast concrete segments should be installed as permanent tunnel lining. This lining is inherently distinct and therefore in analytical and numerical analyses, the continuity assumption is not acceptable for simplifying. The segmental linings show certain behavior under various loads applied by rock, machine and tunneling processes (such as grouting). In this study, the behavior of segmental lining of Sabzkouh water conveyance tunnel has been compared to full (continuous) lining. In this paper, the behavior of tunnel segmental lining by assigning normal and shear stiffness values for longitudinal and circumferential joints of segments is compared with the continuous lining. The effect of the grouting pressure between rock and segments on the behavior of the tunnel segment is analyzed. Under uniform grouting load, the results of numerical modeling executed by finite difference method show maximum internal forces occur in the joints of segments. With increasing grouting pressure, axial force and bending moment in the joints of the segments is reduced. Moreover, the grouting pressure increases displacements in the segmental lining. In practice, this increase sometimes causes cracking or stepping between segments.

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1- Introduction

Tunnel Boring Machine (TBM) is used widely to bore long tunnels in hard rocks. By considering geomechanical properties, geological features and hydrogeological condition through tunnel route, it may be decided on the type of TBM. If you choose shield TBMs, precast concrete segments should be installed as permanent tunnel lining. Because of longitudinal and circumferential joints between segments, these linings are inherently distinct therefore in analytical and numerical calculations, assuming full continuity for segmental linings cannot be reasonable. For accurate determination of displacements and internal forces at the segments, the normal and shear stiffnesses of the joints should be specified. The joints cause special effect on the behavior of the linings [1, 2], but so far, this effect is not clear well.

Do et al. modeled the segmental linings by two-dimensional finite difference method, but didn't study the effects of the grouting pressure on the segments' behavior [3]. In 2012, Lambrughi et al. analyzed a three-dimensional model using FLAC3D for a mechanized tunnel bored by Earth Pressure Balance (EPB) TBM. Despite modeling features such as shield, lining, grouting, and hardening process of the cement grout, they didn't consider segmental linings for the tunnel [4]. Hudoba modeled longitudinal joints numerically as hinges. He considered the joints in different arrays, but ignored other tunneling processes such as grouting [5]. The aim of this study is generation of a three-dimensional model to analyze tunnel segmental lining in interaction with various factors such as rock, in-situ stresses and grouting pressure accurately. The case study of this paper is Sabzkouh water conveyance tunnel that is located in Chahar Mahal-e Bakhtiari province. This tunnel is bored by a hard rock TBM.

2- Methodology, Discussion and Results

FLAC^{3D} software was used to model the segmental lining of the Sabzkouh tunnel numerically. The precast concrete segments have been stimulated with shell structural elements. To investigate the joints' effects on the behavior of the segmental lining, all histories of vertical and horizontal displacements, axial forces, and bending moments were recorded and so that all models could be compared under same conditions. Longitudinal joints of each ring are rotated ±20 degrees relative to each other to avoid the creation of a weak plane. According to Figure 1, the segmental joints have been defined as longitudinal and conferential links between shell elements. Theses links have six degrees of freedom that can be rigid or behave as a linear deformation spring or shear yield deformation spring. The axial forces in both full (continuous) and segmental lining are shown in Figure 2. Also due to the joints, the segmental lining is more deformable than the full one.

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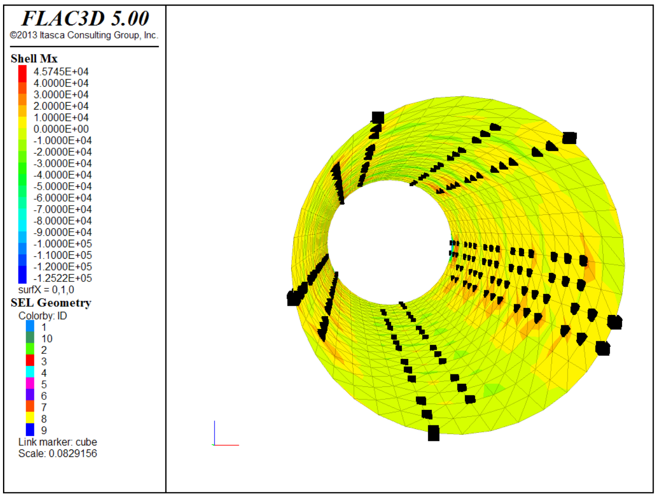

Figure 1. Segmental joints as links between shell elements

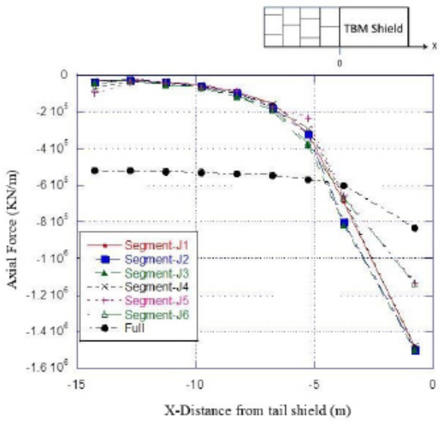

Figure 2. Axial forces in full (continuous) lining and segmental lining

To apply grouting pressure upon the tunnel lining and study its effects on the behavior of the segmental joints, three levels of pressure of 2, 3 and 4 bars were applied upon two last rings connected to the tail shield uniformly and without gradient. Due to compressive stress of grouting, a part of the rock displacements was compensated. However, under uncontrolled pressure, an excessive displacement and stepping may occur in segments or segments may crack. For section close to the tail shield, the bending moments are shown in Figures 3. Based on this figure, the maximum internal forces by grouting occur in the joints. As another result, with increasing grouting pressure, the internal forces in the segmental joints are reduced.

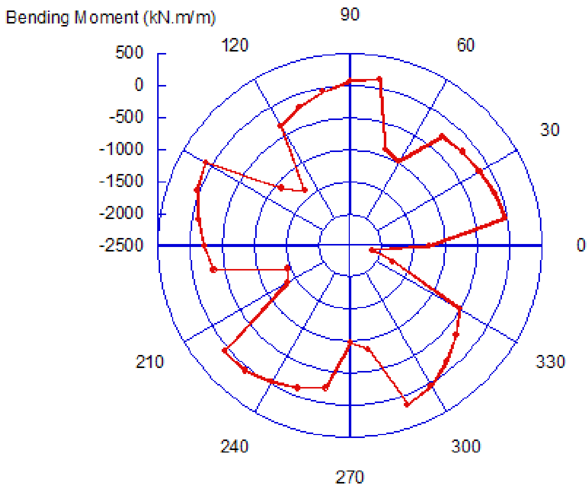

Figure 3. Bending moment in the last segmental ring (close to the tale shield) under grouting pressure 4 bar

3- Conclusions

According to the numerical analyses of this study, it must be said that a continuous and a segmental model for tunnel lining lead to different results that must be considered in the design. In addition, the grouting pressure may induce certain behavior in the segmental lining. Numerical modeling showed that the rigidity and the internal forces in the segmental lining is less than continuous lining and thus the designs will be more reasonable and economical. Such design involves determining the appropriate shear and normal stiffnesses for the segmental joints based on the normal stress acting on the tunnel lining. According to the numerical results presented in this study, the maximum internal force occurs in joint position which is under grouting uniform load. Furthermore, with increasing grouting pressure, the axial force and the bending moment are reduced in the segmental joints. It should be mentioned that the reduction in internal forces is caused by the influence of grouting pressure on the surrounding rock, since the grouting pressure can compensate a part of the earth pressure applied on the lining. In addition, when the grouting pressure is increased, the displacements in the segmental lining are increased. In practice, this increment can sometimes cause cracks and stepping between segments. By considering the concrete lining as continuous, the grouting pressure can slightly reduce the axial force. Also under this condition, the variation of bending moment is significantly upward. Except in the joints, axial forces on the segment lining are much less than the continuous lining. In the continuous lining, axial force is almost uniform and an average value can be considered for it which is higher than the average axial force in the segment lining. Also in the continuous lining, the extreme values of bending moment are located on the roof and the walls of the tunnel, while in the segmental lining, the maximum bending moment occurred only in the position of joints and the body of segments experienced lower bending moment.

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