Reinforced Concrete Lining Suggestion based on Seepage Control of Pressure Tunnels using the Finite Element Model

Ehsan Dadashi[1], Ali Noorzad[2*], Koroush Shahriar[3], Kamran Goshtasbi[4]

1. Department of Mining Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran
2. Faculty of Civil, Water and Environmental Engineering, Shahid Beheshti University, Tehran, Iran
3. Faculty of Mining and Metallurgy Engineering, Amirkabir University of Technology, Tehran, Iran
4. Department of Mining Engineering, Tarbiat Modares University, Tehran, Iran

Received: 22 Oct. 2017 Accepted: 28 Nov. 2018

Extended Abstract

(Paper pages 599-616)

Introduction

Pressure tunnels in hydroelectric plants are used to convey water to powerhouses. These tunnels are the sources of seepage flow to the rock formation, thus, during the water filling, they will have a low resistance to seepage and, by increasing the internal water pressure of the tunnel, the inflow force will be transferred to the rock mass. In these conditions, the cracks, pores and all other elements of the rock mass are affected by the seepage forces in all directions. This hydro-mechanical interaction affects changing the stresses and displacements of the rock mass around the tunnel and causes modifications in the permeability of rock elements during the water filling. Therefore, changes in stress distribution lead to alterations in the permeability coefficient and redistribution of the seepage field. In these conditions, since the analytical solution of the problem is not possible, the numerical analysis based on the finite element method has been used in this study.

Material and methods

In this approach, the rock mass is considered as an equivalent continuum in which the effects of discontinuities are taken into account in its material behavior. High-pressure tunnels under internal water pressure requires reinforced concrete lining to prevent hydro-fracturing. The ABAQUS software is capable of analyzing such as seepage from the tunnel, modeling of the steel bars in concrete, and taking into account hydro-mechanical interaction. Thus, the software is used for numerical analysis.

The pressure tunnel of the Gotvand dam and hydroelectric power plant (HPP) scheme is taken as a case study for the numerical simulation. Pressure tunnel of the Gotvand dam located in the southwest of Iran is taken as a case study for the numerical simulation. Among behavioral models in the software, Mohr-Coulomb failure criterion is considered to describe the rock mass, but the principle of effective stress determines the rock mass behavior. Since the concrete lining of the pressure tunnel will undergo two mechanisms of the cracking due to tension and the crushing due to compression, concrete damaged plasticity model is used to predict the response of the concrete elements. The evolution of the yield surface of the concrete lining is also controlled with tensile and compressive equivalent plastic strains, correspondingly.

In this study, the hydro-mechanical interaction is implemented based on the analysis of the pore fluid/deformation analysis, and the direct-coupled method is used to solve the governing equations of the problem. To verify the proposed model, the elastic behavior of the media is simulated to compare the numerical and the analytical solutions and good agreement is obtained. The numerical analyses are carried out the hydro-mechanical interaction with constant permeability coefficient. When cracks develop in the concrete lining at high water pressure, the properties of the concrete lining change and as a result, the stress dependent permeability of the lining and surrounding rock mass in pressure tunnels should be considered. The coefficient of permeability controls the rate of seepage flow in porous and fractured media. Although permeability represents an original property of the porous media, it can be modified when subjected to the stress variations. Instead of changing aperture, the change in the void space or volume is the typical consequence that results to change the permeability coefficient. In order to bring the model closer to the real conditions and in the validation of the new model, the influence of the permeability coefficient variations of the concrete and rock mass on the deformations and stresses of the model has been added to nonlinear analysis by USDFLD code. Increasing the water head in the tunnel during water filling is also considered with the combination of DLOAD and DISP codes in the model.

Results and discussion

Since the lining and rock mass have nonlinear properties and complex behavior, for verification of the model in ABAQUS software, the model is simulated with homogeneous, isotropic and elastic behavior. The results of seepage flow on the interface of the concrete lining and rock mass obtained by analytical and numerical solutions indicate that there is a ±5 % difference between them. Then, the results of the elastic behavior of the model show a good agreement with the results of analytical solutions. Therefore, this numerical model has been employed for the nonlinear analyses.

Finally, the optimal thickness of the concrete lining with the appropriate arrangement of the reinforcement in the reinforced concrete linings is utilized to minimize water losses from the tunnel based on the new model. Thus, the results of the analysis with the aim of reducing the water losses from the tunnel indicate that the suitable arrangement of the steel bars in the concrete lining leads to the distribution of micro cracks in the lining, and the reinforcement stress stays at a lower value with high internal water pressure. Based on the new numerical model, it is suggested that the lining should be designed with the thickness of 40 cm and the reinforcement with the diameter of 16 mm and the spacing of 20 cm.

Conclusion

The results of the numerical model indicate that to control the seepage outflow from concrete-lined pressure tunnels, the thickness of the lining and the suitable arrangement of the steel bars in the concrete lining play a significant role in preventing excessive seepage from the tunnel.

Keywords: Pressure Tunnel, Reinforced Concrete Lining, Hydro-Mechanical Interaction, ABAQUS software, Seepage Control.

*Corresponding Author: a_noorzad@sbu.ac.ir