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Rock-lining interaction calculations for tunnels excavated in Hoek-Brown rock mass considering excavation damaged zone

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ABSTRACT: In this paper, the behavior of tunnels under different damage conditions is examined. In this regard, a fully analytical solution is proposed. The solution is presented for a lined tunnels excavated in elastic–brittle–plastic rock masses with Hoek–Brown failure criterion. The damaged zone is assumed to have cylindrical shape with reduced parameters. On the other hand, the lining is assumed to be homogenous, elastic and cylindrical shaped. The interaction between the lining and the rock masses is also considered. The results obtained by the proposed solution are compared with other analytical and numerical methods. The results indicated that, the effects of the alteration of rock mass properties in the damaged zone may be considerable.

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1. INTRODUCTION

The excavation impact (e.g. due to Blasting, TBM drilling, etc.) induces an excavation damaged or disturbed zone around a tunnel. The presence of a damage zone around a tunnel boundary is of significant concern mainly with regard to safety, stability, costs and the overall performance of the tunnel. The damaged zone is essentially characterized by reduction in strength and stiffness, and increase in permeability.

Full consideration of the interplay that exists among construction activities, the EDZ, support characteristics, and time requires the use of numerical methods in which all factors can be considered. On the other hand, only in a closed-form analytical solution the effect of the damaged zone is considered [1]. However, in this paper, the interactions between the rock mass and the lining is not considered.

However, generally, the damage induced in the rock masses is taken into account by using the damage factor D introduced by Hoek et al. [2]. In this method, damage factor D is applied to the entire surrounding rock mass. This is a common method, which can greatly underestimate the strength and stability of the surrounding rock mass. In this regard, the blast damage factor D is more appropriate to be applied on the actual zone of damaged rock.

In this paper, a fully analytical solution is proposed for analysis of lined tunnels considering the damaged zone. The solution is presented for a lined tunnels excavated in elastic–brittle–plastic rock masses with Hoek–Brown failure criterion. The damaged zone is assumed to have cylindrical shape with reduced parameters. On the other hand, the lining is assumed to be homogenous, elastic and cylindrical shaped. The interaction between the lining and the rock masses is also considered.

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2. ANALYTICAL METHOD

The problem considered is shown in Fig. 1. A circular deep tunnel of radius r_i is excavated in an initially elastic rock mass characterized by Young's modulus E , and Poisson's ratio ν . Due to a blasting impact a cylindrical damaged zone will develops around the tunnel with different behavior parameters. In this regard the Young's modulus and the Poisson's ratio of damaged zone are E_D and ν , respectively.

Axial symmetry conditions for geometry and loading can be assumed for the problem of the tunnel under uniform initial stress p_0. A uniform internal pressure $\sigma_i = \sigma_{r(r_i)}$ is considered to act at the periphery of the tunnel as a result of a lining installation.

The tunnel is lined with an elastic concrete lining (characterized by Elasticity modulus E_c, Poisson's ratio ν_c .), which has internal and external radii of r_{lining} and r_i ,

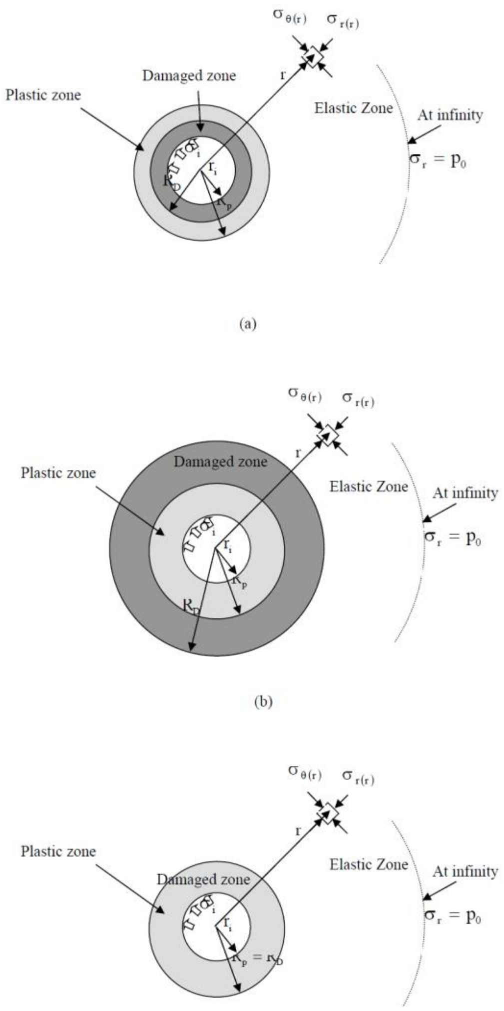


Fig. 1. The circular deep tunnel subjected to a hydrostatic stress field with a cylindrical damaged zone: (a) $R_p > R_D$ (b) $R_p < R_D$ (c) $R_p = R_D$.

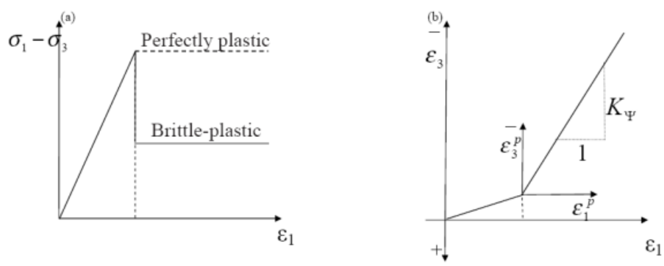
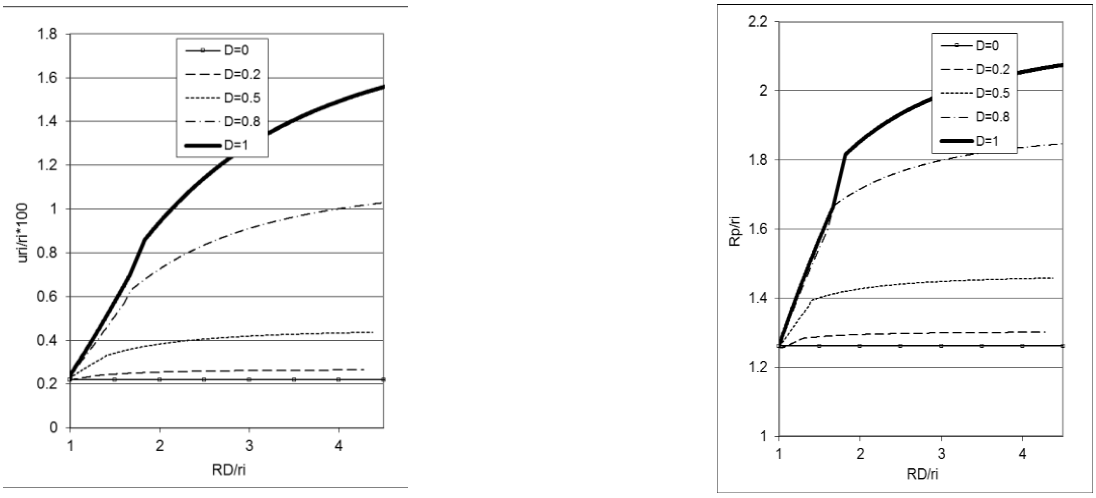


Fig. 2. Behavior model used in this study for both the damaged and undamaged rock masses: (a) Stress-strain

respectively, after the occurrence of initial convergence δu_a . Stress redistribution and displacements will take place, due to excavation of the tunnel, installing the lining and the alteration of the rock mass in the damaged zone . As σ_i is gradually reduced, radial displacement occurs and a plastic zone develops around the tunnel as becomes less than the initial yield stress. After failure, the strength of the rock suddenly drops and follows the post-failure softening behavior. In this study, both the damaged and undamaged rock masses are considered to be elastic–brittle-plastic (in special case: perfectly plastic) as shown in Fig. 2.

Two different zones may forms around the tunnel: an external elastic zone and an internal plastic zone of radius Rp. In this respect, three different cases can be considered, depending on the extent of the damaged zone and the plastic zone (Fig. 1):



(a) (b)

Fig. 3. Influence of disturbance factor (D) and the radius of the damaged zone on (a) tunnel convergence and (b) radius of the plastic zone

Case (a): the radius of the plastic zone is larger than the damaged zone.

Case (b): the radius of the damaged zone is larger than the plastic zone.

Case (c): the radius of the damaged zone is equal to the radius of the plastic zone.

3. ILLUSTRATIVE EXAMPLE

Here, the proposed solution is used for parametric study to observe the effects of the damaged zone on the overall response of a tunnel in an elastic–brittle–plastic rock mass.

Figs. 3 and 4 illustrate the effect of the disturbance factor (D) and the radius of the damaged zone on the radius of the plastic zone and the tunnel convergence, respectively. As observed by increasing the disturbance factor and the radius of plastic zone the effect of it on the analyses increases. It is observed that, when the damaged zone reaches the plastic radius, the damaged zone pull the plastic zone with itself to some extent. Fig. 8 shows that for cases (a) circumferential stresses at the plastic radius are independent of the damaged zone. On the other hand, for cases (b) and (c) the damaged zone affects the circumferential stresses at the plastic radius.

4. CONCLUSIONS

The results, obtained by using the proposed solution, indicate that a blast-induced damaged zone has a significant effect on the stresses and displacements in the rock mass, when the disturbance and the radius of the damaged zone are relatively high.

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