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Effect of highly pervious geological features on ground-water flow into a tunnel

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ABSTRACT

Current practice for estimating water inflow rate relies mostly on analytical solutions which assume a homogeneous, isotropic porous medium around a tunnel. Field measurements indicate that current engineering practice does not consistently make adequate estimate of ground-water flow into a tunnel during excavation due to various factors that analytical solutions do not properly take into account. Among the various factors affecting ground-water flow, the significance of a highly pervious feature located near the tunnel is discussed in this research. The highly pervious feature, which is located near an underground opening and connected to a large source of water, can provide a path for relatively high-head water to the joints intersecting the opening. This paper describes the influence of a highly pervious feature on the ground-water flow regime around a tunnel and the change of inflow rate as the tunnel approaches a highly pervious feature.

1. Introduction

Highly pervious features located near an underground opening can provide a path for relatively high-head water to hydraulically connected joints intersecting the opening or can directly communicate with the tunnel. The presence of a highly pervious feature connected to a large source of water can have devastating effects resulting in flooding and abandonment of the excavation. Using a computer numerical analysis program, UDEC 3.0 which is based on distinct element method (DEM) and can adequately accommodate coupled hydro-mechanical behavior of joints, the numerical analyses simulating tunnels in jointed rock masses were carried out. The influences of a highly pervious feature on the ground-water flow regime as well as the inflow rate into a tunnel were investigated as the tunnel approaches the highly pervious feature.

2. Current practice for estimating water inflow rate into a tunnel

Current practice for estimating water inflow rate relies mostly on analytical solutions which assume a homogeneous, isotropic porous medium around the tunnel, where the main controlling variables are the location of the ground-water table and the rock-mass permeability. Generally, results from field packer tests are used to provide representative hydraulic conductivity values for the analytical model.

For a homogenous, isotropic mass, the magnitude of water flow into a tunnel as well as the pore-water pressure distribution in the surrounding rock mass can be approximated using the image well method proposed by Harr (Harr, 1962; Goodman et al., 1965; Fernández and Alvarez, 1994). The tunnel (sink) and the mirror-image tunnel are located at the same distance from the existing ground-water level prior to excavation (Fig. 1). The flow between two tunnels can be evaluated in an infinite boundary condition regarding the initial ground-water table as an equipotential line, instead of analyzing a complex semi-infinite boundary problem. The flow net that develops under steady-state seepage between the two tunnels is shown in Fig. 1. The lower half of this flow net represents the flow net between the tunnel and the initial ground-water level. The estimated rate of infiltration per unit length of tunnel can be approximated as

$$q_o = -\frac{2\pi H \cdot k_m}{\ln\left[1 + \left({}^{2H}/_{a}\right)^2\right]^{0.5}} \approx -\frac{2\pi H \cdot k_m}{\ln\left({}^{2H}/_{a}\right)} \quad (1)$$

where, k_m = hydraulic conductivity of the surrounding rock mass [LT^{-1}]; H = ground-water level above the springline of tunnel [L]; q_o = flow rate into the unit length of tunnel [L^3T^{-1}]; and a = radius of tunnel [L].

The surrounding fractured rock mass has been idealized as an isotropic and homogeneous medium, and therefore in many cases the actual porewater pressure distribution and inflow rate may differ from those estimated from this analysis. Heuer (1995, 2005) found that the actual water inflow into a tunnel is generally significantly

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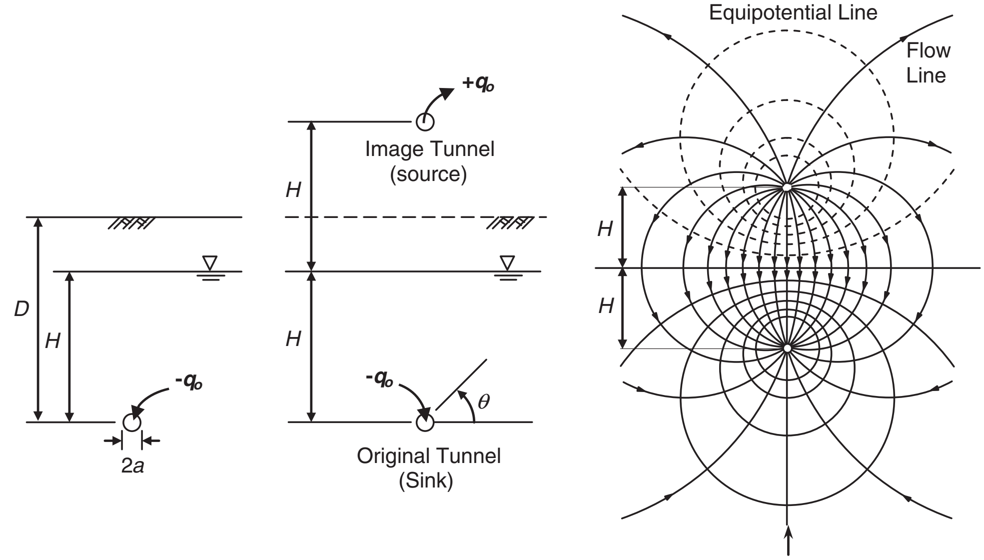

Fig. 1. Image tunnel method.

lower than the estimated water inflow using the analytical solution in Eq. (1). Therefore, appropriate adjustment factors and modifications should be applied for the adequate estimate of ground-water inflow rate. Heuer's (1995, 2005) approach accommodates for this discrepancy by grouping the rock permeability data in "bins" corresponding to various percentages of tunnel length and choosing an inflow intensity curve, flow over head q/H_s (Figure 2), relationship based on the ratio of hydraulic head over tunnel radius. The variance in the measured packer hydraulic conductivity values is assumed to reflect the hydraulic conductivity distribution along the tunnel alignment (Heuer, 1995).

3. Hydro-mechanical joint behavior

The water flow through a joint depends on its hydraulic aperture which is controlled by the effective normal stress across the joint, that in turn, primarily depends on the water pressure within the joint (hydro-mechanical coupling). The correlation between joint closure and joint effective normal stress is generally characterized as non-linear and hysteretic as observed by many researchers (Snow, 1972; Goodman, 1974; Iwai, 1976; Gale and Raven, 1980; Barton and Bandis, 1982; Bandis et al., 1983). The deformation characteristics of a rock joint are known to be affected by joint contact area, joint surface

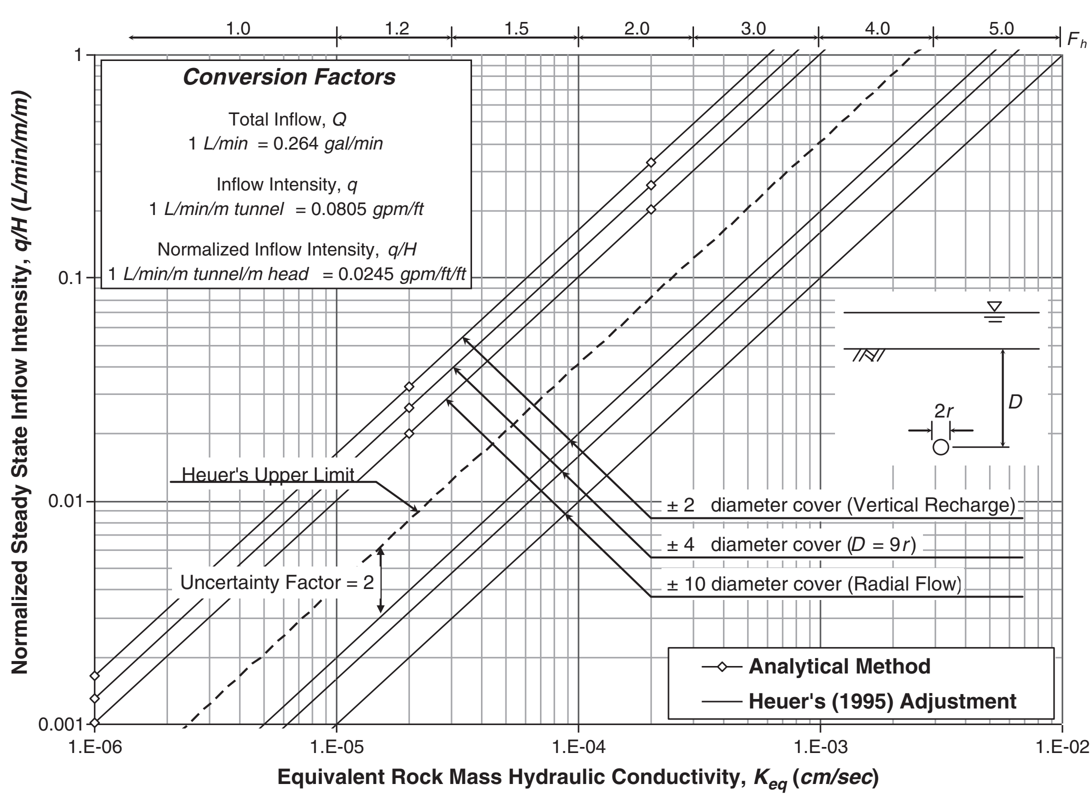

Fig. 2. Relationship between steady state inflow and equivalent permeability (Heuer, 2005).