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PLAXIS

Seepage Flow Out of a Pervious Concrete-Lined Pressure Tunnel

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by

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1. Introduction

Hydropower tunnels, which are lined with concrete, are often assumed impervious by engineers. The effects of seepage flow on the rock mass have frequently been ignored resulting in tunnel alignments with inadequate lateral and/or overburden (Fernández and Alvarez Jr, 1994).

Since concrete lining is in principal a pervious material, water can seep into the cavities in the rock mass and develops seepage pressure, especially when the internal water pressure is greater than the external water pressure. Consequently, seepage affects the rock deformations and may wash out the joint fillings in the grouted rock mass. In many occasions, severe seepage problems have resulted in not only stability problems, but also a huge loss of energy production (Deere and Lombardi, 1989; Panthi and Nilsen, 2010). Therefore, when designing a pervious pressure tunnel, seepage effects should not be overlooked.

To estimate the seepage out of a pressure tunnel, the mechanical-hydraulic coupling needs to be taken into account. It can be described as follows (Schleiss, 1986): the fractures and pores in the rock mass are deformed by the internal water pressure resulting in the change of the rock mass permeability around the tunnel. In turn, the change in the rock mass permeability affects the seepage flow and therefore the seepage pressures in the rock mass.

This report aims to assess the seepage around a concrete-lined pressure tunnel situated above the groundwater level or when the tunnel covered by a dry rock mass. There are three zones considered in the analysis, namely the rock mass, the grouted zone or loosened rock zone covering the pressure tunnel and the concrete lining as shown in Fig. 1.

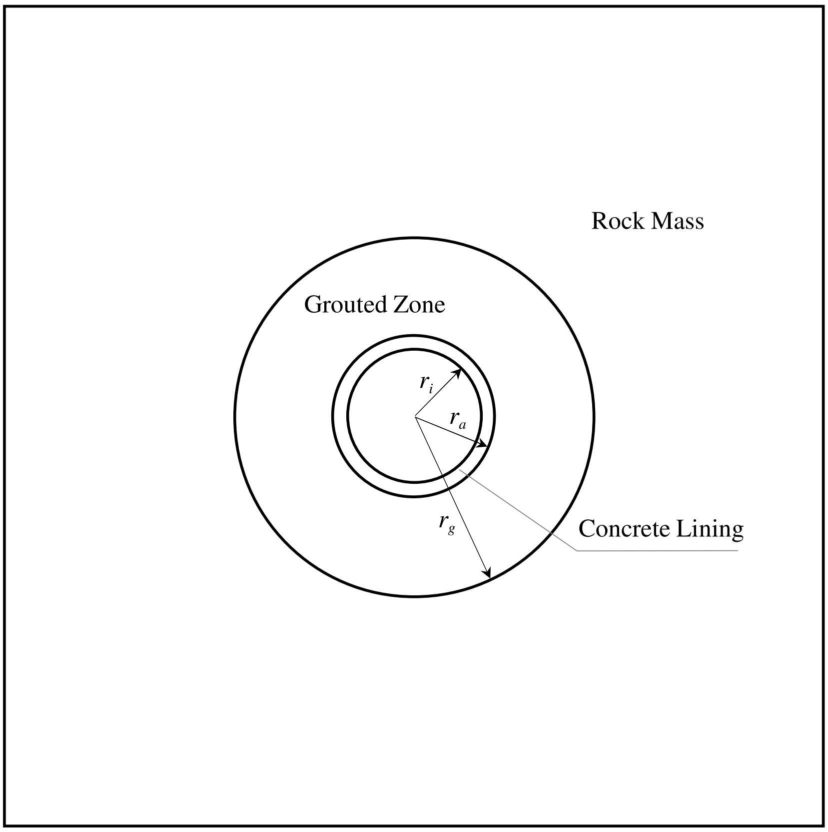

Fig. 1. Schematic Model Geometry

2. Objectives

The study objective is to investigate the rate of seepage around a concrete-lined pressure tunnel embedded in an elastic isotropic rock mass

3. Seepage Flow

Seepage per unit length, q, out of a pervious concrete-lined pressure tunnel situated above the groundwater level can be calculated using (Bouvard, 1975; Bouvard and Niquet, 1980; Schleiss, 1986):

$$\frac{p_i}{\rho_w\ g} - \frac{3}{4} r_g = \frac{q}{2\pi\ k_r} \ln \frac{q}{\pi\ k_r\ r_g} + \frac{q}{2\pi} \left[\frac{\ln (r_a / r_i)}{k_c} + \frac{\ln (r_g / r_a)}{k_g} \right] \tag{1}$$

where r_g is the radius of the grouted zone, r_a is the outer radius of the concrete lining, r_i is the inner radius of the concrete lining, k_r is the permeability of the rock mass, k_g is the permeability of the grouted zone, k_c is the permeability of the concrete lining, p_i is the internal water pressure, g is the gravity acceleration, and ρ_w is the density of water.

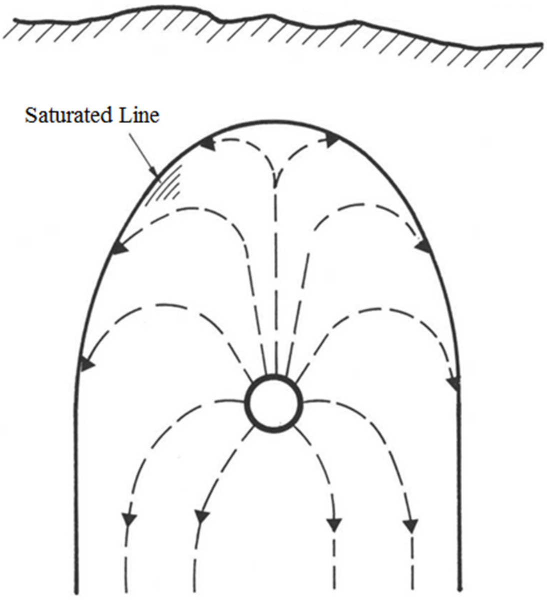

Fig. 2. Saturated Zone around a Pervious Tunnel (Schleiss, 1997)

The seepage around the tunnel is schematized in Fig. 1. Based on the continuity condition, the seepage through an uncracked concrete lining, q_c, a grouted zone, q_g, and a rock mass, q_r, should be equal, and can be calculated as (Schleiss, 1986):

$$q_c = \frac{(p_i - p_a)\ 2\pi\ k_c}{\rho_w\ g \ln (r_a / r_i)} \tag{2}$$

$$q_g = \frac{(p_a - p_g)\ 2\pi\ k_g}{\rho_w\ g \ln (r_g / r_a)} \tag{3}$$

$$q_r = \frac{(p_g - p_R)\ 2\pi\ k_r}{\rho_w\ g \ln (R_v / r_g)} \tag{4}$$

where p_a is the seepage pressure at the final lining extrados, p_g is the seepage pressure at the outer border of the grouted zone, and p_R is the seepage pressure in the rock mass influenced by the reach of seepage flow, R.

The vertical, R_v, and horizontal, R_h, reach of seepage flow can be estimated respectively using:

$$R_v = \left(\frac{q}{\pi\, k_r}\right) \ln(2) \tag{5}$$

$$R_h = \frac{q}{3\, k_r} \tag{6}$$

The seepage pressure at the outer border of the grouted zone, p_g, can be calculated using (Bouvard, 1975; Simanjuntak et al., 2013):

$$\frac{p_g}{\rho_w\, g} - \frac{3}{4} r_g = \frac{q}{2\pi\, k_r} \ln \frac{q}{\pi\, k_r\, r_g} \tag{7}$$

4. Numerical Results

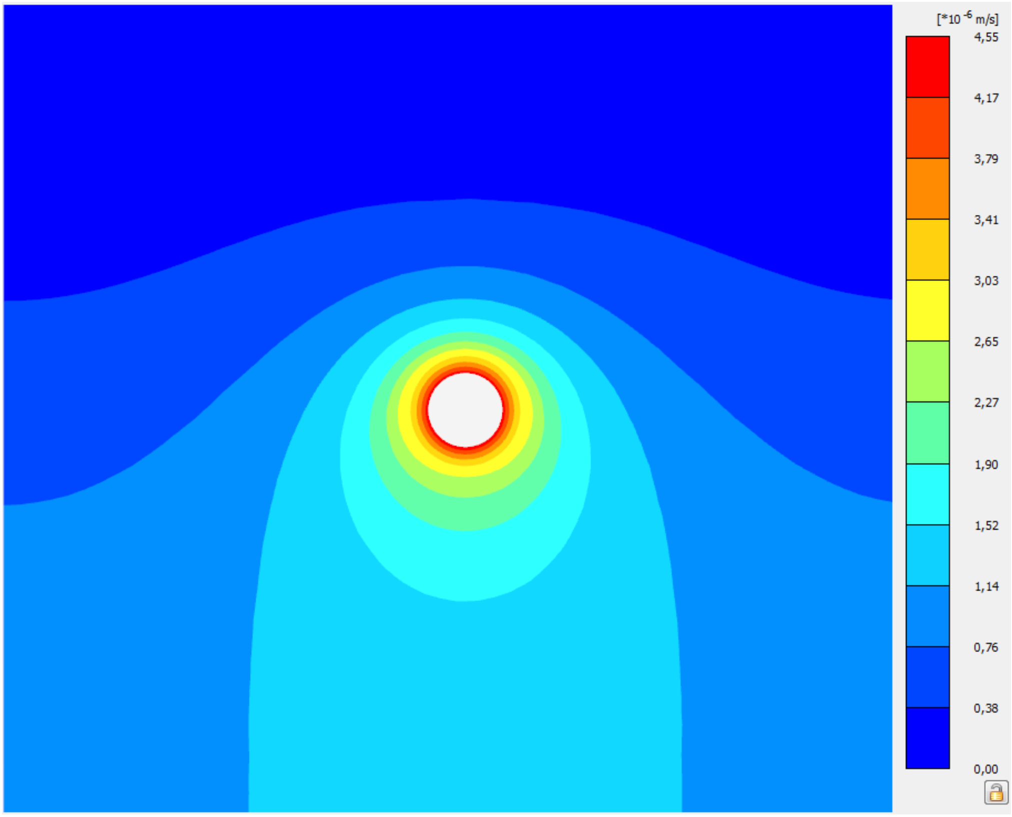

Fig. 1. Seepage Distribution

In this report, a plain concrete-lined pressure tunnel with an internal radius, r_i, of 2 m is used as an example. The lining thickness is 30 cm and the consolidation grouting is executed up to a depth of 1 m behind the concrete lining. The groundwater level is not present and the internal water pressure applied is 1.7 MPa (17 bar).

The problem is in plane strain conditions. The model geometry can be seen in Fig. 1, whereas the properties for the rock mass, the grouted zone and the concrete lining used in the analysis are listed in Table 1.

Table 1. Parameters Used in the Analysis

Material	*E* (GPa)	ν	*k* (m/s)
Rock Mass	15	0.25	10^{-6}
Grouted Zone	15	0.25	10^{-7}
Concrete Lining	31	0.15	10^{-8}

In PLAXIS, the internal water pressure can be assigned directly to the cluster representing the cavity. The user defined type of water boundary conditions was applied and the reference pressure, P_{ref}, was set to 1.7 MPa. The groundwater flow conditions at the outer model domain (*XMin, XMax and YMax*) were set to open, except the one below the tunnel (*YMin*) was set to closed.

The numerical results of seepage around the pressure tunnel is presented in Fig. 3. It is seen that as much as 4.55×10^{-6} m/s of seepage, that corresponds to *q* equals 57.2 l/s/km will occur due to the internal water pressure. When compared to the analytical solution, the seepage *q* was obtained as 55.7 l/s/km. This suggests that the numerical results using PLAXIS 2D show a good agreement with the analytical solution. The comparison of results is presented in Table 2.

Table 2. Comparison of Results

Method	*q* (l/s/km)
Analytical	57.2
PLAXIS	55.7

Furthermore, as the pressure tunnel is situated above the groundwater level, it can be seen that a bell-shaped seepage is formed around the pressure tunnel (Fig. 3). This also corresponds to that has been investigated by Schleiss, 1997 and Simanjuntak et al., 2014.

5. Concluding Remarks

This report presents the seepage around a concrete-lined pressure tunnel using the numerical and analytical approaches. The tunnel considered is embedded in an elastic isotropic rock mass where the groundwater level is not present. It can be seen that the amount of seepage out of the tunnel predicted using PLAXIS 2D is comparable with that calculated using the analytical solution with good accuracy.

6. References

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