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Effect of Model Dimension in Numerical Simulation on Assessment of Water Inflow to Tunnel in Discontinues Rock

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***Abstract*—**Groundwater inflow to the tunnels is one of the most important problems in tunneling operation. The objective of this study is the investigation of model dimension effects on tunnel inflow assessment in discontinuous rock masses using numerical modeling. In the numerical simulation, the model dimension has an important role in prediction of water inflow rate. When the model dimension is very small, due to low distance to the tunnel border, the model boundary conditions affect the estimated amount of groundwater flow into the tunnel and results show a very high inflow to tunnel. Hence, in this study, the two-dimensional universal distinct element code (*UDEC*) used and the impact of different model parameters, such as tunnel radius, joint spacing, horizontal and vertical model domain extent has been evaluated. Results show that the model domain extent is a function of the most significant parameters, which are tunnel radius and joint spacing.

***Keywords*—**Water inflow, Tunnel, Discontinues rock, Numerical simulation.

I. Introduction

Water inflow into the tunnels is one of the most important problems for tunneling in rock media which flows through initial or later created Discontinuities in tunnel walls. This causes some problems in tunneling progress such as decrease in rock mass stability, extra pressures on permanent and temporary stability system, destructive effects on the geomechanical condition of rock and finally physical and economic problems. Due to the impossibility of identifying and determining the whole factors which are affecting water inflow into tunnels especially during drilling, anticipating the exact amount of seepage into the tunnels is very difficult [1], [2].

Water inflow into tunnel can be modeled using numerical methods and then seepage into tunnel can be calculated in various situations in site. These methods require comprehensive data about the site. Numerical methods are very complex and application of them is time consuming, however, the results are more precision in comparison to analytical methods particularly when the tunnel is excavated to fracture rock mass and the impact of geo-structural anisotropy of fractured rocks on tunnel inflows is addressed. Nevertheless, numerical simulations can help to analysis more complicated situations (e.g., [3]-[10]).

A jointed rock mass is defined by the presence of geological structures Which can be tens and hundreds of meters extended faults and dykes or a few centimeters to tens of meters joints, bedding planes and foliations [11]. For engineering purposes, with respect to model size, one of the critical design parameters for numerical modeling is the relative size of geological fractures.

Determining the dimension size of a model for numerical simulation is relatively problematic. The main challenge for estimation of the groundwater flow in fractured rock masses is extrapolating the optimum dimension size obtained from the numerical simulation. In well-defined and connected rock fractures, the flow behavior of a jointed rock mass is controlled by the fracture characteristics, model size and boundary condition. In case of very small model dimensions, due to low distance to the Tunnel’s border, the model boundary conditions affect the estimate groundwater flow into the tunnel and results show a very high inflow into the tunnel. On the other hand, when the model size is very large, numerical simulation requires more memory, strong *CPU* power and more time to implement and run the model.

The optimum Model Extent (*ME*) is dimension at which the boundary condition does not affected for the tunnel groundwater inflow. Few publications have studied the optimum dimension of the model's extent in numerical modeling of groundwater flow into the tunnel. In order to evaluate realistic parameters that control the water ingress to a tunnel, Indraratna and Ranjith analyzed a given type of joint pattern with different stress-hydraulic boundary conditions. Results showed block sizes and the boundary condition play an important role for water inflow to tunnel in discontinues rock masses [12]. Cesano et al. presented a method to quantify the degree of fractured rock hydraulic heterogeneity to predict groundwater inflow into the tunnel. Six experiments were used to prove the existence of a correspondence between the variability in fracture properties and in direction and magnitude of flow in different model sizes [13]. In this regard, another study obtained the optimal model size domain based on water inflow rates into a tunnel and pore water pressure distribution around the opening in a given type of joint [14], [15]. Also, in continuous media, Butscher have also illustrated that to provide accurate results for groundwater inflow into a continues media located tunnel (is unlined or has a drainage layer surrounding the lining), the extent of the model domain

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must be large with respect to the extent of the tunnel. However, none of the studies has so far systematically investigated the impact of the model domain size on calculated tunnel inflow [16].

In this work, we evaluate the effect of model dimension on water inflow in numerical simulation. For this aim, parametric studies with various sizes of the model extent were performed using *UDEC* and the results were discussed. This step is critical importance in numerical analyses because the size of the model has a large impact on water inflow rates into a tunnel and pore water pressure distribution around the opening.

II. Numerical Modeling

The distinct element numerical code *UDEC* is used which facilitates a mechanical hydraulic study in which the rock matrix is considered impermeable and the joints permeability depends on the mechanical deformation, which, in turn, is influenced by the water pressure inside the fractures [17].

To simulate the drainage processes in a fractured medium, an artificial rock mass was considered, crossed by 2 joint sets having E/45°-W/45° orientations, spacing and apertures (Fig 1). A different domain was chosen, to the right side of which a tunnel having N–S direction was positioned. It is clear that these types of hypothesis imply the symmetry of the system. The parameters used for modelling are listed in Table I.

TABLE I
Modelling Parameters in This Study

Type of parameter		Parameter	Range of variation
Geo-mechanical characteristic (with reference to the Mohr-Coulomb constitutive model chosen in the modelling)	Intact rock	Specific weight	26 kN/m3
		Bulk modulus	1.9 GPa
		Shear modulus	1.74 GPa
	Joints	Normal and tangential stiffness	100 MPa/mm
		Friction angle	35
		Cohesion	null
Geometrical characteristics of the discontinuity		Set number	2
		Set strike	Parallel to the tunnel axis (N–S)
		Set dip direction	Toward E or W
		Aperture	5×10^{-3} m3
		Spacing	1, 2, 5 m
Tunnel design parameters		Radius	1- 5 m
		Lining or waterproofing	not present
		Depth	150 m

The following boundary conditions were applied [10]:

- Impermeable boundary along the bottom and along the border of the tunnel location (right vertical boundary)
- Constant load on the opposite side as regards the tunnel location (left vertical boundary)
- No displacements on the bottom and along the groundwater supply boundary
- Free hydraulic boundary conditions at the upper boundary of the modelling domain, simulating dry weather conditions

The following initial conditions were considered [10]:

- Lithostatic load with lateral (horizontal) pressure coefficient equal to 0.5
- Hydrostatic load depending on the applied constant head boundary condition and complete saturation below the water table

The numerical simulations were carried out through a fully hydraulic-mechanical coupled approach. Because, in the present study, only the final steady-state conditions are of interest, a steady-flow option was chosen for the simulation, which therefore does not consider unsaturated flow. [10].

III. Analyses And Discussion

The 2-Dimensional numerical model used in this study includes an assembly of intact rock blocks, different tunnel radius r (1, 2, 3, 4, 5 m), joint spacing s (1, 2, 5 m), horizontal model extent, *ME h*, (20, 50, 100 m) and different vertical model extent, *ME v*, (5, 10, 20, 50, 100 m). Angle between two joint sets is 90° and depth of tunnel below the groundwater level h is 100 m (Fig. 1).

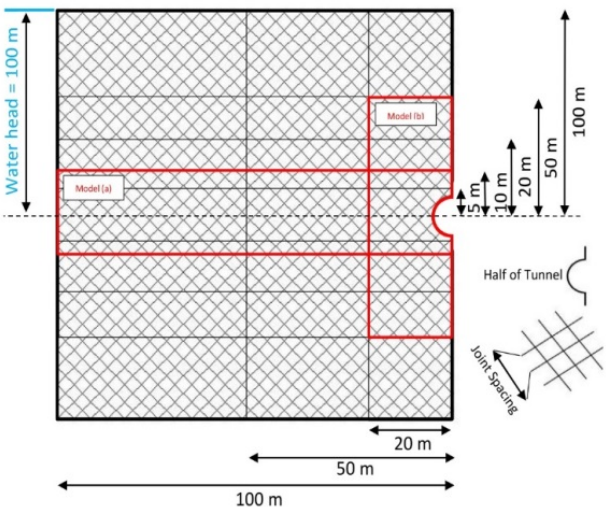

Fig. 1 Model geometry with extent of model domain *ME* for different model dimensions. For example, in model (a) of this figure, the horizontal model dimension (*ME h)* is 100 m and vertical model dimension (*ME v*) is 10 m and in model (b), these dimensions are 20 and 50 m, respectively

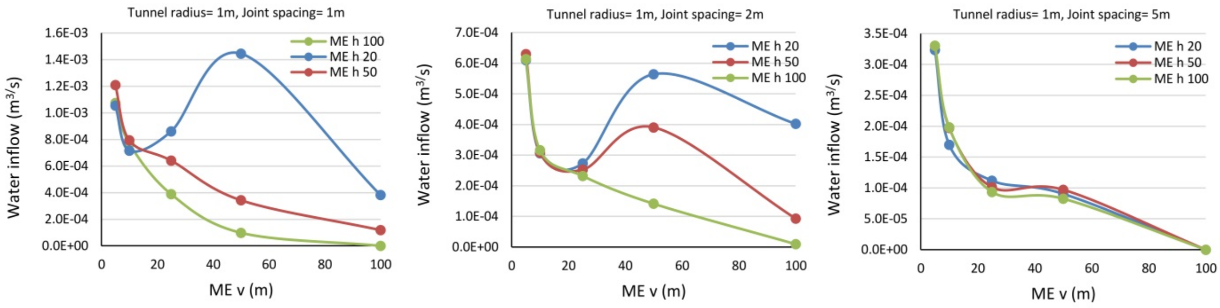

Fig. 2 Trend of the tunnel inflow versus the ME v (surface joint aperture and water head kept constant) for different joint spacing in the case of two conjugate joint families having dip equal to 45° (ME h: horizontal model extent, ME v: vertical model extent)

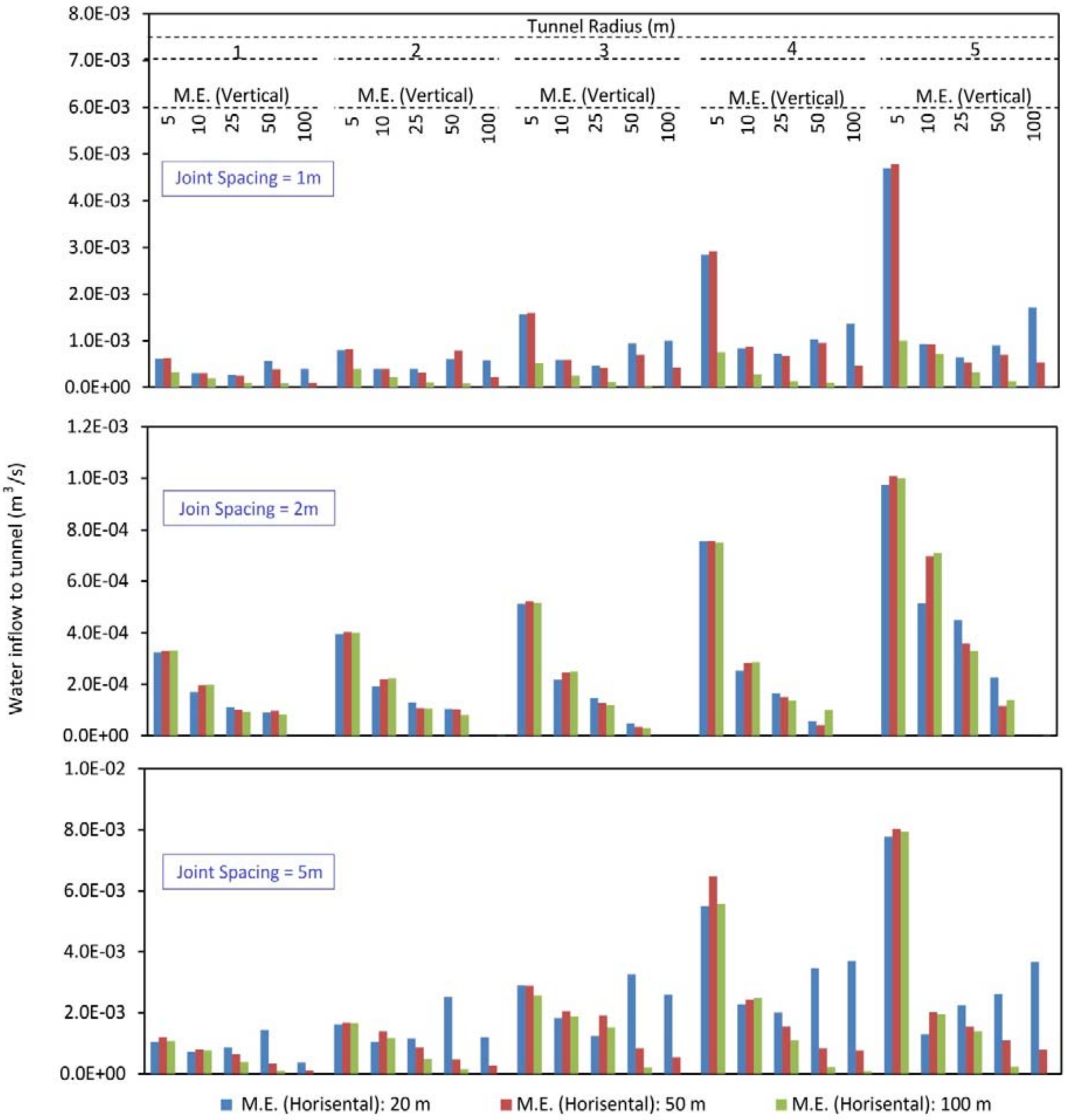

Fig. 3 Effect of significant parameters on groundwater flow into tunnel. (Tunnel radius: 1, 2, 3, 4, 5 m; M.E. vertical: 5, 10, 25, 50, 100 m; M.E. Horizontal: 20, 50, 100 m; joint set spacing: 1, 2, 5, 10 m; dip direction/ dip: E/45°-W/45°; water head: 100 m; Joint aperture: 5×10-3 m)

The lateral extent of the model domain is given by the model extent (*ME*). The geometrical difference between different model extents is illustrated in Fig. 1. For instance, in model (a) of the figure, the horizontal model dimension is 100 m and vertical model dimension is 10 m and in model (b), these dimensions are 20 and 50 m, respectively. Based on different types of parameters, 225 simulations were analyzed in order to evaluate the effects of model dimension on water inflow in numerical modeling.

As can be seen in Fig. 2, simulation results show that by increasing (*ME v*), the tunnel inflow is reducing in a given amount of (*ME v*) in different types of (*ME h*), and after that, the behavior of tunnel inflow is not identifying while increasing of (*ME v*). When the size of model extent is increased, the effects of water pressure on by tunnel boundary intersected discontinuities become less; consequently, a smaller inflow can then be expected due to the reduced hydraulic head [12]. As verified by this analysis, when the model extent size is increased, in the low frequency and high joint spacing, the effect of tunnel radius on the water inflow becomes less that is due to the low number of discontinuities intersected by the tunnel boundary. It should be noted that for the mentioned figure, the head of water above the tunnel (h) is assumed as 100 m and constant.

In tunnels with less joint spacing, the horizontal and vertical model extent have an important role in determining the water inflow, whereas, in tunnels with the further joint spacing, effect of horizontal and vertical model extent on the rate of water inflow is less.

In tunnels with large model dimension, water flow rate is very low and near to zero. In these type of models, effect of joint spacing and tunnel radius can be removed.

According to Fig. 3 in which water inflow to tunnel is obtained base on different tunnel radius, horizontal and vertical model extent and joint spacing, this can be inferred that the joint spacing with the horizontal and vertical model extent (boundary condition) have important role in determining water inflow rate to tunnels.

As you can see in Fig. 3, by increasing the tunnel radius and reducing the joint spacing, the water inflow rate to tunnel has been increased. In joint spacing equal to 2 meter, the appropriate downtrend of columns by the increasing of horizontal and vertical dimension in different tunnel radius indicate the direct effect of joint spacing in determining the appropriate size of model and water inflow. While in the joint spacing 1 and 5 meter, convulsion of columns can be seen.

IV. Conclusion

This study highlighted the effects of model domain extent on tunnel inflow in numerical simulation. A large number of numerical simulations were performed using different structural and geometrical conditions and different model size which were allowed for a sufficient database to evaluate the effect of size of model extent. Sensitivity analysis of parameters affecting the water inflow into the tunnel revealed that the influence of different parameters (joint spacing, tunnel radius) on the tunnel-water inflow is increased by decreasing model extent size. Results are shown that the size of model has a large impact on estimated water inflow rates into a tunnel and pore water pressure distribution around the opening. When the model domain extent is increased, the effects of water pressure on discontinuities intersected by the tunnel boundary become less; consequently, a smaller calculated inflow can then be expected.

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