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A Quantitative Criterion-based Methodology for Selecting Appropriate Domain Size for Numerical Modeling of Groundwater Inflow into Tunnel

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ABSTRACT: Selecting the appropriate model size is a challenging issue in the numerical modeling of groundwater inflow into underground excavation. This issue was studied in this paper by presenting a methodology for selecting appropriate domain size for numerical modeling of groundwater inflow into a tunnel that is excavated inside of semi-infinite aquifer. To reach this goal, first, a dimensionless factor, the so-called normalized rate of inflow variation (NRIV), was defined in cooperation with its limit value, so-called acceptable level of variation (ALV). Then, the appropriate or suitable domain size (SDS) of the numerical model was determined based on the NRIV and ALV. The applicability of the suggested methodology was evaluated for the results of wide range geometrical parameter of tunnel (including different tunnel radiuses and depths) and different flow domain sizes. The results of this study indicated that the required domain size for numerical modeling of groundwater inflow into tunnel increase nonlinearly for larger and deeper tunnels. Moreover, the required domain size increases to 1.8 times by decreasing the level of ALV from 0.0005 to 0.0001, where the relative accuracy of results has only increased up to 4%. Since the larger domain size requires much computational difficulties and insignificant accuracy, the ALV in the level of 0.0005 is suggested for practical numerical modeling of groundwater inflow into tunnels.

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1- INTRODUCTION

The hydraulic behavior and associated mechanical, physical, and chemical processes of geological formations and rock masses have a key role in different engineering applications such as civil, mining, environmental, geothermal energy, and petroleum extraction. Through the wide applications of rock mass hydraulic behavior characterization, the prediction of groundwater inflow into underground excavations (such as tunnels) is one of the most challenging issues, where the successful predictions an appropriate model thorough understanding of the effective features.

The common practices for prediction of groundwater inflow into underground excavations can be performed by application of different methods such as empirical [1], experimental, physical, analytical solutions [2], and numerical models [3]. The numerical modeling of groundwater inflow into the tunnel provides much more efficient quantitative results than others. However, the reliability of numerical methods depends strongly on the several factors, especially the domain size, and boundary and initial conditions [4]. In fact, domain size or model extent is one of the most important factors that directly affect the accuracy and efficiency of numerical modeling results [5]. However, the survey in the literature indicates that different domain sizes have been applied in the previous studies, where this issue leads to inconsistent and biased results. Therefore, the lack of a well-established and generally accepted quantitative criterion-based methodology is highly felt necessary for selecting appropriate domain size for numerical modeling of groundwater inflow into the tunnel that is developed and illustrated in this paper.

The main purpose of this study is to develop and suggest a quantitative criterion-based methodology for selecting appropriate domain size for numerical modeling of groundwater inflow into tunnel. To reach this goal, an algorithm including new quantitative concepts, so-called normalized rate of inflow variation (NRIV) and acceptable level of variation (ALV) was developed for the selection of suitable domain scale (SDS). Several numerical simulations of groundwater inflow evaluated the applicability of the suggested methodology into a tunnel with different radius and depth values.

2- METHODOLOGY OF SUITABLE DOMAIN SCALE

To evaluate the effect of domain scale on the results of numerical simulation of groundwater into tunnel, a general domain flow was defined around the tunnel and the scale of

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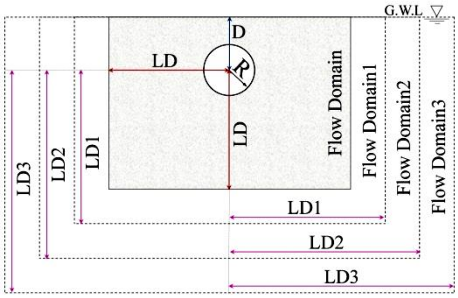

Fig. 1. The flow domain and its increment for modeling the groundwater inflow into tunnel.

the numerical model was gradually increased by increasing the lateral distance (LD) of vertical and floor boundaries (Figure 1). The domain flow was defined around a circular tunnel with radius and depth of R and D, respectively. The LD of domain gradually increased and for each LD values, the groundwater inflow into tunnel was numerically calculated.

In order to select SDS, first, the groundwater simulation was performed for different LD values. Then, the NRIV is calculated for two consecutive LDs as:

$$NRIV = \frac{Q'_S}{LD_{i+1} - LD_i} \qquad Q'_S = \frac{\left|Q^{LD}_{i+1} - Q^{LD}_{i}\right|}{\left(\frac{Q^{LD}_{i+1} + Q^{LD}_{i}}{2}\right)} \tag{1}$$

where, Q^{LD}_{i+1} and Q^{LD}_{i} are the inflow rate for domain size of LD_{i+1} and LD_i, respectively. To select the SDS, it is necessary to define a limit value for NRIV. This limit value was defined as the allowable level of variation (ALV) that indicates the accuracy of desirable modeling results. In this study, two different values for ALV of 0.0001 and 0.0005 was suggested for determined the SDS for research and engineering demands, respectively.

The SDS was defined as a domain size or LD of domain where the numerical model with this size leads to acceptable results. In order to determine the SDS, the domain size or LD of domain is gradually increased until the calculated NRIV by Equation 1 reaches the desirable ALV value.

3- NUMERICAL MODELING

The numerical simulation of groundwater inflow into tunnel was performed with FNETF computational code, which previously developed, verified, and validated for different fluid flow problems [3, 6-8]. The numerical simulation involves different steps such as generation of domain flow, generation of hydraulic attribute inside flow domain, attribution of hydraulic properties, generation of tunnel inside the domain, discretization of domain and equations, applying boundary condition, and numerically solving the flow equations. In this study, the laminar and steady-state flow equation for hegemon media with hydraulic conductivity of 16.6×10^{-7} m/s were used in numerical simulation of groundwater inflow into the tunnel.

In order to investigate the effect of domain size, the numerical simulation of groundwater inflow tunnel was performed for 28 values of LD from 25 m to 400 m. The effect of domain size on the groundwater inflow was evaluated for four different tunnel depth of 25, 50, 75, and 100 m and for ten different radiuses of tunnel including 0.5, 1, 1.5, …4, 4.5, and 5 m. This procedure includes 1120 numerical models with different combinations of (D, R, LD).

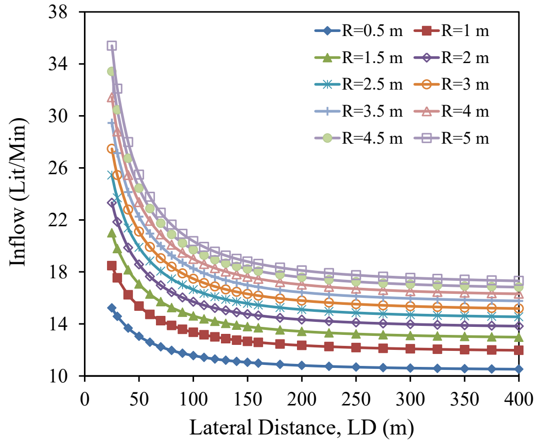

Fig. 2. The effect of LD on the results of numerical simulation of groundwater inflow into the tunnel with a depth of 100 m.

4- RESULTS AND DISCUSSION

The increment of domain size (LD) leads to decreases in the groundwater inflow into the tunnel. A typical example of this effect for groundwater inflow into the tunnel with a depth of 100 m is shown in Figure 2 (similar results have been observed for different tunnel depths). As shown in Figure 2, by increasing the LD, the groundwater inflow decreases gradually and reaches a semi-constant values for large LDs. Moreover, the sensitivity of groundwater inflow to LD increases by increasing the tunnel radius. Therefore, it is anticipated the larger SDS for larger tunnels.

For each tunnel depths and radiuses, the SDS was determined based on the application of ALV and NRIV. The resultant SDS for different tunnel depths and radiuses and both ALVs of 0.0001 and 0.0005 are shown in Figure 3. As can be seen in Figure 3, the larger SDS is observed for larger tunnel depths and radiuses. The comparison between results indicates that the desirable SDSs for ALV of 0.0001 are about 1.76 to 1.91 times of ALV of 0.0005.

In order to evaluate the effect of desirable SDS and ALV on the accuracy of numerical simulation, the results of simulated groundwater inflow into tunnel were compared with the analytical solution of El Tani, 2003 [2]. Moreover, the relative error of the numerical simulation result was calculated based on the analytical solution. A typical of such comparison and relative error for tunnel depth of 100 m is shown in Figure 4. The comparison of results in Figure 4 indicates that the predicted groundwater inflow with numerical simulation has good conformity with the analytical solution. However, in most of the cases, the groundwater inflow predicted by numerical simulation is larger than analytical solution. Moreover, the relative error of numerical simulation with

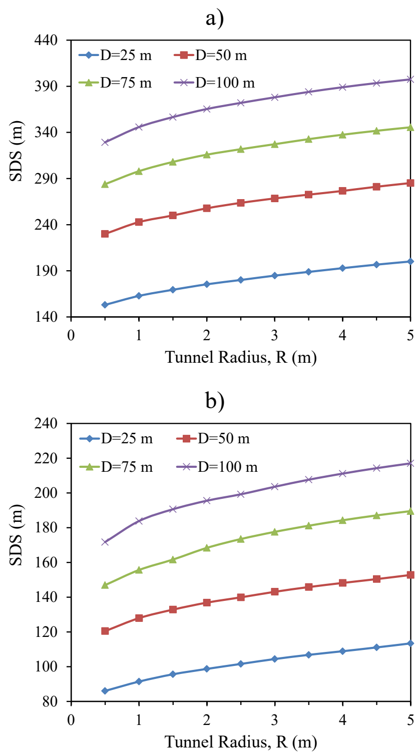

Fig. 3. The effect of tunnel radius on the desirable SDS for different ALV of: a) 0.0001 and b) 0.0005.

SDS corresponding to ALV of 0.0001 is lower than the corresponding results of 0.0005.

Comparison the results of numerical simulation with SDS corresponding to different levels of ALVs indicate that by increasing the ALV (or decreasing the desirable level of accuracy), the required domain size of the numerical model decreases about 1.8 times; without appreciable modification of relative error. Therefore, the SDS corresponding to ALV of 0.0005 is suggested for practical purposes that require very lower computational time and reflects somehow desirable accuracy.

5- CONCLUSION

The effect of domain size on the results of numerical simulation of groundwater inflow into tunnel was studied in this paper. The main purpose of this study is to develop and suggest a quantitative criterion-based methodology for selecting appropriate domain size for numerical modeling of groundwater inflow into tunnel. To reach this goal, first, the dimensionless factor of NRIV was defined in cooperation with the limit value or ALV to determine the SDS or appropriate domain size. Then, the applicability of the suggested methodology was evaluated for the results of wide range geometrical parameter of tunnel (including different tunnel radiuses and depths) and different flow domain sizes.

The results of this study indicate that the accuracy of numerical simulation of groundwater inflow into tunnel is large size of domain size in highly depend on domain size. By increasing the domain size or LD, the groundwater inflow

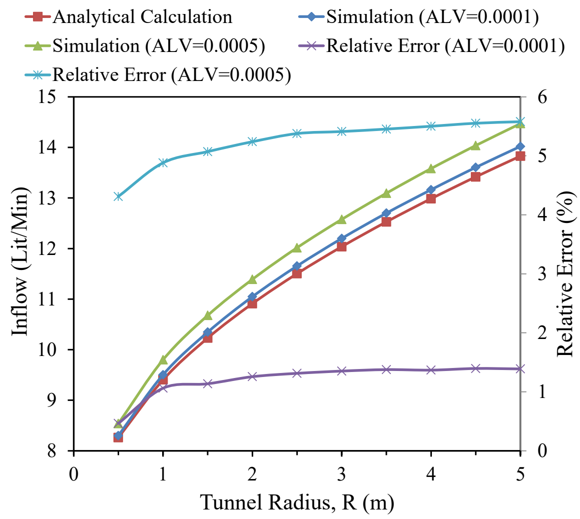

Fig. 4. Comparison of predicted groundwater inflow with analytical solution and numerical simulation.

decreases gradually and reaches a semi-constant values for large LDs. Moreover, the effect of domain size on the results of groundwater inflow increases by increasing the tunnel radius. Therefore, the required domain size (or SDS) for numerical modeling of groundwater inflow into tunnel increase nonlinearly for larger and deeper tunnels. Moreover, the required domain size increases to 1.8 times by decreasing the level of ALV from 0.0005 to 0.0001, where the relative accuracy of results has only increased up to 4%. Since the larger domain size requires much computational difficulties and insignificant accuracy, the ALV in the level of 0.0005 is suggested for practical numerical modeling of groundwater inflow into tunnels.

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