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Water flow in fractured rock masses: numerical modeling for tunnel inflow assessment

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Water circulation in rocks represents a very important element to solve many problems linked with civil, environmental and mining engineering. In particular, the interaction of tunnelling with groundwater has become a very relevant problem not only due to the need to safeguard water resources from impoverishment and from the pollution risk, but also to guarantee the safety of workers and to assure the efficiency of the tunnel drainage systems.
The evaluation of the hydrogeological risk linked to the underground excavation is very complex, either for the large number of variables involved or for the lack of data available during the planning stage.
The study is aimed to quantify the influence of some geo-structural parameters (i.e. discontinuities dip and dip direction) on the tunnel drainage process, comparing the traditional analytical method to the modeling approach, with specific reference to the case of anisotropic rock masses. To forecast the tunnel inflows, a few Authors suggest analytic formulations (Goodman et al., 1965; Knutsson et al., 1996; Ribacchi et al., 2002; Park et al., 2008; Perrochet et al., 2007; Cesano et al., 2003; Hwang et al., 2007), valid for infinite, homogeneous and isotropic aquifer, in which the permeability value is given as a modulus of equivalent hydraulic conductivity Keq. On the contrary, in discontinuous rock masses the water flow is strongly controlled by joints orientation, by their hydraulic characteristics and by rocks fracturing conditions. The analytic equations found in the technical literature could be very useful, but often they don't reflect the real phenomena of the tunnel inflow in rock masses. Actually, these equations are based on the hypothesis of homogeneous aquifer, and then they don't give good agreement for an heterogeneous fractured medium. In this latter case, the numerical modelling could provide the best results, but only with a detailed conceptual model of the water circulation, high costs and long simulation times. Therefore, the integration of analytic method and numerical modeling is very important to adapt the analytic formula to the specific hydrogeological structure.
The study was carried out through a parametrical modeling, so that groundwater flow was simulated with the DEM Model UDEC 2D, considering different geometrical (tunnel depth and radius) and hydrogeological settings (piezometrical). The influence of geo-structural setting (as dip and dip direction of discontinuities, with reference to their permeability) on tunnel drainage process was quantified. The simulations are aimed to create a sufficient data set of tunnel inflows, in different geological-structural setting, enabling a quantitative comparison between numerical and the well-known analytic formulas (i.e. Goodman and El Tani equations). Results of this comparison point out the following aspects:
- the geological-structural setting critical for hydrogeological risk in tunnel corresponds to joints having low dip (close to 0°) that favour the drainage processes and the increasing of the tunnel inflow;
- the rock mass anisotropy strongly influences both the tunnel inflow and the water table drawdown;
- the reliability of analytic formulas for the tunnel inflow assessment in discontinuous rock masses depends on the geostractural setting; actually the analytic formulas overestimate the tunnel inflow and this overestimation is bigger for geostructural setting having discontinuities with higher dips.
Finally, using the results of parametrical modeling, the previous cited analytic formulas were corrected to point out an empirical equation that gives the tunnel inflow as a function of the different geological-structural setting, with particular regard to:
- the horizontal component of discontinuities,
- the hydraulic conductivity anisotropy ratio,
- the orientation of the hydraulic conductivity tensor.

The obtained empirical equation allows a first evaluation of the tunnel inflow, in which joint characteristics are taken into account, very useful to identify the areas where in-depth studies are required.

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