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Fracture characterization using hydrogeological approaches and measures taken for groundwater inrush mitigation in shaft excavation

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ABSTRACT

Plentiful groundwater in fractured rock masses adjacent to a construction site of a shaft in a highway tunnel project has been notified, which might cause groundwater inrush during its excavation. Hydrogeological approaches were used before the construction of the shaft to investigate the hydraulic features of the site, and thus to characterize the site and propose corresponding measures for groundwater inrush mitigation. This study further determines the fractures and the *Q*-values of rock masses in the bare walls following excavation of the study shaft, and the hydraulic conductivity of surrounding rocks, based on the measured variations of groundwater level and pressure in four observational wells around the shaft, to check the predicted results using the hydrogeological approaches and conventional Q-logging. The applicability of the proposed mitigation measures to groundwater inrush is also assessed. The results of comparisons indicate that the spatial distributions of three preferential flow paths that were predicted using hydrogeological approaches based on fractures in rocks are consistent with those revealed after excavation of the shaft. The depths at which groundwater inflow is high and the direction of the source of the groundwater can be predicted more precisely from hydrogeological approaches than using *Q*-values. Mitigation of groundwater inrush involves a grouted curtain that is applied to the regolith stratum from the surface, grouting for sealing that is carried out in the shaft, and aspirating pumps within the shaft and by pumping wells around the shaft. These methods effectively reduce the impact of groundwater on shaft construction. However, the aspirating pump takes time to control the water level inside the shaft. Hydrogeological approaches predicted the hydraulic conductivity of regolith and fractured rock masses nearby the study shaft over four orders of magnitudes, yielding results that are consistent with those obtained by excavation of the shaft, also confirming their reliability in elucidating the hydrogeological characteristics and groundwater inrush potential at a shaft site in a fractured rock mass.

1. Introduction

A fractured rock mass inherently has diverse discontinuities such as bedding planes, foliations, and joints. Spatial distribution of these discontinuities and associated mechanical and hydraulic behaviors lead to the heterogeneity and anisotropy of engineering characteristics for the fractured rock mass (NRC, 1996; Yang et al., 2014b). Prediction of the flow of groundwater in a fractured rock mass, which is always critical in the construction and maintenance of infrastructure, is a tough task because the investigation and related evaluation on its hydraulic parameters are difficult. Versatile explorative approaches using modern equipment have been developed for elucidating the hydrogeological characteristics of fractured rock masses (Moon, 2011; Iwata et al., 2013; Li et al., 2013; Liu et al., 2013; Egaña and Ortiz, 2013; Follin and Hartley, 2014; Chen et al., 2015a). Zhao et al. (2013) introduced advanced geological investigation technology methods, such as seismic wave, land sonar, full space transient electromagnetic method and geological radar, to predict water inrush zone for underground excavation. Reeves et al. (2013) obtained high degree variabilities of groundwater flow in fractured rock masses and pointed out the influence caused by spatial distribution and wide range in transmissivity of discontinuities. Assessment of the potential for groundwater inrush during an underground excavation in rock and its mitigation are still two of most challenging tasks in geotechnical engineering (Wang et al., 2011; Bukowski, 2011; Zarei et al., 2011; Hödl and Höllrigl, 2014; Jiang et al., 2016; Wu et al., 2017).

Distinct models of geomaterials that account for the features of groundwater flow have been presented. They include the Equivalent

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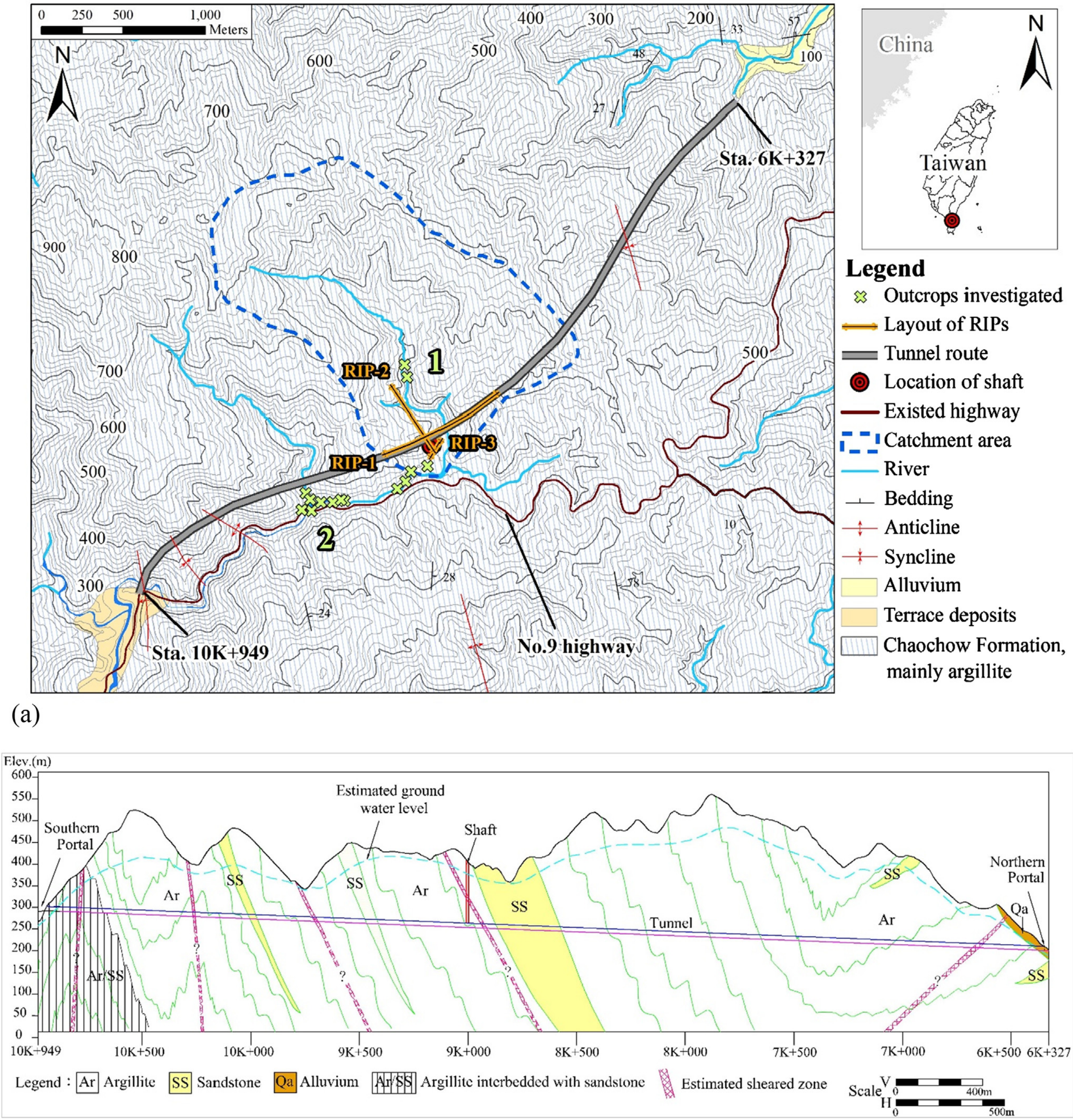

Fig. 1. Topography and geology near study area. (a) Regional geology, (b) geological profile along case tunnel (Wang et al., 2017). Question marks in (b) indicate that boundary of lithology's is inferred with uncertainty.

Porous Medium (EPM) model, Dual Porous (DP) medium model, Discrete Fracture Network (DFN) model, and Stochastic Continuum (SC) model, which have clear physical meanings and corresponding approaches for evaluating related parameters (Fernandez and Moon, 2010; Moon and Fernandez, 2010; Masset and Loew, 2010; Zhai, 2011). Using advanced exploration equipment in investigation of spatial distribution of fractures in rock and in-situ hydrogeological testing (Denis et al., 2002; Schrott and Sass, 2008; Masset and Loew, 2013; Zarei et al., 2013; Yang et al, 2014a), the hydrogeological characteristics of fractured rock masses have been examined in many infrastructural projects to obtain design parameters and/or valuable information for construction proposes (Lemieux et al., 2006, 2009; Follin et al., 2013; Follin and Stigsson, 2014; Chen et al., 2015b). However, comparisons of the predicted results of hydrogeological characterization and the site condition after rock excavation, and relevant discussion regarding construction planning based on site characterization are few.

This study concerns the construction of a shaft. Plentiful groundwater in fractured rock masses adjacent to the shaft site had been notified in geotechnical investigation report, which might cause groundwater inrush during its excavation. A series of hydrogeological approaches had been utilized to investigate the spatial distribution, geometric and hydraulic parameters of fractures in nearby rocks, and to