Editorial: Hydro-Mechanical Coupling and Creep Behaviors of Geomaterials

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Editorial on the Research Topic

Hydro-Mechanical Coupling and Creep Behaviours of Geomaterials

Our Frontiers Research Topic first focused on hydro-mechanical (HM) coupling behaviors of geomaterials. Hydro-mechanical (HM) geomaterials coupling referring to an interaction between fluid and solid *in situ* stress environment is a significant effect factor on the stability of geological engineering. Terzaghi (1943) first proposed the effective stress principle and established a one-dimensional consolidation model of homogeneous saturated geomaterials, which is the basic theory and initial model of hydro-mechanical coupling of geomaterials, and then, Boit (1954, 1956) laid a theoretical foundation for the hydro-mechanical coupling by extending Terzaghi's theory to the study of three-dimensional consolidation. Witherspoon et al. (1980) first defined the term of "coupling effect", and put forward the relevant coupling theory. Since then the studies on hydro-mechanical coupling behavior always have been a focused research topic due to highly nonlinear and complex coupling process. For soil and intact rock which are considered as porous media, during seepage process, pore fluid pressure as an external stress applied on porous media matrix will change the effective stress of the porous media, which reflects the action of pore fluid on stress. Conversely, the change of effective stress will lead to the change of permeability and porosity of porous media, which reflects the effect of stress on seepage. For fractured rock masses, the water flow in fractures will cause the change of fracture aperture (Zimmerman and Bodvarsson, 1996; Singh, et al., 2015; Zhao, et al., 2017b). Conversely, the change of fracture aperture will affect the permeability coefficient and seepage behavior of rock fractures. So the permeability coefficient as a bridge between stress field and seepage field is a dynamic variable during hydro-mechanical coupling analysis. Some previously proposed hydro-mechanical coupling model which supposed the permeability coefficient keeps constant only can reflect the influence of seepage on stress fields, but cannot reflect the influence of stress on seepage fields. So further studies on hydro-mechanical coupling behaviors of geomaterials, such as seepage characteristics of porous and fracture media, new experimental and numerical methods in the field of hydro-mechanical coupling are still needed. To reveal the laws of hydro-mechanical coupling of geomaterials, Our Frontiers Research Topic published some innovative papers related with hydro-mechanical coupling. For experimental research, Deng et al. carried out the seepage-induced suffusion tests, which indicated the appearance of uneven local hydraulic gradients along flow path in soil is a sign of the initiation of suffusion. Yo et al. used high pressure helium gas to measure the permeability of sandstone, and proposed a response surface method to study the effects of confining pressure, internal pressure, effective stress and water pressure on gas permeability, providing technical support for improving the permeability of sandstone. Zheng et al. studied the effect of moisture contents of coal on the strength, crack propagation model and pore structure. They found the micro-pores and meso-pores in coal are

developed into larger pores, while the fracture mode changes from the tensile failure to the tensile–shear failure with an increase in moisture content of coal. The above experimental studies indicated the existence of fluid in pores and fractures can lead to the change of micro-structure of geomaterials, and the seepage pressure affects the distribution of stress field in geomaterials. Modeling of fluid flow in different environments was a focus in the current topic. Li et al. developed a Darcy-Navier- Stokes coupling model to study groundwater flow and transmitting behaviors in karst aquifer. Xie et al. proposed a shear statistical damage constitutive model of rock joints containing seepage pressure, and determined model parameters related with seepage pressure. Moreover, hydro-thermal coupling effect on mechanical and deformation failure behaviors of rock was also investigated in the current topic. Zhao et al. investigated the effect of hydro-thermal treatment on mechanical behaviors of gritstone, and observed that the high temperature, high water pressure and the cooling down methods can affect the mechanical parameters of gritstone.

To date, many hydro-thermal coupling models have emerged to study the seepage-stress coupling effect in rock masses based on either discrete medium model (Indraratna 1995; Wang 2000; Zhang 2015; Ren et al., 2017) or continuous medium model (Suresh, 2014; Shojaei, et al., 2014; Zhang, 2017). Some corresponding numerical simulation include the finite element method (FEM) the extended finite element method (XFEM), and discrete element method (DEM). The above methods reveal the mechanism of the seepage in rock fracture. Nevertheless, there are some major disadvantages. One the one hand, although discrete medium models can effectively describe the heterogeneous and anisotropic hydraulic properties of fractures, the models are unable to determinate geometric parameters of all fractures in rock masses. On the other hand, continuous medium models regard the rock fractures network system as an equivalent continuous medium by some equivalent methods, which is simple and has strong ability of adaptation. However, these continuous models cannot describe the high conductivity behaviors of major fractures in fractured masses. In addition to explaining the seepage effect, another challenge is to account for the damage evolution, which lies in the following two aspects: 1) fluid flow in rock masses results in the change of pore pressure and rock deformation and damage in rock masses; 2) the damage increases the permeability of rock masses, which is a key parameter related with seepage characteristic, and degrades the stiffness of rock masses, which is a key parameter related with mechanical characteristic. Apparently, the above two nonlinear processes are related to the fluid-solid coupling effect and damage evolution, and both can be combined into a seepage-damage coupling. However, little attention has been paid to this complicated seepage-damage coupling effect.

The research on the seepage failure of geomaterials under hydro-mechanical coupling mostly depends on laboratory experiment. The relationships between the parameters such as damage, volume expansion, porosity and permeability have preliminarily been established. However, for engineering rock mass, the existence and development of rock fractures network make the above relationships more complex. The development of

rock fracture network resulting in the change of fracture connectivity enriches water flow path, and directly leads to the change of seepage field; at the same time, the change of seepage field affecting the stress field causes the change of fracture network. The seepage failure mechanism of engineering rock mass under some complex stress conditions (e.g. construction disturbance, and confined aquifer effect, etc) are still in an exploration stage. A lot of works should be done in the study of seepage failure laws of engineering rock mass under hydro-mechanical coupling.

The creep behaviors of various geomaterials as another research focus have been studied in our Frontiers Research Topic. The creep characteristics of geomaterials are very important for assessing the long-term stability of geological engineering. The creep behaviors of geomaterials result in the time-dependent deformation and failure of geological engineering. Griggs (1939) first carried out the creep tests on sandstone, shale and siltstone, and proposed the logarithmic empirical formula to reflect the creep constitutive relationship of rocks, and then Langer (1979) systematically expounded the basic concepts and laws of creep of geomaterials at the fourth International Conference on rock mechanics. Since then, the studies on creep behaviors of geomaterials have always been attracting much attention. At present, the investigations on creep behaviors of geomaterials have focused on the creep tests, creep constitutive models and numerical simulation. The creep tests of geomaterials can reveal the creep mechanical properties of geomaterials under different stress levels, and provide relevant creep parameters to establish appropriate creep constitutive and numerical analysis models. The creep constitutive models can be proposed by connecting viscous, elastic and plastic elements in parallel or series. For a specific geological engineering, how to select one or two suitable creep models and then determine the related creep parameters is an urgent problem to be solved in engineering. For soil creep behaviors, Chen et al. performed creep tests on coral sand revealing the laws of particle fractal and crushing evolution during creep process. He et al. and Xue et al. studied the creep characteristics of coarse-grained soil and red-clay under triaxial compression condition, respectively. For rock creep behavior, Zhao proposed a new experimental method to separate the viscoelastic and viscoplastic strain components from the total creep strain, and established some elastoviscoplastic creep models to realize the strain separation (Zhao et al., 2017a; Zhao et al., 2017c; Zhao et al., 2018). Liu et al. investigated the creep damage characteristics of the marble at high stress using Acoustic Emission (AE) technique, which provide a new idea to predict creep failure of rock. To study the shear creep characteristics of anchorage structure, Wang et al. proposed a non-linear creep model to analyze the viso-plastic deformation behaviors of anchorage structure. To study the effect of weak interlayer on rock creep behaviors, Tang and Zhao studied the influence of weak interlayer inclination angle on the creep properties of sand, and observed the instantaneous elastic and instantaneous plastic strains both increase with an increase in weak interlayer inclination angle.

To date, many creep testing methods have been proposed, such as single-level loading, multi-level loading, and multi-level loading and unloading cycles, among which, the multi-level

loading is a common and conveniently operative method. The laboratory creep tests of geomaterials are usually carried out by multi-level loading from low to high stresses, and the creep test results are arranged by the linear superposition principle to obtain the continuous creep curves. However, the creep characteristics of soft rock are generally highly nonlinear under high stress level, which may not meet the linear superposition principle. Therefore, new experimental methods to precisely capture the creep curves under various stress levels should be studied further. For creep constitutive model studies, the proposed creep constitutive models generally treated model parameters as constant, which are so-called linear creep problems. However, many creep experiments of rock indicated mechanical parameters (e.g. elastic modulus, strength and viscosity) exhibit time dependence. So the creep parameters should be regarded as unsteady variables to reflect the nonlinear viscous characteristics of rock. How to establish some nonlinear creep models with unsteady variables is worthy of further study. The size effect of creep behavior is also a valuable research issue. It is noted the creep parameters from laboratory-scale specimensstill cannot precisely reflect the creep characteristics of engineering rock mass due to the more complex geological structures in engineering rock mass.

Above all, hydro-mechanical coupling and creep behaviors of geomaterials both display time dependence and highly nonlinearity. We hope this Research Topic collection of papers can further enrich the research field.

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