Progressive rock mass failure around a tunnel excavation in a geological formation with discontinuities: A numerical study

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Abstract:
This study aims to develop a numerical methodology to model the progressive rock mass failure around an underground excavation for high-level nuclear waste disposal in fractured crystalline rocks. Two-dimensional (2D) geomechanical modelling of the fractured rock under geological in-situ stresses is achieved by the finite-discrete element method (FEMDEM), which can capture the deformation of intact rock matrix, the heterogeneity of local stress fields, the reactivation of pre-existing discontinuities, and the propagation of new cracks induced by tensile, shear or mixed-mode brittle failure. A calibration is conducted based on the laboratory-scale uniaxial compression test and Brazilian disc test to tune the geomechanical model in order to produce consistent macroscopic tensile and shear strengths with the input microscopic mechanical properties. To realistically simulate the shear strength of naturally occurring rough fractures, a joint constitutive model is incorporated that can take into account the effect of asperity degradation and the scale-dependency of joint roughness. The rock mass model is based on the site characterisation data of a geological formation in the Sellafield area, Cumbria, England. Discrete fracture networks (DFNs) of 20 m × 20 m are constructed to represent the fractured state of the geological medium based on the statistics of four fracture sets observed in the field which exhibit a power law length distribution. The hypothetical circular tunnel with a diameter of 3 m is placed at the centre of the field-scale model domain and the response to stresses is modelled for a range of tunnel depth scenarios. The plain strain numerical experiment is designed with multiple sequential deformation-solving phases (see Fig. A below). An excavation damage zone (EDZ) around the unsupported man-made opening is formed by the coalescence of pre-existing discontinuities linked by new cracks that propagate in response to the excavation process. The results of this study have important implications for designing stable underground openings for nuclear waste repositories as well as other engineering facilities which are intended to generate minimal damage in host media.

Biography:
Qinghua Lei is a 3rd-year PhD student supervised by Dr John-Paul Latham in the ESE department. He holds a BSc degree in Civil Engineering and an MSc degree in Geotechnical Engineering from Tongji University, China. His PhD research is focused on hydromechanical modelling of fracture networks.
Fig. A. Geomechanical modelling of a horizontal underground excavation in a fractured crystalline rock (model size is 20 m × 20 m) at a depth of 1000 m with an overburden stress of 19.80 MPa and a maximum horizontal stress of 23.15 MPa. The numerical experiment is a sequence of different phases: (a) force equilibration under the geological in-situ stress condition that pertains before the excavation, (b) central core relaxation during the excavation, (c) physical removal of materials inside the tunnel after the excavation, and (d) evolution of the excavation damage zone around the unsupported opening. (Note: black lines represent the pre-existing discontinuities in the geological formation, and the colour contours represent the maximum principal stress distribution.)