Introduction to the Special Issue: Nonlinearity and numerical simulation applications in geotechnical engineering

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In the very early engineering design, engineers simplified the deformation behavior, constitutive model and failure mechanism of rock and soil, which were limited to the scope of linear elasticity. Later, with the development of geotechnical engineering, the scale of engineering became larger and larger, and the problems involved became more and more complicated, and engineering accidents caused by computing defects became more and more serious. Thus, scholars have realized that it is not enough to treat rock and soil simply as a linear elastic material. Nonlinear and numerical simulation is indispensable in geotechnical engineering.

Finite element method is the most widely used numerical simulation method in geotechnical engineering. In recent years, scholars have applied finite element analysis software in slope stability analysis [1-3], tunnel excavation [4], foundation pit excavation [5] and other fields. For example, based on the generalized Biot's dynamic consolidation theory, Zou et al. [6] analyzed saturated soils by using the polygon scale boundary finite element method, and the results are in good agreement with the computations of finite element method.

The finite difference method is an old numerical simulation method. In the 1980s, the ITASCA company of the United States developed the FLAC program based on the finite difference method. Subsequently, this method is widely used in numerical simulation of geotechnical engineering [7, 8]. Liu et al. [9] used a finite difference time domain method to establish a three-dimensional hole-bedrock-cave model for sonar detection of karst cavities. Kim and Larson [10] used FLAC3D to model the initiation and initial evolution of a strike-slip fault, and FLAC3D successfully replicated and created 3D fault zone of strike-slip faults within the entire thickness range of the model. There is also a paper in this Special Issue that utilizes the finite difference method in geotechnical engineering, "Numerical Analysis of Hard Rock Tunnel Excavated by Double Shield TBM based on CWFS model, Diyuan Li, Jing Sun, Quanqi Zhu, Xiangyun Xu, Jian Jiao". In their article, Flac3D was utilized to evaluate the practicability of DS-TBM (double shield tunnel boring machine) in a deep-buried high geostress tunnel.

Compared with the finite element method, the advantage of the boundary element method is that it can simplify the calculation by dimension reduction. Mostly, the boundary element method is mainly utilized in an excavation of underground engineering [11], analysis of soil structure interaction [12, 13] and seepage analysis [14]. Based on the boundary element method, Auersch [15] proposed a method combining the finite element boundary element method to calculate the dynamic interaction between soil mass and flexible structures such as single pile or complete wind tower. Xiao [16] proposed a boundary element method based on system partition and coupling strategy.

There are two kinds of geotechnical materials targeted by the discrete element method: one is granular geotechnical material, the other is continuum material. The application of the discrete element method on geotechnical engineering was developed in a paper of this Special Issue: "Numerical simulation of hydraulic fracturing in transversely isotropic rock masses based on PFC2D, Lei Xia, Yawu Zeng". In their article, the bonded-particle element method with embedded smooth joints was applied to establish the transversely isotropic rock masses.

In addition, "Macroscopic and microscopic simulation of silo granular flow based on improved multi-element model, Feng Yong, Yuan Ziran", a paper about the improvement of discrete element numerical simulation, was also included in this Special Issue. In their article, an improved multi-element model consisting of clump elements and ball elements was proposed.

The fracture mechanics no longer regards materials as a homogeneous continuum, but as composite structures with many defects and cracks. The strength analysis of the material is based on the analysis of these defects and cracks. The optimum penetration depth and the synergistic effect of TBM (Tunnel Boring Machine) rock breaking under the different cutter spacings was investigated by Wang Zhu, Cao Ping, Chen Yu, in their paper "Study on the optimum penetration depth by two TBM cutters under different cutter spacings". In their article, a series of studies based on fracture mechanics were analyzed through a model test.

There are still many nonlinearity numerical simulation methods suited for geotechnical engineering which was not mentioned above. The coordination of multiple numerical simulation methods has also become a problem that needs to be solved.

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