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Editorial

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Microstructures and micromechanics of geomaterials

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1 Introduction

Geomaterials, such as soil, rock, and concrete, have a clearly defined microstructure at the level of individual grains (Sprunt and Brace, 1974; Ichikawa et al., 2001). While difficult to observe directly, these microstructures, including their particle size distribution, particle shape, mineralogy, interaction, and bonding behavior, have a strong influence on both micro- and macroscopic behaviors of geomaterials (Gao and Zhao, 2013; He et al., 2018; Alqam et al., 2019; Sun et al., 2020; Yin et al., 2020; Wang et al., 2022). In recent years, various kinds of engineered geomaterials, such as fiber-reinforced and bio-reinforced soils, have been shown to have even more sophisticated microstructures (Uygunoğlu, 2008; Mujah et al., 2019; Akeed et al., 2022). Additionally, the interaction between various microstructures and fluid flows further complicates attempts to understand the associations between the microstructure and performance of geomaterials (Xiong et al., 2021; Wang P et al., 2023).

The significant role of the microstructure has prompted the development of advanced experimental, theoretical, and numerical methods, which have significantly improved our fundamental understanding of the mechanics of geomaterials (Gao et al., 2014). Modern observation technologies, such as X-ray computed tomography (X-ray CT), differential interference contrast (DIC) microscopy, and scanning electron microscopy (SEM), have been widely adopted in experimental analysis, allowing direct observation of the microstructures and their evolution during tests (Karatza et al., 2019; Lei et al., 2019; Zhao et al., 2020). Based on experimental results and observations, a myriad of micro-mechanics based constitutive models has been proposed to establish quantitive relationships between the evolution of microstructures such as particle shape, breakage, and fabric, with the macroscopic behaviors of geomaterials (Daouadji et al., 2001; Romero and Simms, 2008; Hu et al., 2011; Shen et al., 2022). In terms of numerical analysis, novel computational methods have been developed for the multiscale modeling of geomaterials, including discrete element model (DEM), particle finite element method (PFEM), material point method (MPM), smoothed particle hydrodynamics (SPH), and peridynamics (PD) (Zhao et al., 2017; He et al., 2018; Jin et al., 2021; Yin et al., 2021; Yuan et al., 2021; Liang et al., 2023).

This special issue aims to share recent development and knowledge on the microstructures and micromechanics of geomaterials. It provides an up-to-date view as well as an outlook on the cutting-edge research and development on multiscale analysis of geomaterials, including particle–particle and particle–fluid interactions, X-ray CT technology and observations, particle breakage and morphology, and numerical modeling of particles and grains. Several experts in related fields share their most recent research outputs. Herein, we briefly introduce the papers as follows:

Suffusion preferentially occurs in gap-graded soil when, under seepage forces, fine particles erode through the pores among larger particles. A reduction in the fines content (FC) can alter the hydraulic and mechanical behavior of soils, posing a significant risk to engineering safety. Wang T et al. (2023) conducted

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a series of experimental tests on gap-graded soils to analyze the evolution of suffusion under various hydraulic gradients. Then, they developed a numerical model coupling DEM with dynamic fluid mesh (DFM) to understand the suffusion mechanism at the pore scale. Their findings illustrate the migration of fines and the formation of erosion zones. They also conducted a parametric study to explore the impacts of hydraulic gradient, FC, and K_0 pressure on the eroded weight. The results indicate that eroded weight increases with an increase in the hydraulic gradient and FC, but decreases with an increase in K_0 pressure.

The behavior of granular geomaterials varies under different loading conditions, exhibiting hysteresis and other characteristics. To analyze the deformation characteristics of crushable particle materials, Lin et al. (2023) simulated a series of cyclic loading tests considering particle breakage using DEM. They investigated the hysteretic behavior at the particle scale, finding that an increase in particles with fewer than two contacts may contribute to residual strain, while particle breakage promotes rearrangement and volume contraction. Plastic strain accumulation and the resilient modulus were found to be influenced by confining pressures, stress levels, cyclic loading amplitudes, and the number of cycles. Based on these findings, a function was proposed to describe the evolution of the resilient modulus, and a relationship between plastic strain accumulation and the number of cycles was established.

Particle morphology plays an indispensable role in particle kinematics and macroscopic behavior, and thus should be considered in the analysis of granular soils. Xiong et al. (2022) incorporated X-ray micro-computed tomography (X-ray μCT), spherical harmonical-based principal component analysis (SH-PCA), and DEM to generate 27 virtual sand samples with various degrees of morphological gene mutation at different length scales. By constructing the samples with the one-to-one mapping technique and conducting triaxial compression on the samples, they explored the effect of particle morphology on the stress-strain and energy redistribution within granular soils. Simulation results indicate that the effect of particle morphology on the mechanical behavior and energy redistribution is more pronounced for looser samples than for denser ones. In addition, the energy dissipation within a granular assembly is a result of competition between particle morphology and the initial void ratio.

The presence and growth of joints heavily influence the damage sustained by a rock mass, and understanding the mechanical behavior of rock masses requires a proper representation of the loading path. Duan et al. (2023) used the DEM to examine the influence of loading paths on the cracking process of a rock specimen with an open flaw. The simulation results were compared with previous research findings, which confirmed the effectiveness of the model. A wing crack initiates first under a uniaxial compression test, and secondary cracks contribute to the specimen's failure. The simulation results further indicated that both confining pressure and loading path are critical factors in the cracking process. Under axial loading, a higher confining pressure suppresses the development of tensile wing cracks and leads to the formation of secondary cracks in the form of shear bands perpendicular to the flaw. Moreover, they found that an increase in confining pressure reduces the influence of the loading path on the cracking process. During an unloading test, reducing confining pressure amplifies the concentration of tensile stress, ultimately promoting the appearance of a tensile splitting fracture at meso-scale. Finally, the Hoek-Brown failure criterion can accurately predict the confining pressure at the failure stage under quasi-static conditions.

The papers presented in this special issue enhance our comprehension of microstructure and micromechanics, offering a more scientific and fundamental understanding of the macroscopic behavior of geomaterials. Covering diverse topics and backgrounds such as suffusion, particle morphology, fracture propagation, and hysteretic behavior in relation to geotechnical structures, we anticipate that this special issue will offer valuable guidance for infrastructure design and construction. Additionally, we trust that these selected papers will inspire researchers and engineers in their respective areas and provide a solid foundation for future studies.

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Author contributions

Pei WANG conceived and edited the draft manuscript. Zhenyu YIN performed the literature review and revised the first draft of the manuscript. Sheng DAI revised and edited the final version.

Conflict of interest

Zhenyu YIN, Pei WANG, and Sheng DAI declare that they have no conflict of interest.

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Introducing Guest Editor-in-Chief and Guest Editors:

Guest Editor-in-Chief

Prof. Zhenyu YIN has been an Editorial Board Member of *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)* since 2019. Prof. YIN is currently Full Professor of Geotechnical Engineering at The Hong Kong Polytechnic University (China). Prof. YIN received his B.Eng. in Civil Engineering from Zhejiang University (China) in 1997, followed by five years of engineering consultancy at the Zhejiang Jiahua Architecture Design Institute (China). Then, he obtained his M.Sc. degree and Ph.D. degree in Geotechnical Engineering at Ecole Centrale de Nantes (France) in 2003 and 2006, respectively. Prof. YIN has published over 250 articles in peer-reviewed international journals with an H-index of 51 according to the Web of Science. He is an Associate Committee Member of the Granular Materials Committee of American Society of Civil Engineers, Associate Editor of *European Journal of Environmental and Civil Engineering* and *Geotechnique Letters*, and Editorial Board Member of some top journals in the field of soil mechanics and geotechnical engineering (*Canadian Geotechnical Journal*, *International Journal of Geomechanics ASCE*, *Soils and Foundations*, *Acta Geotechnica*, *Transportation Geotechnics*, *Computers and Geotechnics*, *GeoRisk*, etc.).

Guest Editors

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Dr. Sheng DAI is an associate professor in the School of Civil and Environmental Engineering, Ocean Science and Engineering, and holds a courtesy appointment at the School of Earth and Atmospheric Sciences at Georgia Institute of Technology (USA). He earned his degrees from Tongji University (China) and Georgia Institute of Technology, and was an ORISE postdoc at the National Energy Technology Laboratory of the U.S. Department of Energy. Dr. DAI and his group study geomaterials and geomechanics, energy geotechnics, and bio-inspired geotechnics to address emerging energy and environmental challenges. He is an associated editor of *Journal of Geophysical Research: Solid Earth* and serves on the editorial board for *Geomechanics for Energy and the Environment* and *Advances in Geo-Energy Research*. He is the recipient of the NSF CAREER Award.