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Editorial
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Soil particle–fluid interaction problems in geotechnical engineering oriented towards sustainability

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Geo-hazards, such as landslides, debris flows, dike and levee failures, ground subsidence, and sinkhole formation, result in large-scale loss of life and significant damage to infrastructure. Mitigating and preventing these hazards is a persistent challenge in geotechnical engineering. A key mechanism underlying many geo-hazards is particle migration induced by soil–fluid interactions. These interactions govern critical phenomena such as surface and internal erosion, sediment transport, suffusion, piping, slurry and grout penetration, and saturated and unsaturated soil behavior under varying conditions. For example, statistical analyses have identified internal erosion as a major factor compromising the safety of dams and dikes, being one of the primary causes of embankment dam failures. Internal erosion also affects underground structures, as it contributes to land subsidence through water piping-induced erosion, causes lateral displacements during jet grouting, induces surface settlement due to tunnel leakage, and leads to slope instability via migration of fine soil particles during rainfall.

Despite recent advancements in understanding soil–fluid interactions, significant gaps remain, particularly regarding complex interplay and prediction of behavior in real-world conditions. Over the past several decades, experimental studies have provided valuable insights into the mechanisms of soil–fluid interactions. These studies have primarily focused on factors such as soil gradation, critical hydraulic gradient, pore water velocity, stress state, flow direction, particle shape, and soil fabric, to characterize the susceptibility of soils to various geo-hazard phenomena. In parallel, numerical approaches have been developed to model soil–fluid interactions, including continuum-based methods like the finite element method (FEM) (Yang et al., 2019), and particle-based techniques such as computational fluid dynamics coupled with the discrete element method (CFD-DEM) (Wang T et al., 2022; Wang P et al., 2023). These numerical methods enable grain-scale physics and multiphase flow modeling, and have greatly enhanced our understanding of soil–fluid interactions. Recently, big data analytics and artificial intelligence (AI) have emerged to complement conventional physics-based models (Yang et al., 2021), showing potential for addressing practical geotechnical problems and promoting sustainable solutions.

To advance the understanding of the fundamental mechanisms of soil particle–fluid interactions and their associated risks, we are pleased to present a collection of papers authored by leading researchers in the field. These contributions cover experimental investigations, numerical modeling, and practical applications regarding this theme.

Li et al. (2024) explored the impacts of dry–wet cycling on the mechanical properties and microstructural characteristics of fine breccia soil from karst regions, which are characterized by frequent rainfall and karst water environments. By employing triaxial shear tests and electron microscopy, the study analyzes soil samples with varying initial water contents and compaction levels. The findings suggest that high-pressure compaction, along with maintaining an optimal moisture

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content, significantly enhances the soil's resistance to degradation from dry–wet cycles. Moreover, increased compaction improves the particle size distribution and skeleton density, effectively reducing particle erosion and bolstering roadbed stability in karst areas. In addition, the authors develop a micro-to-macro correlation and normalization model to elucidate these relationships.

Zhang et al. (2024) focused on the waterproofing performance of tunnel longitudinal joints under external loads, utilizing full-scale experimental testing. A custom-made rig is employed to investigate the influence of loading magnitude, eccentricity, and load–unload–reload cycle count on the joint's water tightness. The results demonstrate that external loads notably decrease the compression of sealing gaskets, thereby weakening their waterproofing capacity. Additionally, higher bending moments significantly reduce the water tightness limit, while repeated loading cycles cause further deterioration in waterproofing performance. These observations may aid the design of waterproofing systems in segmental tunnel joints, resulting in better long-term operational safety.

Su et al. (2024) examined the resilient modulus (M_r) of fine/coarse soil mixtures in railway substructures under different water contents and deviator stress amplitudes (σ_d). By using mercury intrusion porosimetry (MIP) and multi-stage dynamic triaxial tests, the study identifies two distinct soil fabrics: a fine matrix fabric (w_f>w_p) and a fine aggregate fabric (w_f<w_p), where w_f represents the water content and w_p is the plastic limit of the fine soil. For the fine matrix fabric (w_f>w_p), the results reveal that increasing σ_d leads to decreasing M_r, due to the dominant influence of soil rebounding; this stems from the soil's high deformability. In contrast, for the fine aggregate fabric (w_f<w_p), increasing σ_d results in higher M_r, due to the prevailing hardening effect of the less deformable soil. These findings shed light on the balance between soil hardening and rebounding effects, and may offer guidance for optimizing the mechanical behavior of railway substructure soils under dynamic loads.

Nie et al. (2024) investigated the permeability of structured porous media using a combination of microfluidic models, numerical simulations, and comparisons with the Kozeny-Carman (KC) equation. The study reveals that permeability behavior is governed by the Reynolds number (*Re*): below a threshold of *Re*=1, permeability remains constant, but above this value, it decreases with increases in *Re* due to the dominance of viscous forces. Furthermore, permeability increases with micropillar diameter, while triangular pillar arrangements exhibit 4.5%–7.4% lower permeability and 5.1%–7.9% higher tortuosity than square pillar arrangements. A novel tortuosity model is introduced, establishing an inverse relationship between permeability and tortuosity. The numerical simulations align with experimental results, and the KC equation provides reasonable estimates for porosities between 0.50 and 0.60. Additionally, anisotropy induced by varying the tilt angle of rectangular micropillars affects the flow behavior by reducing effective porosity and tortuosity (from 2.04 to 1.03) and increasing permeability (from 1.0×10^{-11} m^2 to 4.3×10^{-11} m^2), as the tilt angle rises from 0° to 90°. These findings provide insights into anisotropic flow and permeability modeling in microfluidic systems.

This special issue provides a platform for researchers and engineers to present and discuss recent advancements in soil particle–fluid interaction problems within geotechnical engineering. We hope that the shared findings will deepen the understanding of the complex interplay between soil particles and fluid dynamics in geotechnical systems, aiding the advancement of innovative and sustainable engineering solutions. We anticipate that the selected articles will stimulate meaningful discussions among scientific researchers, leading to new ideas and perspectives for readers of this journal.

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Author contributions

Zhen-Yu YIN provided the concept and edited the draft of manuscript. Jie YANG conducted the literature review and wrote the first draft of the manuscript. Ming XIAO edited the draft of manuscript.

Conflict of interest

Jie YANG, Zhen-Yu YIN, and Ming XIAO declare that they have no conflict of interest.

References

Li X, Chen HQ, Su D, et al., 2024. Effect of dry–wet cycles on the mechanical properties and microscopic characteristics

of fine breccia soil from karst areas. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*, 25(12):974-990.
https://doi.org/10.1631/jzus.A2400018

Nie SK, Liu PF, Chen KX, et al., 2024. Permeability of structured porous media: numerical simulations and microfluidic models. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*, 25(12):1018-1036.
https://doi.org/10.1631/jzus.A22300516

Su Y, Zhang Y, Duan JY, et al., 2024. Investigation on the resilient modulus of soil mixture at various water contents and coarse grain contents under train moving loads. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*, 25(12):1006-1017.
https://doi.org/10.1631/jzus.A2300492

Wang P, Ge Y, Wang T, et al., 2023. CFD-DEM modelling of suffusion in multi-layer soils with different fines contents and impermeable zones. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*, 24(1):6-19.
https://doi.org/10.1631/jzus.A2200108

Wang T, Wang P, Yin ZY, et al., 2022. DEM-DFM modeling of suffusion in calcareous sands considering the effect of double-porosity. *Computers and Geotechnics*, 151:104965.
https://doi.org/10.1016/j.compgeo.2022.104965

Yang J, Yin ZY, Laouafa F, et al., 2019. Modeling coupled erosion and filtration of fine particles in granular media. *Acta Geotechnica*, 14(6):1615-1627.
https://doi.org/10.1007/s11440-019-00808-8

Yang J, Liu Y, Yagiz S, et al., 2021. An intelligent procedure for updating deformation prediction of braced excavation in clay using gated recurrent unit neural networks. *Journal of Rock Mechanics and Geotechnical Engineering*, 13(6):1485-1499.
https://doi.org/10.1016/j.jrmge.2021.07.011

Zhang DM, Chen SR, Huang ZK, et al., 2024. Waterproofing performance of longitudinal segmental tunnel joints under external loads: a full-scale experimental investigation. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*, 25(12):991-1005.
https://doi.org/10.1631/jzus.A2400354

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Guest Editor-in-Chief

Dr. Jie YANG has been a Professor of Geotechnical Engineering at Shenzhen University, China since 2023. Dr. YANG received his BEng and MSc in Civil Engineering from Tongji University, China. Then, he obtained his PhD in Geotechnical Engineering at Ecole Centrale de Nantes, France. Dr. YANG worked as a postdoctoral researcher at The Hong Kong Polytechnic University before joining Shenzhen University. Dr. YANG's research interests include soil seepage-induced internal erosion, constitutive modelling for geomaterials, soil-structure interaction, multi-physics analysis in geotechnical engineering, and related topics.

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