Computers and Geotechnics 179 (2025) 106995

Contents lists available at ScienceDirect

Computers and Geotechnics

journal homepage: www.elsevier.com/locate/compgeo

Special issue on Recent Advances in Solving Coupled Problems in Geomechanics, Geophysics, and Geotechnical Engineering[☆]

It is our great pleasure to introduce this special issue of *Computers and Geotechnics*, titled *Recent Advances in Solving Coupled Problems in Geomechanics, Geophysics, and Geotechnical Engineering*. This issue presents a collection of state-of-the-art research papers that address the significant challenges posed by coupled flow-deformation processes in saturated and unsaturated porous media.

Coupled problems are central to many critical applications in geomechanics, geophysics, and geotechnical engineering. These applications include rainfall-induced slope failures and landslides, internal erosion, hydraulic fracturing, oil and gas extraction, CO_2 sequestration and hydrogen storage in geological formations, geothermal energy production, and soil degradation due to chemical dissolution. Addressing such complex phenomena demands sophisticated mathematical models to describe phase interactions and transformations, as well as advanced computational frameworks capable of describing and predicting highly nonlinear responses.

The papers in this issue reflect the depth and breadth of this research area:

1. Investigation of particle segregation in a vertically vibrated binary mixture: Segregation process and mechanism
   Shaoheng Dai, Sheng Zhang, Feng Gao, Xuzhen He, Daichao Sheng
   This study explores particle segregation in binary granular mixtures subjected to vertical vibrations, focusing on global and local segregation processes using discrete element method (DEM) simulations. It reveals the Brazil Nut Effect, where larger particles rise while smaller ones settle, with vertical segregation preceding radial segregation. A segregation index is introduced to quantify such behavior, and phase transitions during particle segregation are identified. Key mechanisms such as pore filling and convective rolling are highlighted. The findings provide insights into microstructural changes in granular materials under external disturbances, with implications for scenarios such as earthquakes, debris flows, and traffic loads.
2. Multiscale modeling of coupled thermo-hydro-mechanical behavior in ice-bonded granular media subject to freeze–thaw cycles
   Jidu Yu, Jidong Zhao, Weijian Liang, Shiwei Zhao
   This paper introduces a novel multiscale framework that combines the single-point multiphase material point method (MPM) and discrete element method (DEM) to model freeze–thaw behavior in ice-bonded granular media. The approach integrates DEM-based representative volume elements (RVEs) within MPM to link macroscopic phenomena with microstructural evolution. It employs a semi-implicit staggered integration scheme to enhance computational efficiency and stability, and introduces ice saturation-dependent bond contacts to replicate thermodynamically sensitive mechanical responses. Validated against analytical solutions and applied to cyclic freeze–thaw simulations, the framework effectively captures loading- and state-dependent thermo-hydro-mechanical responses, providing insights into complex freezing and thawing mechanisms.
3. Hydromechanical embedded finite element for conductive and impermeable strong discontinuities in porous media
   Danilo Cavalcanti, Cristian Mejia, Deane Roehl, Ignasi de-Pouplana, Eugenio Oñate
   This study presents a new fully coupled hydromechanical embedded finite element method (EFEM) to model fault reactivation in porous media. Unlike existing EFEM formulations, the proposed method accurately captures the dual role of faults as either fluid flow paths or barriers, addressing limitations in hydromechanical modeling. The approach leverages the Strong Discontinuity Approach to represent faults within the domain without requiring mesh conformity, simplifying faulted domain modeling. Applied to fault reactivation scenarios, the method reveals critical reactivation mechanisms and examines spurious oscillations along discontinuities, offering insights into their relationship with mesh discretization and improving modeling accuracy.
4. Closed-form solutions for shear wave propagation and attenuation in multiphase porous media
   Babak Shahbodagh, Nasser Khalili
   This paper derives simple yet rigorous analytical solutions for shear wave propagation in saturated and unsaturated geomaterials using multiphase mixture theory, addressing inertial coupling effects among phases. The solutions establish relationships between shear wave velocity and attenuation with excitation frequency, volume fractions, densities, and fluid phase hydraulic conductivities. These insights are valuable for characterizing geomaterials via in-situ, geophysical, and laboratory tests. Model simulations, validated against experimental data, demonstrate the practical application of the solutions. The work provides a rigorous framework for advancing geotechnical and geophysical investigations involving shear wave-based parameter evaluations

[☆] This article is part of a special issue entitled: 'Solving coupled problems' published in Computers and Geotechnics.

https://doi.org/10.1016/j.compgeo.2024.106995

Available online 13 December 2024

5. Numerical framework for coupling SPH with image-based DEM for irregular particles
   Mehryar Amir Hosseini, Pejman Tahmasebi
   This paper proposes a numerical framework integrating Smoothed Particle Hydrodynamics (SPH) with the Image-based Discrete Element Method (iDEM) to model fluid-particle interactions while accounting for realistic particle shapes. Validated through water entry simulations of spheres and cubes, the framework was applied to a dam break scenario involving irregular and cubic grains. Results highlight the influence of particle shape, with cubic grains enabling greater fluid mobility due to reduced interlocking and increased surface area, leading to higher velocities and displacements. This work advances the understanding of fluid-particle interactions in complex systems, emphasizing the role of particle shape in such analyses.
6. Coupled vibratory roller and layered unsaturated subgrade model for intelligent compaction
   Chuxuan Tang, Zheng Lu, Lang Qin, Tingzhou Yan, Jian Li, Yang Zhao, Yu Qiu
   This paper presents an analytical model to study the coupled dynamic interaction between a vibratory roller and a layered unsaturated subgrade, aiming to enhance intelligent compaction practices. The roller is modeled as a lumped parameter system, and the subgrade as a layered poroelastic medium. Using the double Fourier transform, the steady-state solution is derived and validated against published analytical results and field test data. Key findings reveal the subgrade modulus and underlying layer thickness significantly influence roller drum acceleration responses. The study recommends low-frequency excitation for thin subgrades (<2 m) and both low and high frequencies for thicker subgrades, optimizing compaction assessment strategies.
7. A three-phase two-point MPM for large deformation analysis of unsaturated soils
   Yosuke Higo, Yudai Takegawa, Fan Zhu, Daichi Uchiyama
   This paper presents a three-phase, two-point formulation of the Material Point Method (MPM) for modeling large deformations in unsaturated soils. The formulation uses separate layers of material points to represent solid, liquid, and gas phases, with a u-U formulation that eliminates advection terms between the solid and liquid phases while assuming small advection between liquid and gas phases. The method is validated against numerical models for small and finite deformation problems and applied to simulate seismic-induced ground liquefaction in an unsaturated embankment. Results show the method's ability to capture large soil deformations, excess pore pressure generation, and pore pressure dissipation via rapid water drainage in high-permeability soils.
8. Crack opening calculation in phase-field modeling of fluid-filled fracture: A robust and efficient strain-based method
   Fan Fei, Jinhyun Choo
   This paper presents a novel method for calculating the crack opening (aperture) in phase-field modeling of fluid-filled fractures, addressing the challenge of representing complex fracture geometry without requiring algorithms. The proposed approach transforms the displacement-jump kinematics of fractures into a continuous strain-based formulation, which is then incorporated into a force balance equation with phase-field approximation. The method yields a simple equation for crack opening, computable directly from quantities at individual material points, avoiding the need for additional algorithms or element-dependent parameters. The approach is validated through comparisons with analytical and numerical solutions, demonstrating its robustness and accuracy across varying element sizes and alignments.

We would like to extend our deepest gratitude to the authors for their outstanding contributions and to the reviewers for their invaluable feedback and dedication. Their efforts have ensured the high quality of this special issue. We also thank the editorial team at Computers and Geotechnics for their continued support throughout this process.

We hope this special issue serves as a valuable resource for researchers and practitioners, fostering innovation and collaboration in geomechanics, geophysics, and geotechnical engineering.

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