Contribution ID: **699** Type: **Oral Presentation**

New insights into unsaturated soil mechanics: analytical derivation of pore-pressure coefficients using a generalized effective stress framework

Wednesday 21 May 2025 12:35 (15 minutes)

Geotechnical operations such as slope excavation, earth dam construction, and drawdown scenarios often involve rapid mechanical loading or unloading in unsaturated soils. These dynamic processes typically progress so quickly that they do not allow for pore water and air migration, thereby inducing significant changes in pore water and air pressures. Accurately predicting these pressure changes is crucial for understanding the mechanical response of the soil. Predicting the induced pore water pressure change for saturated soils involves calculating or experimentally determining the pore-pressure coefficients using effective stress-based analyses. However, similar methodologies for unsaturated soils are lacking. This paper introduces analytical expressions for determining the pore pressure coefficients in unsaturated conditions, employing a generalized effective stress concept. The formulations apply to various stress paths, including isotropic, oedometer, uniaxial, and triaxial, and they account for the coupled responses of pore water and air pressures under undrained isothermal conditions. The proposed method requires fewer constitutive parameters than existing models; it aligns with traditional formulations for saturated soils at full saturation and uniquely enables the analytical derivation of the undrained soil water retention curve (uSWRC). Traditionally, the SWRC is determined under drained conditions, describing variations in the degree of saturation-suction relationship. In contrast, this study provides the relationship between the degree of saturation and suction during an undrained process, marking a significant departure from conventional practice. The model's performance has been validated against experimental data from diverse loading paths, demonstrating robust correlations in the predicted pore-pressure evolutions. Detailed flowcharts and the "UnDra" computational tool to support engineering applications are provided. This model is particularly valuable for analyzing undrained unloading and loading in overconsolidated states, thus enhancing safety assessments and decision-making for short- and long-term scenarios.

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References

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Session Classification: MS12

Track Classification: (MS12) Advances in computational and experimental poromechanics