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Editorial

Environmental Geotechnics

Editorial: Multiscale innovation and resilience in environmental geotechnics

Xiaohao Sun
Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, Kowloon, China (xiaohao.sun@polyu.edu.hk)

The field of environmental geotechnics has entered a pivotal era where the traditional boundaries of soil mechanics are expanding to meet global imperatives of climate action, resource circularity, and environmental restoration. As we confront the dual challenges of a rapidly changing climate and the accumulation of industrial waste, the role of the geotechnical engineer has evolved. Today, it encompasses not only the physical stability of infrastructure but also the chemical, biological, and geophysical integrity of the Earth's surface. This issue presents six papers that collectively illustrate this evolution, offering innovative solutions ranging from microscopic bio-stabilisation and engineered barriers to regional monitoring of thawing Arctic shelves and the integration of geothermal energy in tunnel systems.

The issue begins with a focus on sustainable soil modification. Song *et al*. (2026) addressed the persistent geotechnical challenge of expansive soils, which caused billions in annual damage due to their extreme volume instability. Moving away from carbon-intensive stabilisers such as ordinary Portland cement, the authors explored microbially induced calcium carbonate precipitation as a low-carbon alternative. By utilising the metabolic activity of *Bacillus pasteurii*, the study identified an optimal cementing solution concentration (1 mol/l) that maximised strength and minimised swelling. Through scanning electron microscopy and nuclear magnetic resonance, the authors provided a definitive look at how calcium carbonate crystals bridged soil particles and fill macropores, effectively re-engineering the soil's microstructure for long-term resilience.

The integrity of engineered systems was further explored by Polat *et al*. (2026) who examined the barrier performance of geosynthetic clay liners (GCLs). GCLs are thin, composite barriers used worldwide for waste containment, but their effectiveness relies heavily on the uniformity of bentonite distribution. The authors highlighted a practical but often overlooked problem: bentonite migrated within a GCL roll during transportation and installation, leading to variations in the bentonite mass per unit area (MPUA). By testing these liners against calcium chloride solutions, the study revealed that while GCLs performed excellently with deionised water, their resistance to aggressive leachates was highly sensitive to MPUA. At lower mass levels (3.0 kg/m^2), the bentonite was insufficient to block preferential flow paths through 'bundles of fibres' in the GCL structure, particularly as cation exchange suppresses the bentonite's swelling capacity. This research serves as a critical warning for practitioners, emphasising that site-specific testing and rigorous quality control are non-negotiable for long-term waste containment.

Ozenturk *et al*. (2026) shifted the discipline's focus towards environmental restoration. Salinisation is an escalating threat to coastal agricultural sustainability and infrastructure durability, often rendering land infertile and corroding steel and concrete. The authors presented a laboratory-scale study on electrokinetic remediation (EKR) using soil from the Kavak Delta (Türkiye), a region vital for rice and grain cultivation. By applying a constant electrical potential, the study successfully mobilised and redistributed salts towards the cathode, achieving a significant reduction in salinity and total dissolved solids in the anode region. Despite challenges such as electrode corrosion, this research proved that EKR was a viable, high-tech solution for reclaiming saline land and supporting long-term food security and structural resilience in coastal plains.

Li *et al*. (2026) bridged the gap between waste management and construction materials by investigating Red Mud (RM), a hazardous by-product of aluminium production. RM stockpiles pose massive ecological risks due to heavy metal leaching, particularly chromium (Cr) and lead (Pb). The authors developed RM-based engineered cementitious composites (RECC) and systematically evaluated the solidification mechanisms of these heavy metals. By introducing stabilisers like attapulgite, the study achieved solidification rates exceeding 99% for several metals. The authors further elucidated how hydration products immobilised metals via physical encapsulation, chemical adsorption, and ion exchange. This work represents a significant step towards the circular economy, transforming a high-risk industrial waste into a high-value construction material for infrastructure projects.

Jiang *et al*. (2026) explored the thermal behaviour of 'energy tunnels', an innovative technology that integrated ground-source heat pump systems into tunnel linings. In regions affected by permafrost, tunnels often suffer from frost damage, including icing and lining deformation. By utilising geothermal energy, the authors demonstrated through model tests how heat exchange fluid increased the tunnel's inner wall temperature by about 6°C, providing active frost protection. Their study analysed the effects of fluid flow rates and inlet temperatures, offering practical guidance for implementing affordable, clean energy solutions in underground infrastructure. This research highlights the potential for energy tunnels to serve as both structural conduits and renewable energy heat exchangers.

Finally, the issue concludes with a study on resource circularity and stress-dependent behaviour by Han and Choo (2026). Addressing the global stockpile of waste scrap tires, the authors investigate the coefficient of lateral stress at rest (K_0) of rigid sand-soft tyre chip mixtures. Using a modified oedometer cell, they revealed a non-linear relationship between tyre chip content (TC) and K_0. Interestingly, for mixtures with an overconsolidation ratio (OCR) ≤ 4, K_0 initially increased at low TC before decreasing and eventually converging to the behaviour of pure tyre chips. Due to the high elastic recoverability of the rubber, the influence of stress history on K_0 was significantly reduced at higher concentrations. The authors proposed a modified K_0-estimating equation and a new OCR-adjustment parameter, providing critical design guidelines for utilising recycled elastomers in sustainable construction.

Collectively, these papers demonstrate that engineering a sustainable future depends on understanding fundamental mechanisms across all scales. Whether harnessing microbial pathways, modelling biochemical strength loss, or repurposing industrial and rubber waste, the research shows that innovation is the primary tool for environmental protection. We see a common thread in how we address chemical, biological, and thermal interactions, whether it is cation exchange in bentonite, heavy metal solidification, or geothermal heat exchange.

We thank the authors for their contributions and the reviewers for ensuring scientific rigor. We hope these articles serve as a catalyst for practitioners and researchers to continue pushing the boundaries of environmental geotechnics for a more resilient and sustainable planet.

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