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Surface erosion behavior of MICP-treated sands: Experimental study and numerical modeling

Soo-Min Ham[1)], Min-Kyung Jeon[2)] and *Tae-Hyuk Kwon[3)]

[1), 2), 3)] *Department of Civil Engineering, KAIST, Daejeon 34141, Korea*
[3)] *t.kwon@kaist.ac.kr*

ABSTRACT

Soil erosion is a ubiquitous phenomenon that often causes scouring and failures of underwater structures. Accordingly, the erosion characteristics of soil such as critical shear stress and erodibility coefficients have been investigated by extensive laboratory experiments (Hanson and Cook, 2004; Wan and Fell, 2004). Identifying the mechanism of soil erosion process requires a thorough understanding the fluid-particle interaction. The numerical modeling approaches are taken to model soil erosion behavior via the continuum-based models, which can simulate the overall erosion process but cannot analyze at a particle level. To analyze the physics of granular materials, coupling computational fluid dynamics (CFD) and discrete element method (DEM) has been investigated by the previous researchers (Zhou et al., 2011; Guo and Yu, 2016). However, the soil surface erosion has not been studied at the particulate scale via coupled CFD and DEM analysis, referred to as the coupled CFD-DEM. To increase the soil erosion resistance, several techniques have been used, and the microbially induced calcium carbonate precipitation (MICP) treatment has been proven to contribute to enhancement in the critical shear stress and reduction in the erosion coefficient for internal erosion (Bang et al., 2011; Jiang et al., 2017), as the precipitated calcium carbonate from MICP treatment contributes to the inter-particle cementation. Whereas, the use of MICP treatment for improvement of surface erosion resistance is still limited. Therefore, this study demonstrated that the calcium carbonate precipitated by the MICP process improves the surface erosion resistance of sands, and presented a numerical model of coupled CFD-DEM to study MICP treated-soil erosion mechanisms at the particle. The surface erosion behaviors of two different specimens having different calcium carbonate contents were investigated at different flow velocities via the erosion function apparatus (EFA) developed by Briaud et al. (1999). Further, these processes occurring in the EFA test were simulated through the coupled CFD-DEM. The cohesion bonding model and the corresponding parameters were suggested to reflect the calcium carbonate effect. The MICP treatment increased the overall erosion resistance, and the contributions of

[1)] Postdoctoral Researcher
[2)] Postdoctoral Researcher
[3)] Associate Professor

the calcium carbonate to the erosion resistance and the critical shear stress were quantified in relation to calcium carbonate contents. The simulation results were compared with the experimental results as shown in Figure 1, and the developed model well predicted the critical shear stress of MICP-treated sand with cohesion bonding model. Also, the pure shear stress applied to the soil particles were obtained. This work shows that the MICP treatment has effect on enhancement of soil erodibility by bonding the particles, and coupled CFD-DEM is a useful and promising tool to analyze the soil erosion behavior for MICP-treated sand at the particle scale.

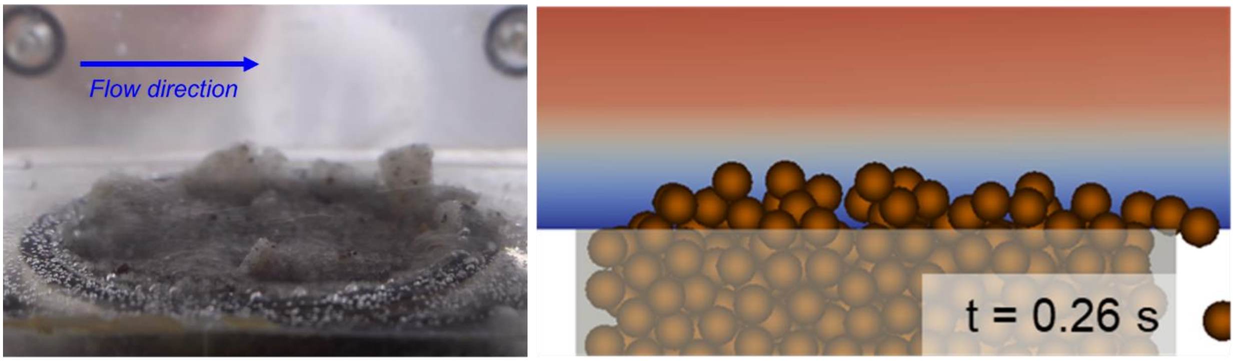

Fig. 1 Erosion behaviors of MICP-treated soil: (a) experimental and (b) numerical results.

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