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Discrete element analysis of the mechanical properties of deep-sea methane hydrate-bearing soils considering interparticle bond thickness

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ABSTRACT

Due to increasing global energy demands, research is being conducted on the mechanical properties of methane hydrate-bearing soils (MHBSs), from which methane hydrate (MH) will be explored. This paper presents a numerical approach to study the mechanical properties of MHBSs. The relationship between the level of MH saturation and the interparticle bond thickness is first obtained by analyzing the scanning electron microscope images of MHBS samples, in which is the bridge connecting the micromechanical behavior captured by the DEM with the macroscopic properties of MHBSs. A simplified thermal-hydromechanical (THM) bond model that considers the different bond thicknesses is then proposed to describe the contact behavior between the soil particles and those incorporated into the discrete element method (DEM). Finally, a series of biaxial compression tests are carried out with different MH saturations under different effective confining pressures to analyze the mechanical properties of deep-sea MHBSs. The results of the DEM numerical simulation are also compared with the findings from triaxial compression tests. The results show that the macromechanical properties of deep-sea MHBSs can be qualitatively captured by the proposed DEM. The shear strength, cohesion, and volumetric contraction of deep-sea MHBSs increase with increasing MH saturation, although its influence on the internal friction angle is obscure. The shear strength and volumetric contraction increase with increasing effective confining pressure. The peak shear strength and the dilation of MHBSs increase as the critical bond thickness increases, while the residual deviator stress largely remains the same at a larger axial strain. With increasing the axial strain, the percentage of broken bonds increases, along with the expansion of the shear band.

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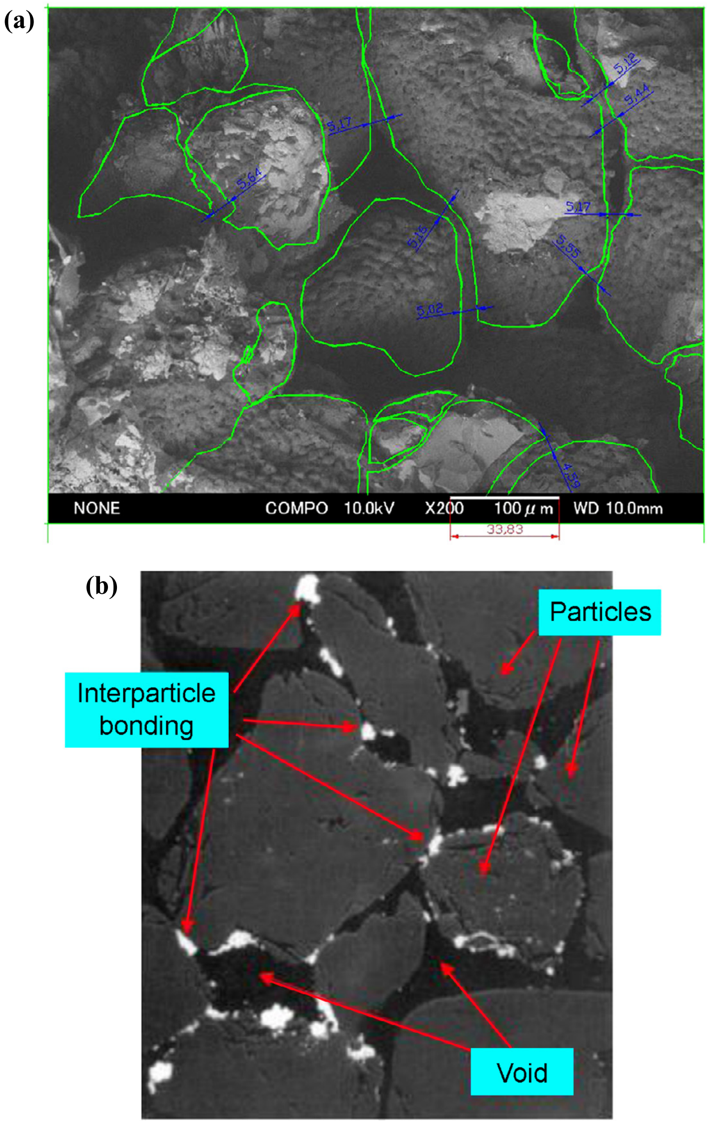

Fig. 1. SEM images: (a) MH bonds in the methane hydrate-bearing soil [11]; (b) inter-particle bonds in the natural sands [12].

1. Introduction

Methane hydrate-bearing soils (MHBSs), which are natural soil deposits that contain methane hydrate (MH) inside their pores, are abundantly available in the continental margins and permafrost regions [1]. MH is recognized as one of the most promising resources for resolving the current energy crisis [2]. Due to the increasing global energy demand, significant research attention is being directed toward examining the physical, chemical and mechanical properties of MHBSs, and devising methods to quantify and identify MH-bearing deposits [3]. However, commercial exploitation of these deposits could have catastrophic effects, such as submarine landslide and Tsunami. Therefore, the study of the mechanical properties of MHBSs is of great significance from a geotechnical point of view [4].

Previous studies show that the mechanical characteristics of MH-bearing sediments are highly dependent on the hydrate morphology [5,6]. According to the MH morphology, MHBSs are generally categorized as either pore filling or cementing, depending on where the MH is formed in the pore space [7]. MH-bearing sediments are easily formed by cementing in gas-rich environments and, in general, the MH in the cementing type has a greater effect on the ensemble strength and stiffness of the MHBSs, especially at lower MH saturation values, compared with the pore-filling type [5–7]. Very little research has examined the cementing type soil [8–10]. This constitutes one of the strong motivations of this paper.

Fig. 1a presents a scanning electron micrograph (SEM) of a MH-bearing sample, in which different bond thicknesses of MH can be observed among the soil particles [11]. Fig. 1b provides a SEM of a Lower Green natural sand sample obtained by

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