Simple Modelling of the Mechanical Response of Methane Hydrate-bearing Sediments

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Introduction

Methane gas hydrates are clathrate solids constituting methane gas trapped within the hydrogen-bonds of water molecules. They are found in the deep seabed and permafrost regions and regarded as one kind of promising energy sources for the next generation. They are formed under controlled temperature and pressure conditions. A clear understanding of the mechanical properties of methane hydrate-bearing sediment is of great relevance to evaluate the safety of production wells and drilling structures constructed in the deep seabed and to reduce the risk of geotechnical engineering related geo-hazards. In recent ten years, a large number of triaxial shear tests had been performed on artificially prepared MH bearing sand without fines particles to clarify the influences of MH saturation, effective confining pressure, temperature, density and pore water pressure on their shear response (Miyazaki et al. 2011; Hyodo et al. 2013). The geological survey conducted in Nankai Trough in the south of the Japan's island of Honshu indicated that methane hydrate was mainly concentrated in the sand and silty stratified layers with a wide range of grain size distribution called turbidite (Suzuki et al. (2009)). Therefore, the mechanical properties of MH bearing sand containing fines require further examination.

A series of triaxial compression tests were performed in order to examine the shear and deformation behavior of artificially synthesized methane hydrate-bearing sediments under various test conditions. The ability to accurately model the mechanical behavior of methane hydrate-bearing sediments is crucial for evaluating the stability of seabed ground during gas production. Some constitutive models (Uchida et al. 2013) for methane hydrate-bearing sediments have been established in the past several years by using the elasto-plastic theory and introducing a new hardening parameter to consider the cementation stress. However, the determination of the parameters associated with the new hardening parameter is exhaustive and a little arbitrary. This study proposes a simple constitutive model to represent the mechanical properties of methane hydrate-bearing sediments using a few well-established relationships of granular materials and to make it accessible for practical application. The influence of cementation stress induced by methane hydrates on the geomechanical properties of methane hydrate-bearing sediments is directly introduced to the peak shear strength evaluation expression, stress-dilatancy relationship, stress characteristics at critical state and shear stress-strain hardening law without introducing any new parameter for cohesion.

The framework of simple constitutive model

Gutierrez (2003) proposed the following equation to evaluate the peak strength considering the combined effect of relative density and confining pressure over a wide range of sands. In this study, a unique relationship between the peak shear strength and state parameter is adopted. The state parameter is defined as the difference between the current void ratio and the void ratio determined on the critical state line at the current confining pressure. It incorporates the combined influences of the effective confining pressure and void ratio. The peak shear strength tends to decrease as the state parameter varies from the negative value to positive value. A state-dependent dilatancy relation is integrated into the constitutive model framework to describe the density-dependent properties of the granular material. An upward shift of the critical state line with the rise in methane hydrate saturation on the void ratio and logarithmic stress plane has been revealed in previous experimental investigations and is also considered in modelling to properly calculate the state parameter. The intercept of the critical state line at atmospheric pressure becomes a function of the methane hydrate saturation. Also, a simple distortional hardening law is selected to represent the monotonically varying tendency of the stress ratio until the peak strength value is attained. The accumulative method of the incremental forms of the particular equations is employed to reproduce the stress-strain response of methane hydrate-bearing sediments. Figure 1 shows that the predicted values are agreeable with the measured results of methane hydrate-bearing sediments containing variable fines.

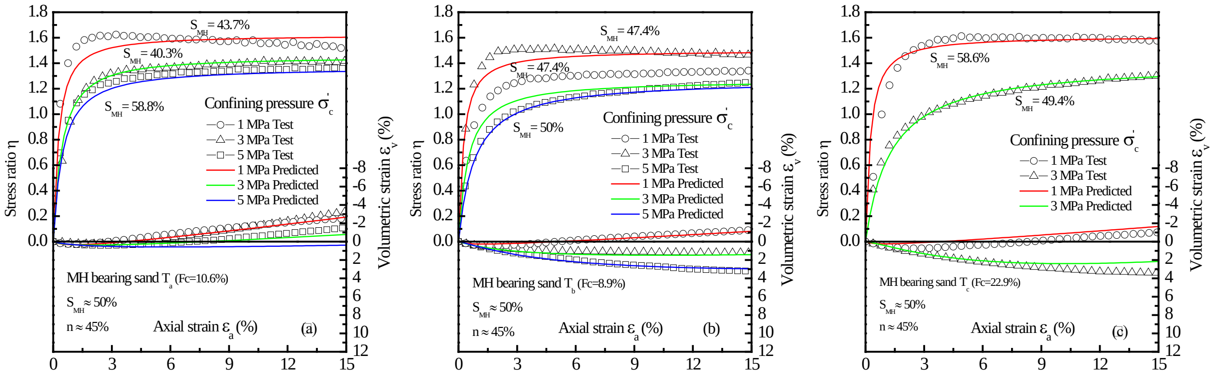

Fig. 1: Predicted and measured stress-strain relationship of methane hydrate-bearing sediments containing various fines

Conclusions

Some important conclusions on the predicted drained behavior of methane hydrate-bearing sediments can be obtained.

The predicted values of the proposed constitutive model show good satisfactory with the measured results under triaxial compression condition. This proposed simple constitutive model is capable of adequately predicting the enhancement of shear strength and stiffness as well as the dilation behavior of methane hydrate-bearing sediments with the rise in the methane hydrate saturation over a wide range of effective confining pressures and densities. The influence of methane hydrate saturation on the inclination of the stress-dilatancy relationship at higher stress ratios is also examined and reflected in the modeling. The parameter representing the inclination of stress-dilatancy curves at higher stress ratios also increases with the rise in methane hydrate saturation. This constitutive model can also reproduce the strain-softening behavior due to the integration of the state parameter. The peak stress ratio is not a constant value but varies along with the varying state parameter during shearing. The shear deformability parameter A exhibits a tendency to decrease with the rise in methane hydrate saturation at a given effective confining pressure. The parameters of the proposed constitutive model can be determined from isotropic consolidation tests and conventional drained compression tests on methane hydrate-bearing sediments and hydrate-free sediments.

References

Gutierrez M (2003) Modeling of the steady-state responce of granular soils. Soils Found 43(5): 93-105. doi:10.3208/sandf.43.5_93

Hyodo M, Yoneda J, Yoshimoto N and Nakata Y (2013) Mechanical and dissociation properties of methane hydrate-bearing sand in deep seabed. Soils Found 53(2): 299–314. doi: 10.1016/j.sandf.2013.02.010

Miyazaki K, Masui A, Sakamoto Y, Aoki K, Tenma N and Yamaguchi T (2011) Triaxial compressive properties of artificial methane-hydrate-bearing sediment. J. Geophys. Res. Solid Earth. 116(B6): 1–11. doi: 10.1029/2010JB008049

Suzuki K, Ebinuma T and Narita H (2009) Features of Methane Hydrate-bearing Sandy-sediments of the Forearc Basin along the Nankai Trough: Effect on Methane Hydrate-Accumulating Mechanism in Turbidite. J. Geogr. (Chigaku Zasshi) 118(5): 899–912 doi: 10.5026/jgeography.118.899 (In Japanese)

Uchida S, Soga K sand Yamamoto K (2012) Critical state soil constitutive model for methane hydrate soil. J. Geophys. Res. Solid Earth., 117(B3): 2156-2202. doi: 10.1029/2011JB008661