Effects of hydrate in sediments on sand crushing

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Introduction

Gas production from hydrate-bearing sediments via depressurization can increase effective stress, that governs the geomechanical response of the sediments and may even induce sand crushing. This study investigates how the presence of hydrate affect the physical and geomechanical properties of sediments subjected to vertical stress up to 25 MPa.

Experimental setup

The loading and unloading tests are conducted using an instrumented oedometer cell with an inner diameter of 53.8 mm. This cell is equipped with piezo elements for p- and s-wave measurements, a T-type thermocouple for temperature monitoring, and a linear variable displacement transducer (LVDT) for displacement measuring. Vertical stress up to 25 MPa is applied to tested specimens using a hydraulic piston within a stiff reaction frame (Kim et al., 2018, under review).

The specimens are prepared using F110 fine sands (mean grain size D_{50} = 120 µm) with various tetrahydrofuran (THF) hydrate saturation, i.e., S_h = 0, 0.3, 0.6, and 0.96. The specimens are saturated with THF-water mixture in a series of predetermined mass ratios for targeted hydrate saturation. The hydrate formation is triggered by lowering the temperature toward -5ºC in an environmental refrigerator. Once a thermal spike is observed, indicating hydrate formation, the temperature is raised up to 1ºC and kept constant. The hydrate is formed under 7 kPa vertical stress (top cap self-weight), and then the specimens undergo a series of vertical stresses up to 25 MPa. Then the specimens are unloaded to 2 MPa and hydrate dissociation is induced by increasing temperature at this stress. The p- and s-wave velocities are measured at each loading and unloading steps. The grain size distributions of the specimens before and after the tests are quantified to evaluate the effects of hydrate on sand crushing.

Experimental results and analyses

Fig. 1(a) plots the p- and s-wave velocities in specimens with various hydrate saturation subjected to different vertical stresses. Measured p- and s-wave velocities increase with increasing hydrate saturation and stress. The increase of stress dependent wave velocity is accelerated at higher stresses, may due to increased skeleton stiffness (refer to the results of the hydrate-free specimen). The Poisson's ratios are then computed (Fig.1b):

$$v = \frac{(V_p/V_s)^2 - 2}{2(V_p/V_s)^2 - 2}$$

Results show that the Poisson's ratio of the water saturated hydrate-free sediments decreases from nearly 0.5 at low stress to 0.41 at 25 MPa, suggesting a dominate role of the water phase in the Poisson's ratio at low stress and an increased role of the skeleton at high stress. The Poisson's ratios of hydrate-bearing sediments decrease with increased hydrate saturation and slightly increase with stress.

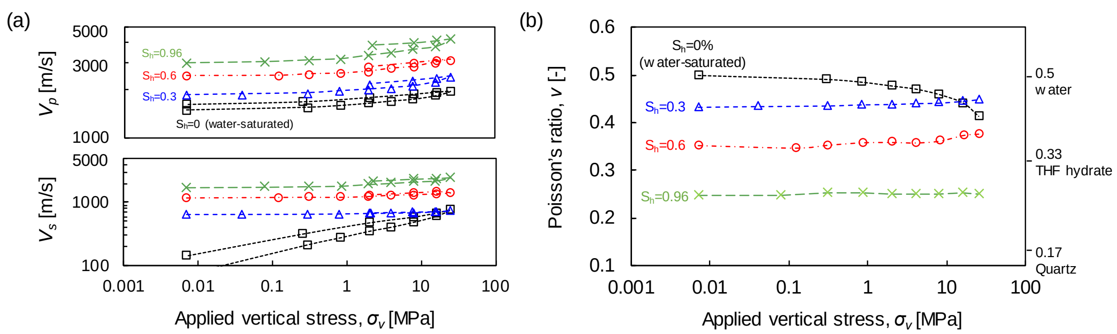

Fig. 1: Measured elastic properties in sediments with various hydrate saturation subjected to vertical loading. (a) P- and s-wave velocities. (b) Calculated Poisson's ratios.

Fig. 2(a) shows the post-testing grain size distributions (dashed lines) of the specimens with various hydrate saturation, in comparison with their initial grain size distribution (solid line). The results show that the grain size distribution curves for specimens with S_h = 0, 0.3, 0.6, and 0.96 shift rightward with increasing hydrate saturation, indicating inhibited sand crushing due to hydrate.

To quantify the sand crushing, Fig. 2(b) shows the mass fraction of fines (< 75 μm) before (an open circle) and after (solid dots) loading. The results show that all specimens after being loaded up to 25 MPa maximum vertical stress have experienced sand crushing and generated fine-grained particles. The amount of fine-grained particles decreases with increasing hydrate saturation in the specimens, indicating an inhibited effect of hydrate on sand crushing. Hydrate in the pores shares the load with the particles and refrain particles from being crushed. Therefore, during gas production from hydrate deposit, the loss of hydrate crystals as a cementious component will lead to more pronounced sand crushing.

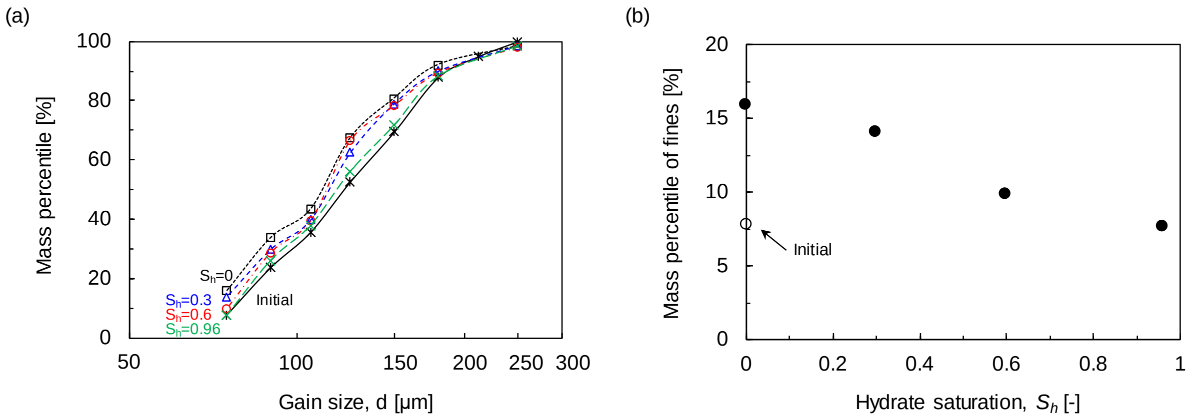

Fig. 2: Quantitative analysis of particle crushing. (a) The initial and post-testing grain size distribution curves. (b) Mass fraction of fines from sand crushing.

Conclusions

Oedometer tests are conducted using F110 fine sand with various THF hydrate saturation S_h = 0, 0.3, 0.6, and 0.96. The specimens are loaded up to 25 MPa to evaluate the stiffness of hydrate-bearing sediments and the effects of hydrate on sand crushing. Salient findings are as follows.

- P- and s-wave velocities increase with increasing hydrate saturation and stress. The stress dependent velocity increase is accelerated at higher stresses due to increased skeleton stiffness.
- The Poisson's ratio of hydrate-bearing sediments decreases with increasing hydrate saturation. The Poisson's ratio of hydrate-bearing sediments is governed by that of the stiffest phases, i.e., water and/or hydrate at low stress and water, hydrate and skeleton at high stress.
- Sand crushing is inhibited with increasing hydrate saturation, as the hydrate phase shares partially of the load and constrains sand paricle movement. Therefore, the loss of hydrate crystals during gas production can lead to more pronounced sand crushing.

Acknowledgments

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References

Jongchan Kim, Sheng Dai, Junbong Jang, William F. Waite, Timothy S. Collett, and Pushpendra Kumar (2018). Compressibility and particle crushing of Krishna-Godavari Basin sediments from offshore India: Implications for gas production from deep-water gas hydrate deposits. *Marine and Petroleum Geology*, (accepted with minor modifications)