The dynamic characteristics of hydrate-bearing sands measured by resonant column under controlled stress and strain

Zhichao Liu[1], Dongdong Wang[1], Fulong Ning[1, *], Changling Liu[2], Lele Liu[2]

[1] Faculty of Engineering, China University of Geosciences (Wuhan), Wuhan, China
[2] The Key Laboratory of Gas Hydrate, Qingdao Institute of Marine Geology, Qingdao, China
* nflzx@cug.edu.cn

Introduction

The dynamic properties of hydrate-bearing sediments are essential factors in hydrate production. However, the seismic survey and well logging are the few effective methods to obtain the dynamic properties of hydrate deposits in situ [Guerin and Goldberg, 2002&2005; Guerin et al., 1999], and the interpretation of the dynamic measurements may be uncertain because of the poor understandings of the dynamic responses in hydrate-bearing sediments [Best et al., 2013; Priest et al., 2006]. Investigating the dynamic properties of hydrate-bearing specimens by some conventional laboratory methods can be benefit for solving these challenges. The resonant column test, employing the wave propagation in cylindrical specimens, is one of the common nondestructive method to obtain the dynamic characterizations of soils, including hydrate-bearing sediments.

Experimental study

The China ISO standard sand (purchased by Xiamen ISO Standard Sand CO., LTD.) is sieved to simulate the grain size distributions of natural hydrate-bearing sediments in Nankai Trough (as shown in Figure 1) [Hyodo et al., 2013&2014], tetrahydrofuran (THF) with HPLC level purity of 0.998 is purchased from Sinopharm Chemical Reagent Co., Ltd., CH4 with purity of 0.999 is purchased from Nanjing Changyuan Industrial Gases Co., Ltd., and the distilled water we used is produced by our laboratory.

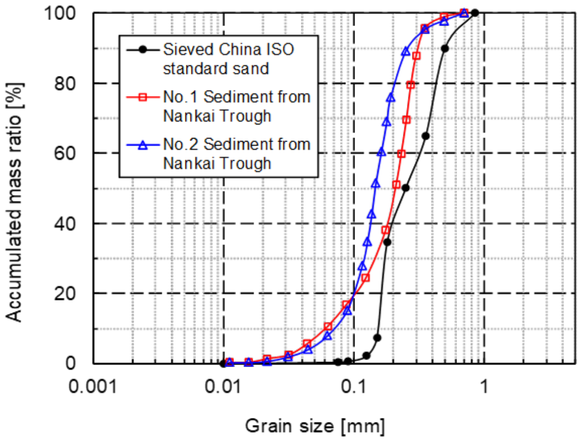

Fig 1. The grain size distribution of the tested specimens

The hydrate is mainly formed by THF because of its advantages of random miscible with water, accurate control in hydrate saturation and relative short induction time of formation [Lee et al., 2007; Yun et al., 2007]. In addition, the CH_4 hydrate and ice are also formed to compare with THF hydrate.

To demonstrate the dynamic responses of hydrate-bearing sandy sediments, the resonant frequency and the free vibration decay curve of specimens with various hydrate saturation of 0.3, 0.5 and 0.7 are obtained by resonant column tests on the forced vibration mode and the free vibration mode, respectively. The total testing cycles of each specimen start from low confining stress of 0.5 MPa to high confining stress of 2.5 MPa with the interval increment of 0.5 MPa. Then, under the constant confining stress of 2.5 MPa, the shear strain of specimens increases from about 10^{-6} to 10^{-4}.

Results

The shear moduli of all specimens increase with high stress and decrease with large strain, and the damping ratios of all specimens decrease with high stress and increase with large strain. All the above relationships generally follow a power-law trend. With the THF hydrate saturation increasing in specimens, both the shear moduli and the damping ratios increase. Especially, the specimens with THF hydrate saturation of 0.7 have the significant higher shear modulus than those of other specimens. Compared to the ice- and the CH_4 hydrate- bearing specimens with identical saturation, the ice-bearing specimen shows the highest shear modulus and the lowest damping ratio, while the CH_4 hydrate-bearing specimen shows the comparable shear modulus and damping ratio to those of THF hydrate-bearing specimens.

The influences of hydrate saturation and type on the function between the shear modulus G and the tested stress σ ($G = a*\sigma^b$) are reflected by the constant b, and 0.5 is a typical value of b for granular materials. The b values of the THF hydrate-bearing specimens decrease from 0.5 to 0.2, corresponding with the hydrate saturation increasing from 0.3 to 0.7, which implies the THF hydrate-bearing specimens transforming from a granular material to a partly cemented material. While with the identical saturation, the ice-bearing specimen has the lowest b value, because the capillary effect of unsaturated-water system may connect grains together. The CH_4 hydrate-bearing specimen has the smaller b value than that of the THF hydrate-bearing specimen, because the hydrate formed from methane in the gas phase may easier to cement grain than the hydrate formed from THF in the dissolve phase.

The influences of hydrate saturation and type on the function between the shear modulus G and the tested strain γ are represented by the shear modulus degradation curves ($G/G_{max} \sim\gamma$). The hydrate-bearing specimens with high hydrate saturation suffer great reduction in shear modulus under the identical increment of tested strain. The stiffer hydrate-bearing specimens may be more sensitive to the changes of tested strain.

Conclusions

The dynamic properties of the specimens are greatly affected by pore medium. For pure sandy specimens, the dynamic response mainly depends on the porosity. For hydrate-bearing sandy specimens, the dynamic response mainly depends on the hydrate type and amount, which are able to change the micro connection of grains. The presence of hydrate in specimens increases the shear modulus. The linear increasing correlation of damping ratio to hydrate saturation is also confirmed in our tested specimens. The dynamic properties of hydrate-bearing sediments appear to be stress-dependent at low hydrate saturation, and the shear modulus degradation curves shift left with hydrate saturation increasing.

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