Proceedings of the Twenty-eighth (2018) International Ocean and Polar Engineering Conference
Sapporo, Japan, June 10-15, 2018

ISBN 978-1-880653-87-6; ISSN 1098-6189

www.isope.org

Experimental Study on Mechanical Properties of Clay Sediment Containing Tetrahydroguran Hydrate

Shuyun Wang, Xiaobing Lu, Xuhui Zhang
Institute of Mechanics, Chinese Academy of Sciences
Beijing, China

ABSTRACT

Based on remolded clay sediment obtained from a certain area in the South China Sea, a series of tri-axial unconsolidated untrained compression tests on clay sediment containing tetrahydrofuran hydrate were performed under the conditions of different hydrate saturation and confining pressure. The stress-strain curve of clay sediment containing hydrate consists of three stages: elastic (when strain is less than 1.5%), plastic (when strain is between 2% and 6%) and strain hardening (when strain is greater than 6%) stage, and very different from that of clay sediment which behaves only plastic failure. Moreover, the undrained shear strength of clay sediment containing hydrate increases about 1~7 times than that of clay sediment and decreases by 50% after hydrate dissociation.

KEY WORDS: tetrahydrofuran hydrate; clay sediment; clay sediment containing hydrate; compression tests; stress-strain; strength.

INTRODUCTION

Gas hydrates, as a potential energy resource, are usually occurring as ice-like solids and widespread in sand and clay sediments in deep marine continental margins and permafrost regions. The mechanical properties of hydrate-bearing sediments are one of the most important information and parameters for analyzing the stability of seabed and foundation during the exploration of gas hydrates. Because of the low temperature and high pressure conditions which hydrates form in natural sediments, the synthesis and tri-axial compression tests in laboratory on hydrate-bearing sediments have been more difficult to simulate in situ environment and perfectly be accomplished than clay and sand sediments. The study on mechanical property of sediments containing gas hydrate has always been a hot research topic since 2000.

Until now, most of studies on mechanical properties of hydrate-bearing sediments are focus on sand sediment containing methane hydrate and based on triaxial compression test results in laboratory. Previous researches (Winters 2007, Waite 2004, Hyodo 2007/2013, Masui 2005/2007, Miyazaki 2011, Masui 2005/2007) show that the strength of hydrate-bearing sediments depends on hydrate saturation, confining pressure, grain size distribution, density, temperature, strain rate, synthesis method and other factors. However, there are seldom researches (Yun 2007, Song 2014) on mechanical properties of clay sediment containing hydrate, and the part of reason is because gas hydrate is more difficult to be synthesized in clay sediment in laboratory. Yun compared triaxial test results of sand, silt and kaolinite containing tetrahydroguran hydrate and concluded that the stress-strain behavior of clay sediment containing hydrate is very different from sand sediment containing hydrate and strongly relative to the grain size and cementation. Therefore, the further study on shear strength and stress-strain behavior of clay sediment containing hydrate is necessary and should to be taken more attention.

Based on the remolded clay sediment obtained from the seafloor at a certain area in South China Sea, clay sediment samples containing tetrahydroguran hydrate were firstly synthesized in laboratory with different hydrate saturation. And then a series of the triaxial compression tests were performed. Finally, the stress-strain relationship and shear strength of clay sediment samples containing hydrate were analyzed.

EQUIPMENT, TESTING METHODS

The integrated synthesis and triaxial equipment, shown in Fig.1, consists of high pressure triaxial compression test system, gas inlet/outlet controlling/measurement system, low temperature system and data acquisition system. The remolded clay sediment is fine clay and some physical parameters are as follows: specific gravity 2.70, dry density 1.3g/cm^3, void ratio 0.52, permeability 10^{-9} m/s. The grain size of distribution of clay is shown is Fig.2.

The clay sediment samples containing hydrate are formed with a certain weights of clay and tetrahydroguran solution which are calculated by the degree of hydrate saturation in clay sediment. The clay sediment and tetrahydroguran solution are firstly mixed and put in a moisturizing pot for 24 hours to be interpenetrated each other. And then, the samples containing clay and tetrahydroguran solution are made by 5 layers in a split cavity and sealed in a refrigerator with temperature of – 8^0C for 24 fours. Finally, the clay sediment samples containing hydrate are formed.

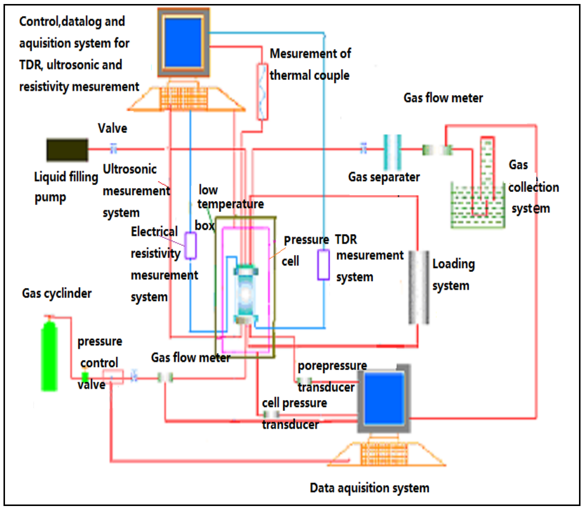

Fig. 1 Sketch of the tri-axial compression test equipment for hydrate-bearing sediment

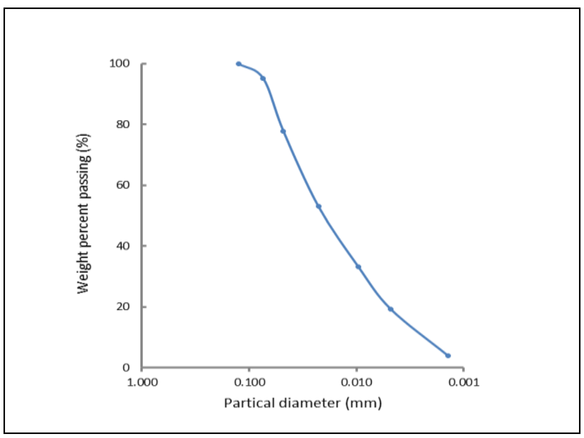

Fig.2 Grain size distribution of clay sediment

A series of unconsolidated undrained triaxial compression test (UU) are performed with 0.9mm/min shear rate and the maximum axial strain is 15%. When conducting hydrate dissociation in UU tests, the surrounding temperature of chamber should be kept 25^0C for 24 hours in order to make hydrate dissociate completely in clay sediment samples containing hydrate.

TEST RESULTS AND ANALYSES

Figs.3~5 show deviator stress versus axial strain from UU tests conducted on clay sediment samples containing different degree of hydrate saturation (S_h=0%, 25%，45% and 90%) under the conditions of confining pressure ($б_3$) 2.5MPa, 5.0MPa and 7.5MPa . Table 1 lists shear strengths corresponding to those samples.

From Figs.3~5, it is shown that the stress-strain of clay sediment samples containing hydrate behaves as elastic (when strain is less than 1.5%), plastic (when strain is between 2% and 6%) and strain hardening (when strain is greater than 6%) characteristics. While the stress-strain of clay sediment samples without hydrate behaves only plastic failure.

As shown in Figs.3~5 and Table 1, the triaxial compressive strength of clay sediment cotaining hydrate increases with the increase of hydrate saturation and confining pressure. When hydrate saturation is respectively equal to 25%， 45% and 90%, the shear strength is corresponding equal to 2, 4 and 8 times as great as clay sediment (S_h =0%), and that is obviously shown in Fig.6.

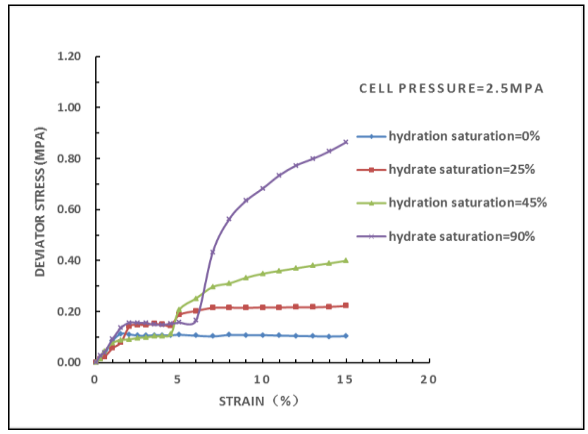

Fig.3 Stress-strain curves of clay sediment samples containing different hydrate saturation under $б_3$ = 2.5MPa conditions

Figs.3~5 also show that deviator stress of clay sediment samples containing hydrate increases suddenly when strain is more than 4.5%. That is because samples become more and more dense and the pores among particles gradually reduced with the increase of strain. Meanwhile, more hydrate particles full into these pores and hydrate plays more and more supporting role. When the accumulate role reaches a critical, the deviator stress has a jump increase although the change of strain is small. And after that, the stress-strain behaves as strain hardening.

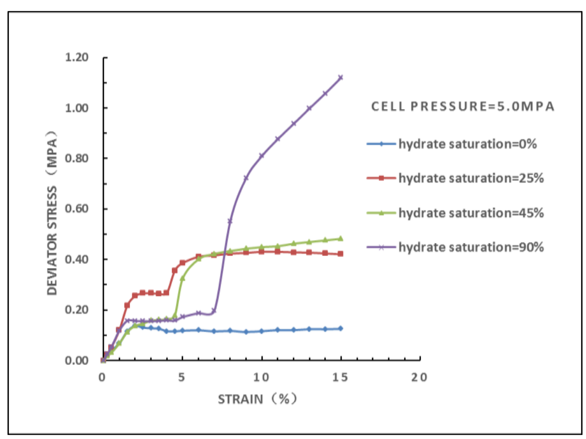

Fig.4 Stress-strain curves of clay sediment samples containing different hydrate saturation under $б_3$ = 5.0MPa conditions

The phenomenon of jump increase of deviator stress in Figs.3~5 was explained by the microstructure X-CT image of sand sediment containing hydrate (Shi et al 2015). The particles and the void ratio of clay sediment are much smaller than sand and silt sediment, and less hydrate is needed to fill pores of clay and easier to form the cementation among soil particles. Therefore, the cementation plays strong supporting role and lead to the substantial increases of stress and strength of clay sediment when hydrate formed in pores. The stress-strain curve of clay sediment containing hydrate has a jump increase when the degree of hydrate saturation is more than 25%, and 25% is thought as a critical value of hydrate saturation. But for silty sand, the critical degree of hydrate saturation is 40% (Lu et al 2013).

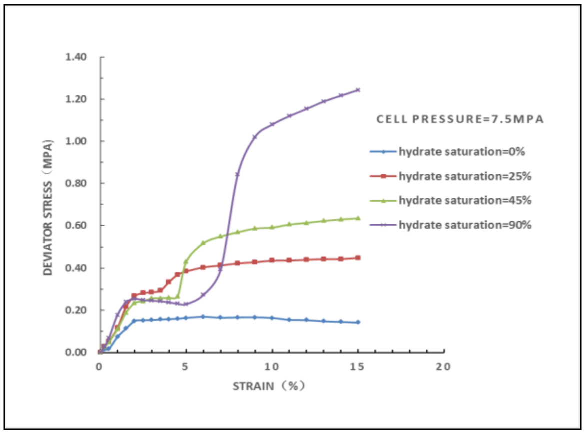

Fig.5 Stress-strain curves of clay sediment samples containing different hydrate saturation under б$_3$ = 7.5MPa conditions

Table 1 Strength parameters of clay sediment samples containing different degree of hydrate saturation

Strength coefficient	S_h= 0%	S_h=25%	S_h= 45%	S_h=100%
Cohesion (MPa)	0.04	0.08	0.15	0.3
Friction angle (^{0})	0.5	1.1	1.2	2.3

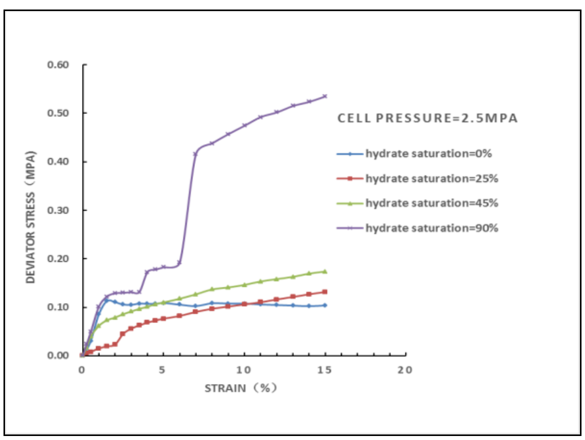

Fig.6 Stress-strain curves of clay sediment samples containing different hydrate saturation after hydrate dissociation under б$_3$ = 2.5MPa conditions

Fig.6 shows the comparision of stress-strain relationships of clay sediment samples containing hydrate before and after hydrate dissociation. Even if hydrates decomposition, the stress-strain curve of clay sediment samples containing hydrate is different from that of clay sediment samples, and the shear strength of them after hydrate association is greater than that of clay sediment samples. Only the failure strain of clay sediment samples containing hydrate is bigger than that of clay sediment samples (failure strain of 12% corresponding to samples with hydrate saturation 25% ; strain of 7% corresponding to samples with S_h=45%, strain of 2% corresponding to samples with S_h=90%). The stress-strain behaviors of different samples verified that hydrates have changed the structure of clay sediment samples and can make the shear strength of hydrate-bearing clay sediment increase whether or not hydrate dissociates.

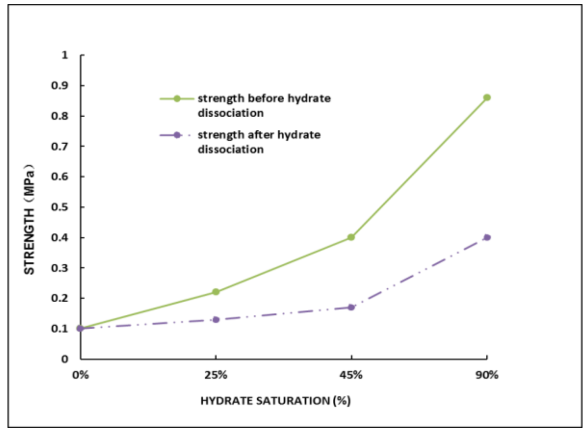

Fig.7 Undrained shear strength of clay containing hydrate before and after hydrate dissociation under б$_3$ = 2.5MPa conditions

Fig.7 shows the shear strength of clay sediment samples containing different degree saturation of hydrate before and after hydrate dissociation. After hydrate dissociate completely, the undrained shear strength of clay sediment samples containing hydrate decreases by about 50% than that of samples before hydrate dissociation.

CONCLUSIONS

Based on the analyses of mechanical properties of clay sediment containing tetrahydroguran hydrate before and after hydrate dissociation, and comparing them with those of clay sediment samples, the following conclusions are summarized:

1) The stress-strain curve of clay sediment containing hydrate includes elastic (when strain is less than 1.5%), plastic (when strain is between 2% and 6%) and strain hardening (when strain is greater than 6%) stages, and very different from clay sediment which behaves plastic failure.

2) The undrained shear strength of clay sediment containing hydrate increases about 1~7 times than that of clay sediment and the stress-strain curve has a jump increase when strain is more than a certain value (4%~7%).

3) The undrained shear strength of clay sediment containing hydrate decreases by about 50% when hydrate dissociates completely.

ACKNOWLEDGEMENTS

This study is supported by National Natural Science Foundation of China (11072245, 51239010，41376078).

REFERENCES

Hyodo, M, Nakata, Y, Yoshimoto, N (2007). “Shear Behavior of Methane Hydrate-Bearing Sand,” *Proc 17th Int Offshore and Polar Eng Conf*, Lisbon, ISOPE, Vol 3, pp1326–1333.

Hyodo, M, Yoneda, J, Yoshimoto N, Nakata Y (2013). "Mechanical and dissociation properties of methane hydrate-bearing sand in deep seabed", *Soils and Foundations*, 2013, 53(2): 299–314.

Lu, XB, Zhang, XH, Wang, SY (2013). "Advances in Study of Mechanical Properties of Gas Hydrate Bearing Sediment", *The Open Ocean Engineering Journal*, 6:26-40.

Masui, A, Haneda, H, Ogata, Y (2007). " Mechanical Properties Of Sandy Sediment Containing Marine Gas Hydrates In Deep Sea Offshore Japan," *Proc 17th Int Offshore and Polar Eng Conf, Ocean Mining Symposium*, Lisbon, Portugal, pp53–56.

Masui, A, Haneda, H, Ogata, Y (2005). " Effect of Methane Hydrate Formation on Shear Strength of Synthetic Methane Hydrate Sediment," *Proc. 15th Int. Offshore and Polar Eng Conf,* Seoul, ISOPE, pp364–369.

Miyazaki, K, Masui, A, Sakamoto, Y (2011). " Triaxial Compressive Properties of Artificial Methane-Hydrate-Bearing Sediment," *Journal of Geophysical Research,* Vol 116, B06102.

Waite WF, Winters WJ, Mason, DH (2004), "Methane hydrate formation in partially water-saturated Ottawa sand", *American Mineralogist,* 89(8): 1202–1207.

Winters, WJ, Waite, WF, Mason, DH (2007). " Methane Gas Hydrate Effect on Sediment Acoustic and Strength Properties", *Journal of Petroleum Science and Engineering,* No 56, pp127–135.

Shi,YH, Zhang, XH, Lu XB, Wang SY, et al (2015). "Experimental Study on the Static Mechanical Properties of Hydrate-Bearing Silty Clay in the South China Sea", *Chinese Journal of Theoretical and Applied Mechanics*, 47(3):521-528.

Song, YC, Zhu, YM, Liu, WG (2014). "Experiment Research on the Mechanical Properties of Methane Hydrate-bearing Sediments During Hydrate Dissociation", *Marine and Petroleum Geology*, 51:70-78.

Yun, TS, Santamarina, JC, Rupple, C (2007). " Mechanical Properties of Sand, Silt and Clay Containing Tetrahydrofuran Hydrate," *Journal of Geophysical Research,* Vol 112, B04106.