Mechanical characteristics and localized deformation of Methane Hydrate-bearing sand using high pressure plane strain shear tests

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ABSTRACT

Methane Hydrate (hereafter referred to as MH) is being researched and developed in order to prepare for production in the Nankai Trough of Japan. The grain size distribution and the degree of MH saturation of MH bearing sand varies based on location with varying fines content. Also, the shear behaviour is affected by particle shape. In order to investigate the effect of the characteristics of host sand on the shear behaviour of MH-bearing sands, MH was artificially produced in specimens composed of four kinds of materials with varying particle shape, fines content and degree of MH saturation. In this study, a high stress and low temperature triaxial plane strain testing apparatus was used. A marked increase in stiffness and strength was observed in all MH-bearing materials. In the case of glass beads, higher peak stress appeared in MH-bearing material than that without MH and the softening behaviour of MH bearing sand after peak strength was most predominant. In the case of MH-bearing sand, an increase in fines content leads to an increase in strength. An increase in degree of MH saturation leads to an increase of the angle of the shear band and the width of shear band becomes narrower.

Keywords: plane strain compression test, methane hydrate, local deformation

1. INTRODUCTION

MH, which exists in the deep sea bed, has come to be seen as a future energy source and as such research and development is being conducted in order to prepare for its production in Japan. The target sea area is called the Nankai Trough as the existence of MH rich reservoirs has been confirmed at around 100m below the deep sea bed at a depth of around 1000m – 1500m below sea level. MH mostly exists in the void spaces of the sand, cementing the particles. It is necessary to investigate the risks associated with stability of the well and the environmental influence on the deep sea bed caused by changes of the underground stress and the loss of the cementation due to well digging and MH production. The geology of the sea bed of the Nankai Trough is called turbidite and consists of sand and clay stratified layers. Rich MH deposits are concentrated in these sand layers. The grain size distribution of MH bearing sand varies based on location with various fines content and quantity of MH (the degree of MH saturation). A series of mechanical tests have been performed on MH bearing Toyoura silica sand to clarify the basic mechanical properties of MH bearing sand (Hyodo, 2013). It is important to make clear and understand the effect of particle properties of the host sand on the mechanical properties of MH bearing sands as it is expected that the surface properties of the host sand affect the shear behaviour of MH bearing sands (Katagiri, 2007). Therefore, in this study, focus is given to the particle shape and fines contents of MH bearing sand varies based on location with various fine contents.

Fig. 1 The picture and Schematic view of testing apparatus

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the host sand and the effect of the degree of MH saturation is also investigated. In this study, four kinds of material with different particle shapes and different fines contents were used as the host sands of MH bearing materials. MH was produced in the void spaces of these materials during the tests. The shear tests were performed using high pressure and low temperature plane strain testing apparatus to evaluate the mechanical characteristics and localized deformation of MH bearing sand.

2 PLANE STRAIN TESTING APPARATUS

This apparatus can produce temperature and stress conditions in order to create MH in the sand specimen, simulating the MH reservoirs in the deep sea bed. A picture of the testing equipment is shown in Fig.1(a) and a schematic view of the apparatus is shown in Fig.1(b). The testing equipment was installed in a temperature controlled room as shown in Fig.1(a). The temperature can be controlled by adjusting the temperature of the room. The specimen is 16cm in height, 6cm in length and 8cm in width as shown in (e) of Fig.1(b). A 5mm×5mm grid is drawn on the front of the membrane. The pictures of the specimen are taken using a digital camera ((g) of Fig.1(b)) installed on the observation window using a timer, and local deformation was evaluated through PIV analysis of the obtained images. The temperature during generation and dissociation of MH was measured by the thermocouples shown in (k) and (l) of Fig.1(b) which were installed in the bottom of the specimen.

3 TEST PROCEDURE

In this study, Toyoura silica sand, glass beads with smooth surfaces and 2 kinds of artificially composed sand simulating the sediment of the MH reservoir were used. In Fig.2, the grain size distribution curves for the four materials are shown. In addition, the physical properties of each material is shown in Table 1. The pictures of each material taken with a microscope are shown in Fig.3. It is evident from Fig.3 that the glass beads are more spherical in shape compared with the other materials. The artificially composed sand is made by combining No.7, No8, and R5.5 silica, kaolin, and MK-300 mica by the weight ratios as shown in Table 2 (hereafter the material with a low fines content will be referred to as \( T_c \), and the material which has a high fines content will be referred to as \( T_b \). The initial T stands for turbidite) (Hyodo, 2013). The gray area in Fig.2 represents a range of particle distributions found in MH rich layers in the Nankai Trough. It is evident that \( T_c \) is an approximate average for the distribution curves of the MH rich layers. The initial water content was adjusted for each material in order to give the target degree of MH saturation. The specimen was prepared using the wet tamping method, divided into 12 layers to a relative density of 90%. In order to produce MH, methane gas was injected at a temperature of 5°C over about 72 hours, with a constant pressure of 5MPa. After formation of MH, the gas in the pore spaces was replaced by filtrated pore water.
to give water saturated conditions, and then the pore pressure was increased to 10MPa and a given effective stress was applied. After that, consolidation and shear testing were performed. The rate of applied axial loading was 0.1%/min.

4 TESTING RESULTS

Test results for each host sand with effective confining stresses of 3MPa are shown in Fig.4. It is evident from Fig.4 that the initial shear stiffness and peak strength decreased with increasing fines contents in Toyoura sand, T_b, and T_c, the main constituent of which is silica. The volumetric strain behaviour of all materials was strong contractive behaviour, which increased with increasing fines contents. In the case of glass beads, the initial shear stiffness was the highest of all the materials and the peak strength was the lowest, despite the particle distribution curve of the glass beads being similar to that of T_b. Also, the volume does not change much compared with the other materials. Furthermore, the stick-slip phenomenon appeared after the appearance of peak strength in the case of glass beads.

Tests were performed on MH bearing materials. The results of Toyoura sand are presented in Fig.5, glass beads in Fig.6, T_b in Fig.7 and T_c in Fig.8. In addition, the results of tests on the host sand are also shown in each figure. The Toyoura sand and T_c had a degree of MH saturation SMH =
is most predominant in the glass beads. Furthermore, the stick-slip phenomenon for glass beads becomes weaker after MH production in the material.

In Fig. 9, the difference between the peak strength of MH bearing sand and that of the host sand was plotted against fines content. Although the degree of MH saturation of Toyoura sand is higher than that of the other materials, there is an almost linear trend in at a similar degree of MH saturation, peak strength difference increases with increasing fines content, which can be thought of as being due to the production of MH. In the case of unconfined compression tests using cement-treated sand, there is a trend for an increase in strength increment with increasing fines contents for the same dosage of chemical solution (Yoneda 2011). It is assumed that a similar structural change happened in MH bearing sand during this research.

Next, PIV analysis was performed on the images taken by the camera during the experiments. Figures 10 and 11 show the analytical results for Toyoura sand and Tc, respectively. The fines content of Toyoura sand is 0% and that of Tc is the highest of all the materials. By comparison of these results it can be seen that the axial strain at which the shear band appears is far smaller in the case of Toyoura sand than Tc. Large local deformation concentrated in the shear bands in the case of Toyoura sand, whereas big shear deformation was distributed over a wider area for Tc. By comparison of these results, it is assumed that a material with a low fines content is more susceptible to local deformation.

Next, the effect of degree of MH saturation for the angle and width of the shear band for Tc is shown in Fig. 12. In this study, the angle and width of the shear band at the axial strain where strength decreases rapidly after peak strength (points of plot in Fig. 8) is investigated. The edge of shear band was defined at the points of maximum curvature of the grid that was pre-drawn on the membrane (points of plot in Fig. 12) (Yoneda 2013). The angle of the shear band is defined as the average angle of the top and bottom approximate lines drawn between the points of the shear band. (lines as shown in Fig. 12). The angle of the shear band tends to increase with an increase in the degree of MH saturation and the width of shear band tends to decrease with an increase in the degree of MH saturation.

5 CONCLUSIONS

In this study shear tests were performed in plane strain conditions on four kinds of materials which had differing physical properties. The results gained are concluded as follows:

1) Although having a similar particle distribution curve to Tc, the softening behaviour after peak strength is more predominant for that of glass beads.
2) The strength increase due to the existence of MH in MH bearing sand increased with fines content.
3) The initial modulus and peak strength of MH bearing sand increased with an increase in degree of MH saturation. In addition, the volumetric strain behaviour changes from contractive to dilative behavior and the dilative behavior is stronger, as well as the angle of shear band increasing and the width of shear band narrowing with increase degrees of MH saturation.

REFERENCES