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Deformation of Stratum after Exploitation of Gas Hydrate

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The deformation and stability of the stratum after exploitation of gas hydrate have been numerically analyzed. Dissociation zone is assumed being separated in a given distance. The maximum of the settlement locates at the center of the exploitation area. The maximum horizontal displacement locates at the interface of the over layer and the gas hydrate layer. The maximum stress locates at the edges of the remained areas. Therefore, it is effective to decrease the settlement and sliding to keep some stratum not be exploited.

KEY WORDS: Gas hydrate; exploitation; stability of seabed.

INTRODUCTION

Natural gas hydrate, a crystalline solid composed mainly of methane gas molecules and water molecules, is stabilized in conditions of high pressure and low temperature. It is conservatively estimated that more than 50% of the 18.8 terratonnes of organic carbon is present in ocean sediments, continental margins and deep lakes in the form of gas hydrate. Extraction of methane from hydrates could provide a future strategic energy resource in the 21st century (Sloan, 1998).

Hydrate-bearing sediments (HBS) may destabilize spontaneously as part of geological process, unavoidably during petroleum drilling/production operations (Briaud et al., 1997), or intentionally as part of gas extraction from the hydrate itself, which will directly change the strength of HBS. Generally, 1 m^3 methane gas hydrate releases about 164 m^3 methane gas and m^3 water at 1 atm and normal temperature. If the released gas could not drained quickly, the excess pore gas pressure will generate and the strength of the HBS will decrease, which may lead to environmental disasters, geological disasters and engineering damage such as destruction of ocean platforms, seabed, oil wells, or even gas blowouts (Milkov, 2000; Xu and Germanovich, 2006, Zhang et al.,2010).

Dissociation of methane hydrate can trigger long run-out submarine landslides in the ocean. It was reported that the Storegga landslide on the Norwegian continental shelf, the largest landslide in the world with 2500~3200m^3 sediments brought away, was caused by thermal dissociation of GH (Bugge et al., 1987). Hydrate dissociation is also thought to be the main reason for the US mid-Atlantic coast slides with the continuous rise of the sea water temperature (Jung and Peter, 2004). These events caused heavy tsunamis and widespread flooding and devastation along the continental littoral.

Oil and gas exploration are now extending far from the continental shelf where hydrates can be present in relatively shallow layers below the sea bed. There is a concern that hydrocarbon exploration can trigger hydrate dissociation to result in seabed instability and local well or offshore foundation damage (Choauch and Briaud, 1997; Zhang et al., 2010). Recently, the Deepwater Horizon explosion in the Gulf Mexico might be caused by the dissociation of GH since the drilling rig had reached the sediments where the pressure and temperature is suitable for hydrate formation (Brooks et al., 1986).

In fact, evolution of GHS failure is a basic physical-chemical-mechanical process due to the dissociation of GH. Heat transfer leads to the dissociation of GH and the simultaneous generation of variable stress field and deformation of the soil layer with the seepage of pore fluids. Accordingly, stratum failure and the damage to projects and environmental disasters can occur.

The hydrate dissociation front around a high temperature oil pipe with 1m diameter can reach 20m after 15 years, and 30m after 40 years, which can cause the instability of stratum (Briaud et al., 1997). If the hydrate in HBS dissociates without fluid flow, an excess pore pressure of more than 40MPa can form under initial hydrate fraction of 0.2, temperature of 6℃, pressure of 4.9MPa, and HBS stiffness of 10^{10} Pa. The excess pore pressure increases with hydrate fraction and sediment stiffness increase (Xu and Germanovich, 2006; Kwon et al., 2008).

Several analytical and numerical studies on gas extraction from HBS have been carried out, which coupled hydrate dissociation, gas or/and water flow and heat conduction without consideration of soil deformation (Lu et al., 2010; Wang et al.,2009). However, the coupled theoretical models are difficult to deal with and the simulation results need to be verified by laboratory or situ data. Furthermore, little is known about the initiation and patterns of the sediment failure due to hydrate dissociation.

In this paper, Finite Element Method is used to investigate the responses of stratum with the dissociation of gas hydrate. Deformation and stress are analyzed by considering the dissociation zone being separated in a given distance.

NUMERICAL MODEL

In numerical model, the stratum is consisted of two layers. The upper (cover layer) is soft soil or rock, the lower is HBS. Dissociation zone is divided by non-dissociated zone with a given width (interval). The interval-to-dissociation width ratio (IDWR) is adopted as 1:3; 1:6 and 1:9.

The material parameters of stratum is referenced the literatures (Zheng et al., 2004; Lu et al., 2008). The Drucker-Prager constitute relation is adopted. The surface of the stratum is free. The other boundary faces are all normally fixed. The displacement at the interface between the cover layer and HBS layer is continuous.

The material parameters of the over layer: $E = 1\times10^6 Pa$, $C = 10kN$, $\varphi = 20^\circ$, $\rho = 2000kg/m^3$.

The material parameters of HBS layer before dissociation of gas hydrate: $E = 1.86\times10^8 Pa$, $C = 0$, $\varphi = 39.4^\circ$, $\rho = 2.15kg/m^3$.

The material parameters of HBS layer after dissociation of gas hydrate: $E = 1.86\times10^7 Pa$, $C = 0$, $\varphi = 34.3^\circ$, $\rho = 2.11kg/m^3$.

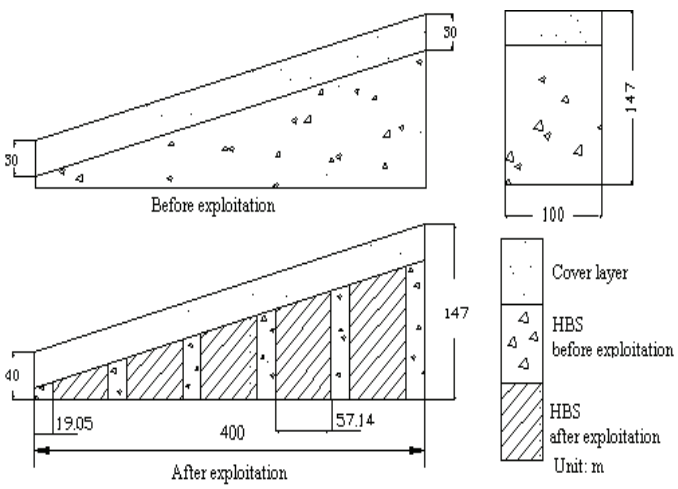

Fig.1 Sketch of numerical model

3. Numerical results and discussion

Figs.2 and 3 show the distribution of the Misses stresses in the stratum under different IDWRs. It is shown that the smaller the IDWR is, the smaller the stress is.

Figs.4 and 5 show the settlement with different IDWRs. The settlement in the dissociation zone is obviously larger than that in the non-dissociation zone. The settlement increases with the increase of IDWR.

Figs. 6 and 7 show the distribution of lateral displacement with different IDWRs. It is shown that the soil moves from the interval to the dissociation zone. The reason is that the strength of the interval layer is larger than that of dissociation zone.

Fig. 8 shows the lateral displacement along depth. It is shown that the maximum lateral displacement is located at the interface of upper and lower layer. The reason is that the interface is a discontinuous face and so stress concentration is easy to occur. The lateral displacement increases with the decrease of IDWR.

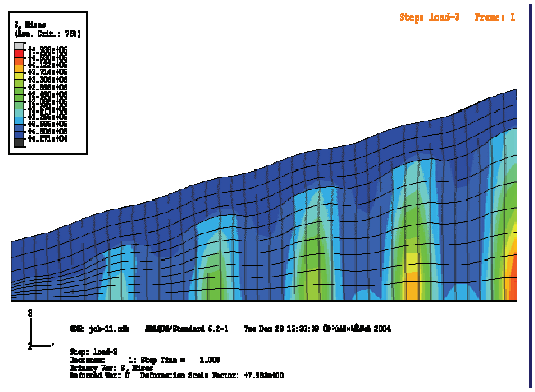

Fig. 2 Stress distribution under IDWR of 1:3

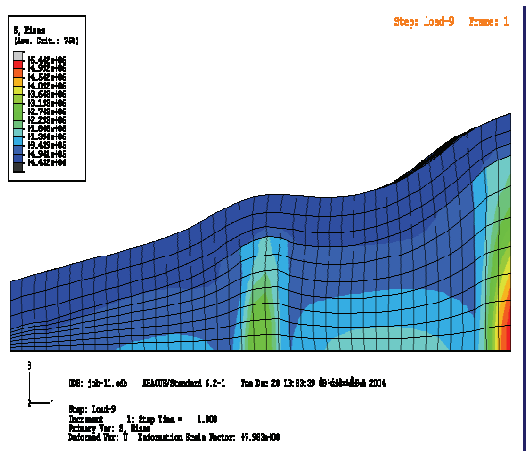

Fig. 3 Stress distribution under IDWR of 1:9

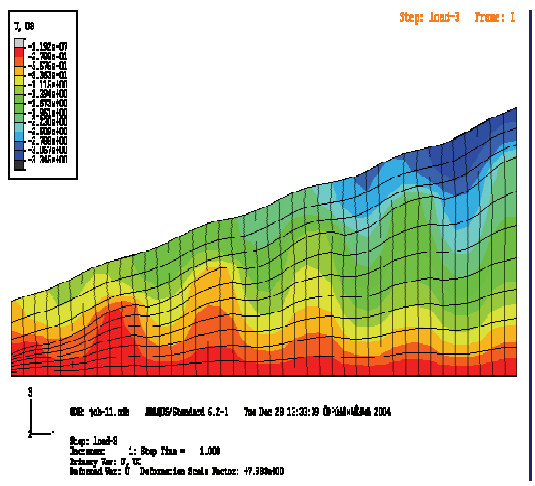

Fig. 4 Settlement under IDWR of 1:3

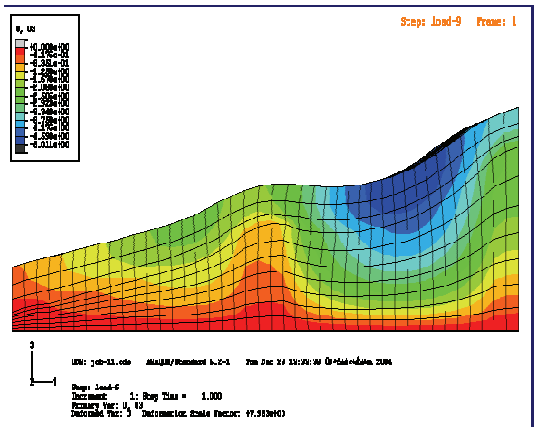

Fig.5 Settlement under IDWR of 1:9

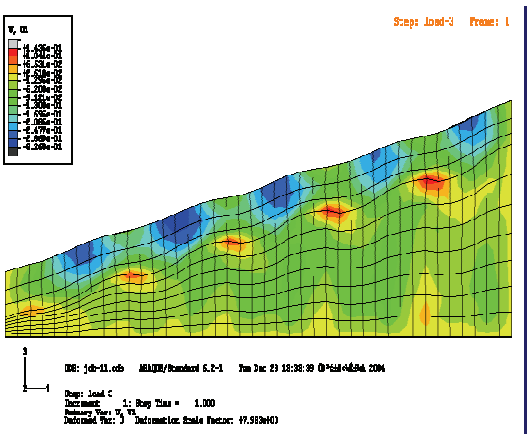

Fig. 6 Horizontal displacement under IDWR of 1:3

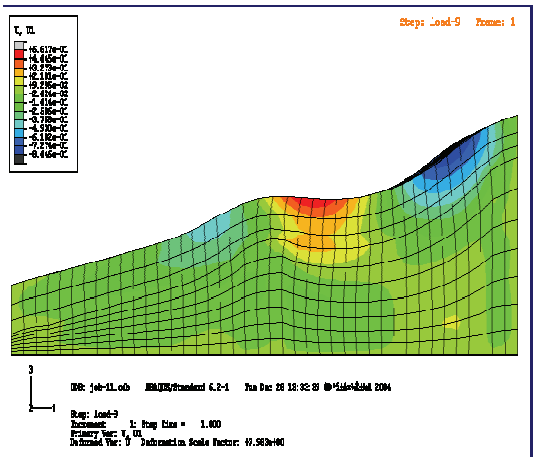

Fig. 7 Horizontal displacement under IDWR of 1:9

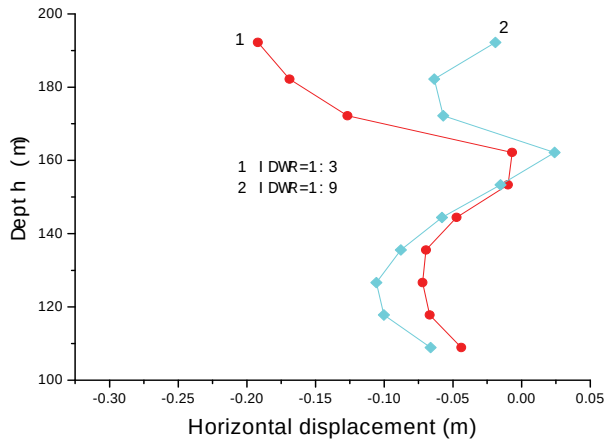

Fig. 8 Horizontal displacement versus depth (Location x=195.122m, y=50.00m）

CONCLUSIONS

The stratum stability induced by the dissociation of gas hydrate is investigated numerically by using of the finite element method. Effects of and discontinuous exploitation are discussed. The effects of IDWR on the displacement and stability are investigated also.

The maximum settlement is located at the center of the HBS dissociation zone. The maximum horizontal displacement is located at the interface between the cover layer and the gas hydrate layer. The maximum stress is located at the boundary of the unexploited area. Thus it is effective to decrease the displacement of the stratum to keep some zones unexploited.

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