On Soil Layer Damage Due to Gas Escape

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Lu Xiaobing, X. D. Chen, X. H. Zhang, and S. Y. Wang

Abstract

Dissociation of natural gas hydrate (NGH) in seabed can product amounts of gas. If the soil layer over NGH layer is permeable, gas will escape. Gas escape can on one hand lead to the damage of seabed, on the other hand lead to the decrease of the density of sea water and so threatens the structures nearby. In this paper movement and expansion behavior of gas in water was first studied, then the damage of seabed due to gas escape was studied. Effects of gas pressure, thickness of soil layer were investigated. The expansion angle of gas in the water was obtained. The characteristics of the hole size induced by gas escape with gas pressure and soil thickness were also obtained. These results can be as references of deeper research and practice.

Keywords

Gas hydrate • Gas escape • Seabed damage

1.1 Introduction

NGH is a new potential source of energy. More and more researchers study the exploitation and exploration of NGH recently. Most of previous attentions are paid on the exploitation of NGH (Hisashi et al. 2002). However, NGH dissociation can lower the strength of NGH sediment and induce kinds of hazards such as landslide of stratum (Lu et al. 2008, 2010, 2011; Locat and Lee 2002).

Large amount of NGH dissociation can causes leakage of gas from seabed (Gilles et al. 1999). If the soil layer over the NHG layer is permeable, gas can percolate through this over layer and causes not only the damage of seabed, but also the formation of bubbles in sea water. Bubbles will flow upwards and decreases the density of sea water, which can lead to the damage of offshore structures such as platforms and ships (Zhang 1998; Sultan et al. 2004). Thus it is important to study the hazards caused by the leakage of gas dissociated from NGH.

1 m^3 NGH can product 164 m^3 methane gas after dissociation. If there is no leakage of gas, pore pressure with 50 MPa can form (Briaud and Chaouch 1997). The over layer will damage once the pore pressure is over its weight and tensile strength. For example, layered fracture or outburst can be observed (Zhang et al. 2011).

In this paper experiments were carried out to observe the diffusion of bubbles. The damage characteristics of the soil layer caused by the leakage of gas were studied also. Effects of pressure and thickness of the over layer were mainly considered.

1.2 Experiment of Gas Diffusion

The aim of this paper is to study the mechanism and phenomenon that gas percolates through the over layer and diffuses in the sea water during flowing upwards. Although gas produced from dissociation of gas hydrate is in a relatively large zone and passes the hole in the over layer with a variable pressure at field conditions, the model box adopted

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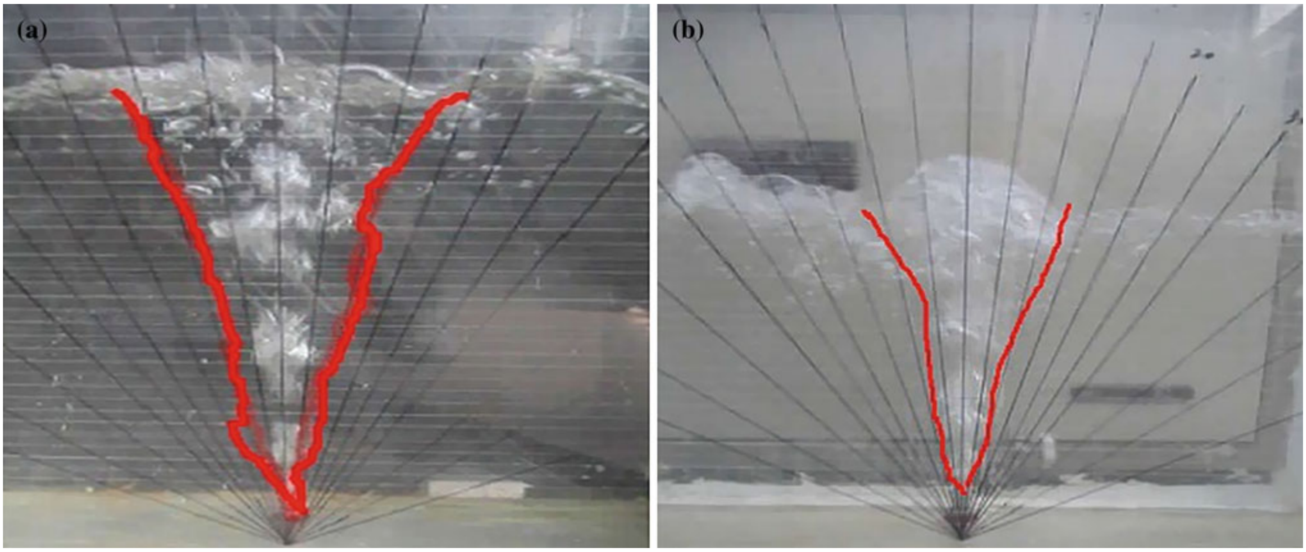

Fig. 1.1 Photo of the bubble expansion (hole diameter 3 cm, water depth 35 cm) **a** Gas pressure is 7.5 kPa, **b** Gas pressure is 25 kPa

here is with a size is length × width × height = 50 cm × 10 cm × 50 cm and gas flowed directly out from a hole at the bottom of the box to model the gas flow from the dissociation zone. It is difficult to model the whole process from dissociation of gas hydrate to seepage and damage of over layer. Though the adopted device is not designed by the similar law, it is enough to obtain the required results if only we control the main parameters (pressure, water depth, soil layer depth). Meantime, this choice can make the experiments be carried out fast and convenient. Controlling device of gas pressure and gas pump was used to output gas flow with different pressures.

A hole was set at the bottom of the box. Gas with designed pressure can pass through the hole into water. Two diameters of the holes, 3 and 6 cm, are chosen to control the output flow rate and pressure at the hole because the pressure of the gas source is fixed. Three depths of water layer, 25, 35 and 40 cm, were adopted to investigate the effects of water depth. Gas pressures at the hole were controlled as 2.5, 5, 7.5, 12.5, 15, 17.5 and 20 kPa. Camera was used to record the bubbles' movement during flowing upwards.

Diffusion of gas under different conditions is similar (Fig. 1.1). Bubble flow is with a diffusion angle 5°–10° near the bottom, and a little bigger than 10° near the surface. Depth of water and hole diameter have little effects on the diffusion angle in the range of water depth in our experiments.

1.3 Critical Bubble Content Which can Cause a Structure Settle

Assuming it is the critical state when a structure just settles in the water with bubbles, that means, the weight of the structure is just equal to the floating force, so

$$\rho_c = G/V_s \tag{1.1}$$

in which ρ_c is the water density in the critical state, V_s is the total volume of the structure, G is the weight of structure and load on it.

The weight of the bubble is neglected because it is too small relative to the weight of water, so for any water with density ρ:

$$\rho = \frac{\rho_w V_w}{V_w + V_g} \tag{1.2}$$

Let $V_g/(V_g + V_w)$, volume percentage of bubbles corresponding to density ω is:

$$\omega = \rho/\rho_w \tag{1.3}$$

So volume percentage of bubbles corresponding to critical density ω_c is:

$$\omega_c = \rho_c/\rho_w \tag{1.4}$$

in which V_w is the water volume, V_g the bubble volume, ρ_w water density.

The diffusion angle is assumed as 10° by the above experiments. The area with bubbles is assumed as a cone (Fig. 1.1). Water depth is h, then the radius of the zone with bubbles at the surface is $x = h \cdot \tan 10°$. Assuming the total gas volume in this zone is a, solubility of methane gas hydrate in sea water is β.

Volume of the circular cone is

$$V = \frac{\pi r^2 h}{3} = \frac{\pi \tan^2 10 \cdot h^3}{3} \tag{1.5}$$

According to the critical density obtained in the above section, the total gas volume which can causes the settlement of structures can be obtained as follows considering it contains the bubbles in water and the dissolved gas in water.

$$a = [(1 - \omega_c)\beta + \omega_c]V \tag{1.6}$$

1.4 Experiment on the Soil Layer Damage Caused by Seepage Gas

1.4.1 Experimental Setup

The aim in this section is to study the damage of soil layer caused by the seepage of dissociated gas from NHG, so gas flowing with different pressures from a hole into the soil layer is used to model the gas seepage from NGH sediment into water but not NGH sediment. The silty sand with dry density of 1600 kg/m^3 was used.

Initial water content of the soil was $w = 6.35$ %, thickness of soil layer is adopted as 10, 15 and 25 cm respectively. Output pressures were 2.5, 5, 7.5, 10 and 12.5 kPa respectively. Soil layer was first prepared to the designed thickness, then water was percolated slowly from a hole at the bottom of the box till the water level was 20 cm over the surface of the soil layer. Experiments were carried out after the model stayed statically for some time. The course and damage forms of soil layer were observed. The size of the damage zone was recorded.

1.4.2 Experimental Results of Sediment Damage

(a) Results when the thickness of soil layer is 10 cm

It is observed that bubbles get out from the surface of the soil layer when the pressure is 2.5 kPa and gas seepage causes the damage of the soil layer. The damage zone is cone type whose width and depth are 9 and 2 cm respectively. The damage zones are similar under other pressures. Damage zone expands fast at first and then becomes stable gradually. The duration to arrive at the stable state increases with the rise of pressure. The width and depth of the damage zone under different pressures are shown in Figs. 1.2 and 1.3. The size and expansion speed of the damage zone increase with the rise of pressure. Obviously, gas flows faster when the pressure is larger, so the effects of erosion and damage are stronger.

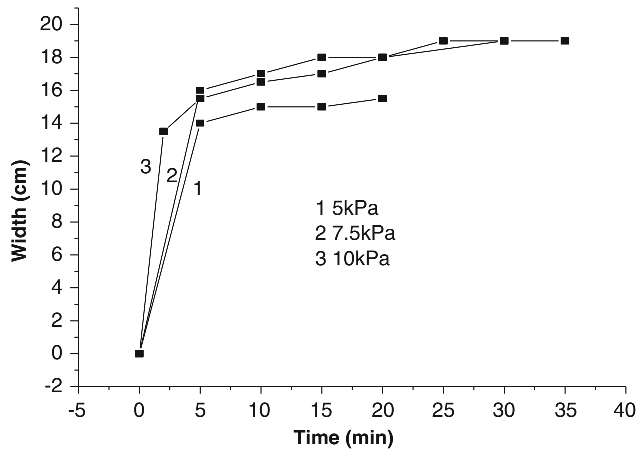

Fig. 1.2 Width of the damage zone

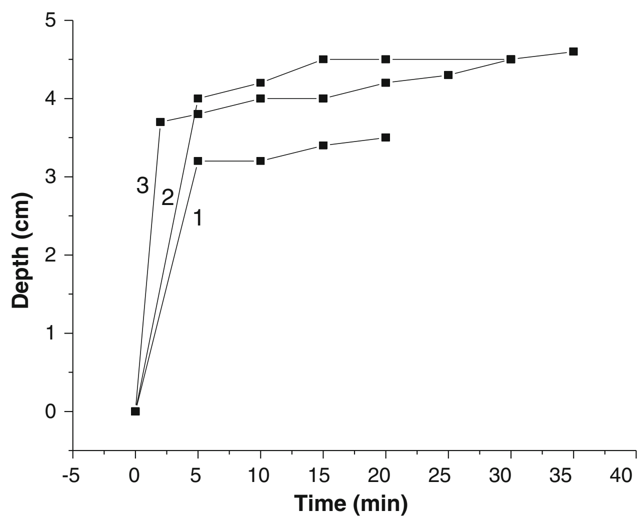

Fig. 1.3 Depth of damage zone

(b) Results when the thickness of soil layer is 15 cm

It is observed that after the valve is opened, bubbles are shown at the surface of soil layer just above the gas hole. Water becomes unclear gradually. After some time, grains are taken out by bubbles. The damage zone increases with pressure and is larger than that under the thickness of soil layer 10 cm (Figs. 1.4 and 1.5). The reason is that the seepage line and the diffusion zone increase with the rise of the thickness of soil layer.

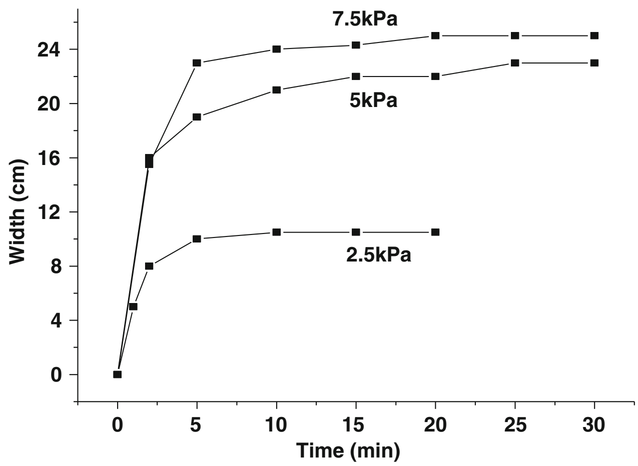

Fig. 1.4 Width of damage zone

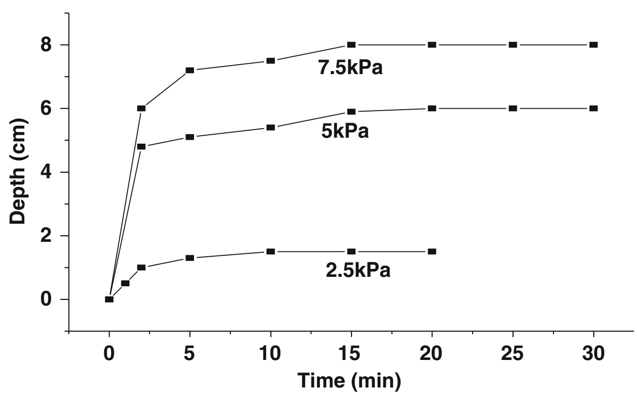

Fig. 1.5 Depth of damage zone

(c) Results when the thickness of soil layer is 25 cm

Under pressure of 2.5 kPa, there is no bubble is observed even 30 min after the valve is opened. Soil layer is not damaged. Under pressure of 5 kPa, a few grains are taken into water by bubbles. The soil layer is damaged gradually but the damage zone is small. The width and depth of the damage zone are 7 and 3 cm respectively. Shown in Table 1.1 are the width and depth under the pressure 7.5 kPa. When the gas pressure is given, the resistance is larger at larger depth of soil layer. Gas can not take grains away from soil layer when the thickness is over some value at given pressure. Thus no damage zone can be observed. For a given gas pressure, there exists a thickness of soil layer corresponding to maximum damage zone. Less than this thickness, damage zone increases with the increase of thickness. Otherwise, damage zone decreases.

Table 1.1 Depth and width of damage zone at pressure of 7.5 kPa and 25 cm thick

Pressure = 7.5 kPa		
Time (min)	Width (cm)	Depth (cm)
0	0	0
5	10	4
10	11	4.5
15	13	4.5
20	13	4.5
25	13	4.5

The changes of the width and depth of damage zone with gas pressure are shown in Fig. 1.6. It can be seen that the width and depth is linear to the gas pressure when the pressure is less than some value. After that the width and depth keep almost stable. The duration to arrive at maximum damage zone and the required pressure to cause the damage of soil layer increase with the thickness of soil layer. The depth of the damage zone first increases with soil thickness and then decreases because the seepage pressure can cause larger zone be damaged when the soil thickness is not large enough to induce the seepage pressure decrease obviously. However, with the increase of soil thickness, seepage pressure decreases largely so the erosion power of seepage decreases.

1.5 Discussion

During passing through the soil layer, gas has momentum and so can take some fine grains out from the soil layer. With the loose of fine grains, soil skeleton becomes unstable. Some part near the surface becomes catastrophic and the soil grains are taken away by the water flow and bubbles. During flowing upwards, velocity of water flow and bubble decrease gradually. Grains settle gradually and at last an eroded hole is formed.

With the increase of the thickness of soil layer, the resistance that the gas must overcome and the seepage route become large, meanwhile the duration for gas to pass through the soil layer becomes longer, thus the required pressure is large. For example, when the soil layer is 10 cm thick, gas can pass through the soil layer in about several

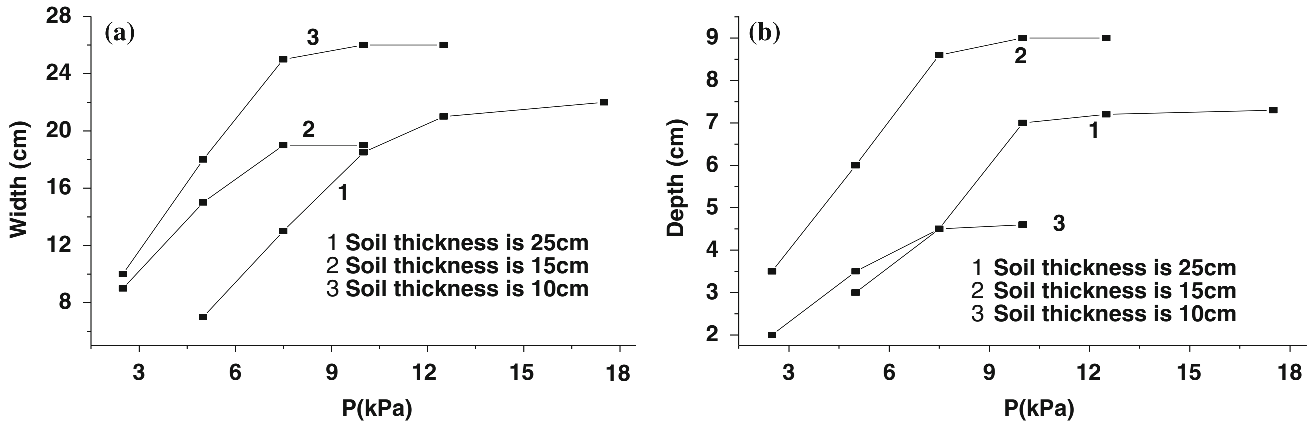

Fig. 1.6 Development of the depth of damage zone with gas pressure **a** Width versus pressure, **b** Depth versus pressure

seconds under 2.5 kPa; while the thickness of soil layer increases to 15 cm, gas can be observed after 1 min; when the soil layer is 25 cm thick, no gas is observed to pass through the soil layer, and it is observed to pass through only if the pressure is increased to 5 kPa.

1.6 Conclusions

Movement and expansion behavior of gas in the water and the damage of the soil layer due to gas escape were studied. Main conclusions obtained under the experimental conditions of this paper are as follows:

(1) Expansion angle of the escape bubbles in the water is about 5°–10°.
(2) Width and depth of the damage zone is linear to the gas pressure when the pressure is less than some value.
(3) Thickness of soil layer is the main factor to determine the size of damage zone. There is a critical thickness of soil layer, less than which the size of the damage zone increases with the thickness.

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References

Briaud JL, Chaouch A (1997) Hydrate melting in soil around hot conductor. ASCE J Geotech Geoenviron Eng 123(7):645–653
Gilles G, David G, Aleksandr M (1999) Characterization of in situ elastic properties of gas hydrate-bearing sediments on the Blake Ridge. J Geophys Res 104(B8):17781–17795
Hisashi OK, Sridhar N, Song F, Duane HS (2002) Synthesis of methane gas hydrate in porous sediments and its dissociation by depressurizing. Powder Technol 122:239–246
Lu XB, Wang L, Wang SY et al (2008) Study on the mechanical properties of THF hydrate deposit. In: Proceedings of the 18th international offshore and polar engineering conference, Vancouver, pp 57–60
Lu XB, Wang L et al (2010) Instability of seabed and pipes induced by NGH dissociation. In: Proceedings of the 20th international offshore and polar engineering conference, Beijing, pp 110–114
Lu XB, Zhang XH, Wang SY (2011) Strong failure of seabed induced by gas hydrate dissociation In: 7th international conference gas hydrate, Edinburgh
Locat J, Lee HJ (2002) Submarine landslide, advances and challenges. J Canada Geotechnol 39:93–212
Sultan N, Cochonat P, Foucher JP et al (2004) Effect of NGHs melting on seafloor slope instability. J Marine Geol 213:379–401
Zhang Youxue (1998) Experiment simulations of gas-driven eruptions: kinetics of bubble growth and effect of geometry. Bull Volcanol 59:281–290
Zhang XH, Lu XB, Zheng ZM (2011) Layered fracture and outburst due to dissociation of hydrate. J Petrol Sci Eng 76:212–216