Modeling the behaviors of hydrate-bearing sediment at different pore pressure and temperature environment

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Gas hydrate is a clathrate compound synthesized from gas (i.e. CH_4 and CO_2) and water under a relative high pressure and low temperature condition. In nature, methane hydrate often exists in the deep water marine sediment or permafrost region. The sediment containing hydrate within pores is referred to as hydrate-bearing sediment (HBS). Due to a high concentration of methane stored in form of methane hydrate, methane hydrate is considered to be an attractive potential source of energy (Sloan, 2003). To produce methane from natural hydrate reservoir, three typical approaches, such as heating, depressurizing and hydrate inhibitor injection, are developed to dissociate hydrate back into methane and water, and then extract methane gas in field. Apparently, hydrate dissociation within pores could decrease the strength of GHBS, perhaps leading to submarine landslides, platform foundation failures, and borehole instability. Therefore, understanding and modeling mechanical behavior of GHBS are key components in evaluating the stability of GHBS for methane production from natural hydrate reservoir (Grozic et al., 2010; Lee et al., 2010).

It has been observed that pore pressure and temperature have remarkable effects on the mechanical behavior of HBS (Hyodo et al., 2013). In the simulation for gas production from hydrate, the temperature and pore pressure dependency of HBS should be addressed in the constitutive model. The authors are aiming to propose an elasto-plastic constitutive model for HBS with considering the temperature and pore pressure effects on mechanical property of HBS.

In the proposed model, a new variable, referred to as 'P-T condition parameter θ', is introduced to address the effects of temperature and pore pressure on mechanical behaviors.

$$\theta = \frac{T_{eq} - T}{T_0} \qquad [1]$$

where T_{eq} is the equilibrium temperature corresponding to testing pore pressure; T is the testing temperature, and T_0 is the reference temperature (T_0=273.15K).

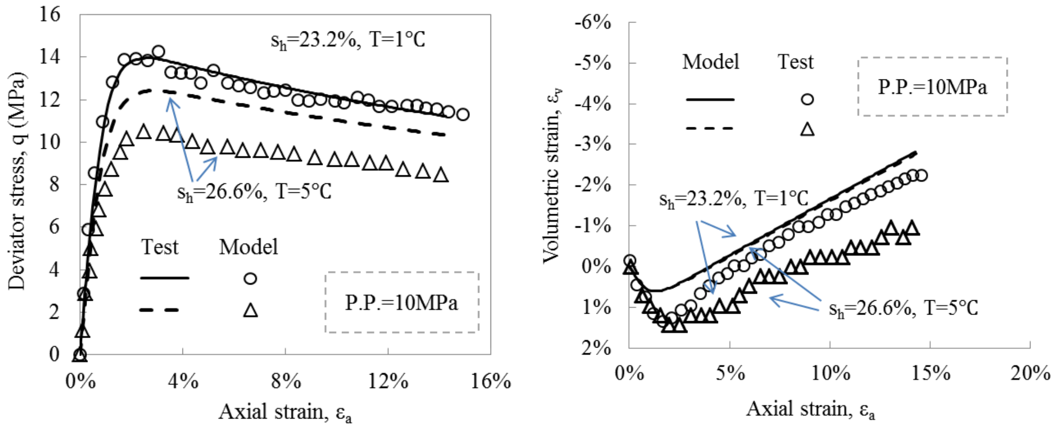
Moreover, a basic relationship between mechanical index of HBS and P-T condition parameter θ is presented as,

$$\frac{\mathrm{X}}{\mathrm{X}^0} = \exp(\omega \cdot \theta) \qquad [2]$$

Where X represents the mechanical index of hydrate-bearing sediment, such as stiffness, bonding stress, strength, etc., X^0 denotes the mechanical index of hydrate-bearing sediment at $\theta = 0$.

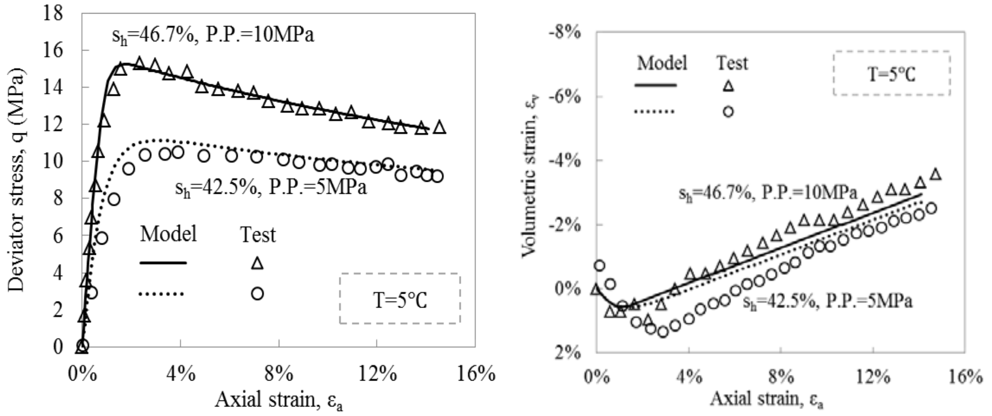
According to the proposed new variable " P-T condition parameter θ ", the corresponding new yield function, hardening and debonding laws, and dilatancy function to consist of the constitutive model considering temperature and pore pressure effects.

Via comparing the predicted results to experimental data from triaxial compression tests (Hyodo et al., 2013), as shown in Fig 1, it is demonstrated that the proposed model is able to address the influences of temperature and pore pressure on the mechanical behavior of HBS. Besides, the further analysis on the mechanical responses of hydrate-bearing sediment subjected to depressurization shows that it is very perilous for commercial gas production from hydrate if ignoring the influence of temperature and pore pressure.



(a) (b)

Fig. 1: Comparison between the experimental data and the predicted results for gas hydrate-bearing sediments with varying testing temperature: (a) stress-strain curves and (b) volumetric strain-axial strain curves [Hyodo et al., 2013]



(a) (b)

Fig. 2: Comparison between the experimental data and the predicted results for gas hydrate-bearing sediments with varying testing pore pressure: (a) stress-strain curves and (b) volumetric strain-axial strain curves [Hyodo et al., 2013]

References

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