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Effects of hydrate on the stiffness of the hydrate bearing sediments in Ulleung Basin

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1 Introduction

Hydrates in the pores of hydrate bearing sediments result in a cementation effect between the particles that results in an increase in stiffness. The stiffness of hydrate-bearing sediments has been found to vary with the degree of hydrate saturation during the gas production (Miyazaki et al., 2011). For accurate stability analysis, the changes in stiffness of hydrate-bearing sediments have to be considered in numerical analyses. However, due to the lack of experimental results for the hydrate bearing sediments from the Ulleung Basin, a correlation stiffness model was used in a previous study (Kim, 2016). This previous study used the model that estimates the initial elastic modulus from the effective vertical stress, as follows:

(1) $E_0 = \alpha(\sigma'/1\,kPa)^{\beta}$

where E0 is the initial elastic modulus without hydrate [Pa], σ' is the effective vertical stress [kPa], and the empirical parameters α and β were calibrated using experimental data from the literature (Uchida et al., 2012). The previous stiffness model for the Ulleung Basin is the function of the initial elastic modulus without the hydrate, E_0, and the hydrate saturation, S_h (Kim 2016), as follows:

(2) $E_{hyd} = E_0(1 + 13.25S_h)$

where E_{hyd} is the elastic modulus with hydrate saturation [Pa], and S_h is the hydrate saturation [-]. However, this model is hard to apply the productivity and stability analysis of the Ulleung basin due to the differences of characteristics of soil specimen between the sites.

2 Model Description

A TRT was undertaken on an energy screw pile built in This study used the stiffness model derived by the triaxial experimental test using an artificial specimen of the Ulleung basin (Equation 3).

(3) $E_{hyd} = E_0(1 + 5S_h)$

Figure 1 shows the comparison between stiffness models and literature experimental data (Miyazaki et al. 2011). The literature experimental data were taken the results using silica sand No.8, which has a same mean particle size of 130 μm with the Ulleung Basin specimen (e.g., silty sand, 130μm). The elastic modulus tendency of the Ulleung Basin model showed more similar with the literature experimental data than those of previous model. And the previous model showed more sensitive to the hydrate saturation than the Ulleung Basin model. It means that the stability evaluation will be differ in accordance with the applied stiffness model.

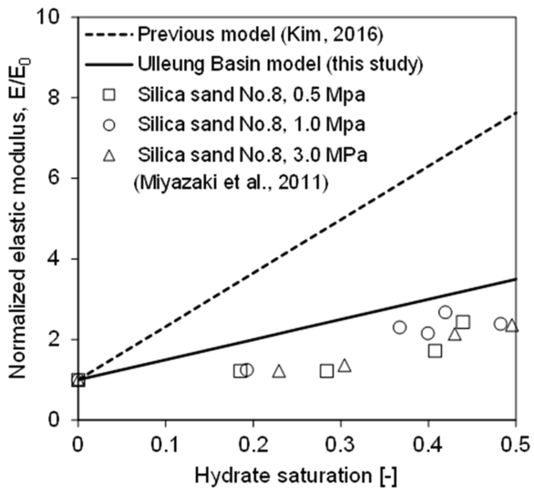

Fig. 1: Comparison of stiffness models and literature data

3 Verification

The proposed stiffness model was compared with the existing theoretical models in terms of wave velocity. In previous studies, the relationship between wave velocity and hydrate saturation was suggested as shown in Table 1. The relationship between these were derived by the

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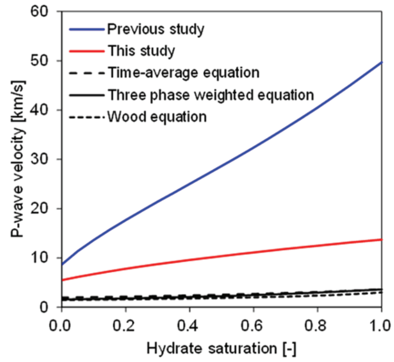
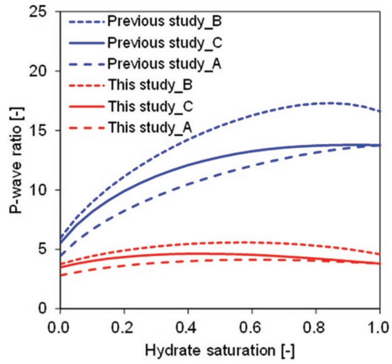
measured P-wave velocity in lab-scale experimental tests and in-situ core samples. The P-wave velocities of stiffness model (Equation 3) and previous stiffness model (Equation 2) can be estimated by follows:

$$V_p = \sqrt{(K + 4G/3)/v} \quad (4)$$

where K is the bulk modulus [MPa], G is the shear modulus [MPa], and ν is the Poisson's ratio [=0.25]. The estimated P-wave velocities were compared as shown in Fig. 2a. The differences between the stiffness models (Equations 2 and 3) and existing models (Table 1) were plotted in Figure 2b.



(a)



(b)

Fig. 2: Comparison of models: (a) P-wave velocity estimation; (b) P-wave velocity ratio of stiffness models and existing models

The P-wave velocity estimated by the stiffness model (this study) showed less sensitivity than that of the previous stiffness model. The stiffness model proposed in this study has similar trends in the P-wave velocity according to the hydrate saturation with the existing models (Figure 2a), but in the case of the previous stiffness model, the P-wave velocity was overestimated as the hydrate saturation increased (Figure 2b). Additionally, the P-wave velocity derived by the stiffness model proposed in this study was generally larger than that of the existing model. This is because the existing model has limitations in the relatively shallow regional characteristics and the core sample were disturbed during testing. On the other hand, in the case of the model proposed in this study, the experiment was performed by applying a large confining pressure to simulate a relatively deep depths (about 2000 m) and sediments located about 145 m below the sea floor. Therefore, it is inferred that the proposed stiffness model is suitable for representing the stiffness according to the hydrate saturation of the Ulleung Basin sediments.

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Table 1. Wave velocity models and comparison cases of P-wave velocity estimation

Notation	Stiffness model	Existing model	Equation
Previous study_A	$E_{hyd} = E_0(1 + 13.25S_h)$	Time-average	$1/V_p = \emptyset(1 - S_h)/V_w + \emptyset S_h/V_h + (1 - \emptyset)/V_m$ (Wyllie et al., 1958)
Previous study_B		Wood	$1/\rho V_p^2 = \emptyset/\rho_w V_w^2 + (1 - \emptyset)/\rho_m V_m^2$ (Wood et al., 1994)
Previous study_C		Three phase weighted	$1/V_p = W\emptyset(1 - S_h)^n/V_{p1} + (1 - W\emptyset(1 - S_h)^n)/V_{p2}$ (Lee et al., 1996)
This study_A	$E_{hyd} = E_0(1 + 5.0S_h)$	Time-average	Refer the first row
This study_B		Wood	Refer the second row
This study_C		Three phase weighted	Refer the third row