Numerical Analysis of Deformation of Methane Hydrated Contained Soil due to the Dissociation of Gas Hydrate

Sayuri Kimoto\textsuperscript{1}, Fusao Oka\textsuperscript{1}, Masaya Fujiwaki\textsuperscript{1} and Yuji Fujita\textsuperscript{2}

\textsuperscript{1}Kyoto University, Japan.
\textsuperscript{2}Former student of Kyoto University, Japan.

Summary

We have developed a simulation method to predict the ground deformation due to the dissociation of methane hydrate. In the dissociation process, the phase change from solid to fluids leads to the change in partial stresses in the porous media, which will cause the ground deformation. The simulations are based on the chemo-thermo-mechanical coupled finite element analysis, in which the phase change, the flow of pore fluids, the mechanical behavior of solid skeleton, and heat transfer are simultaneously solved. We treat the ground as unsaturated soils, and apply an elasto-viscoplastic constitutive model to the soil skeleton. Using the proposed method, we have numerically analyzed the dissociation process for heating methods. Ground deformation has been predicted which is caused by water and gas generation during the dissociation.

1 Introduction

Hydrates are treated as a potential energy resource for the 21st century because a large amount of methane gas is contained in hydrate reservoirs. The impact of gas hydrate dissociation on the ground stability is important for evaluating the safety of offshore structures as well as for understanding environmental effect. From an environmental point of view it is necessary to predict the long-term behavior of reservoir and surrounding ground due to the dissociation. In order to accurately predict the behavior of sea ground due to the dissociation of natural gas hydrate, it is necessary to
develop a powerful simulator considering soil deformation as well as gas production. In the past few years, some numerical simulators to evaluate gas production values have been developed. Masuda et al. (2002) and Ahmadi et al. (2004) have developed a numerical model by using finite difference method for predicting gas and water flow with hydrate dissociation. They consider fluid transfer and heat transfer, however, solid phases are assumed to be immobile. Some other simulators have been developed, however, in most of them the solid phases are assumed to be rigid (e.g., Bejan et al. 2002; Tsypkin 2000; Bondarev and Kapitonova 1999). Klar and Soga (2005) presented flow-deformation analysis of methane hydrate extraction problems using finite difference code. They treat hydrate-solid mixture as plastic material which strength is a function of hydrate saturation. Heat transfer has not been considered in the model. Therefore the powerful simulator which can consider chemo-thermo-mechanical coupling behavior needs to be developed in order to investigate the ground stability during gas production.

The proposed analysis in the present paper is based on the fundamental concept of theory of porous media (e.g. Ehlers 2003) and the extended Biot’s theory (1956). Materials are assumed to be composed of solid, water, and gas, which are continuously distributed over the space. In the simulation, dissociation occurs when hydrated pass out the stability zone which is described by pressure and temperature (Bejan et al. 2002). In order to consider phase change caused by dissociation, the mass increasing ratio of water, gas and dissociation heat ratio is introduced in the mass conservation law and the energy conservation law. Water and gas flows are assumed to be controlled by Darcy’s type law.

In the dissociation process, the generated gas pressure cannot be neglected, and hence soil mechanics under unsaturated state becomes important to predict the ground deformation. In the modeling of mechanical behavior for unsaturated soil, it is necessary to choose appropriate stress variables which control the mechanical behavior. Furthermore, the effect of suction has to be described in the model. In the present study the average skeleton stress, which is determined from the difference between the total stress and the average pore fluid pressure, is used as the stress variables in the constitutive model. The effect of suction is expressed in the constitutive equation, as shrinkage or expansion of the yield surface. An elasto-viscoplastic constitutive model is adopted for the soil skeleton, since the hydrate reservoir around Japan archipelago is laminated with sand, clay, and silt. Several material parameters were determined considering the results obtained by the field research at Nankai Ocean.