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Coupled Soil Deformation-Flow-Thermal Analysis of Methane Production in Layered Methane Hydrate Soils

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Abstract

A potential of methane hydrate to be an alternative energy resource has triggered numerous researches to investigate the physical, chemical and mechanical properties of methane hydrate bearing soils. Among various issues, geotechnical characterization of methane-hydrate soil is particularly important. For example, depressurization process used for methane gas extraction significantly changes the stress state and the mechanical properties of hydrate soils, which may lead to potential geotechnical hazards such as submarine landslide or wellbore collapse. At present, most of the geotechnical analyses associated with methane gas extraction assume that depressurization of methane hydrate happens in a homogeneous hydrate soil layer. This paper presents results of the analyses of methane hydrate extraction in alternating layers of clay and hydrate-bearing sand, which are encountered in the Nankai Trough. Using a coupled deformation-flow-thermal code implemented in *FLAC*, the methane gas extraction process in such soil conditions is simulated. Results show that heat flows from the clay layer to the sand layer leads to faster rate of hydrate dissociation in the hydrate region near the clay/sand boundary than at the center of the hydrate-sand layer, which influences stress distribution around the wellbore. As the soil relaxes toward the wellbore, arching effect in the vertical plane can be seen in the sand layer in addition to the usual increase in the circumferential stress. This is due to the force transfer from the casing to the clay layer, which deforms greater than the sand layer during depressurization. The thickness of the layered soils is also varied and it is demonstrated that the heat flow from the interface has a greater effect in the case of a smaller thickness of the clay-sand layer. Consequently, the arching effect and vertical compression are more prominent inside such case. The above findings highlight the importance of understanding geotechnical characteristics of methane hydrate soil in production.

Introduction

Methane hydrate is an ice like solid material composed of a gas molecule caged in a structure made of water molecules, and its natural form only exists under high pressure and low temperature condition, i.e. permafrost regions or beneath deep seabed. It is formed inside soil pores and it will dissociate into methane gas and water if the stable temperature-pressure equilibrium is breached. Sites with high concentration of methane hydrate are considered to be a possible energy resource for future years. This has triggered numerous researches to investigate the physical, chemical and mechanical properties of methane hydrate soils. Two methods are generally accepted to be feasible for dissociating methane hydrate and hence extracting methane gas in situ: (1) the use of depressurized wells, which reduce the pressure in the soil around the wells, and (2) the use of thermal injection wells, which increase the temperature in the surrounding soil by injecting hot fluid.

Since methane hydrate is likely to behave as a cohesive material to sedimentary unconsolidated sandy soils (Soga et al., 2006), the dissociation reduces its bonding effect and hence the methane hydrate soil loses its apparent cohesion associated with the hydrate. The mechanical properties of hydrate soils are significantly changed and excessive ground deformation is possible. Potential geotechnical hazards such as submarine landslide and collapse of wellbore wall may occur. Therefore, the stability of a gas-hydrate extraction well during depressurization process has been studied and a homogeneous hydrate sand layer was assumed for simplicity in the work by Klar and Soga (2005) and many others. However, in sites such as Nankai Trough and Mallik Mackenzie Delta, a soil profile of alternating layers of sands and clays is encountered (e.g. Soga et al, 2006). In the Nankai Trough, the soil underneath the 950 m deep of water is firstly 40 m of calcareous silt and clay with volcanic ash layers. Then, 90 m of calcareous silt and clay with volcanic ash and thin sand layers are encountered. Underneath this is about 70 m hydrate-bearing stratum, which has alternating layers of weakly consolidated calcareous silt/clay and thick,