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MECHANICAL AND NUMERICAL MODELING OF GAS HYDRATE BEARING SEDIMENTS

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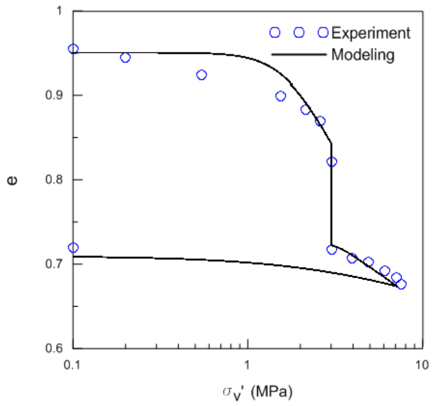
Summary. Gas hydrates soils are generally found in sub-marine sediments and in permafrost regions. The stability of hydrates depends on temperature, pressure and water chemistry. If these conditions shift from the stability zone, hydrates dissociate and move from the solid to the gas phase. Hydrate dissociation is accompanied by huge changes in sediment structure affecting its mechanical behavior. Unfortunately, the experimental study of Hydrate Bearing sediments (HBS) has been hindered by the very low solubility of methane in water and inherent sampling difficulties associated with depressurization and heating during core extraction (i.e., limited testing of natural specimens). This situation has prompted more decisive developments in numerical modeling in order to advance the current understanding of HBS, and to investigate production strategies and implications. However, modeling is also affected by the complex behavior of HBS. The presence of hydrates has a great impact on the mechanical behavior of soils, affecting stiffenss, strength and dilatancy. The behavior of HBS is very complex and its modeling poses great challenges. This paper presents constitutive and numerical models to simulate the coupled Themo-Hydro-Chemo-Mechanical (THCM) behavior of HBS. The model was applied and validated against experimental data from different experiments. The model performance was very satisfactory in all the cases studied. It managed to capture very well the main features of HBS behavior and it also assisted to interpret the behavior of this type of sediment under different loading and hydrate conditions.

COUPLED THERMO-HYDRO-CHEMO-MECHANICAL APPROACH

During hydrate formation and dissociation several THCM phenomena that take place in the sediments, amongst others: i) heat transport through conduction, liquid and gas phase advection; ii) formation-dissociation heat, iii) water and methane fluxes; iv) heat of ice formation/thaw; v) effect of water salinity on phase boundary; vi) mechanical behavior (including hydrate concentration dependent sediment behavior). A fully coupled mathematical formulation is proposed to deal will the phenomena quoted above and their mutual interactions. The proposed framework encompasses the main following components: balance equations, constitutive equations, equilibrium restrictions, and kinetic reactions. The main balance equations considered are: mass balance of water, methane and mineral; internal energy balance; and momentum balance. Constitutive equations for the different physics (i.e. thermal, mechanical, and hydraulic) aimed at capturing the complex behavior of HBS are also proposed. The suggested mathematical framework have been implemented in the finite element computer program CODE-BRIGHT [1].

The mechanical modeling of HBS is a key component in the numerical simulation of engineering problems involving this kind of soil. The elasto-plastic framework proposed in this work contemplates the presence of two basics components: sediment skeleton and hydrate. Specific constitutive equations for these two basic structural components are proposed using the stress partition approach [2]. For the sediment skeleton, the HISS elasto-plastic model based on critical state soil mechanics concepts is adopted. As for the hydrates, a damage model that considers the material degradation due to loading and dissociation is suggested. The model described above is very well suited to simulate problems involving hydrate dissociation. A case of this last type is discussed below.

Two natural core samples were tested under oedometric conditions [3]. Figure on the right shows the results related to specimen coded as 'core 10P', with an initial hydrate saturation of 74%. This sample was loaded until σ'_v=3 MPa. At this normally-consolidated condition, the effective stress was hold constant and hydrate dissociation was induced. After hydrate dissociation, the sample was loaded up to σ'_v=9 MPa and then unloaded. The model managed to capture very satisfactorily the main trends observed in both tests. It is worth to highlight the model ability to reproduce the volumetric collapse compression behavior observed during dissociation at constant stress. The performance of the model and numerical approach to simulate different conditions involving HBS has been successfully investigated [4].



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