Laboratory tests on geo-mechanical properties of gas hydrate-bearing sediments

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Abstract

Methane hydrates are considered to be promising resources for natural gas due to their wide and numerous occurrences along continental margins as well as permafrost areas. An important precondition for the safe and efficient production of these reservoirs is the knowledge of the initial geo-mechanical properties of the reservoir as well as the reservoirs’ response under production. In the weakly consolidated surface sediments of marine slopes, gas hydrates may drastically alter the sediment stiffness and strength depending on their saturation, their pore-scale morphology and habit, and their subsequent decomposition. Owing to experimental difficulties and missing standards, strength measurements on gas hydrate-bearing sediments are insufficient in number, accuracy, and precision.

In our high-pressure lab we currently develop methods to determine the geo-mechanical properties of hydrate-bearing sediments with a specific emphasis on tensile and shear strength. Both parameters are vital for predicting sediment integrity and slope stabilities from numerical simulations, which in turn are essential for environmental risk assessments and safe production. Since production is considered more efficient from sandy sediments it is these sediments we focus on. In sands naturally occurring gas hydrates commonly form in the pore spaces and have a pore-filling or load-bearing habit depending on the hydrate saturation, whereas cementing hydrates play a minor role for hydrate reservoirs interesting for gas production. So do gas hydrate lenses and veins, which are more pronounced in finer sediments.

The limited knowledge on the strain-strength behavior of hydrate-bearing sediments is based on the fact that undisturbed natural samples are extremely rare and laboratory studies often struggle with a) the formation of homogeneously distributed gas hydrate with a natural habit and b) the absence of free gas. Cementing hydrates - the most common form in laboratory experiments - strongly support the grain skeleton, take over effective stress, and considerably increase sediment stiffness even at low concentrations. They are commonly formed from free gas at low water concentrations with resulting hydrate saturations not exceeding 65% or even 45%. At GFZ we developed a “quick-look” method using ice formed in sandy sediments as a model for pore filling and load-bearing gas hydrates with saturations of 10 – 95%. We have been able to prove the validity of this model for acoustic and electrical properties (see Spangenberg et al., this volume) and will now apply and evaluate this method for the determination of shear and tensile strength of ice and hydrate-bearing non-consolidated sediments. So far the indications for the validity of this model are contradictory.

Currently, sands with high ice saturations are tested for tensile strength. The specifically designed set-up uses a perforated model-borehole in a sediment core of 7 * 20 cm. To avoid any errors induced by melting, the pressurizing fluid is cooled to below 0°C and separated from the sediment-ice-brine core using very flexible silicone tubing, which remains tight even at higher pressures. The fluid is blended with a color indicator to visualize possible leakage. In the early measurements a significant decrease of shear strength has been observed when reducing ice saturation in the sand core from 100 to 90% pore space. Temperatures have been constant; the confining pressure is equal to atmospheric pressure. While continuing this series of measurements, a pressure resistant set-up is currently being manufactured that allows for tensile strength measurements in one of our pressure vessels.

To measure the shear strength of these sediments we constructed and manufactured an **e**xternal ring **s**hear **te**st **r**ig (ESTER), which is currently in the testing phase. The stand-alone test rig will allow for the formation of ice or pore-filling, load-bearing, and cementing gas hydrates in porous sediments under simulated in situ conditions. The maximum load is 25 MPa, the temperature range is -30 to 100°C, and the sample volume 32 cm^3. A strong servomotor provides propulsion. It is equipped with an electrical break that can throttle the shear velocity to a minimum of approx. 0.001 ° / min; a typical velocity for common shear cells without additional loading. The maximum torque is as high as 1 kNm.

Unlike the more common triaxial test cells, a ring shear apparatus enables the direct measurement of the shear strength. Its functional principle is based on a separated upper and lower pan of an annular sample chamber. Whereas the lower sample space is decoupled and static, the upper half is rotated stepwise via a driver shaft and a tappet. The shaft contains the fluid capillary and three vents that expel fluid via a filter plate above the sample in order to allow for a better fluid distribution and to prevent the entrainment of fines into the capillary. The load is transferred to the sample via sealing rings. The shearing is forced to occur at the shear plane between the two parts of the shear ring and not at the weakest plane as is the case in triaxial tests. Especially in gas hydrate research, where a homogeneous formation of hydrates in a sample is extremely difficult, this is a considerable advantage. The shear stress is determined using the readings of a high-resolution torque sensor and the predetermined angle of rotation. Initial tests on dry, wet, and ice-bearing sand have demonstrated the correct functioning of the system just recently. The calibration of the system is still pending.