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Research paper

PCATS Triaxial: A new geotechnical apparatus for characterizing pressure cores from the Nankai Trough, Japan

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ABSTRACT

Understanding the physical nature and mechanical behaviour of hydrate-bearing sediments is of fundamental importance in assessing the resource potential of methane gas hydrates. Advances in pressure coring techniques and associated processing equipment have enabled intact samples to be recovered under *in-situ* pressures. However, testing of these samples under the *in-situ* stress conditions has not been possible. To help address this issue, the PCATS Triaxial apparatus was developed to enable the physical properties of such samples to be measured. The apparatus was deployed for the first time during the JOGMEC funded site investigation of the Eastern Nankai Trough in the summer of 2012, prior to a planned hydrate production test in 2013.

A number of pressurized core were recovered and sub-samples successfully tested in PCATS Triaxial to determine a range of geomechanical properties, including small strain stiffness (from resonance testing), stress–strain properties (triaxial shear tests) and permeability. Samples tested included fine-grained soils with no appreciable hydrate, sands with hydrate saturation greater than 20%, and one sample that had a combination of both materials. Testing showed an increase in stiffness and undrained shear strength with increasing grain size, hydrate saturation and applied effective stress. Permeability was significantly reduced for hydrate-bearing sands compared to clayey samples with no hydrate present.

1. Introduction

In recent years a number of national and international field expeditions have been undertaken to assess the energy resource potential of methane gas hydrate; an ice-like crystalline compound that contains significant volumes of methane gas and forms beneath the permafrost in the Arctic and in deep water marine sediments. These studies highlighted the significant volumes of hydrate that exist: high concentrations within the pore space of coarse-grained sediments, as found beneath the permafrost in the Arctic (Dallimore et al., 1999; Dallimore and Collett, 2005) or in marine sediments such as, Nankai Trough, Japan (Fujii et al., 2008) and Gulf of Mexico, USA (Frye, 2008); or, more dispersed grain displacing fracture filling gas hydrate in fine grained sediments, such as observed in the Cascadia Margin (Riedel et al., 2006; Tréhu et al., 2003); Krishna–Godavari Basin, India (Collett et al., 2008); Ulleung Basin, South Korea (Ryu et al., 2013) and the South China Sea, China (Yang et al., 2014).

The results of production tests conducted during the winter of 2007/2008 at the Mallik gas hydrate production well, Mackenzie Delta, Northwest Territories, Canada (Dallimore et al., 2012), and from numerical simulations (Konno et al., 2010), suggest that the recovery of methane gas from hydrate within coarse-grained sediments, using formation depressurization, maybe economically feasible. Therefore, in 2013, an offshore methane hydrate production test was carried out in the Eastern Nankai Trough by the Japan Oil, Gas, and Metals National Corporation (JOGMEC) to investigate the applicability of the depressurization technique in offshore methane hydrate production. As part of the preparations for this test (Yamamoto, 2014), the production well and two monitoring wells were drilled from the D/V Chikyu drilling vessel in the summer of 2012 with extensive downhole data being acquired

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including pressure core samples. The core samples (Yamamoto et al., 2012), obtained from both within and outside the gas hydrate concentrated zones, were to help provide an understanding of the physical nature and mechanical behaviour of the sediment at this location, and thereby help assess the response of the sediment during the production tests. Pressure cores maintain the *in-situ* hydrostatic pressures within the cores, limiting both hydrate dissociation and exsolution of gas from the gas saturated pore water (normally associated with conventional coring), which can irrevocably alter the structure of the sediment and prevent accurate characterisation of the intact behaviour of the sediment.

Recent advances in pressure coring techniques and associated processing equipment (Schultheiss et al., 2006, 2008), such as the Pressure Core Analysis and Transfer System (PCATS), which has evolved into an essential component of pressure core analysis, now allows non-destructive analysis of pressure cores (X-ray imaging, gamma density and p-wave velocity, V_p) and their subsequent subsectioning and transfer into pressure chambers for further detailed analysis (Schultheiss et al., 2011, 2014). A number of geotechnical test apparatus have been specifically developed to provide more detailed measurements of the physical properties of these sectioned cores without releasing the *in-situ* hydrostatic pressures (Yun et al., 2006 Lee et al., 2009). However, these apparatus are not able to reapply *in-situ* stress conditions (radial and axial) during testing, and as such the true *in-situ* soil behaviour cannot be fully captured. To help address these limitations a UK funded research project was established to develop a geotechnical test apparatus, herein known as PCATS Triaxial, that would enable testing of pressure core samples under full *in-situ* stress condition. This paper provides a background to the design and development of PCATS Triaxial and details the results of some of the very first tests carried out using the apparatus on pressure core samples obtained as part of the JOGMEC methane hydrate production test program.

2. PCATS Triaxial

2.1. Background

The analysis of complex problems, such as the sediment response during hydrate production, requires sophisticated soil models that can fully describe the stress–strain behaviour of the soil. As almost all soils behave non-linearly even under low stress levels, a wide number of soil parameters under both small strain and large strain conditions, maybe required. The difficulty and cost of acquiring pressure cores from deep-water sediments is such that the number of cores available for characterizing soil behaviour is limited. Therefore, it is imperative to maximize the range of soil parameters that can be determined from a given sample under different stress/strain conditions. With this in mind the PCATS Triaxial was designed to accept pressurized core sub-samples with a length/diameter aspect ratio of 2:1 and enable both small and large strain geotechnical tests to be performed on the sample as well as direct-flow measurements of permeability.

2.2. Sample transfer

In traditional geotechnical testing apparatus specimens can be prepared and set up by hand at atmospheric pressures, including sealing of the specimen in a rubber membrane, placement of end platens, and subsequent attachment of measurement instrumentation before testing. For pressure core samples this must be done remotely. Figure 1 highlights the main components of the complete PCATS Triaxial system. The system allows pressure cores to be tested at up to 25 MPa *in-situ* hydrostatic pressures and comprises of a series of interconnected sections: A lower motor driven manipulator; the Triaxial Transfer Vessel (TTV) housing the subsampled section of core from PCATS (under pressure); the test cell in which geotechnical testing is carried out; the upper motor driven manipulator.

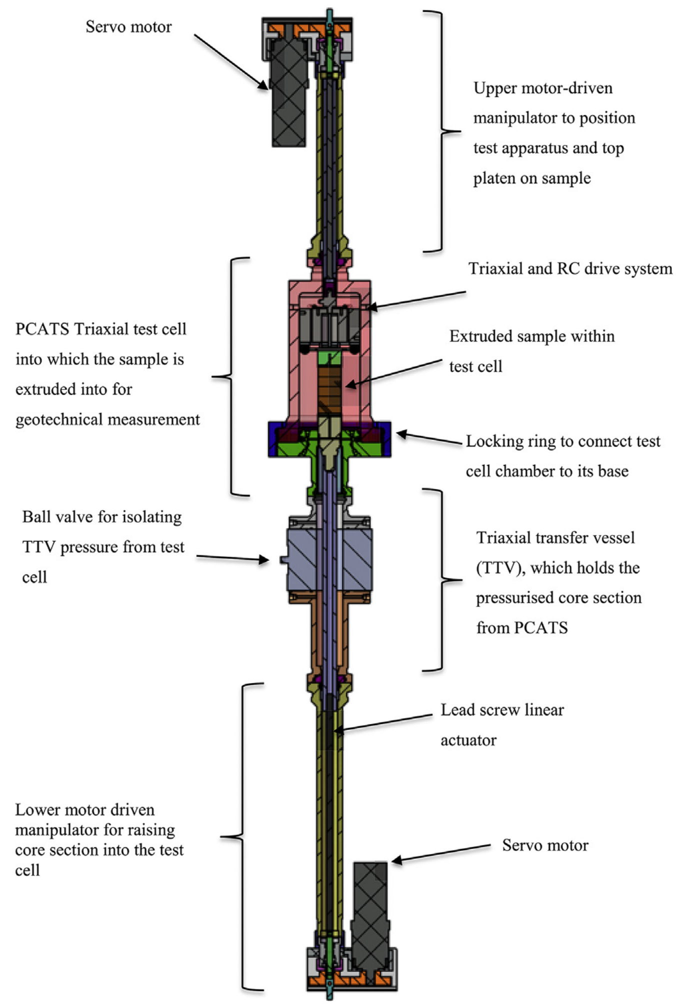

Figure 1. Layout of the complete PCATS Triaxial.

During initial test set up, the lower manipulator, consisting of a high precision lead screw linear actuator controlled by a step driven servomotor at the lower end, is connected to the TTV via a specially designed base platen housed in the bottom of the TTV. The base pedestal of the test cell is next connected to the top of the TTV. A butyl membrane is initially ruched over and fixed to an up stand on the base pedestal with the other end fixed to a top platen that is lowered and positioned 1 mm into the extension tube (Fig. 2a). The top platen is connected to the measurement system that is supported by the upper manipulator, which consists of the same linear actuator as the lower manipulator and controlled by a step driven servomotor. Once the membrane is fixed the pressure chamber for the test cell is lowered and secured in place with the locking ring. The system is pressurized to the same pressure as the TTV. The test cell and upper manipulator are pressurized using gas as the confining fluid (to allow resonant column testing-see later Section 2.3), while water is used to pressurize the bottom manipulator. Once the system pressure is equalized, the ball valve isolating the TTV from the PCATS Triaxial system can be opened to begin sample transfer from the TTV into the test cell.

During transfer the ball screw linear actuator allows the base platen and core sample (within a plastic core liner) to be raised