Laboratory Quantification of Geomechanical Properties of Hydrate-Bearing Sediments in the Shenhu Area of the South China Sea at In-Situ Conditions

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Objective

Determination of reservoir parameters from testing hydrate-bearing sediment samples with uninterrupted pressure history:

- Permeability
- Shear strength
- Elastic properties (V_S, G_{max})
- Gas hydrate saturation

Guangzhou Marine Geological Survey (GMGS) 4, Leg 3

Site locations, South China [1]

- 2 drilling areas, northern continental slope, South China Sea
- June - August 2016
- R/V Fugro Voyager
- Pressure and conventional coring
- 9 pressure core subsamples selected for geotechnical testing

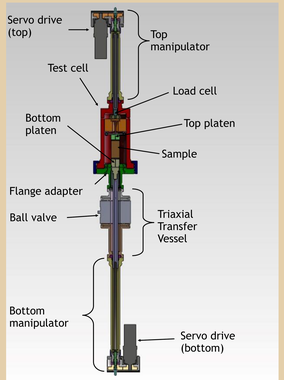
Transfer of PCTB autoclave with pressurised core from cold bath into PCATS laboratory container

Fugro Voyager with Geotek laboratory containers in place on afterdeck

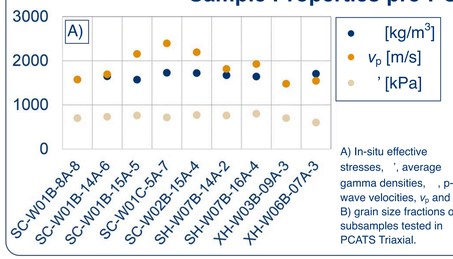
PCATS Triaxial

Determination of soil parameters at **in situ hydrostatic pressure and stress conditions**

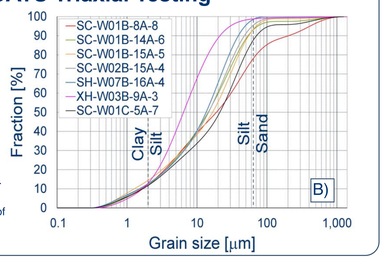
- P_{max} = 25 MPa
- p'_{max} = $'_{3,\,max}$ = 3000 kPa
- Fluid flow control to L precision
- Resonant column for small strain geotechnical testing
- Large strain triaxial testing
- Extrusion of core samples into 0.5 mm butylene membrane by computer-controlled servo motors
- Control of confining pressure for quantitative degassing of samples



Sample Properties pre-PCATS Triaxial Testing

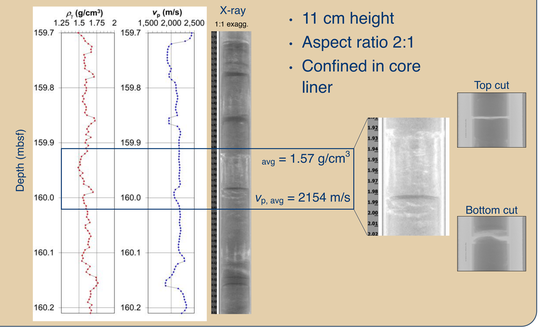


A) In-situ effective stresses, ', average gamma densities, , p-wave velocities, v_p and B) grain size fractions of subsamples tested in PCATS Triaxial.



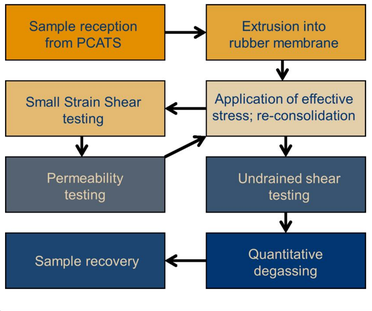
Sample selection

- Reception of pressure cores at in-situ hydrostatic pressure
- Core characterisation with Geotek **Pressure Core Analysis and Transfer System (PCATS)**[2] based on
  - X-ray CT imaging
  - p-wave velocity
  - -density
- Sub-sampling at in situ pressure
- Transfer of subsamples to pressure chambers for further analysis

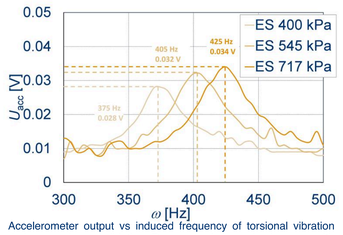


- 11 cm height
- Aspect ratio 2:1
- Confined in core liner

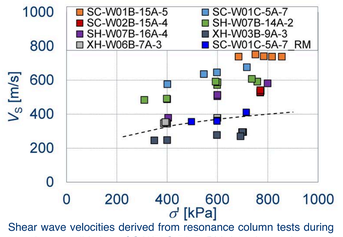
Test sequence



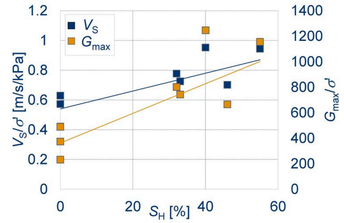
Small Strain Testing



Accelerometer output vs induced frequency of torsional vibration during sample consolidation. Resonance frequencies increase with degree of consolidation as effective stress rises up to in-situ values.

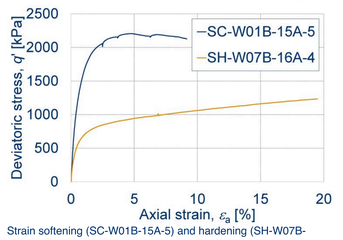


Shear wave velocities derived from resonance column tests during sample consolidation. SC-W01C-5A-7_RM has been degassed and remoulded before renewed testing. Shear velocities reported by Hamilton [3] for turbidites and silty clays without gas hydrates are shown for reference.



Effective stress-normalised V_S and G_{max} show a good linear correlation to S_H (R^2 = 0.73 and 0.80, respectively). The data points for subsample SC-W01B-15A-5 were not included in the regression due to the uncertainty associated with S_H

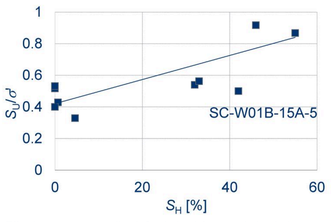
Undrained Triaxial Testing



Strain softening (SC-W01B-15A-5) and hardening (SH-W07B-16A-4) during undrained triaxial shear tests.

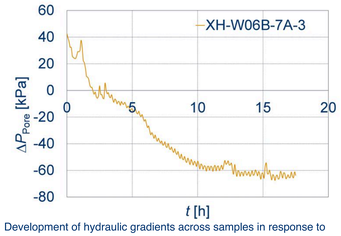
SH-W07B-16A-4 SC-W01B-15A-5

Samples SH-W07B-16A-4 (left) SC-W01B-15A-5 (right) after recovery. The barrel-type deformation shown by the former sample is indicative of plastic deformation and strain hardening, while the clearly visible shear plane of the latter (right) indicates sudden failure typical to a brittle soil. The vesicles in the image on the right indicate ongoing degassing after recovery.

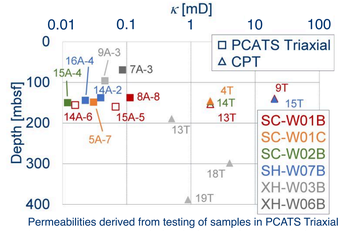


Effective stress-normalised S_U derived from undrained shear tests. The fair linear correlation of S_U to S_H (R^2 = 0.73) illustrates the cementing effect of the hydrate on the investigated sediments (see also Luo et al. [4]).

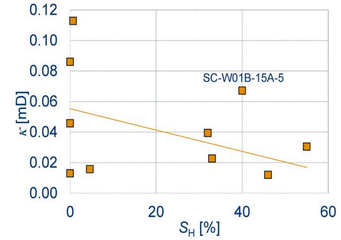
Permeability Testing



Development of hydraulic gradients across samples in response to directing flow through the sample at -100 nL/s (the negative sign denotes upward flow direction).



Permeabilities derived from testing of samples in PCATS Triaxial (squares) and cone penetration tests (CPT, triangles). A strong sample anisotropy is suggested by $_{CPT}$ exceeding (vertical) $_{Triax}$ by ~2 orders of magnitude.



Vertical permeabilites $_{Triax}$ vs S_H. Overall, the vertical permeability is only poorly correlated to S_H (R^2 = 0.36)

References

1. South China Sea. (14.09.2016). Google Maps. Google. Retrieved from https://www.google.co.uk/maps/@17.3598535,114.8666787,2096433m/data=!3m1!1e3.
2. P.J. Schultheiss, M. Holland, J.A. Roberts, Q. Huggett, M. Druce, P. Fox, "PCATS: Pressure Core Analysis and Transfer System" Proc. 7th Intl. Conf. Gas Hydrates (ICGH 2011), Edinburgh, UK, 17-21 July 2011.
3. E. Hamilton, "Shear-wave velocity versus depth in marine sediments: a review", Geophysics 41: 985–996, 1976.
4. T. Luo, Y. Song, Y. Zhu, W. Liu, Y. Liu, Y. Li, Z. Wu, "Triaxial experiments on the mechanical properties of hydrate-bearing marine sediments of South China Sea", Marine and Petroleum Geology 77: 507-514, 2016.

Summary

- Hydrate saturation controls shear wave velocity, small strain shear modulus and shear strength ...
- … but only weakly affects permeability!
- Hydraulic anisotropy revealed by strongly different vertical to CPT permeabilites