The grantee is required to submit a scientific report (3-5 pages) to the host institution, MC Chair the STSM coordinator for approval within 30 days after the end date of the STSM

Scientific Report:

STMS within the COST action “MIGRATE” by K. Heeschen (GFZ) at University of Southampton, Department for Engineering and the Environment, Infrastructure Research Group

Hosts: Prof. A Zervos & Dr. Murthy

Period: 12.3. – 31.3.2017

Purpose of the STSM

The goal of this short term scientific mission (STSM) at the University of Southampton was to get familiarized with the “gas hydrate resonant column” (GHRC) and carry out initial measurements on a sample used in experiments within the SUGAR III project at GFZ. Compared to equipment at GFZ, the GHRC allows for the determination of geomechanical and geophysical sediment properties using similar frequencies to those applied in seismic field investigations, e.g., surveying gas hydrate reservoirs. At GFZ geophysical parameters are determined using ultrasonic and sonic frequencies (Spangenberg et al., 2008; Heeschen et al., 2016). For most properties the difference is assumed to be negligible, however, for the attenuation of soundwaves by the specimen it is likely not. Unlike other resonant columns commonly used in civil engineering and soil sciences, the instrument in Southampton can withstand pressures up to 25 MPa and temperatures of -10°C, a prerequisite for the investigation of ice or gas hydrate-containing sediments. Using the GHRC we anticipated to measure the attenuation of seismic waves using the same ice-bearing sandy sediment, environmental parameters, and ice-forming method we use at GFZ. In this case, ice is used as a model for gas hydrate (“Quick look method”; Heeschen et al., 2016). The goal was to get a first insight into the dependency of attenuation on frequency in our samples.

Description of the work carried out during the STSM

Over a period of 2.5 weeks we worked on the GHRC. The instrument had not been used in over a year and meanwhile parts had been dismantled and integrated in other experiments. During the first week the GHRC was assembled and test runs were performed on calibration bars. It turned out that part of the GHRC had to be replaced, which entailed a new calibration. Since calibration of the GHRC is very time consuming it will be carried out by the host institute following the STMS. As a consequence the data presented in the following sections are of qualitative nature only.

Following the familiarization with the instrument and the preparation of both, instrument and sample, the sample was placed in the instrument, pressurized, and cooled to temperatures of -4°C. The homogeneous sample consisted of quartz-sand with a broad grain size spectrum and a porosity of 33% (SUGAR III model sand). The pore water was a potassium chloride solution with 2% salinity, which enabled partial freezing with a eutectic temperature at roughly -10°C. The ice saturations within the pore space could be determined based on the given temperatures.

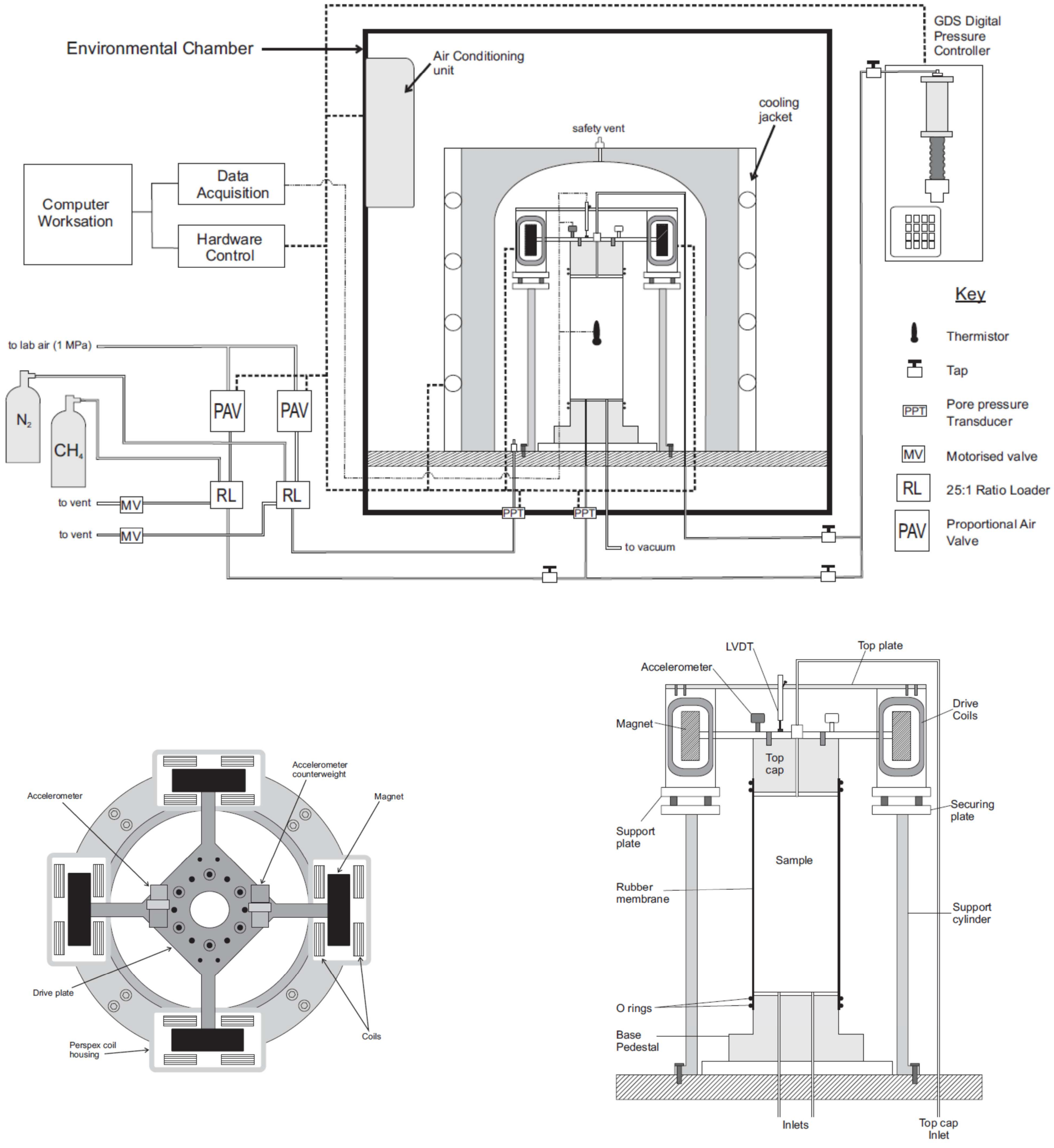

Figure 1 Upper panel: Overview of the GHRC including gas supply, environmental camber and cooling jacket for temperature control, the pressure vessel (darker grey), and sample set-up. The latter is shown in more detail in the lower panel as is the drive mechanisms for the flexural and torsional movement of the flexible drive plate, top cap, and sample. The resonance is detected by an accelerometer attached to the drive plate. For the flexural mode only 2 out of 4 coils are activated. (Figs. 3.13 and 3.14 from Rees, 2009). The linear variable differential transformer (LVDT) is used for measuring linear displacement throughout the experiment.

Within the GHRC, the cylindrical sample (7 * 14 cm) is excited at its first torsional or first flexural mode using the drive mechanism attached to the free top end of the sample while the bottom of the sample is fixed (Fig. 1 lower panel). An accelerometer detects the resonance of the free top end.

Running a frequency sweep the natural resonant frequency (f_n) of the sample is specified for both modes. Once the input frequency equals the natural frequency of the sample set-up, the latter vibrates with the maximum amplitude. The natural resonant frequency is used for further measurements. Using f_n to exite the sample, the GHRC allows for the determination of the shear modulus and vertical Young's modulus, two geo-mechanical properties (Rees et al., 2011). Geophysical parameters such as the compressional (v_p) and shear wave velocity (v_s) can be derived from flexural and torsional excitation, respectively. The attenuations ($1/Q_p$ and $1/Q_s$) of the compressional and shear waves are measured as damping (D) (Priest, 2004; Rees, 2009…).

Owing to long equilibration periods at given temperatures and the breakdown of the cooling system due to overheating before completion of the measurements, the number of reliable readings is limited to four at 1°C, -2.7°C, -3.4°C, and -4.1°C with 1°C representing the ice-free sample. Measurements at temperatures below -4°C could not be achieved despite the instrument's specifications.

Description of the main results obtained

As yet the presented results are of qualitative value since calibration of the instrument is missing by the time this report will be handed in. The complex geometry of the GHRC does not allow for a geometrical calculation. Instead the mass polar moment of inertia of the drive unit needs to be determined using calibration bars of known properties.

The attenuation of a seismic wave by a specific material/sample is described by the ratio of dissipated to stored energy (1/Q). Using the resonant column, the attenuation is determined via the so called free vibration decay (FVD) method. This method is based on the relationship of successive peak amplitudes once the sample is allowed to vibrate freely after excitement using f_n (Fig. 2).

After assemblage, the sample was cooled to 1°C and left to equilibrate for 24 h. The f_n was determined in the torsional and flexural mode immediately followed by the measurement of the damping in both modes. By definition the attenuation (1/Q) equals half of damping (D). Following the measurement the next temperature step was set. Due to time constrains the equilibrations periods were shortened to 24 h instead of 48 h. It can be observed that with increasing ice content f_n increased in both modes (Table 1). This observation indicates an increasing stiffness of the sample with increasing ice contents, which further results in faster shear and compressional wave velocities, clearly shown in the data (Table 2). At -2.7°C an exception occurs in the flexural mode – despite repeated measurements. Using the old calibration and comparing, e.g. v_s, the body wave velocity is much lower compared to published data and models with hydrate saturations of 0.7 – 0.8 reviewed in Waite et al. (2009). The review does not mention pressure regimes, sediment type and gas hydrate morphologies, which need to be considered. In Priest et al. (2005) vs date for gas hydrate free sediments are comparable to our data. However, the new calibration needs to be accounted before any more reliable comparisons can be made.

Comparisons can well be made despite the small range of ice saturations (70 – 81% pore space) that could be covered during the STSM. Saturations of 50 and 90% are missing due to the breakdown of the cooling system 1 week after the experiment started. Once the calibration is known it will be possible to compare v_p and Q_p^{-1} data with measurements carried out at the GFZ using ultrasonic frequencies. In addition, a comparison with data from Best et al. (2013) using the same GHRC but a different method to form gas hydrate can be made. Best's method allows hydrate saturations of up to 45%. Using the old calibration on our results (Table 2) an increase in attenuations Q_p^{-1} and Q_s^{-1} with ice saturation can be observed. This is also true for Q_s^{-1} if compared to data from Best et al. (2013). Q_p^{-1} stays rather constant. Again, these observations need to be confirmed using a valid calibration.

A complete set of measurements covering gas hydrate saturations in the range of Best's data as well as higher concentrations and with longer equilibration periods would be very desirable. Funding for this experiment and additional measurements using the GHRC are proposed for in the MarTERA call (project: Gitaro.JIM) handed in to the EU by the end of March (also see below).

Table 1 Natural resonant frequency for torsional and flexural mode at given temperatures after equilibration times of 24 – 48 h. A confining pressure of 1 MPa was applied. Observe: The instrument is not yet calibrated.

Temperature / K	Ice Saturation	Torsion resonant frequency / Hz	Flexure resonant frequency / Hz
274.15 (1°C, Fri)	0	189.2	79.7
270.45 (-2,7; Mon)	0.70 ± 0.01	195.4	77.7
269.65 (-3,5; Sun)	0.77	239.6	90.4
268.95 (-4,2; Tue)	0.81	255.2	93.2

Table 2 Derived parameters v_p*,* v_s*,* Q_p^{-1}*, and* Q_s^{-1}*; calculations are based on the work by Priest, 2004 and Rees, 2009. Due to the lack of a valid calibration up to know, the calculation of any data in this table is based on the old expired calibration.*

Temperature / K	Ice Saturation	v_p /km/s	v_s /km/s	Q_p^{-1}	Q_s^{-1}
274.15	0		0.410	0.016	0.012
270.45	0.70 ± 0.01		0.424	0.057	0.082
269.65	0.77		0.530	0.11	0.08
268,95	0.81		0.568	0.129	0.113

Future collaboration with the host institution

The incentive for the STMS was to get to know the instrument and test whether or not it would be a useful addition to a recent EU-proposal written by part of the SUGAR III consortium (MarTERA call). The group of Prof. A. Zervos is now a cooperator within the call and additional short term scientific missions are accounted for in the proposal.

Foreseen publications/articles resulting from the STSM (if applicable);

Publications are foreseen given a funding of the proposed MarTERA call and a more successful measuring campaign.

References

Best, A. I., Priest, J. A., Clayton, C. R. I., and Rees, E. V. L., 2013, The effect of methane hydrate morphology and water saturation on seismic wave attenuation in sand under shallow sub-seafloor conditions: Earth and Planetary Science Letters, v. 368, p. 78-87.

Heeschen, K., Spangenberg, E., Seyberth, K., Priegnitz, M., and Schicks, J. M.,2016, An experimental challenge: Unraveling the dependencies of ultrasonic and electrical properties of sandy sediments with pore-filling gas hydrates, *in* Proceedings EGU General Assembly Conference Abstracts, 18, 11958.

Priest, J.A., 2004, The effect of methane gas hydrate on the dynamic properties of sand: PhD Thesis, University of Southampton, Southampton.

Priest, J. A., Best, A. I., and Clayton, C. R. I., 2005, A laboratory investigation into the seismic velocities of methane gas hydrate-bearing sand: Journal of Geophysical Research: Solid Earth, 110(B4), doi:10.1029/2004JB003259.

Rees, E. V., 2009, Methane gas hydrate morphology and its effect on the stiffness and damping of some sediments: PhD Thesis, University of Southampton, Southampton.

Rees, E. V., Kneafsey, T. J., & Nakagawa, S., 2011, Geomechanical properties of synthetic hydrate bearing sediments, in Proceedings of the 7th International Conference on Gas Hydrates (ICGH 2011), Edinburgh, Scotland, United Kingdom.

Spangenberg, E., Beeskow-Strauch, B., Luzi, M., Naumann, R., Schicks, J., and Rydzy, M., 2008, The process of hydrate formation in clastic sediments and its impact on their physical properties, *in* Proceedings of the 6th International Conference on Gas Hydrates (ICGH 2008), Vancouver, Canada.

Waite, W. F., Santamarina, J. C., Cortes, D. D., Dugan, B., Espinoza, D., Germaine, J., Jang, J., Jung, J., Kneafsey, T. J., and Shin, H., 2009, Physical properties of hydrate-bearing sediments: Reviews of Geophysics, v. 47, no. 4.