EXPERIMENTAL STUDY
ON THE THERMO-HYDRO-MECHANICAL BEHAVIOUR OF BOOM CLAY

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INTRODUCTION
To study the thermal-hydro-mechanical properties of Boom clay, a stiff clay from the Underground Research Laboratory (URL) at Mol (Belgium), an experimental investigation was carried out. To minimise the possible swelling of soil during the re-saturation phase, a specific saturation procedure was proposed and applied (Figure 1). Consolidation results were analysed to clarify the influence of the saturation phase on soil characteristics. A compression velocity much lower than that in the literature seemed to be necessary to guarantee the full consolidation of the soil samples. Non-isothermal tests showed a heating effect on the creep behaviour of soil.

EXPERIMENTAL METHODOLOGY
In-situ measurements during the excavation of the URL (223 m underground) gave an average natural water content comprised between 24.3% and 25.9%. However the water content of the soil samples when opening the package in the laboratory was around 23%, showing the necessity to re-saturate the soil sample before each experiment.

Based on the system reported by Delage et al. (2000), two experimental systems permitting high pressure triaxial tests at controlled temperature (up to 100 °C) have been developed. The confining pressure, back pressure, and deviator pressure are applied by three volume/pressure controllers (pₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑ euler = 32 MPa). During the experiment, volume changes are measured by monitoring the volume changes of the cell water or pore water.

A specific saturation procedure was applied before each experiment (Figure 1). At the beginning, the cell temperature was regulated at 25 °C and a confining pressure of 100 kPa was applied to establish the initial

![Figure 1](image_url): Stress path followed during the saturation phase.
system stabilisation. After that, confining pressure was increased in slope of 0.5 kPa/mn to 2500 kPa. This practice aims to bring the soil back to its in situ condition. When the soil volume was stabilised at 2500 kPa of confining pressure, Boom Clay Synthetic Water (BCWS) was injected at a pressure of 100 kPa by the back pressure controller from the sample’s bottom. The soil swelling was observed by the volume of the confining pressure controller, while water entering the soil sample was measured by the back pressure controller. After around 8 days, BCSW was injected from the head of the soil sample. The sample was afterward saturated by increasing simultaneously in steps of 250 kPa the confining pressure and back pressure to respectively 3500 kPa and 1000 kPa. During this phase, the effective pressures was always 2500 kPa and Skempton B value was measured.

Two experiments were however carried out following the saturation procedure as suggested by Sultan (1997), i.e. saturation under low effective pressure that equals to 100 kPa.

After the saturation phase, soil samples were then compressed in a isotropic fashion under different rates (0.1, 0.5 kPa/mn, or in steps) at two constant temperatures of 25°C and 80°C. The heating of soil sample was also carried out under different heating rates (0.1, 0.3 °C/h, or in steps).  

RESULTS AND INTERPRETATION

Soil swelling during the saturation
During water injection, it was observed that the volume of water adsorbed in the soil samples was five times more than the soil swelling. This difference shows that water entering the sample on the one hand swells the clay pellets, on the other hand fills the existing voids or dissolves the remaining air bulbs, thus saturates the samples. The application of the proposed saturation procedure gave very small soil swelling: 0.8 % to 1.8%, as compared to the swelling of 4% - 5% obtained under low effective pressure. These swelling values are comparable to those obtained by Coll (2005) who followed the similar saturation procedure. It shows that the soil volumetric strain depends significantly on the experiment boundary conditions.

Mechanical and thermal consolidation
The elastic limit values obtained from mechanical consolidation tests have been found to be strongly dependent of saturation stress. It is in the order of 0.8 MPa under low stress (as Sultan 1997) and of 2.5 MPa under high stress (as Coll 2005). The results presented a good repeatability though experiments were carried out on soil samples of different ages.

The volume change was time-dependant at a constant effective pressure. The applied compression velocity of 0.5 kPa/mn, which was reported to be slow enough to guarantee a complete consolidation by Sultan (1997), has been found to be too high. This remark again confirms the influence of saturation procedure on the soil behaviour. A consolidation velocity of 0.1 kPa/mn was then applied in order to guarantee full soil consolidation. Interestingly, when compressing initially unsaturated soil samples 100 to 2500 kPa under a velocity of 0.5 kPa/mn, no time-dependant volume change behaviour was observed, showing a significant effect of water saturation on the soil volumetric behaviour.

Heating tests presented an important creep behaviour of natural Boom clay. The volume change at a constant temperature higher than 30°C showed to be relatively significant (10⁻⁵ s⁻¹). Interestingly, the higher the temperature, the more significant the creep is.

References
