Experimental study of a swelling clay application to the radioactive waste storage

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ABSTRACT

The storage of radioactive wastes in rocks requires a backfilling material between the canisters and the rock to delay the migration of radionuclides, in the case of an hydration. This work aims to characterize such a material using laboratory tests with an original triaxial cell. The main results show the influence of water content and confining pressure on the mechanical properties of the material, especially the volumetric strains.

INTRODUCTION

The storage of high activity wastes in deep rocks needs to take cares in order to avoid the contamination of the biosphere after a period of thousands years. It is planned to place between the canister and the host rock an engineered barrier which has the function of delaying the movement of radionuclides in the case of an arrival of underground water. This barrier is made with highly compacted clay [PUSH, 1982; JORDA, 1990]. Many roles must be assured by this barrier, among them, to remove the heat coming from the wastes, to contribute to reduce voids and discontinuities, a long - term stability, swelling ability is a fundamental property to determine the efficiency of the storage. This last point needs the use of a clay with a high smectite content.
It is important to notice that this work is placed in the case of a storage in a hard rock medium.

According to the previous considerations, the first step has lead to choose the material whose the characteristics are summarised on the table 1 [COULON, 1987]. As it is previously mentioned, it is very important to minimize water movements towards the wastes.

In a such problem, the hydration state plays a crucial role, that is the reason why the study presented in this paper consists in two parts, the first one is relative to the partially saturated material and the second one deals with the saturated material.

<table>
<thead>
<tr>
<th>smectite Ca/kaolinite :</th>
<th>80%</th>
</tr>
</thead>
<tbody>
<tr>
<td>quartz, feldspath, etc.</td>
<td>20%</td>
</tr>
<tr>
<td>Specific area :</td>
<td>280 m²/g</td>
</tr>
<tr>
<td>Grain density :</td>
<td>2.7</td>
</tr>
<tr>
<td>Water content (%) :</td>
<td>10% (at 20°C)</td>
</tr>
<tr>
<td>Liquidity limit :</td>
<td>100%</td>
</tr>
<tr>
<td>Plasticity limit :</td>
<td>33%</td>
</tr>
<tr>
<td>Shrinkage limit :</td>
<td>30%</td>
</tr>
<tr>
<td>Activity :</td>
<td>0.94</td>
</tr>
</tbody>
</table>

Table I: Characteristics of material

BEHAVIOUR OF THE PARTIALLY SATURATED MATERIAL

Clay tested
A french clay easily available in great quantities is chosen. This material is taken from the field, is dried (105 °C during 24 hours) and finely crushed. Then, the clay powder is mixed with water and submitted to an isotropic compression in order to obtain samples with an uniform and controlled water content. The final samples are cylinders with 65 mm of diameter and 110 mm of height.

Test equipment and procedure
Measurement of the volumetric strains: The study consists of non drained triaxial tests with the measurement of the volumetric strain. The mechanical behaviour is known with the deviatoric stress and the volumetric strains. The measurement of volumetric strains is made with a circular collar (figure 1) on
which four strain gauges are fixed [LAHLOU, 1991]. During the triaxial test, the lateral deformation of the sample is transmitted by the gauges and recorded with a microcomputer and a scanner - multimetre.

The triaxial cell The studied material presents important strains (until 15 %) so the confining pressure may raise during the test. To avoid this problem, the cell is designed with a self compensating system which keeps constant the pressure during the whole test. An electrical valve placed on the cell and driven by the microcomputer allows to keep the confining pressure constant, with high accuracy. The cell is autonomous, that is to say, it allows tests without a press. The piston is moved with an hydraulic pump which sends a constant oil flow into the head of the cell (figure 3) that moves the piston at a constant rate. The interest of this autonomous cell is in the long tests of many days (saturation tests under constant stress, creep tests, etc.). A second hydraulic pump is used to apply the confining pressure as indicated on figure 2. The displacement is measured with an LVDT transducer while the force is deduced from the hydraulic pressure applied by the first pump. The equipment is driven by a microcomputer and a multimetre scanner. The displacement rate is 0,1 mm/min which corresponds to a strain rate of about 0,1 %/min.
Results and discussion

The main results are shown at the end of this paper. The behaviour is studied with varying two parameters, the water content (from 5 to 18 %) then the confining pressure (from 0 to 15 MPa). Some typical curves are presented at the end of this paper. The volumetric strain is calculated with the axial strain (fixed) and the lateral strain (measured).

Observing the figure 4, it can be noticed that the stress/strain curve is non-linear even for the small values of the axial strain. The failure deviator increases with the decreasing of the water content. The axial strain versus volumetric strain curve shows a compressibility phase followed by dilatancy. Dilatancy increases when water content decreases.

The influence of the confining pressure can be seen on figure 5. Logically, the strength of the studied clay increases at high confining pressure, at the same time, the volumetric deformations become compressible.

The main result of this part is that, for the studied material, an increase of confining pressure has the same effect than a decrease of the water content. The
elastic constants shown in table 2 indicate a mean cohesion of 3 MPa and a frictionnal angle varying between 14 and 22 degrees.

<table>
<thead>
<tr>
<th>Water content (%)</th>
<th>E (MPa)</th>
<th>ν</th>
<th>φ (degrees)</th>
<th>Cu (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>300 à 600</td>
<td>0,26</td>
<td>22</td>
<td>3,2</td>
</tr>
<tr>
<td>10</td>
<td>400 à 600</td>
<td>0,33</td>
<td>15,5</td>
<td>3</td>
</tr>
<tr>
<td>14</td>
<td>490 à 540</td>
<td>0,36</td>
<td>14</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 2. Triaxial tests results on the partially saturated material.

BEHAVIOUR OF THE SATURATED MATERIAL

The aim of this part of the work is to study the mechanical behaviour of the saturated samples. The material is first saturated with the measurement of its swelling, then the triaxial test is performed.

Clay tested
The material is the same than previously but the samples are smaller in order to get them saturated after only some weeks. The initial sample of 110 mm height is cut to 4 samples of 20 mm height and the same diameter (65 mm).

Test equipment and procedure
Saturation phase The saturation of the highly compacted clay needs some particular cares. This operation is set in an oedometric cell as shown on figure 6. The axial stress applied by a hydraulic pump can reach 30 MPa. Paper filter is placed between the sample and the porous stone in order to avoid that clay particles go up towards the piston (see figure 6). Four oedometric cells are used for a same test. At the end of the saturation, the saturated samples are piled up and put into the triaxial cell. After a consolidation period of some hours, the triaxial compression test is performed in the same conditions than previously.
In this paper, swelling is defined as the increase in thickness of the clay sample during wetting. It is expressed by the ratio between the actual and the initial sample thickness. The measured sizes during the test are the swelling, the absorbed water and time.

Results and discussion
The figure 7 shows the result of a swelling test with an oedometric stress of 15 MPa. It can be seen from this figure that the swelling and the absorbed water increase practically at a same rate. The increasing is weak during the first hours, then it becomes very more important and finally the two curves show a stabilization of the swelling and the absorbed water versus time. The final swelling value of 5 % may be considered as very high under an oedometric stress of 15 MPa. This result confirms that the studied clay will develop high swelling when set around the waste canisters.

Finally, the triaxial tests performed and reported in figure 8 indicate that the saturated clay is characterized with a frictional angle of 10 degrees and a cohesion of 0 MPa.

CONCLUSIONS

The initial aim of the study presented in this paper is to characterize the mechanical behaviour of a clay of an engineered barrier in the case of the radioactive waste storage. The triaxial compression tests performed on the partly saturated material indicate that the volumetric strains decrease when the water content increases. For a constant water content, the increase of the confining pressure leads to an increase of the compressibility.

The tests performed on the saturated material have shown the swelling ability of the studied clay under a high oedometric stress. The followed triaxial tests indicate that when the material is saturated, its cohesion becomes equal to 0 and its frictional angle to 10 Degrees.

Acknowledgments

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REFERENCES


FELIX B. ‘Mesure de la déformation radiale des éprouvettes de sol par un système de bagues’ Revue Française de Géotechnique, n°15, pp. 53-57, 1980.


Figure 3. Scheme of the triaxial cell.
Figure 4. Triaxial tests on the partially saturated material, influence of the water content.
Figure 5. Triaxial tests on the partially saturated material, influence of the confining pressure.
Figure 6. Scheme of an oedometric cell.
Figure 7. Swelling and saturation test.
Figure 8. Triaxial tests on the saturated material, influence of the confining pressure.