Medium-scale experiments on highly-compacted bentonites

Expériences à échelle moyenne sur des bentonites fortement compactées

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Synopsis: A 1:20 scale model of a 5 m section of the repository gallery has been built to carry out experiments on highly compacted bentonites. In this paper, the results of two tests running over a period of about 240 days are presented. In one test, a sodium bentonite, in the other test a calcium bentonite has been investigated. The results with respect to the water uptake, the swelling pressure and the saturation of the bentonite are given and compared to values obtained in earlier laboratory tests.

1 INTRODUCTION

The "Gewähr 1985" project was developed by the National Cooperative for the Storage of Radioactive Waste in view of the problems arising with the disposal of highly radioactive wastes (Nagra 1985). The project is characterized by a system of successive safety barriers, namely a glass matrix in which the radionuclides are embedded, the steel canister which encloses the glass matrix, the bentonite fill material, the host rock, and the sedimentary overburden.

The bentonite fill material consists of highly compacted blocks of bentonite which are isostatically compressed and cut to the proper sizes before being transported to the site and placed around the canisters in the storage galleries. The bentonite barrier has both mechanical and hydraulic functions. One of the important hydraulic functions of the bentonite is to limit and to retard the access of water to the canisters and thus to retard the corrosion of the steel canisters. They are expected to be fully tight for at least 1000 years. Afterwards, the bentonite has to ensure that the radionuclides are isolated to the maximum extent. For this function, the diffusivity and the swelling potential of the highly compacted bentonite are of great importance. Detailed investigations of the relevant properties of the bentonite such as the uptake of water, the swelling behavior, and the diffusivity have been carried out at the Institute of Foundation Engineering and Soils Mechanics as part of a research study commissioned by Nagra.

2 BENTONITE PROPERTIES

Two types of bentonites have been selected for the investigations. One is a sodium bentonite from Wyoming, USA with the designation MX-80. The other one is a calcium bentonite from Bavaria, West Germany with the designation Montigel. The properties of the two bentonites have been extensively investigated (Müller-Vonmoos and Kahr 1983).

For the medium scale experiments, the bentonites were isostatically compacted under a pressure of about 350 bar and subsequently worked into discs of 185 mm in diameter and 62.5 mm in width. Initial dry densities were around 1.75 Mgm^{-3} and initial water contents around 9%.

3 TESTING EQUIPMENT

To accomplish numerous test results which have been obtained at small scales, it was decided to carry out medium scale laboratory tests. A 1:20 scale model of a 5 m section of the repository gallery was built. The designed test cylinder allows the examination of samples 250 mm in length and 185 mm in diameter. A cross section is given in Fig. 1. It shows that the bentonite sample is allowed to take up water from six filter strips. The water uptake is measured during the tests. The swelling pressure of the bentonite may be measured by pressure transducers located at the center of the end plates.

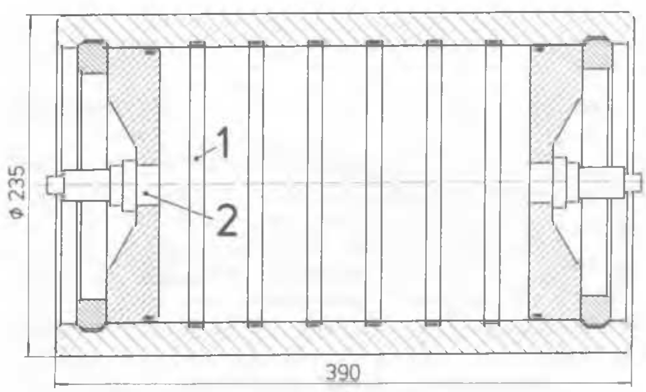

Figure 1. Cross-section of the test cylinder
1. Filter strips
2. Pressure gauges

4 TEST RESULTS

Test results obtained on a MX-80 sample and on a Montigel sample are presented here. Both tests were run over a period of about 250 days.

4.1 Water uptake

The uptake of water in the cylinder case is described by the following differential equation:

$$\frac{\delta c}{\delta t} = \frac{1}{r}\frac{\delta}{\delta r}\left(r D \frac{\delta c}{\delta r}\right)$$

Solutions for various boundary conditions can be found in (Crank 1975). The concentration i.e. the water content in our tests, depends on time, the distance r from the center of the cylinder, and the diffusion coefficient D. Using the diffusion coefficient D=3.10-10 m^2/s determined in small scale tests (Kahr et al. 1986), one obtains the water uptake as a function of time. Both calculated and measured curves are plotted in Fig. 2 and Fig. 3. The discrepancy at the beginning of the test can be explained by the fact that water does not reach the specimen over the entire surface of the cylinder but only along the 6 filter strips.

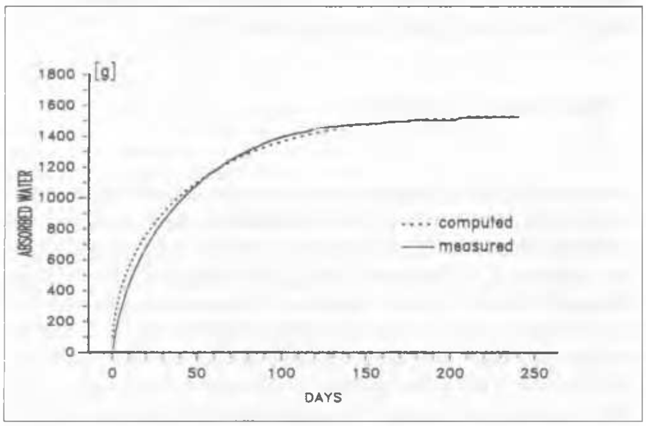

Figure 2. Water uptake of MX-80 bentonite

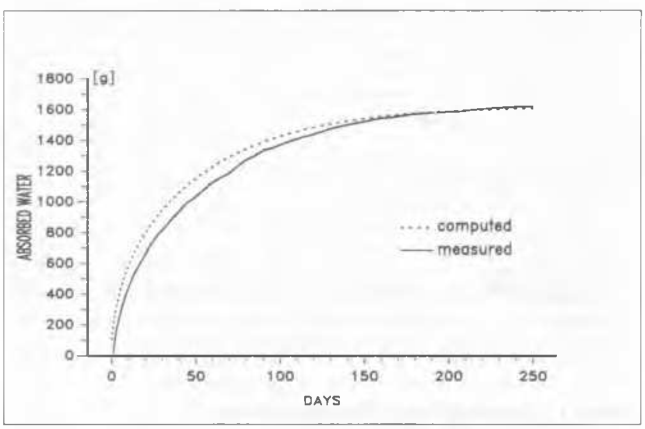

Figure 3. Water uptake of Montigel bentonite

4.2 Swelling pressure

The development of the swelling pressure as a function of time is shown in Fig. 4 and 5. As the pressure transducers are located at the center of the end plates, a delay of about 20-40 days between the beginning of the tests and the beginning of the build-up of the swelling pressure was observed. For MX-80, both transducers gave about the same value of pressure which reached 14.5 N/mm^2 at the end of the test.

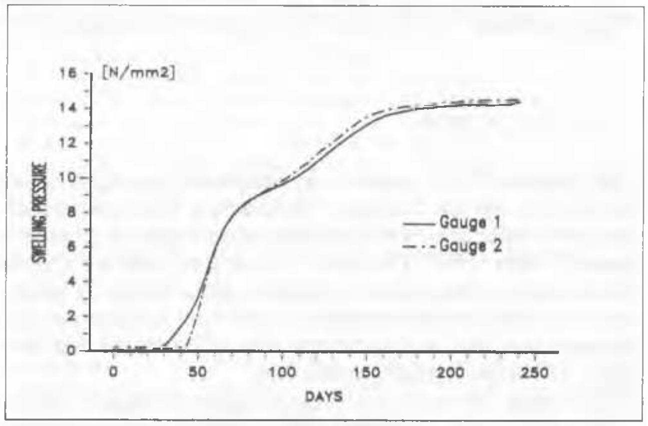

Figure 4. Development of the swelling pressure of MX-80

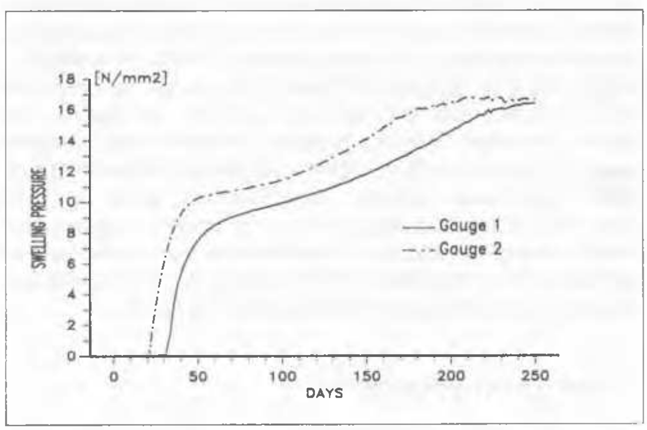

Figure 5. Development of the swelling pressure of Montigel

For Montigel, the transducers indicated a greater difference in the build-up of the swelling pressure which corresponds to an observed non-uniformity of the water uptake. At the end of the test however, both gauges gave about the same values of 16.6 N/mm^2.

In Fig. 6 and 7, values of swelling pressure measured in the swelling pressure apparatus and values calculated from isotherms measurements are plotted as a function of the dry density for both bentonites (Bucher and Müller-Vonmoos 1988). The values obtained from the model tests are also plotted in the figures. It is evident that in both model tests slightly higher pressures have been obtained.

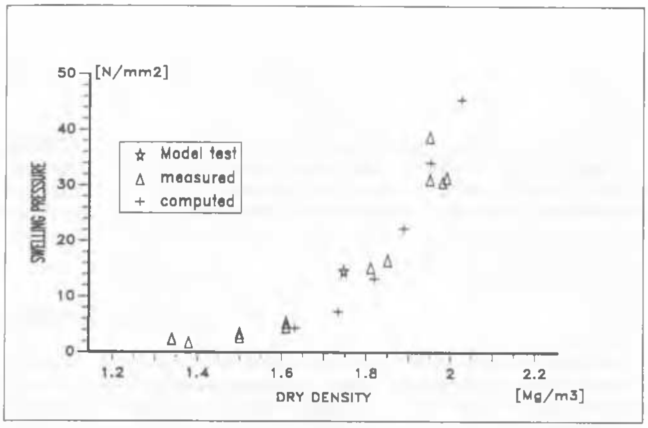

Figure 6. Swelling pressure as a function of the dry density of MX-80.

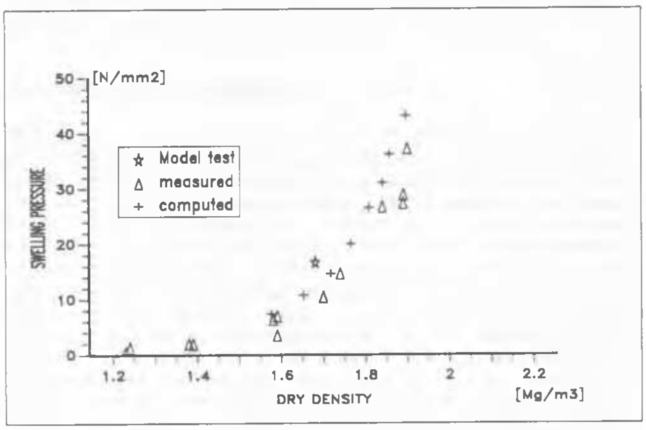

Figure 7. Swelling pressure as a function of the dry density of Montigel.

4.3 Saturation

At the beginning of the test, the MX-80 sample had the following initial properties

dry density	1.746 Mgm^{-3}
water content	8.33 %
degree of saturation	39.7 %

For the calculation of the degree of saturation, a specific density of 2.755 Mgm^{-3} was assumed.

After 241 days, at the end of the test, one obtained the following final values

dry density	1.731 Mgm^{-3}
water content	21.4 %
degree of saturation	99.7 %

The small decrease of the dry density was due to initial voids between the bentonite blocks and the cylinder and due to an increase in the cylinder volume because of the displacements of the end plates.

1464 cm^3 of air was initially enclosed in the bentonite at an air pressure which was determined in the order of 3 bars. During the test, it was observed that only some few percent of the air escaped from the cylinder.At the end of the test, the air in the bentonite was reduced to a volume which was 8 or 27 cm^3 according to two different determinations. One may assume that at the end of the test the air in the bentonite has been compressed by the swelling pressure as there does not exist free pore water in the highly compressed bentonite (Bucher and Müller-Vonmoos 1988). Proceeding from the assumption and applying Boyle-Mariotte's equation

$$p \cdot V = \text{const.}$$

where p is the air pressure and V is the air volume, one obtains for $p = 14.5\ N/mm^2$ a volume of 30 cm^3, i.e. a volume in the order of the measured values.

5 CONCLUSIONS

- The water uptake of highly compacted bentonite in the medium scale experiments may be described as a diffusion process with diffusion coefficients obtained from small scale tests.
- The swelling pressures measured in the experiments are slightly higher than the swelling pressures from earlier investigations.
- The volume of air initially enclosed in the bentonite was compressed during the experiments and is finally under a pressure about equal to the swelling pressure.
- Medium scale experiments on highly compacted bentonite have proved to be a valuable tool inbetween small scale laboratory tests and large scale field tests.

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