The laboratory models for EPSP experiment in DOPAS project - the saturation of bentonite pellets and bentonite powder

Dagmar Trpkošová[1], Petr Večerník[1], Jenny Gondolli[1], Václava Havlová[1]

[1] *ÚJV Řež, a. s.; Hlavní 130; 250 68 Husinec - Řež; CZ*

Summary

As the EPSP underground laboratory experiment would have not been dismantled during the course of the project, the construction of physical hydraulic models (PHM) at the laboratory scale was proposed in the laboratory work plan. The aim of physical hydraulic models was to describe the hydraulic and mechanical processes during saturation of bentonite and give sufficient data for subsequent numerical modeling. Two physical hydraulic models were therefore constructed. The first one use bentonite powder and the other one use bentonite pellets, both materials being used during EPSP construction. Bentonite with bulk density of 1 400 kg/m^3 was pressed into the stainless steel chambers, equipped with a number of sensors and gradually saturated with water under 2MPa pressure, simulating presumed plug performance. The experiment was then dismantled after defined time period. Bentonite material was divided into the layers with an estimated thickness of 1cm. The water content in each layer was then determined.

1. Introduction background

The Czech deep geological repository (DGR) concept assumes that waste packages containing spent nuclear fuel (SNF) assemblies will be enclosed in steel-based canisters placed in vertical or horizontal boreholes at a depth of ~ 500m below the surface. The void between the canisters and the host crystalline rock will be filled with compacted bentonite which will make up the final engineered barrier. DGR safety will be enhanced by the efficient performance of the plugs and sealing systems which will make up an important part of the overall disposal system.

One of the experimental plugs within DOPAS project was built at Underground Laboratory Josef (EPSP) - see Svoboda et al. (2016).

As the EPSP underground plug will not be dismantled during the course of the DOPAS project, the construction of physical hydraulic models (PHM) at the laboratory scale was proposed as an efficient method to verify model presumptions and gain data for further modeling.

2. Scope and objectives

The aim of physical hydraulic models was to describe the hydraulic and mechanical processes during bentonite saturation and to provide data for subsequent numerical modeling.

3. Laboratory tests

3.1 Physical models

Two physical hydraulic models (PHM) were constructed, both being based on nine stainless steel chambers of cylindrical shape with approximate dimensions 0.05m in length and 0.08m in diameter (total length of bentonite in PHM is 45 cm, Fig. 1). Bentonite with bulk density of from 1 400 kg/m3 (the same bulk density as in the EPSP experiment, material is described in detail in report Vašíček et al., 2016) was pressed into the nine chambers and was gradually saturated with water under pressure. The level of water pressure was based on the field testing of the grouted rock at the Josef Underground Laboratory, being set on 2MPa. After defined time period the bentonite material was dismantled and divided into layers with an estimated thickness of 1cm. The water content in each layer was then determined. These data were combined with measured data of relative humidity and all together were compared with the retention curve derived by blocks method on small samples.

The following data were determined during the experiments:

- The volume of water infiltrated into sample
- Pressure, under which water has been pressed into the sample
- Development of relative humidity (RH) in observation points
- Development of swelling pressure at the end of the sample

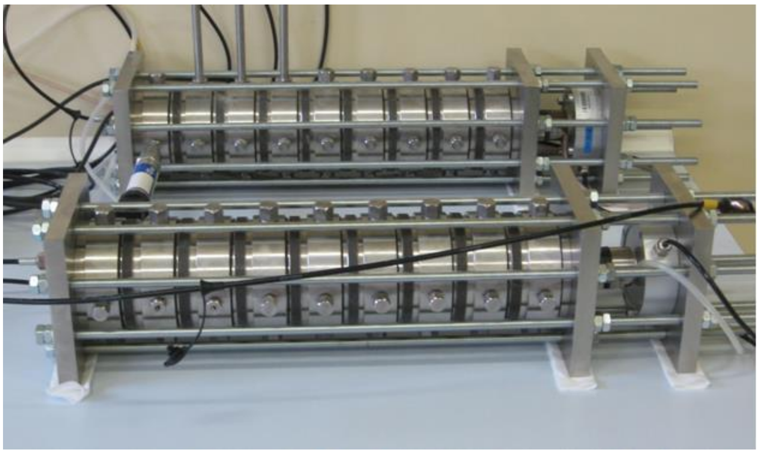

Fig. 1 Two physical hydraulic models, one filled by bentonite powder, second one filled by bentonite pellets.

3.2 Results and discussion

The PHM results with bentonite powder are shown in Fig. 2 to Fig. 4. Observing the Fig. 2 to Fig. 4 it is clear that the material saturation rate decreases in the flow direction. Furthermore, it is apparent that the response of swelling pressure is consistent with the response of the relative humidity at a distance of 2.5 cm from the sensor for measuring the swelling pressure (the distance between these two sensors is 2.5 cm).

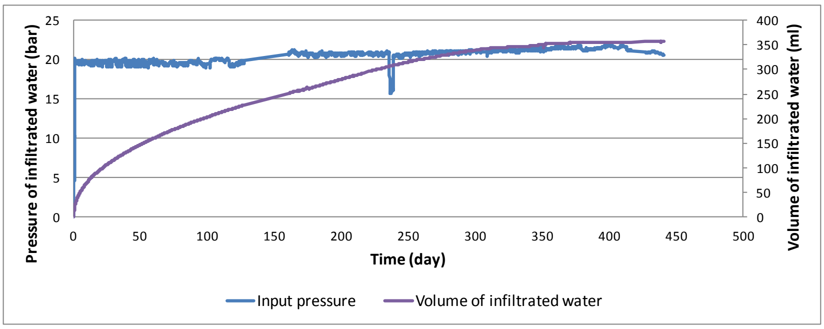

Fig. 2 The pressure and volume of water infiltrated into the sample. Pressure drop around 230 days was caused by the failure of the pressure reducing valve.

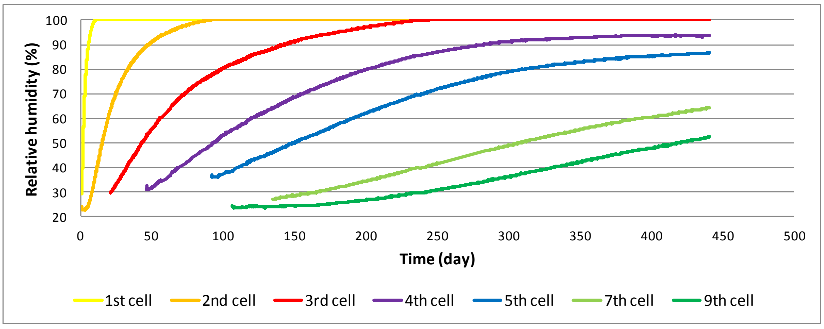

Fig. 3 Development of the relative humidity in different observation points.

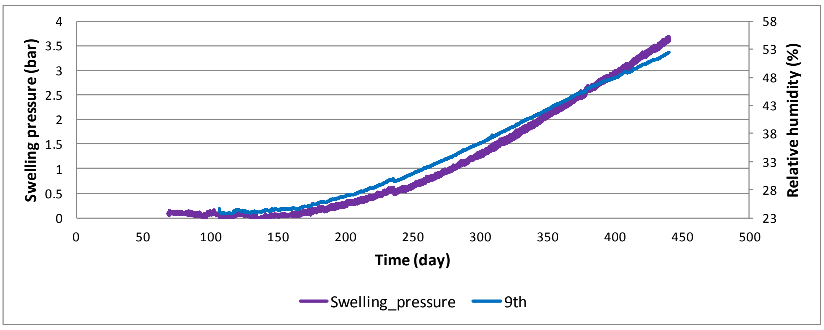

Fig. 4 The comparison of the development of swelling pressure and relative humidity in the 9th observation point.

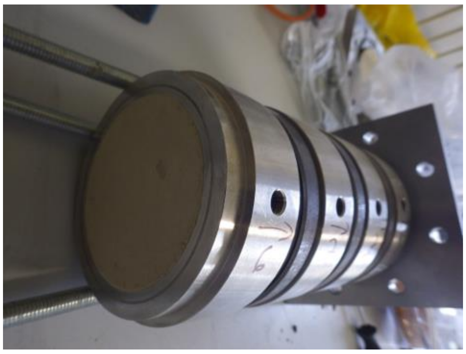

Fig. 5 The dismantling of physical hydraulic model to each cell.

After about 450 days, the saturation of bentonite was terminated and physical model was dismantled into an individual cell (a total of 9 pieces, Fig. 5). 5 cm block of bentonite was extruded from each cell and was cut into approximately 1 cm plates (samples). Subsequently water content of each sample was determined using method of drying sample to constant weight; the resulting values are shown in Fig. 6.

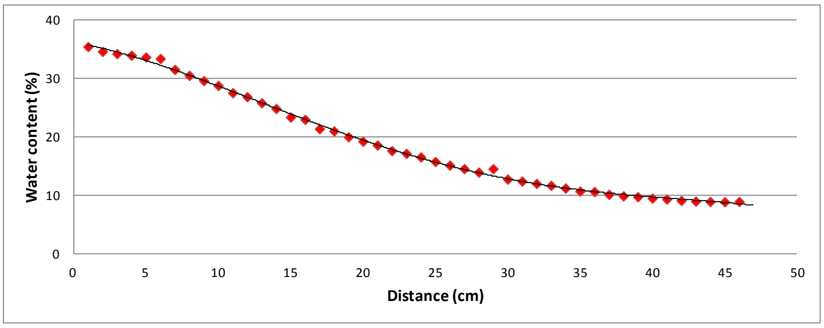

Fig. 6 Profile of mass water content in the PHM, distance indicates the sample position from PHM edge.

The comparison of Fig. 3 and Fig. 6 shows that although the RH sensors show a value of 100%, the material is not fully saturated. This is due to the principle of functionality RH sensor. The sensor is not capable to measure material in a state close to its full saturation (Villar, 2007). Fig. 6 shows a gradual distribution of moisture, when the state of the material at the beginning of the PHM is controlled by the condition/state of the material at its end.

The moisture retention curve was determined from the measured values of relative humidity (after conversion to suction pressure) and the corresponding water content, which was compared with the retention curve obtained by using the block method (Villar, 2007, Fig. 7). The results indicate, that despite the difference in scale (sample in the block method has a volume of about 53 cm^3, volume of one cell in PHM was about 251 cm^3), both retention curves are very well comparable.

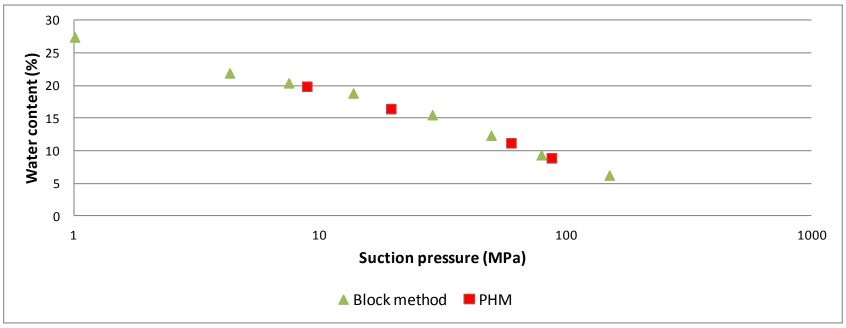

Fig. 7 Comparison of retention curves of bentonite B75 obtained by block method (Villar, 2007) and after dismantling of the physical hydraulic model.

Physical hydraulic model with bentonite pellets has the same geometry as a PHM with bentonite powder. To ensure gradual saturation along the entire 45 cm sample, model contains in the first cell 5 cm thick layer of bentonite powder compacted to dry bulk density 1400 kg/m^3, which will protect the filling of void spaces among pellets by pressure water. Bentonite pellets were placed in the second to ninth cell. The resulting data are illustrated in Fig. 8 to Fig. 10. The same processes as in PHM with bentonite powder are observed.

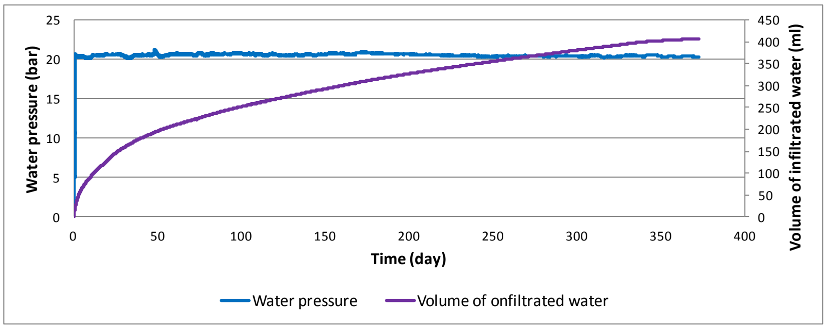

Fig. 8 The pressure and volume of water infiltrated into the sample.

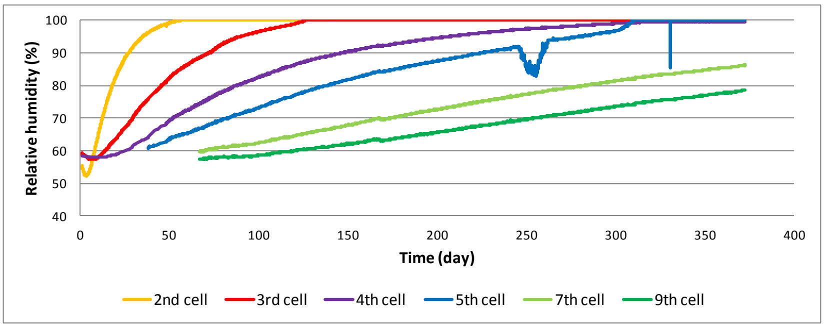

Fig. 9 Development of the relative humidity in different observation points. The sensor in the fifth observation point was damaged during the experiment.

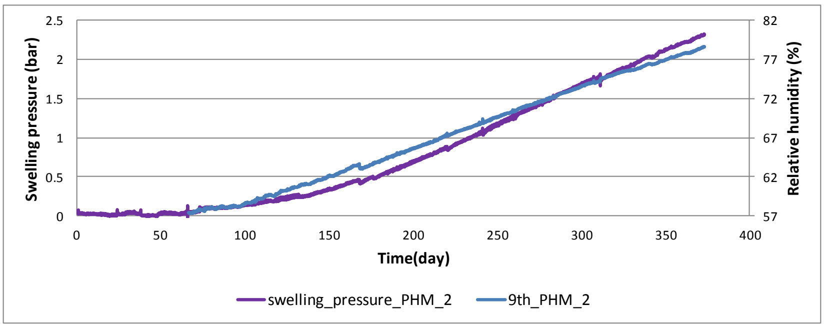

Fig. 10 The comparison of the development of swelling pressure and relative humidity in the 9th observation point.

After a period of around 380 days, the saturation of the bentonite was terminated and the physical model dismantled. Subsequently, the water content of each sample was determined; the results are shown in Fig. 11.

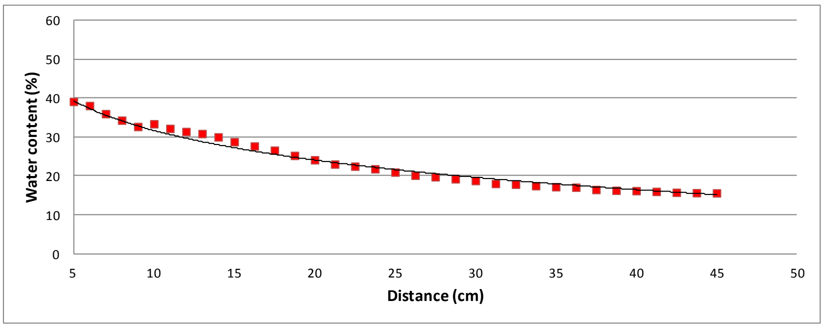

Fig. 11 Profile of mass water content in the PHM with bentonite pellets, distance indicates the position of the samples from the beginning of the physical model

6. Conclusions

Physical models gave data for the calibration of numerical models, when the model parameters were calibrated with aim to achieve the best possible agreement between the measured and model results. The calibrated parameters were then used for predictive modeling, when the most important question was to predict the expected time necessary for whole saturation for 45 cm long bentonite sample. According to the model prediction, the time saturation of the whole sample would take 2992.4 days in the case of the sample with bentonite powder and 1833.8 days in the case of the sample with bentonite pellets.

7. Acknowledgement

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8. References

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