Solid Earth Discuss.,
doi:10.5194/se-2016-171-AC2, 2017

Solid Earth Discussions

Interactive comment on "The response of Opalinus Clay when exposed to cyclic relative humidity variations" *by* Katrin M. Wild et al.

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Received and published: 1 March 2017

Dear Reviewer,

we would like to thank you for the valuable comments on our paper. We could address the majority of your comment. Please see below.

Received and published: 26 January 2017 This scientific contribution focuses on the effect of ambient Relative Humidity (RH) variations on hydro-mechanical behaviour of OPA clay. Specimens of OPA clay were placed in chamber with dif-ferent constant RH value (66 % or 93 %) in order to mimic in situ cyclic variations observed in Mont Terri URL. Monitoring of strains in major directions show an anisotropic response with irreversible volumetric strains in the direction normal to bedding. Observed damage such as cracks do not seem to affect the tensile strength (from Brazilian tests) of the

specimens. This is an interesting contribution well-written. I recommend the publication after minor revisions. I have several comments : Why focus on tensile strength? What is the interest in the context of EDZ problematics?

This part of the study focused on the degradation of strength as a function of RH variations in gen-eral. Due to the extremely long equilibration time of a significantly larger specimen typically used for unconfined compressive strength tests we decided to use Brazilian Tensile Strength discs to show potential tendencies. The paper is not intended to focus on the EDZ problematic (even though it is related), but provides a fundamental contribution to the understanding of RH variations on long term deformations and strength reduction.

Page 1 Line 21 "The evolution of the EDZ is an important factor for the long-term safety of a nuclear repository as it may significantly influence the permeability of the confining host rock and offer pathways for radionuclide transport."

We agree and changed the sentence accordingly.

Page 2 Line 20 "irreversible deformation components (due to seasonal RH variations) can contribute to both long-term tunnel convergence and self- sealing of the EDZ." Please precise the "long-term" scale. In a long-term scale, what should be the RH variations in a sealed repository ?

We agree that the seasonal variations in RH are limited to the open-drift phase and changed the sentence accordingly.

Please discuss the involved spatial scales in shrinkage and swelling and how these small-scale pro-cesses could be involved in larger one such as EDZ sealing, or tunnel convergence. Involved scales should be more discussed in the paper

Field scale tests (Möri et al. 2011) suggest that at least two processes are relevant for the long-term deformation and fracture sealing behavior. In their study they show that the overall, longer-term closure of EDZ fractures, likely associated with consoli-

dation, is superimposed by annual opening-closure cycles which are associated with RH variations. The latter process is limited to the immediate near field of the tunnel circumference, where RH fluctuation affect the swelling and shrinkage behavior. This scale is in a similar range as for the performed laboratory tests.

Please, prefer "cracking" than "fissuring"

We changed the term.

In 2.1 Material description Please discuss the pore fluid nature of the OPA Clay

We added a sentence about the nature of the pore fluid of OPA at the Mont Terri URL.

2.2 2.2 Sampling and specimen preparation Line 29 "electronic strain gauges" do you mean "electric resistive strain gauges" ?

Yes. We changed the term accordingly.

Could you please precise the position of the extracted samples from the tunnel and in particular from the EDZ ?

The E-specimens were taken from core samples from 2.5-3.3 m depth, the A-specimens from depths between 8.5 and 9.4 m. No EDZ related fractures were detectable at these depths. We added this information to the text.

Page 4 Line 2 What is the impact of such a preparation time (30 minutes) on saturation state?

The initial water content of the specimens ranged between 6.95 and 7.34 % (see section 3) and is therefore comparable with the water content we measured on cores right after core extraction (published in Wild 2016: 7.0-8.1%). Furthermore, Wild et al. (2015) showed that the water loss at ambient condition can reach up to 0.6% in 30 minutes. A significant influence of the preparation on the saturation state is therefore considered to be minor (and largely not avoidable).

Wild, K.M., Wymann, L.P. Zimmer, S., Thoeny, R., Amann, F. (2015). Water Retention Characteristics and State-Dependent Mechanical and Petro-Physical Properties of a Clay Shale. Rock Mechanics and Rock Engineering, 48, 427-439. Wild, K.M. (2016). Evaluation of the hydro-mechanical properties and behavior of Opalinus Clay. Doctoral Dissertation, No. 23875, ETH Zürich, Switzerland, 222 pp.

In 2.3 Experimental layout Please precise clearly how the RH cyclic variations is performed.

The RH in the desiccators was established by using supersaturated salt solutions. The specimens were alternately exposed to either 66% or 93% of RH until they were equilibrated with the environment (i.e. showed constant weight). We clarified the text.

How the homogeneity of the ambient humidity in desiccator boxes was checked or controlled?

CPU cooling fans usually used to cool computers were installed at the back of each desiccator (and operated with 6V; i.e. for a very low wind velocity) to distribute the air inside the box and ensure homogeneity of the level of RH in the box.

For all quantity please add the associated errors (due to instruments or others) What is the accuracy for temperature measurements, for mass monitoring ? Please precise the sampling rates (dt) for temperature, mass and RH monitoring.

We added the accuracies and sampling rates of the individual quantities.

In 2.5 Mechanical testing procedure "A, E" specimens "P" and "N" to gain in clarity

We changed the names accordingly in the text and figures.

Please precise the constant loading rate and accuracy

We defined the constant loading rate more precisely and added the accuracy.

In 3 Results "The temperature was kept between 19 and 23°C throughout the exper-

iment" Should be present-ed/discussed in the 2.3.

We agree and moved the sentence to section 2.3.

Fig. 7 Please discuss and quantify the sparcity of the results for each cycle. Median points with associated ranges should be a better representation.

We changed the figure as requested to median points with associated ranges.

"Thus, a change in Brazilian tensile strength as a response to the RH variations was not measurable" why ? "or insignificant." why ?

Within the natural variability we could not see a significant change is the Brazilian Tensile Strength. Thus, the change is assessed insignificant.

In 4 Discussion 4.1 Fig. 8 is not clear: hysteresis is not clear in the figure. Please change the focus, two figures should be clearer first discuss the contribution results (zoom in) then add the other datas

The grey symbols show the main drying path and the black symbols the main wetting path that is offset to the drying path. We refer the reviewer to the paper Wild et al. (2015) for further explana-tions. We also feel that the results need to be shown in a combined figure to allow a comparison.

4.2 Strain and Damage Please discuss the concerned scales : interlayer scales etc.

Unfortunately we do not understand the comment.

Last paragraph, Page 7, Line 5 to 12 Do we have here an estimate of crack aperture? Is it corroborating the volumetric deformation estimates ? What are the volume/suface concerned by cracks ?

It is difficult to estimate the above quantities since the cracks that formed due to desiccation opened and closed and had no constant crack aperture along their length.

What are the orientation/direction of these damage features ? Are they interconnected

?

These fracture formed parallel to the bedding plane orientation, we could not observe any inter-connections

Please also discuss the number and duration of peformed drying/wetting cycles and observed damage and impact on tensile strength.

We discuss the number of drying/wetting cycles and specify the time; we also discuss the observed damage and the impact on tensile strength.

Discuss the representativity of the procedure with regard to in situ RH variations.

We used long-term in-situ measurements to define the upper and lower limit of the RH cycles. The duration of one in-situ RH cycle is 1 year and changes in RH are continuous rather than abrupt (as in the desiccators). The equilibration time in the laboratory is in the range of 25 days. The scope of this study was to analyze the peak to peak amplitude of the RH cycles and not the transient phases in between.

5 Conclusions From (e.g.) Benavente et al. Engineering Geology 59 (2001) 313±325 we can read that "Salt weath-ering, i.e. salt crystallization/dissolution into the pore space, is one of the most important degrada-tion mechanisms that a porous stone undergoes at and near the Earth's surface." What would be the results of drying/wetting cycles on salty poral fluid in the OPA Clay?

Certainly an interesting idea for future experiments

Could we have salt cristals precipitation during drying cycles ?

Certainly; there is, however, a lack of field observations that would support salt crystallization and associated swelling pressures. From some places in the Underground research Laboratory it is de-scribed that sulfate nodules grow on open fracture surfaces that are exposed to the tunnel envi-ronment. Thus some transport of salt and precipitation

What would be the impact of such crystallization/dissolution cycles on the poral structure ?

Again, an interested research question for future studies

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