

OPONENT APPRAISAL

Title: Investigation of the thermo-hydro-mechanical behavior of Czech bentonite used as a model material for planning of high level nuclear waste disposal

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Short summary

The focus of the evaluated thesis was thermo-hydro-mechanical behaviour of Czech bentonite B75 that is considered to be used as a potential engineering barrier material for deep geological repository of nuclear waste. The work was focused on measurement of water retention properties under temperature dependence, microstructure analyses under different compaction and suction environment; furthermore, also on bentonite mechanical behaviour. Moreover, except laboratory analyses and mechanical tests, modelling was involved in the work plan, proposing new approach toward modelling of swelling pressure. The theory and modelling were based on the diffuse double layer (DDL) theory, which evaluated applicability for both sodium and calcium bentonites.

Thesis content

The thesis contains 46 pages, 15 figures and 6 tables, accompanied by 3 papers, published or accepted into scientific journals. Czech and English abstracts are included. The text includes list of abbreviation that is highly appreciated, especially for bentonite non-specialists.

The thesis is divided into 7 chapters. Chapter 1 presents the research background and organization of the thesis. Chapter 2 gives a short introduction of the aim of the thesis. Chapter 3 presents the materials and methods used in the thesis. Chapter 4 presents all the tests results and discussions. More detailed, in section 4.1, the water retention properties under 20 - 80 °C are presented. In section 4.2, the microstructure of the bentonite under different compaction and suction are presented and discussed. In section 4.3, the mechanical behaviour is presented. The conclusions are summarized in Chapter 5. Chapter 6 lists all the references. Finally, the three impact factor journal articles are attached in Chapter 7.

The impact papers that were dedicated to the above mentioned work are following

Sun, H., Mašín, D., Najser, J., Neděla, V., & Navrátilová, E. (2019). Bentonite microstructure and saturation evolution in wetting–drying cycles evaluated using ESEM, MIP and WRC measurements. *Géotechnique*, 69(8), pp. 713-726, doi: doi.org/10.1680/jgeot.17.P.253

Sun, H (2018). A new method to predict swelling pressure of compacted bentonites based on diffuse double layer theory. *Geomechanics and Engineering*, 16(1), 71–83. <https://doi.org/10.12989/GAE.2018.16.1.071>

Sun, H., Mašín, D. Najser, J., Neděla, V., & Navrátilová, E. (2019 accepted), Fractal characteristics of pore structure of compacted bentonite studied by ESEM and MIP methods, *Acta Geotechnica* (Accepted)

Comments

Firstly I have to appreciate the publications. If the thesis includes published or at least accepted scientific papers, those are an individual proof of scientific revision of the work itself. Thesis then are summing and aligning tool and represent a kind of overbridging the papers. I can appreciate high quality of papers. Concerning that, I can also evaluate the thesis as advanced and matured. However, I would like to know proportion of the author input and direct involvement. This is not acknowledged in the text.

Hereby are the most important comments that would deserve the explanation at the thesis defence.

The impact of results, namely studies of water retention under different temperatures or new insight into the modelling of swelling pressure, were not fully explained in the context of bentonite role as a barrier in deep geological repository (DGR). A small attempt we can find at the paper Sun H. (2018), however namely focusing on introducing safety role of bentonite in DGR. Neither the paper, nor the thesis translates the results into the Czech disposal concept in larger detail. Not talking about the broad general context itself.

Thesis itself might deserve more detailed introduction of the system of Czech bentonites. The illness of the research on bentonites of Czech origin consists in too many types and designations for samples, used over the time, even though primarily originating from one deposit (Rokle, Sabenil, B75, BAM, and BCV). One could get lost easily. The thesis should clearly identify at the beginning which type of bentonite (here B75 and Sabenil later on) is used and introduce full chemical and chemical analyses, accompanied by other properties as CEC, specific surface, porosity etc. The bentonite chemical analysis is included only in the papers. More detailed mineralogical composition should be introduced as well. The abbreviation should be used through the whole text and in all the papers.

I am missing an explanation for using different salts in vapour equilibrium method measurement in Chapter 3 and also in the paper Sun et al. (2019).

As not being a bentonite specialist, using mercury porosity (MIP) as a standard method for porosity determination surprised me. Could you please explain the procedure how the bentonite porosity is determined using this method? Does the MIP process itself not affect the structure too due to quite high pressure applied? Would it not be better to use e. g. surface area measurement for determining porosity? I am also missing values for total porosity of bentonite samples through the whole thesis, namely for those prepared at different compactions and studied under different suction.

Getting back to the broader context, DDL approach is mentioned here in Chapter 4 and one part of thesis is based on using it. Do you also know the other approaches, as multiporosity concept, introduced by Karnland et al.? It might be also mentioned in State of the art at the introduction of the thesis or in the paper Sun (2018).

It seems that model developed predicts swelling pressure better for Ca-bentonites (ref. Fig. 15 at the thesis, figures 10 and 11 at the paper Sun 2018)? Can the author explain the differences between the fit for both types of bentonite? What is the reason for the difference? However, the trend claimed for Czech bentonite is opposite – “Sab65 as the Na activated product claims to fit better to the model than Ca-Mg B75”? The problem at Fig 15 (page 37) seems to me based more on inconsistency of experimental data. Discussion over the results is appreciated.

Reflecting that, the conclusion “The proposed equations are valid in prediction of swelling pressure of compacted bentonite” in the paper Sun (2018) seems to me little bit ambitious.

There are listed some of the other important issues that might deserves comment and explanation:

- Through the whole thesis reference style should be kept through the text – either (Cornelius et al 2019) or (Cornelius et al., 2019)
- Page 5 missing abbreviations e_0 and ε_v . Can you explain those quantities?
- Page 11 bentonite should be well labelled. Directly B 75 abbreviation should be used, though whole thesis. I am missing detailed characterization (mineralogy, chemical analyses, surface area determination, and total porosity) or reference to them
- Page 12 Explain use of salts to determine humidity
- Page 13 Does the freezing not affect the structure of the saturated bentonite on both micro- and macro- levels?
- Page 17 Which Czech bentonite was used for intercomparison (see the comments above)?
- Page 23 Why only macropores are sensitive to suction? Why smaller macropores are sensitive to compaction only, on the other hand large macropores are sensitive to both suction and compaction?
- Page 36 Sabenil (Sab65) is activated Czech bentonite (B75). It is not a natural Na-bentonite, as it can be understood from the text. Again precise bentonite labelling would be appreciated.
- Page 37 and paper Sun (2019). It seems that model developed predicts swelling pressure better for Ca-bentonites (ref. Fig. 15 at the thesis, figures 10 and 11 at the paper Sun 2018). Can you explain that in more detail – see comments above?
- Page 40 The conclusion “This indicates a certain change of the pore structure of the samples exposed to oven drying“ seems to be in contradiction with the conclusion of the paper Sun et al. (219), page 718: „The authors therefore consider the effect of oven drying does not affect the qualitative and quantitative evaluation of the presented data.“ Can you explain that?

Papers

Those underwent the individual scientific review when accepted into the journals, however I still have some comments

Consistent referring of bentonite characterization would be highly appreciated. Mineralogy is generally missing (content of monmorillonite is not sufficient), chemical composition is a must.

Sun et al. (2019) page 715 reference to wax immersion method would be appreciated

Sun et al. (2018 accepted)

Page 13 Why did you used two methods, determining fractal dimension, if there are incomparable?

Table 4 Units of pressure are missing.

Fig. 16 Evaluating the trends, are 3 point enough? Especially at 1.9 dry density...

Sun (2018) “Compacted bentonites are clays with high content of montmorillonite.” Such a statement is not true or needs to be explained in detail. To my knowledge, compaction is not relevant to montmorillonite content.

Recommendation and conclusions

Concluding, as a main contribution of the evaluated thesis I can consider

- The thesis includes both laboratory and technical analysis, accompanied with modelling, both at advanced and sophisticated level
- The thesis brings new insight into the well known conventional modelling approach for determination of bentonite mechanical behaviour
- The results, described in the thesis and papers. contribute to the detailed characterization of the material that has to fulfil strict requirements, concerning safety functions in deep geological repository
- The publications of results in the scientific papers are highly appreciated; they independently underwent international evaluation during journal acceptance process. This can be considered as an independent result review.

Concerning all the mentioned positives and comments that can be stated, I can only appreciate the high quality of both the scientific approach and the results reached.

I suggest that after discussion over the results and comments, stated above, the thesis can be accepted.

A handwritten signature in blue ink, appearing to read 'Václava Havlová' with a stylized flourish at the end.

In Prague, September 16, 2019

RNDr. Václava Havlová, PhD.