WORK PACKAGE 6
DELIVERABLE D6.2

CS perspectives with a focus on verification and validation of models, and comparing models with situations close to disposal conditions (task 5.1 and 5.2 of WP5)

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Abstract

This report is a part of the Work Package 6 (WP 6) effort to disseminate to civil society the work and results of the Beacon project. While providing a short description of the development of the work of Work Packages 2-4 of the project, the main focus of the work of the WP 6 civil society (CS) experts is on providing a description of the work and the results of subtasks 5.1 and 5.2 of WP 5 oriented towards the verification and validation of models developed by WP 3.

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1 Introduction

This report is a part of the Work Package (WP) 6 effort for civil society dissemination for the Beacon project. In the previous deliverable D6.1 “Scoping of the Beacon project, initial civil society (CS) perspectives and enhanced work plan for years 2-4”, an enhanced work plan for the work of WP 6 for the years 2-4 of the project was described. The work during the remainder of the project for the WP 6 civil society (CS) experts in the project is to focus on the WP 5 subtasks and deliverables, and to provide a description of the work and results targeted at civil society. The other Work Packages are also followed, but not in the same detail.

Generally, the Beacon project studies the behaviour of clay materials that are proposed to be used in repositories of different types for radioactive waste. A characteristic of the clay used is that it swells when exposed to water. The Beacon project studies the swelling of clays and more specifically tries to model how the clay swells. The clay has a tendency to sometimes swell unevenly, or inhomogeneously, it is a challenge to model this in an accurate way.

The project has five Work Packages focusing on different aspects of the project. The development of the work in WPs 2-4 during the second and third year is shortly described in the report.

However, during the second and third year of the project the focus of the WP 6 CS experts was to follow and study the work done in the subtasks 5.1 and 5.2 of WP 5. Subtask 5.1 was oriented towards the verification and validation of models developed in WP 3 by using the models to try to emulate the results of laboratory experiments that had already been carried out before the project started. During the subtask the modelling methods of WP 3 were developed. Subtask 5.2 was oriented towards the continued verification and validation of models developed in WP 3 by using the models to try to emulate the results of test cases consisting of previous larger experiments made in situations close to repository conditions.

The result of the work of WP 6 during year 2 and 3 is this report D6.2 "CS perspectives with a focus on verification and validation of models, and comparing models with situations close to disposal conditions (task 5.1 and 5.2 of WP5)”.

As the work of WP 5 has been progressing it became clear to WP 6 that the results and the final report from task 5.2 would not be available until the spring of 2020. This was according to the original plan for WP5 and therefore the finalisation of this report has awaited the deliverable D5.2.2 with the synthesis of the results of the test cases from task 5.2.

2 The progress of the Beacon project in years two and three

2.1 The progress of the work done in Work Package (WP) 6

Due to the restructuring of the work plan for WP 6 that was complete in the spring of 2019, the focus of the work done by the CS expert group developed for the project has changed. The whole CS expert working group (four experts assisted by a technical specialist) attended the Beacon project first annual meeting on Milos on May 29-31, 2018 and were involved in the discussions on the revision of the work plan.

With the new work plan focused on dissemination the intensity of work within WP 6 has decreased. At the second annual meeting in Prague on May 21-23, 2019, two CS experts were present, as was the case also at the online annual meeting on May 13, 2020.

The leader of WP 6 has also attended the combined WP3/WP5 meetings in Paris on January 29-30, 2019, and February 13-14, 2020, as well as the WP 2 online meeting on May 12, 2020.

During 2019 and 2020 the leader of WP 6, Johan Swahn, has mainly collaborated with one of the WP 6 CS experts, Nadja Železnik, in participation in the project. These persons are also the authors of this report.

The focus of the work in WP 6 is now on dissemination. The texts in this chapter are intended for use in the development of the dissemination of the work and results of the Beacon project to the civil society/public. The descriptions are based on the presentations and discussion at the annual meetings and the meetings of W3/WP5.

2.2 The progress of the Beacon project Work Packages 1-5

At the annual meetings the progress of the different work packages of the Beacon project have been described in presentations. Below is a short summary of the work done in each of the Work Packages 1-5.

2.2.1 Work Package 1

In the Work Package (WP) 1 on “Definition of assessment case/Application to the assessment case” the main result presented at the first annual meeting was an initial report called “Beacon - Bentonite Mechanical Evolution: State-of-the-Art Report” (deliverable D1.1). The report was produced by having a questionnaire distributed to the main European organisations working on implementing final repositories for radioactive waste. These organisations, called implementers or waste management organisations (WMOs), are Nagra in Switzerland, SKB in Sweden. Posiva in Finland, Surao in the Czech Republic, Enresa in Spain, Andra in France and GRS in Germany.

In general, the goal of the WMOs involved in WP 1 is to increase the understanding of how clays may swell, sometimes unevenly (or inhomogeneously), when they get in contact with water in a radioactive waste repository. Also, the clay may be in an uneven form, such as pellets, when used as filling in a repository and it is then important to understand and be able to model the way the clay becomes more even after swelling.

The WMOs have criteria for how the clay should be like after it has swollen for the repository to be safe. There is still an uncertainty that enough knowledge is available to be able to predict how clay will swell and the purpose of the Beacon project is to lessen this uncertainty.

The questionnaire that was used to make the initial report from WP 1 collected so-called state-of-the-art information of how the different WMOs presently handle clay issues when they analyse the safety of a repository. This information is presented in the report and it allows the groups that develop the models (WP 3) and the experimentalists in the project (WP 4) to better understand what the whole project is aiming at.

In the end, the WMOs want to have models that can predict as accurately as possible how clay may swell with time. Such models can be very useful for determining whether planned repositories are safe enough.

WP 1 has had no tasks during the second and third year but has provided three assessment cases for WP 5 to attempt to model during the last year of the project.

Also, WP 1 will await the results of the project and may at the end of the project be able to use the results to formulate requirements for how clay can be used in different kinds of repositories.

2.2.2 Work package 2

The most important result from WP 2 on “Collection and compilation of existing data and available models” presented at the first annual meeting was also a report. The report is called “Review of data and models on the mechanical properties of bentonite available at the start of Beacon” (deliverable D2.2). The aim of work package 2 is to collect as much information as possible about previous experiments with clay and efforts to model how clay behaves in the laboratory and in a repository environment.

In order to collect this information, the work package organised a workshop at the kick-off meeting of the Beacon project in Kaunas in Lithuania in June 2017. There were many presentations made on different experiments and modelling work.

The next thing that the work package did was to provide forms that could be filled in to describe previous experimental and modelling projects. These forms were filled in by the large number of participant organisations in the Beacon project, but the people responsible for the work package also filled in forms for other projects they identified. There was also a special meeting for the work package in London on October 2017 to assist in the collection of information.

The final result is the report that was ready in December 2017 with long lists of previous work on the swelling of clay listed.

WP 2 has had no tasks during years two and three. At a meeting on May 12, 2020, the work package started a process to update the review report. An updated report will be published towards the end of the project.

2.2.3 Work package 3

The work package 3 on “Model development” consists of a large number of modelling groups. The nine groups are using models they have previously developed to see how closely they can come to modelling a number of test experiments with swelling clay. In order to be able to compare and develop their different models the groups in the work package in the beginning of the project used a special form to describe how their particular model works.

The result was the first report from WP 3 called “Description of the constitutive models available at the start of the project. Conceptual bases, mathematical description and model capabilities and shortcomings” (deliverable D3.1).

The modelling groups in work package three have been working in work package 5 doing modelling to see if they can model the results of a chosen experiment carried out before the Beacon project (see below).

2.2.4 Work package 4

Work package 4 on “Laboratory testing” also consists of a large number of groups that are experimental. The eight groups from six countries have carried out a number of new experiments to provide new results that the modellers in work package 3 can work on. Time was first spent on defining which experiments were to be carried out so that the modellers would have a broad choice to choose from. The experiments were then carried out and reported in the report ”Bentonite mechanical evolution – experimental work for the support of model development and validation” (deliverable D 4.1).

2.2.5 Work package 5

The work package 5 on “Testing, verification and validation of the models” is the most central work package in the Beacon project. In the work package the modellers from WP 3 test their models. During most of the project they test the models against experimental data from experiments that have been carried out before the Beacon project started. Towards the end of the project they will model with data from the experiments done in WP 4.

From the results of WP 2 with the long list of previous experiments on clay, two lists of experiments that the modellers should test their models on were made. The first list is composed of three smaller laboratory test and the second of large-scale experiments. In the beginning of the project the work focussed on the smaller tests and then the modelling continued with the larger tests.

The final year of the project will focus on the modelling of an experiment from WP 4 as well as on three assessment cases provided by WP1.

A description of the work of WP 5 is developed in the next section.

3 A more detailed description of the progress of WP 5

The work of WP6 on civil society dissemination focuses on the work of WP5 that involves testing, verifying and validating the developing work of the modellers in WP 3. There are ten groups of modellers from the following institutions:

Universitat Politècnica de Catalunya (UPC)
Charles University in Prague (CU)/Czech Technical University in Prague (CTU)
Technical Research Centre of Finland (VTT)/University of Castilla–La Mancha (UCLM)
University of Liege (ULg)
The Federal Institute for Geosciences and Natural Resources (BGR)
Lithuanian Energy Institute (LEI)
Clay Technology AB (ClayTech)
École polytechnique fédérale de Lausanne (EPFL)
Imperial College London (ICL)
Quintessa

The idea has been to first allow the modelling groups to try and model some small laboratory tests that were selected from the large list of experiments that were identified by WP 2. The modelling groups could compare their different ways of approaching the task and learn both from their own work and from other groups. This was the subtask 5.1 in the project and the work was done during the first years and the final report was ready in May 2019. It was called "Synthesis of results from task 5.1" (deliverable D5.1.2).

The modelling groups learnt much from this first subtask. The next subtask called 5.2 was to model a selection of large-scale experiments also chosen from the lists prepared by WP 2. The work was completed by the spring of 2020 and the final report was ready in June 2020. It was called "Synthesis of the results obtain of test cases from task 5.2" (deliverable D5.2.2).

The work and results of the two subtasks are described below.

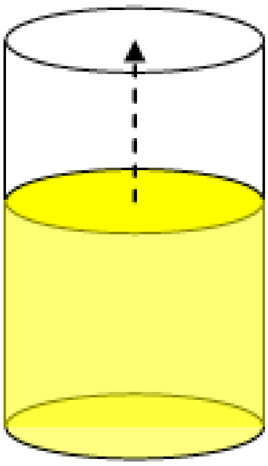
3.1 The smaller laboratory tests (subtask 5.1)

In subtask 5.1 the modelling groups modelled three smaller laboratory tests. Three tests were chosen:
- "Swelling pressure tests for compacted plugs with free volume available" that was carried out by the Swedish company Clay Technology AB together with the Swedish WMO called SKB (actually 2 experiments called 1a01 and 1a02);
- "Swelling pressure tests for pellets mixture" that was carried out by the French research organisation CEA together with the French WMO called Andra (called 1b); and,
- "Swelling pressure tests for block and pellets structure" that was carried out by the Finnish WMO called Posiva (called 1c)

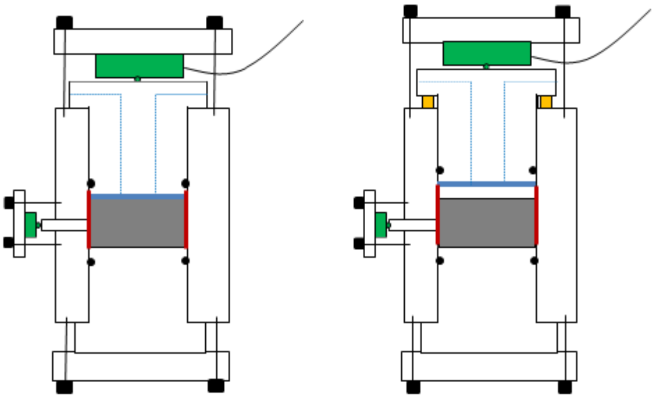
The laboratory tests are described below.

3.1.1 The test 1a "Swelling pressure tests for compacted plugs with free volume available"

The laboratory test 1a, called "Swelling pressure tests for compacted plugs with free volume available" were the ones the modellers of WP 3 modelled during the first year. The laboratory tests were made by the Swedish company Clay Technology. The principle of the test is shown below

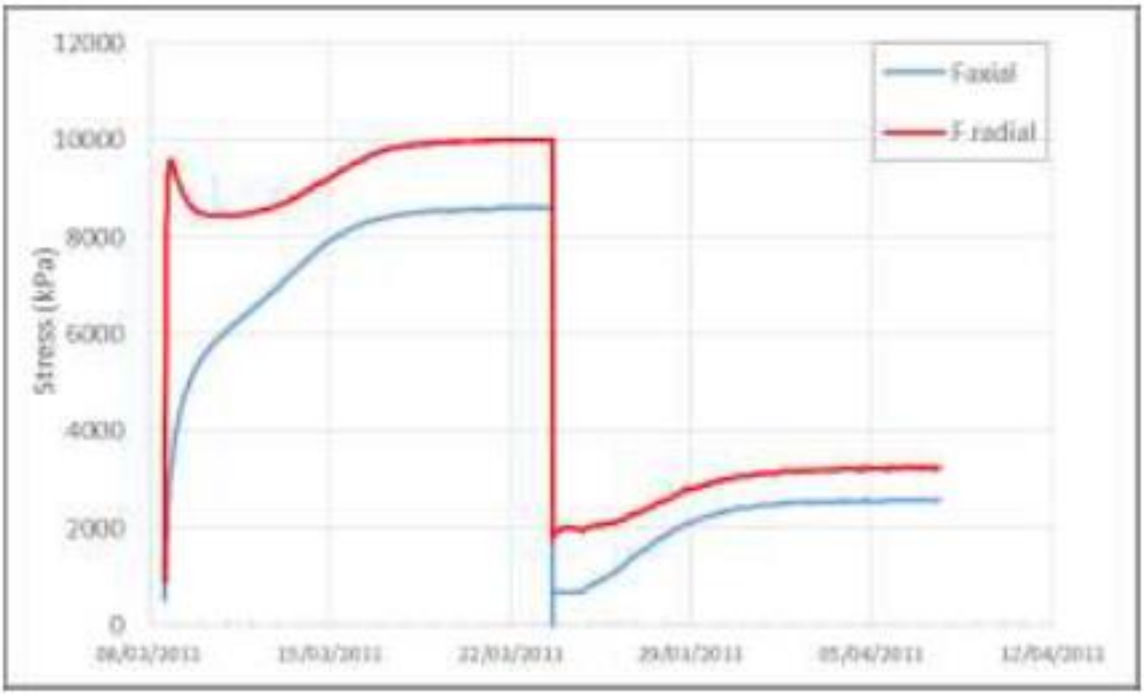


The test is having the clay in a cylindrical container and then allowing it to swell as water is introduced into the container. The test was actually done in two versions. The first version is shown below. It was called test 1a01.



In the test the clay is first allowed to swell in an enclosed volume. After a while the top of the container is lifted to give a gap, allowing the clay to swell upwards (the figure on the right).

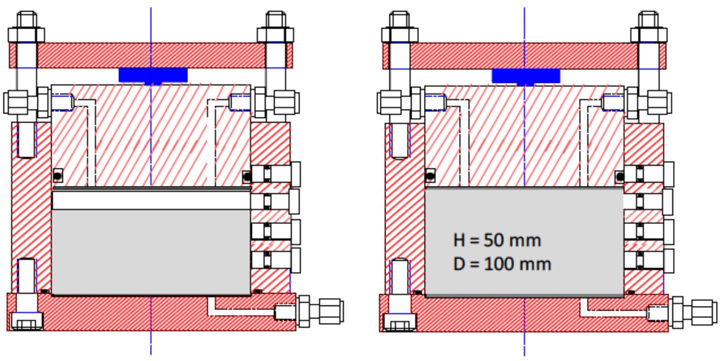
When the clay swells a pressure is built up in the clay. This is called the swelling pressure and it is measured with different sensors. In this case the pressure is measured radially (to the sides) and axially (up and down). In the figure below the swelling pressure is presented in a diagram.



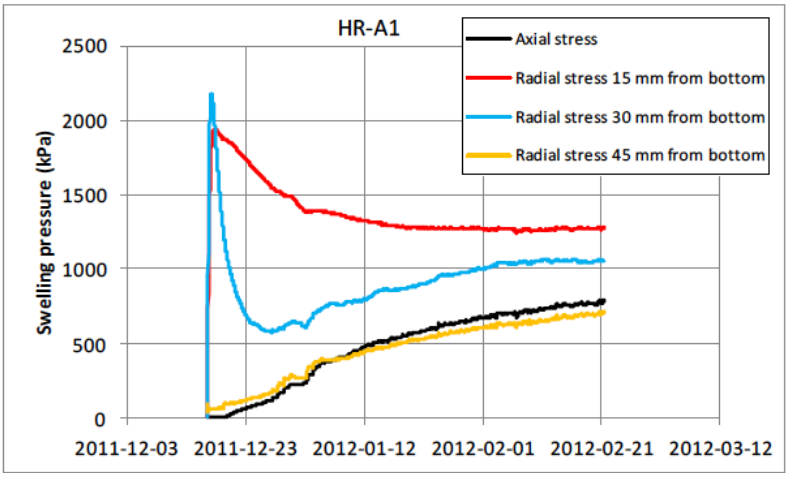
In the diagram we can see that the swelling to the sides goes quite fast (red line) and the swelling up and down goes slower (blue line). After a while the swelling is complete and the swelling pressure is constant. The gap above the clay is then opened and the swelling pressure drops very fast. The clay then continues to swell up into the gap and the swelling pressure increases again. The pressure levels of at a lower pressure than before.

It is this behavior as shown in the diagrams that the modelers of WP 3 have to try and show that their models can replicate. The modelling results for all the small laboratory tests are shown in section 3.2.

The second version of test 1a, called 1a02, and is shown below.



In the test clay is just allowed to swell into a gap above. But the clay is already full of water to start with (fully saturated). Water is also added from the top. The resulting swelling pressure is shown in the diagram below.



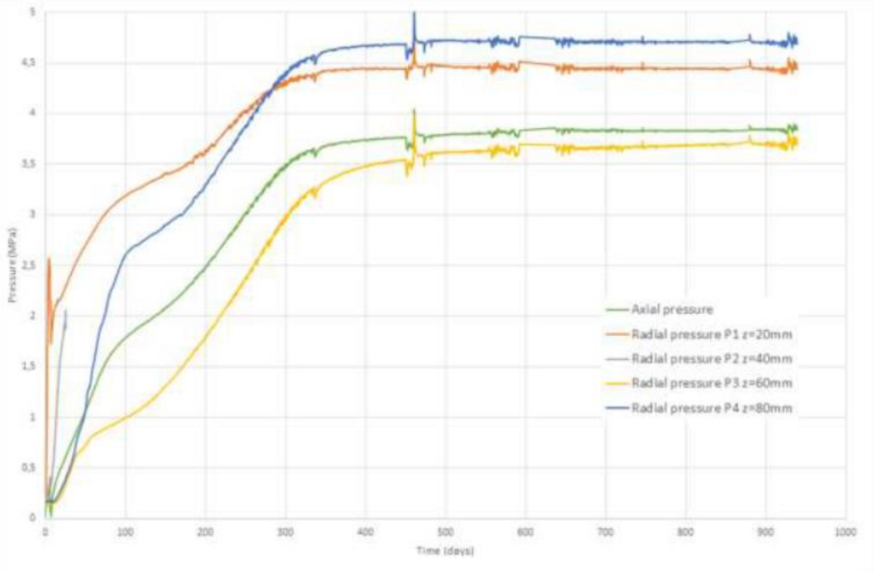
In the diagram it can be observed that the pressure up and down (axial stress, black line)) slowly increases until a constant value is reached. The pressure from side to side (radial stress, red, blue and yellow lines) varies quite a lot with time depending on how far up the cylinder it is measured.

3.1.2 Test 1b "Swelling pressure tests for pellets mixture"

The second small laboratory test that was modelled was called Test 1 b "Swelling pressure tests for pellets mixture". It was carried out by the French implementer Andra. The test was done by filling a container with clay pellets and the adding water. An example of the laboratory equipment is shown below.

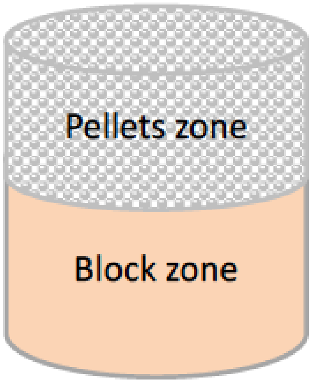
The pellets were of differing sizes and in addition clay powder made out of crushed pellets was added.

The result from the test is shown below. The swelling pressure both up and down (axial) and to the sides (radial) at various positions on the side of the container stabilized at different values after about 300 days.

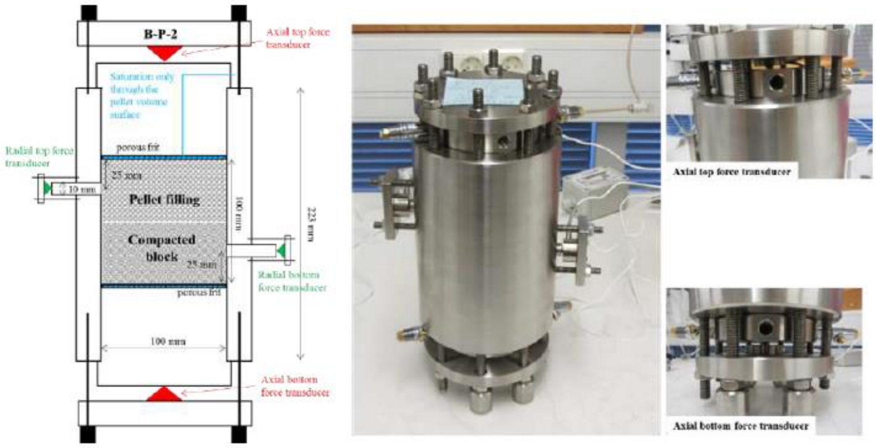


3.1.3 Test 1c “Swelling pressure tests for block and pellets structure”

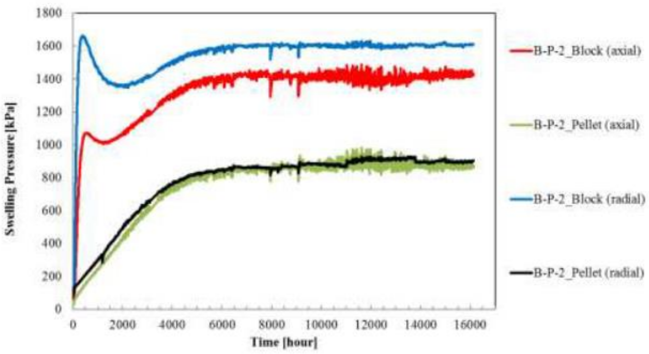
The third small laboratory test was called text 1c “Swelling pressure tests for block and pellets structure”. In the test a block of clay was put in the bottom of a cylinder and pellets at the top and then water was added (see the figure below).



The experimental apparatus is shown on the next page.



The results from the laboratory test is shown in the diagram below.



The swelling pressure up and down in the clay block (axial, black line) and the swelling pressure up and down in the pellets (axial, green line) increases until it levels off. The side to side swelling pressures in the block (radial, red line) and the pellets (radial, blue line) increase quite fast in the beginning, then fall slightly to finally levelling off.

In the next section the results of the modelling of the three small laboratory tests are described.

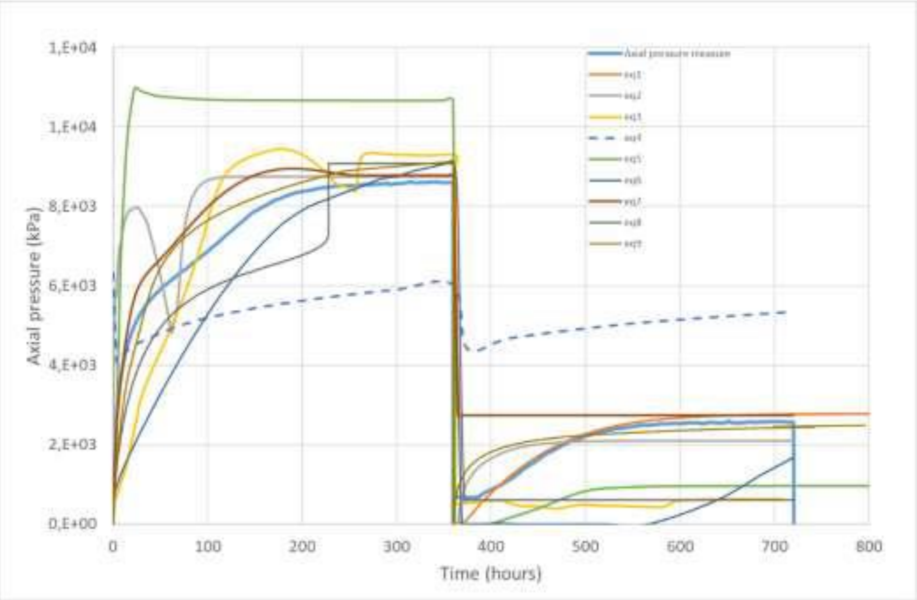
3.2 The results of the modelling of the smaller laboratory tests (subtask 5.1)

In this section the results of the modeling of the modelers of WP 3 of the three small laboratory tests are described.

3.2.1 The results of the modelling of test 1a "Swelling pressure tests for compacted plugs with free volume available"

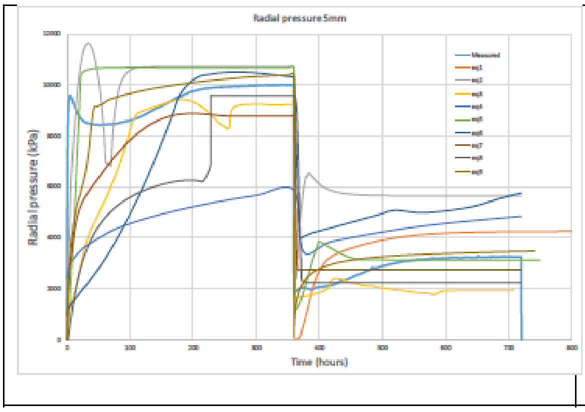
The small laboratory test 1a was in reality two experiments, 1a01 where a gap was created above a clay block and 1a02 where the gap existed from the beginning.

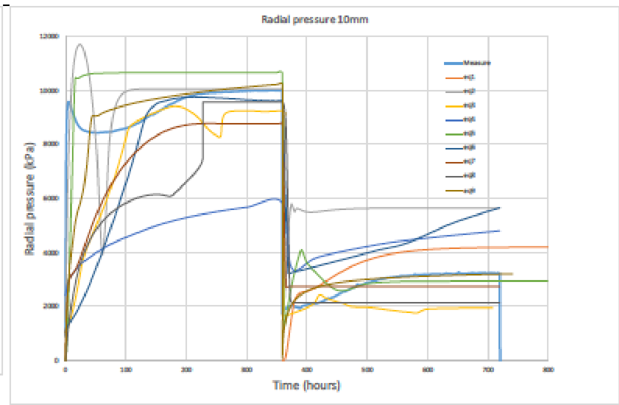
The results of the modelling of the swelling pressure up and down (axial) for test 1 a01, where a gap above the clay was created after a while, is shown below.



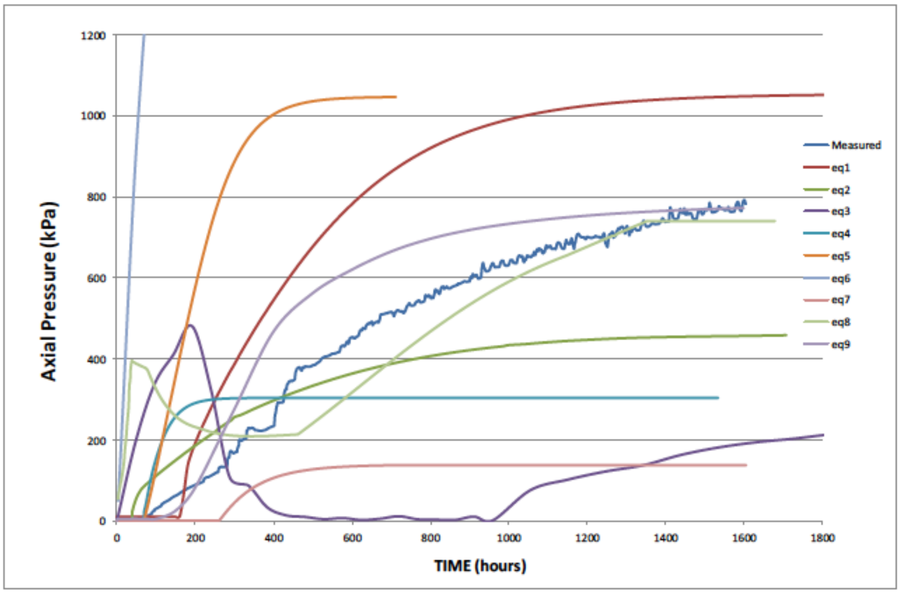
The real result is the solid blue line and it can be seen that the different models from the different groups have difficulties in repeating the results completely. Many of the models are able to get the swelling pressure after the first swelling right, but after the change that is made and when the gap is created there are bigger problems.

The results are a bit worse when the modellers try and repeat the pressures from side to side (radial) at two different heights as is shown in the diagram below. Here only a few modellers are able to repeat the swelling pressure even the first swelling.

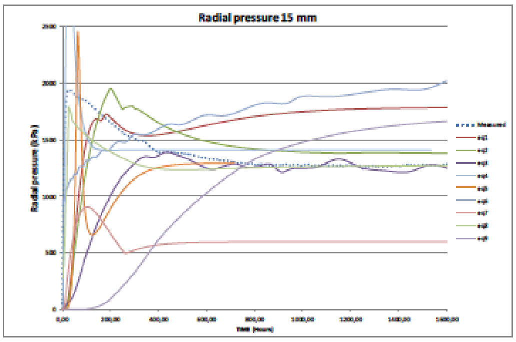


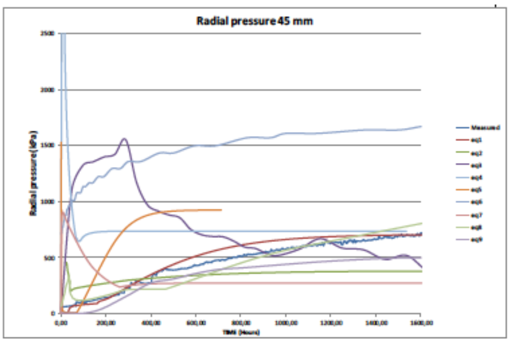


For the test 1a02 where the gap above the clay existed before the test was started the modelling results for the swelling pressure up and down (axial) is shown below.



The actual swelling pressure from the test is the curvy blue line. As can be seen it was difficult for the modelers to repeat the experiment. The situation was similar for the side to side (radial) pressures as can be seen in the diagram below.





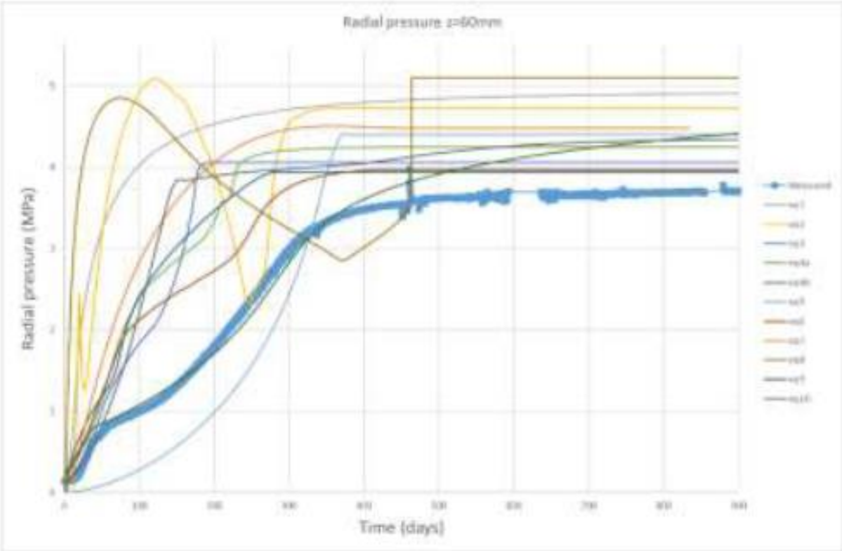
It is clear from the modelling results that it is generally difficult to use the models that the modelling teams had from before the project to the test cases.

The models did manage to capture the swelling pressure of the first part of test 1a01 well. The reason for this is that it is a classic swelling pressure test at constant volume. This is a test that the models have been developed to capture

As the modelers now approached the modelling of the small laboratory tests 1b and 1c they had the possibility to learn from each other. This allowed the development of the models.

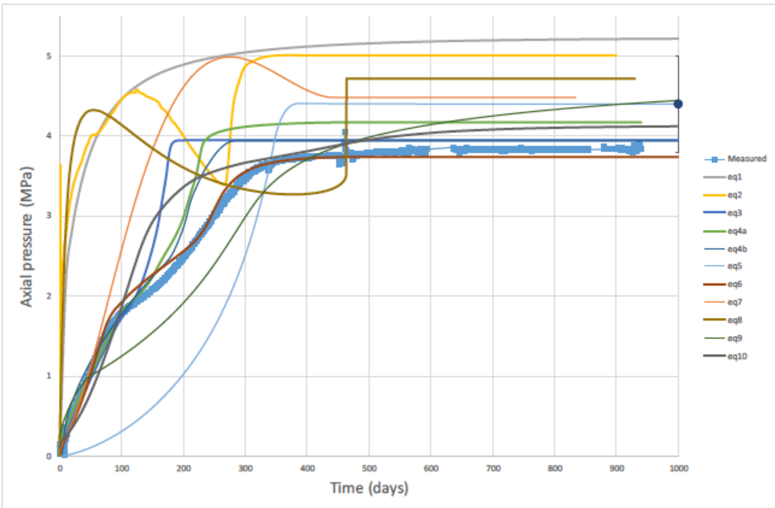
3.2.2 The results of the modelling of test 1b “Swelling pressure tests for pellets mixture”

In the small laboratory test 1b pellets were allowed to swell in a container. In the diagram below the up and down pressure (axial) in the experiment has been modelled.



The experimental swelling pressure is the thicker blue line. Even though all the models do not reach the same swelling pressure it can be said that they are in a good range as there are some uncertainties about how much water was in the pellets to start with.

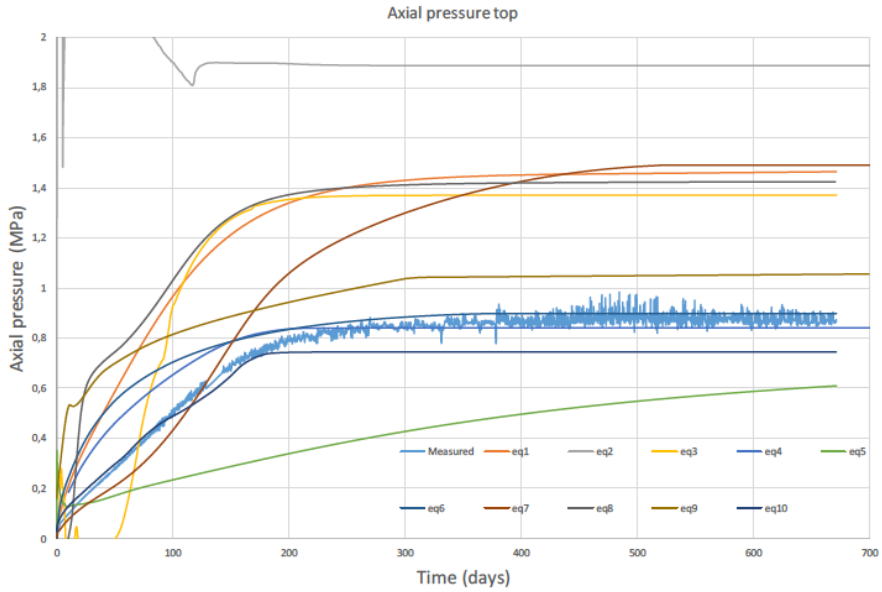
In the diagram below the results of the side to side (radial) swelling pressure at one point on the side of the container are shown.



In a similar way the end results for the swelling pressure are quite good.

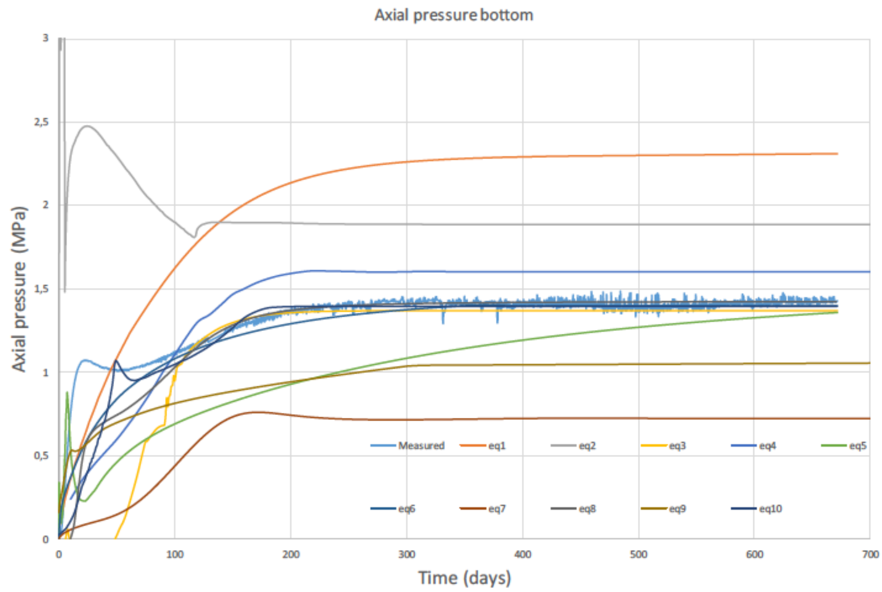
3.2.3 The results of the modelling of test 1c "Swelling pressure tests for block and pellets structure"

In the small laboratory test 1c there was one part with a clay block and one part with pellets in the container. The results of the up and down (axial) swelling pressure of the upper part with pellets are shown in the diagram below.

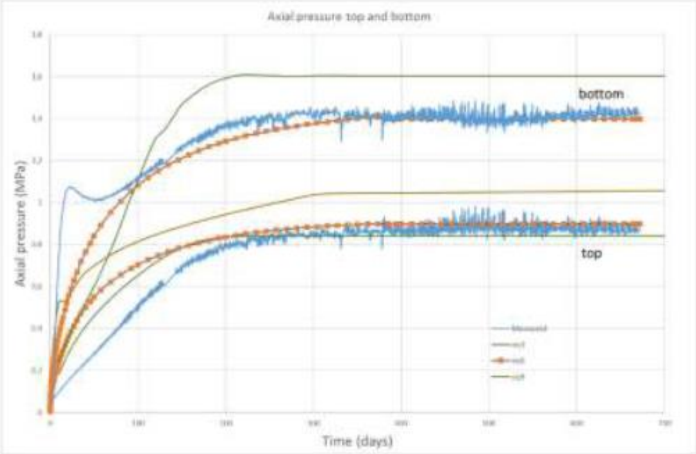


The real value of the swelling pressure is the wiggly blue line. Most of the modelers have reached too high values, but some modelers are more successful.

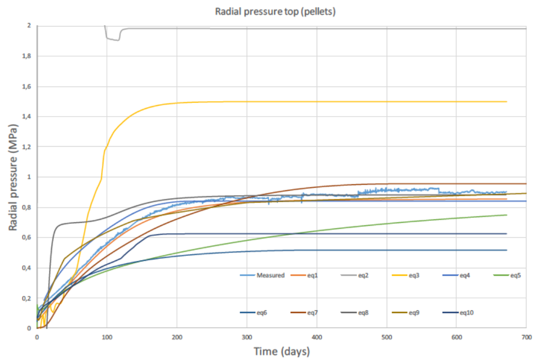
The results for the up and down (axial) swelling pressure of the clay at the bottom of the container is shown below. The results here are more spread out here.

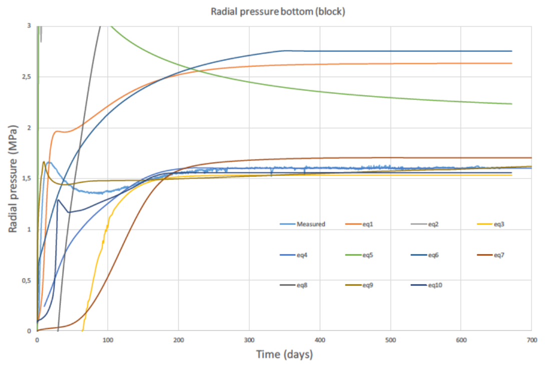


Some of the modeling groups managed to get good results for both the pellets and the block which can be seen in the figure below.



The diagrams below show the side to side (radial) swelling pressure of the pellets (left) and clay block (right). Also here, many groups capture the swelling well.





After modelling the small laboratory tests the modelling groups started working on modelling the large-scale experiments in subtask 5.2.

3.3 The large-scale experiments (subtask 5.2)

In subtask 5.2 the modelling groups modelled three large-scale experiments. The work was done by the modelling of three large-scale experiments performed in the Grimsel, Äspö and Mont Terri laboratories. The tests were chosen from the initial inventory made in WP2 from the Beacon project. Three experiments were chosen:

– EB - Engineered Barrier Emplacement Experiment (experiment 2a), NAGRA
– FEBEX - Full-scale Engineered Barrier Experiment in Crystalline Host Rock (experiment 2b), International consortium
– CRT - Canister Retrieval Test (experiment 2c), SKB

Main characteristics of the experiments are as follows:

– For two experiments FEBEX and CRT, the bentonite is submitted to both water saturation and temperature during the test.
– Febex bentonite was used for EB and FEBEX. Another type of bentonite, MX-80, was used for CRT
– In EB, most of the excavation was filled with pellets mixture.
– In FEBEX and CRT, the majority of the volume was filled with compacted blocks.

The tests were chosen as they are relevant for the Beacon project objectives and they have already been dismantled and they are well documented. This means that a large amount of data is available that are important to evaluate the final homogeneity of the swelling clay. The experiments and the results to be modelled are described in the next section and the results of the modelling is described in the final section.

3.3.1 Experiment 2a "EB - Engineered Barrier Emplacement Experiment"

The Engineered Barrier Emplacement Experiment (EB experiment) at the Mont Terri underground research laboratory in Switzerland was dismantled in 2012 after almost eleven years of operation. It was operated by the Swiss implementer NAGRA.

In the experiment a dummy canister made out of steel was placed in a tunnel in the bedrock and surrounded by clay. The canister was not heated. After the tunnel is closed the clay swells around the canister.

The experiment was carried out in a gallery excavated in the Opalinus clay of the Mont Terri Underground Research Laboratory. The EB experiment was designed in order to demonstrate a new emplacement technique of the bentonite barrier according to the Swiss concept. There is a compacted block located below the canister and small pieces of bentonite clay was used to fill the rest of the tunnel. The figures below show the experiment.

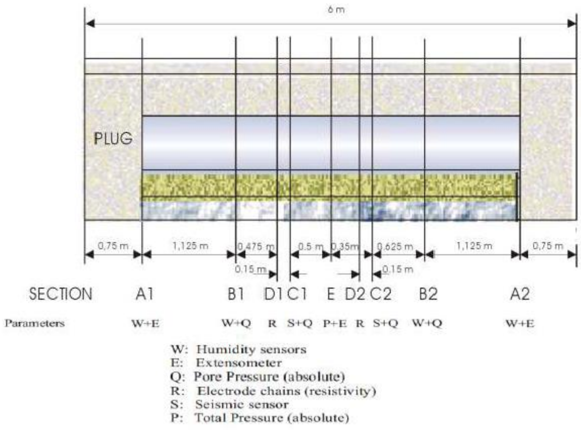
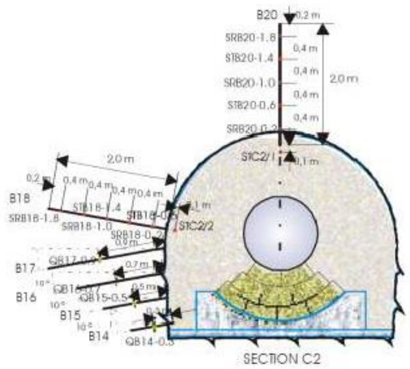


Figure 2-7 Position of instrumented sections in EB Niche



The experiment is relevant for the Beacon project mainly due to the presence of the different clay types in the tunnel at the beginning of the experiment. Water was introduced in the experiment both by natural inflow and through a special hydration system.

Analysis done after the experiment was finished showed that the clay had swollen differently in different parts of the tunnel. The challenge for the modellers of WP3 was to reproduce how the clay had swollen during the experiment as the different clay parts were saturated with water and also the final state of the experiment to show how the water was distributed and how much the clay had swollen.

Two stages of modelling were proposed for the experiment. The first was how the clay evolved in a cross section of the clay. The second was to model how the clay in the whole tunnel evolved.

In the figure below the dry density of the clay of a cross section is shown.

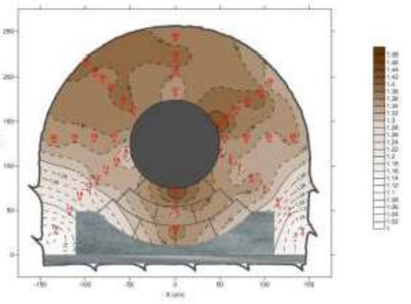


Figure 2-14 Dry density – section E

In the figure below the water saturation and water content of a section is shown.

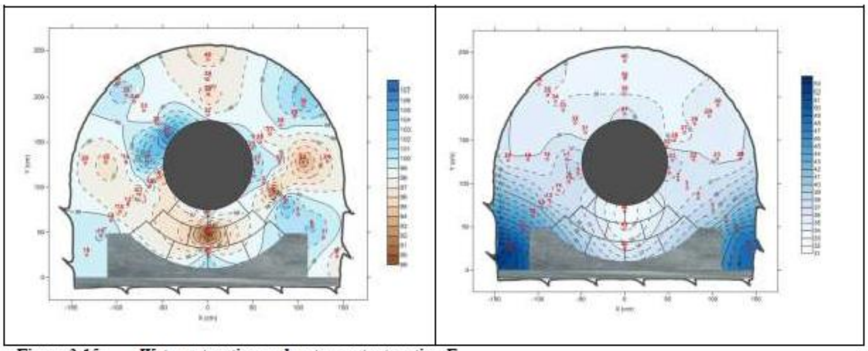
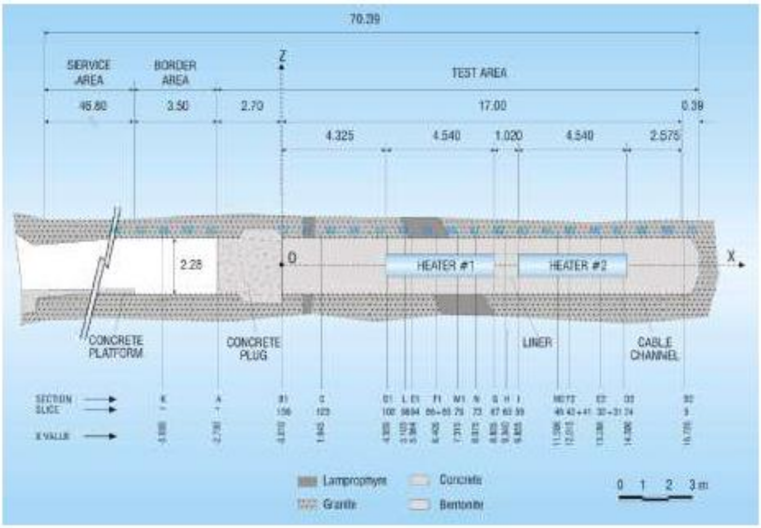


Figure 2-15 Water saturation and water content section E

3.3.2 Experiment 2b "FEBEX - Full-scale Engineered Barrier Experiment in Crystalline Host Rock"

The FEBEX experiment (Full-scale Engineered Barrier Experiment in Crystalline Host Rock) ran for 18 years at the Grimsel underground laboratory in Switzerland and was finally dismantled in 2015. It was operated by an international consortium of Waste Management Organisations.

The general layout of the experiment is shown below. There are heated steel canisters surrounded by clay. The first part with the canister was removed after five years. The second canister was removed in 2015 after the experiment had been running for 18 years.



The gaps between the bentonite blocks used to fill the tunnel as well as the gap between the blocks and the granite rock walls play an important role in how the clay is saturated with water and the stresses in the clay that are a result of the clay swelling. The gaps can be considered as initial heterogeneities in the system and means that the experiment is relevant for the Beacon project. As the canisters are heated there is also an aspect of the temperature that develops in the clay and affect the clay properties. The heating also affects how the water can swell the clay.

The modelling test case from the FEBEX experiment is the evolution of the clay around the inner canister from 1997 to 2015. How the models of WP3 will be able to predict both the evolution of different characteristics in the bentonite blocks and then the final distribution of main properties such as dry density, total pressure or water content are important for the objectives of the Beacon project.

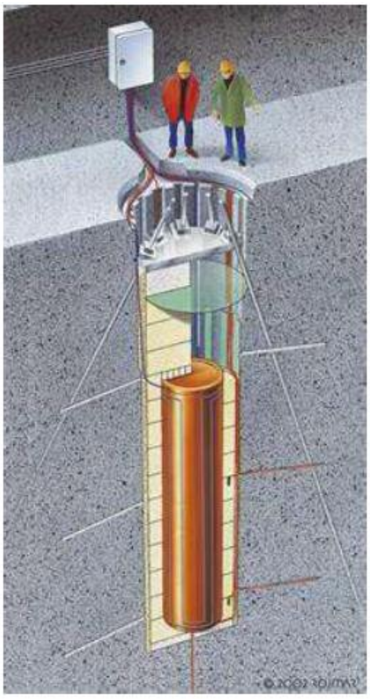
The results to be modelled are the (1) distributions and evolutions of relative humidity; (2) distributions and evolutions of temperature; (3) evolutions of total stresses; (4) distributions and evolutions of dry density, water content and degree of saturation.

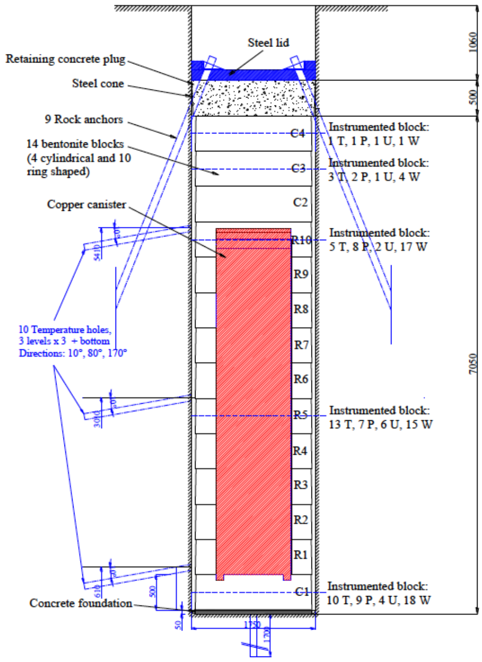
3.3.3 Experiment 2c “CRT - Canister Retrieval Test”

The Canister Retrieval Test (CRT) was a full-scale field experiment simulating a deposition hole with a copper canister and clay buffer according to the Swedish KBS-3 method. The experiment was carried out at the Äspö Hard Rock Laboratory in Sweden from 1999 to 2006. It was financed by the Swedish implementer SKB.

It was designed to demonstrate the ability to retrieve a deposited canister after the clay had swollen completely.

The CRT experiment is shown in the diagram below. There is a copper canister deposited in a hole in the tunnel floor and the canister is surrounded by a buffer made up of rings of clay. The space between the clay blocks and the surrounding rock is filled with clay pellets. The copper canister was heated, and water was artificially introduced in the experiment. It was dismantled after 5 years of operation.





For the modellers the objective was to show that their models can reproduce the observations and measurements in the experiment, including the role of uneven properties of the clay. Of special interest is the area with clay pellets between the clay blocks and the surrounding bedrock. This is a similar situation as the small laboratory test 1c with the clay block and pellets.

Systems with clay blocks and pellets are very relevant for Beacon project. In the beginning after starting operation of a repository the total clay barrier relies on the possibility of the blocks and pellets to form a uniform system.

In the next section the results of the modelling of the three experiments are described.

3.4 The results of the modelling of the large-scale experiments (subtask 5.2)

In subtask 5.2, the purpose was to model some large-scale experiments done in a real repository environments in underground laboratories. This task was much more difficult than the previous one with the smaller experiments in a laboratory. There is a more complex geometry and there are uncertainties in the boundary and initial conditions and sometimes the information given by the sensors in the experiments is difficult to interpret.

In addition, for two of the experiments (CRT, Febex) it was necessary to take into account the heating of the experiment and how the temperature affects the swelling behaviour of the clay.

In subtask 5.2 the following modelling teams took part in the modelling of the different experiments:

Universitat Politècnica de Catalunya (UPC): EB
Charles University in Prague (CU)/Czech Technical University in Prague (CTU): CRT
Technical Research Centre of Finland (VTT)/University of Castilla–La Mancha (UCLM):CRT
University of Liege (ULG): EB
The Federal Institute for Geosciences and Natural Resources (BGR): Febex
Lithuanian Energy Institute (LEI): Febex
Clay Technology AB (ClayTech): Febex, CRT
École polytechnique fédérale de Lausanne (EPFL): Febex
Imperial College London (ICL): Febex, CRT
Quintessa: Febex

The modellers have throughout the project had a diversity of modelling approaches. This is one of the strengths of the Beacon project and the different approaches have been applied to the test cases of task 5.2.

It is interesting that even the modelling groups that started the project with limited modelling tools and experience have been able to produce some very good results during this stage of the project. This is an important contribution of the project which shows the beneficial returns for all participants. This task is a perfect illustration of the progress made by all partners in terms of improving the models and constituent laws or developing skills.

As it was observed in the previous subtask, that it is necessary to look at two aspects of the experiments, the transient phase and the end state. The models used by the modellers in WP3 have sometimes had difficulties in reproducing the evolution of all the physical parameters during the transient phase, even if they in most cases were better at reproducing the trend and the magnitude of the measured parameters. On the other hand, the final states were in most cases quite well modelled, both regarding the dry density distribution and the final distribution of water in bentonite materials.

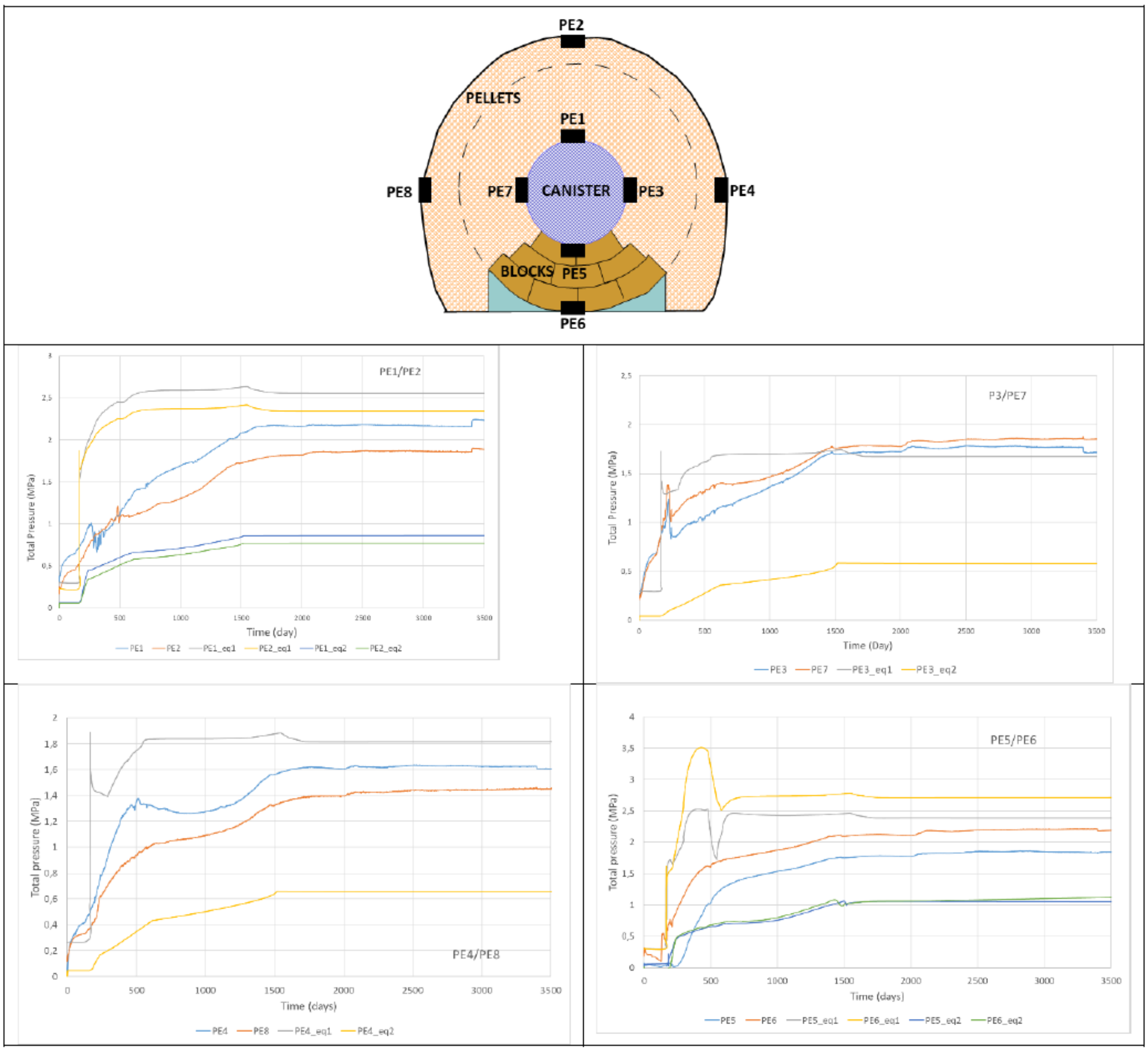
Most of the modellers that took part in subtask 5.2 used a double porosity model to represent the mechanical behaviour of bentonite materials. This means that both the porosity inside the clay grains and the porosity between clay grains, and how they connect, were modelled. The modellers used a different model on a micro (clay particle) and macro (entire sample/buffer) levels and also a model for how the two levels connect. This approach was important to try and correctly simulate the clay evolution during hydration and to predict the final state.

In this section some results are shown for each experiment.

3.4.1 Experiment 2a “EB - Engineered Barrier Emplacement Experiment”

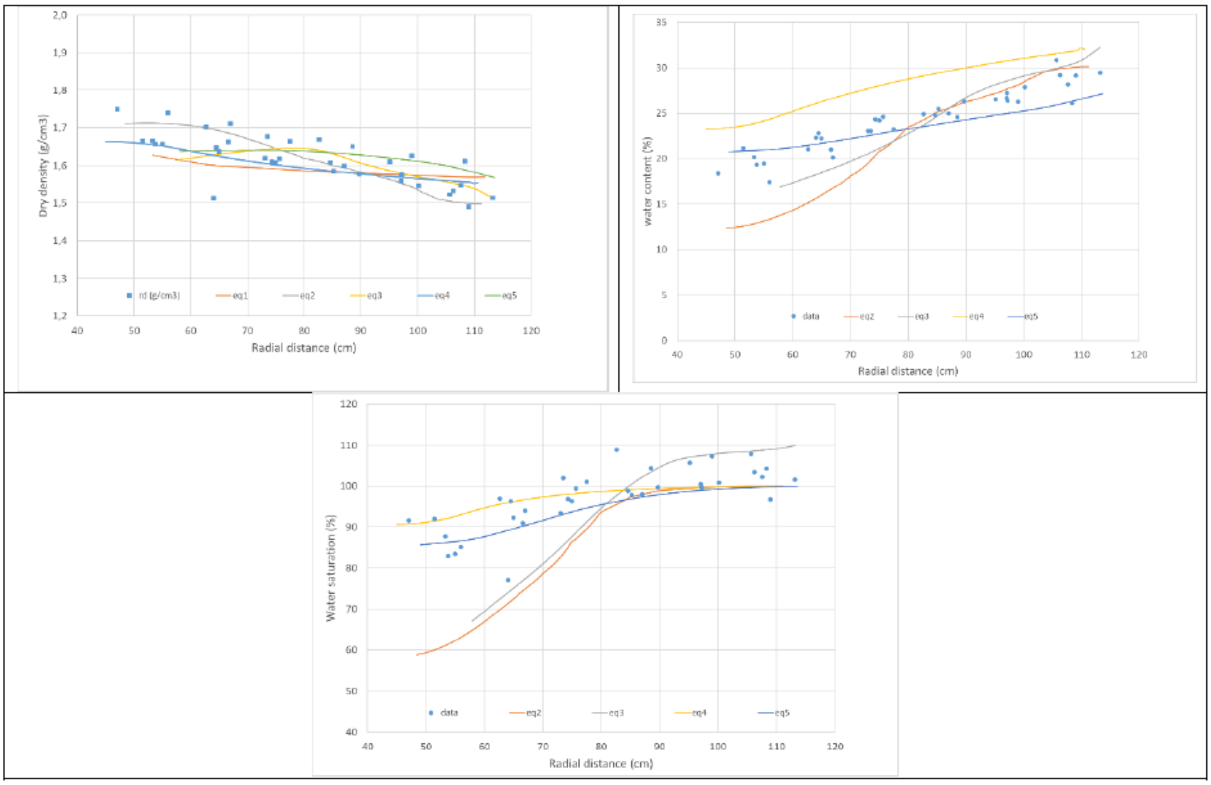
The EB experiment was only modelled by the groups UPC and ULG. The results obtained by both modelling groups are in good agreement with the measured values in the actual experiment. All the measurements could not be reproduced with the same accuracy – especially during the transient phase – but this was foreseen.

An example of modelling results is shown in the figure below for the total pressure at several locations. The actually measured values for the pressure at different points are without the “eq” behind and the modelled values are with the “eq” behind for different models.



3.4.2 Experiment 2b "FEBEX - Full-scale Engineered Barrier Experiment in Crystalline Host Rock"

The large amount of data available from the FEBEX experiment and the many different modelling results produced by the participants of the FEBEX part of the modelling tasks means that it is difficult to describe all the results. Just one example is shown in the figure below.

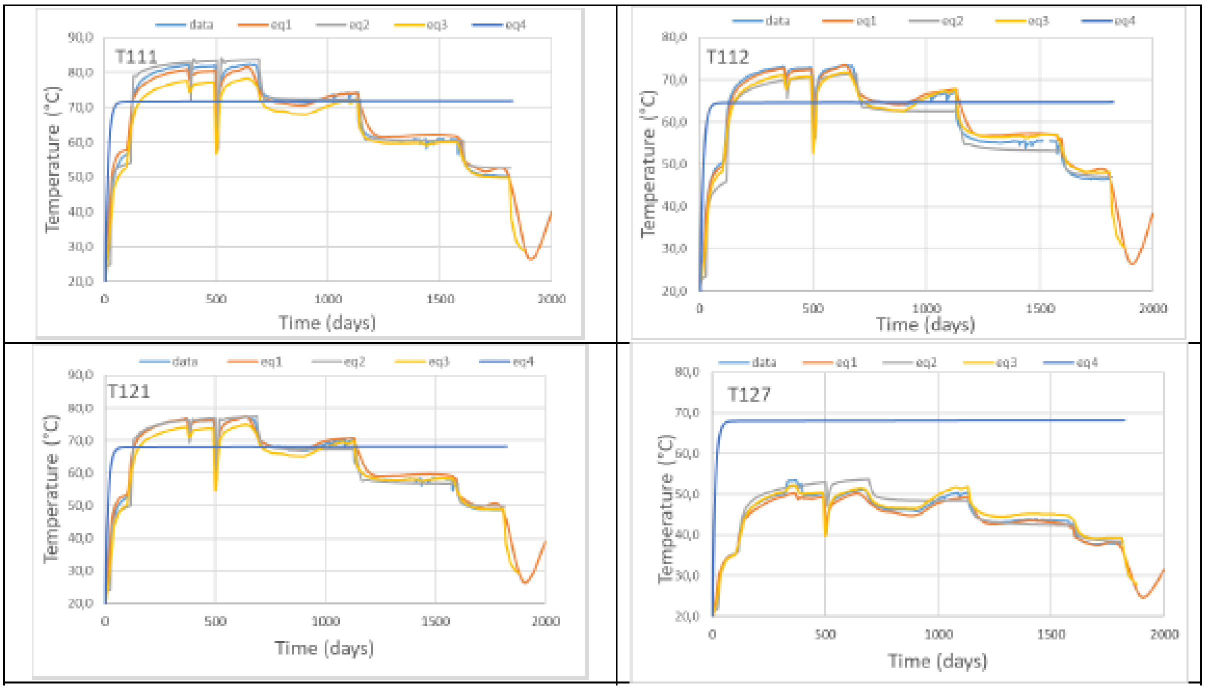


What is shown are the values for the dry density, water content and water saturation profiles after dismantling section S49 of the experiment. The measured values are the blue dots and the differently coloured lines are the results of different models used.

3.4.3 Experiment 2c "CRT - Canister Retrieval Test"

The CRT experiment was modelled by three groups with Clay Technology using two different models. This experiment requires temperature to be taken into account. This introduces a new complexity in the physical processes and challenges in the models.

The main difficulties in reproduction of the data from the experiment in the models was in the stress/pressure measurements. Temperature values were easier to model. The figure in the next page presents the evolution of temperature at several locations in the buffer: at half-height of the canister (T111, T112 and T121), on the top of the canister (T127) and above it (T129). The data is the light blue line, and the other lines are different models. Most models are very successful in modelling the development of the temperature at the different points.


T111
T112
T121
T127
data
eq1
eq2
eq3
eq4
Temperature (°C)
Time (days)