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China-Mock-up data analysis report

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CNNC Beijing Research Institute of Uranium Geology

CONTENTS

ABSTRACT

Deep geological disposal is internationally recognized as a feasible and effective way to dispose of High-level Radioactive Waste (HLW). Repositories are generally designed on the basis of a multiple barrier system concept, which is composed of engineered and natural barriers between the HLW and the biosphere. According to the preliminary concept of the HLW repository in China, a large-scale mock-up facility, named China-Mock-up was constructed in the laboratory of BRIUG, a heater, which substitutes a container of radioactive waste, is placed inside the compacted GMZ-Na-bentonite blocks and pellets. Water inflow through the barrier from its outer surface is to simulate the intake of groundwater.

The current experimental data of the facility is reported and analyzed in the report. The real-time data acquisition and monitoring system has recorded all the measurement data from 1st April 2011 to 11th December 2013. Data analysis of China-Mock-up before dismantling is reported. It is revealed that the saturation process of the compacted bentonite is strongly influenced by the competitive mechanism between the drying effect induced by the high temperature and the wetting effect by the water penetration from outer boundary. For this reason, the desiccation phenomenon is observed in the zone close to the heater. The displacement of the heater and the stress evolution is also mentioned.

KEYWORDS: High-level radioactive waste (HLW), geological repository, bentonite, lab testing, thermo-hydro-mechanical-chemical (THMC), data analysis

1. Background

Deep geological disposal is internationally recognized as a feasible and effective way to dispose of High-level Radioactive Waste (HLW). Repositories are generally designed on the basis of a multiple barrier system concept, which is composed of engineered and natural barriers between the HLW and the biosphere. In the life cycle of the high-level radioactive waste disposal project, the buffer/backfill will be subjected to temperature increase due to heat emitted by the waste and hydration from water coming from the adjacent rocks (Gens et al, 2010). The buffer/backfill material is designed to stabilize the repository excavations and the coupled thermo-hydro-mechanical-chemical (THMC) conditions, and to provide low permeability and long-term retardation (Wang, 2010). A bentonite-based material is often proposed or considered as a possible buffer/backfill material for the isolation of the HLW.

To understand the complex behaviors of the buffer/backfill material located in the coupled THMC environment, in recent years, there has been an increasing interest internationally in the construction of large-scale mock-up experimental facilities in the laboratory and in situ such as the Long Term Experiment of Buffer Material (LOT) series at the Äspö HRL in Sweden (Karnland et al, 2000), FEBEX experiment in Spain (Lloret & Villar, 2007), OPHELIE and PRACLAY heater experiments in Belgium (Li et al, 2006, 2010, Romero & Li, 2010) and Mock-Up-CZ experiment in Czech Republic (Pacovsky et al, 2007) etc. The experimental results and achievements obtained from these large-scale experiments provide important references on investigating the behaviors of bentonite under simulative nuclear radioactive waste repository conditions.

At the present stage, the Gaomiaozi (GMZ) bentonite is considered as the candidate buffer and backfill material for the Chinese repository. Lots of basic experimental studies have been conducted and favorable results have been achieved (Liu et al., 2003; Liu & Cai, 2007a; Ye et al. 2009a). In order to further study the behavior of the GMZ-Na-bentonite under relevant repository conditions, a mock-up facility, named China-Mock-up, was proposed based on a preliminary concept of HLW repository in China (Liu et al., 2011). The experiment is intended to evaluate THMC processes taking place in the compacted bentonite-buffer during the early phase of HLW disposal and to provide a reliable database for numerical modeling and further investigations.

The overall approach is based on performing experiments according to the needs for additional studies on key processes during the early EBS evolution. The study will make use to the extent possible of on going experiments being conducted in the laboratory of Beijing Research Institute of Uranium Geology (BRIUG).

2. The T-H-M-C China-Mock-Up experiment

The China-Mock-up is mainly made up of eight components, namely compacted bentonite blocks, steel tank, heater and corresponding temperature control system, hydration system, sensors, gas measurement and collection system, real-time data acquisition and monitoring system (Fig. 1).

It is assumed that the duration of the China-Mock-up experiment will not be shorter than 4 years. Then, after a cooling period, the experiment will be dismantled and all the available results will be collected and evaluated.

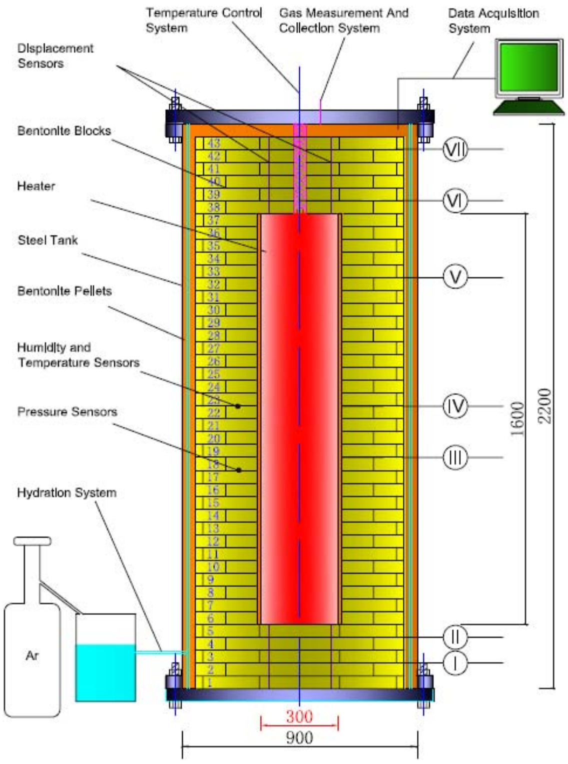

Figure 1 Sketch of the China-Mock-up facility (unit: mm).

3. Experiment results of China-Mock-up

The China-Mock-up is equipped with 10 different types of sensors to monitor the comprehensive performances of GMZ Na-bentonite under coupled THMC conditions. The sensors placed in the bentonite have provided reasonable and consistent recordings, and continue to do so in the next operation phase of the experiment. The experimental results of characterization performed concerning coupled T-H-M properties are reported and analyzed in this chapter. The time variation of the water consuming, relative humidity, temperature, and swelling pressured of the compacted bentonite are studied. The real-time data acquisition and monitoring system has recorded all the measurement data from 1st April 2011 to 11th December 2013.

3.1 Mock-up operation

The China-Mock-up experiment was assembled completely on 10th September 2010. After a pre-operational phase, the real-time data acquisition and monitoring system has recorded all the measurement data from1st April 2011, and the data identified as “day 0” on the time scale.

3.1.1 Heating

The heater was switched on to reach a low temperature at 30°C from 1st April 2011 until 8th July 2011. The T-H-M-C experiment was commenced on 8th July 2011, then the power rises at 1°C/d to reach a maximum temperature at 90°C. Finally, the heating system was switched to the constant temperature control model automatically at 90°C. The heating phase with the time is illustrated in Fig. 2.

3.1.2 Hydration

The hydration process was carried out with Beishan groundwater. In order to avoid potential damage to the sensors by a sudden saturation process, the hydration was initially controlled by a water injection rate which was increased gradually from 400g/day to 1500 g/day in the first stage, and the injection was controlled by a constant pressure at 0.2Mpa from 25th August 2013. The water consuming with the time is illustrated in Fig. 2. To mentioned here, the water injection was preformed artificially every day in the first stage, and the platforms illustrated in Fig. 2 indicates no water supply during the corresponding period of time.

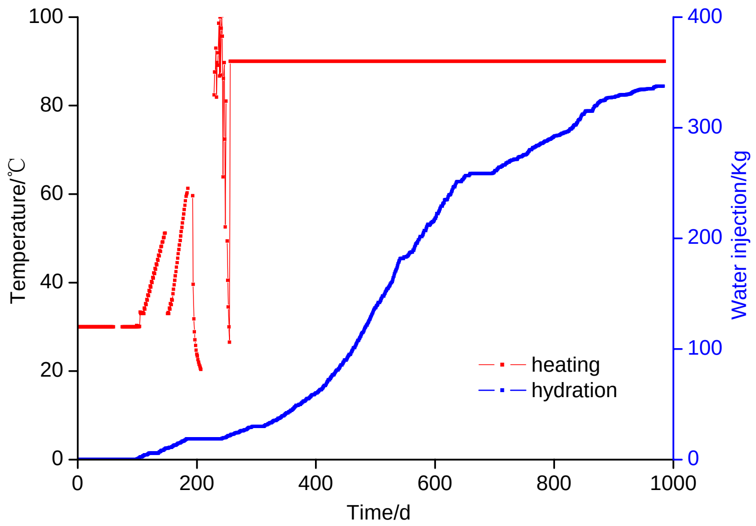

Figure 2 Mock-up operation.

3.2 Temperature

The temperature variation with time in different sections of the facility is illustrated in Fig. 3-9. As the beginning of the test, the temperature is increased globally with time, especially for the sensors close to the heater, the temperature has decreased distance from the heater. Due to the interrupt of electricity power, some fluctuation can be observed. It is noticed that the change of seasons has a significant effect on temperature, but unfortunately some of the sensors are out of work because of the harsh environment.

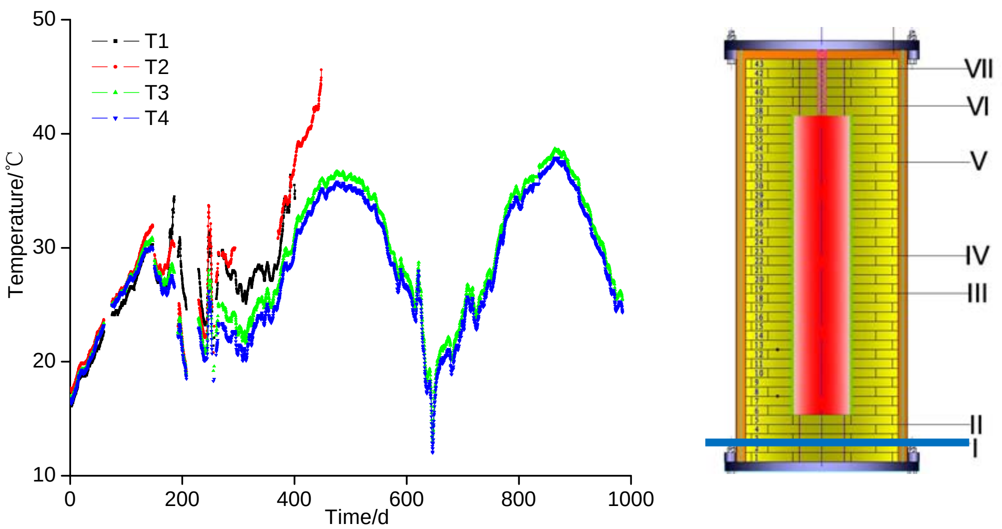

Figure 3 Temperature variation with time at section I.

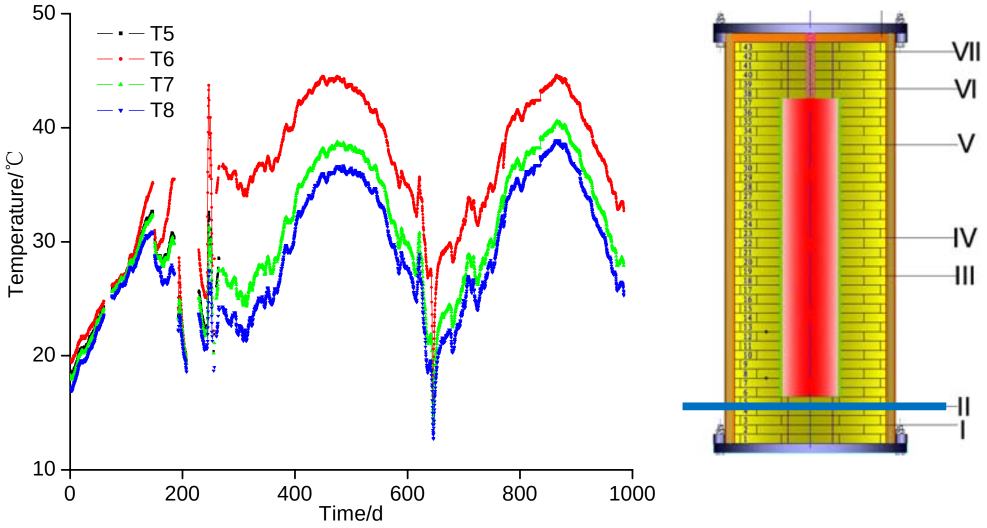

Figure 4 Temperature variation with time at section II

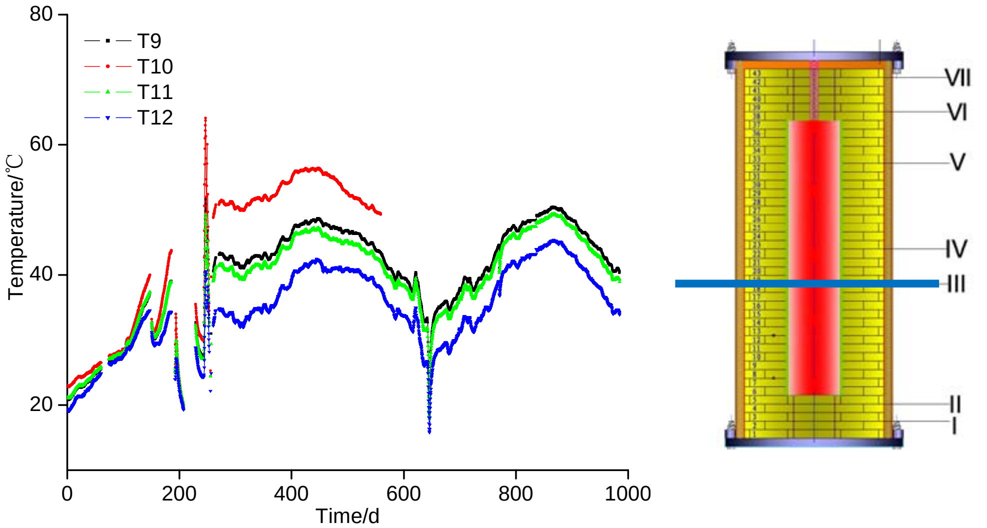

Figure 5 Temperature variation with time at section III.

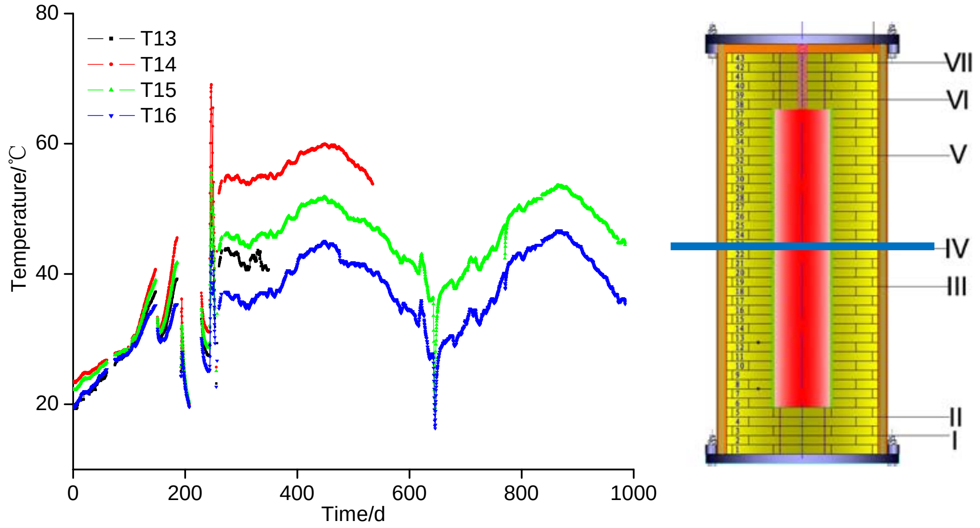

Figure 6 Temperature variation with time at section IV.

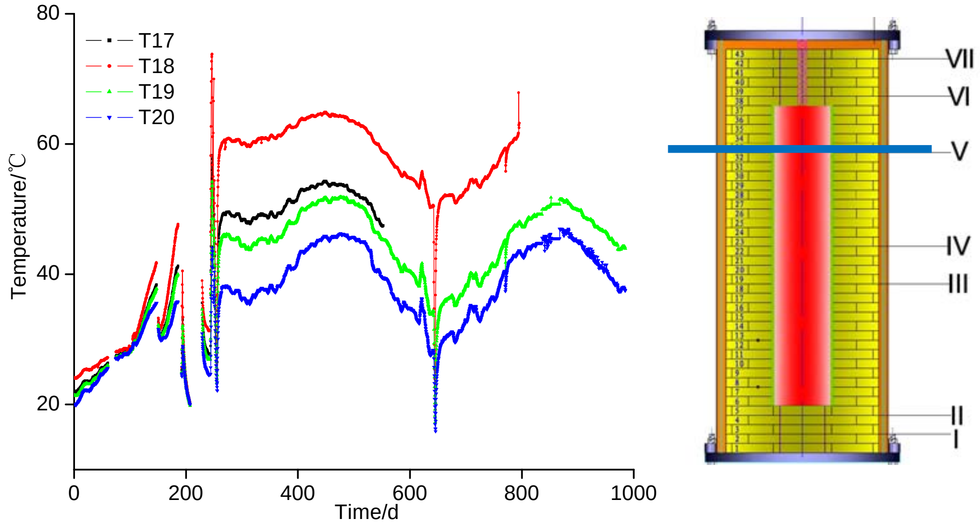

Figure 7 Temperature variation with time at section V.

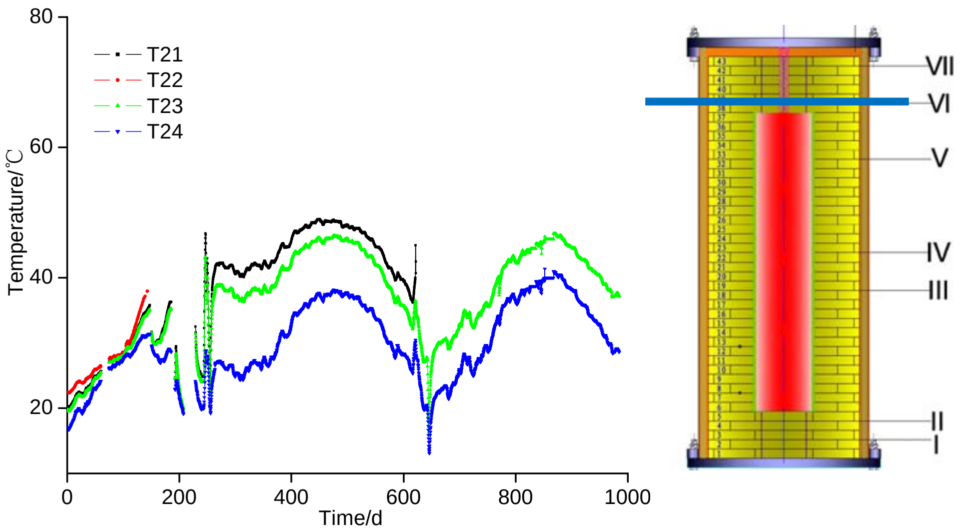

Figure 8 Temperature variation with time at section VI.

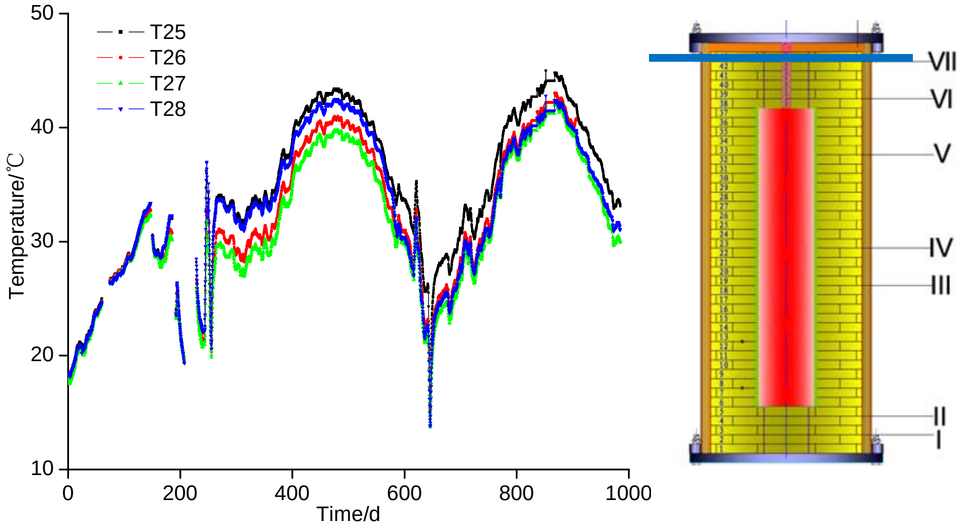

Figure 9 Temperature variation with time at section VII.

3.3 Relative humidity

Fig. 10 and Fig. 11 present the relative humidity variation with time at the bottom of the mock-up facility. As illustrated in the figures, the compacted bentonite is progressively saturated with time in section I and II, and the distance to the outer boundary has a significant influence on the saturation velocity. In the area close to the outer boundary, the compacted bentonite is almost saturated after 200 days. Due to the extremely low permeability of compacted bentonite, the variation of relative humidity is limited in the central part of the facility. However, the bentonite in section I and II is totally saturated with the increase of the injection water after 600 days.

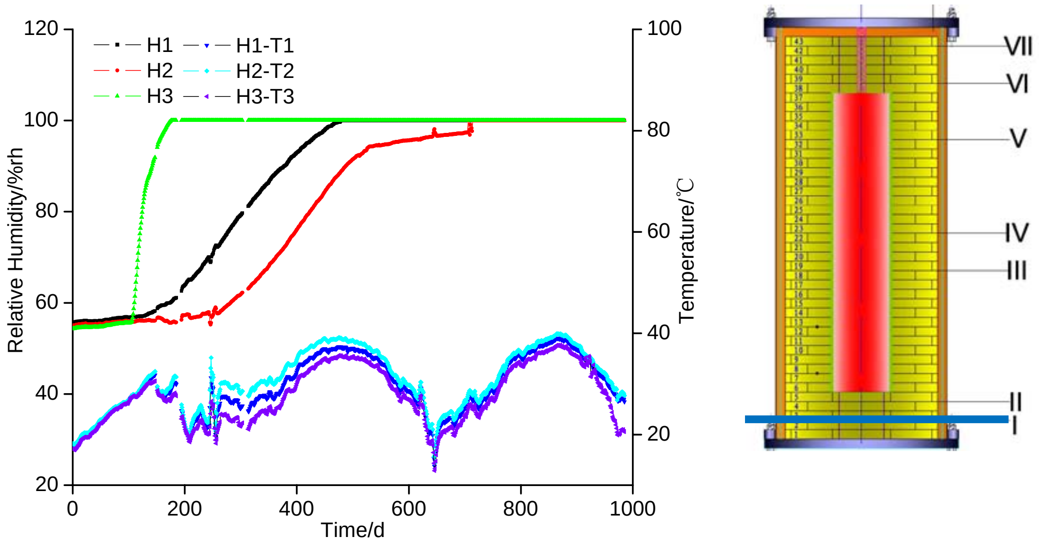

Figure 10 Relative humidity distribution at section I.

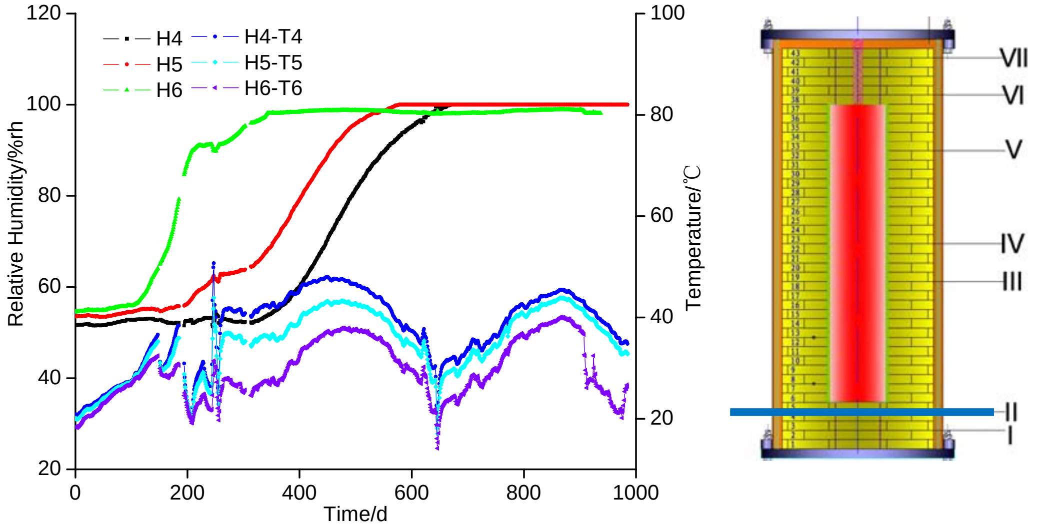

Figure 11 Relative humidity distribution at section II.

Fig. 12-14 presents the variation of relative humidity with time in the sections III-V. It can be noticed that, the variation of relative humility in this area is much more complex. In the zone close to the heater, the decrease of relative humidity can be observed. This phenomenon can be attributed to the competitive mechanism between the saturation process induced by the water penetration and the drying effect by the high temperature of the electrical heater. The desaturation phenomenon indicates that, due to the low permeability of the compacted bentonite, the drying effect is dominant at the beginning in the zone close to the heater. Then with the increase of the injection water, the saturation process is dominant after 500 days, and the humility is increased gradually.

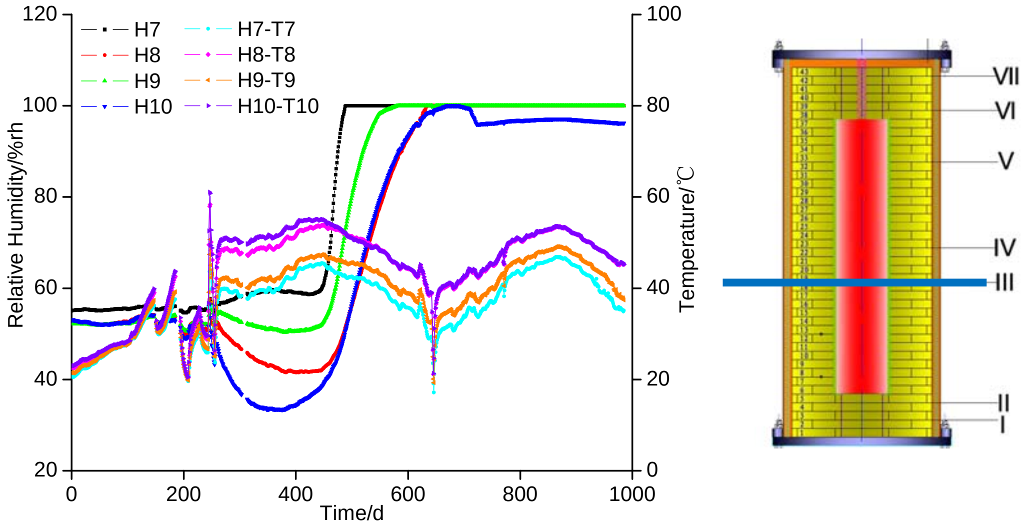

Figure 12 Relative humidity distribution at section III.

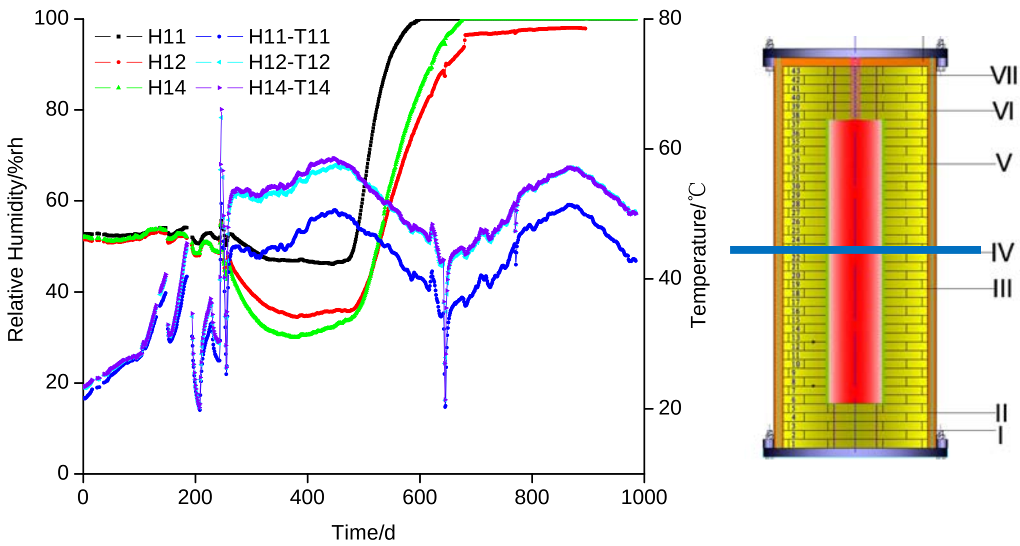

Figure 13 Relative humidity distribution at section IV.

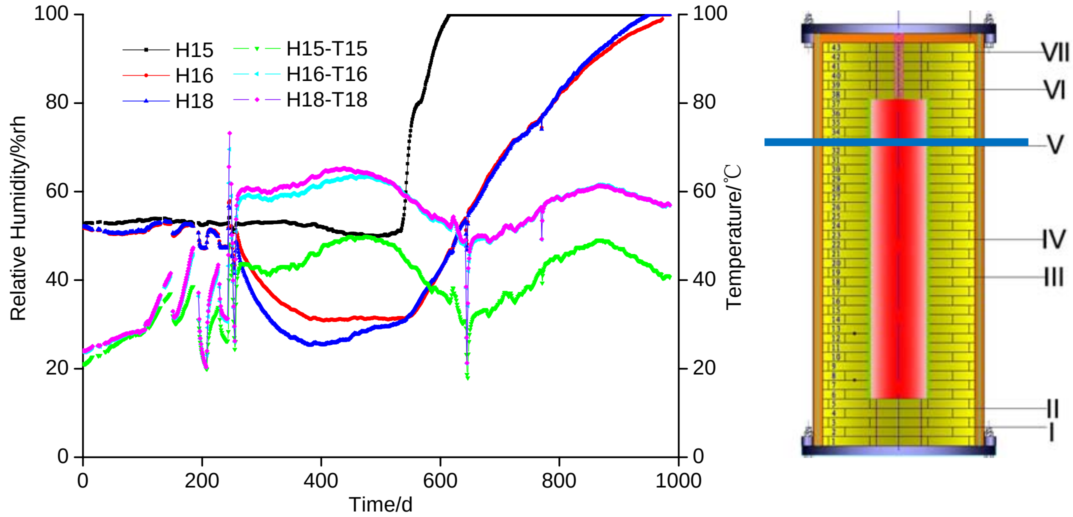

Figure 14 Variation of relative humidity at section V.

The variation of relative humidity with time on the top of the China-mock-up facility is illustrated in Fig. 15-16. Thanks to the longer distance to the heater, it can be noticed that the desiccation induced by the high temperature is less evident in this area. However, the desaturation phenomenon is still noticed in the central part of the section with the increase of temperature in this area. In addition, the relative humidity is sensitive to the fluctuation of the temperature.

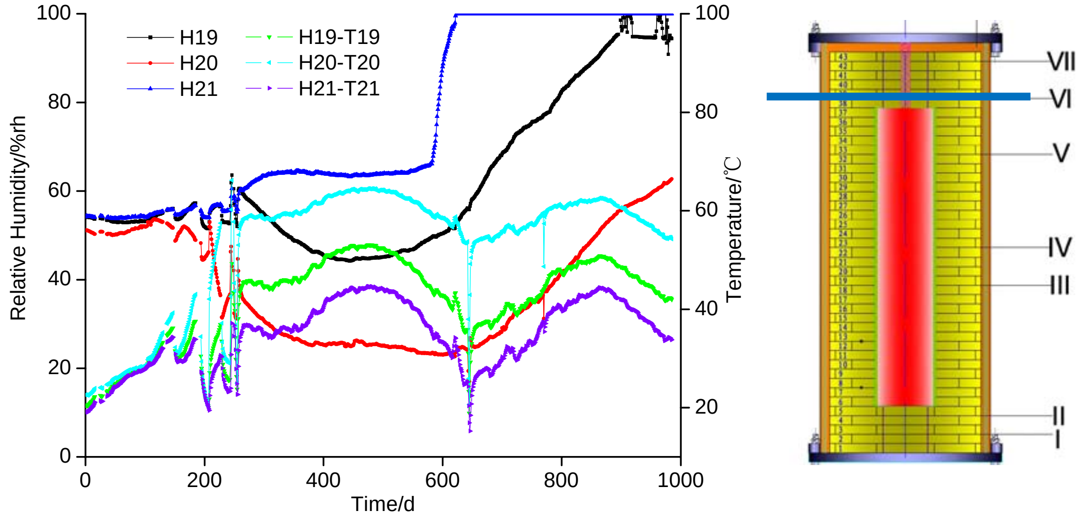

Figure 15 Variation of relative humidity with time at section VI.

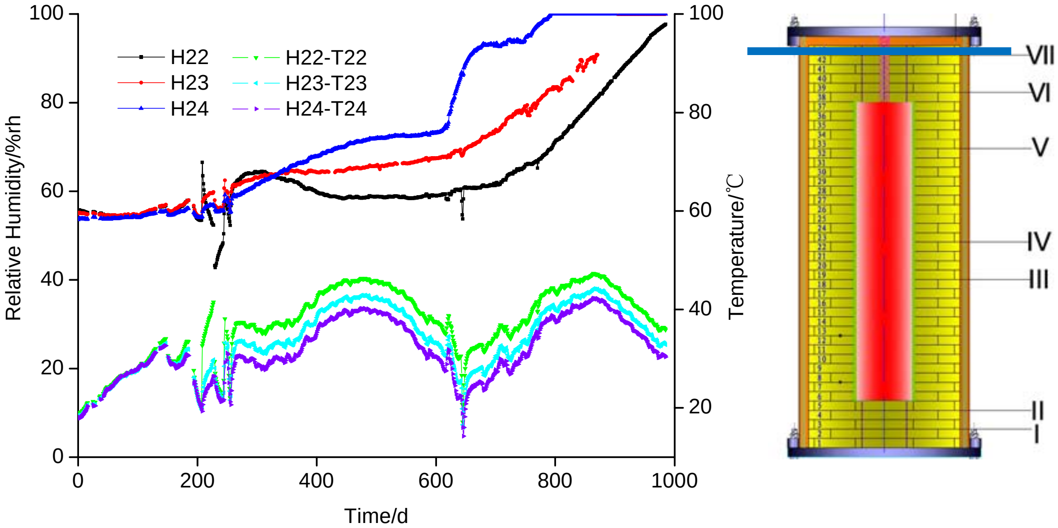

Figure 16 Variation of relative humidity with time at section VII.

3.4 Vertical displacement of the canister

In order to investigate the potential movement of canister in long-term, six LVDT sensors are installed in the China-Mock-up test to monitor the vertical displacement of the electrical heater. Three of them are installed at the bottom of the heater, and the others are installed in the upper part. The variation of the vertical displacement of the heater is presented in Fig. 17. It can be noticed that, the electrical heater moved upward after a stable phase. This phenomenon could be attributed to the thermal expansion of compacted bentonite, and the increased swelling of bentonite induced by the water penetration from outer boundary. In the proceeding of the test, the displacement became more and more flat. However, unfortunately the sensors in upper part are out of work because of the harsh environment after 800 days.

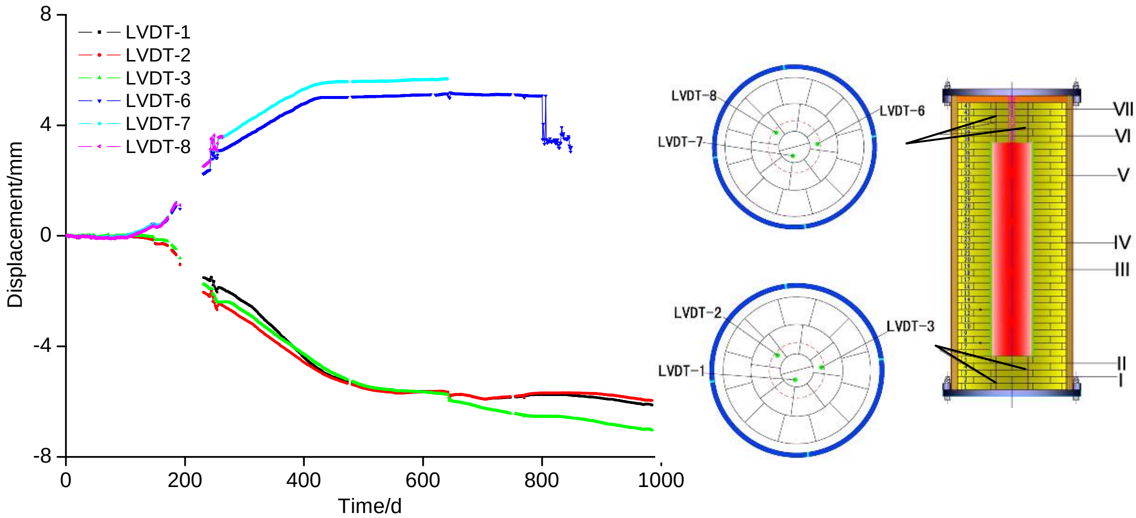

Figure 17 Vertical displacement of the heater with time.

3.5 Stress evolution

In the China-Mock-up facility, the stress variation of the compacted bentonite is influenced by several mechanisms, including the thermal expansion induced by the high temperature, the swelling pressure generated by the water penetration, and etc. The stress evolutions are presented in Fig. 18-24. As illustrated in the figures, with the increase of the injection water, the saturation process is dominant, and the stress in this area is increased gradually to 2.0Mpa especially in the outer boundary. In other sections, almost no significant variation of stress in compacted bentonite is observed up to now near the heater. This could be attributed to two reasons: at first, the saturation process is relatively limited near the heater; and the second reason is the initial space between the sensors and the blocks of the compacted bentonite. It can be noticed that there are some fluctuation in hot section III-V because of the power supply incident.

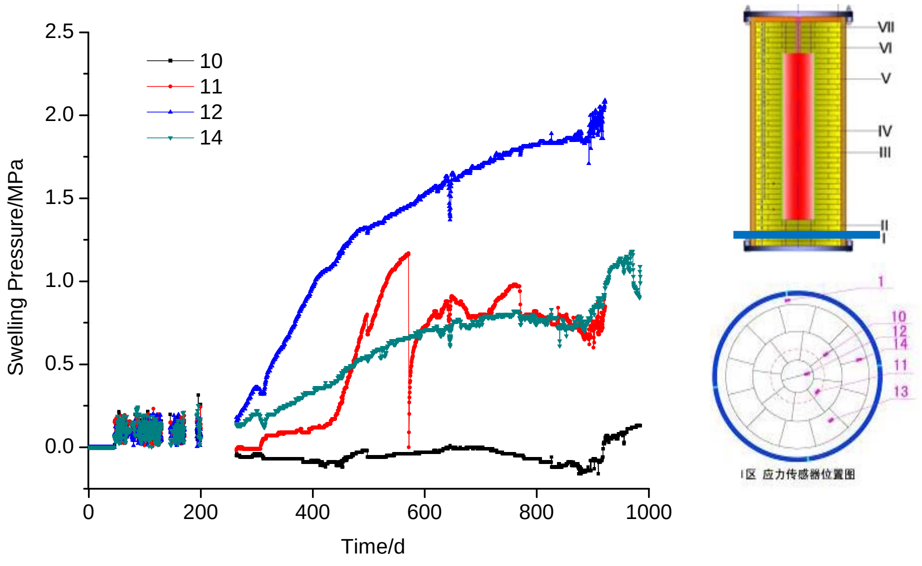

Figure 18 Stress evolution at section I of China-Mock-up.

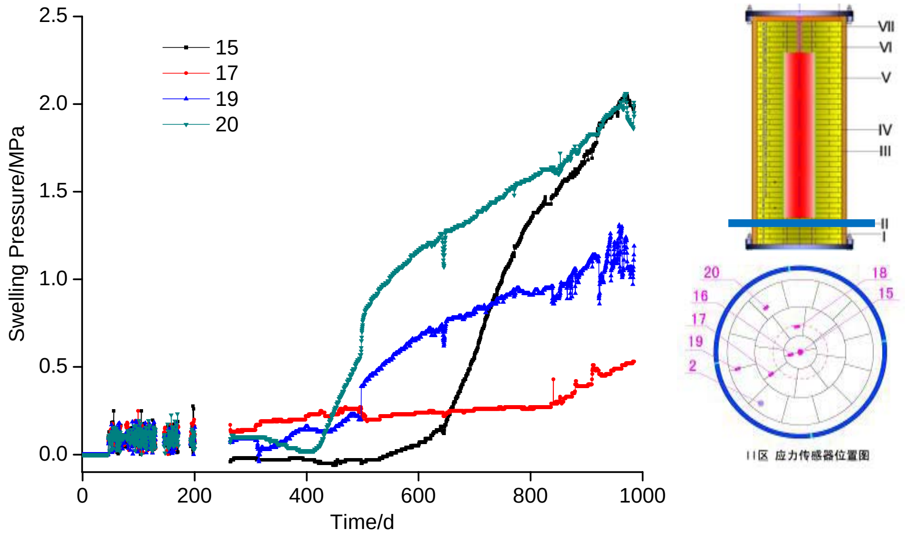

Figure 19 Stress evolution at section II.

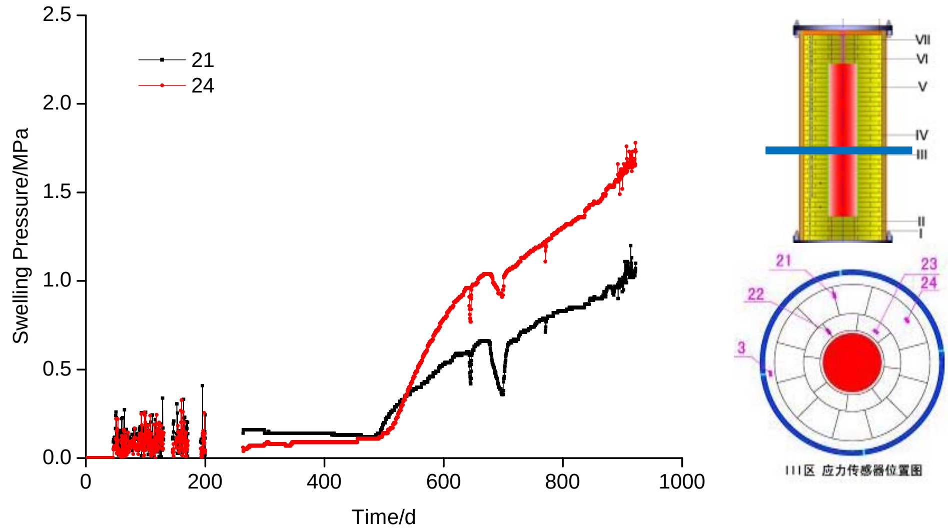

Figure 20 Stress evolution at section III.

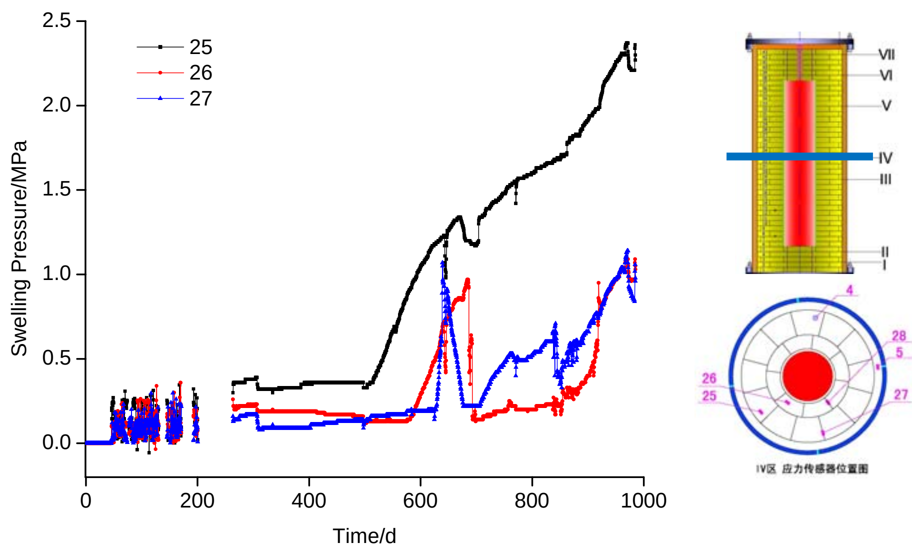

Figure 21 Stress evolution at section IV.

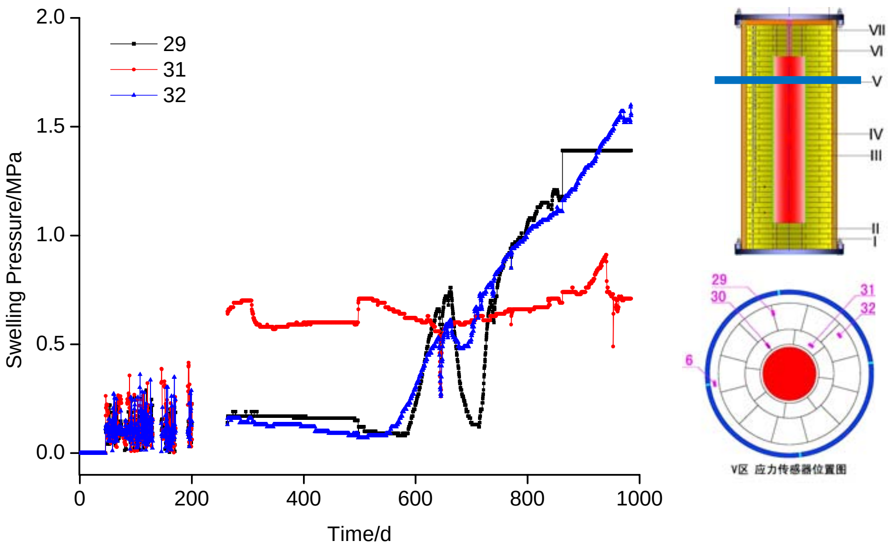

Figure 22 Stress evolution at section V.

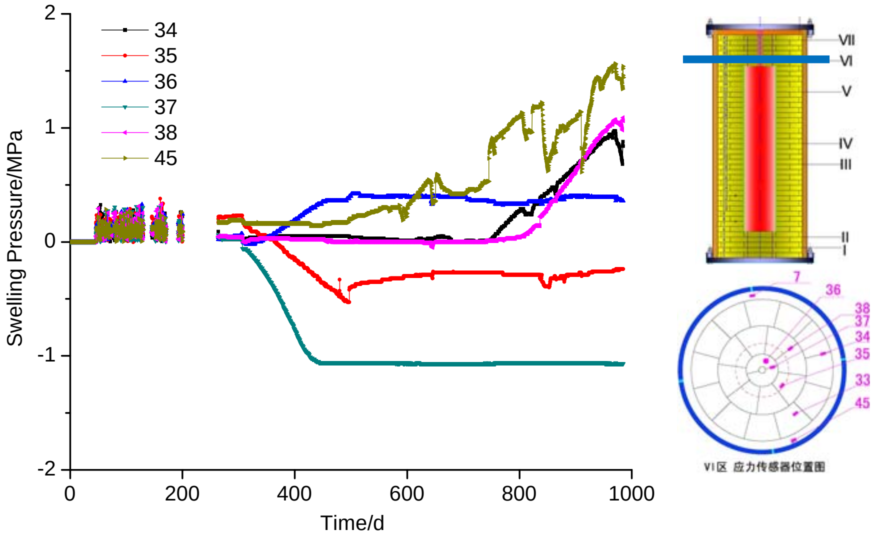

Figure 23 Stress evolution at section VI.

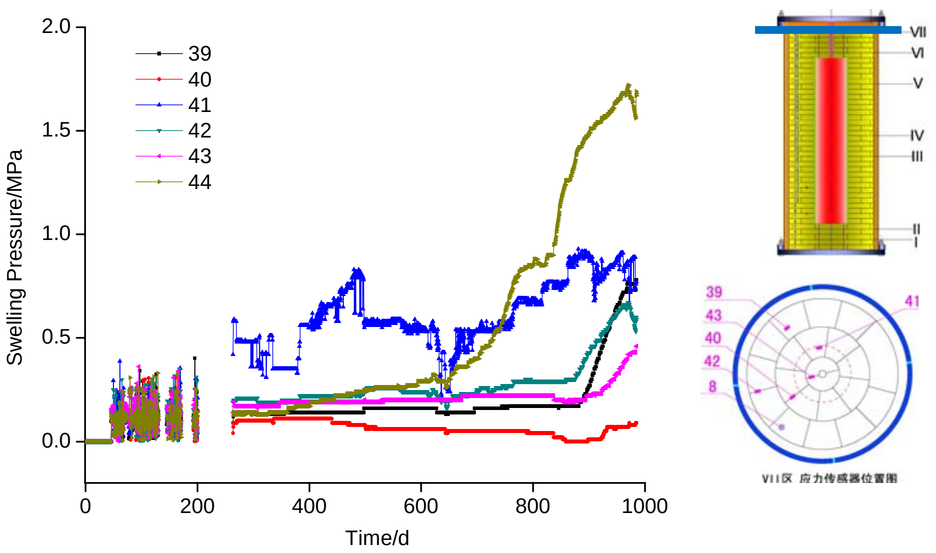

Figure 24 Stress evolution at section VII.

4. Conclusion

The buffer material is one of the main engineered barriers for the HLW repository. In order to study the behavior of the compacted GMZ-Na-bentonite under coupled THMC conditions, a large-scale mock-up facility, China-Mock-up based on a preliminary concept of HLW repository in China, has been designed and constructed in the laboratory of BRIUG.

The current experimental data is presented in the report, including the variation of temperature, relative humidity, stress and displacement etc. According to the analysis of the experimental, some conclusions are obtained and summarized as follows:

(1) The experimental data indicates that the saturation process of the compacted bentonite is strongly influenced by the competitive mechanism between the drying effect induced by the high temperature and the wetting effect by the water penetration from the outer boundary. For this reason, the desiccation phenomenon is observed in the zone close to the heater.

(2) Except for the temperature change induced by the interruption of electrical power supply, the temperature within the bentonite has increased with time. Considering the saturation may change the thermal conductivity, the temperature distribution is influenced by the coupling mechanism between the thermal conduction and the saturation process in the mock-up test. However, it is noticed that the change of seasons has a significant effect on

temperature.

(3) For China-mock-up test the upward displacement of the heater suggests that the thermal expansion and saturation process of the buffer material may influence the stability of canister in the long-term, which should be considered in the design of the repository. It has to be mentioned here, the displacement of electrical heater is strongly influenced by the experimental configuration and boundary conditions. Considering the repository conception in China is not finalized yet, the similar weight of the canister and electrical heater cannot be assumed. Therefore, this result is not totally representative of the real ones, and further validation is still necessary.

(4) In the China-Mock-up facility, the stress variation of the compacted bentonite is influenced by several mechanisms, including the thermal expansion induced by the high temperature, the swelling pressure generated by the water penetration, and etc.

(5) Based on the analysis of the current experimental data, the China-Mock-up test is considered as a source of valuable data to improve the knowledge of the THM process in the EBS, and to establish the reliable numerical method to predict the THM coupled behavior of EBS in long-term. With the progress of the experiment, the conclusions achieved will be further examined and refined.

The China-Mock-Up experiment is an important milestone of the buffer material study for HLW disposal in China. The observed THMC processes taking place in the compacted bentonite-buffer during the early phase of HLW disposal can provide a reliable database for numerical modeling and further investigations of EBS, and the design of HLW repository.

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