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Short- and long-term behaviors of drifts in the Callovo-Oxfordian claystone at the Meuse/Haute-Marne Underground Research Laboratory

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ABSTRACT

Since 2000, the French National Radioactive Waste Management Agency (ANDRA) has been constructing an Underground Research Laboratory (URL) at Bure (east of the Paris Basin) to perform experiments in order to obtain in situ data necessary to demonstrate the feasibility of geological repository in the Callovo-Oxfordian claystone. An important experimental program is planned to characterize the response of the rock to different drift construction methods. Before 2008, at the main level of the laboratory, most of the drifts were excavated using pneumatic hammer and supported with rock bolts, sliding steel arches and fiber shotcrete. Other techniques, such as road header techniques, stiff and flexible supports, have also been used to characterize their impacts. The drift network is developed following the in situ major stresses. The parallel drifts are separated enough so as they can be considered independently when their hydromechanical (HM) behaviors are compared. Mine-by experiments have been performed to measure the HM response of the rock and the mechanical loading applied to the support system due to the digging and after excavation. Drifts exhibit extensional (mode I) and shear fractures (modes II and III) induced by excavation works. The extent of the induced fracture networks depends on the drift orientation versus the in situ stress field. This paper describes the drift convergence and deformation in the surrounding rock walls as function of time and the impact of different support methods on the rock mass behavior. An observation based method is finally applied to distinguish the instantaneous and time-dependent parts of the rock mass deformation around the drifts.

1. Introduction

Clay formations in their natural state exhibit very favorable conditions for repository of radioactive waste, as they generally have a very low hydraulic conductivity, small molecular diffusion and significant retention capacity for radionuclide. These properties provide favorable conditions for repository of radioactive wastes.

In France, in order to demonstrate feasibility of a radioactive waste repository in claystone formation, the French National Radioactive Waste Management Agency (ANDRA) started in 2000 to build the Meuse/Haute-Marne Underground Research Laboratory (URL) at Bure (nearly 300 km east of Paris, Fig. 1). The host formation consists of a claystone (Callovo-Oxfordian argillaceous rock – COX) lying between depths of 420 m and 550 m (Fig. 1). The COX claystone is overlain and underlain by poorly permeable carbonate formations.

The first objective of the research program was to characterize the confining properties of the clay through in situ hydrogeological tests, chemical measurements and diffusion experiments and to demonstrate that the construction and operation of a geological disposal will not introduce pathways for radionuclide migration (Delay et al., 2007). In 2005, ANDRA demonstrated the feasibility of repository in a deep claystone layer (ANDRA, 2005).

Since 2006, further researches are ongoing in the URL to increase the knowledge on the rock properties, to test and optimize repository concepts at full scale on site. The excavation worksite in the host layer is a scientific experimentation in itself to characterize the impacts of digging, to understand the hydro-mechanical (HM) behavior of the claystone and to study the excavation damaged zone (EDZ). To know, to control and to be able to remediate the impact of the excavation in terms of EDZ are the main issues for

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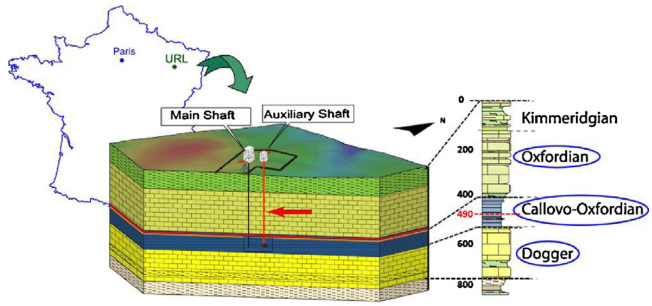

Fig. 1. Meuse/Haute-Marne URL: location and geology (ANDRA, 2005).

the repository safety (Bauer et al., 2003; Blümling et al., 2007). Furthermore, understanding the impact of the support system and excavation methods on the HM behavior of the drift at short- and long-term is a key issue for optimizing the support designs.

An extensive program of experimental studies was planned to characterize the response of the host rock to different shaft and drift excavation/construction methods. The study of the formation and evolution of the EDZ around the structures is a main part of the program. Numerous experiments and direct measurements have been performed in the laboratory drifts during their construction. Fig. 2 presents the extent of the URL until 2015. Indeed, the construction of about 150 m of new galleries is planned each year.

The main level of the URL at −490 m is the most representative level of the future disposal in terms of mechanical behavior. An important experimental program is planned to characterize the response of the rock to different drift construction methods (Fig. 2) at the main level. Before 2008, most of the drifts have a horseshoe shape cross section (17 m^2 area, with $r \approx 2.3$ m) excavated with a pneumatic hammer. Since 2008, a counter vault has been used to reduce uplift of the foot plate (drift GED). The spans of the excavation are mainly 1 m long and are immediately covered with 3–5 cm of fibered shotcrete. Excavated zone was supported immediately by bolts and sliding arches; and 10 cm thick layer of shotcrete was set in place. Martin et al. (2010) presented the efficiency of the different support elements – at the front and at the faces – under different digging configurations during the laboratory construction. Other excavation technique using a road header has been tested with the same support and with other types of supports. In drift GCS, the support is ensured by an 18 cm thick fiber reinforced shotcrete shell, interrupted by 12 yieldable concrete wedges (hiDCon®); completed by a crown of 12 HA25 radial bolts of 3 m length every meter. Drift GCR was built in a similar way as drift GCS and left "unsupported" for 7 months. A concrete lining of a 27 cm thick was casted in place at this time. Two types of concretes were used, namely C60/75 and C37/40 to obtain different stiffnesses and strengths.

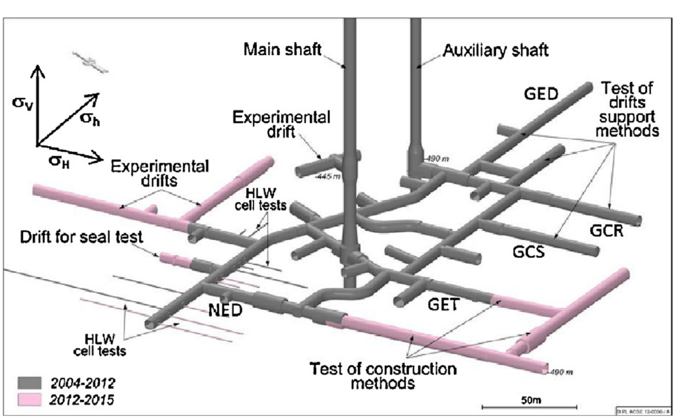

Fig. 2. Meuse/Haute-Marne URL drifts network (gray: already excavated, pink: to be excavated).

A complete description of the work can be found in Bonnet-Eymard et al. (2011). For BPE experiment, excavation was performed with the pneumatic hammer and support is made of 4-layer fiber reinforced shotcrete (12 cm thick) emplaced after the four successive excavation steps. A thick lining of 45 cm is emplaced at a distance of maximum one diameter (d = 6.2 m) from the excavation front. Four above-mentioned drifts are illustrated in Fig. 3.

These various configurations, constructed in different directions, provide insights into the influence of the structure geometry, the support system, the excavation methods and the natural stress state, and on the drift HM behavior. The in situ experiments in parallel drifts are performed considering enough spacing to avoid any mechanical interaction.

This paper presents the results of the mine-by experiments performed around various drifts at the main level of the URL, and discusses the observation and link between the deformation and the observed excavation induced fractures. Pore pressure evolution is not presented and discussed in the paper.

2. Callovo-Oxfordian claystone and in situ stress state

2.1. In situ stress state

At the Meuse/Haute-Marne URL, the anisotropic stress state of the claystone was determined by Wileveau et al. (2007). The major stress (σ_H) is horizontally oriented at NE150°. The vertical stress (σ_v) is nearly equal to the horizontal minor one (σ_h):

$$\sigma_v = \rho g Z \tag{1}$$

$$\sigma_H = \sigma_v \tag{2}$$

where Z is the depth, ρ is the density, and g is the gravity.

The ratio σ_H/σ_h is close to 1.3 and varies with depth and the rheological characteristics of the respective layers.

2.2. Mineralogical composition

Mineralogical composition varies slightly within the stratigraphic levels. At the −490 m level, mineralogical study showed a rather homogeneous composition of tectosilicates (20%), carbonates (20%–25%) and clay minerals (50%–55%) together with subordinate pyrite and iron oxides (3%). The clay minerals composition is relatively constant at 55% I/S (illite–smectite interstratified minerals), 30% illite and 15% kaolinite and chlorite.

2.3. Hydro-mechanical behavior

Different laboratory tests have been conducted on core samples to obtain the HM properties of the claystone. Due to a very small mean pore diameter (about 0.02 μm), the claystone has a low permeability (5×10^{-20} to 5×10^{-21} m^2) while its average porosity varies between 14% and 21% and is equal to 18% ± 1% at the main level of the URL. That level of permeability makes the measurement of pore pressure complex during triaxial tests. Research is ongoing to get better data on that subject.

Natural water content of core samples ranges between 5% and 8%. Pore pressure at the main level (−490 m) is around 4.7 MPa.

The main features of the short-term mechanical behavior observed on the samples of claystone under triaxial tests can be summarized as follows (Fig. 4a): a linear behavior is observed under low deviator stresses; the loss of linearity of stress-lateral