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Three-dimensional and time stepping modelling of the whole Meuse Haute Marne URL

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ABSTRACT

The Meuse Haute Marne underground research laboratory of Meuse (ANDRA) is constituted by several shafts and drifts. The whole of the laboratory is mainly located in a volume of several millions cubic meters in the Callovo–Oxfordian geological layer. The shafts and the various drifts form a complex structural design. In order to see possible interference between drifts and shafts and to assess the in situ stresses in specific areas of the laboratory, a numerical study was performed to model the mechanical behaviour of the whole drifts by using a chronological sequence of the excavations, close to what was actually realised.

Numerical modelling, with considering the geometric scale of the problem, was carried out by finite elements with relatively simple constitutive models describing the argillites. It is on the one hand a linear isotropic elastic model and on the other hand a nonlinear modified associated elastic-perfectly plastic Drucker–Prager model. The different numerical problems were solved within the infinitesimal strains and displacements framework. The finite elements are tetrahedrons (with quadratic basis) which imply more than 2.5×10^6 degrees of freedom. The main interest of such a modelling on a large scale, even using a simple constitutive model, is to measure and analyse the evolution of various mechanical fields such as stresses, strains and displacements, during the time evolution of the laboratory. The excavation was performed in 26 steps based on monthly excavation rate performed in situ.

The greatest displacements are located in the vicinity of the shaft at the main level of the laboratory, where the cross section is biggest. The areas concerned by shaft–drift or drift–drift intersections are also places of high stress and strain concentration. The area disturbed by the excavation of the shafts is relatively wide. The perturbations induced by the excavation propagated preferentially in a radial direction. However, the zone of extension is relatively restricted such as the plasticity zones. This explains the observation that in the “radial” direction, the influence of the excavation decrease in $O(1/r)$ for the displacement and in $O(1/r^2)$ for the strain and stress. Thus beyond a given distance, different parts of laboratory work mechanically in a quasi independent manner.

1. Introduction

The Meuse/Haute-Marne Underground Research Laboratory (URL) is located on the eastern boundary of the Paris basin, at the border of the Champagne–Ardenne and Lorraine regions, at Bure. The French national radioactive waste management agency Andra) (Andra, 2005a,b) started in 2000 to build this URL in order to demonstrate the feasibility of a radioactive waste repository in a claystone formation (Piguet, 2001). The host formation consists of claystone (Callovo–Oxfordian argillite) layer which is 130 m thick between 420 m and 550 m deep (Andra, 2005a). The main level of the URL lies at 490 m. The Callovo–Oxfordian clays are overlain and underlain by poorly permeable carbonate formations.

The main objective of the URL during 2000–2006 period was the in situ characterization of the physical and chemical properties of this rock. This involved achieving a level of knowledge that may be used to develop disposal designs and to perform safety studies. The confining properties of the clay were studied by in situ hydrogeological experiments, chemical measurements and diffusion analysis. An understanding of the fundamental physical and chemical properties and processes that govern geological isolation in clay-rich rocks has been acquired (Delay et al., 2007a). This knowledge includes both the host rocks at the laboratory site and the regional geological context.

Another aspect of the research program was to demonstrate that the construction and operation of a geological disposal

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will not create pathways which allow for the migration of radionuclides. This study involved a deep understanding of the hydromechanical behaviour, and building impacts (e.g. the excavation-damaged zone). That is why the construction of the laboratory itself serves for a research purpose by means of in situ monitoring of the excavation effects and for the construction technology optimisation.

The laboratory consists of two shafts and several drifts constructed for scientific and technical purposes. The architecture is fully described by Delay et al. (2007b). The laboratory is located within a volume of several millions cubic meters in the Callovo–Oxfordian.

Numerical modelling has been performed in order to analysis the in situ measurements, mainly the time evolution of strains and pore pressure. However, numerical models are usually focused on the specific area of the URL where instrumented boreholes have been located. For example, during the main shaft sinking a "vertical mdine by test", called REP experiment, has been performed between 460 m and 475 m deep. Measurements have been performed using sensors located in boreholes from a "niche" at 445 m (Fig. 1). In parallel to this large in situ characterization, the MODEX-REP European project (5th Euratom project MODEX-REP: FIKW-CT-2000-00029) was undertaken with the aim to develop and validate constitutive models and numerical tools able to predict the observed hydromechanical behaviour of these argillites. Most of the numerical models, like those used by Souley et al. (2006) are able to reproduce in situ measurements, but do not take into account explicitly the drift at 445 m. The two shafts and the various drifts form a geometrically complex structure. Two questions appear: It is interesting or necessarily to understand the effect of this drifts network on stresses distribution and to evaluate accurately the stress state at the URL main level? And during a step-by-step construction of the different drifts, can we measure interaction between drifts and their intensity? The effect of new excavation to perform new scientific experiments (Delay et al., 2007b) on the existing ones has also to be considered.

This paper presents mainly a numerical study performed to analyse the mechanical behaviour of the whole drifts in the Callovo–Oxfodian layer by using a chronological evolution (time stepping) of the excavations, close to what was realised in reality.

It has to be underlined that at this stage the analysed problem is considered as a purely time-independent mechanical problem, thus, time is not taken as an intrinsic parameter and pore water is not taking into account. It only gives the chronology of the incremental problems.

Considering the size and the complexity of the geometry of the problem, finite element modelling has been carried out using relatively simple constitutive models describing the argillites mechanical behaviour. The numerical model and several results are presented and discussed. The authors also discuss the scientific contribution of such huge computations and give some perspectives.

2. The Meuse Haute Marne URL drifts and shaft network

2.1. General design

The underground installations consist of two shafts and drift networks (Delay et al., 2007b). The main shaft, 5 m in diameter after lining, gives access to a 445 meter-deep drift and to the 490 meter-deep main drift network. The auxiliary shaft, 4 m in diameter after lining, is also connected to the URL's main level. The drifts have a horseshoe-shaped cross section. The drift at 445 m is 45-meter-long and T-shaped. This experimental zone has been equipped to perform monitor a mine by test during shaft sinking. The cross sectional area of these drifts is 17 m^2.

At the main level located at 490 m, the network consists of experimental and technical drifts. By mid 2007, this network was 485 meter-long, out of which 80 m are dedicated to experiments. The orientation of the scientific drifts has been determined according to the orientation of the in situ stress field (Wileveau et al., 2007). The current drifts cross sectional area is 17 m^2, however, some technical zone have been excavated in different diameters, up to 40 m^2.

2.2. Excavation methods and time schedule

The shaft sinking method was drill-and-blast (Delay et al., 2007a). The main shaft was sunk at 509 m and the auxiliary shaft at 505 m. The shaft walls were lined, 6 m at a time, with a 45 cm

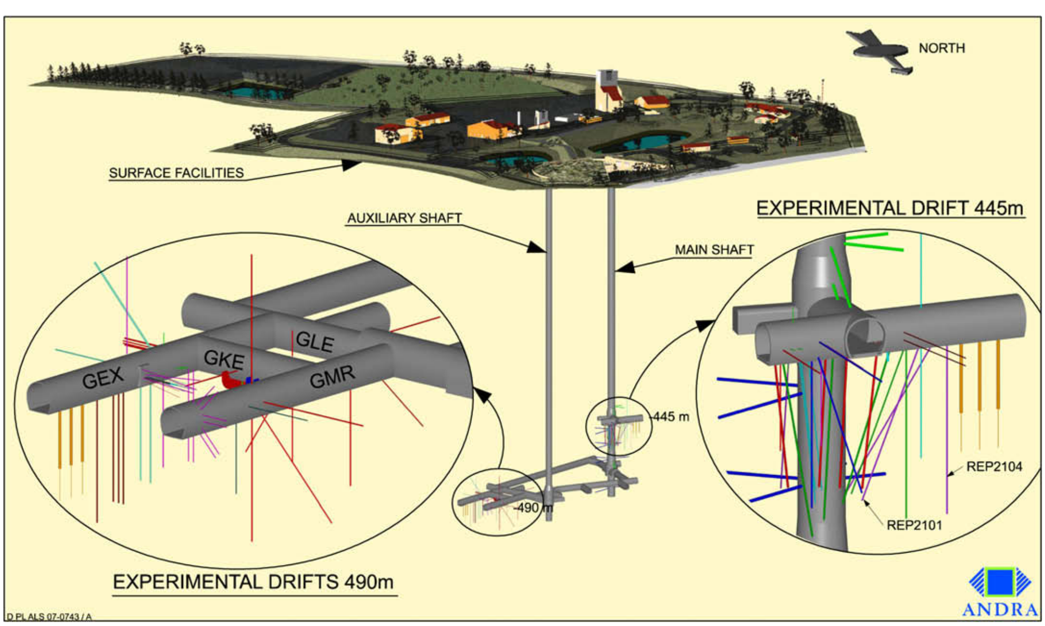

Fig. 1. Overview of the Meuse Haute Marne Underground research laboratory (state in 2006).