EXTENSION OF AN UNDERGROUND LABORATORY IN A DEEP CLAY FORMATION

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ABSTRACT

A deep tertiary clay formation, "Boom Clay", present under the Mol-Dessel nuclear site, was selected as a potential host formation for the disposal of high-level and long-lived radioactive waste (HLW). An underground laboratory (HADES) has now been operational for more than 15 years. An extension of the facility is necessary to implement full-scale demonstration tests. Its construction started in 1997 and consists of the construction of a second shaft (1997-1999), and the excavation of a gallery 84 m long to connect the new shaft with the existing facility.

The knowledge acquired since the beginning of the construction of the underground laboratory has led to the use of improved techniques, which have significantly reduced both the disturbance of the host rock and the cost. The paper describes the changes made due to the new techniques and the construction of the second shaft. Stress and convergence measurements on the lining are discussed. Finally conclusions are drawn and the future underground construction work is outlined.

INTRODUCTION

The R&D programme for finding appropriate geological sites for the disposal of high-level and long-lived waste was initiated in Belgium at the Belgian nuclear research centre SCK•CEN in 1974. For this purpose an underground laboratory was constructed in Boom Clay at Mol at a depth of 223 m. As at that time Boom Clay was expected to creep quickly, the first part of the laboratory was constructed using the ground freezing technique. Later the feasibility of digging in unfrozen clay was demonstrated. The facility currently consists of one shaft and one horizontal gallery 110 m in length. An extension consisting of a second shaft and a connecting gallery is necessary to implement full-scale demonstration tests. This work is managed by EIG PRACLAY (Economic Interest Grouping between the Belgian radioactive waste agency NIRAS/ONDRAF and the SCK•CEN).

The paper describes how the design assumptions and the construction techniques have evolved. The construction of the second shaft is described. The construction of the connecting gallery is being accompanied by an extensive instrumentation programme that concentrates particularly on the zone to be excavated. Numerical simulations of the excavation process of the connecting gallery are presented.

GEOLOGY

During the Lower Oligocene period, the North Sea covered large areas of northern Europe. In the deeper part of the North Sea basin, a clay deposit was formed. In Belgium,

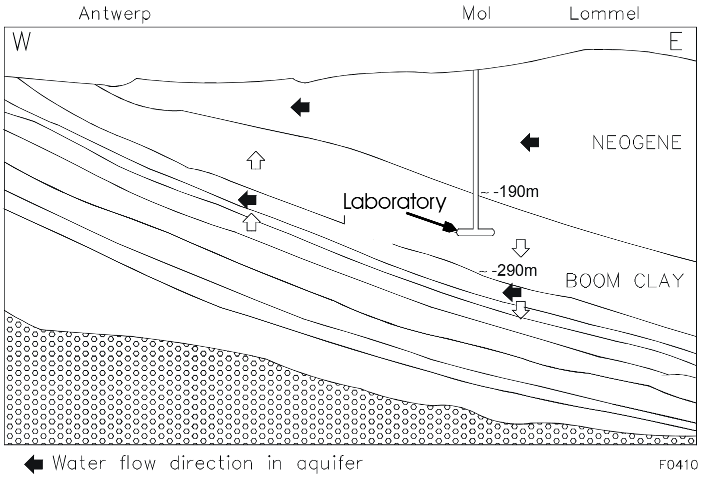

Figure 1: The Boom Clay formation

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this clay formation is known as Boom Clay. At Mol, Boom Clay is present at a depth of 190-290 m (see Figure 1). The Boom Clay layer is covered by a succession of water bearing sands (Neogene).

Boom Clay is characterised by a fairly constant chemical and mineralogical composition (Vandenberghe, 1978). Variations in grain size, organic matter, and carbonate content are present and result in the typical layering of Boom Clay. The variations reflect changes in local tectonics, eustacy and climate, and are associated with Milankovitch cyclicity.

THE HADES UNDERGROUND LABORATORY (1980 – 1987)

The digging of the access shaft (1980-1982) through the water-bearing sands was performed using the ground freezing technique (see Figure 1 and Figure 2). As, at that time, non-frozen Boom Clay was expected to creep quickly at a depth of 200 m, the ground freezing method was also chosen by the contractor to excavate in clay (Funcken *et al*., 1983). PVC membrane was used to prevent water from entering from the water bearing sands. During the thawing of the rock, we observed a lot of water leaking in, so we injected the joints of the concrete lining with watertight resin.

The digging works for the URL (1982-1983; see Figure 2) were planned in two freezing phases (Neerdael *et al*., 1991). At that time, the design calculations considered the whole overburden pressure (4.5 MPa) with a K_0 value around 0.6 and classical safety factors (De Bruyn and Neerdael, 1991). Cast iron segments were chosen for the lining given the considerable thickness (1.5 m) required when considering concrete blocks. The construction of the URL has shown how difficult it is to excavate Boom Clay by means of the ground freezing technique. Indeed freezing leads to the swelling of the clay and therefore to the development of high stresses in the massif. A loosening and a creeping of the soil when opening the excavations is a consequence of this phenomenon. Consequently, the ground freezing technique is not feasible from either the technical or economic point of view for the digging of several kilometres of storage galleries.

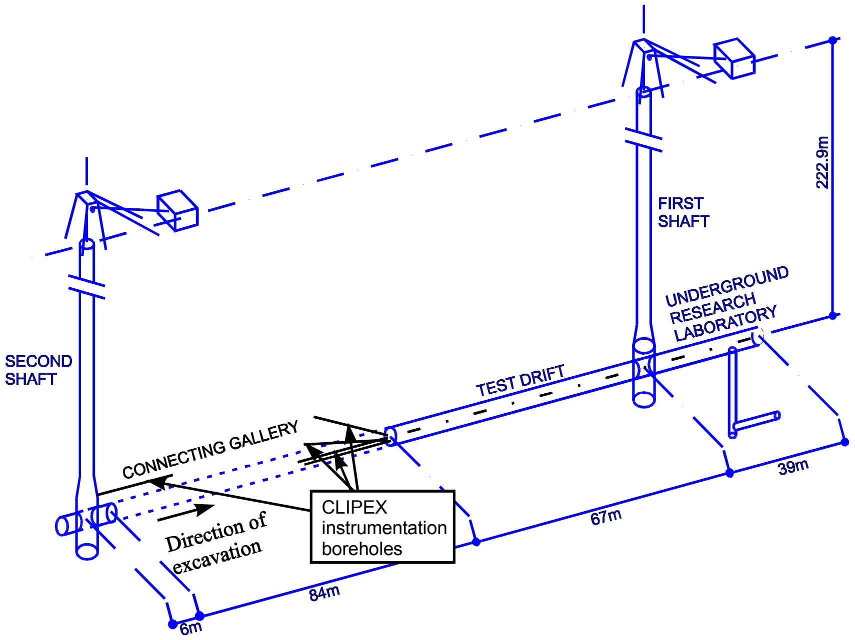

Figure 2: Extension of the existing laboratory HADES

Through exploratory work, we gained more knowledge of the geomechanical behaviour of Boom Clay. A small shaft and a 7 m long exploratory drift with an internal diameter of 1.4 m were realised from the end of the URL in order to study the feasibility of digging galleries in unfrozen clay at great depth (see Figure 2). Both were lined with small concrete segments separated by wooden plates in order to decrease the modulus of elasticity and so the stresses in the lining (De Beer *et al*., 1978). Convergence during excavation was less than with frozen clay. The success of this experiment led to the construction of the Test Drift (T.D.) in unfrozen clay (1987) with the same type of lining. The design hypothesis considered the whole overburden pressure with a K_0 value around 0.7 and smaller safety factors than were used for the URL (De Bruyn and Neerdael, 1991). This led to a thickness of the concrete blocks around 60 cm. Steel sliding ribs were also tested in a part of the T.D. for the French radioactive waste management agency ANDRA.

Comprehensive geotechnical instrumentation was developed to confirm the validity of the design and to model the response of the clay mass to the excavation process. The interpretation of the convergence measurements of the lining has led to a revised value of K_0 of about 0.9. Comparison between the *in situ* measurements from the construction of the T.D. and numerical predictions using different types of models led to the following conclusion (Barnichon, 1998): the radial convergence and the hydraulic pressure obtained with bounding plasticity models are closer to *in situ* measurements than the more classical models such as Modified Cam-Clay and Mohr Coulomb. However, the amplitude of the hydraulic disturbance is still much lower than the one measured. It is difficult to know whether this difference is due to the limitation of the models or poor knowledge of the excavation parameters. Indeed, as the gallery was excavated manually with an excavation rate about 25 cm/day, it is difficult to assess the over-excavation and the influence of time-related effects correctly.

THE EXTENSION OF THE UNDERGROUND LABORATORY (1997-2001)

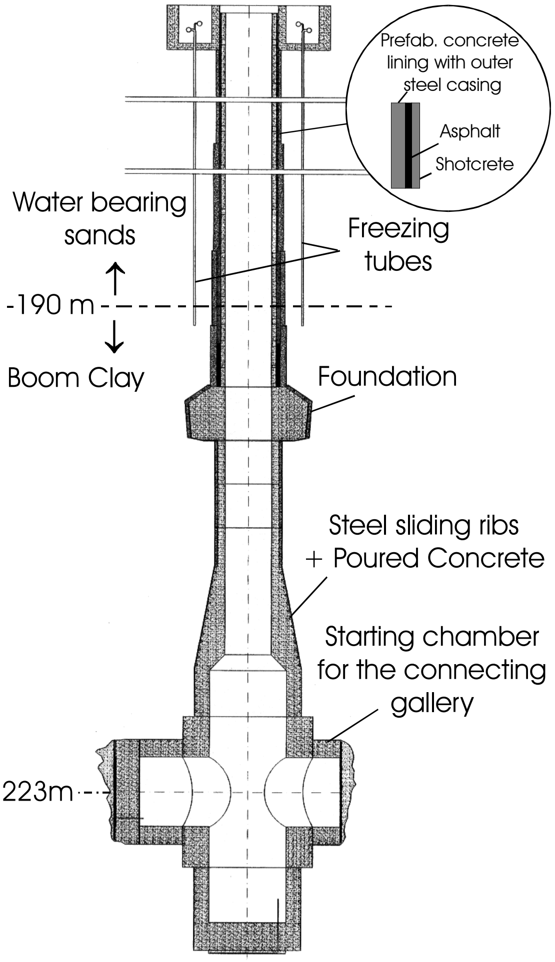

Figure 3: Design of the second shaft

To implement full-scale demonstration tests, an extension of the facility is necessary, for which the mining authorities require the sinking of a second shaft. An 84 m long gallery will then connect the second shaft to the existing facility (see Figure 2).

Figure 4: Excavation in unfrozen clay with steel sliding ribs as the primary lining (Oellers and De Bruyn, 1999)

The second shaft has been constructed by the joint venture SCM (Schacht Combinatie Mol, with Deilmann-Haniel, Wayss & Freytag and Smet-Boring). The ground freezing technique was used to sink the shaft through the water bearing sands (see Figure 3). The freezing pipes were anchored into the top of the clay layer at a depth of 192 m. The internal diameter of the shaft is about 3 m. The frozen wall was secured by a primary lining composed of a 20 cm thick layer of shotcrete. In the top of the clay layer, a reinforced foundation was constructed in unfrozen clay to support the secondary lining. This lining consists of prefabricated reinforced concrete rings with a 8 mm thick outer steel casing. The gap between the two linings is filled with asphalt (De Bruyn *et al.*, 1998).

Taking into account the good mechanical behaviour of the clay during the excavation of the foundation, the contractor proposed excavating the unfrozen clay down to the bottom of the shaft (-230 m) using steel sliding ribs as the primary lining (Oellers and De Bruyn, 1999 - see Figure 4). Next, concrete was poured from the bottom up to the foundation. This has been realised successfully although significant convergence has been measured. Taking into account a mean over-excavation of 5 cm, we can assess a convergence of about 25 cm on the diameter (this value does not include the convergence occurring ahead of the excavation front). This has led to significant decompression of the rock, which was confirmed by the low total pressures recorded on the lining (less than 0.5 MPa). Convergence measurements are given in Figure 5. We can observe the influence of the excavation phases.

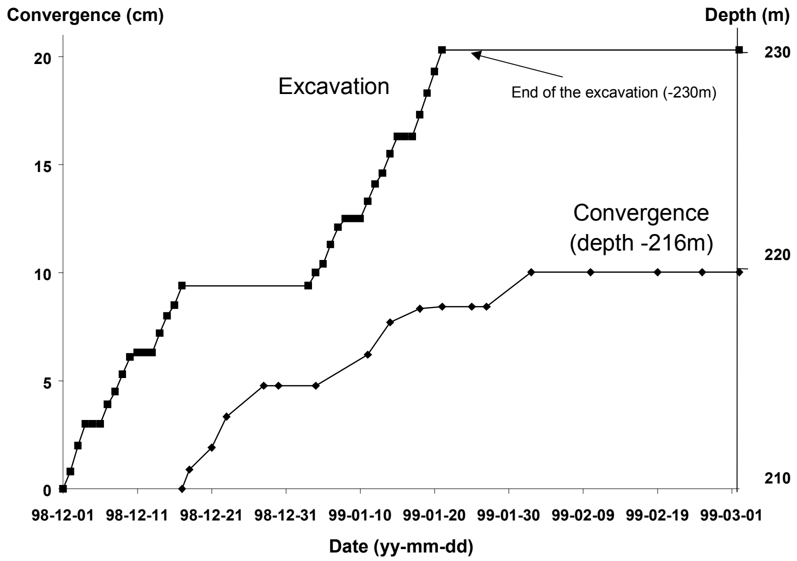

Figure 5: Convergence of the diameter of the sliding ribs at 216 m depth

During the construction of the starting chambers at the bottom of the shaft, large slip surfaces (equal to the whole cross-section of the gallery: ~ 7 m) were observed both on the North and the South side (see Figure 6). This led to the detachment of some blocks causing many problems during the excavation. They consist of an interconnected network of conjugated planes inclining at 35° towards the centre of the shaft. The circular shape of the slip surfaces (as you can observe in Figure 6) indicates clearly that they are symmetric around the shaft axis. Slickensides were visible on the slip surfaces. They indicated a movement towards the centre of the shaft, which can be related to the excavation of the shaft.

Figure 6: A slip plane observed during the excavation of the starting room

No active support was installed from the beginning of the excavation works of the starting rooms. Indeed, in the first excavation phase, support was installed mainly to protect the miners and not to limit convergence. This lack of active support and the low excavation rate have certainly favoured the opening of the fractures and the difficulties encountered. The installation of an active support in the last excavation phase considerably improved the behaviour of the rock.

The gallery connecting this second shaft with the existing facility (HADES) will be constructed in the coming months. Up to now, knowledge derived from previous work led to consider a ground pressure of about 3.5 MPa and a K_0 of around 0.9 used for the design calculation. An additional thermal load of about 1 MPa is taken into account since thermal experiments will be performed from this new drift. The gallery will be excavated by semi-mechanised techniques, which will allow better control of the over-excavation and a much faster excavation rate (2 m/day) than was possible for the T.D. The results of a preliminary simulation by a Cam-Clay model are given on Figures 7, 8 and 9. We can observe the spherical response of Boom Clay ahead of the front. When the detailed excavation technique is known in detail, more sophisticated blind modelling will be performed and compared with *in situ* measurements (Bernier and Van Cauteren, 1998).

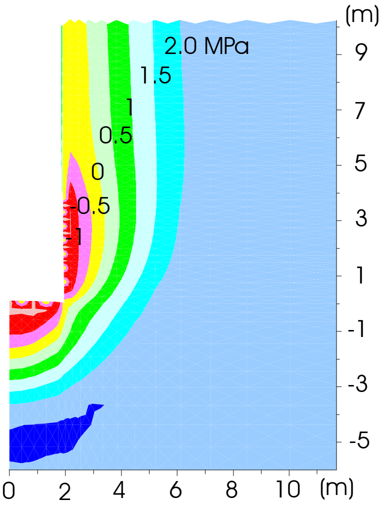

Figure 7: excavation of the connecting gallery: contour plot of the pore water pressure

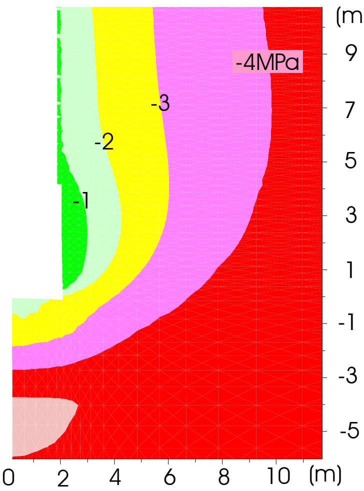

Figure 8: contour plot of the radial stress

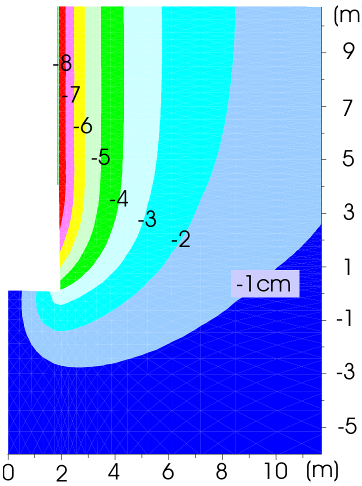

Figure 9: contour plot of the radial displacement

CONCLUSIONS AND PERSPECTIVES

The feasibility of digging in unfrozen Boom Clay from the top to the middle of the Boom Clay layer (250 m) has been demonstrated. During the excavation of the second shaft, the mechanical behaviour of the rock was quite homogeneous regardless of the depth. During the construction of the starting chambers, significant slip planes were observed. Their symmetry around the shaft axis indicated that the fractures were induced by the excavation work. Active temporary support installed immediately after the excavation reduced the opening of the fractures and the risk of detachment of blocks considerably. A seismic campaign will take place in the coming months to assess the extent of the fractured zone. A piezometric network will also be installed to follow up the change in permeability with time around the shaft. This is of course of prime importance in the context of radioactive waste disposal.

The connecting gallery will be excavated by semi-mechanised techniques with an excavation rate of about 2m/day, or even more, allowing better control of overexcavation and of the time effect than in the previous works. The results of the accompanying instrumentation programme will be compared with blind predictions. This project will give reliable data for the correct assessment of the initial conditions and for the better interpretation of the future *in situ* experiments to be performed from the connecting gallery.

ACKNOWLEDGMENT

The authors wish to express their gratitude to all parties involved in the construction of the second shaft, including the SCM joint venture, BELGATOM the engineering consultants, the SECO control office, and their colleagues at NIRAS/ONDRAF and SCK•CEN.

The European Commission supported the modelling work in the frame of the CLIPEX project. The authors gratefully acknowledged this support.

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