# Instrumentation programme near the face of an advancing tunnel in Boom Clay

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ABSTRACT: The CLIPEX project (CLay Instrumentation Programme for the EXtension of an underground research laboratory) is realised in the frame of the extension of the underground research facility (HADES) in a deep tertiary clay formation at Mol (Belgium). The extension is now under construction and consists in the realisation of a second shaft and a connecting gallery of 90 m length. The CLIPEX instrumentation programme aims to provide experimental data to assess the short-term hydro-mechanical behaviour of the Boom Clay induced by a gallery excavation. As the connecting gallery will be excavated from the second shaft to the existing facility, an unique and original opportunity is then given to monitor hydro-mechanical parameters ahead of the face of the advancing gallery.

ACKNOWLEDGEMENT

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## 1 INTRODUCTION

The R&D programme on geological disposal for high-level and long-lived waste (HLW) was initiated in Belgium at SCK•CEN in 1974. A deep tertiary clay formation, the "Boom Clay", present under the Mol-Dessel nuclear site, was selected as a candidate host formation for experimental purposes. An underground laboratory, called HADES, was constructed allowing to perform large scale integrated tests close to real conditions. The facility consists of one shaft and one horizontal gallery of 110 m length at 223 m depth.

The construction by the EIG PRACLAY (Economic Interest Grouping between NIRAS/ ONDRAF and SCK•CEN) of a second shaft and of a 90 m length connecting gallery has started in June 1997 and is planned to be completed before year 2000. The CLIPEX project aims to elaborate an instrumentation programme for this extension and to compare the experimental results with blind predictions obtained by five modelling teams.

The CLIPEX project is a joint project of EIG PRACLAY acting as co-ordinator, ANDRA and ENRESA acting as main contractors and G3S, GEOCONTROL and UPM acting as associated contractors. The project started in January 1997 and covers a period of three years.

The CLIPEX instrumentation programme will allow to assess the performances of the mechanised excavation techniques and the corresponding reduction of the plastic zone in the frame of a radioactive waste repository. For the first time in the Boom Clay formation, the displacements ahead of the face of the advancing tunnel will be measured in order to assess the initial convergence occurring before the excavation. An important part of the project is also devoted to blind predictions. This paper presents the objectives of the CLIPEX project, describes the instrumentation programme and gives the results of the first blind predictions.

## 2 OBJECTIVES

The CLIPEX project aims to study the hydro-mechanical response of the Boom Clay (see table 1) ahead of the face of an advancing gallery (Bernier et al. 1998). Indeed, since the connecting gallery will be excavated from the second shaft, it will be possible to install the instrumentation from the Test-Drift (T.D. - see Fig. 1) in the zone to be excavated. Although this problem has been extensively studied on a theoretical point of view, only few experimental

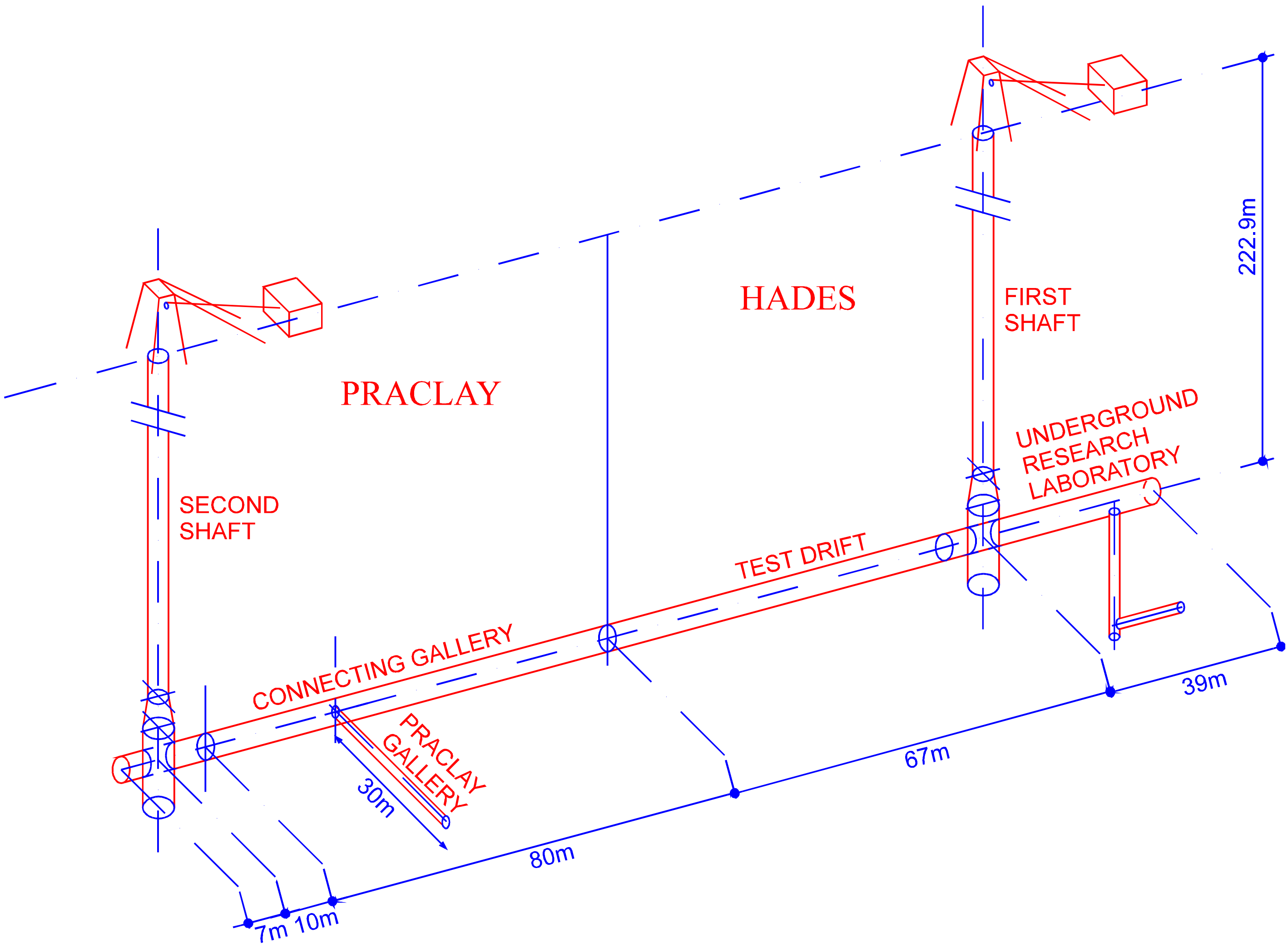


Figure 1. The extension of the underground laboratory

data exist.

The instrumentation programme includes essentially total stress, pore water pressure and displacement measurements. Special attention will be paid to determine the total stress and the pore-water pressure at the same locations to derive effective stress variations. A reliable assessment of these values is essential to validate properly the hydro-mechanical models. A characterisation programme has also been planned to get more reliable data on the initial hydro-mechanical field conditions. Blind predictions of the hydro-mechanical behaviour of the clay massif during and after the construction of the connecting gallery are performed by five different modelling teams: G3S, UPM, GEOCONTROL, SCK•CEN and ONDRAF/NIRAS.

## 3 THE CONNECTING GALLERY

The extension of the underground laboratory will consist in the construction of a second shaft and a connecting gallery of 90 m length (see Fig. 1). The construction of the connecting gallery will be realised with a semi-mechanised technique in order to reduce the plastic zone extent created by the tunnelling process. To this purpose, a fast advancing rate of about 2 metres per day is required. The overexcavation will be reduced to a minimum (about 2 cm) and the lining will be installed behind the excavated face as soon as practical to minimise radial movement of the wall. At the present time, the excavation method and the type of lining are not selected yet.

*Table 1. Boom Clay characteristics*

| | |
|---|---|
| Young Modulus | 200 - 400 MPa |
| Poisson's Ratio | 0.4 - 0.45 |
| Cohesion | 0.8 - 1 MPa |
| Internal Friction | 4° |
| Bulk density | 2 t/m$^3$ |
| Porosity | 0.39 |
| Water content | 0.19 - 0.24 |
| Hydraulic conductivity | ~4.10$^{-12}$ m/s |

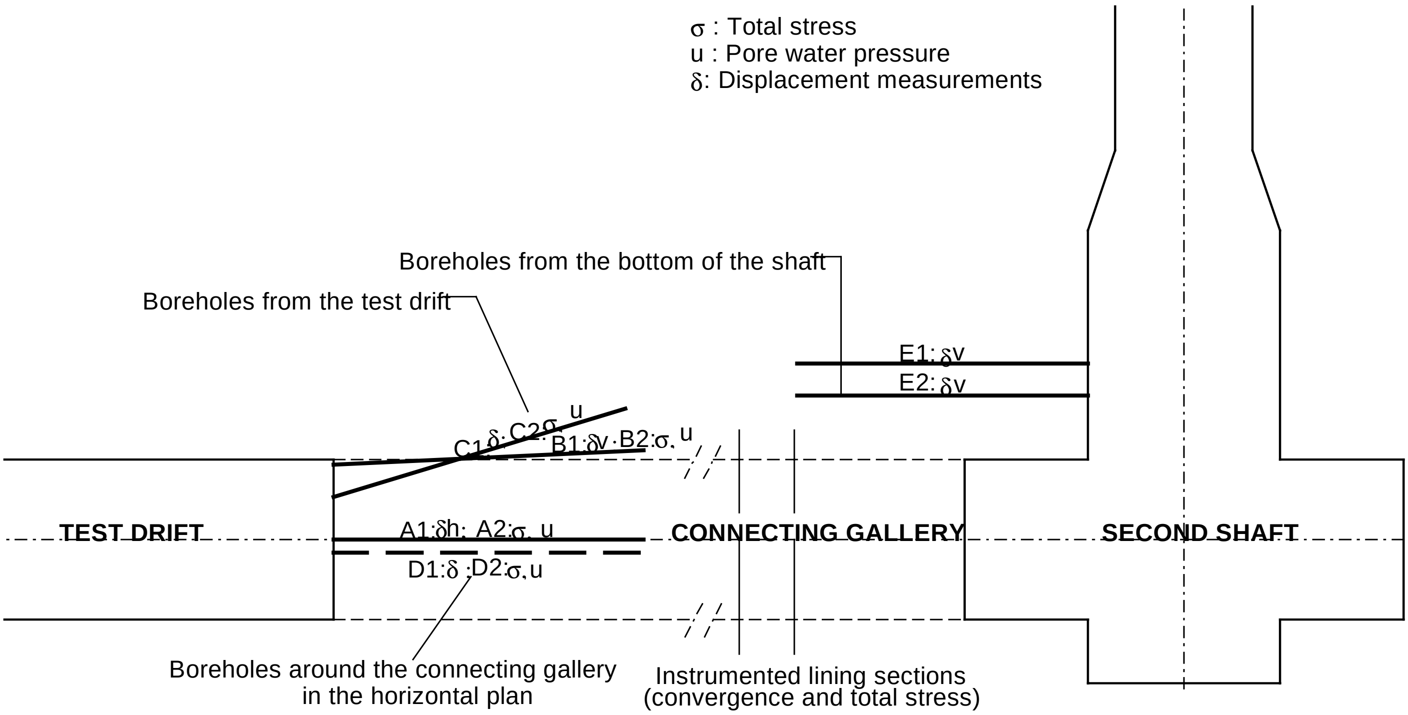



Figure 2. Instrumentation programme (not on scale)

## 4 THE INSTRUMENTATION PROGRAMME

The programme has been designed so that the experimental data can be used directly to test and refine the hydro-mechanical models. The preliminary results from the blind prediction (see chapter 6) have allowed the evaluation of the monitoring ranges and the location of the instruments (Barnichon & Bernier, 1998).

The CLIPEX instrumentation will be located in three zones around the connecting gallery (see Fig. 2):

1. eight instrumented boreholes from the T.D.;
2. two instrumented boreholes from the bottom part of the second shaft;
3. several lining sections of the connecting gallery.

From the T.D. four subzones are to be instrumented : the axis of the future connecting gallery (subzone A), the upper interface between the future gallery lining and host rock (subzone B), around the gallery in the vertical plane (subzone C) and one in the horizontal plane (subzone D). Each subzone is instrumented by means of two boreholes: one for the deformation (type 1) and another for the total pressure and the pore water pressure measurements (type 2), totalling eight boreholes.

From the shaft, two boreholes E1 and E2, 30 m deep, will monitor the vertical displacements above the future connecting gallery by means of an inclinometer probe.

Several sections of the future gallery lining will be instrumented to monitor:

- stresses in the lining by means of load cells (if concrete lining) or strain gages (if cast iron lining);
- total pressure on the lining outer face by means of pressure cells;
- lining convergence using tape extensometers.

## 5 CHARACTERISATION PROGRAMME

The characterisation programme is co-ordinated by GEOCONTROL. In order to obtain more reliable blind predictions, a testing programme to better characterise the clay level under investigation was planned. It consists of in-situ measurements of natural stresses, permeabilities, deformability and strength of rock mass.

The following "in-situ" tests will be realised:

- pressuremeter and dilatometer tests: to determine the in-situ deformability modulus, the anisotropic behaviour, the time dependent behaviour and the strength parameters;
- hydrofracturing tests: to determine natural in-situ stress and rock mass in-situ permeability measurements;
- self-boring pressuremeter tests: to determine the confining stress and the in-situ shear modulus.

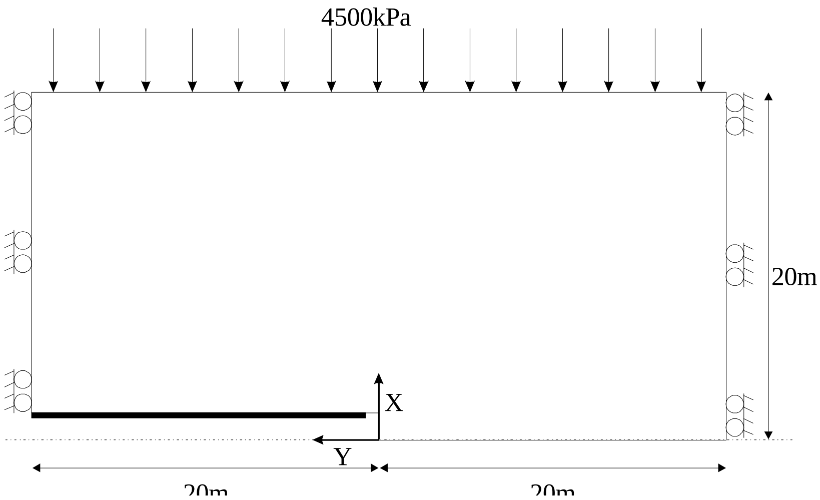



Figure 3. Geometry of the test case

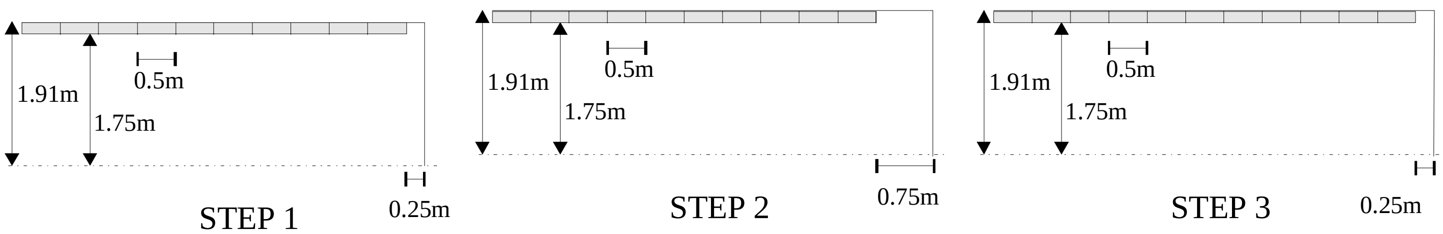



Figure 4. Schematic view of the sequential tunnelling and lining process.

6 BLIND PREDICTIONS

The blind predictions of the CLIPEX programme consists in:

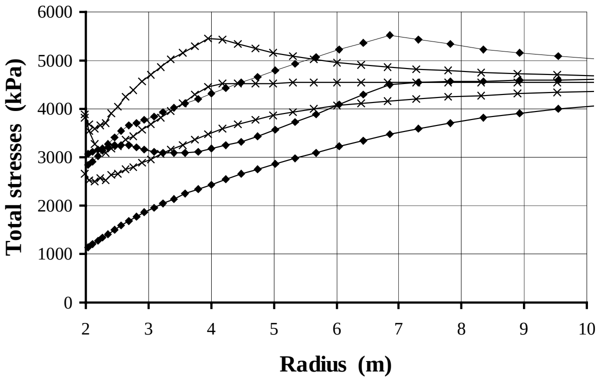
- case studies to compare the predictions of the different codes for problems related with the excavation of underground structures. In those calculations, all the data are imposed: geometry, boundary conditions, constitutive model, geotechnical characteristics, and construction sequence;
- further calibrations of constitutive models and geotechnical properties for Boom Clay, from the existing laboratory and in situ data;
- blind predictions of the hydro-mechanical behaviour of the clay mass during and after the construction of the connecting gallery. They will quantify the evolution with time of pore pressures, stresses and displacements in the medium as well as pressures on the gallery lining. Based on their experience, the modelling teams will be free to use the data and the constitutive model they consider the most appropriate.

At present, the first stage has been completed. Within this stage, a 2-D axisymmetric problem has been realised, which accounts for the decompression of the clay mass ahead of the excavation face, for the support laying distance and for the sequential tunnelling process.

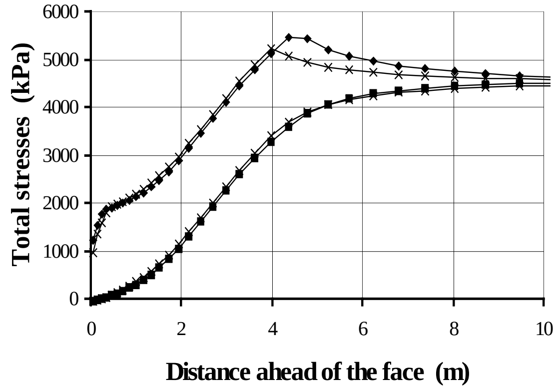
The geometry and the boundary conditions of this test-case is given on Figure 3. Since the supporting system of the connecting gallery is not yet decided, a lining consisting of cast iron segments (internal radius 1.75 m, segments thickness 16 cm) has been assumed for the modelling.

According to the working sequence, the following assumptions are made in the calculations (see. Fig. 4): the entire cross section of the gallery is excavated in a single step by semi-mechanical means (backhoe of roadheader type of machinery); the rounds are 0.5 m long and after each round a 0.5 m wide ring is installed; the distance between the front and the segments varies within 0.25 and 0.75 metre; the tunnel advance rate is about 2 m/day.

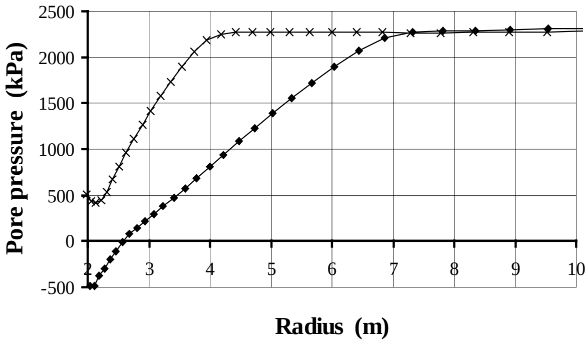
The presence of a gap between the outer face of the lining and the excavation wall has a significant influence on the equilibrium state around the gallery, and more particularly on the magnitude of the hydro-mechanical disturbances. To appraise the importance of this factor, two calculations were carried out: one without any



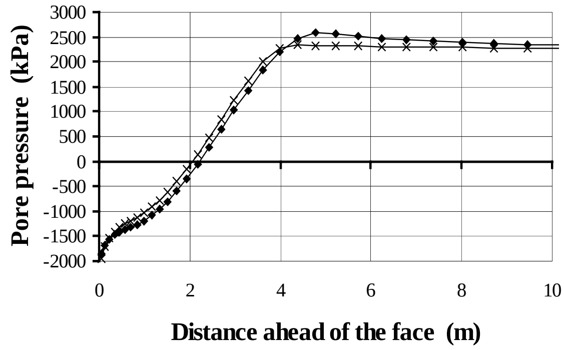

a) Cross section 10 m behind the front - Total stresses



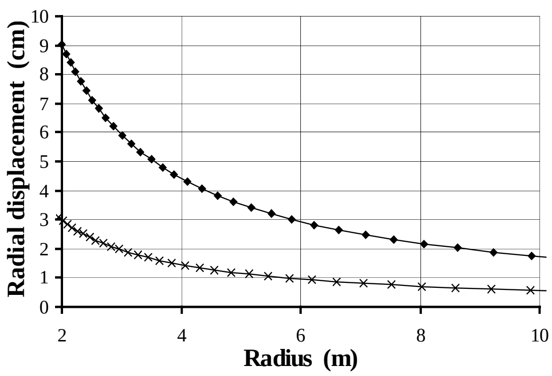

b) Profiles along the symmetry axis - Total stresses



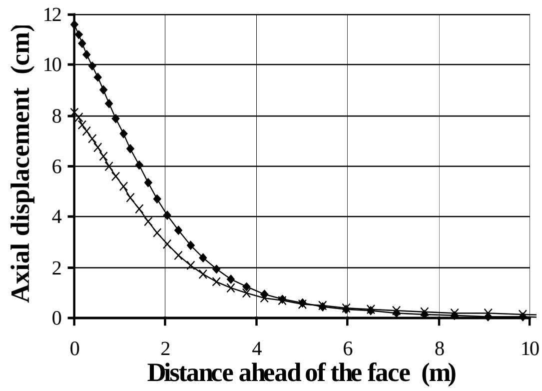

c) Cross section 10 m behind the front - Pore pressure



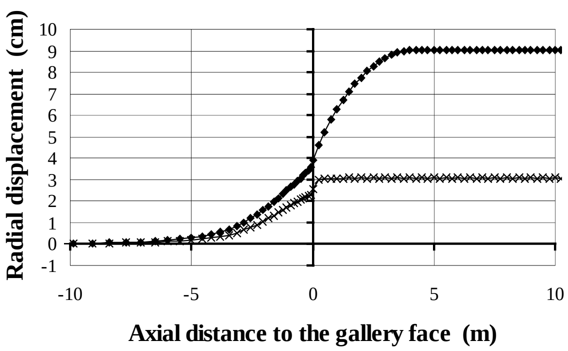

d) Profiles along the symmetry axis - Pore pressure



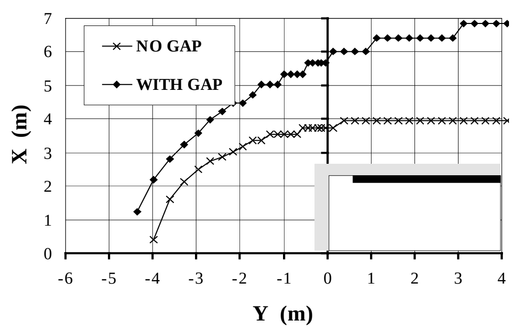

e) Cross section 10 m behind the front - Radial displacements




f) Profiles along the symmetry axis - Axial displacements




g) Radial displacement at the tunnel circumference




h) Plastic zone extent

Figure 5. Results obtained from numerical simulations based on the 2-D test-case with the Cam-clay model

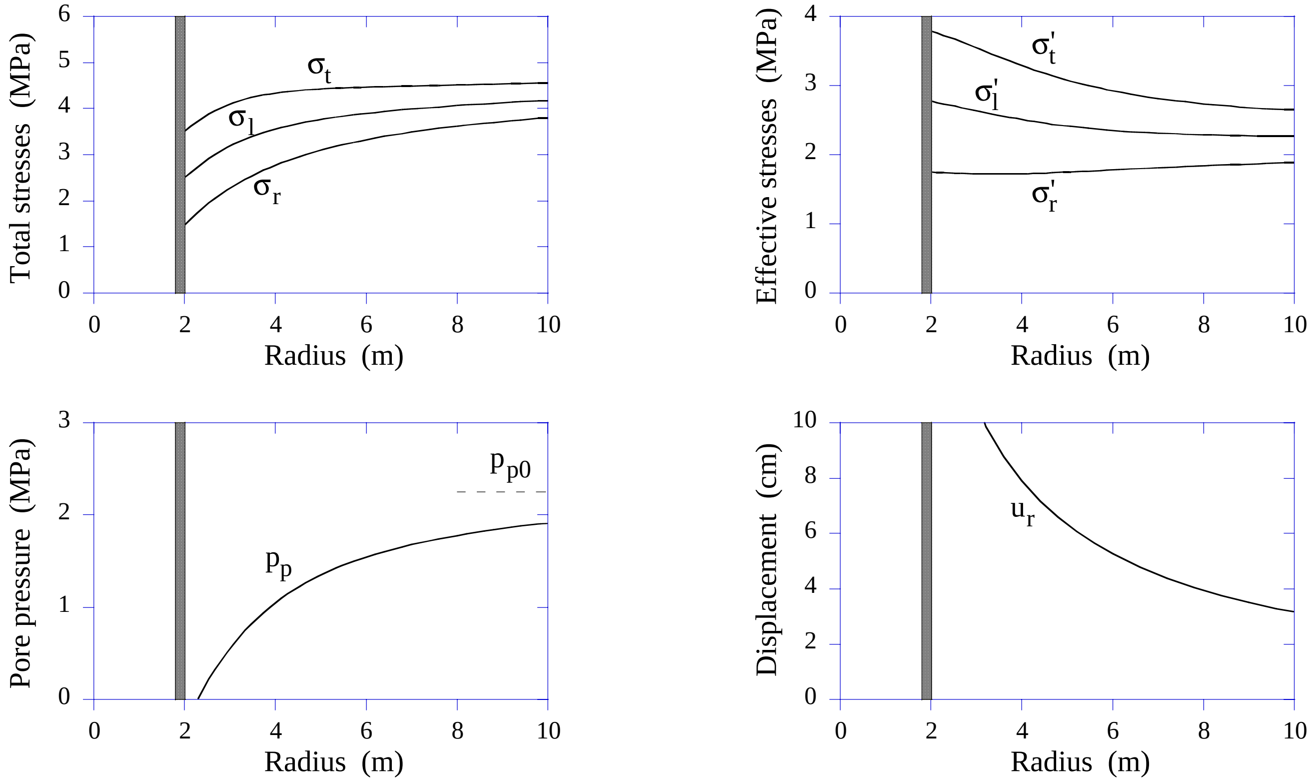



Figure 6. Results obtained from numerical simulations based on a 1-D test-case model with the two-surface "bubble" model, from (Labiouse, 1997)

overexcavation gap and another with an overgap of about 5 cm.

Since the CLIPEX instrumentation programme is mainly planned to assess the hydro-mechanical disturbances arising during the excavation of the connecting gallery, this case study will consequently merely focus on the gallery construction and will not evaluate the hydro-mechanical changes arising from the pore water pressure dissipation after excavation.

Owing to the very low permeability of the Boom Clay formation, a 2 m/day advancing rate can be assumed as very fast, and accordingly to the response of the medium the excavation can be idealised as undrained.

Calculations were performed considering a modified Cam-clay model using the geomechanical characteristics given in Table 2.

*Table 2. Cam-clay parameters*

| | | |
|---|---|---|
| Slope of the normal consolidation line | $\lambda$ | 0.13 |
| Slope of the elastic swelling line | $\kappa$ | 0.02 |
| Critical state friction angle | ■'$_c$ | 21° |
| Preconsolidation pressure | $p'_c$ | 6 MPa |
| Poisson's ratio | [illegible]' | 0.2 |
| Specific volume at 1 kPa on the NCL | N | 2.75 |

From the obtained results, we can observe (see Fig. 5):

- that the radial plastic zone extent lies between 4 m (no gap) and 7 m (with gap);
- axial displacements ahead of the face of the gallery up to 9 cm (no gap) and 12 cm (with gap);
- a total stress up to 5.5 MPa;
- an initial radial convergence at tunnel circumference between 2.5 cm (no gap) and 4 cm (with gap);
- a pressure on the lining between 1 MPa (with gap) and 2 MPa (no gap).

Numerical simulations have also been performed considering a sophisticated constitutive model (the two-surface "bubble" model developped by (Al Tabbaa and Wood, 1989)). This model is actually an extension of the modified Cam-clay that incorporates a bounding surface and a yield surface. Both surfaces evolution is described through an isotropic hardening law, and the yield surface also evolves through a kinematic hardening rule. At this stage, only a 1-D axisymmetric problem has been studied (Labiouse 1997). The results are presented on Fig. 6. We observe that the profiles of stresses are smother, the hydraulic disturbance extends much further in the clay mass and the convergence is more important.

These preliminary numerical predictions have lead to the following choice for the location and magnitude of the sensors:

- pore water pressure and total stress measurements will be performed from the axis of the connecting gallery (in the zone to be excavated) up to a radial extent of 12 m;
- displacement measurements will be performed from the axis of the connecting gallery up to a radial extent of 7 m;
- sensors around the gallery will be located in two planes (vertical and horizontal planes) in order to check for a possible stress anisotropy;
- maximum displacements of 12 cm are expected along the gallery axis;
- a maximum radial convergence at tunnel circumference of 4 cm is expected;

## 7 CONCLUSIONS

The CLIPEX instrumentation programme will allow for the first time in the Boom Clay formation to measure the convergence ahead of the face of the advancing tunnel. An important part of the project is devoted to blind predictions. Preliminary results have helped to optimise the location of the instruments and to assess their magnitude.

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