Available online at www.sciencedirect.com
SCIENCE DIRECT®
Applied Clay Science 33 (2006) 21–34
Applied CLAY Science
www.elsevier.com/locate/clay

Electrical tomography monitoring of the excavation damaged zone of the Gallery 04 in the Mont Terri rock laboratory: Field experiments, modelling, and relationship with structural geology

Dominique Gibert [a,*], Florence Nicollin [a], Bruno Kergosien [a], Paul Bossart [d], Christophe Nussbaum [b], Agnès Grislin-Mouëzy [a], Frédéric Conil [a], Nasser Hoteit [c]

[a] *Géosciences Rennes (CNRS UMR 6118) and GdR FORPRO (CNRS-ANDRA G788), Université Rennes 1, Bât. 15 Campus de Beaulieu, 35042 Rennes cedex, France*
[b] *Geotechnisches Institut AG, Gartenstrasse 13, 3007 Bern, Switzerland*
[c] *ANDRA, Scientific Direction and Geomechanics Department, 92298, Chatenay-Malabry, France*
[d] *Federal Office of Topography, Swisstopo, Seftigenstrasse 264, 3084 Wabern, Switzerland*

Received 22 July 2005; received in revised form 2 March 2006; accepted 8 March 2006
Available online 5 May 2006

Abstract

The excavation of the new G04 gallery in the Opalinus clay of the underground rock laboratory at Mont Terri offered a unique opportunity to perform an electrical monitoring experiment of the evolution of the excavation damaged zone (EDZ) during the progression of the excavation. An electrode array was installed near the end of the first section of the gallery in order to monitor the evolution of the EDZ at the restart of the excavation works. Data sets acquired at different time intervals show conspicuous changes of the electrical resistivity. Forward modelling of a data subset indicates resistivity variations from 6 Ω m for undamaged Opalinus clay to 45 Ω m in the most damaged zones. Comparison with geological observations shows that the resistivity changes are strongly controlled by the local tectonics and by the bedding in the rock formation.

PACS: 41.20.Cv; 62.20.Mk; 91.25.Qi; 93.30.Ge
Keywords: Electrical tomography; EDZ; Mont Terri; Radioactive wastes

1. Introduction

Among the different rock formations aimed at being used for radioactive waste disposal, argillaceous formations are particularly studied for their remarkable confinement and self-sealing properties (Meier et al., 2000). To investigate the suitability of waste disposal in these formations, a number of organisations dealing with radioactive waste disposal have initiated the Mont Terri Project in 1995 and the construction of the Mont Terri Underground Rock Laboratory (URL) in a Mesozoic shale formation constituted by the Opalinus clay. Now there are 12 organizations joining the project, these are: ANDRA (France), BGR (Germany), CRIEPI (Japan), GRS (Germany), HSK (Switzerland), ENRESA

* Corresponding author. Tel.: +33 223236091; fax: +33 223236090.
E-mail addresses: dominique.gibert@univ-rennes1.fr (D. Gibert), florence.nicollin@univ-rennes1.fr (F. Nicollin), bruno.kergosien@univ-rennes1.fr (B. Kergosien), paul.bossart@swisstopo.ch (P. Bossart), christophe.nussbaum@geo-online.com (C. Nussbaum), nasser.hoteit@andra.fr (N. Hoteit).

0169-1317/$ - see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.clay.2006.03.008

(Spain), IRSN (France), JNC (Japan), NAGRA (Switzerland), OBAYASHI (Japan), SCK.CEN (Belgium), and SWISSTOPO (Switzerland) which manages the consortium. The URL is managed by the Swiss National Hydrological and Geological Survey (now Swisstopo) and constitutes a multidisciplinary platform hosting numerous research programs (Thury and Bossart, 1999) among which the study of the so-called Excavation Damaged Zone (EDZ) is of a particular importance. The EDZ is produced by the stress changes resulting from the excavation of a gallery and it constitutes a diffuse layer of fractured rock with a variable thickness controlled by the regional stress regime, the local tectonic, the stratigraphic conditions and the shape of the gallery (Bossart et al., 2002). Both the geomechanical and the transport properties of the EDZ are important for galleries aimed at receiving high-level radioactive waste and spent fuel, and several studies have been devoted to the study of the EDZ (Bossart et al., 2002, 2004; Hunsche et al., 2004; Martin et al., 2004; Blümling et al., 2005). For further information concerning the EDZ studies, the reader is referred to the report by McEwen (2002).

Among the different methods used in these studies, geophysical non-invasive techniques are of a particular interest since they might be used in actual repository galleries where no destructive methods are to be used for obvious safety conditions. As shown by Schuster et al. (2001), the seismic method is particularly efficient to locally investigate the EDZ and to obtain both geometrical and geomechanical data. While the seismic technique is particularly efficient when used in boreholes, non-destructive seismic reflection and surface-wave methods also provide useful information. In a recent study Kruschwitz and Yaramanci (2004) show that electrical tomography also constitutes an interesting method to probe the EDZ. Despite the low resolution inherent to the method when compared to seismic, electrical impedance tomography has the advantage of being a non-destructive and low-cost method which allows to easily investigate large volumes of the EDZ. Other experiments that have already used geo-electrical measurements in the Mont Terri are: VE (Ventilation Test) installed by GRS, EB (Engineered Barrier) and ED-B (EDZ Evolution before, during and after excavation) installed by BGR. In the present study, we discuss the first results of the EZ-G electrical tomography experiment designed to monitor the EDZ evolution during the excavation of the new G04 gallery in the Mont Terri URL. The particularity of the EZ-G experiment is to concern a gallery with a large diameter of about 5 m and, more important, that the orientation with respect to bedding makes the experimental area particularly exposed to excavation damages.

2. Field experiments

2.1. Experimental setup

The EZ-G experiment was installed in the start niche (i.e. the entrance) of the G04 gallery in order to best monitor the EDZ evolution during the excavation of G04. This resulted in heavy constrains both on the time schedule and on the technical aspects of the experiment. The G04 gallery is located at the southern end of the URL and is aimed at providing the URL with numerous additional experimental facilities (Fig. 1). The first section of the gallery is oriented in a NW–SE direction with its axis making an angle of 20° northward with respect to the bedding strike. This section was excavated in the so-called shaly facies (see Nussbaum and Bossart, submitted for publication, for details) during the Spring 2004 and over a total length of 80 m (20 m for the start niche and 60 m for the G04 gallery). A detailed plan view of the excavation stages is given in Fig. 2. After the completion of the excavation of the first 20 m, we proceeded to the installation of the experimental electrical tomography setup within a few days of July 2004 during which we also performed a whole set of measurements. These first data are of a particular importance for the entire experiment since they constitute the data set representative of the initial state of the geo-electrical structure of the EDZ before the restart of the excavation.

In order to suppress any electrical shortcut, the metallic fibbers normally used to reinforce the shotcrete layer have been replaced by plastic fibbers in the 20-m-long start niche in May 2004. In September, at the beginning of the excavation of the G04 gallery, a further 15-m long segment of the gallery was also shotcreted with plastic fibbers. In the same way, no steel reinforcement was placed in the concrete floor in the same segment of gallery. In order to eliminate the changes produced in September by the filling of the 2 gaps kept to install the floor electrodes, an insulating plastic sheet was placed in the voids before pouring the concrete (Fig. 3). By this way, these new volumes of concrete have no geo-electrical effects, and the comparison between the data sets obtained at different dates is made easier. The profile of the gallery has the classical horseshoe cross-section and is circular in its upper part with an average diameter of 5.1 m. The shotcrete layer has a thickness between 10 cm and 35 cm, with an average of 15 cm.

The electrode array consists of three rings of electrodes completed by one horizontal line located on the south wall of the gallery 1.1 m above the floor level. As shown in Fig. 3, the rings of electrodes are placed near the gallery face to best monitor the evolution of the EDZ at the restart of the excavation. Ring 1 is located at about 1 m from the gallery face and ring 2 is 50 cm apart toward the entrance of the gallery. Because of the great probability of a total destruction of rings 1 and 2 at the restart of the excavation works, we decided to place ring 3 at a safer place, 4 m away from the gallery face.