Tunnelling and Underground Space Technology 45 (2015) 227–248

Contents lists available at ScienceDirect

Tunnelling and Underground Space Technology

journal homepage: www.elsevier.com/locate/tust

The excavation of a circular tunnel in a bedded argillaceous rock (Opalinus Clay): Short-term rock mass response and FDEM numerical analysis

A. Lisjak [a,b], B. Garitte [c], G. Grasselli [a,*], H.R. Müller [c], T. Vietor [c]

[a] Department of Civil Engineering, University of Toronto, 35 St. George Street, M5S 1A4 Toronto, ON, Canada
[b] Geomechanica Inc., 90 Adelaide St. W., Suite 300, M5H 3V9 Toronto, ON, Canada
[c] National Cooperative for the Disposal of Radioactive Waste (NAGRA), Hardstrasse 73, 5430 Wettingen, Switzerland

ARTICLE INFO

Article history:
Received 16 January 2014
Received in revised form 1 August 2014
Accepted 20 September 2014

Keywords:
Excavation damaged zone
Numerical modelling
FDEM
Brittle failure
Clay shales
Mechanical anisotropy
Instrumentation

ABSTRACT

The Opalinus Clay formation is currently being investigated as a potential host rock for the deep geological disposal of radioactive waste in Switzerland. Recently, a test tunnel was excavated at the Mont Terri underground rock laboratory (URL) as part of a long-term research project (“Full-scale Emplacement (FE) experiment”) aimed at studying the thermo-hydro-mechanical (THM) effects induced by the presence of an underground repository. The objective of this paper is twofold. Firstly, the results of the rock mass monitoring programme carried out during the construction of the 3 m diameter, 50 m long FE tunnel are presented, with particular focus on the short-term deformation response. The deformation measurements, including geodetic monitoring of tunnel wall displacements, radial extensometers and longitudinal inclinometers, indicate a strong directionality in the excavation response. Secondly, the deformational behaviour observed in the field is analyzed using a hybrid finite-discrete element (FDEM) analysis to obtain further insights into the formation of the excavation damaged zone (EDZ). The FDEM simulation using the Y-Geo code is calibrated based on the average short-term response observed in the field. Deformation and strength anisotropy are captured using a transversely isotropic, linear elastic constitutive law and cohesive elements with orientation-dependent strength parameters. Overall, a good agreement is obtained between convergences measured in the field and numerical results. The simulated EDZ formation process highlights the importance of bedding planes in controlling the failure mechanisms around the underground opening. Specifically, failure initiates due to shearing of bedding planes critically oriented with respect to the compressive circumferential stress induced around the tunnel. Slippage-induced rock mass deconfinement then promotes extensional fracturing in the direction perpendicular to the bedding orientation. The simulated fracture pattern is consistent with previous experimental evidence from the Mont Terri URL.

1. Introduction

The deep geological disposal of nuclear waste in an indurated clay formation, called the Opalinus Clay, is currently being assessed in Switzerland. Owing to its very low hydraulic conductivity, high radionuclide retention capacity, and self-sealing of fractures, the Opalinus Clay is considered a potential host rock formation for the long-term storage of radioactive waste (Blümling et al., 2007). However, the development of an excavation damaged zone (EDZ) around the underground structures, including emplacement tunnels and shafts, needs to be considered when assessing both short- and long-term safety of the repository. Apart from directly affecting the stability of the excavation during construction, the EDZ is typically associated with a permeability increase of several orders of magnitude due to the formation of newly connected porosity related to the fracturing of intact rock and shearing along structural features, such as tectonic faults and bedding planes. Therefore, the formation of the EDZ, and its evolution with time, needs to be evaluated as part of the safety assessment for any potential disposal site.

Over the past 15 years, an extensive experimental research programme has been conducted at the Mont Terri underground rock laboratory (URL) to characterize the EDZ in Opalinus Clay. A distinctive feature of damage development in this type of argillaceous rock is the fundamental role played by the anisotropic material

* Corresponding author. Tel.: +1 416 978 0125.
E-mail address: giovanni.grasselli@utoronto.ca (G. Grasselli).

http://dx.doi.org/10.1016/j.tust.2014.09.014
0886-7798/