Coupled thermo–hydro–mechanical processes for the Dutch radioactive waste repository

Buragohain, Poly; Vardon, P.J.; Hicks, Michael

Publication date
2016

Published in
Proceedings of the 2nd Petrus-OPERA PhD and early stage researcher conference 2016

Coupled Thermo–Hydro–Mechanical Processes for the Dutch Radioactive Waste Repository

P.Buragohain[1], P.J. Vardon [2], M.A. Hicks[3],

P.Buragohain@tudelft.nl / P.J.Vardon@tudelft.nl / M.A.Hicks@tudelft.nl

[1,2,3] Section of Geo-Engineering, Delft University of Technology
P.O. Box 5048, 2600 GA Delft, The Netherlands

[1]Post-Doctoral researcher. [2]Assistant Professor, [3]Professor

Abstract

Disposal of spent nuclear fuel and long lived radioactive waste in deep clay geological formations is one of the promising options worldwide. In this concept of the geological disposal system, the Boom Clay is considered as a potential host rock when designing a generic waste repository in the Netherlands. For design and evaluation of a repository for geologic disposal of nuclear wastes one of its principal concern is the thermal loading. High-level radioactive waste and spent fuel generate considerable amounts of heat. When those waste types are disposed in a geological repository the elevated thermal effect on the behaviour of soils surrounding nuclear waste disposal give rise to change in hydraulic and mechanical properties is a significant factor for repository design. Understanding these time-dependent phenomena processes in relation to both the effects of pore water dissipation and of the thermal expansion is essential for reliably assessing repository performance and evaluating the safety case. This paper presents some of the investigation on the thermal processes with emphasis on the coupled Thermo-Hydro-Mechanical (THM) processes for the disposal concept of a radioactive waste disposal facility, in Boom Clay at a depth of about 500m.

Keywords: radioactive waste, disposal, Boom clay, thermal, thermo-hydro-mechanical behaviour.

Introduction

Deep geological disposal of high level radioactive waste and spent fuel is considered the safest and most sustainable option long term nuclear waste containment and isolation. The Boom Clay is considered as a potential host rock when designing a generic waste repository in the Netherlands. As a starting point in the third Dutch research programme OPERA, in a Dutch disposal concept, a geological disposal facility is assumed to be constructed in bedrock 500 meters depth and with a stratum thickness of about 100m. As the high level nuclear waste generates a great amount of heat it needs to be temporarily stored for some years before disposal. For Netherlands the interim storage period is for 100 years. However even after this, the residual heat production is expected to produce a raise of temperature in the near as well as the far field. Various coupled mechanical (M), hydraulic (H) and thermal (T) perturbations will be induced in the surrounding clay host rocks and create a disturbed zone, during the various stages of the repository evolution: the excavation, construction, emplacement and post-closure. Of particular importance in such a clay rock is the zone surrounding the disposal galleries, which will have plastic deformations, influencing the stability of the tunnel and the hydraulic conductivity of the rock. The prediction of the evolution of various changes in properties within this zone are major issues especially in the context of underground nuclear waste disposal. To further planning and design the Boom Clay response for coupled THM is terms of performance and safety functions, as well as financial and engineering feasibility is addressed in this paper.

Methods

A 2D plane strain model was utilised, as the disposal tunnels are designed to be 50 m in length. An elasto-plastic hardening material model, the Hardening Soil (HS) model, was previously calibrated for Boom Clay behaviour [1] from limited experimental data and these parameters are utilised here. An initial mechanical and thermal assessment, taking into account the uncertainties in the material behaviour is presented in [1] and this paper extends that work to consider the thermo-hydro-mechanical (THM) coupled behaviour. The major THM coupled processes are first presented and then a numerical simulation utilising a commercial geotechnical numerical model [2] for this specific case is presented. The model incorporated the excavation, construction and post-closure stages of the repository.

The domain of the numerical model was 80 × 160m, discretised using 15-node triangular elements and refined in the close vicinity of the tunnel, excavated at a 500 m depth and with a 1.6 m radius, in the Boom Clay layer. The initial vertical effective stress in the domain was set to increase with depth (10 kPa/m) with a total vertical stress of 4.2 MPa applied along the top boundary, the pore pressure was initially hydrostatic and the initial temperature set to 295 K. The bottom mechanical boundary was fixed, the left-side and right-side boundaries were fixed in the horizontal direction (due to symmetry) and free in the vertical direction. The analysis was conducted in 3 stages: (i) a K0 stage, where the horizontal stresses were calculated, (ii) an excavation and construction stage, where the tunnel lining was included and contracted representing rock relaxation, and (iii) a heating THM stage, where a heat flux representing the flux from the emplaced waste was applied to the tunnel boundary. An initial heat flux of 11 W/m^2 was applied and reduced over time, based upon the expected radioactive decay.

Results and Discussions

Figure 1 presents contour plots of the drained response showing the variation of (a) the pore pressures at the end of 30 years, (b) the temperatures at the end of 30 years when the temperature is at its peak, and (c) the plastic and failure points of the model after construction and after 30 years. The results are presented in terms of the pore pressures changes, the stress/strain response, the temperature and the plastic zone development. The simulated results indicated a rapid increase in pore water pressure during the first few decades in conjunction with temperature increase, followed by stabilisation and decay of both. This sharp initial increase in pore water pressure and the occurrence of thermal consolidation at the beginning is explained to the slower water dissipation rate of the Boom Clay. This is followed by a rapid increase in pore water pressure.

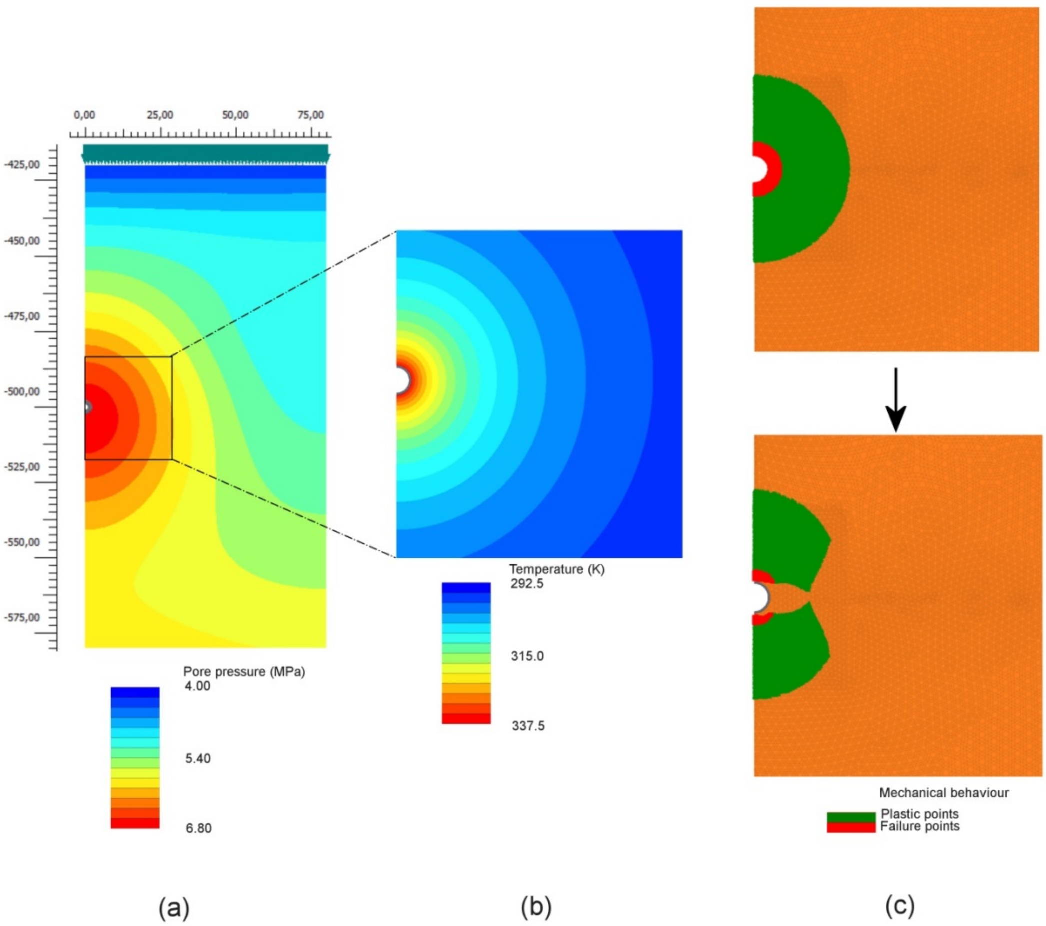

Figure 1. Contour plots of (a) pore water pressure at 30 years, (b) temperature at 30 years, and (c) plastic zone after construction and at 30 years

The study indicated that the magnitude of the excessive pore pressure depends not only on the temperature increase, but is sensitive to the hydraulic conductivity. It can be seen that at 30 years the extent of the hardening zone (plastic points) increases negligibly in the vertical direction and decreases in the horizontal direction. This reduction in the plastic zone is due to the thermal expansion of the liner and an increase in the confining pressure. This pore pressure increase causes a decrease in the mean effective stress, albeit with the impact reduced by an increase in confining pressures by the thermal expansion of the tunnel lining. This leads to an increase in the plastic shear deformation and the extent of the plastic zone and an increase in total stresses on the liner. The hydraulic conductivity plays a critical role in the development of the plastic zone, as this controls how easily the thermally induced excess pore pressures are dissipated.

Conclusion

The stability of the performance and safety assessment during operation and post-closure stage was addressed in this study. Coupled Thermo-hydro-mechanical behaviour of the boom clay was utilised as well as studies related to peak temperature, thermally induced pressurization of boom clay pore water, on the repository design was analysed*.* The modelling results demonstrated there exists a strong coupling between the thermal, mechanical hardening behaviour and the hydraulic response The results showed that while the temperatures reached in this disposal concept are not of concern, the additional mechanical load should be considered. For safety assessment, a low hydraulic conductivity is favoured to reduce the possibility of advective flow, which causes an additional mechanical load on the liner.

Acknowledgments

The research leading to these results has received funding from the Dutch research programme on geological disposal, OPERA. OPERA is financed by the Dutch Ministry of Economic Affairs and the public limited liability company Elektriciteits-Produktiemaatschappij Zuid-Nederland (EPZ), and is coordinated by COVRA.

References and Citations

[1] P. Arnold, P.J.Vardon, M.A. Hicks, J. Fokkens, P.A. Fokker, “ A numerical and reliability-based investigation into the technical feasibility of a Dutch radioactive waste repository in Boom Clay.” Report no. OPERA-PU-TUD311. COVRA. 2015, pp. 316. (available http://www.covra.nl/cms-file/get/iFileId/2844)

[2] Plaxis, *PLAXIS 2D Anniversary Edition - Reference Manual*. Plaxis bv: Delft, 2014.