Earthquake Modelling and Application to Long-term Safety Analysis of a Final Repository of Spent Nuclear Fuels in Forsmark Sweden

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1. Introduction

In 2011, the Swedish Nuclear Fuel and Waste Management Company (SKB) has submitted a license application to the Swedish Government to obtain a license for construction of a final repository for spent nuclear fuels at Forsmark. This study was conducted as a part of the review by the Swedish Radiation Safety Authority (SSM) on SKB's application. This study addresses one of several scenarios that could impair the physical integrity of the repository of spent nuclear fuel at the Forsmark site, which is a seismic event, i.e. earthquake, occurring at a nearby fault. The effect relevant to the repository safety is the shear displacement of rock fractures induced by an earthquake. In SKB's assessment, a shear displacement of 50 mm of a target fracture that crosses a canister position in the repository area is regarded as the upper limit of canister failure. For such analysis, we developed a numerical modelling work flow using a discrete element model and applied to this task.

2. The Forsmark Repository Model

The Forsmark repository model is generated based on the integrated deterministic geological model [1] shown in Fig. 1. Our discrete element based Forsmark model is generated to contain the deformation zones (green traces) and the discrete fracture network (red) distributed in the repository rock mass at the depth of the repository, i.e. depth = 450 m [2]. The arrows indicate the orientation of the maximum horizontal stress at present day in situ stress condition.

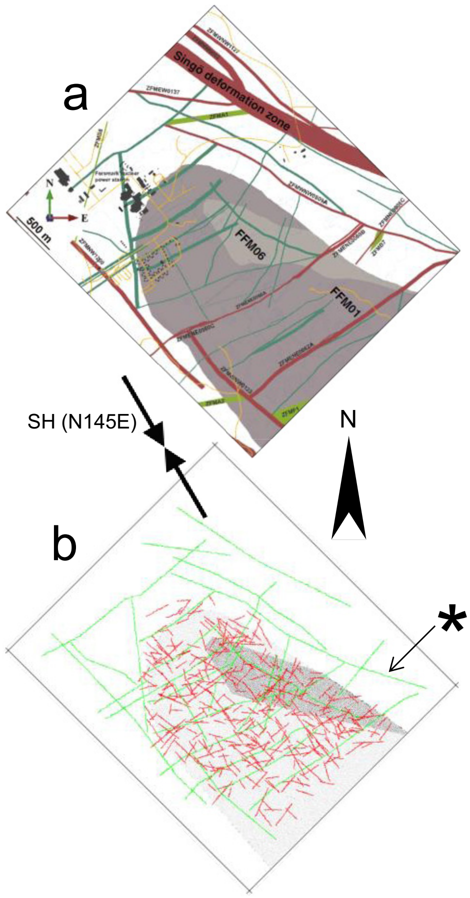

Fig. 1. (a) Integrated deterministic geological model of the Forsmark site at the depth of the repository [1], (b) the Forsmark repository model generated in this study using discrete element model [2].

3. Modelling Earthquake Source: Dynamic Fault Rupture, and Fracture Slip

For simulation of an earthquake, we chose a deformation zone named ZFMWNW0809A (indicated * in Fig.1b). An earthquake is simulated by releasing the strain energy that is accumulated along the trace of ZFMWNW0809A under a given stress field. Upon releasing the strain energy, a seismic wave is generated from the rupturing fault trace and travels through the model and at the same time attenuates due to the damping of the rock mass, failure of the rock mass and slip of the discrete fracture network where the seismic energy is partially consumed. After a seismic wave passes through the repository rock mass, a redistribution of the stress field follows due to permanent deformation (slip) of the ruptured fault which further induces repository rock mass failure and post-seismic slip of the discrete fracture network. In this way, a main-shock and an after-shock of an earthquake are truly simulated. Here in this study, we only analyze the coseismically induced slip of the discrete fracture network. Fig. 2 demonstrates the results showing the hypocentre of the fault rupture (black star with M4.9) and coseismically induced slip of the discrete fracture network.

We also show in Fig. 2b distribution of the fracture slip induced by the same fault rupture under glacially induced stress condition, especially when the glacial ice cover approaches the repository area and results in lithosphere forebulge. The comparison shows that in both cases, there is no fracture with slip displacement exceeding the 50 mm canister damage limit, which led to a conclusion that for the tested cases (activation of the fault ZFMWNW0809A) the integrity of the repository can be ensured.

4. Application to Seismic Risk Study of Kyeong-Ju Repository

Recent Kyeong-Ju earthquakes occurred on 12 September 2016 have resulted in uprising attentions in Korea. The earthquake was followed by 365 aftershocks (as of 18 Sep. 2016; 341 M1.5-3, 14 M3-4, 1 M4-5). The seismic risk of the earthquake is higher than any other cities as the city of Kyeong-Ju hosts an underground repository for low and intermediate nuclear wastes at 500 m depth and Wolseong Nuclear Power Plant (NPP) which are 25 km distance from the epicenter of the earthquake.

The modelling method we present in this paper can be applied to a study of seismic risk of Kyeong-Ju repository and NPP. Such study would be highly needed as there is an ongoing debate that the repository was build in a geological condition where the presence of the nearby faults and their reactivation potential are poorly investigated at the time of site selection and construction of the repository. The three recent earthquakes near Kyeong-Ju with M>4 have clearly demonstrated that the nearby faults have potential to reactivate. In particular, seismic risk of resulting from Yang-San fault earthquake should be carried out using a numerical modelling of this kind, as it is the largest fault in that area and estimated to host M>6 earthquakes in the future.

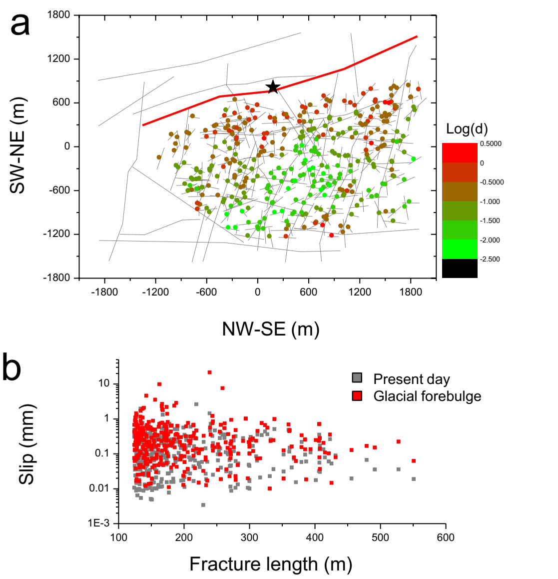

Fig. 2. (a) Distribution of the coseismically induced slip, d, (mm) of the discrete fracture network, colored by log(d), (b) Comparison of the fracture slip distributions induced by an earthquake occurring under present day stress (gray) and glacially induced forebulge stress (red) conditions.

REFERENCES

[1] MB. Stephens, S. Follin, J. Petersson, H. Isaksson, C. Juhlin, A. Simeonov, “Review of the deterministic modelling of deformation zones and fracture domains at the site proposed for a spent nuclear fuel repository, Swede, and consequences of structural anisotropy”, Tectonophysics, 653, 68-94 (2015).

[2] JS. Yoon, O. Stephansson, A. Zang, KB. Min, F. Lanaro, “Numerical modelling of earthquakes and induced seismicity under various in situ stress conditions at Forsmark, the site for a final repository of spent nuclear fuel”, In Proc of the 7th Int Symp on In-Situ Rock Stress – RS2016 Symposium, May 2016, Tampere, Finland.