Shear Slip Potential Induced by Thermomechanical Loading in an Underground Repository for Nuclear Waste

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1. Introduction

Various studies have shown that shear slip at existing fractures is an important mechanism for block sliding, increase of fracture permeability, and microseismicity. In the context of a deep geological repository for nuclear waste, the thermal stress generated by nuclear waste is expected to contribute to shear slip and dilation, which will eventually alter the fracture permeability in the region. In this study, the probability of the occurrence of shear slip at a fracture was examined by the Mohr-Coulomb failure criterion. The study was based on the fracture orientation generated by the Latin hypercube sampling (LHS) method, which can improve the efficiency of Monte Carlo simulations by the use of a more systematic approach for selecting the input samples. Statistical data of fracture orientations from the site investigation in Forsmark, Sweden, were used in this study. The historical assessment of thermal stress was based on three-dimensional finite element modeling (FEM) of a geological repository that measures 800 m by 2000 m and on a time scale up to 10,000 years. The results show that the probability of shear slip evolved differently at six selected points due to the difference stresses at each point. However, it was evident that the probability of shear slip was more than twice as large as the initial probability of failure. This increased probability of failure has implications for changes in permeability and microseismicity, which can be an issue during the initial operation of the repository. The study provided a quantitative assessment of the probability of shear slip at a fracture, which is an important parameter for assessing the performance of a geological repository.

2. Probability of shear slip at the selected points

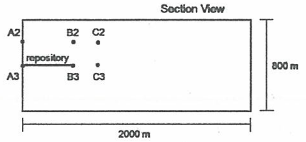
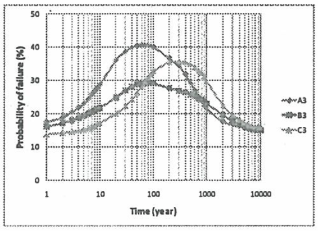
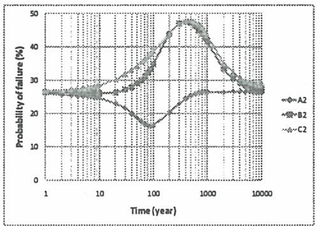


Fig. 1. Section view of repository with selected points

Six points around the repository were selected to estimate the probability of shear slip at depths of 200 m and 400 m as shown in Fig. 1 [1].



(a)



(b)

Fig. 2. Probability of failure with time of general data with random distribution - (a) A3, B3, and C3 and (b) A2, B2, and C2

Figure 2 shows the probability of shear slip at randomly oriented fractures at six selected points. The main observations are described below.

In Figure 2(a), the probability of failure increases as thermal stress increases because the thermal stress creats significant differences in the horizontal and vertical stresses. Also the location of A3, B3 and C3 makes the difference of probability and the delay of maximum probability. Interestingly, the maximum probability of failure at C3 was greater than B3 because the differences between horizontal thermal stresses at C3 are larger than that at B3.

In Figure 2(b), the initial probability of failure at A2, B2, and C2 is greater than A3, B3, and C3 because the ratio of horizontal stress to vertical stress is greater at shallower depth. It is noted that the shape of the graph for A2 is distinctly different from that of the other graphs. When the temperature at A2 is increased, tensile stress occurs at A2, and that stress causes a decrease of failure probability.

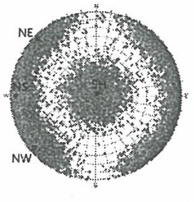
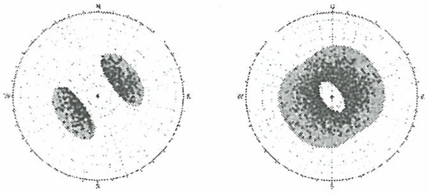
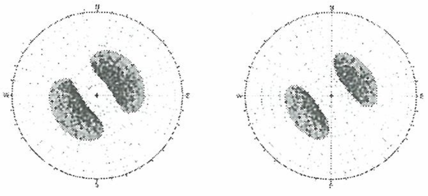


Fig. 3. Fracture data and mean poles from Forsmark



(b) Initial state (c) After 100 years



(d) After 1,000 years (e) After 10,000 years

Fig. 4. Evolution of shear slip zone (shaded area) at A3 with time and the actual fracture vulnerable to shear slip (point) are shown in the plots.

The probabilities of failure with actual fracture orientation at Forsmark site are far less than 1 % even if the shapes of the graphs are similar to the graph in Fig. 2. In order to investigate the cause of this low probability of failure, we plotted the evolution of shear slip zone as shown in Fig. 4. The shaded area is the distribution of fractures for which shear slip can occur, and the points are the distribution of actual fractures vulnerable to shear slip. As Fig. 4 shows, the number of overlapping fractures with the shear slip area is very small, and that means the majority of the fracture set orientations are not vulnerable to shear slip.

3. Conclusions and Ongoing work

Conclusions are summarized as follows:

- With random orientation data, the probability of shear slip around the repository model increases with increased thermal stress.
- The probability of shear slip depends on the manner in which the thermal stress is generated. Higher shear slip is expected with higher differential thermal stress.
- The probability of shear slip at Forsmark was less than 1 %. If different sites have fracture sets with more overlap, however, the probability may become increase. Therefore, a site-specific study must be conducted to investigate the potential for shear slip.

As a further development, a study to quantify the extent of permeability increase is ongoing using an analytical study by Oda's crack tensor [3].

4. Acknowledgement

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5. References

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