Indicator diagram for underground fluid injection induced seismicity

Xiaochen Wei[1,2], Qi Li[1,2], Zhiyong Niu[1,2], Xiaying Li[1,2]

[1]State Key Laboratory of Geomechanics and Geotechnical Engineering, Institute of Rock and Soil Mechanics, Chinese Academy of Sciences, Wuhan 430071, China

[2]University of Chinese Academy of Sciences, Beijing 100049, China

Abstract

Geological carbon sequestration (CCS) is widely regarded as an effective approach to achieving large reductions in greenhouse gas emissions to alleviate climate change during the next several decades. Pressure build-up induced by geological carbon sequestration will decrease the effective stresses in the storage formation, and geomechanical effects of overpressure may affect fault stability, possibly resulting in felt induced seismicity. Predicting the geomechanical stability of faults is of crucial importance for the safety of geological carbon sequestration. In this paper, with the purpose of reducing the risk of fault reactivation by optimizing well placement, we focused on the geometry and structures of the fault zones based on comprehensive analyses of the fault burial depth, fault dip and well location and applied a numerical approach to evaluate the potential magnitude of the fault slippage for a specific stress regime. Based on the relationships of D, H and Φ (where D is the distance between the fault and the injection well, H is the burial depth of the target reservoir, and Φ is the fault dip) with the corresponding fault behavior, we obtained a traffic light indicator diagram and a danger surface to indicate the risk of induced seismicity at a specific level of each factor. This simplified approach provides a fast way for prioritizing the well location to avoid the risk of inducing strong seismicity. The following conclusions can be drawn based on the investigation:

1. Because of the reduced pore pressure increase at spots farther from the injection zone, the negative correlation between the magnitude of the induced slippage and the distance between the fault and the injection well (D) is not site-specific but exists at every thickness of the overburden and fault dip.
2. The induced fault slippage events present similar tendencies (with the upper portion of the fault plane slipping downward and the lower portion of the fault plane slipping upward) and become violent at 180 m and 320 m, resulting in squeezing at the middle position of the fault plane; the induced slippage here is reduced to zero.
3. The induced fault slippage generally decreases with depth when the fault is gentle or steep. However, this correlation become complicated at medium fault dips (40°, 50°, 60°, 70°and 80°): at a shallow depth (800 m to 1400 m), the induced fault slippage more or less decreases with depth, whereas below 1400 m, this induced fault slippage unpredictably becomes even more significant with depth. At certain fault dips (40°, 70°and 80°), the induced fault slippage is found to increase with depth below 2200 m, and at 60°, the induced fault slippage is relatively large at all depths.
4. The distance from the injection well to the fault (D) is the key factor to avoid felt seismicity, as indicated by Figure 7 (a). In the traffic light indicator diagram, no felt seismicity would be

induced in the green zone, and in the amber zone, felt seismicity is unlikely at certain fault dips (10°, 20°, 30° and 90°). In the red zone, the risk is high for induced felt seismicity for all fault dips.

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