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May underground gas storage induce/trigger anthropogenic seismicity?

Underground Gas Storage (UGS) represents an increasingly widespread approach to cope with the need for a concentrated energy demand in many countries worldwide. Gas is injected in depleted deep reservoirs during the hot season when consumption is limited and withdrawn in the cold season mainly for heating. The UGS operations involve a gas pore pressure fluctuation between a maximum close to the value pi prior to field development and a minimum usually larger than the lowest pore pressure experienced by the field during its primary production life. The risk of a possible seismicity of anthropogenic origin is connected with the likely reactivation of existing faults in the reservoir and its surroundings. The high (i.e. yearly) frequency variation of the pore pressure generally confines the volume where changes occur to the reservoir volume without importantly affecting the formations closest to the hydrocarbon field, i.e. the upper caprock and the lateral/bottom aquifers (the so called waterdrive).The risk of inducing seismicity is therefore restricted to those cases where existing faults/thrusts cross or bound the gas bearing strata. The prospective fault reactivation caused by UGS activity is herein investigated by an advanced 3-D transversally isotropic Finite Element (FE) – Interface Element (IE) elasto-plastic geomechanical model implemented into the Emilia reservoir, Italy, which is used as a representative test case. The gas field was developed during the 1960s and later converted to UGS from the mid 1970s. Two reversed faults cross the field and confine the aquifers hydraulically connected to the reservoir. Gas storage/withdrawal is ongoing with pressure p ranging approximately between pi in October/November and 60% pi in April/May with a p fluctuation on the order of 50 bars. The FE-IE model is quite successfully calibrated using the vertical and west-east land displacements measured by advanced persistent scatterer interferometry over the period 2003-2010 with a most realistic evaluation of the shear modulus G of the rock hosting the activated portion of the faults. It is shown that the rock stress variations are basically confined within the gas field and negligibly propagate into the caprock and the waterdrive. Based on the Mohr-Coulomb failure criterion, IEs allow for the prediction of the fault activated area A, located at the reservoir depth, as expected, and slip displacement d. A few parametric scenarios are investigated to address the major uncertainties of the geomechanical fault properties, i.e. cohesion c and friction angle Φ of the fault materials, and the initial stress regime (passive or compressive basin). The magnitude M of the prospective seismic events induced/triggered by the fault reactivation is assessed by an empirical relation derived from seismological theories and used worldwide. M turns out to be correlated to the activated volume A·d and the shear modulus G. With $G = 3.9 \cdot 10^4$ bar, as provided by the calibration of the geomechanical model, the prediction points out that M does not exceed 1 in the most conservative scenario, namely c = 0 bar and Φ = 30°, entirely instantaneous slip and a passive stress basin. With c = 10 bar and a compressive stress regime, both most plausible conditions for the investigated reservoir, the fault practically does not activate with M decreasing to negative values. Consistent with the records from a local micros seismic network, the study provides conclusive evidence that the UGS activity for the case addressed herein is not a matter of concern in relation to the risk of induced anthropogenic seismicity.

Biography

Giuseppe Gambolati graduated with honors in Mechanical Engineering at the Polytechnic of Turin. After a brief stint as assistant of Applied Mechanics, he was hired by IBM Research Center in Venice therein completing a scientific career to senior researcher. There he developed, among many other activities, the first model of anthropogenic land subsidence in Venice (1973). In 1980, he became Professor of Numerical Methods in Engineering at the University of Padova. In 2008, he received the Excellent Contributions Award of IACMAG (International Association for Computers Methods and Advances in Geomechanics) for "significant contributions in research, academic activities and professional service in different regions of the globe". In 2011, he was elected Fellow of the American Geophysical Union for his unique and seminal contributions to geomechanical aspects of subsurface fluid flow.

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