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孔隙水圧変化による応力分布と亀裂進展
Stress field and fracture propagation due to the change of injection pressure

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Hydraulic fracturing is an indispensable scheme to stimulate fluid production in hydrocarbon reservoir development in conjunction with various well testing methods such as drill stem, buildup tests, etc. In recent years, it is also well known that hydraulic fracturing plays a major role in the development of shale oil or gas reservoirs.

The extension length and the orientation of fractures induced by hydraulic fracturing are strongly influenced by the crustal stress field under which any reservoirs are located. Therefore the propagation of fractures is controlled by the regional stress field. It is, in general, necessary to get some understanding of regional stress field before the application of hydraulic fracturing as well as acquiring the rock physical properties of reservoir formations.

However, hydraulically induced fractures may not be created as planned and could cause some environmental issues such as pollution, induced seismicity, etc. It is, we think, very important to estimate how fractures are induced under various crustal conditions to cope with unexpected behavior of fracture propagation.

We focused the effects of the in-situ stress on the stress field around the pre-existing fracture and the fracture propagation with both steady and non-steady hydraulic pressure conditions. To simulate failures in crustal materials under the complicated stress field, we use an extended finite element method (X-FEM) in this study, which can retrieve the stress distribution affected by fractures effectively and estimate the fracture propagation based on linear elastic fracture mechanics (LEFM). Numerical simulations are conducted for a 2D elastic medium having a borehole and a pre-existing fracture. We put the pre-existing fracture around the borehole initially and simulate the propagation of this fracture by applying the hydraulic pressure. The velocity of fracture propagation and the interval of the stress recovery from the stress drop caused by the propagation are set uniformly for the kinetic simulation.

We first simulate the fracture propagation around the borehole under different steady hydraulic pressures with regional stress field. Then we try to see how the fracture could propagate with the non-steady hydraulic pressure during the propagation.

We confirmed that the orientation of the fracture propagation converges to that of the principal stress. Moreover, the convergence speed could be inversely related to the hydraulic pressure. We also found the time delay of the influence of the hydraulic pressure change to the fracture propagation with non-steady hydraulic pressure condition.

From the results of our numerical simulations, we would like to have two conclusions. First, the curvature of the fracture trace depends on hydraulic pressure, but no matter how the fluid pressure is, the orientation of fracture propagation converges to that of principal stress. Second, the transition of the stress field involves the time delay, which leads to the delayed response of the fracture propagation in the non-steady hydraulic pressure condition.

When we develop a hydrocarbon reservoir using hydraulic fracturing, the orientation of maximum in-situ principal stress and the fluid pressure for fracturing should be quantitatively taken into account for the environmental safety and for the stimulation efficiency. It might be also necessary to consider the time delay of the transition of the stress due to the non-steady hydraulic pressure.

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