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The role of local stress perturbation on the simultaneous opening of orthogonal fractures

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Orthogonal fracture networks (ladder-like networks) are arrangements that are commonly observed in outcrop studies. They form a particularly dense and well connected network which can play an important role in the effective permeability of tight hydrocarbon or geothermal reservoirs. One issue is the extent to which both the long systematic and smaller cross fractures can be simultaneously critically stressed under a given stress condition. Fractures in an orthogonal network form by opening mode-I displacements in which the main component is separation of the two fracture walls. This opening is driven by effective tensile stresses as the smallest principle stress acting perpendicular to the fracture wall, which accords with linear elastic fracture mechanics. What has been well recognized in previous field and modelling studies is how both the systematic fractures and perpendicular cross fractures require the minimum principle stress to act perpendicular to the fracture wall. Thus, these networks either require a rotation of the regional stress field or local perturbations in stress field.

Using a mechanical finite element modelling software, a geological case of layer perpendicular systematic mode I opening fractures is generated. New in our study is that we not only address tensile stresses at the boundary, but also address models using pore fluid pressure. The local stress in between systematic fractures is then assessed in order to derive the probability and orientation of micro crack propagation using the theory of sub critical crack growth and Griffith's theory. Under effective tensile conditions, the results indicate that in between critically spaced systematic fractures, local effective tensile stresses flip. Therefore the orientation of the least principle stress will rotate 90°, hence an orthogonal fracture is more likely to form. Our new findings for models with pore fluid pressures instead of boundary tension show that the magnitude of effective tension in between systematic fractures is reduced but does not remove the occurring stress flip. However, putting effective tension on the boundaries will give overestimates in the reduction of the local effective tensile stress perpendicular to the larger systematic fractures and therefore the magnitude of the stress flip. In conclusion, both model approaches indicate that orthogonal fractures can form while experiencing one regional stress regime. This also means that under these specific loading and locally perturbed stress conditions both sets of orthogonal fractures stay open and can provide a pathway for fluid circulation.