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Verification of Fracture Extent Using Surface Deformation Data

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Background/Objectives. Fracturing technologies have been used for decades to place remedial agents within contaminated formations. A variety of methods have been employed to measure the resulting fracture forms – the extent, aperture, elevation, dip, etc. – and thereby assess effectiveness of the fracturing method and establish expectations for remedial performance. Among these methods are measurements of ground surface deformation – either tilt, uplift, or both.

Often the interpretation of uplift or tilt merely assigns the extent of the fracture to occur at locations of some threshold value of the data, e.g. along a contour of “zero” uplift that, essentially, is extrapolated from discrete, non-zero data. Difficulties of extrapolation aside, this approach has validity only for the shallowest fractures (shallow being defined by the ratio of depth and extent) that essentially are horizontal. More sophisticated quantitative methods have been developed to deal with deeper and dipping fractures. While such quantitative approaches soundly consider the physics of elasticity in homogeneous media, the simplifying assumptions of planar form, idealized simple plan shape, aperture distribution, and overburden structure too often contradict the saucer-shaped or bowl-shaped forms that have been revealed by excavation, and cannot accommodate lobe-like emplacement of proppant that is known to occur during fracture growth. One frustrating consequence of the poor models is imprecision and inaccuracy leading to unreliable or unusable estimates of fracture form.

These shortcomings define at least a pair of needs: 1) an assessment method that is applicable to deep, intermediate, and shallow fractures of realistic form, and 2) a robust method that is sufficiently rapid and easy to use that it can be applied to site-scale datasets and provide answers in near-real time.

Approach/Activities. We developed a parameterized finite element model (FEM) of soil or rock deformation around an induced fracture. We used parameter estimation to establish best-fits of tilt and uplift data for fractures created at multiple sites where subsequent excavation revealed the fractures for detailed measurement and characterization. Having verified and validated the FEM, we can use it predict the magnitude and distribution of tilt and uplift that may occur over planned fractures and thereby better design the surface deformation monitoring program.

Results/Lessons Learned. The FEM approach does match tilt and uplift data more precisely than previous methods. For example, a rudimentary method for assessment of uplift data overestimated extent of fractures created in saprolite and residuum in Piedmont soils, whereas a simplistic analysis of tilt underestimated extent. At another site, the FEM approach provided parameter estimates with smaller statistical variance than the simplistic analysis of tilt that utilizes simple planar form. Tilt and uplift predicted by the FEM approach for hypothetical shallow, horizontal fractures depends strongly on sharpness of lateral changes of fracture aperture, and thus whether selected threshold values of tilt and uplift occur within or outside the plan of fracture extent requires a priori assessment of fracture form.

In summary, this FEM approach promises to serve as a more reliable evaluation tool in fracturing projects.