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Verification and Validation of computational models for shaped charge jet completion of well bores in fluid saturated sandstone

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Completion of cased and cemented wells by shaped charge perforation is a now standard method to establish a pathway liberating oil entrained in reservoir sandstone. However, the penetration event causes its own damage to the formation, potentially reducing well productivity by lodging fragmentation fines in pore throats. To simulate the perforation and penetration process, a computational framework must accommodate massive deformations (usually necessitating an Eulerian solver) while at the same time preserving the integrity of highly history-dependent internal state variables in constitutive models for inelastic flow, damage, and fracture. Results from a three year effort to improve predictive capability of numerical models of well bore completion are summarized. A hierarchical approach to verification and validation (V&V) is underway that begins with numerous straightforward verification tests, then introduces simple partial constitutive validation tests for simple loading (such as demonstrations that the constitutive models can reproduce observed unconfined and confined uniaxial stress data for drained and undrained sandstone), partial validation of the solvers for penetration of aluminium plates, and culminating in a full-scale simulation of the entire completion process consisting of: manufacture of the shaped charge jet liners, explosive formation of the jet, perforation of the metal well bore casing and cement, penetration of the compressed saturated sandstone, and subsequent flow of water and oil from the formation. The parts of this V&V effort to be discussed include: qualitative trend testing of the manufacturing process for power-compacted liners, trend testing (with some quantitative verification against idealized models) of the new effective-stress component of the sandstone constitutive model, convergence testing for benchmark tests of localization and fracture, massive deformation kinematics trend testing in a converging plate problem (which emulates shaped charge jet formation without having to worry about the explosives model), incorporation of aleatory uncertainty, and quantitatively assessing accuracy and convergence of the particle-based momentum solver via new manufactured solutions (*cf.*[2]). These new manufactured solutions allow quantifying accuracy of the host code's solver when it is used with history-dependent plasticity and damage constitutive models (these tests also assess basis and frame indifference of the constitutive model). Benefits of hierarchical approaches to V&V include catching anomalous behaviours, such as under-integration of the Jacobian in large shear time steps, that would not have been otherwise detected in "reasonable looking" simulation results.[3] These verification tests are illustrated in an example that quantitatively reveals advantages of a particular enhancement of the material point method[4] over other large-deformation solvers.

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[2]P. Knupp and K. Salari, *Verification of Computer Codes in Computational Science and Engineering*, Chapman and Hall/CRC, (2003).