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SIMULATION OF SHAPED-CHARGE JET PENETRATION INTO DRAINED AND UNDRAINED SANDSTONE USING THE MATERIAL POINT METHOD WITH NEW APPROACHES FOR CONSTITUTIVE MODELING

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Simulation of well-bore completion by shaped-charged jet penetration in porous rock is highly nontrivial and requires a computational method that can support high-rate large deformation, with multiple materials and evolving contact surfaces. The material point method (MPM) is well suited for this application, allowing for large deformation and contact while also supporting history-dependent constitutive models[1]. The material point method can be enhanced using convective particle domain interpolation[2] (CPDI), which uses the evolving deformation gradient of each material point to define the integration domain for mapping to/from the background grid. A novel and straightforward strategy for MPM domain scaling retains the benefits of CPDI while allowing for controlled numerical fracture as well as parallel implementation of the algorithm.

The constitutive model of the target material must account for nonlinear elasticity, pressure dependent strength, porosity effects, and pore fluid effects, all of which may evolve with plastic deformation. For example, depth of penetration typically increases with the ratio of densities of the jet to target material, but the presence of a pore fluid increases the penetration depth despite the increased target density. A constitutive model has been developed that predicts this behavior by using a dynamically evolving pore pressure within an effective stress framework. New plasticity numerical solution methods were developed for this model to allow for robust performance even with highly nonlinear hardening laws.

Results will be presented showing key experimental validation of the trends in penetration depth vs. pore pressure and confining stress. The examples in Fig. 1, which show the

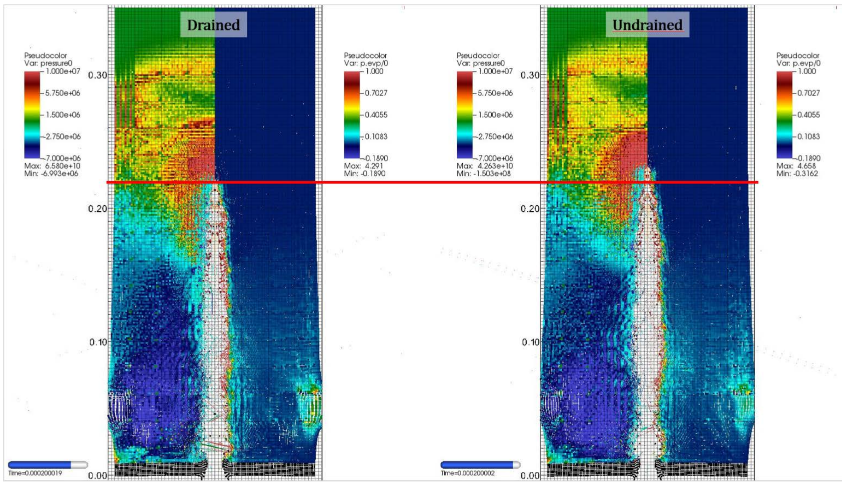

Figure 1: Axisymmetric simulation of channel formation during penetration into drained and undrained sandstone. Each simulation shows a reflected image with contours of pressure (left) and volumetric plastic strain (right)

partially-formed penetration channel for a drained and undrained target material, use the Uintah open-source computational framework[3] that supports massively parallel MPM simulations.

Uintah has been used to simulate formation of the shaped charge jet, but for computational efficiency it is preferable to import a fully-formed jet with a momentum and energy flux defined to match flash x-ray measurements from a real shaped charge. The jet description can be either continuous or discrete, and the relative merits of each approach will be described.

To mitigate mesh dependency in the results, it is necessary to employ variability and scale effects in the strength properties of each material point. This will be discussed along with deformed glyph visualization methods that provide insight into material state and damage in the region surrounding the penetration channel.

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