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Laboratory and Numerical Simulations of Hydraulic Fracturing

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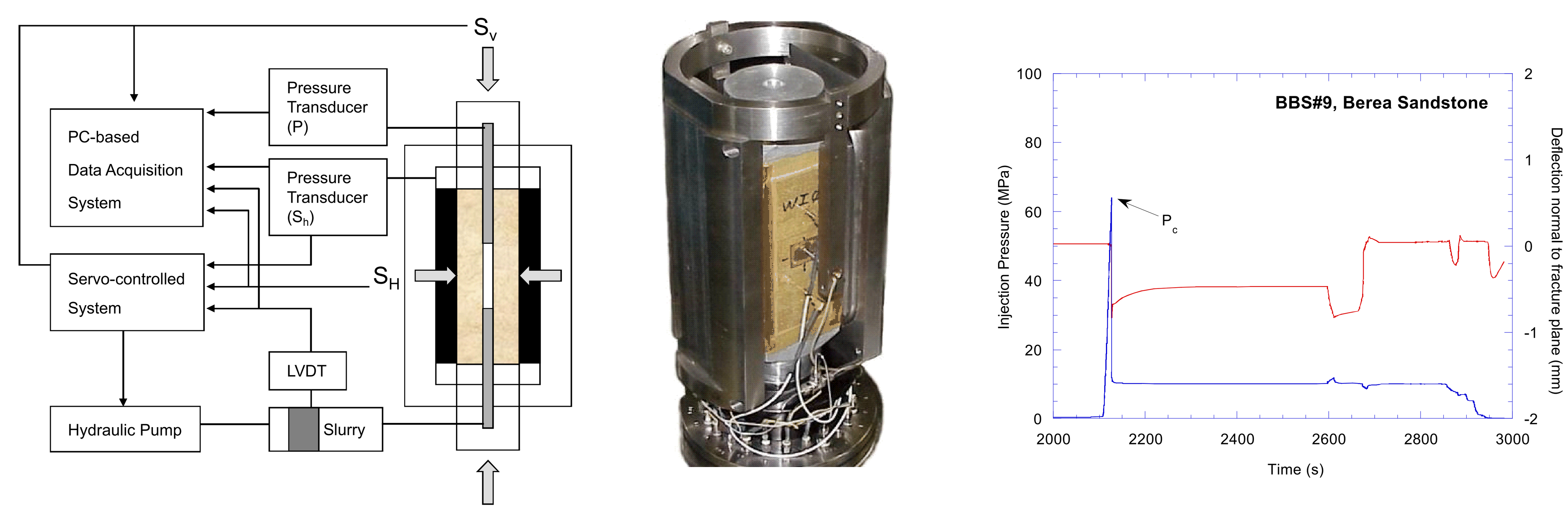
Summary

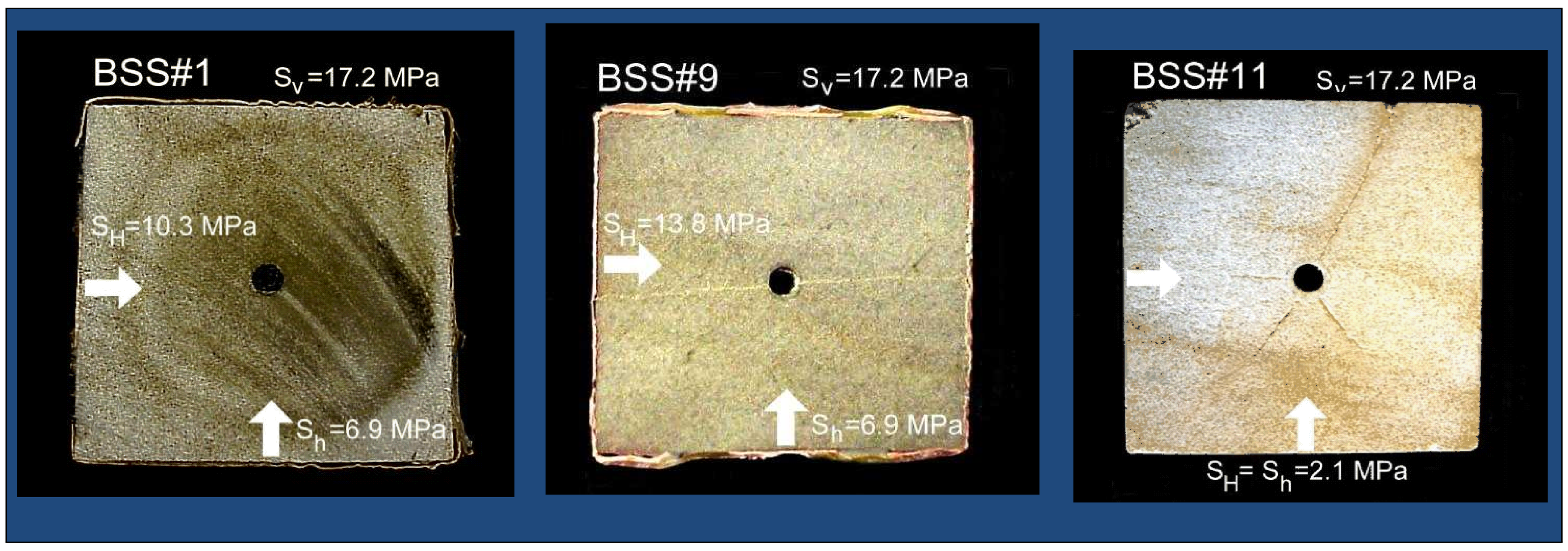
A computationally efficient numerical model based on the discrete-element method (DEM) is described and applied to simulate well-known borehole failure phenomena: hydraulic fracturing and borehole breakouts. Radially graded, two-dimensional DEM models of the near-wellbore region were created of bonded disk elements. Inspired by the molecular model of a fluid, source elements were used to simulate fluid pressurization of the model borehole subjected to far-field stresses.

The calibration and validation of such numerical tools will require extensive comparison against experimental and field data (Wawersik, 2000). To address this challenge, a joint experimental-numerical research effort has been undertaken to develop a robust numerical simulation capability for the exploration and prediction of near-wellbore mechanics. A true-triaxial vessel has been designed and constructed to enable the realistic laboratory simulation of the three-dimensional stress conditions present in the field (Wawersik et. al, 1997).

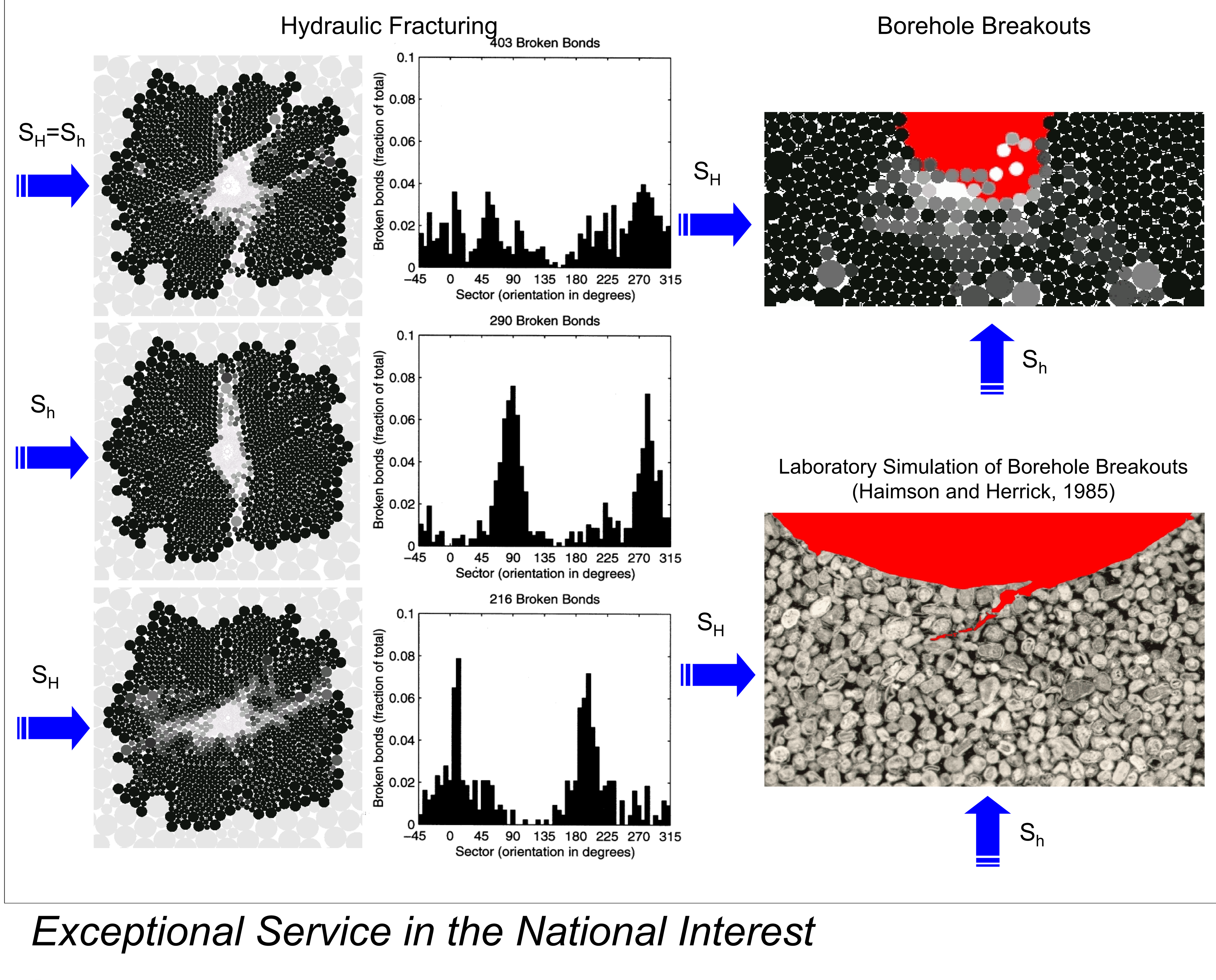
The structural damage in the DEM models was analyzed using histograms of the angular distribution of bond damage; results obtained for various stress states showed qualitative reproduction of the gross failure mechanisms associated with both hydraulic fracturing and borehole breakouts. The results from the laboratory simulation of near-wellbore failures demonstrate DEM's ability to capture the discontinuous failure processes under different stress conditions.

Laboratory Simulation of Hydraulic Fracturing





DEM Simulation of Borehole Failure Phenomena



Particle contact model

The contact deformation is represented by a spring-dashpot system, with shear force magnitude limited by friction. The incremental normal and shear contact force magnitudes, DF_n and DF_s, are given by

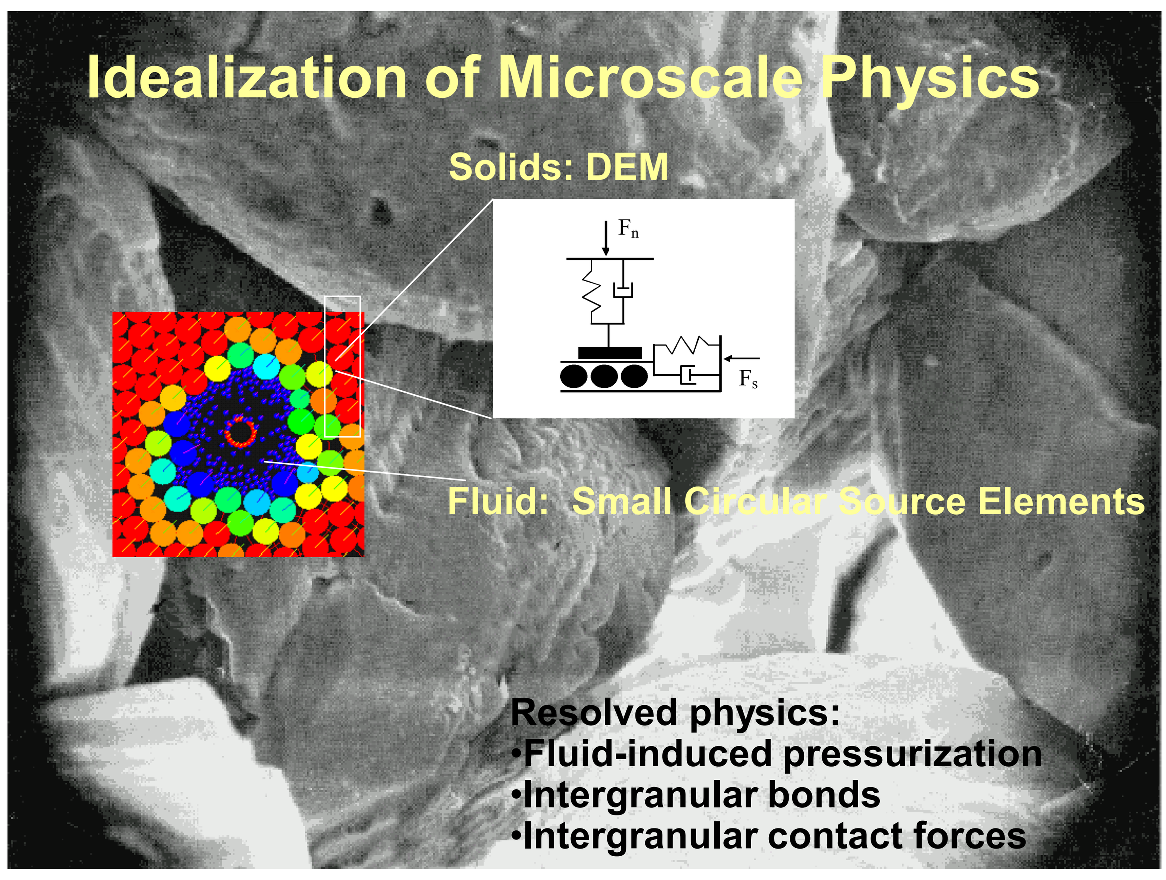
$$\Delta F_n = k_n \Delta t \mathbf{v}_r \cdot \mathbf{n} + c\mathbf{v}_r \cdot \mathbf{n} \quad \Delta F_s = k_s \Delta t \mathbf{v}_r \cdot \mathbf{t} + c\mathbf{v}_r \cdot \mathbf{t}$$

Pressurization of the borehole

Small disc particles are streamed from the source ring into the center cavity, where they collide with the larger elements that define the borehole wall and each other. At each time step a constant force is applied to the source particles to generate the pressure on the wall.

Conclusions

The simulation results clearly demonstrate DEM's ability to reproduce - at least qualitatively - the macroscopic failure processes associated with hydraulic fracturing and breakouts. The laboratory simulation of slurry injection in the anisotropic stress state produced fractures in Berea sandstone that were consistent with the theory of conventional hydraulic fracturing. In contrast, under the isotropic condition multiple fractures were produced in some specimens. Using a discrete particle pressurization technique, the DEM simulations of anisotropic confining stresses exhibited bi-modal distributions of bond failures that were aligned with the axis of maximum confining stress in agreement with laboratory and field data. The DEM simulation of the isotropic condition produced multiple fractures similar to those seen in the laboratory slurry injection tests, suggesting that the DEM fluid more closely represents a slurry than an ideal fluid. DEM simulations of the inverted confining stress conditions induced compressive failures near the borehole wall indicative of the intergranular form of the borehole breakouts phenomenon.



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