MODEL EXPERIMENTS IN HYDRAULIC FRACTURE

J. Dundurs
Civil Engineering Department
Northwestern University
Evanston, Illinois 60201

Hydraulic fracturing of rock cannot be seen in situ, and the end result must mostly be judged on basis of roundabout evidence. As there is no question about the desirability of visual observations and direct measurements, the only way out of the dilemma seems to lie in experimental models. This part of the work carried out at Northwestern University is therefore directed toward the development of suitable experimental techniques and transparent laboratory models that could be used to simulate the various problems associated with drilling into hard impermeable rock and fracturing it for energy extraction.

The material selected for the transparent models is epoxy resin (Epon 828 resin with phthalic anhydrate hardener). This material is commonly used for three-dimensional photoelastic experiments which employ the stress freezing technique. The principal reason for using this material, at least for the present, in studies of hydraulic fracture is that it can be cast into large blocks with relative ease in the laboratory. The only equipment needed for this purpose is a curing oven with accurate temperature control.

The model consists of a block of the transparent epoxy resin. A hole is drilled into the block, and stainless steel tubing is cemented into the hole. The tube terminates at about two diameters from the bottom of the hole. The stainless steel tubing used is 0.063 in. OD, 0.018 in. wall and is capable of withstanding pressures up to 36000 psi. The hole is drilled and reamed so that there is about 0.002 in. radial clearance between the block material and the tube. The drilling of accurate holes in the epoxy resin is a tedious operation because of the large length, say 4 in., in comparison to the diameter.

A special technique had to be developed for cementing the stainless steel tubing into the model block. First a pool of the cement is placed on the surface of the block around the tube. Then a fixture in the form of a cup is attached to the surface of the block. The fixture seals against surface of the block, but connects the end of the tube to the atmosphere. Next the space between the surface of the block and the cup-like fixture is pressurized to about 40 psi. This drives the cement from the pool into the clearance between the hole and the tube. The flow is rather slow because of the high viscosity of the cement and the small clearance, and it can be observed visually from the change in contrast. Finally, the pressure is removed before the cement has a chance to flow into the tube and plug it.

In case the initial orientation of the hydraulic fracture must be controlled, as in experiments intended to study the interaction between two hydraulic fractures, a small penny-shape crack is introduced at the bottom of the hole before cementing the tubing into the hole, The best means of prefracturing was found to be pressing a rod that fits into the hole and is sharpened to a wedge against the bottom of the hole.

The fluid used in the fracture experiments is mercury. There are two reasons for choosing mercury: First, its high bulk modulus minimizes the energy stored behind the fracture as it is initiated, and thus avoids catastrophic growth in the initial stages. Second. the fractures filled with mercury are perfectly visible.

Several experiments have been done on the interaction and joining of two hydraulically induced fractures. The observed interaction and the subsequent behavior of such cracks after joining is quite fascinating. For instance, the interaction was seen to be very strong for cracks in paralle planes. Such cracks were observed to have the tendency to join and curve sharply toward each other. The growth after joining led to very intricate three-dimensional shapes. It was also seen that, if one crack is kept at constant volume and the second made to expand, the shape of the first crack changes as the second fracture approaches it. In fact, it was observed that under these circumstances the first fracture may even close over part of its extent.