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NEW EXPERIMENTAL DEVICE FOR THE VISUALISATION OF FLUID-DRIVEN CRACKS IN CLAYS

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Abstract:

Gas-induced fracturing in liquid-saturated clay-rich materials presents challenges in understanding and predicting fracture behaviour, due to the complex mechanical and transport properties of clays and the compressibility of gas. This paper introduces a novel experimental device for visualising fluid-driven cracks in clays. The device allows for the induction and observation of two-dimensional cracks in clay-rich, low-permeability materials through the injection of gas or water. The experimental setup comprises precision instrumentation for measuring compression forces, displacement, and fluid pressure, along with high-resolution imaging capabilities. Preliminary tests with Helium gas injection into Boom clay samples demonstrate the device's ability to track fracture evolution. This innovative experimental tool offers insights into the mechanisms governing fluid-driven fractures in clay-rich materials and provides a means to validate numerical models.

1. Introduction

The generation or injection of gas into a liquid-saturated, clay-rich material can lead to the development of narrow channels or fractures, a result of the mechanical action of gas pressure. The complexity inherent in the mechanical and transport properties of clays, along with the high compressibility of gas, present significant challenges in understanding and addressing this phenomenon. Gas fracturing occurs in various engineered processes such as gas (CO_2, H_2, CH_4…) injection and storage in subsurface reservoirs, pneumatic fracturing for enhanced remediation of contaminated soils, and gas transport through natural and engineered clay barriers in geological disposal facilities for radioactive waste. Despite its wide-ranging environmental and economic implications, predicting and controlling gas fracturing remains a challenge due to a lack of fundamental scientific insight.

In this context, this paper introduces a novel experimental device currently under development at TU Delft. This device is designed to study gas-driven cracking in clays within a model system. It enables the induction and observation of 'two-dimensional' cracks in clay-rich, low-permeability materials through the injection of gas or water. The device design draws inspiration from the work of Wiseall et al. [1, 2], albeit with significant enhancements.

2. Experimental setup

The proposed experimental device is schematically described in Figure 1. In this setup, a thin layer (~1mm) of clay paste is compressed between two transparent discs of 110 mm diameter and 50 mm height. The bottom disc has a central hole through which a steel pipe is inserted to inject the fluid at the centre of the clay sample through a tip filter. A perimeter filter contains the sample laterally while allowing control of the back-pressure during the fluid injection. The transparent discs and the perimeter filter are positioned by means of three steel rings, which are guided by four precision shafts. The compression of the clay sample is achieved by tightening nuts at the threaded ends of the shafts.

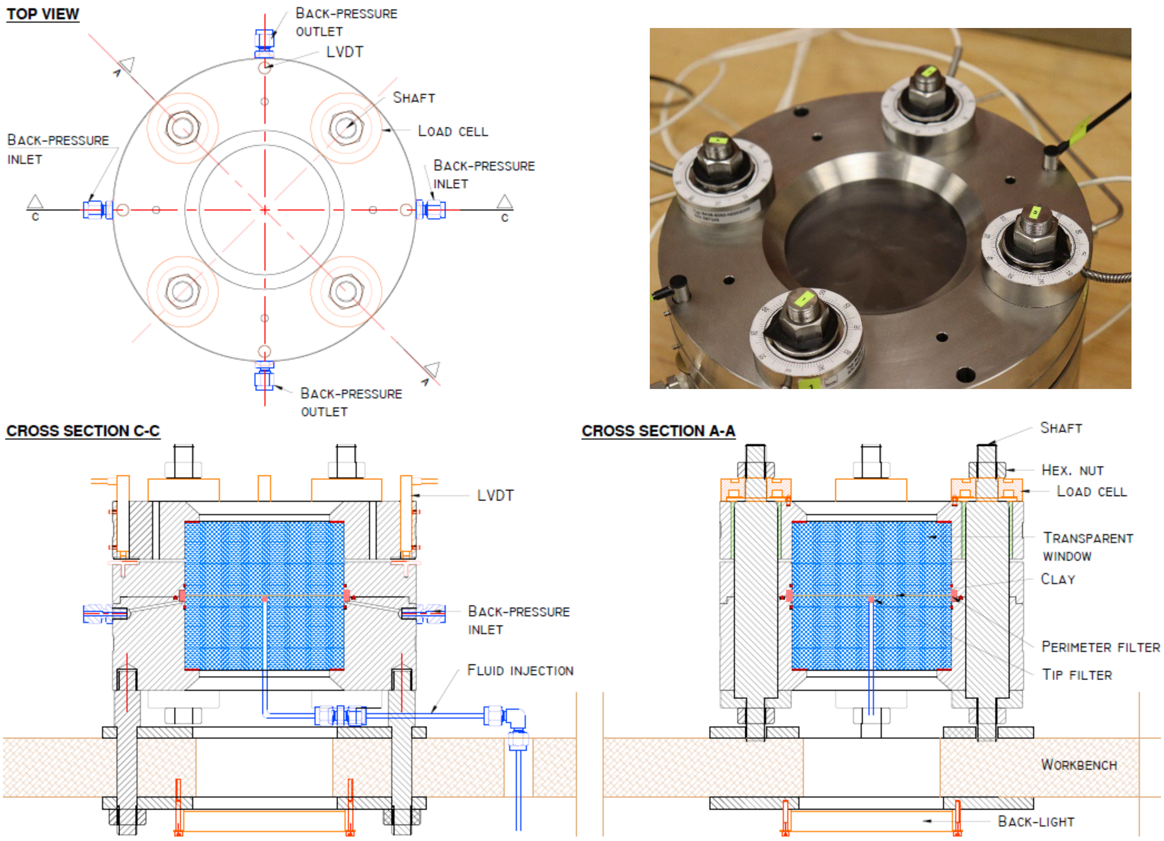

Figure 1. Drawings and picture of the new experimental device.

The device is instrumented with four donut load cells (one per shaft) placed in between the tightening nuts and the top ring to measure the compression forces, two displacement traducers (LVDT) to measure the relative displacement of the transparent discs, and fluid pressure transducers connected to the injection pipe and to the perimeter filter. The experimental setup is completed with two high-precision high-pressure pressure-volume controllers, that permit control of the fluid injection rate and the back-pressure. In addition, pictures are taken with a high-resolution camera at a regular rate during the fluid injection, through the top transparent disc. To enable the detection of thin cracks, the device and the camera are placed in a dark box, with a collimated backlight panel placed under the bottom transparent disc.

3. Preliminary results

The new experimental setup and the associated testing protocol have been evaluated in a series of preliminary tests. To illustrate the performance of the new device, results obtained from a Helium gas injection test on a reconstituted Boom clay sample are presented.

To prepare the sample, the clay was oven dried, sieved (< 0.125mm), and mixed with synthetic pore solution (SPS) to obtain a homogeneous clay paste with 65% water content. After saturating both the tip and perimeter filters with SPS, approximately 33 g of clay paste was uniformly distributed

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on the bottom transparent disc. The clay paste was then compressed between the two transparent discs in small loading steps over two days until reaching the target initial vertical stress of 0.6 MPa. During this loading process, the sample underwent consolidation as the pore water drained through the perimeter filter.

The gas to be injected was previously water-saturated by pressurising it to 0.4 MPa in a 150 mL gas-water interface vessel to prevent drying shrinkage effects in the sample. To start the gas injection the valve connecting the top of the vessel with the injection filter was opened, and immediately SPS was injected at the bottom of the interface vessel at a constant rate of 75 mL/h. The gas injection was stopped after two hours when the vessel was completely filled with water.

Figure 2 shows the time evolution of the gas pressure at the injection point and the forces applied by the vertical shafts. Figure 3 displays images taken at selected times indicated in Figure 2 (left). The sharp increase of gas pressure from 0 to 0.4 MPa reflects the opening of the valve connecting the injection point with the interface vessel. The subsequent injection of water at a constant rate led to the pressurisation of the gas in the vessel until the pressure was high enough to invade the sample, creating cracks that propagated into the sample towards the back-pressure filter (time B). When cracks connected the injection and back-pressure filters, a sharp drop was observed in the injection pressure. This depressurisation was followed by a partial sealing of the cracks (times C and D). The sudden change in slope after time E indicates the end of the SPS injection into the interface vessel. The following depressurisation was accompanied by the formation of new thin cracks in the sample (times F and G). Note that before gas invasion, the shaft forces were practically unaltered by the injection pressure, but once the gas invaded the sample forming cracks, the shaft forces followed a similar evolution to that of the injection pressure.

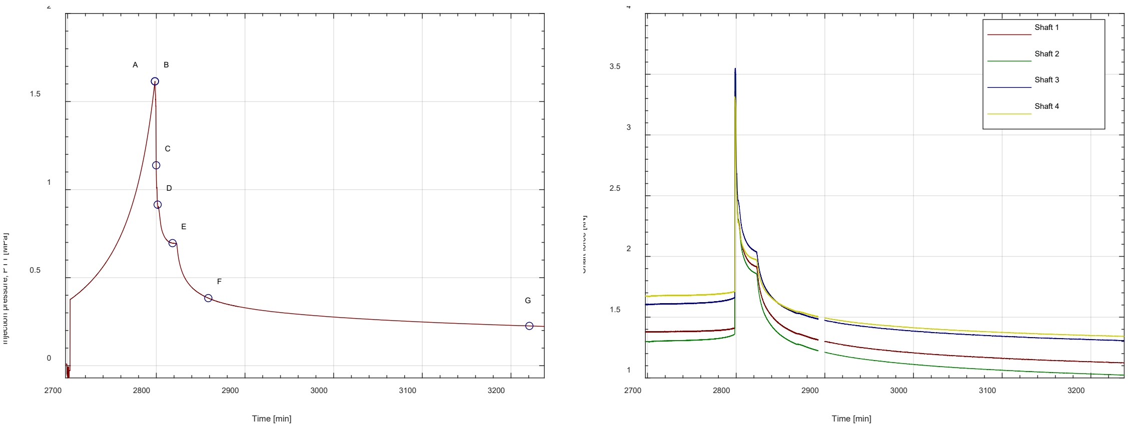

Figure 2. Gas injection test in Boom clay. Left, time evolution of the gas injection pressure. Right, time evolution of the force applied by the shafts of the device during the gas injection.

3. Conclusion

Gas-induced fracturing in clay-rich materials presents challenges due to complex properties and gas compressibility. The presented experimental device allows visualisation of fluid-driven cracks, offering insights into fracture behaviour. Preliminary tests, including a Helium gas injection into Boom clay, demonstrate the device's ability to track fracture evolution. The observed phenomena provide valuable insights into fracture mechanisms. In particular, this device has potential for validating numerical models with explicit representations of fluid-driven fractures, such as the one recently proposed by the authors elsewhere [3].

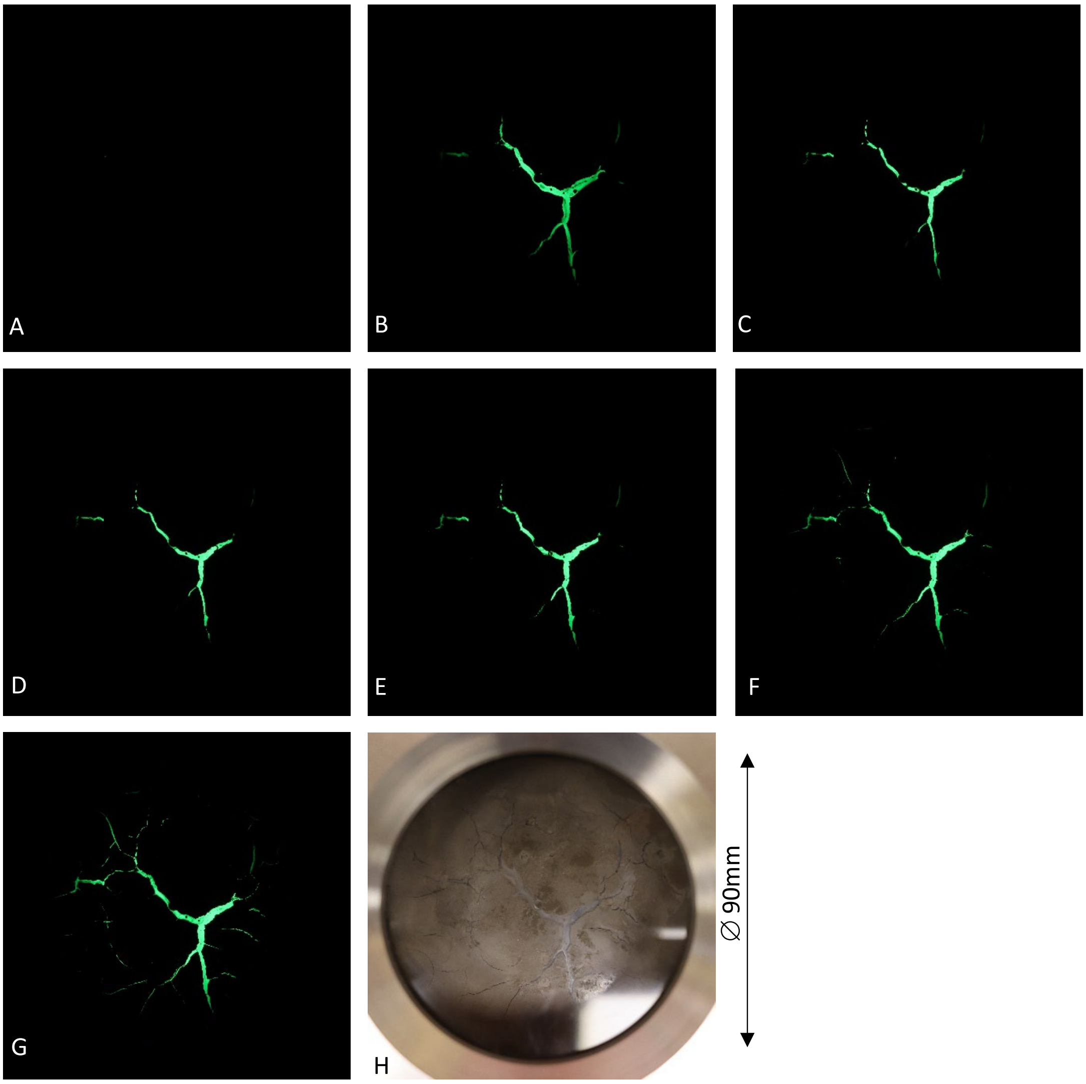

Figure 3. Gas injection test in Boom clay. Pictures A to G were obtained at the times indicated in Figure 2 (left) taken pictures obtained with a dark box and collimated green back-light. Picture H obtained after the test with normal room light.

Acknowledgments

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