Technical Report *

Experimental Investigation of Effect of Pore Fluid Pressure on Stick-Slip Events

Project Objectives

High pore fluid pressures are often observed within the subduction zone where slow-slip events take place. However, the mechanical link between pore fluid pressure and shear slip is understood. To understand the effect of pore fluid pressure on fault slip, we conducted friction experiments on saw-cut sandstone samples containing a thin layer of fine-grained quartz gouge. The saw-cut samples were deformed under a wide range of confining and pore fluid pressures and the fault slip along the saw-cut surface during deformation was observed. Using different combinations of confining and pore fluid pressures, we produced a spectrum of slip behaviors from dynamic, seismogenic slip to transitional slow-slips. We observed that at the same effective normal stress, the magnitude and duration of the stick-slip events are sensitive to the magnitude of pore fluid pressure. This result suggests that pore fluid pressure build-up may cause a transition in slip behaviors. Pore fluid pressure plays an important role in faulting instabilities and earthquake cycles as well as induced seismicity. This study sheds light on the underlying mechanisms that impede the instability to produce slow slip events.

Methodology

For each experiment, a thin layer of fine-grained quartz gouge power was place along a 30 saw-cut in a cylindrical porous sandstone sample. The sandstone sample is 25.4 mm in diameter and 50.8 mm in height and used as a shearing block. The mean grain size of the quartz powder is 3.4 μm. The dry weight of gouge material is 0.5 g, yielding a gouge thickness of ~0.18 mm. The gouge is then damped with drops of water to allow an even distribution along the saw-cut surface. The sample is jacketed using 2 layers of polyolefin tubes and joined with alumina spacers and steel end-caps (Figure 1).

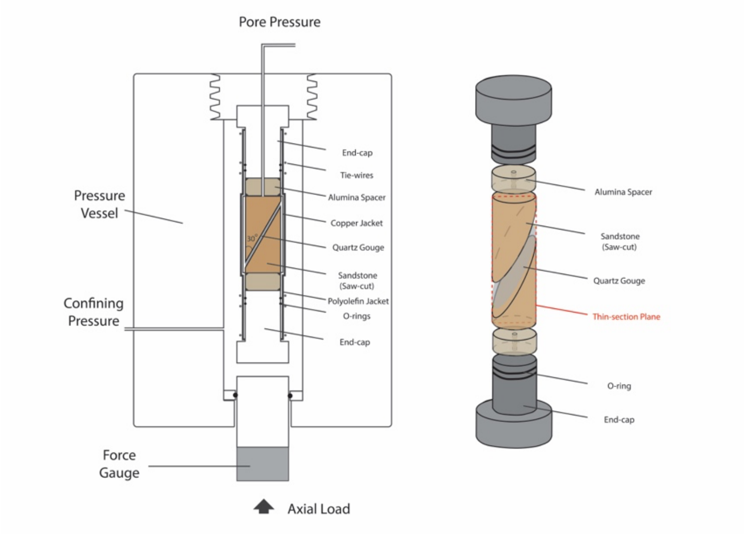

Figure 1. Experimental setup.

The friction experiments are conducted under triaxial stress conditions (principal stresses $\sigma_1 > \sigma_2 = \sigma_3$). An external force gauge is mounted at the piston outside the vessel from which the axial load (σ_1) is measured. The differential stress ($\Delta\sigma = \sigma_1 - P_c$) is calculated from the force gauge reading. Axial displacement on the sample is calculated using a linear voltage displacement transducer (LVDT) affixed to the axial piston.

Two suites of experiments were conducted. In suite I, the pore fluid pressure P_f was kept at 5 MPa and we varied the confining pressure P_c from 35 up to 105 MPa. The effective pressures (P_c-P_f) in this suite of experiments are 30, 60, 70, 80, and 100MPa respectively (Figure 2). In suite II, the effective pressure (P_c-P_f) in was kept at 70 MPa and we varied the pore fluid pressure P_f from 5 up to 120 MPa (the corresponding confining pressures P_c are 75, 100, 130, 160 and 190, respectively). low slip events were observed (Figure 3).

Results

A) Suite I experiments: at constant pore fluid pressure

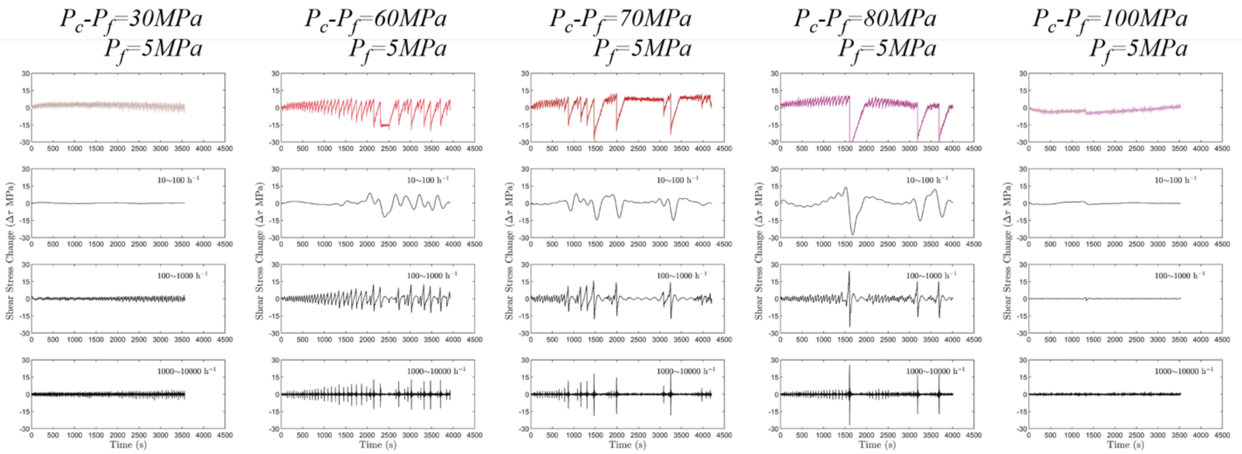

Figure 2. Influence of effective pressure (P_c-P_f) on stick-slip behavior. The pore fluid pressure P_f in all experiments is 5 MPa. As the effective pressure increases from 30MPa to 80MPa, the amplitude of stress-drop during a stick-slip event increases. Stick-slip events are prohibited beyond 100MPa, indicating a brittle-ductile transition. The time-evolution of shear stress shown in 3 different occurance frequency ranges (10-100 1/Hz, 100-1000 1/Hz, and 1000-10000 1/Hz) illustrate that at these conditions all slip events consist of both high and low frequency components.

Results from suite I experiments show that amplitudes of stick-slip events increase with increasing effective pressure (Figure 2). At low effective pressure of 30 MPa, the slip events are all small amplitude events. These slip events are quiet at the beginning and gradually become semi-audible as deformation continues. At 70 MPa effective pressure, the magnitudes of some slip events are much larger than others, and all events are semi-audible to audible. As effective pressure increases to 80 MPa, the small amplitudes events become quiet and semi-audible again, while the large amplitude events become very loud. At 100 MPa, no slip occurred on the saw-cut surface, indicating a transition to ductile creep. In general, the recovery intervals following a large amplitude event are larger. The frequency of reoccurrence between similar amplitude slip events is relatively constant. Both high and low frequency components are present in these stick-slip events at a pore fluid pressure P_f of 5 MPa.

B) Suite II experiments: at constant effective pressure

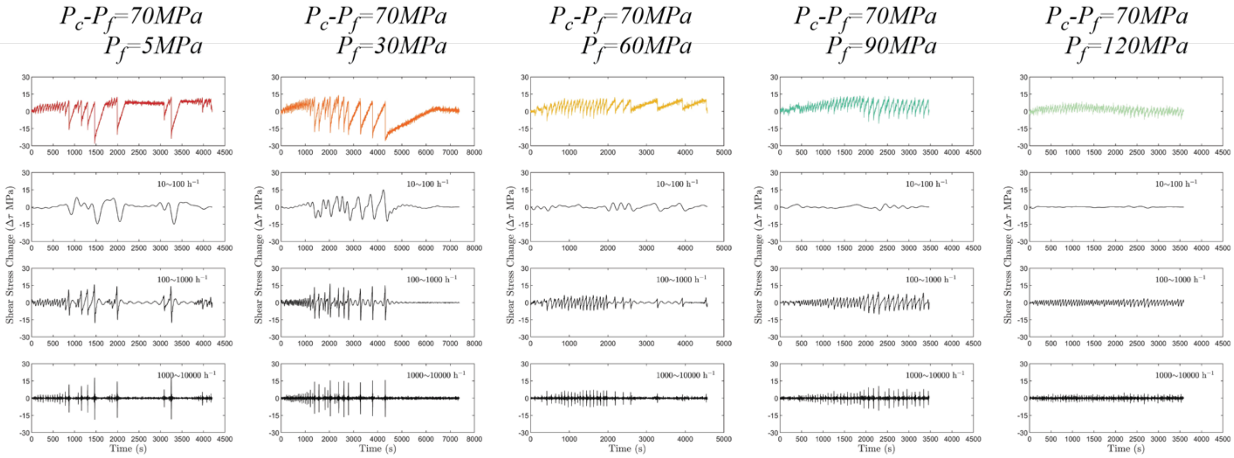

Figure 3. Influence of pore fluid pressure P_f on slip behavior. The effective pressure (P_c-P_f) in all experiments is 70 MPa. As the pore fluid pressure increases from 5MPa to 120MPa, the amplitude of stress-drop during a stick-slip event decreases. The time-evolution of shear stress shown in 3 different occurance frequency ranges (10-100 1/Hz, 100-1000 1/Hz, and 1000-10000 1/Hz) illustrate that as the pore fluid pressure increases, the higher frenquency components deminishes from the slip events.

Results from suite II experiments show that increasing pore fluid pressure impedes large amplitude stick-slip events (Figure 3). At relatively low pore fluid pressures (5 to 30 MPa) the slip events are irregular with various magnitudes of stress perturbations and the recovery time between of large events is longer. As pore fluid pressure increases (60 to 120 MPa), the stick-slip events morphs into relatively homogeneous, small amplitude events. The frequency of reoccurrence between these events becomes constant. At pore fluid pressure of 5 MPa, the slip events are audible from the beginning. With increasing pore fluid pressure, the slip events go through a transition from highly audible to semi-audible to silent. At high pore fluid pressure of 120 MPa, all slip events are semi-audible to silent. Slip-events occurring at high pore fluid pressures (>60MPa) become devoid of high frequency components (Figure 3).

Significance

Our major findings include:

1) The slip behavior is sensitive to both the effective pressure and the pore fluid pressure;

2) A spectrum of slip behaviors can be obtained by changing pore fluid pressure;

3) Increase in effective pressure tend to increase stiffness and cause unstable slip to emerge until a threshold is met where no slip is allowed on the fault;

4) Increase in pore pressure tends to decrease the stiffness and lead to slow slips and transitional slip behaviors.

Our experimental data support the idea that the unstable earthquake and slow-slip events could arise from the same tectonic setting and in same lithologic unit. The observed correlation between the slip behavior and pore fluid pressure provides new insights to the dynamics of earthquakes and faulting.

A manuscript is in preparation and will be submitted soon.