Effect of Pore Fluid Pressure on Slip Behavior of Experimental Fault with Gouge

Dashaun Horshaw, Advisor: Dr. Wenlu Zhu

Introduction

During geological exploration, waste water wells inject fluid into the Earth to make use of filtering properties. There has been an increase in earthquakes, that is correlated to the use of waste water wells. In the slip model, earthquakes occur when shear stress, $\boldsymbol{\tau}$, reaches critical shear stress, $\boldsymbol{\tau}_{cr}$. The critical shear stress threshold can be reduced by increasing pore pressure, P_f, lowering the effective stress, σ_{eff} . Recent experiments investigating pore pressure (fluid pressure) do not include gouge, a layer of crushed rock, which occurs in frequently in nature.

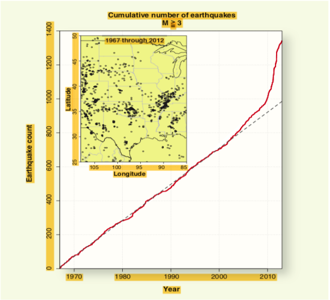

Fig 1: Cumulative count of earthquakes with M ≥ 3 in the Central and Eastern United States between 1967 – 2012 [Ellsworth, 2013].

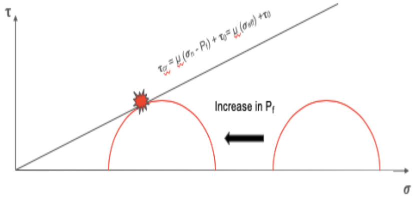

Fig 2: Mohr's circle showing relationship between normal stress, shear stress, and pore pressure].

Hypotheses

- ❑ Different pore pressures will have an effect on slip behavior when a gouge layer is included in the experiments.
- ❑ Increasing pore fluid pressure leads to lower critical stress threshold and subsequent fault slip.

Methods

- ❑ Experimental fault composed of Berea Sandstone sample and quartz gouge.
- ❑ Triaxial apparatus increased normal stress on sample. Observed slip behavior.

Experiment	Confining Pressure, P_c (MPa)	Pore Fluid Pressure, P_f (MPa)	Differential Stress, MPa
1 (Dry)	70	0	70
2 (Wet)	75	5	70
3 (Wet)	100	30	70
4 (Wet)	130	60	70

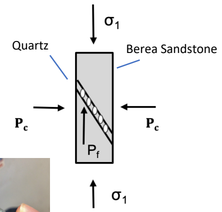

Fig 3 (top): Schematic of stresses acting on experimental fault.
Fig 4 (Left): Quartz gouge layer applied on Berea Sandstone experimental fault.
Table 1: Pressure Conditions.

Conclusions

- ❑ The addition of gouge will better characterize the effect pore pressure has on critical stress and slip behavior.
- ❑ While the presence of pore fluid did change the yield stress, as pore pressure increased, so did the yield stress. This is explained by the pore fluid pressure strengthening the rock before failure.
- ❑ Different pore pressures also changed the slip behavior. Increasing the pore fluid pressure yielded more slips that were greater in magnitude than initial slip.
- ❑ This experiment can be applied to geological exploration and waste water well use by understanding the consequences of increasing pore pressure on a fault.

Experimental Results

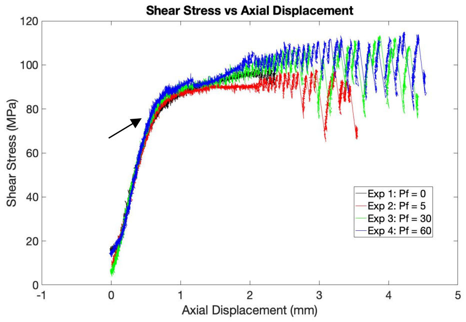

Fig 5 (top): Graph of shear stress vs axial displacement of the loading ram for all four experiments. Used to compare yield stress. Arrow marks area of yield stress.
Table 2 : Table comparing approximate yield stress and initial stress drop for each experiment.

Experiment	Approximate Yield Stress (MPa)	Avg Stress Drop (MPa)
1 (Dry)	68.41	5.81 ± 0.61
2 (Wet)	73.04	8.79 ± 2.31
3 (Wet)	80.75	9.92 ± 1.41
4 (Wet)	83.8	10.61 ± 1.87

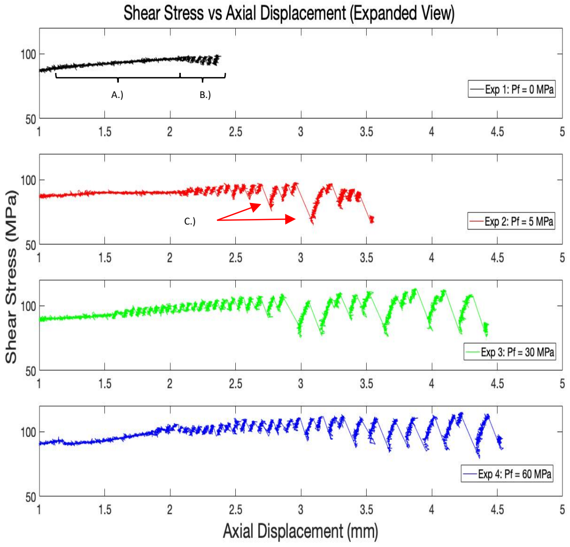

Fig 6: Expanded view of shear stress vs displacement to observe slip behavior.

The expanded view provides a better look at the slip behavior. For section A, there is a period where the stress is being acted on the sample but there is no slip. Every graph experiences this until the sample fails. Slip occurs at B, where the shear stress "drops" and increases again. As seen from the graph, the slip magnitude for Experiment 1 was small in comparison to the other experiments. When pore pressure was included, there were greater stress drops during slip. Increasing the pore pressure increased the amount of slip events with these greater stress drops, as see by point C on the second graph and the drops on the following graphs.

Ref: Ellsworth, W. L. "Injection-induced earthquakes." Science 341.6142 (2013): 1225942.

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