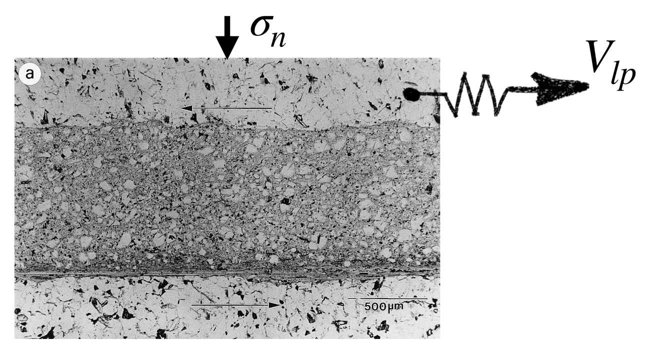
Understanding the Controls of the Transient Friction of Granular materials

Aizhan Zhakupova*, Behrooz Ferdowsi

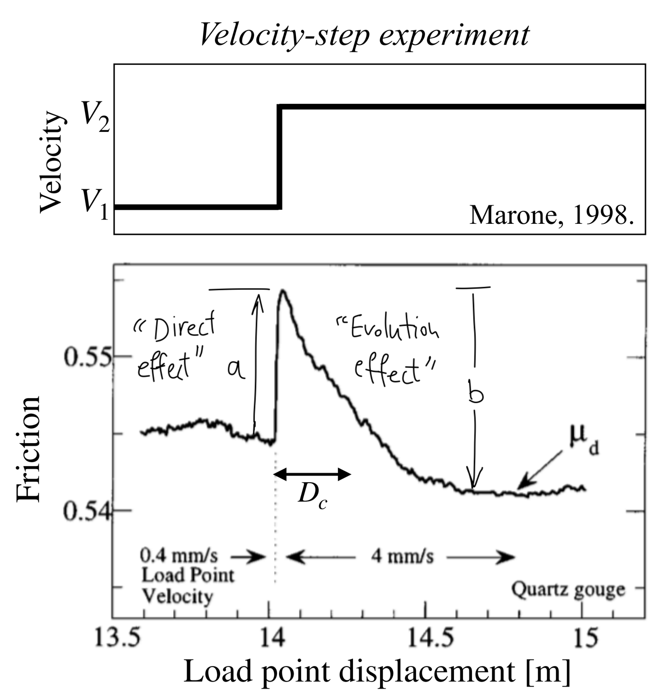
Department of Civil and Environmental Engineering, University of Houston, Houston, TX 77004, USA *Email: azhakupo@cougarnet.uh.edu

UNIVERSITY of HOUSTON

Empirical Rate-and-State-Dependent Friciton Framework



Scruggs and Tullis, 1998



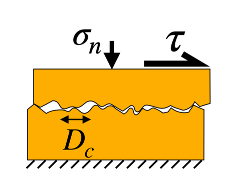
The constitutive modeling framework of Rate-and-State dependent Friction (RSF) attempts to capture the empirical observation underlying the transient frictional behavior of geological materials. The transient frictional response controls the initiation phase of geological instabilities with a frictional origin (e.g., landslides and earthquakes).

The RSF framework simulates the variation of shear stress in two parts: rate-dependence and state-dependence (Ruina, 1983; Dieterich, 1972). Here, state is an internal variable describing the frictional state of the rock or geological shear zone interface. Different versions of the state evolution equation have been proposed in the past several decades. Among them, the Slip or Ruina law equation has been proven to be significantly more successful in describing most lab data in velocity-step experiments, although without a physical justification.

$$\tau = \sigma_n\, f(V, state) = \sigma\, f(V, \theta)$$

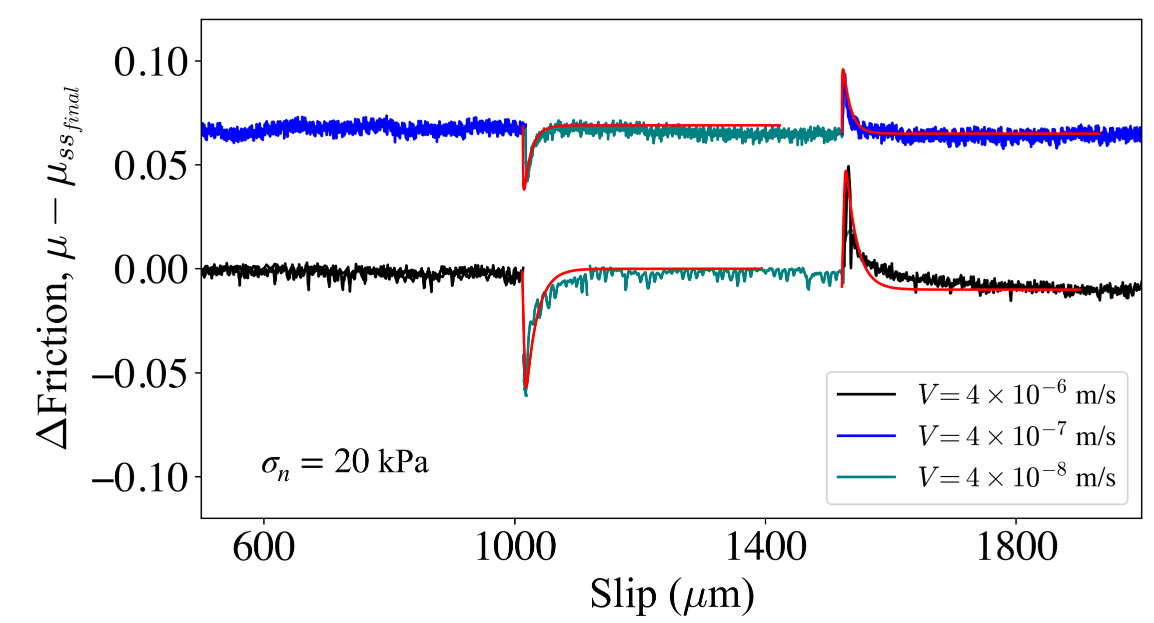
$$\tau = \sigma_n \left(f^* + \underbrace{a \log \frac{V}{V^*}}_{\text{Rate}} + \underbrace{b \log \frac{\theta}{\theta^*}}_{\text{State}}\right)$$

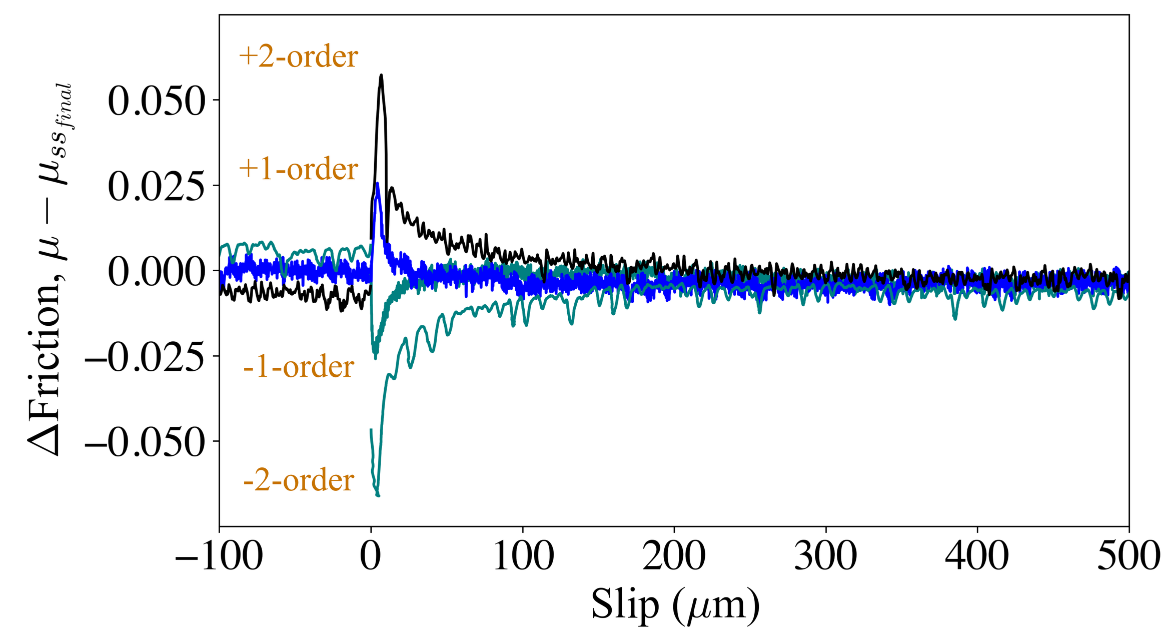
Slip law: $$\frac{d\theta}{dt} = -\frac{V\theta}{D_c} \log \frac{V\theta}{D_c}$$



For most rock types:
$a \sim 0.01 - 0.02$,
$b \sim 0.01 - 0.02$,

Results for Silica Powder — Velocity-Stepping (VS) Behavior

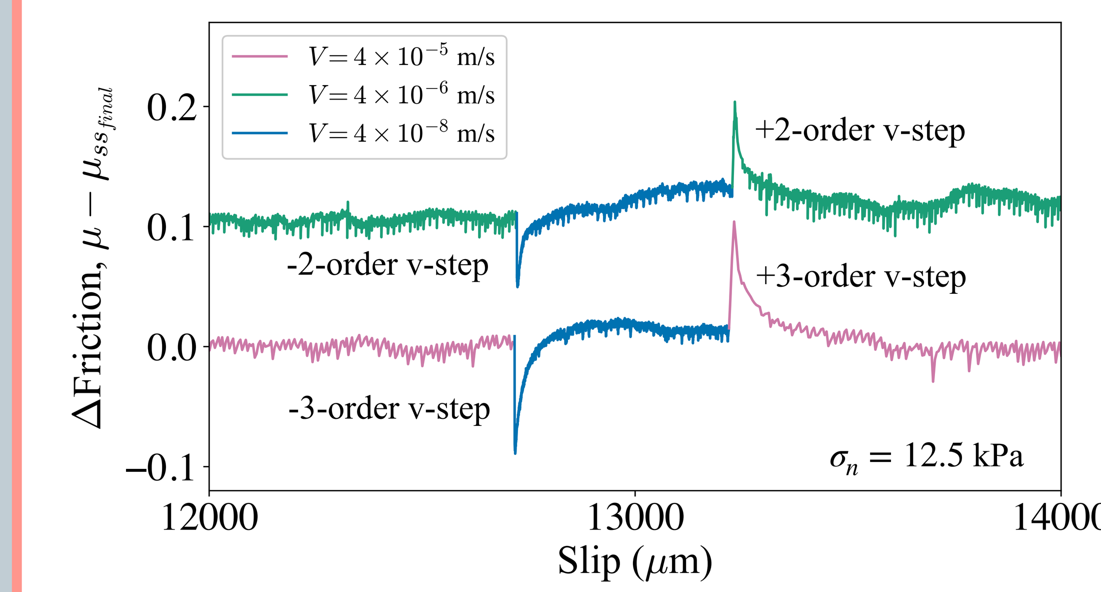


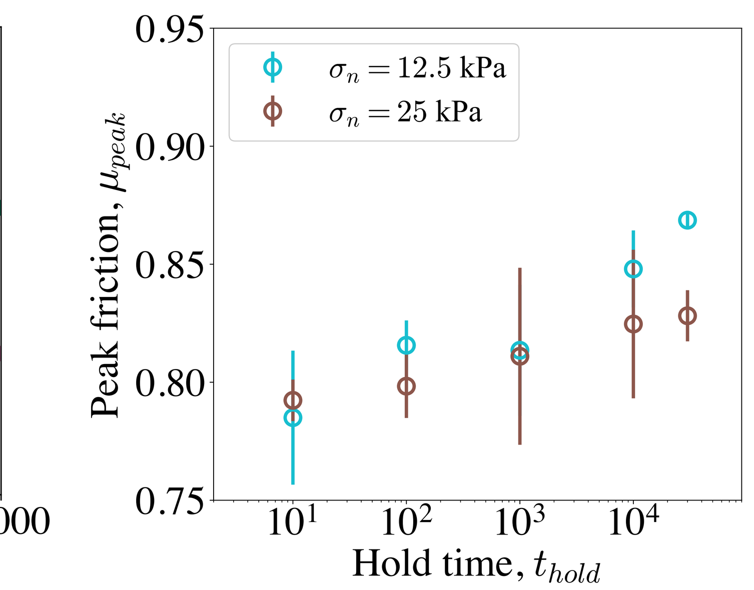


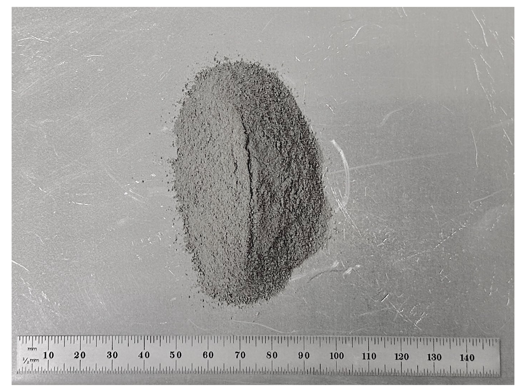
- Granular materials at low pressures show classical transient rate-and-state response.
- The behavior fits well with the Slip/Ruina version of the state evolution, parameters in the common range for rock gouge.

Rate-and-state parameters:
a ~ 0.0094
b ~ 0.0096
D_c ~ 13 µm

Results for Natural Shear Zones — VS and SHS Behaviors



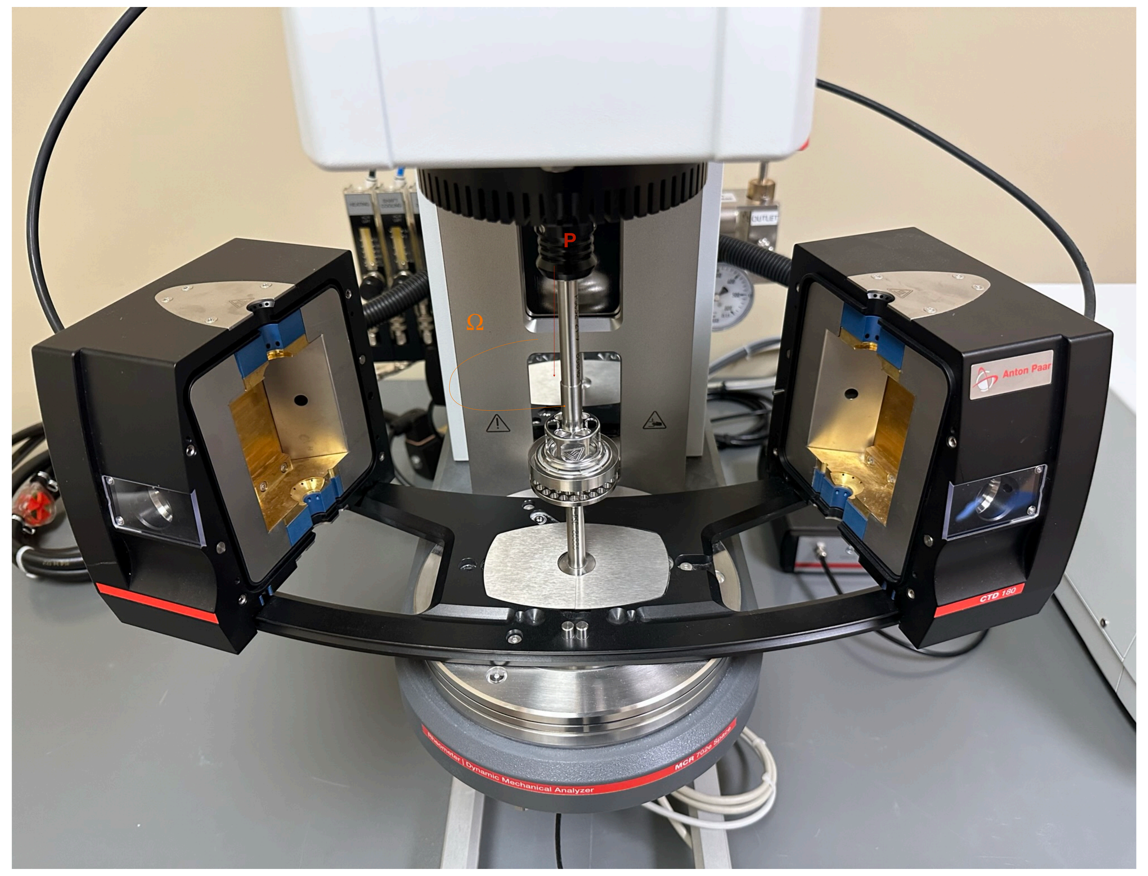




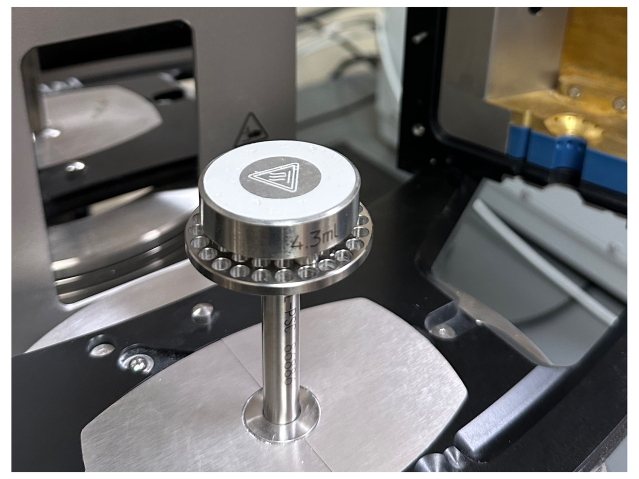
Landslide shear zone sample from the Oak Ridge Earthflow Observatory, Courtesy of Prof. Noah Finnegan (UCSC)

Rate-and-state parameters:
a ~ 0.0133
b ~ 0.0141
D_c ~ 31 µm

Experimental Facility, Materials, and Measurements

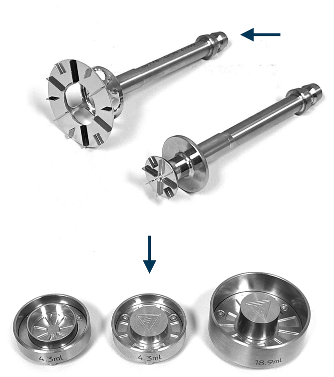


Customized Modular Compact Rheometer

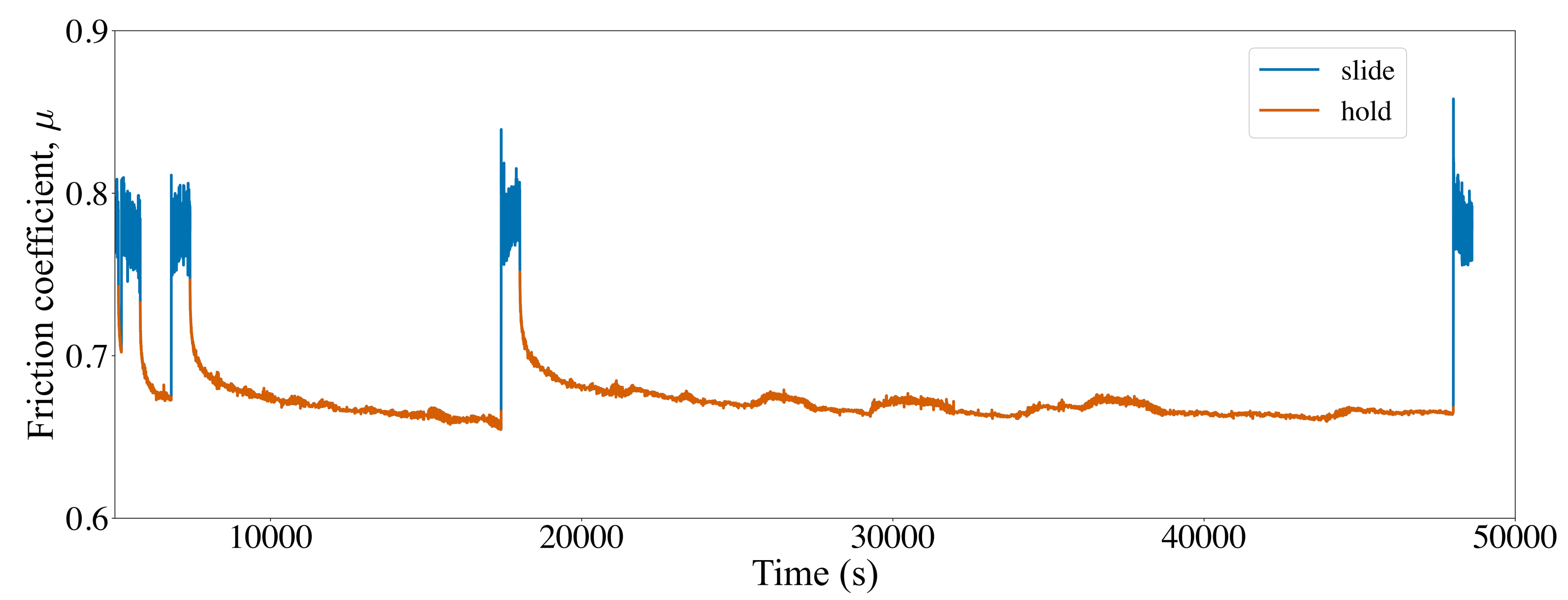


Quartz/silica powder, D_{avg} = 50 µm

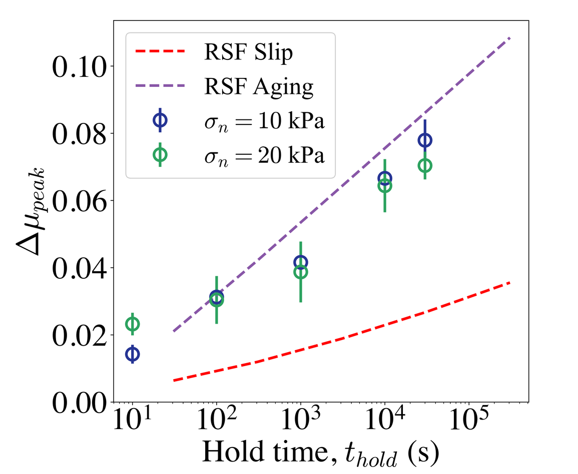
We use a customized rheometer to examine the transient frictional behavior of granular materials at normal stresses relevant to Earth's near surface.

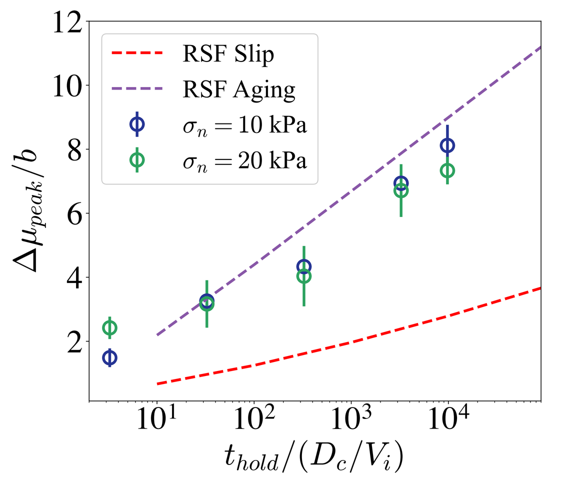


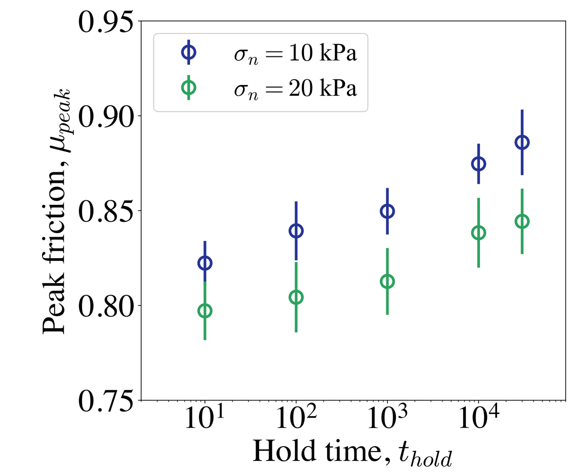
Results for Silica Powder — Slide-Hold-Slide (SHS) Behavior



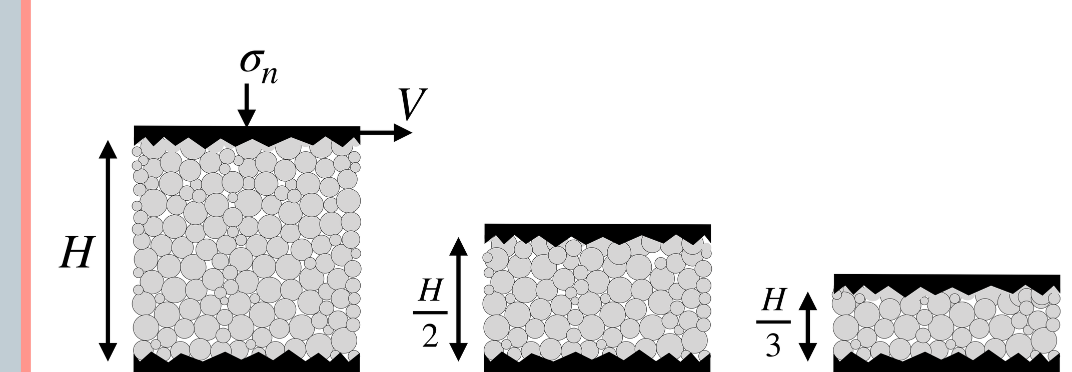
- Frictional sliding is interrupted for a specified time (10 *s*, 100 *s*, 1000 s, 10000 *s*, and 30000 *s*), after which loading resumes at the original sliding velocity.
- By systematically varying the duration of the hold phase, the time dependence of frictional strength and frictional healing can be evaluated.



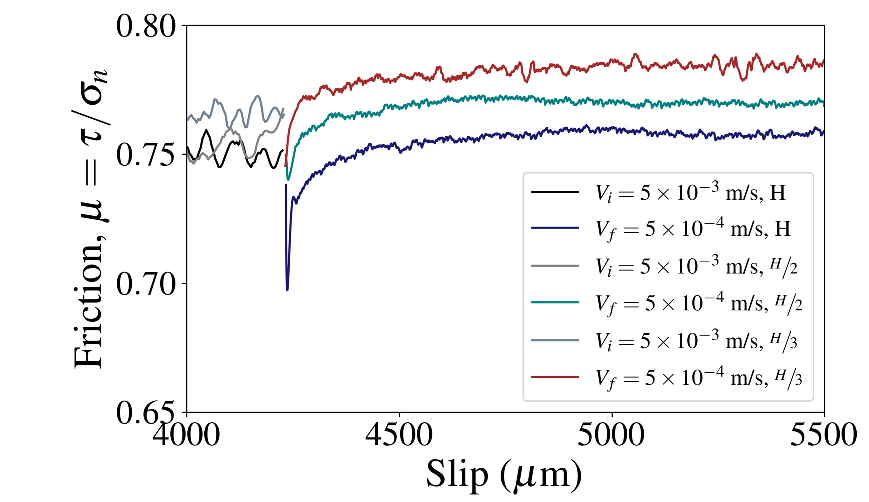


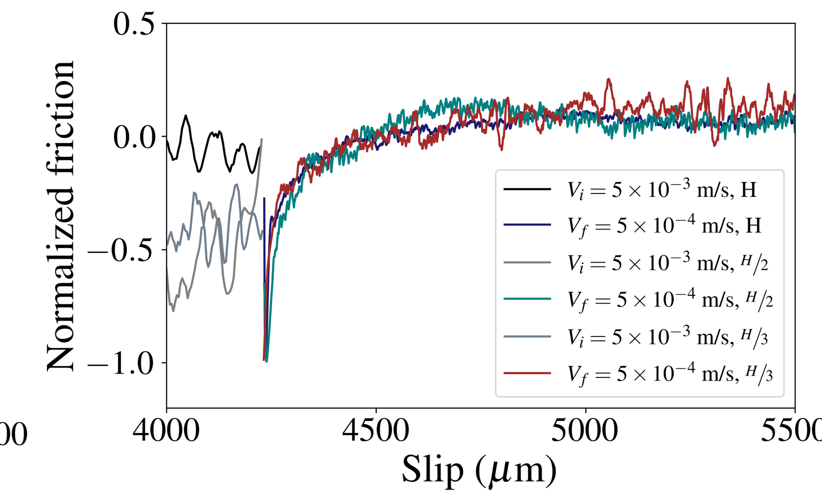


The Effect of Shear Zone Thickness



- We conducted velocity-step experiments on granular layers with different layer thicknesses.
- The weakening distance does not vary with layer thickness, and this has important implications for continuum-mechanics-based models of frictional instabilities.





Conclusion

We performed an experimental investigation of the transient frictional behavior of granular materials. RSF parameters are within the range previously observed for earthquake fault zones in rock friction experiments at tectonic stresses.

- The response in ±1- to 3-order velocity steps appears to be symmetric. The results are in agreement with RSF Slip law.
- The healing response in slide-hold-slide experiments does not vary significantly with normal stress within the range explored here.

Acknowledgments:

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