Earthquake Dynamics in Laboratory Model and Simulation
– Accelerated Creep as Precursor of Instabilities

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Overview

Stick-Slip Mechanism

- Earthquakes can be considered as systems performing stick-slip
- stick-slip is a typical frictional instability phenomenon
- stick to slip transition can not be completely sudden

Stick-Slip Mechanism

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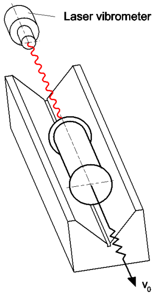
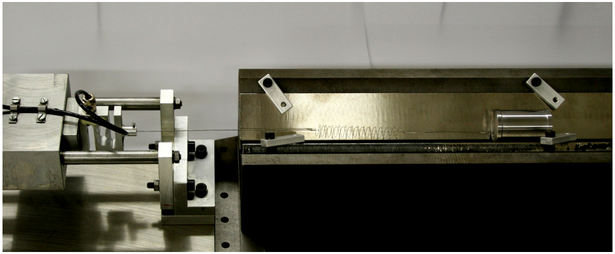
- is a preceding creep measurable?
- if yes, is it sufficiently regular to serve as a precursor?

Laboratory Experiments | Setup

- Elementary system with tribological instabilities: one specimen on a plane pulled by a soft spring
- Measurement of the displacement (laser vibrometer) and the force (load cell)





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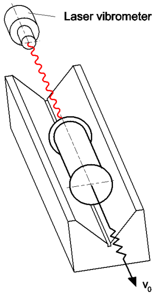

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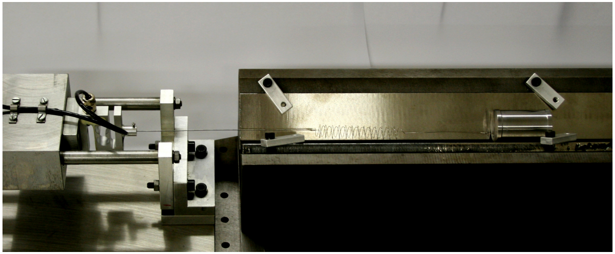
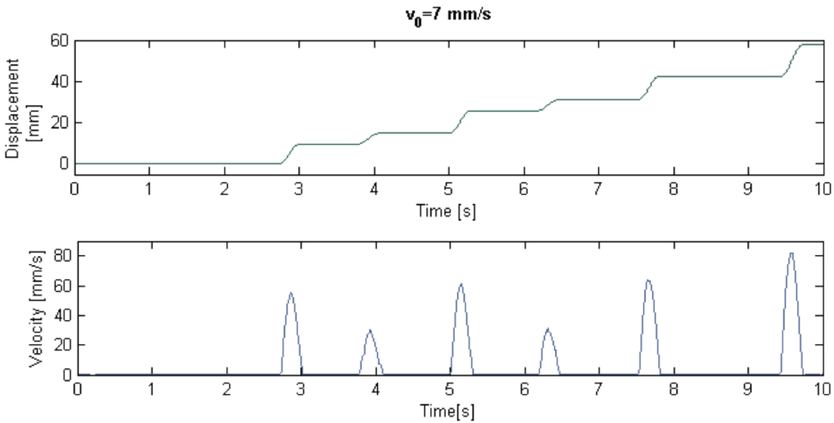
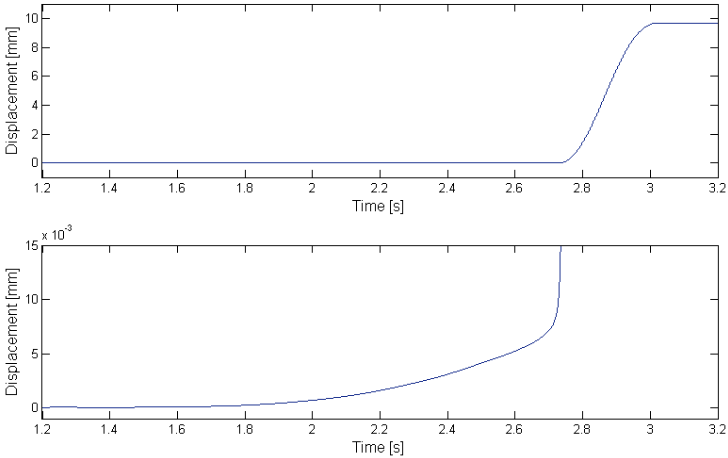


- Displacement resolution of 8nm
- several pulling velocities (0.05 - 7mm/s)
- Material pairings (**steel–steel**, steel–glass, marble–granite)

Laboratory Experiments | Results



Laboratory Experiments | Creep as Precursor



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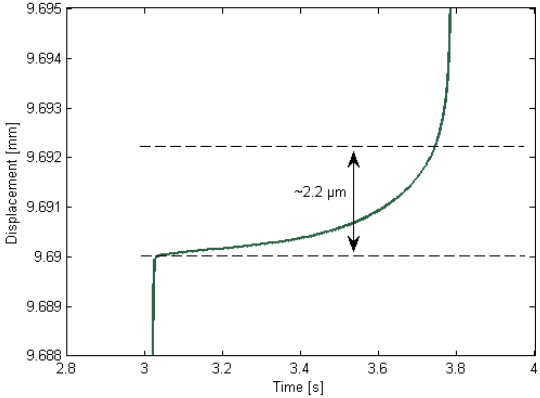
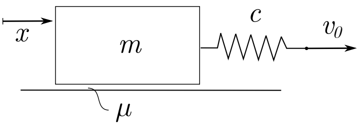


- in fact the specimen creeps before reaching the instability
- very regular acceleration during the whole stick–phase

Simulation | Model Using Rate-and-State Friction

One-dimesional model of the experiment



Equation of motion:

$$m\ddot{x} = c(v_0 t - x) - \mu F_N$$

$$\mu(v,\theta) = \mu_0 - a\ln\left(\frac{v^*}{|v|} + 1\right) + b\ln\left(\frac{v^*\theta}{D_C} + 1\right)$$

Simulation | Model Using Rate-and-State Friction

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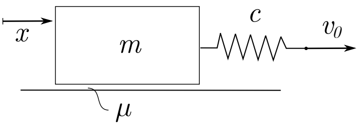

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- Dependence on the velocity v and the state variable θ
- Dimensionless positive parameters a and b
- Standardisation velocity $v^* >> v$
- Characteristic dimension of the micro contacts D_C

Simulation | Fitting the Solution

- Adjust the form parameters a, b and D_C by gradient method
- Creep period before jump is of special interest
- Additional parameter $\hat{v}$ to describe contact stiffness

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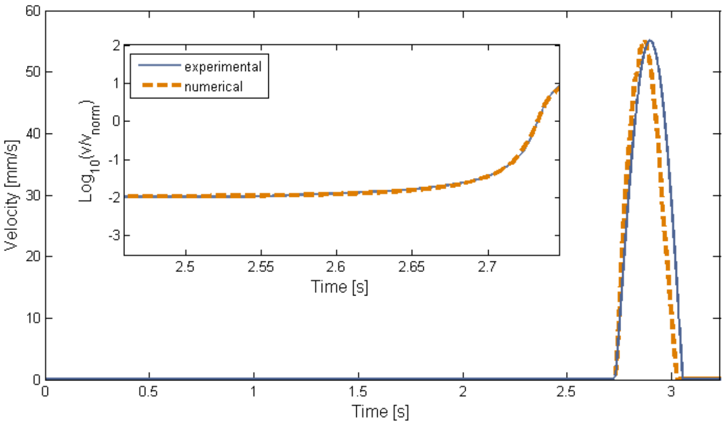
$$v_0 = 7\,\mathrm{mm/s}$$



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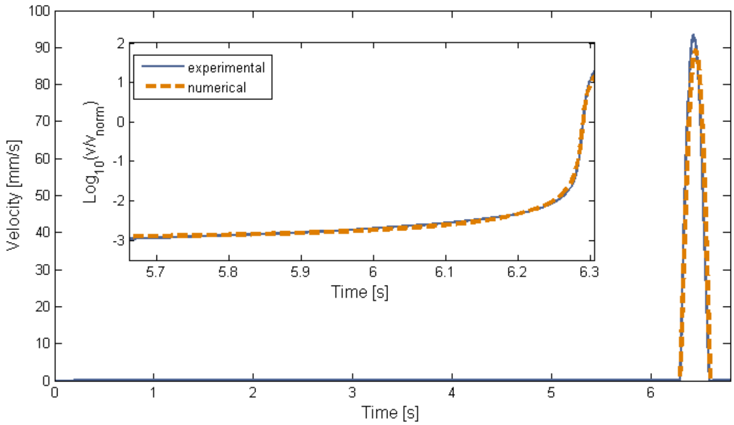
$$v_0 = 2\,\mathrm{mm/s}$$



Simulation | Fitting the Solution

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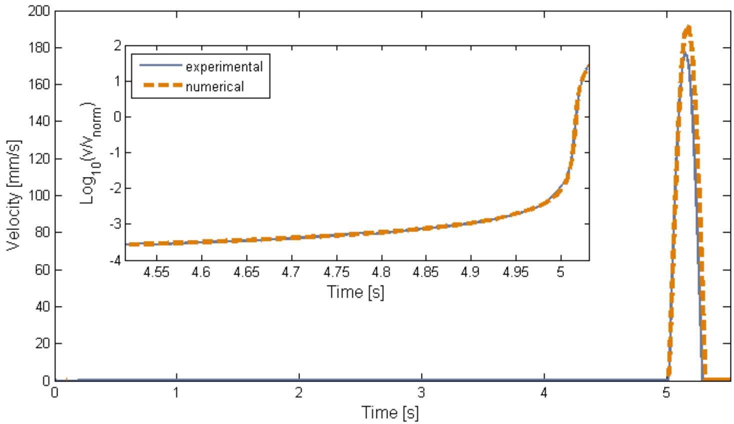
$$v_0 = 0.1\,\mathrm{mm/s}$$



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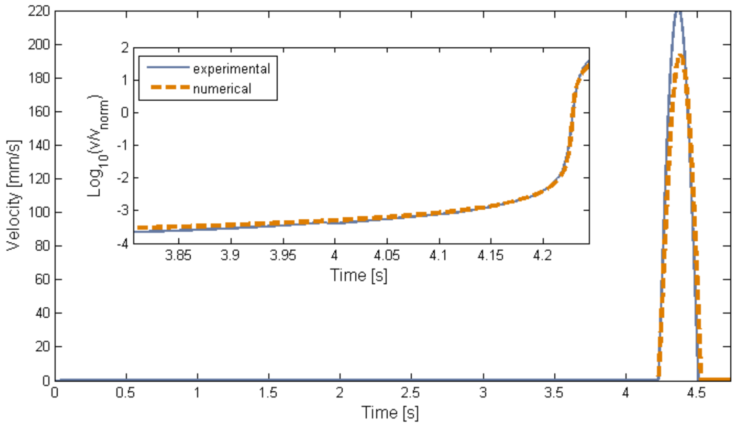
$$v_0 = 0.05\,\mathrm{mm/s}$$



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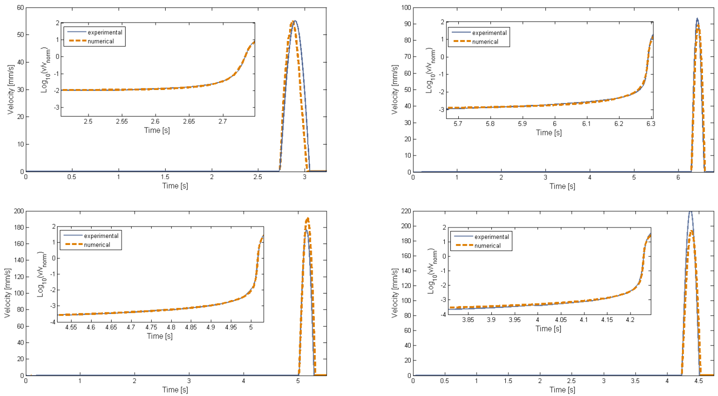

- **curve correspond very well over several orders of magnitude**

Forecast of the Time of Jump | Theory

- Approximation for the creep velocity near the instability

$$v \approx \frac{a}{\frac{b}{D_C} - \frac{c}{F_N}} (t_c - t)^{-1} \quad \Rightarrow \quad \frac{v}{\dot{v}} \approx (t_c - t)$$

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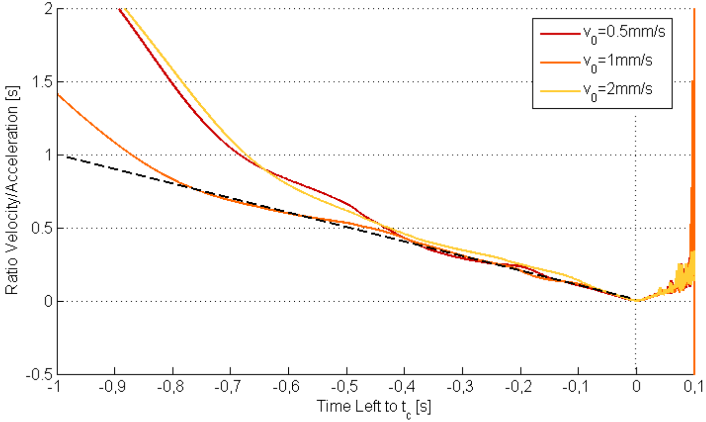
- Value of the ratio gives directly the time left before the instability
- Ratio is independent of all parameters
- Ratio should present a straight line with gradient of -1 and intersect with the time axis at the time of jump t_c
- Approximation holds for the last few percent of the stick time

Forecast of the Time of Jump | Experimental Data

Linear behaviour of the ratio $v/\dot{v}$ can be shown

- for different pulling velocities



Forecast of the Time of Jump | Experimental Data

Linear behaviour of the ratio $v/\dot{v}$ can be shown

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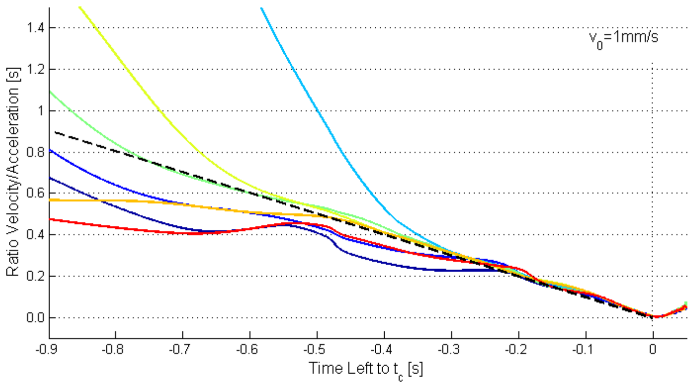
- for several runs with the same pulling velocity



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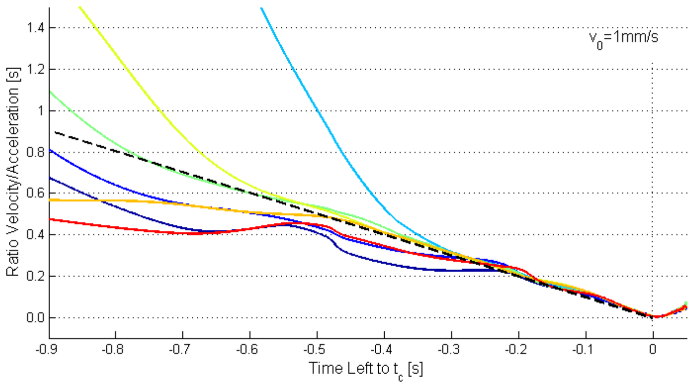

- data from simulation shows similar behaviour

Conclusion & Outlook

- Stick-Slip mechanism of a laboratory model can be described by a rate-and-state friction law
- Velocities are covered in a region of 5 orders of magnitude
- Examination of the ratio $v/\dot{v}$ is promising to provide a short-term forecast

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Further steps:

- Verify identical behaviour for rock contact
- Analyse the interaction of two (and more) coupled blocks performing stick-slip
- Study implications for the magnitude of slip events

Thank you for your attention.

More details can be found in the corresponding paper:
Tectonophysics 532-535 (2012) 291-300
„Rate and state dependent friction laws and the prediction of earthquakes: What can we learn from laboratory models?“

by V.L. Popov, B. Grzemba, J. Starčević and M. Popov.