

Earthquake Dynamics in Laboratory Model and Simulation - Accelerated Creep as Precursor of Instabilities EGU General Assembly 2012

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

TU Berlin Department of Mechanics System Dynamics and Tribology EQ Dynamics in Lab Model and Sims

General Introduction

Laboratory Experiments

Numerical Simulation

Forecast of the Instability

Conclusion & Outlook



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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

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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

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

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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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Laboratory Experiments | Setup



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

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Laboratory Experiments | Results





Laboratory Experiments | Creep as Precursor





Laboratory Experiments | Creep as Precursor



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

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Simulation | Model Using Rate-and-State Friction

One-dimesional model of the experiment



Equation of motion:

$$\begin{split} m\ddot{x} &= c(v_0 t - x) - \mu F_N \\ \mu(v,\theta) &= \mu_0 - a \ln \left(\frac{v^*}{|v|} + 1 \right) + b \ln \left(\frac{v^*\theta}{D_C} + 1 \right) \end{split}$$

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Simulation | Model Using Rate-and-State Friction

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

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- Dependence on the velocity ν and the state variable θ
- Dimensionless positive parameters a and b
- Standardisation velocity
 v* >> v

 Characteristic dimension of the micro contacts D_C



- 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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Numerical Simulation

Simulation | Fitting the Solution

- Adjust the form parameters a, b and D_C by gradient method
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 $v_0 = 7 \text{ mm/s}$



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Simulation | Fitting the Solution

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



- Adjust the form parameters a, b and D_C by gradient method
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experimental numerical Log₁₀(V/V_{norm}) 0 -1 -3 4.95 4 55 46 4.65 47 4.75 4.8 4.85 4.9 5

3

Time [s]

Time [s]

2

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

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200 180

160

140

120 100

> 80 60

40 | 20 |-0 |

1

Velocity [mm/s]

4

5

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- Adjust the form parameters a, b and D_C by gradient method
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 $v_0 = 0.05 \text{ mm/s}$



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- Adjust the form parameters a, b and D_C by gradient method
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curve correspond very well over several orders of magnitude

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Forecast of the Time of Jump | Theory

Approximation for the creep velocity near the instability

$$v pprox rac{a}{rac{b}{D_{C}} - rac{c}{F_{N}}} (t_{c} - t)^{-1} \quad \Rightarrow \quad rac{v}{\dot{v}} pprox (t_{c} - t)$$

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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

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Forecast of the Time of Jump | Experimental Data

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

for different pulling velocities



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Forecast of the Time of Jump | Experimental Data

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

- for different pulling velocities
- for several runs with the same pulling velocity



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data from simulation shows similar behaviour

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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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Conclusion & Outlook

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- 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

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

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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.