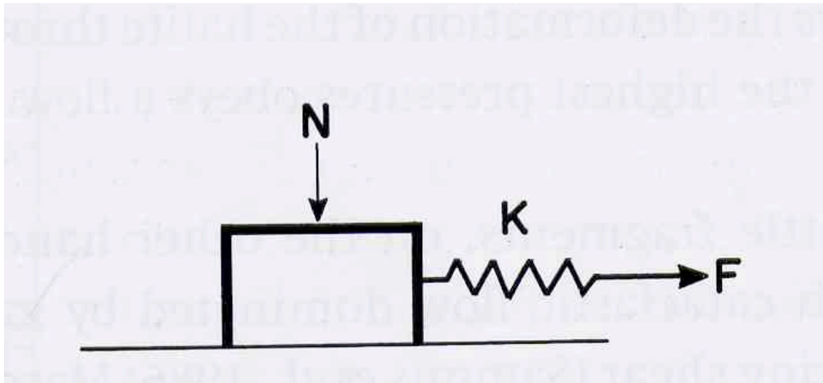
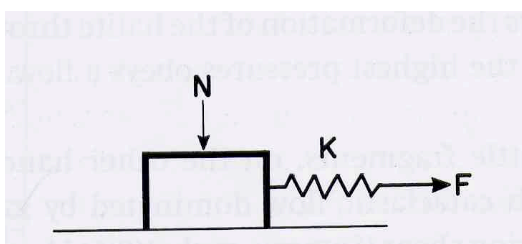
Spring-slider activity: slip stopped because...



Today: a closer look at the conditions leading to instability, and why the earthquake ends.



This is a battle between the shear force pulling the block and the friction force resisting it

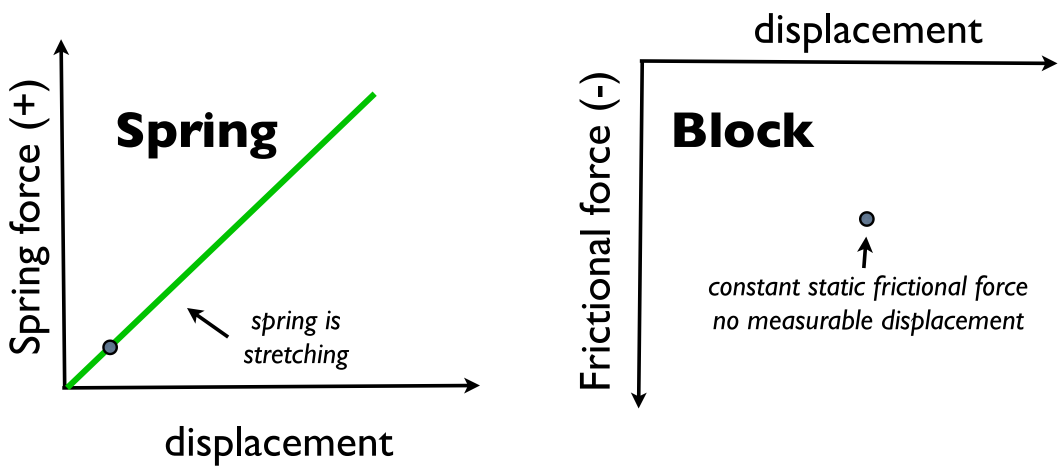
$$\tau \times A = k \times x = F_{spring}$$

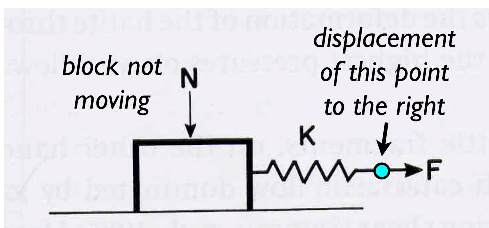
$$\sigma_n \times A \times \mu = N \times \mu = F_{friction}$$

$$F_{spring} + F_{friction} = 0$$

directions these forces are acting?

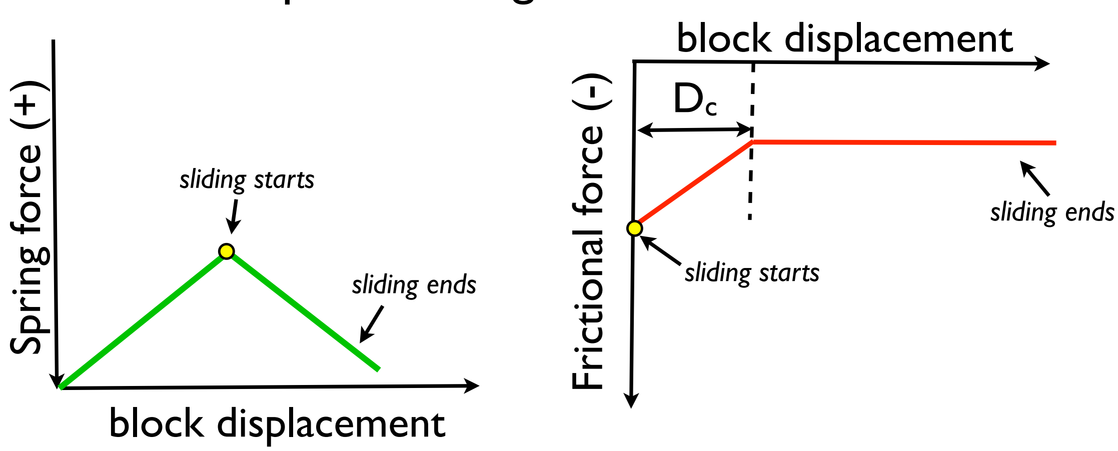
Before the block started to slide...

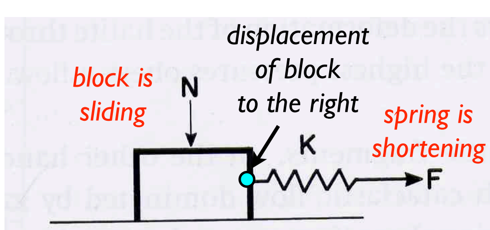




to the right =
+ x direction

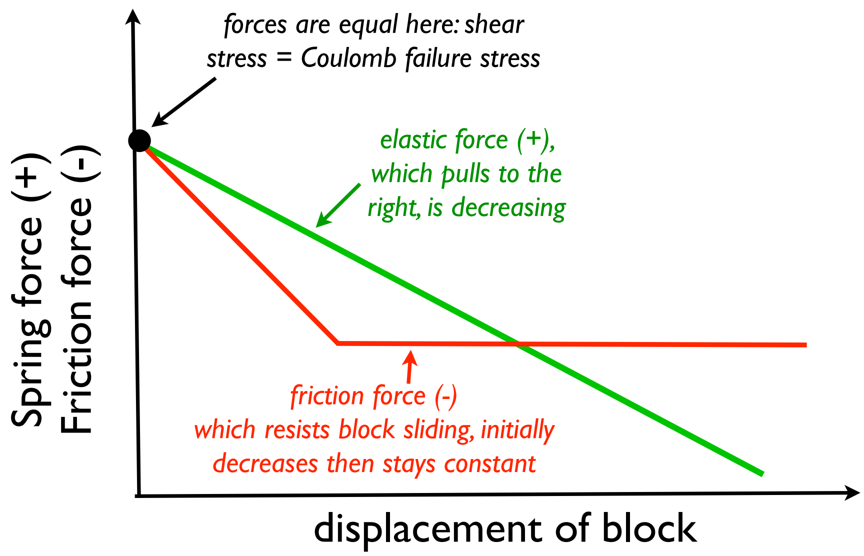
Now block sliding begins... assume slip weakening friction

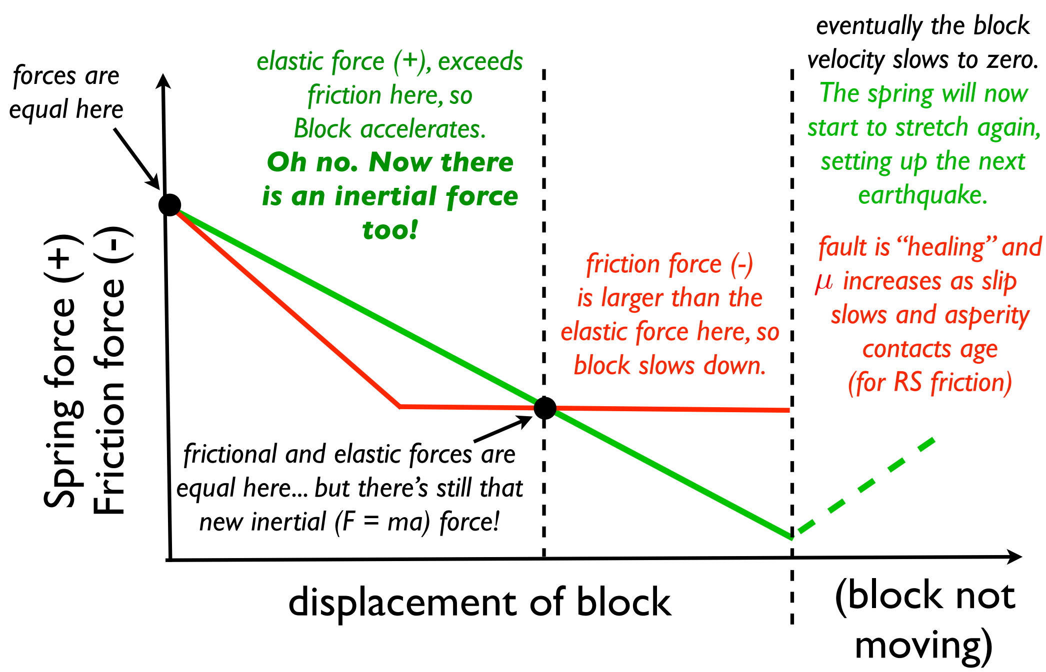


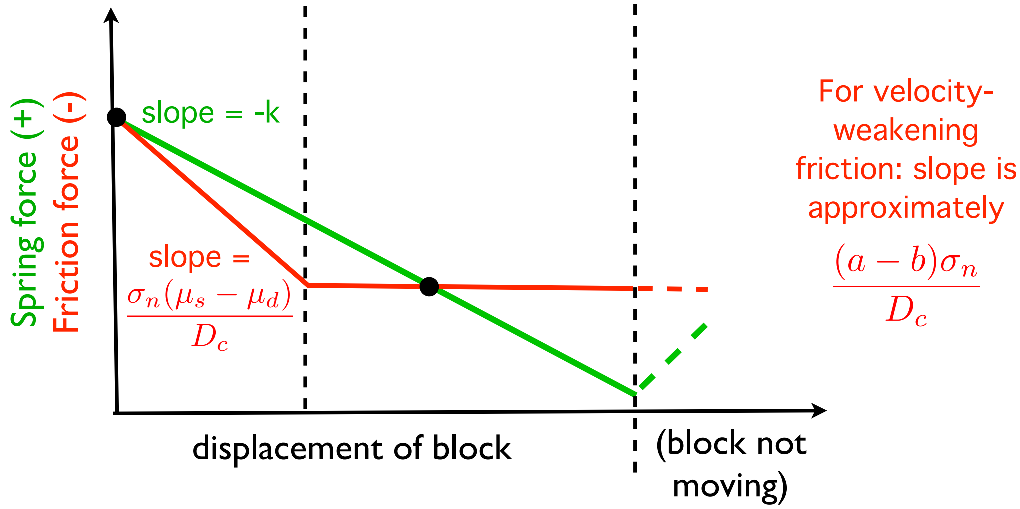


to the right =
+ x direction

Redraw this with absolute values of forces so the lines cross where |friction force| = |spring force|







Instability happens if friction decrease during sliding is steeper than elastic force decrease...

Instability if

$$k < \left| \frac{\sigma_n(b-a)}{D_c} \right|$$

Instability happens if friction decrease during sliding is steeper than elastic force decrease...

Instability if

$$k < \frac{\sigma_n(b-a)}{D_c}$$

Friday, what happened in the “stiff spring” experiment?

Instability happens if friction decrease during sliding is steeper than elastic force decrease...

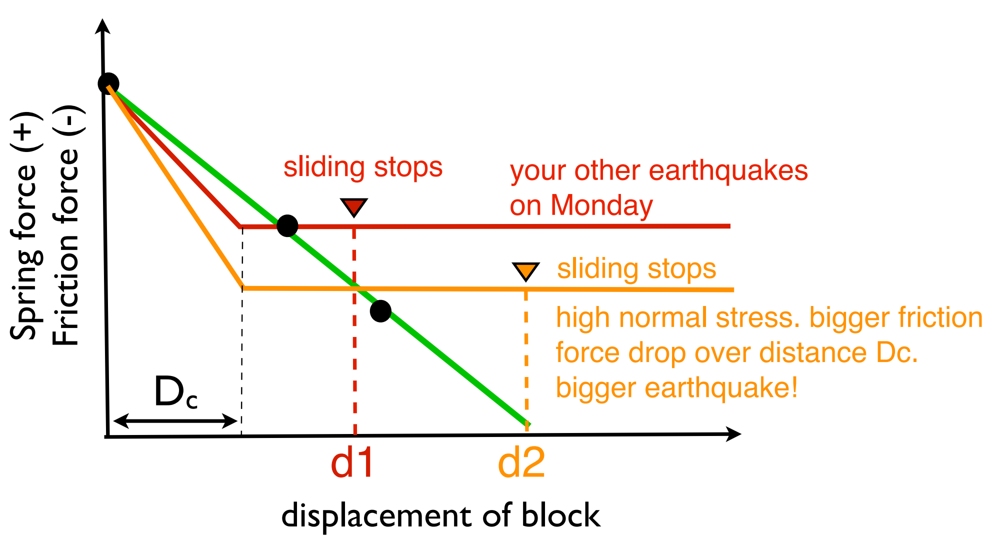
Instability if

$$k < \frac{\sigma_n (b-a)}{D_c}$$

- stiff spring?
- high normal stress?
- weak spring?
- low normal stress?

What about those big earthquakes you made by adding weight to the block?

- high normal stress (added a weight)
- no change to the spring stiffness (same old spring)



What does this mean in the Earth?

$$k < \frac{\sigma_n(b-a)}{D_c}$$

D_c and (a-b) : from lab experiments

σ_n : from (approx.) $\rho g h$

k: spring: k related block slip to elastic force decrease of the spring.

Earth: k relates fault slip to elastic shear force decrease of the rock

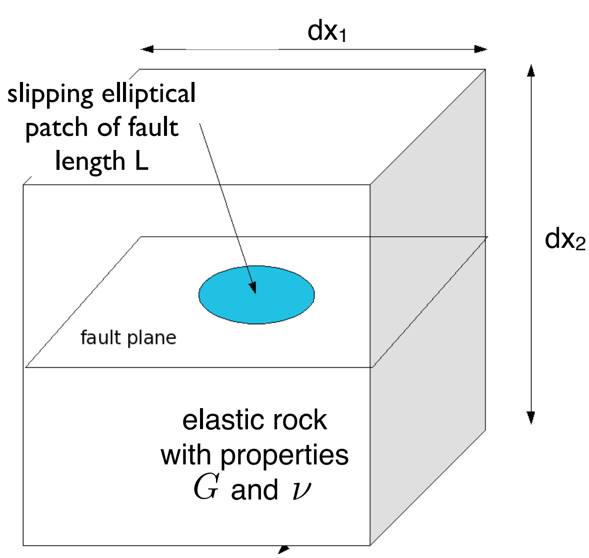
In the Earth, we use an equation for the stiffness k of a small, elliptical crack which comes from elasticity theory (and is proven by experiments)

k relates slip (offset) to the shear stress change

Equation for stiffness k for a small, elliptical crack is:

$$k = \frac{G}{(1-\nu)L}$$

G = shear modulus
ν = Poisson's ratio
L = length of slipping area



Earthquake machine: k is the spring stiffness: elastic force due to stretching the spring.

Earth: k is the elastic force due to offset along the crack (length L).

$$k < \frac{\sigma_n(b-a)}{D_c}$$

$$\frac{G}{(1-\nu)L} < \frac{\sigma_n(b-a)}{D_c}$$

k = crack stiffness
G = shear modulus
ν = Poisson's ratio
L = length of slipping area
$(b-a)$ = friction weakening parameter
σ_n = normal stress
D_c = friction weakening distance

$$L > \frac{D_c G}{(1-\nu)(b-a)\sigma_n}$$

This tells us that <u>the slipping patch of fault must be bigger than a critical size to go unstable</u>, *even* for a velocity weakening fault

<u>The slipping patch of fault must be bigger than a critical size to go unstable</u>

Determine the minimum earthquake size (magnitude and moment) assuming: G=30 GPa, normal stress = 150 MPa, b-a = 0.01, ν= 0.25, and Dc = 10^{-4} m.

$$L > \frac{D_c G}{(1-\nu)(b-a)\sigma_n}$$

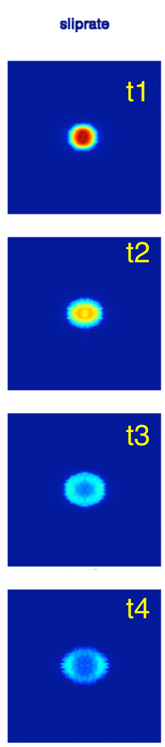
log M_o = 1.5(M_w + 6.0333)
M_w = log M_o/1.5 - 6.0333
M_o = AsG

Get L and then get moment and moment magnitude.
Assume offset (slip) is 0.01 times L.

Conditions required to start an earthquake?

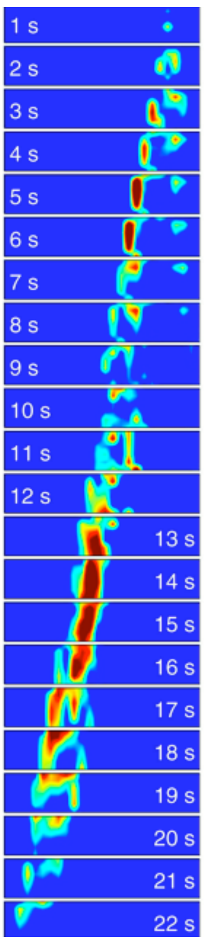
upper crust property: ______
fault friction: _______
shear stress on fault exceeds: _______
(at a point? over an area?) ________

$$L > \frac{D_c G}{(1-\nu)(b-a)\sigma_n}$$



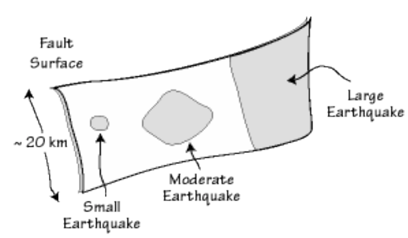
Madariaga,
Wald and Heaton 1994

vs.



We now know what it takes to start an earthquake.

What does it take to make a large earthquake?



They all start small at the hypocenter...