  

New insights in the modelling of slope stability and avalanche sizes

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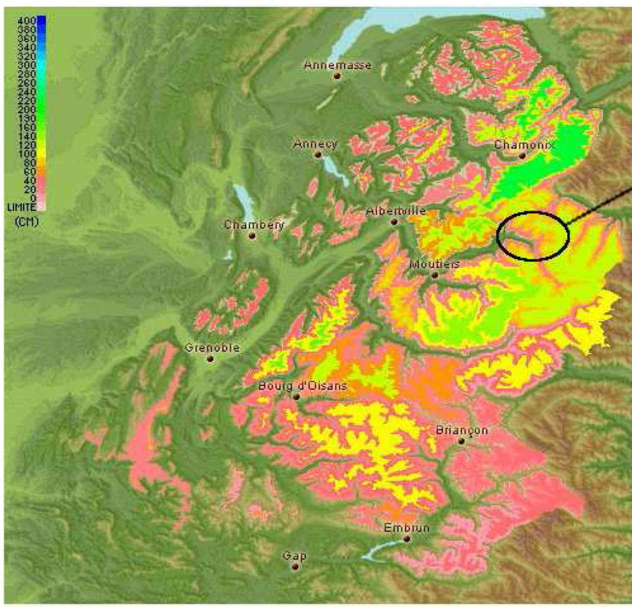
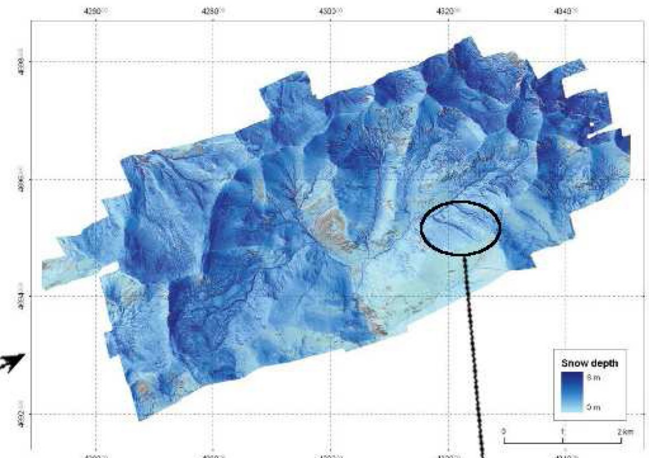
OSUG Snow workshop – 15/11/2013

Context

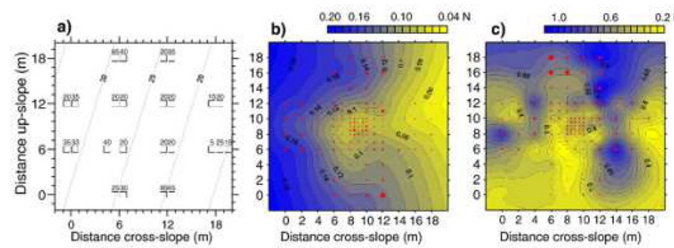
Complexity of avalanche forecasting due to a multi-scale spatial variability



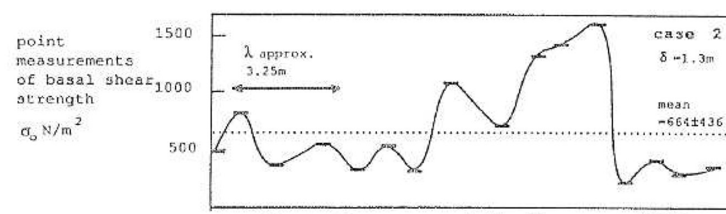
(c) Avalanches-net



From Banos et al 2011



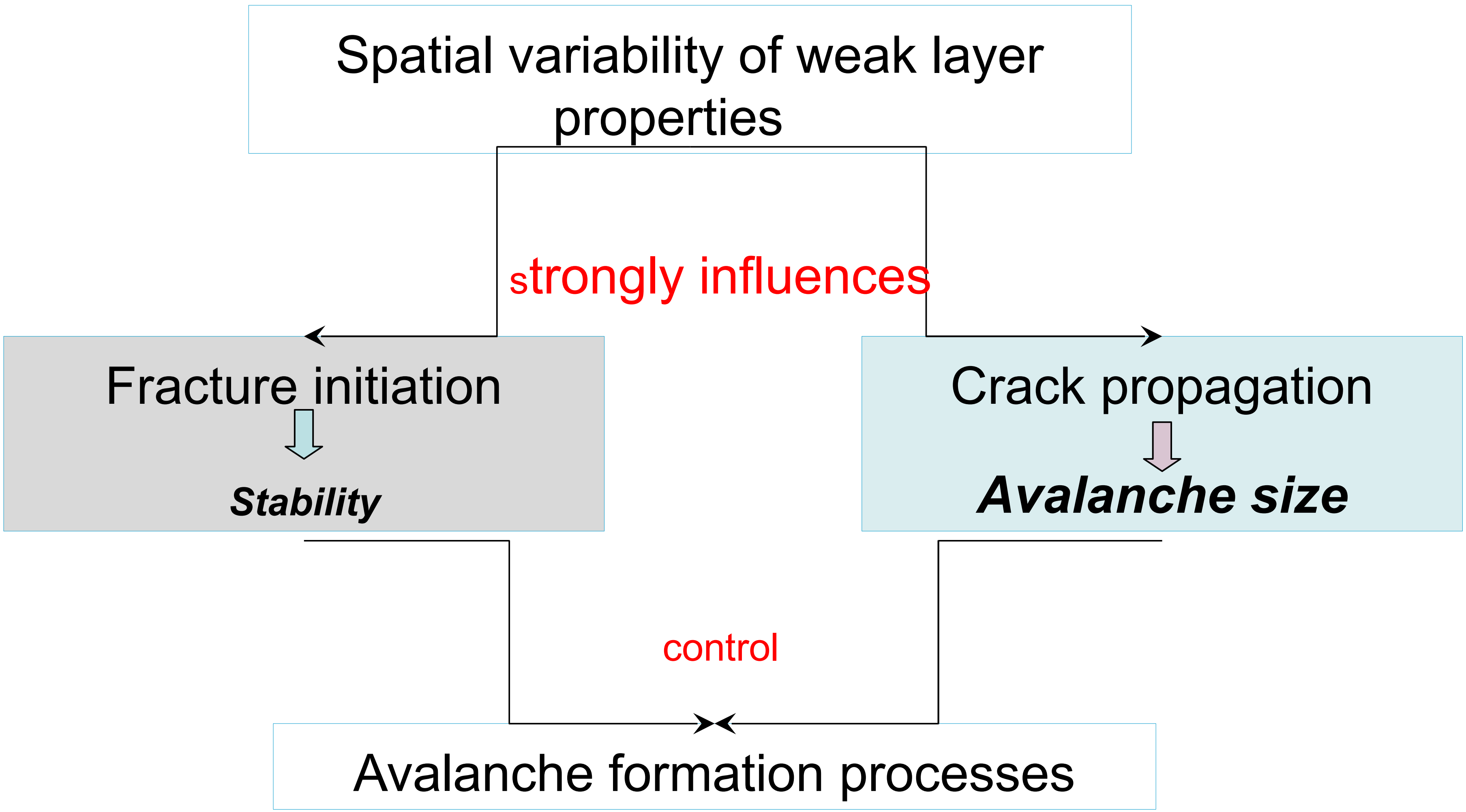
From Schweizer 2008



From Conway and Abrahamson 1988

Context

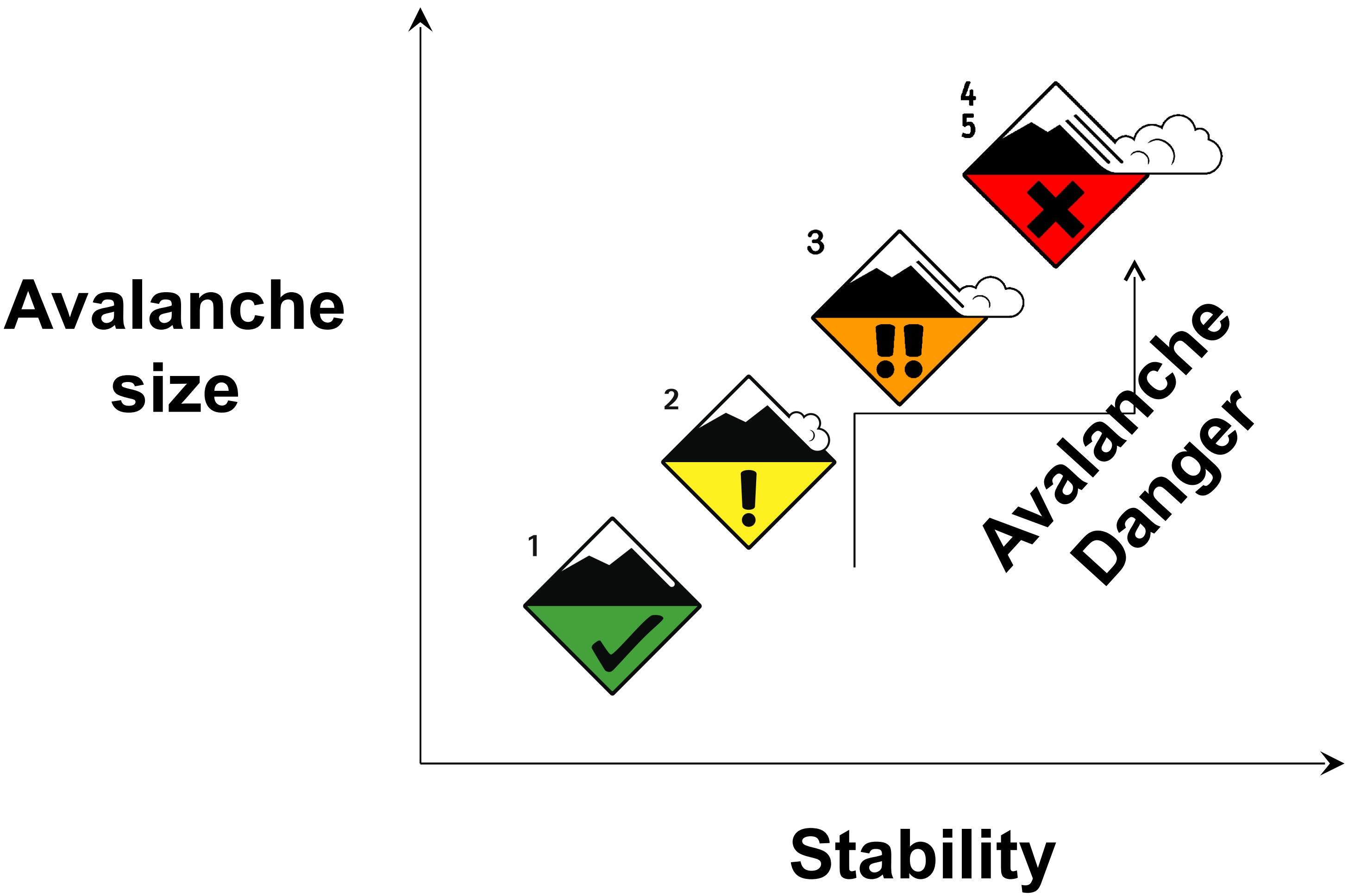
Importance of spatial variability for avalanche formation



Schweizer et al., 2008. Review of spatial variability of snowpack properties and its importance for avalanche formation. *CRST*, 51, 253-272

Context

Forecasting requires both stability and the avalanche size



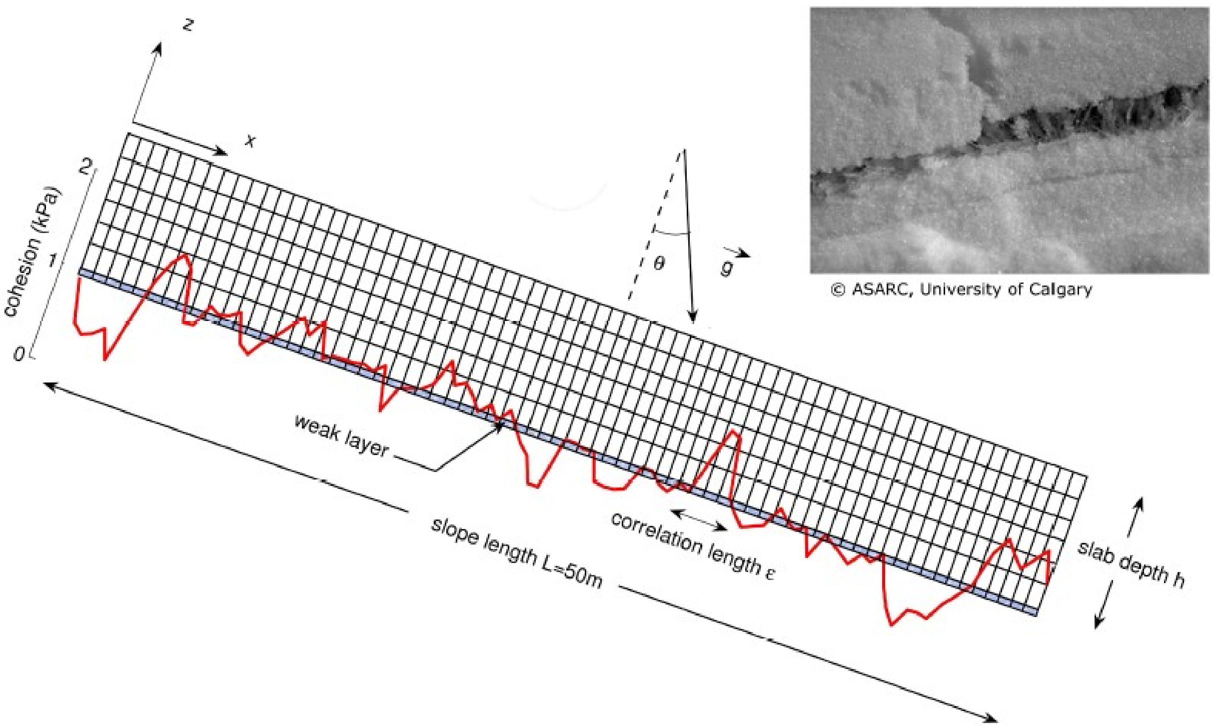
Objective and method

Objective

Spatial variability → ? → slope stability and avalanche size

Method

Mechanically-based statistical model of slab avalanche release
Gaume et al. (2012, 2013)



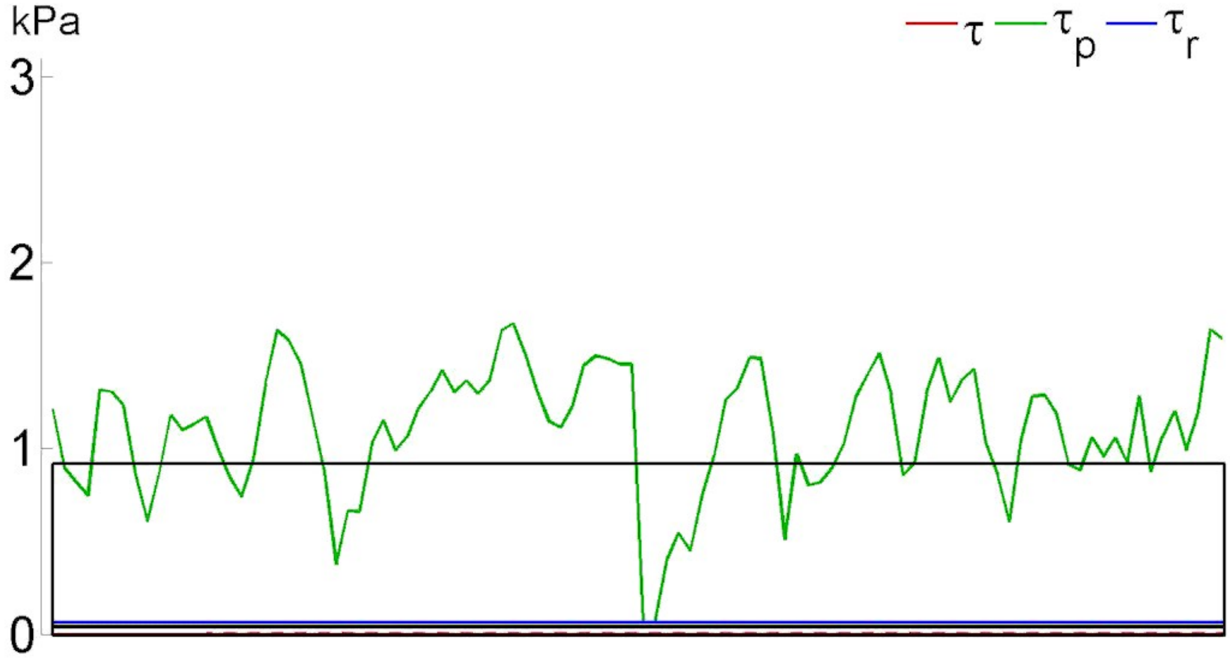
This model takes into account, in particular:

(1) the spatial variations of WL mechanical properties (shear strength)

(2) a shear quasi-brittle constitutive law for the WL

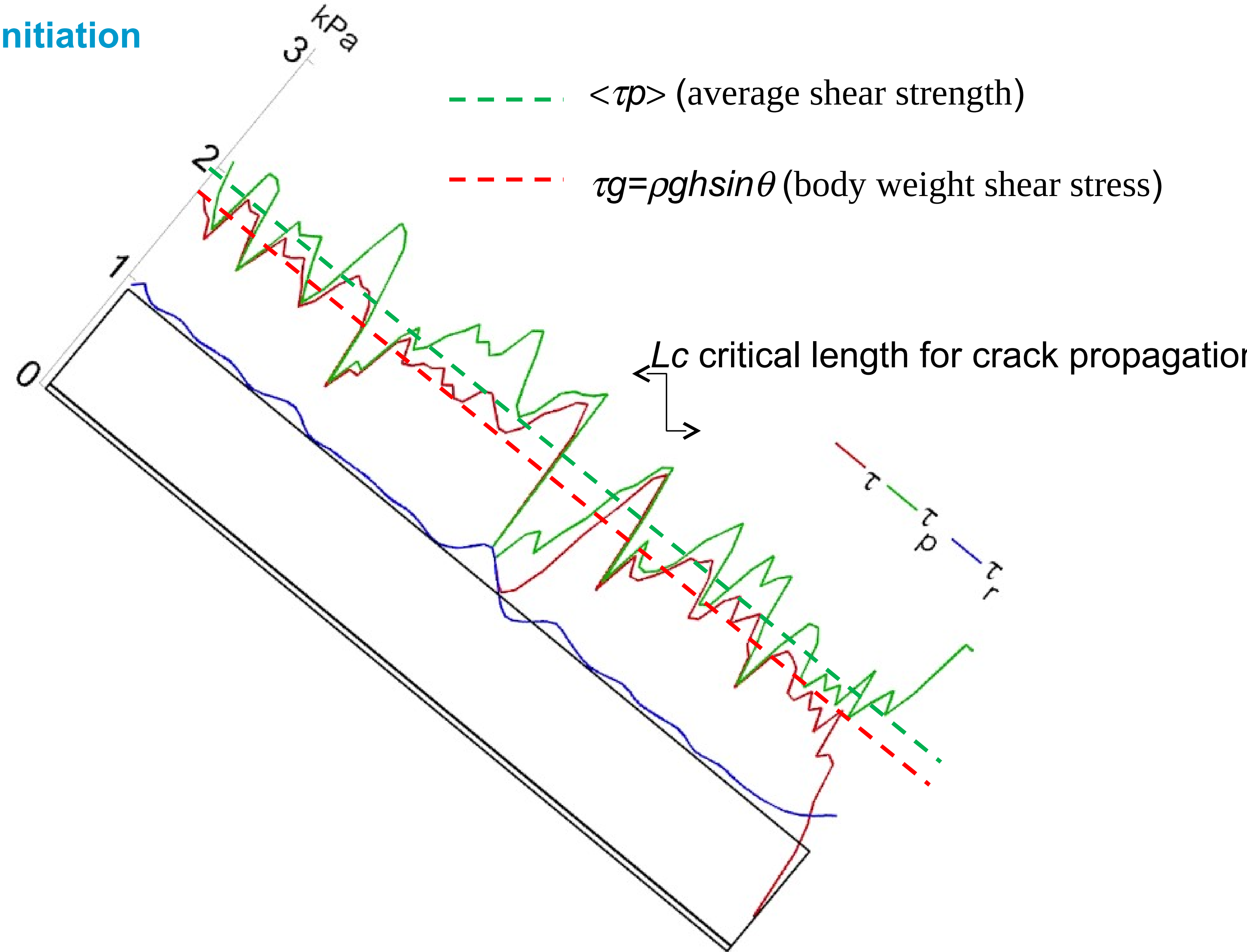
(3) stress redistribution effects by elasticity of the slab

Illustration



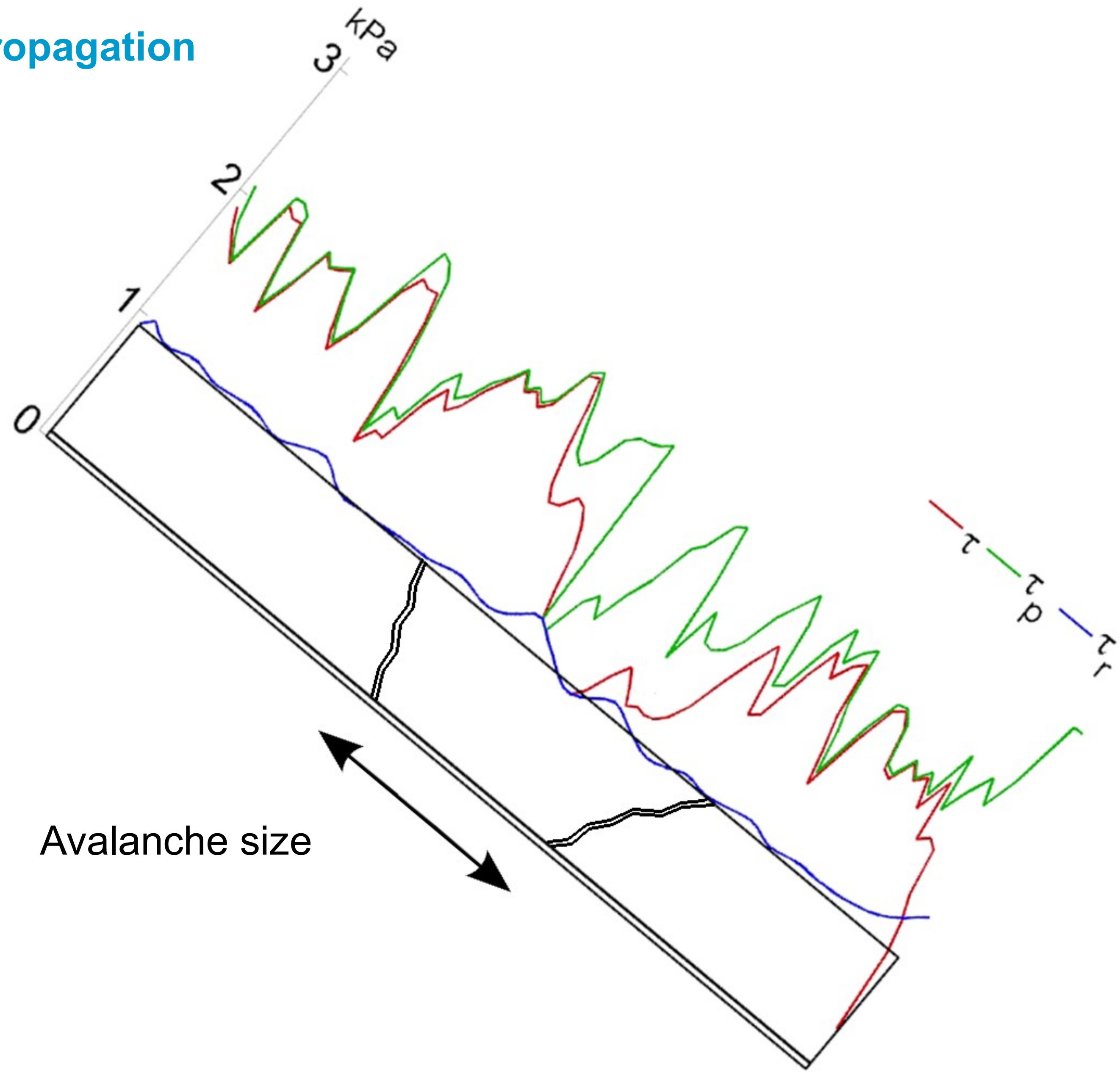
Illustration

Failure initiation



Illustration

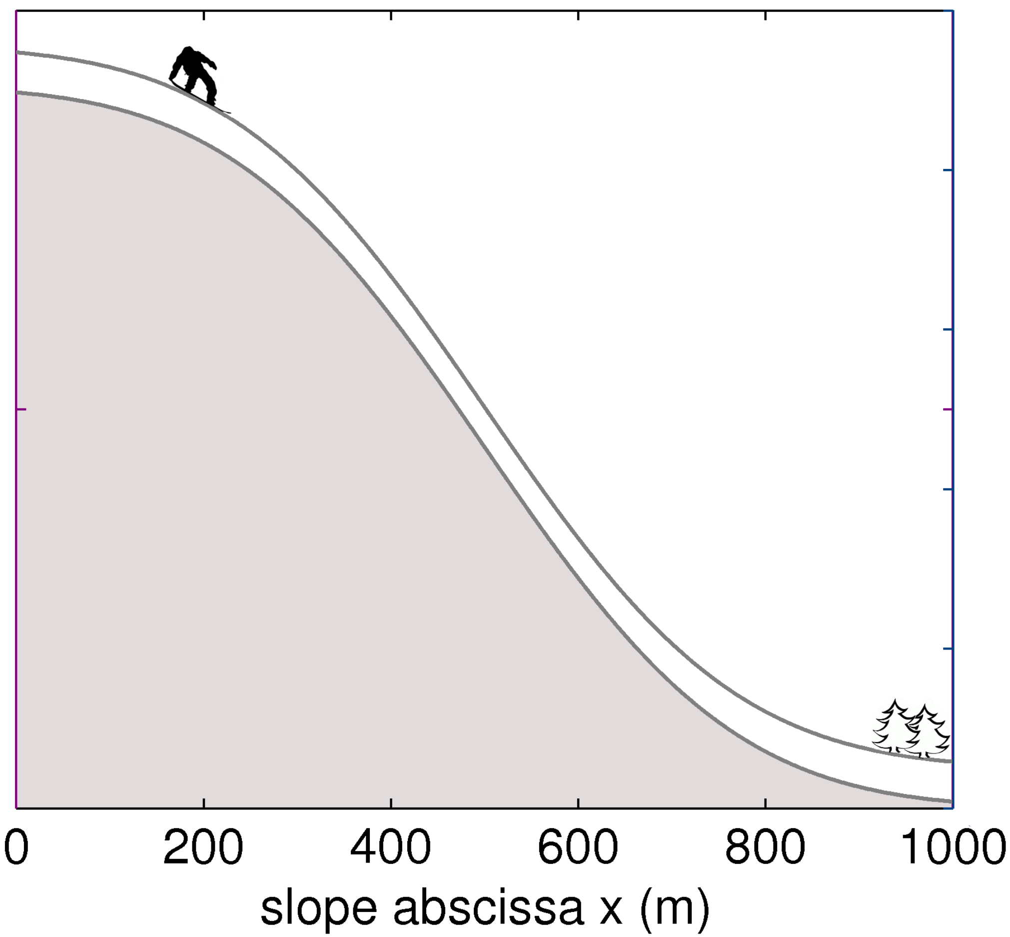
Crack propagation



Results

Slope stability evaluation

hz=50cm
ρ =250kg/m3
E=1MPa
τp=800Pa

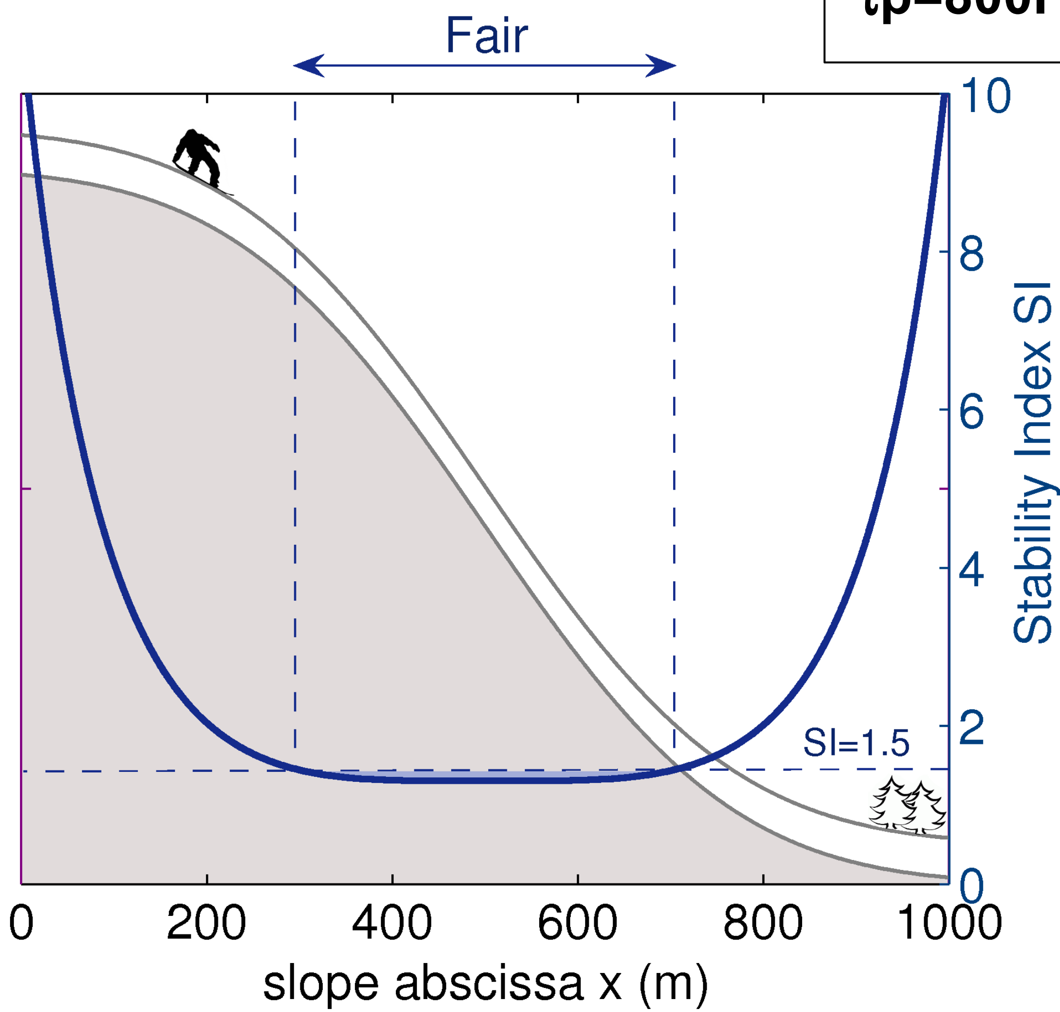


Stability index SI = $\dfrac{\text{shear strength}}{\text{shear stress}}$ = $\dfrac{\tau_p}{\tau_{xz}}$

Results

Slope stability evaluation

hz=50cm
ρ =250kg/m3
E=1MPa
τp=800Pa



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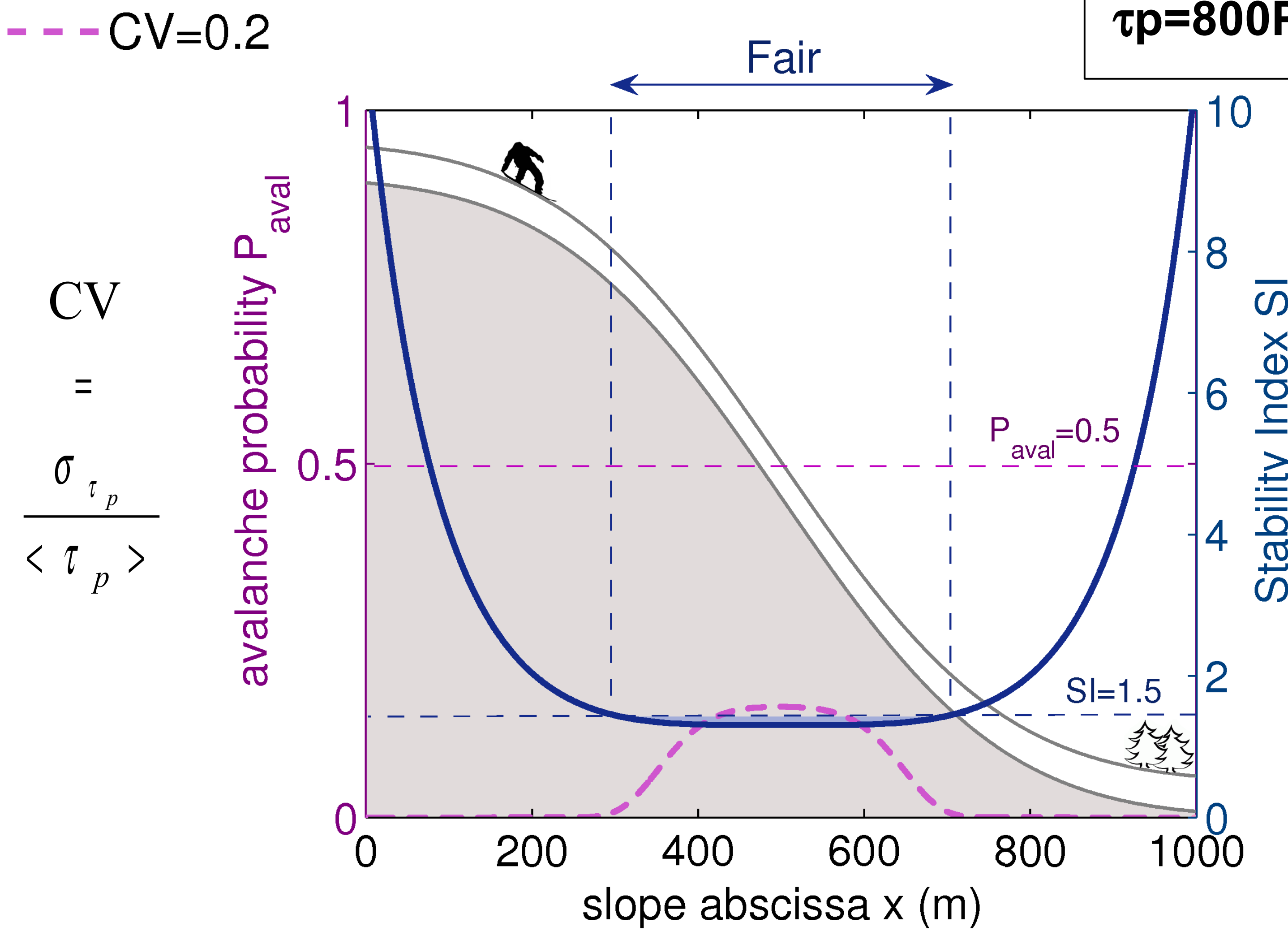


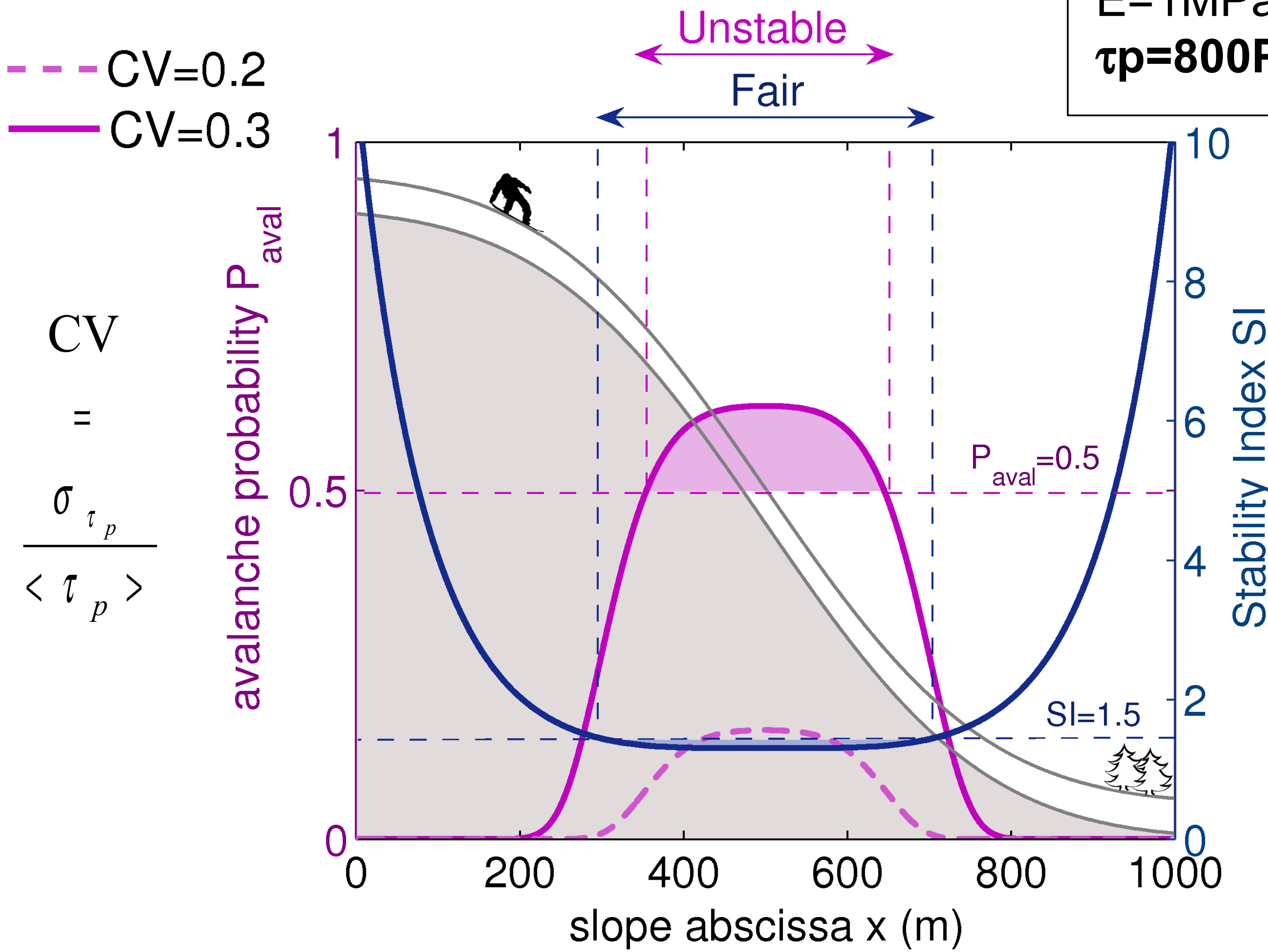
hz=50cm
ρ =250kg/m3
E=1MPa
τp=800Pa

$$CV = \frac{\sigma_{\tau_p}}{\langle \tau_p \rangle}$$

Stability index SI = $\frac{\text{shear strength}}{\text{shear stress}} = \frac{\tau_p}{\tau_{xz}}$

Results

Slope stability evaluation



hz=50cm
ρ =250kg/m3
E=1MPa
τp=800Pa

$$CV = \frac{\sigma_{\tau_p}}{\langle \tau_p \rangle}$$

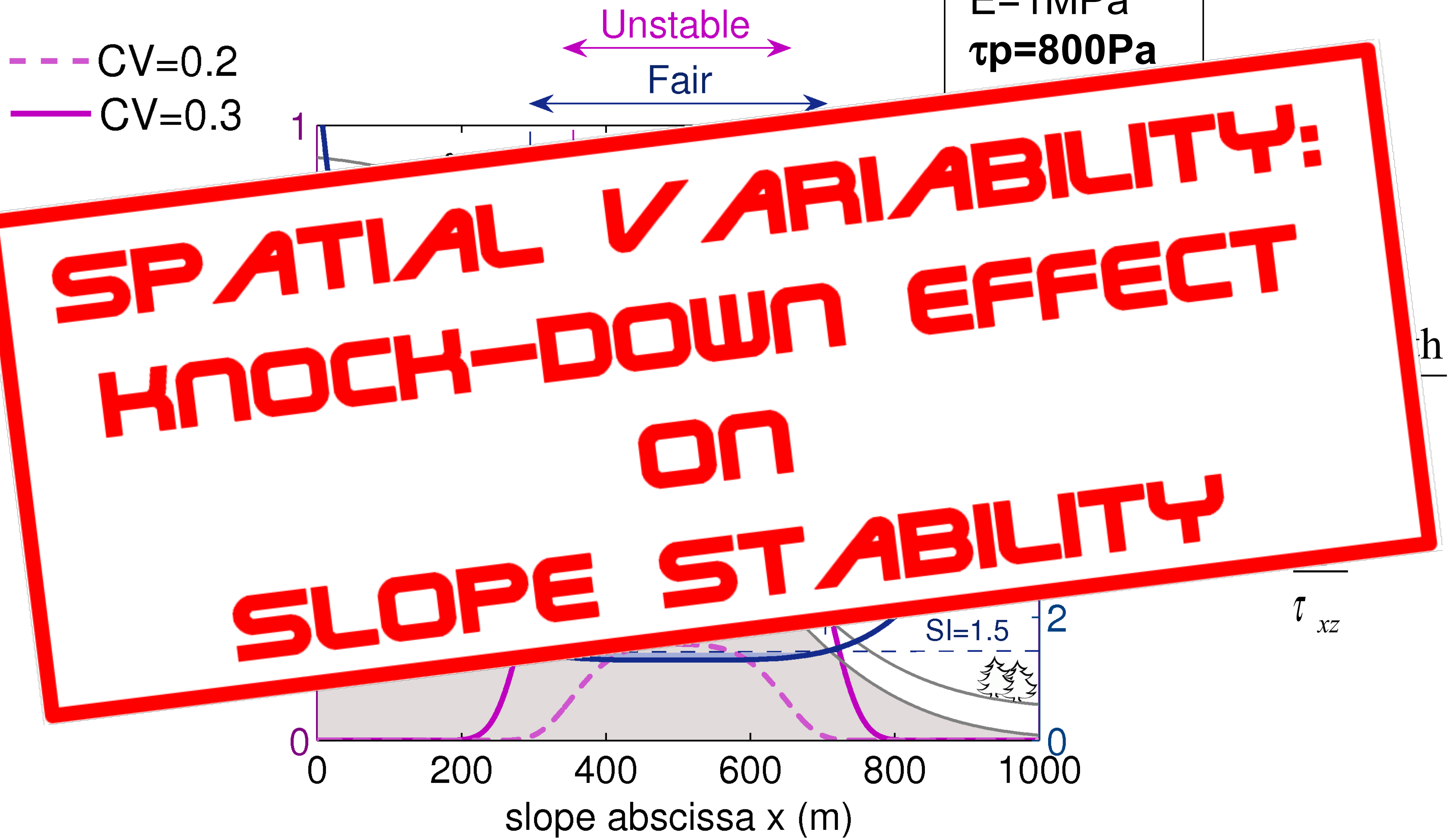
Stability index SI = $\frac{\text{shear strength}}{\text{shear stress}} = \frac{\tau_p}{\tau_{xz}}$

Results

Slope stability evaluation

hz=50cm
ρ =250kg/m3
E=1MPa
τp=800Pa

SPATIAL VARIABILITY:
KNOCK-DOWN EFFECT
ON
SLOPE STABILITY

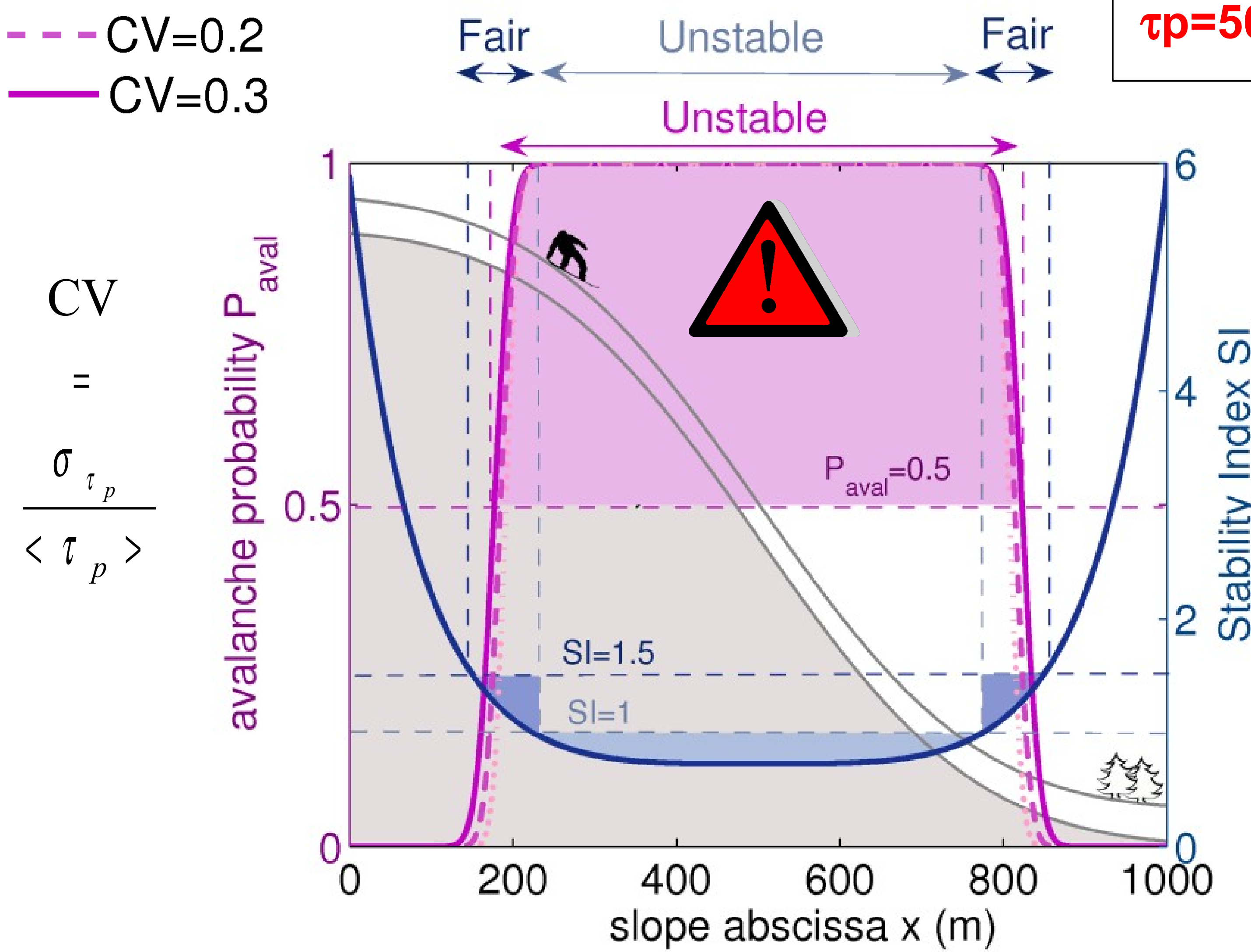


Results

Slope stability evaluation

hz=50cm
ρ =250kg/m3
E=1MPa
τp=500Pa

CV = $\frac{\sigma_{\tau_p}}{\langle \tau_p \rangle}$



Stability index SI = $\frac{\text{shear strength}}{\text{shear stress}} = \frac{\tau_p}{\tau_{xz}}$

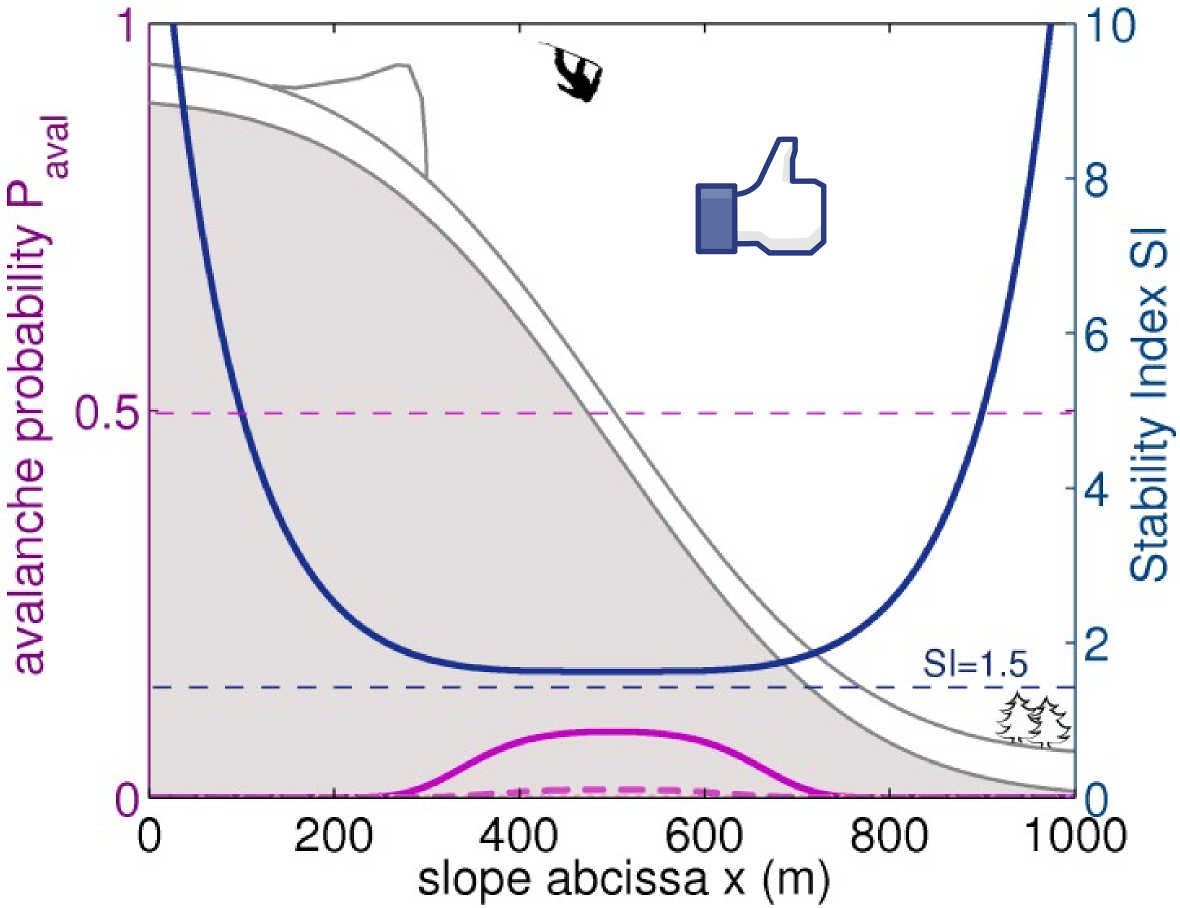
Results

Slope stability evaluation

- - - CV=0.2
—— CV=0.3

hz=50cm
ρ =250kg/m3
E=1MPa
τp=1000Pa

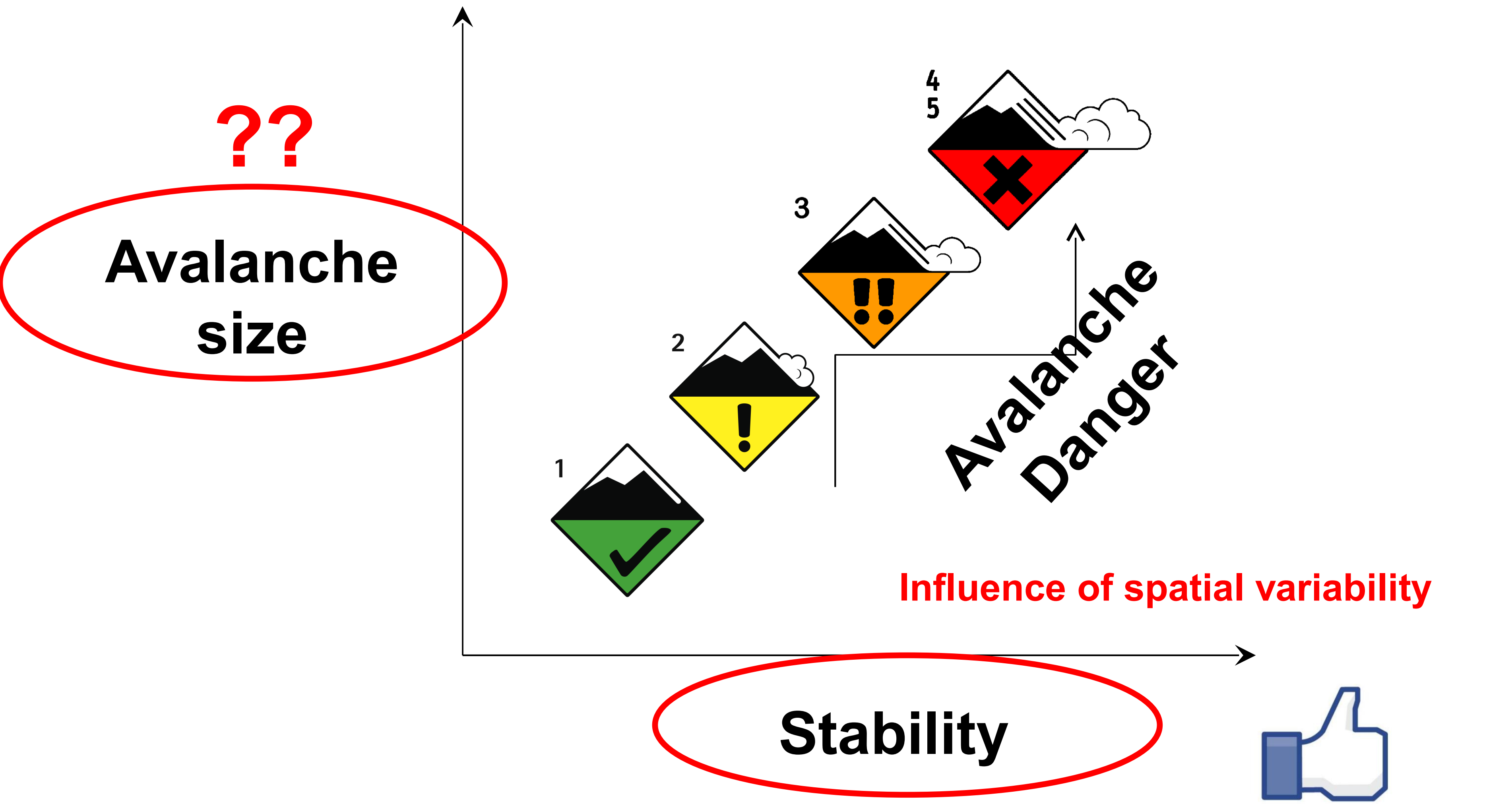
$$CV = \frac{\sigma_{\tau_p}}{\langle \tau_p \rangle}$$



Stability index SI = $\frac{\text{shear strength}}{\text{shear stress}} = \frac{\tau_p}{\tau_{xz}}$

Objective

Evaluation the size of the release area



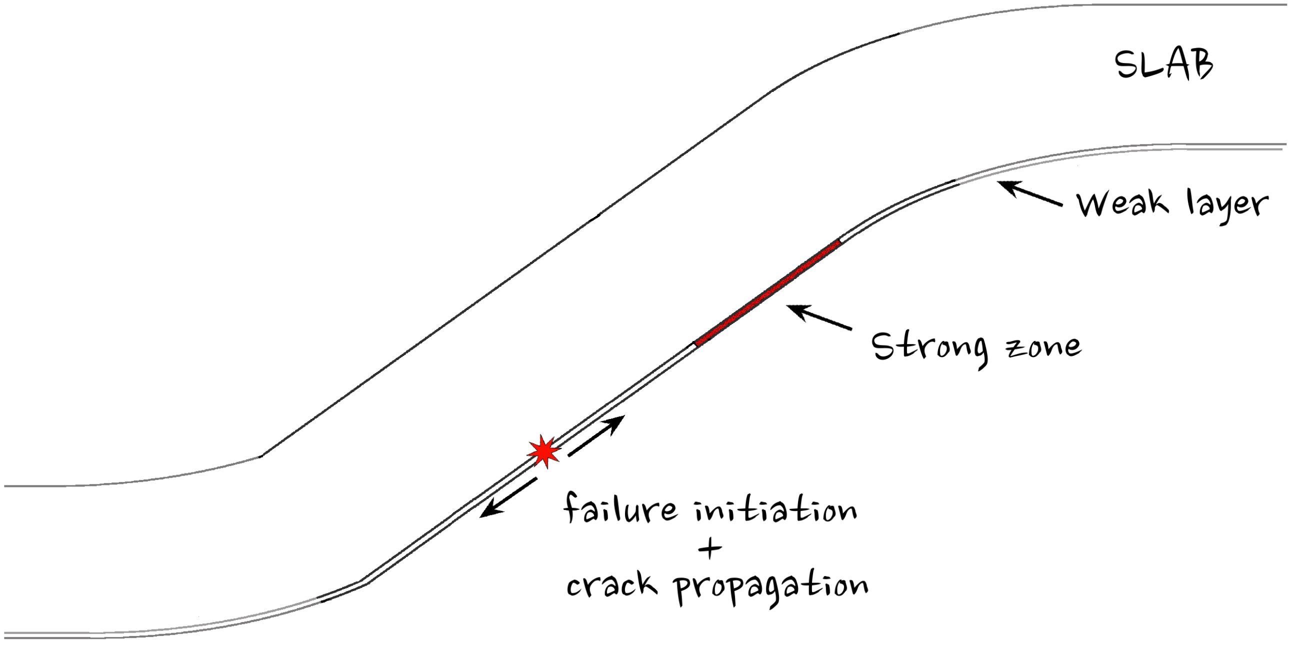
Objective

Answer the question:

Spatial variability of weak layer shear strength

? possible trigger ?

Slab tensile failure



Objective

Answer the question:

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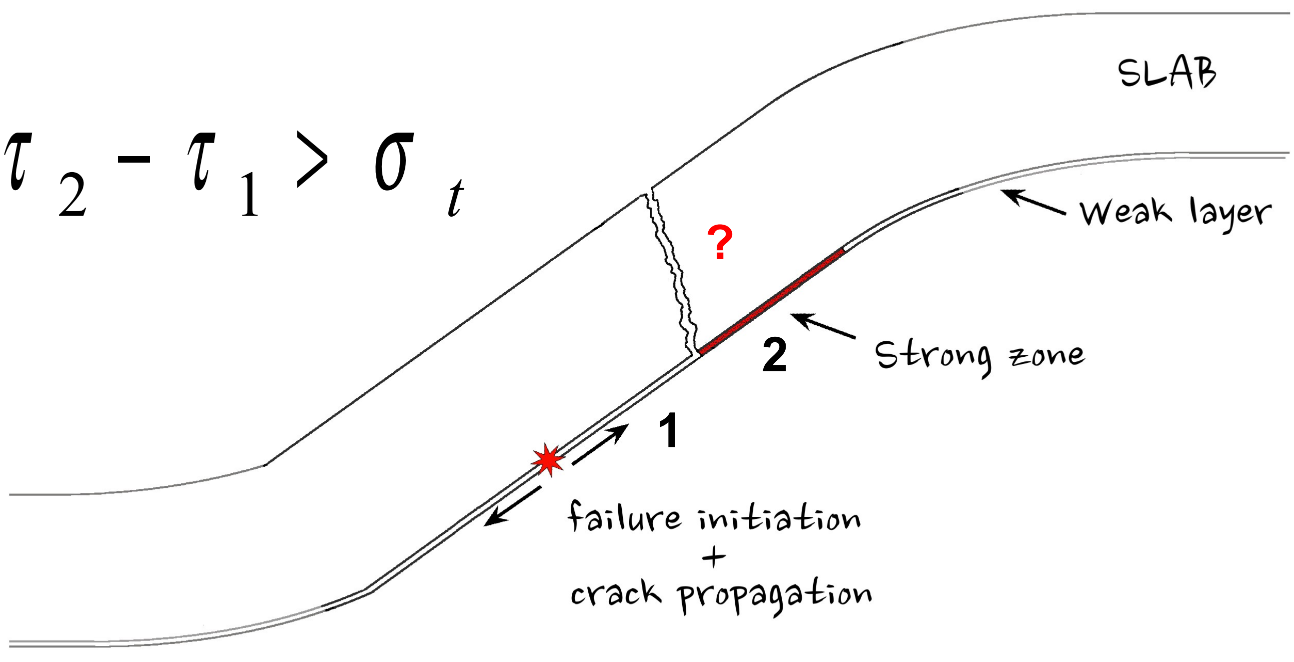
Slab tensile failure

$$\Delta\tau = \tau_2 - \tau_1 > \sigma_t$$



Objective

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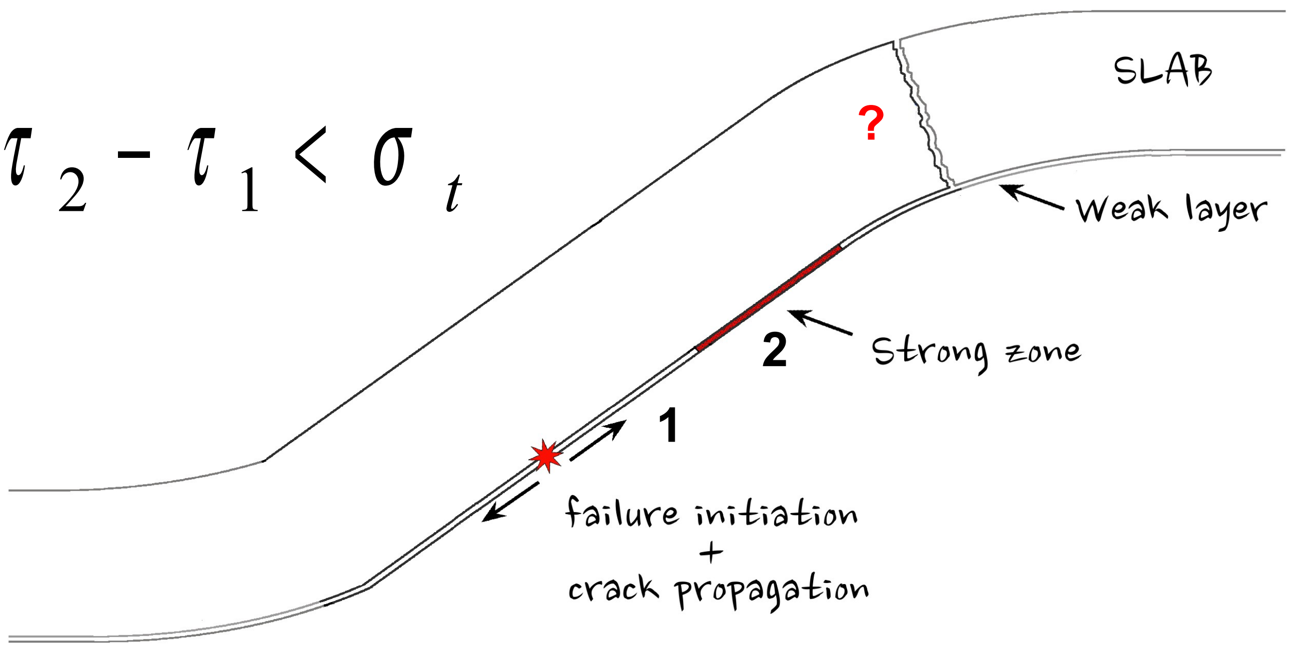
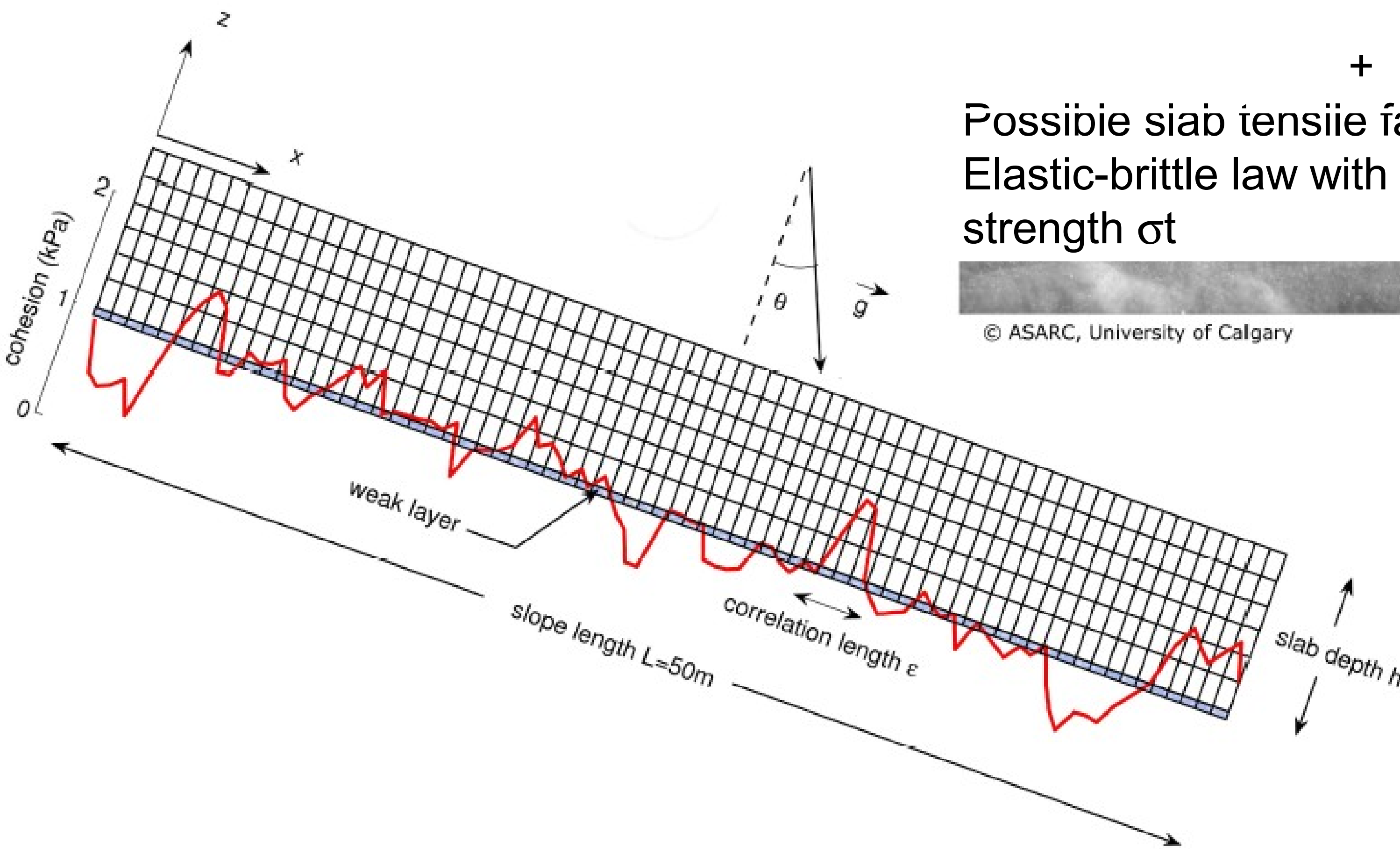


Method

Coupled mechanical - statistical model of slab avalanche release



Same ingredients

(1) the spatial variations of WL mechanical properties (shear strength)

(2) a shear quasi-brittle constitutive law for the WL

(3) stress redistribution effects by elasticity of the slab

+

Possible slab tensile failure: Elastic-brittle law with tensile strength σt

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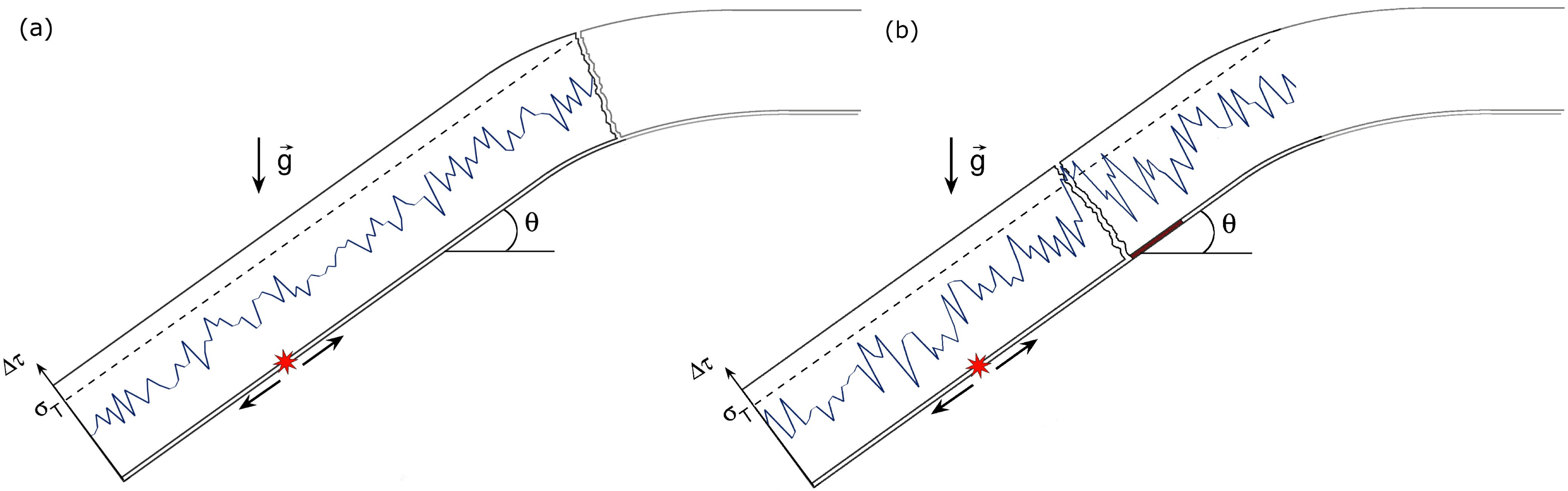
Results

Two release types



Full-slope releases $\Delta\tau < \sigma_T$

Partial-slope releases $\Delta\tau > \sigma_T$

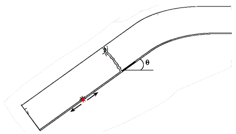
- The heterogeneity is not sufficient to trigger a tensile failure within the slab
- The position of the slab tensile failure is influenced by morphological features (rocks, trees, ridge, curvature...).

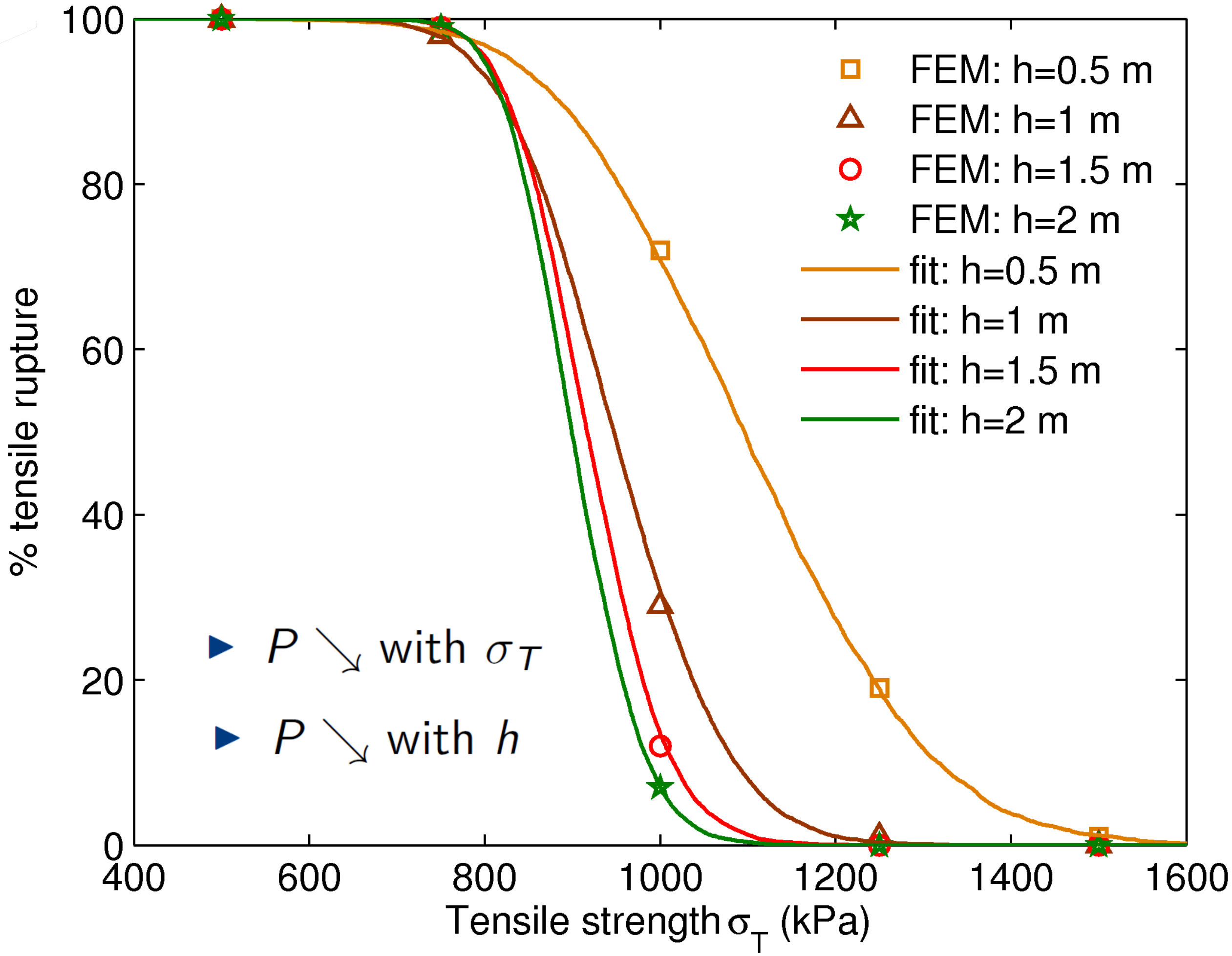
- The heterogeneity can trigger a tensile failure within the slab

Results

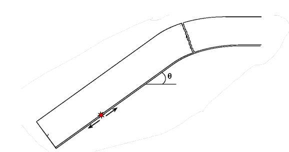
Proportion between release types

ρ =250kg/m3
E=1MPa
<τp>=1kPa
CV=30%





- $P \searrow$ with σ_T
- $P \searrow$ with h



$$\%\ \text{tensile rupture} = \%\ \text{of partial-slope releases} = P(\Delta\tau > \sigma_T)$$

Results

Proportion between release types

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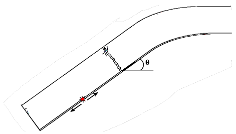
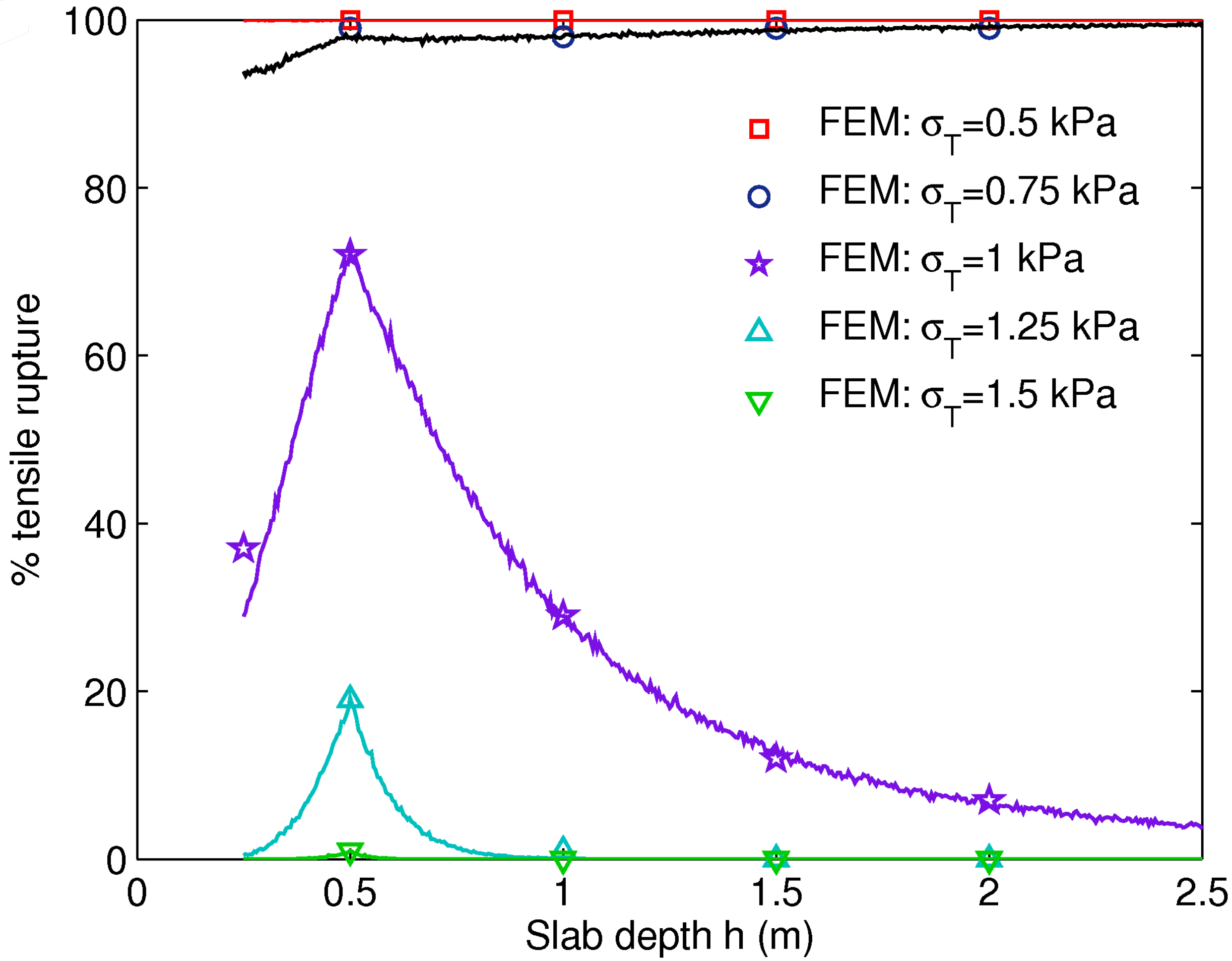
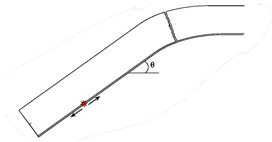
<τp>=1kPa
CV=30%





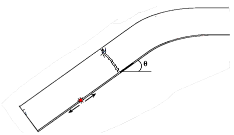


$$\%\ \text{tensile rupture} = \%\ \text{of partial-slope releases} = P(\Delta\tau > \sigma_T)$$

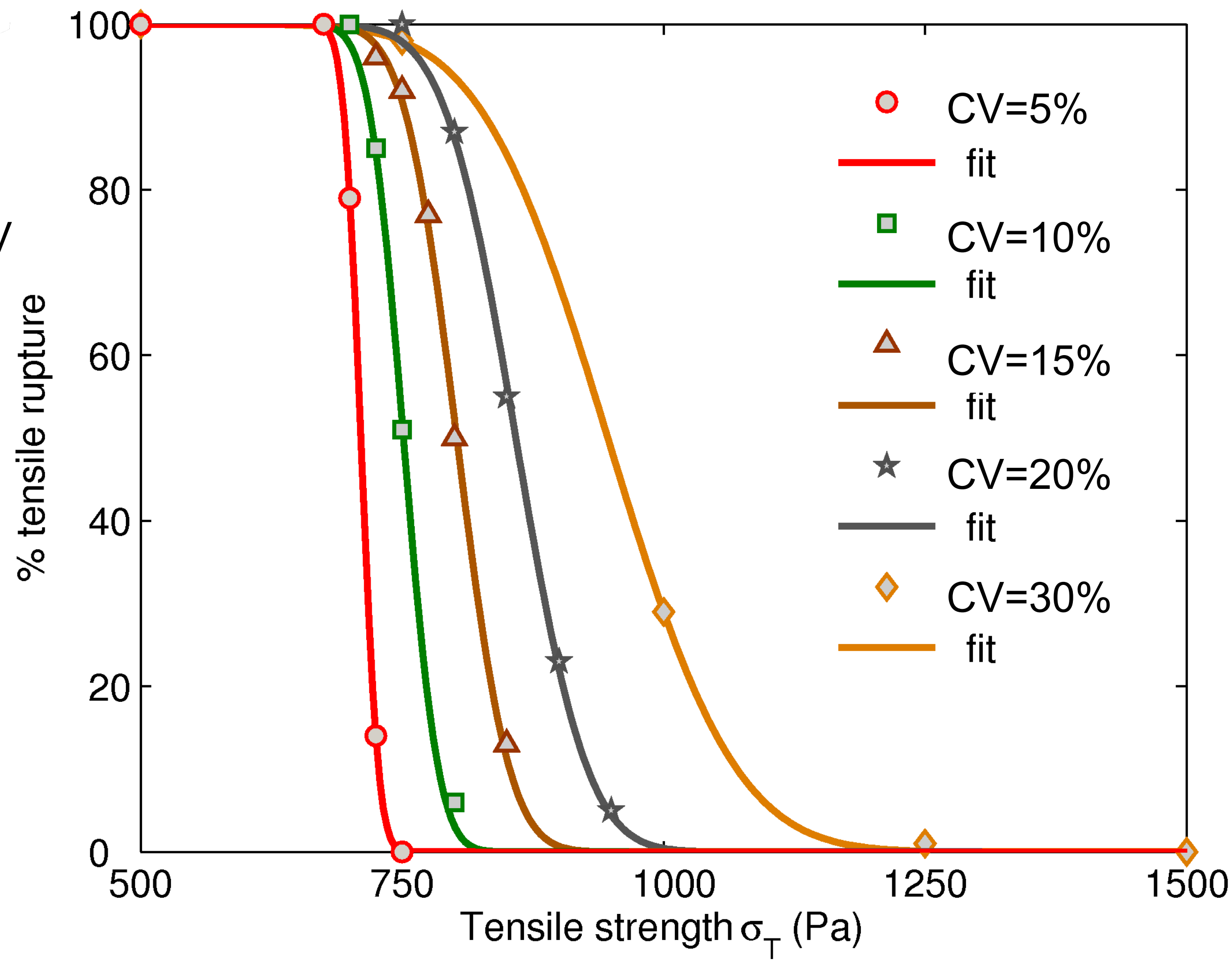
Results

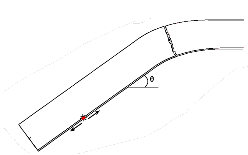
Proportion between release types

ρ =250kg/m3
E=1MPa
<τp>=1kPa
h=1m



- P ↗ with CV





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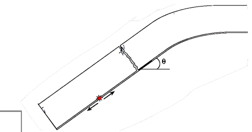
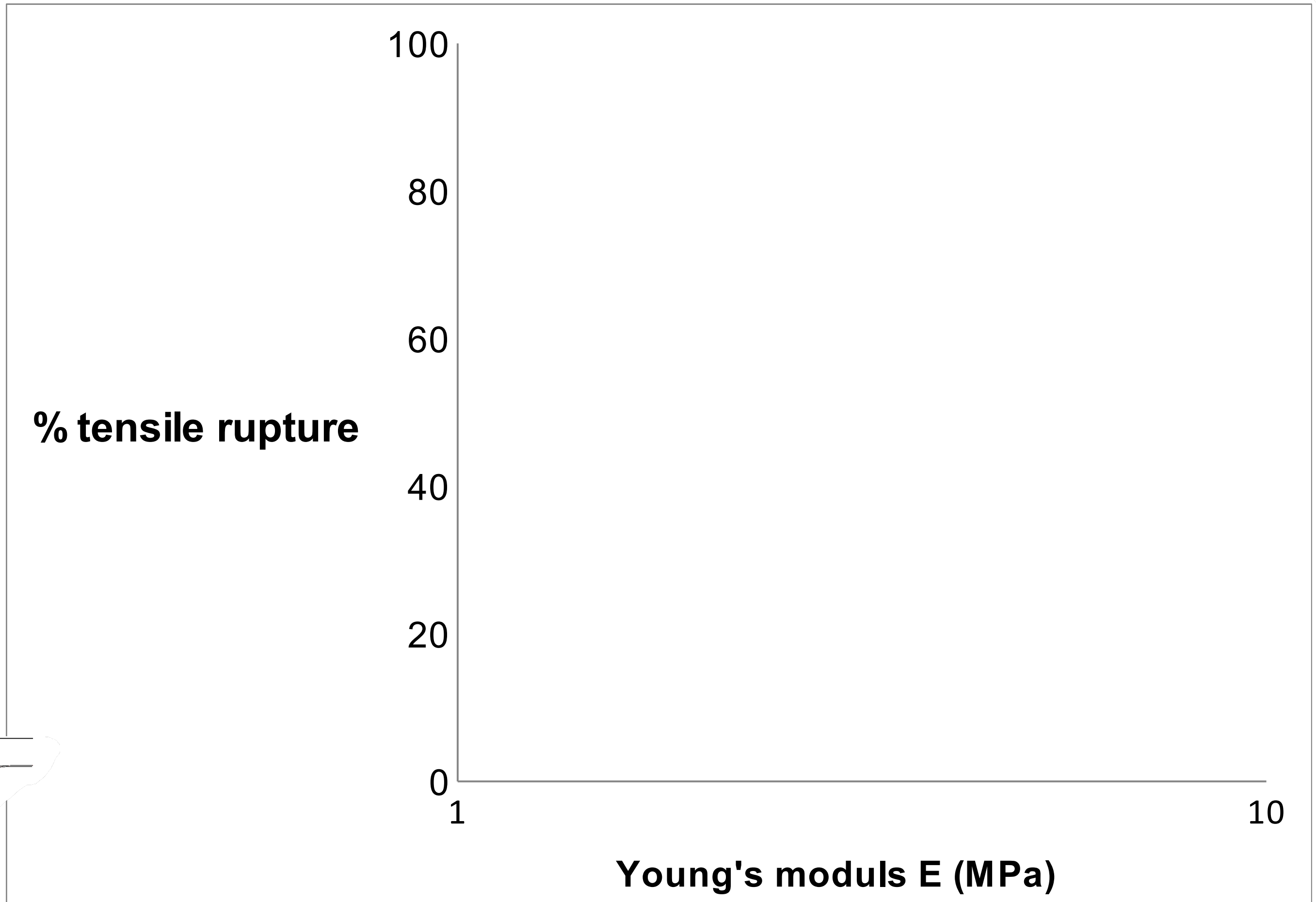
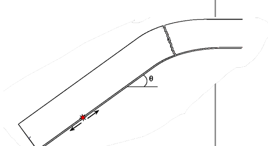


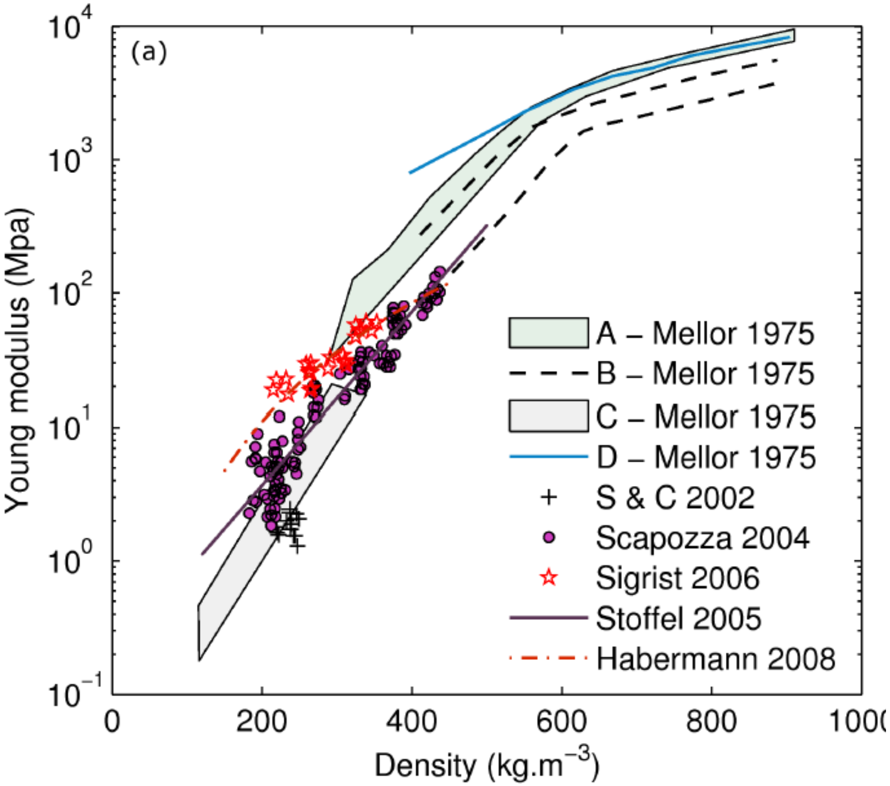


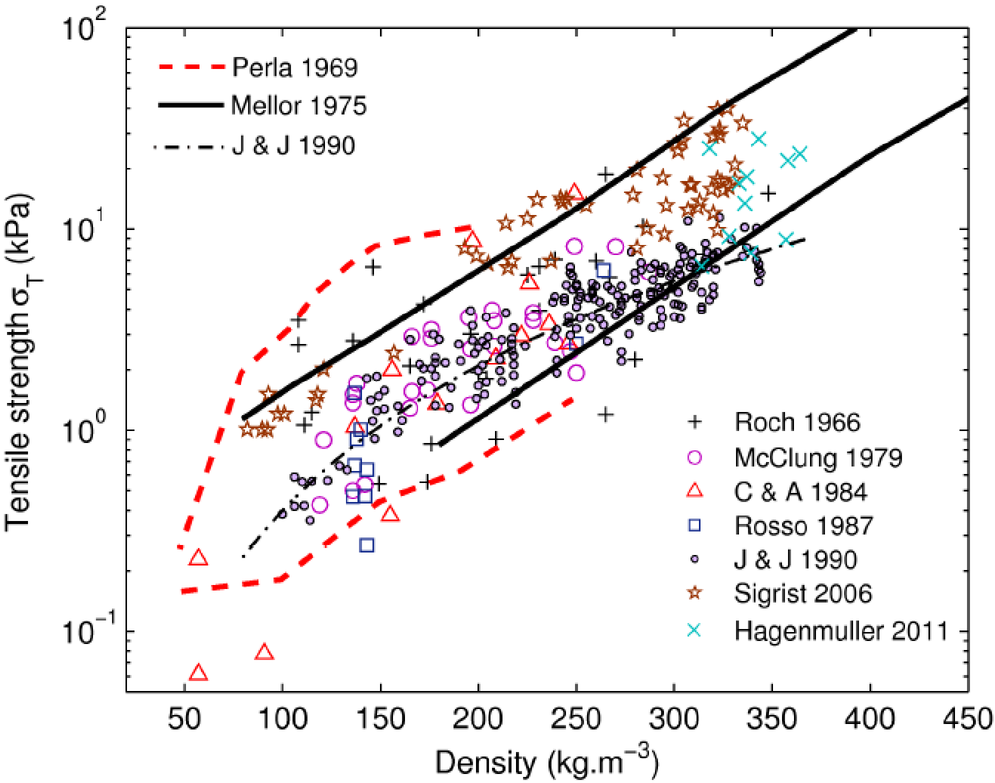


Interlude

Snow properties

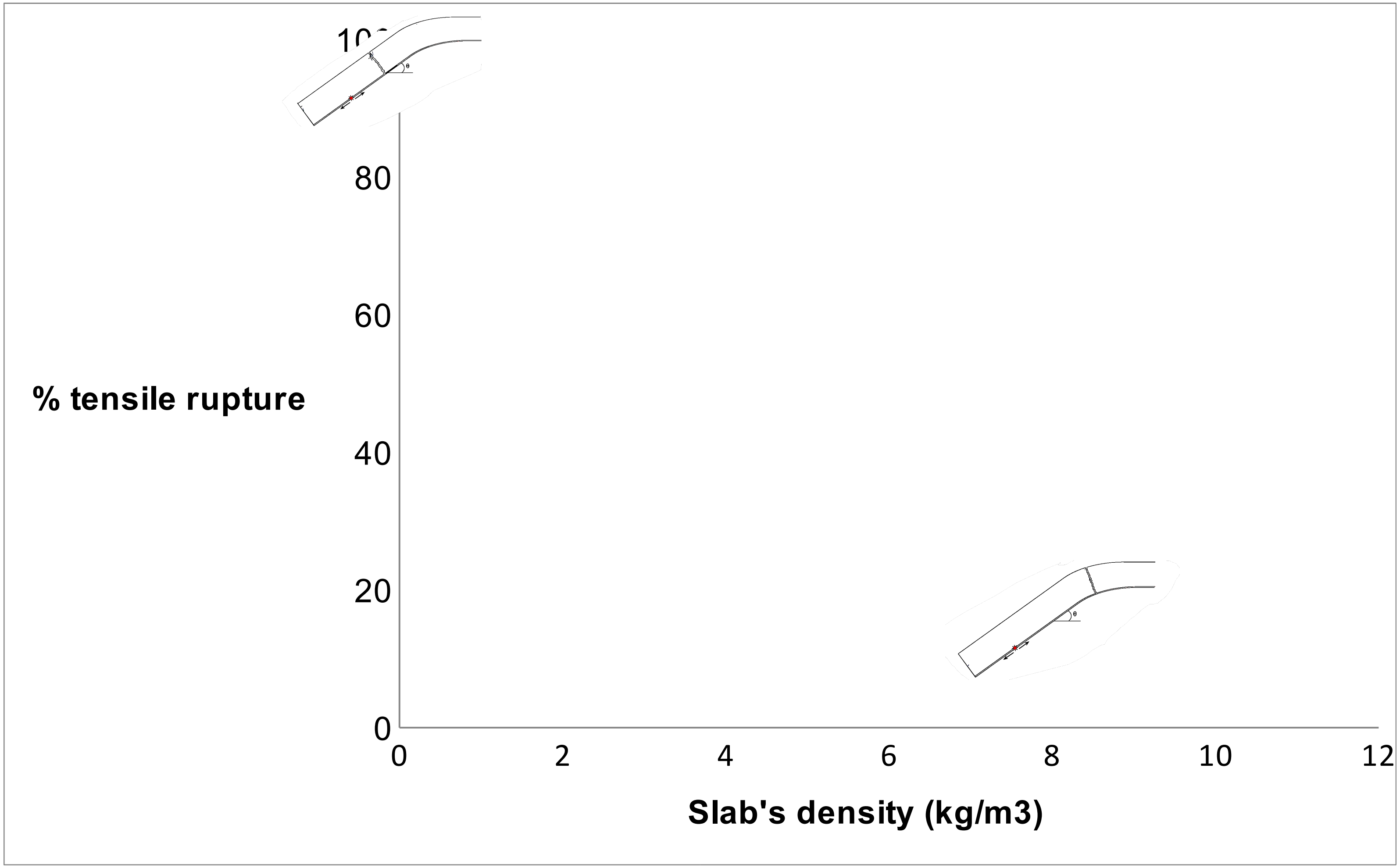
Evolution of Young modulus E and tensile strength σt of the slab with density





Back to the results

Using Sigrist (2006)'s evolutions of E and σt with ρ



Results

Position of slab's tensile failure

For realistic sets of parameters

$\Downarrow$

The position of the slab tensile failure is influenced by morphological features (rocks, trees, ridge, curvature...)

Conclusions

Mechanical-statistical model of the slab-weak layer system

→ the spatial variations of WL mechanical properties (shear strength)
→ a shear quasi-brittle constitutive law for the WL
→ stress redistribution effects by elasticity of the slab
→ slab possible tensile failure

… to study the influence of weak layer shear strength spatial variability

on both

Fracture initiation

⇓

Stability

↓

Very important **knock-down effect** on slope stability highlighted

Crack propagation

⇓

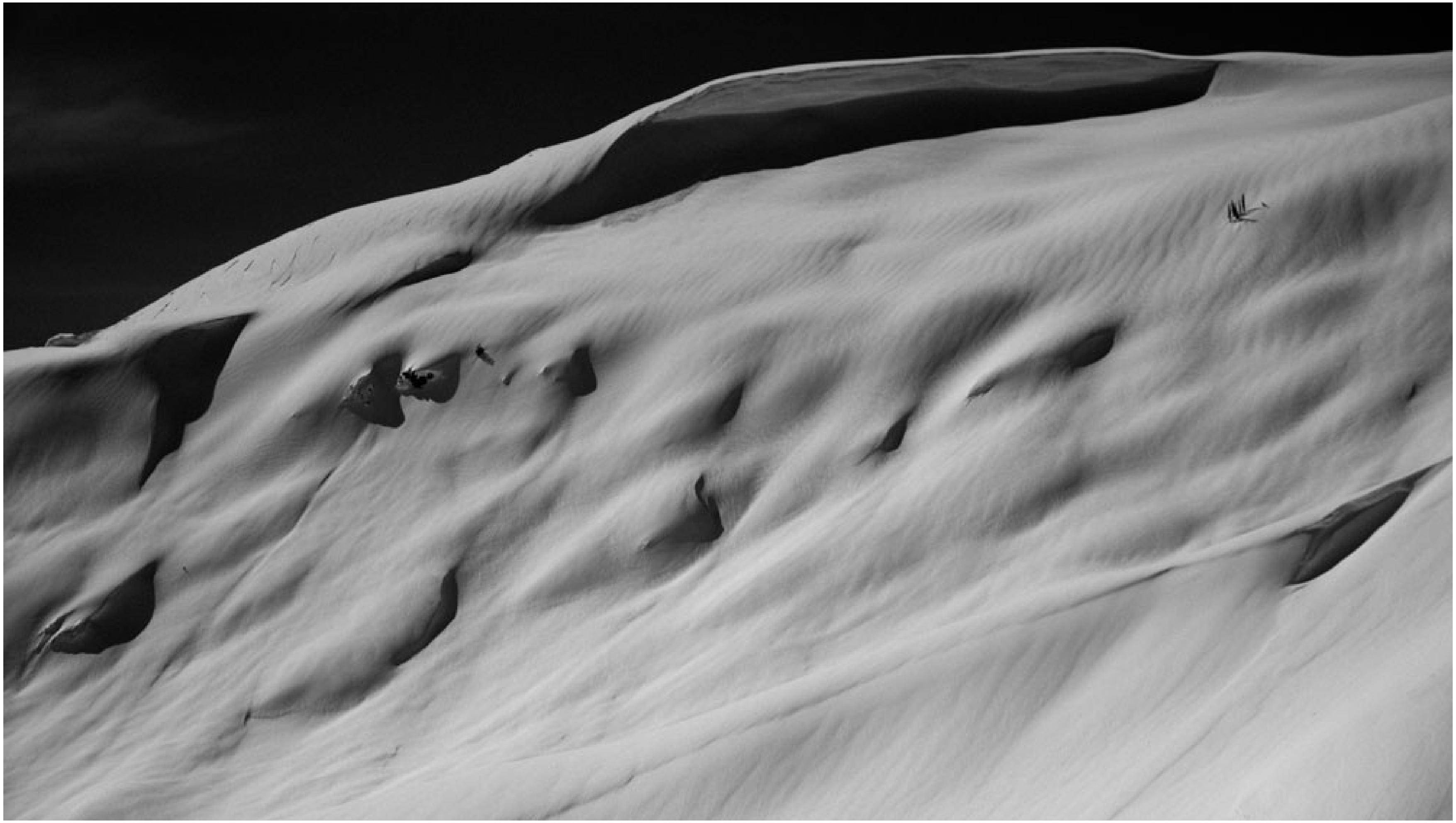
Avalanche size

↓

Major influence of **slope topography** and of the **snow cover distribution**

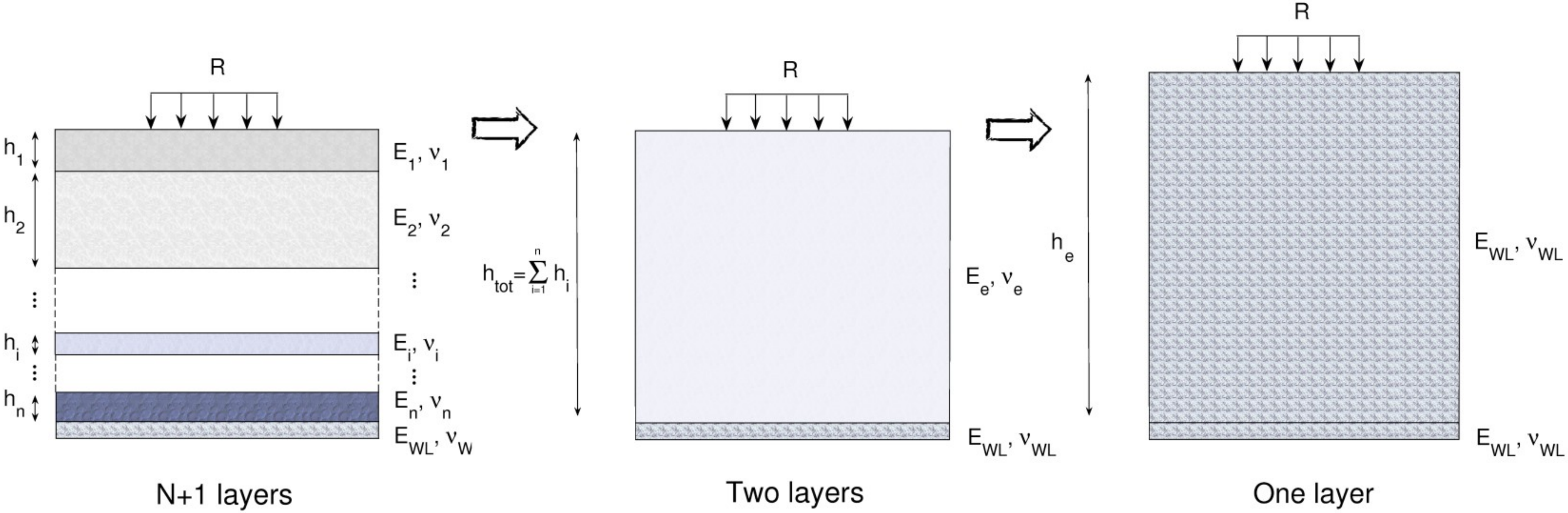
Outlook

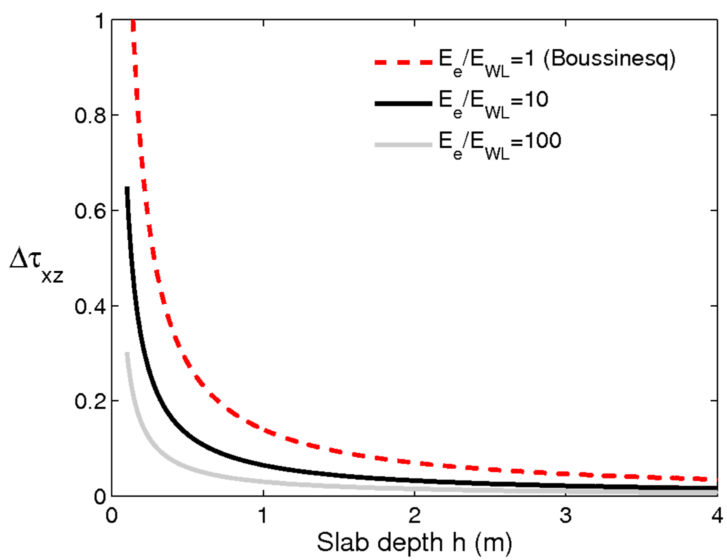
Influence of snow cover distribution on avalanche sizes using the same approach



Outlook

Influence of snowpack layering on skier-triggered avalanches





Outlook

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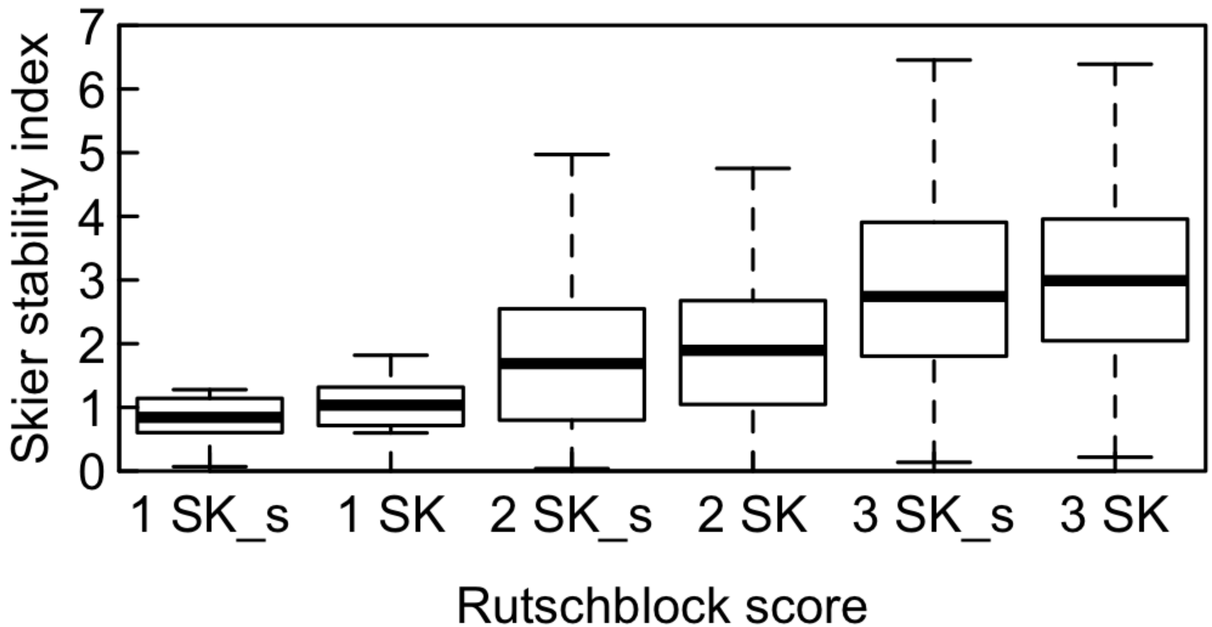

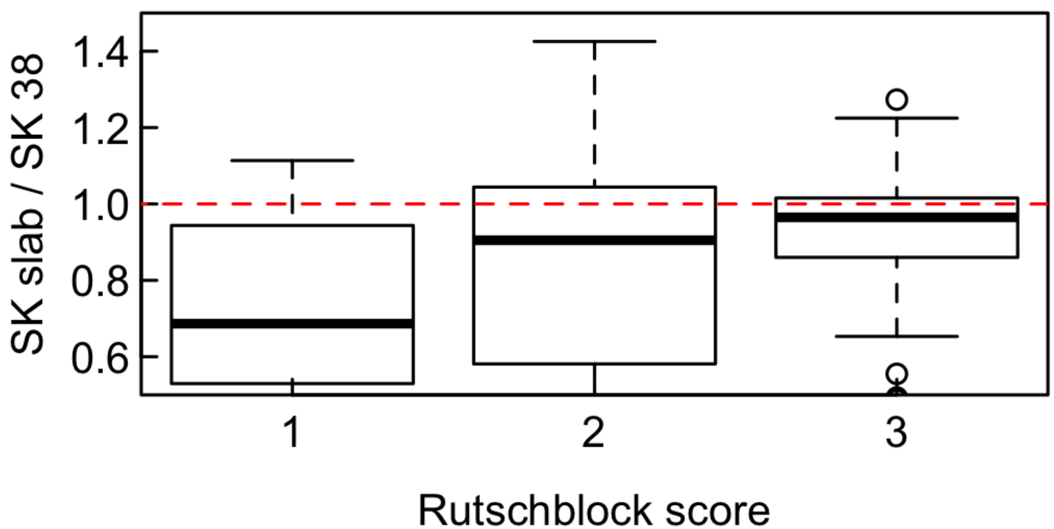

Thanks for your attention!

Do you have any questions?