Modeling Snow slab failure in Propagation saw test using Drucker-Prager model EGU21-13989

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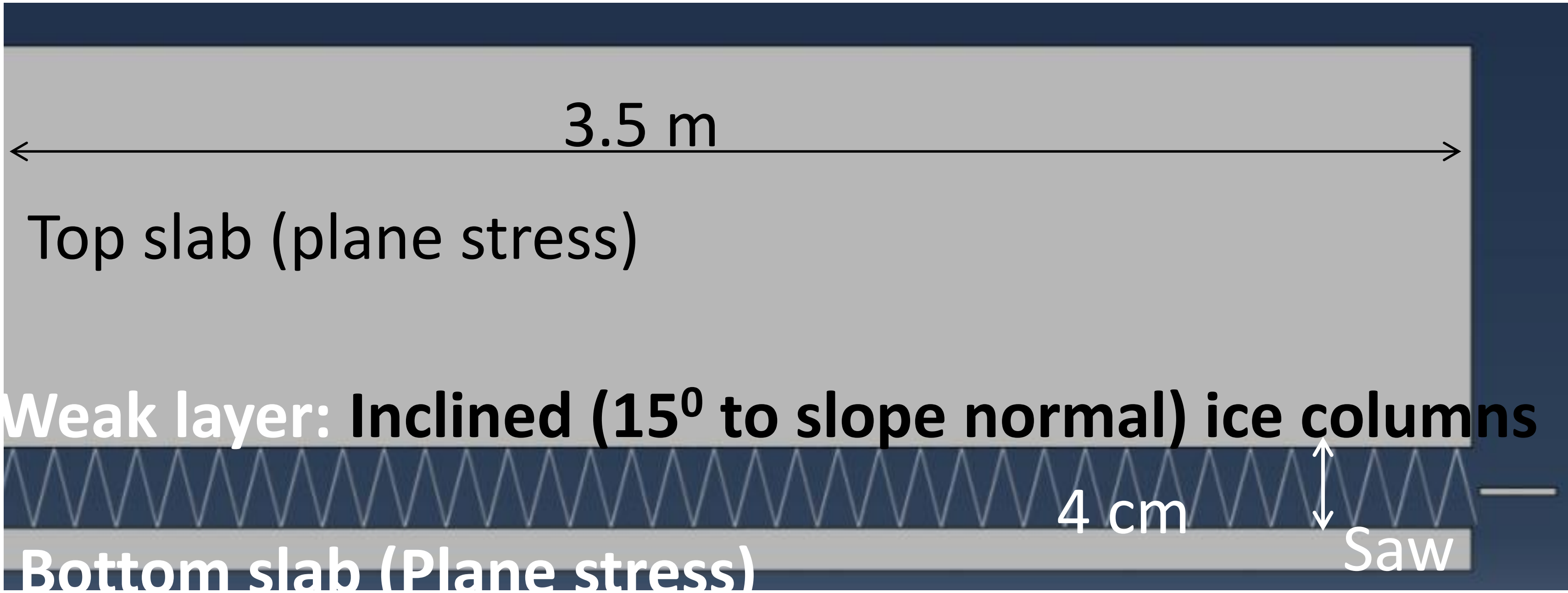
Introduction

Why snow slab failure modelling?

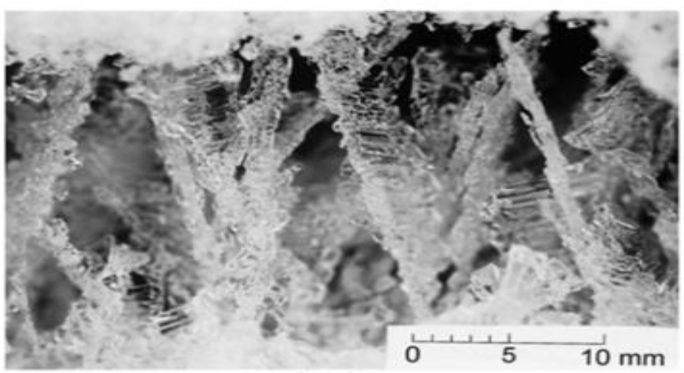
- Snow properties may influence the size of avalanche release
- Useful for estimation of potential avalanche release areas and volumes
- Avalanche hazard assessment in a more precise manner

FE Model for Numerical Propagation saw test

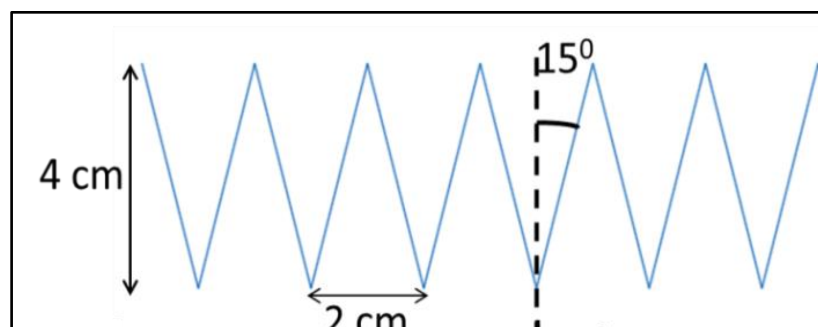
Two dimensional snow cover model with three snow layers



Geometrical model for weak surface hoar layer: On the basis of field observations



Field photograph Jaemeison et. al. 2000



Geometrical model for weak layer

Material model for snow and ice

Isotropic Elastic-plastic-damaging material model

Yield surface (Von mises (ice))

$$f = \sigma - \left(\sigma_y + H\varepsilon^{pl}\right) = 0$$

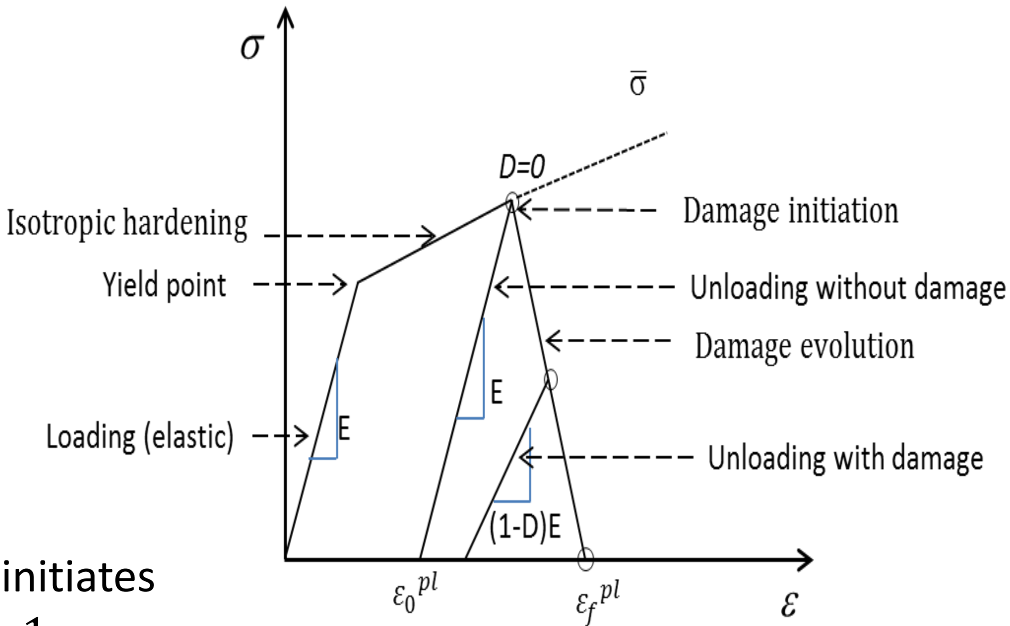
where,

σ: Stress,

σ_y : Yield stress

H : Hardening modulus

ε^{pl}: axial plastic strain



Condition for damage initiation

$$\omega_D = \int \frac{d\varepsilon^{pl}}{{\varepsilon_0}^{Pl}} = 1$$

Damage initiates for $\omega_D = 1$

ε^{pl}: plastic strain

${\varepsilon_0}^{Pl}$: plastic strain at the onset of the damage.

Stress in damaged material: $\sigma = (1 - D)\bar{\sigma}$

$\bar{\sigma}$:stress in an undamaged state

D : scalar damage variable. (D=1, for fully damaged material)

Material model for snow and ice

Damage evolution:

- linear variation of stresses during damage evolution

- Relation of incremental plastic displacement and incremental damage variable

$$\dot{D} = \frac{L\dot{\varepsilon}^{pl}}{u_f^{pl}} = \frac{\dot{u}^{pl}}{u_f^{pl}}$$

u_f^{pl}: Plastic displacement at failure
u^{pl}: Plastic displacement
L : Characteristic length (Generally element size)

- Plastic displacement at failure (complete damage, D=1)

$$u_f^{pl} = 2G_f/\sigma_{y0}$$

σ_{y0} is the yield stress at damage initiation
G_f :Fracture energy

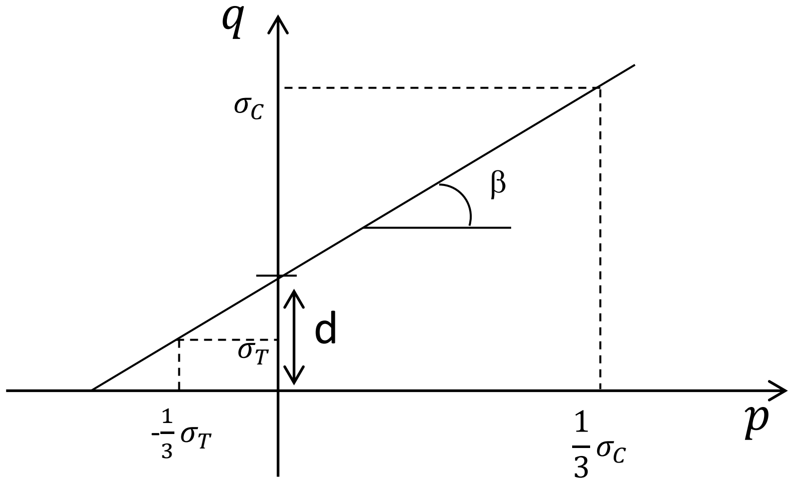
Properties of ice used for simulation (through literature survey)

Ice density = 917 Kg/m^3, Elastic modulus= 950 MPa
Plasticity hardening modulus= 95 MPa, Yield stress (σ_0)=2.25 Mpa,
Plastic strain at which damage initiates (ε_0^{pl}) =3e-6, Fracture energy of ice (G_f)= 1.05 J/m^2

Material model for snow and ice

Yield criterion (snow): Extended Drucker-Prager Model

Yield function: $$F = q - (d + H\bar{\varepsilon}_p) - p\tan\beta = 0$$



$q = \sqrt{\frac{3}{2}S:S}$, Mises equivalent stress

$S = \sigma + \frac{1}{3}pI$, Deviatoric stress

$$p = -\frac{1}{3}trace(\sigma)$$

$cohesion\ of\ the\ material,$ $$d = \frac{(2\sigma_c\sigma_T)}{(\sigma_c + \sigma_T)}$$

$$\tan\beta = 3\frac{(\sigma_c - \sigma_T)}{(\sigma_c + \sigma_T)}$$

σ_c: Uniaxial compressive strength
σ_t: Uniaxial tensile strength

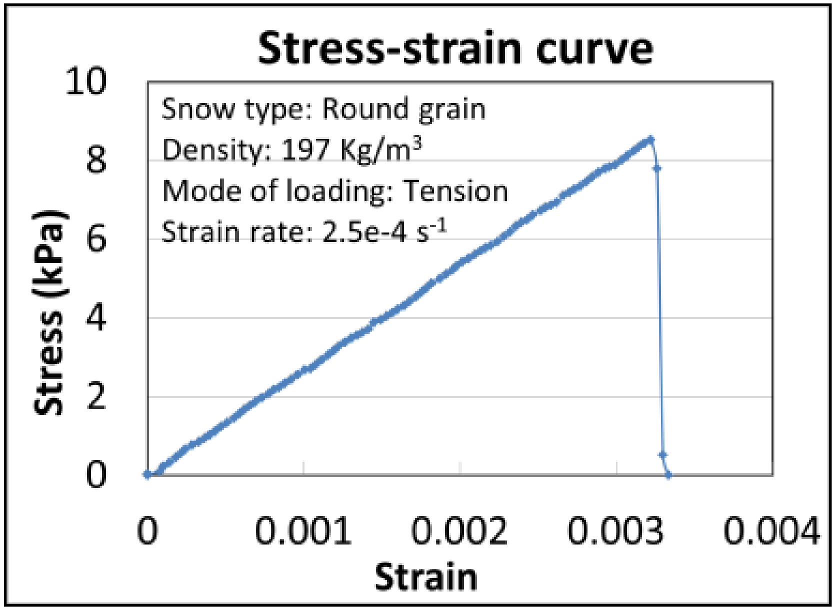
Estimation of snow properties through mechanical tests

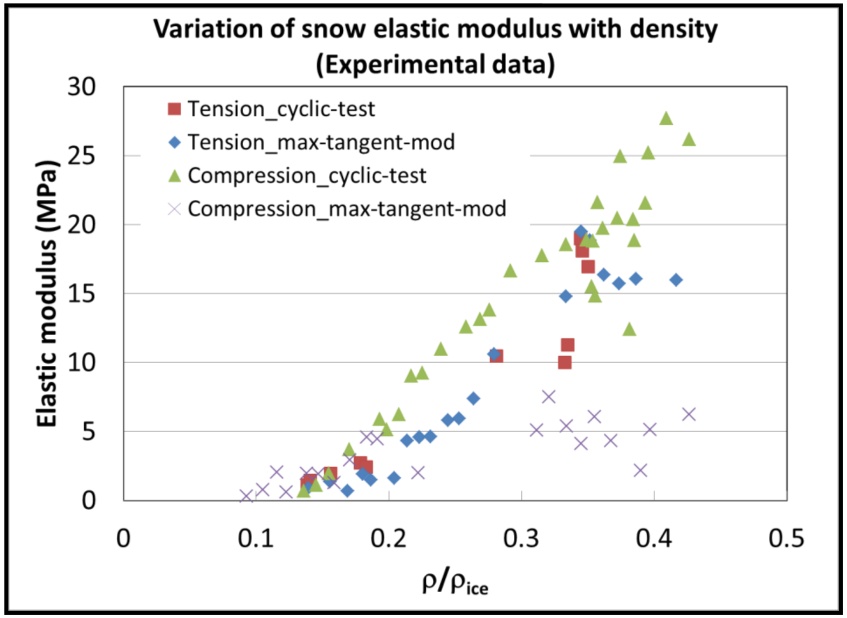
Mechanical tests

- Uniaxial tension and compression
- Uniaxial loading-unloading tests in tension and compression
- Snow type: Natural
- Snow density range: 100-400 Kg/m^3
- Strain rate: > 1e-4 s^{-1} (Moderate to high strain rates)

Estimation of snow elastic modulus

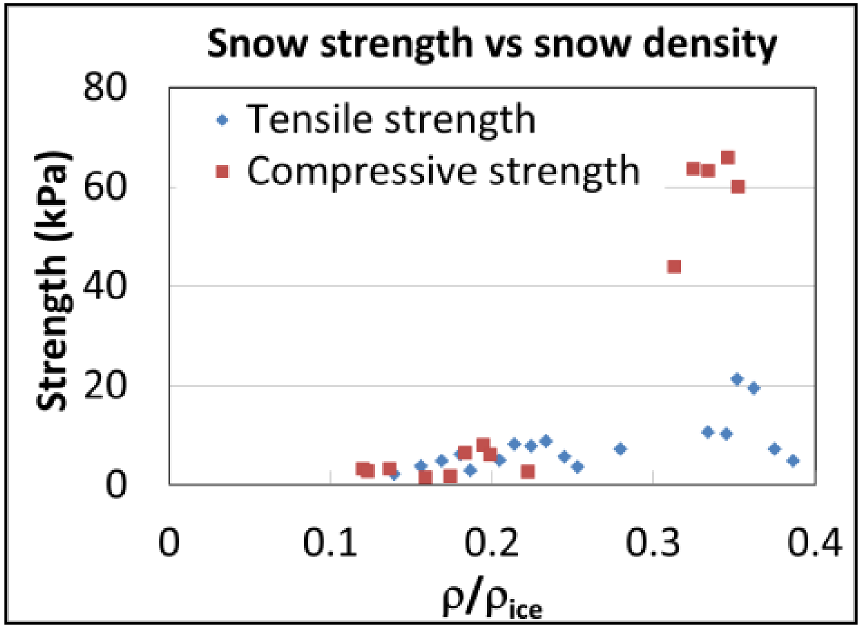
- Maximum tangent modulus through stress-strain curves
- Elastic modulus through loading unloading tests





Estimation of snow properties through mechanical tests

Estimation of snow failure strength (peak stress in stress-strain curves) in tension and compression



Power laws for snow elastic modulus and strengths (Through curve fitting of experimental data)

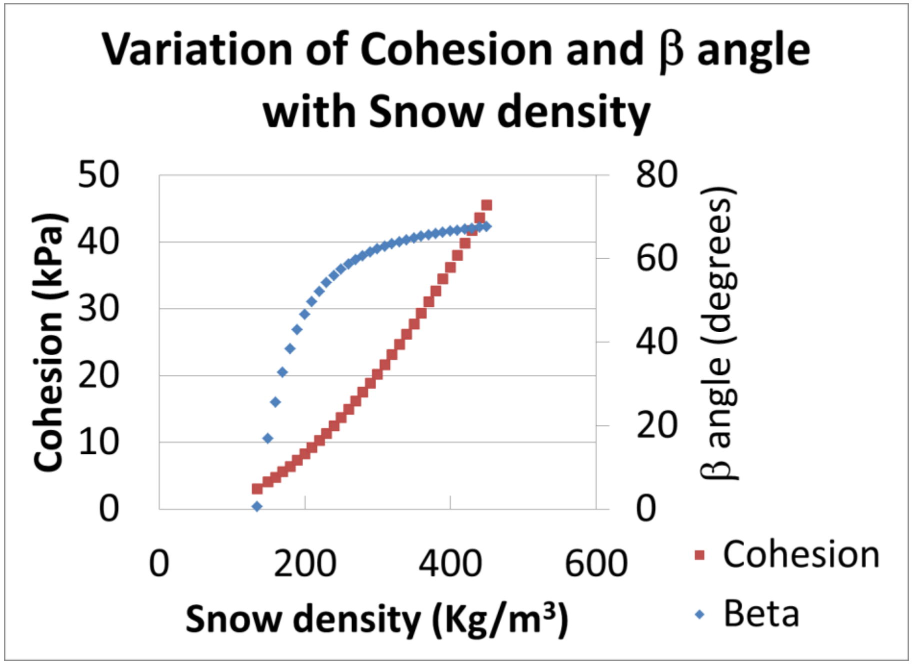
$$E, \sigma = a\left(\frac{\rho}{\rho_{ice}}\right)^{b}$$

	a	b	R^2
E-mod (MPa)	332.03	2.86	0.95
T-strength (kPa)	41.72	1.25	0.61
C-strength (kPa)	3844.85	3.83	0.98

Estimation of snow properties through mechanical tests

Estimation of Drucker-Prager parameters for snow

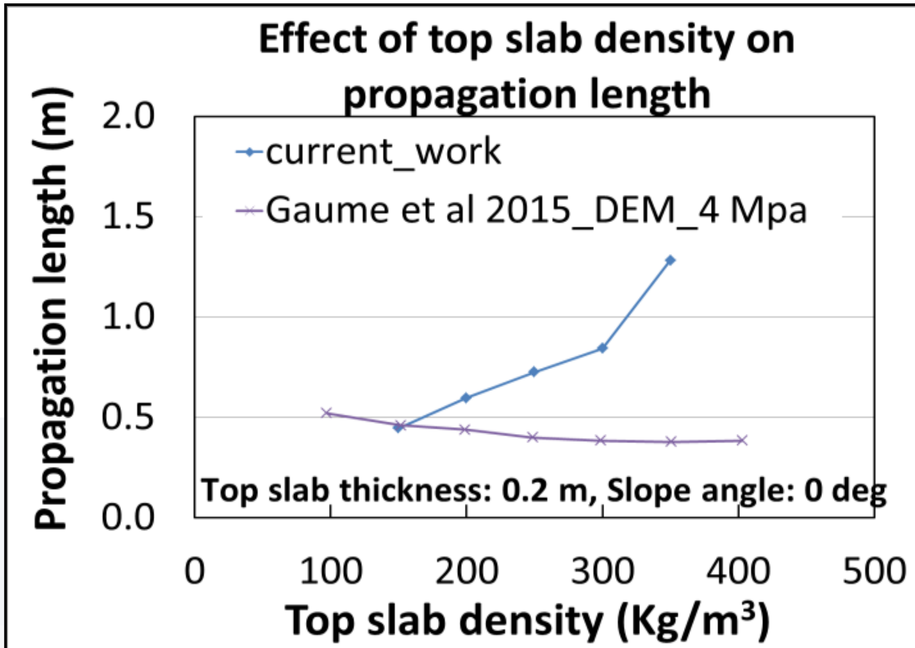
- Estimated Drucker-Prager parameters using density dependent power laws for snow strength



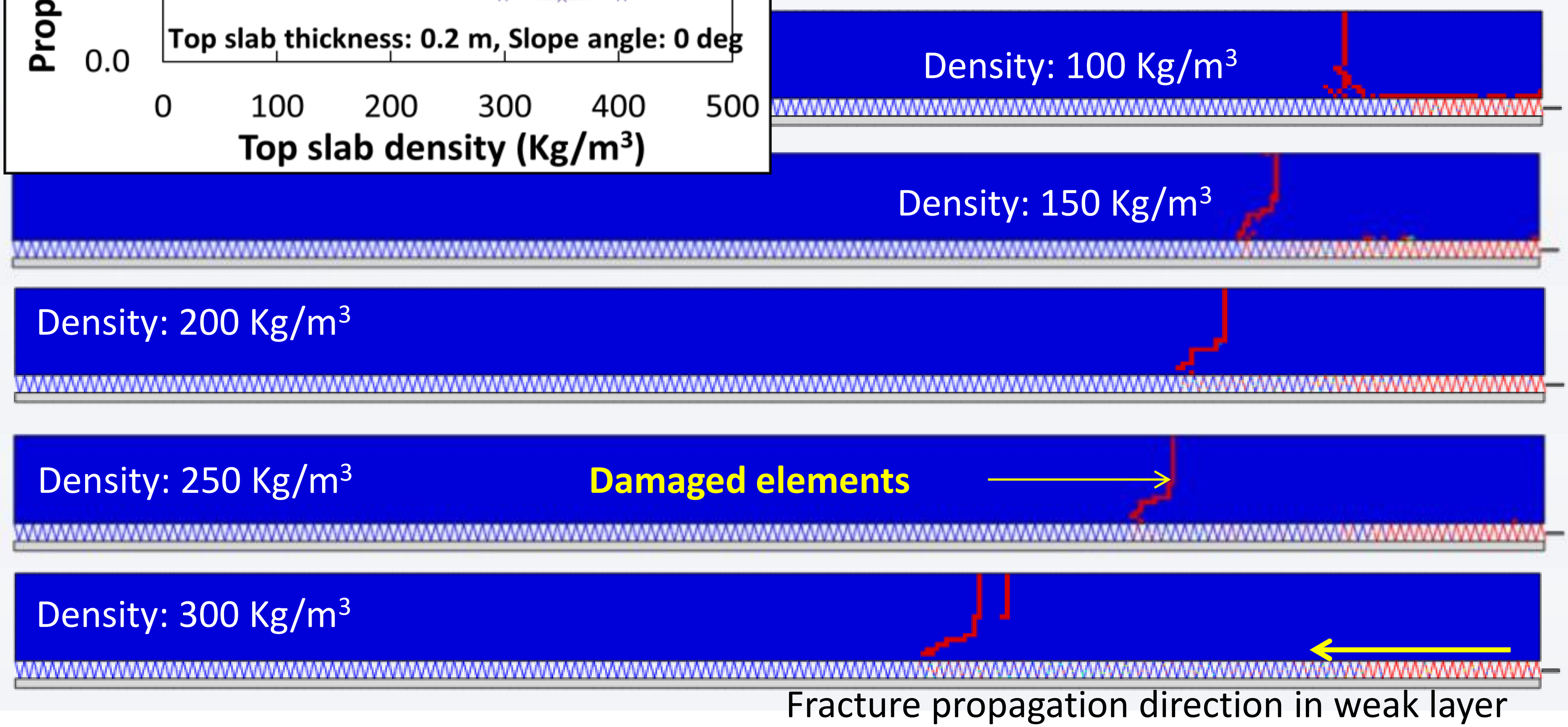
Other snow properties used for simulation

- **Hardening Modulus:** 1-10 MPa (assumed, no major influence for small damage initiation plastic strain)
- **Associated flow**
- **Damage initiation plastic strain:** 1e-6 (assumed, (for near brittle failure as observed in experiments))
- **Fracture energy:** 0.03-0.15 J/m^2 (linear variation with density, Experimental data)

Results: Variation of propagation length in top slab with density

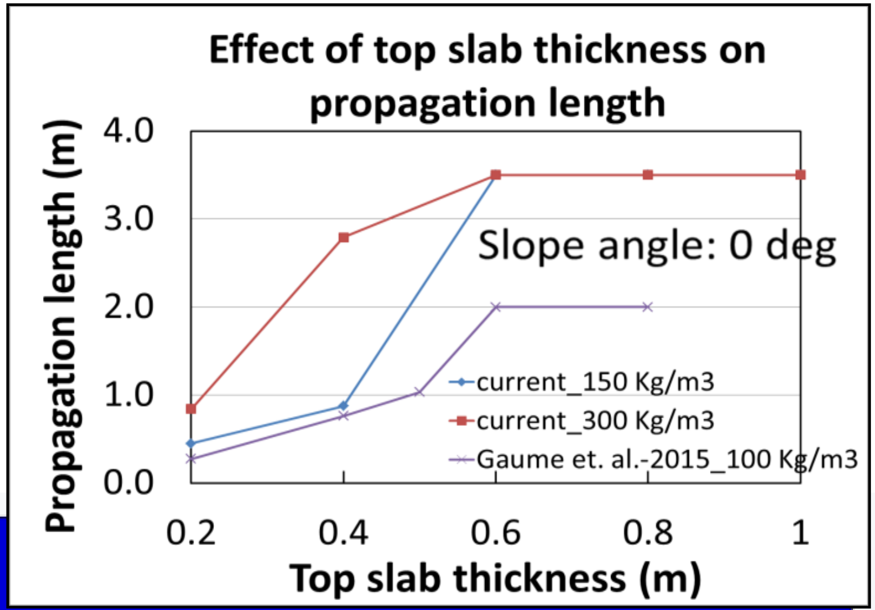


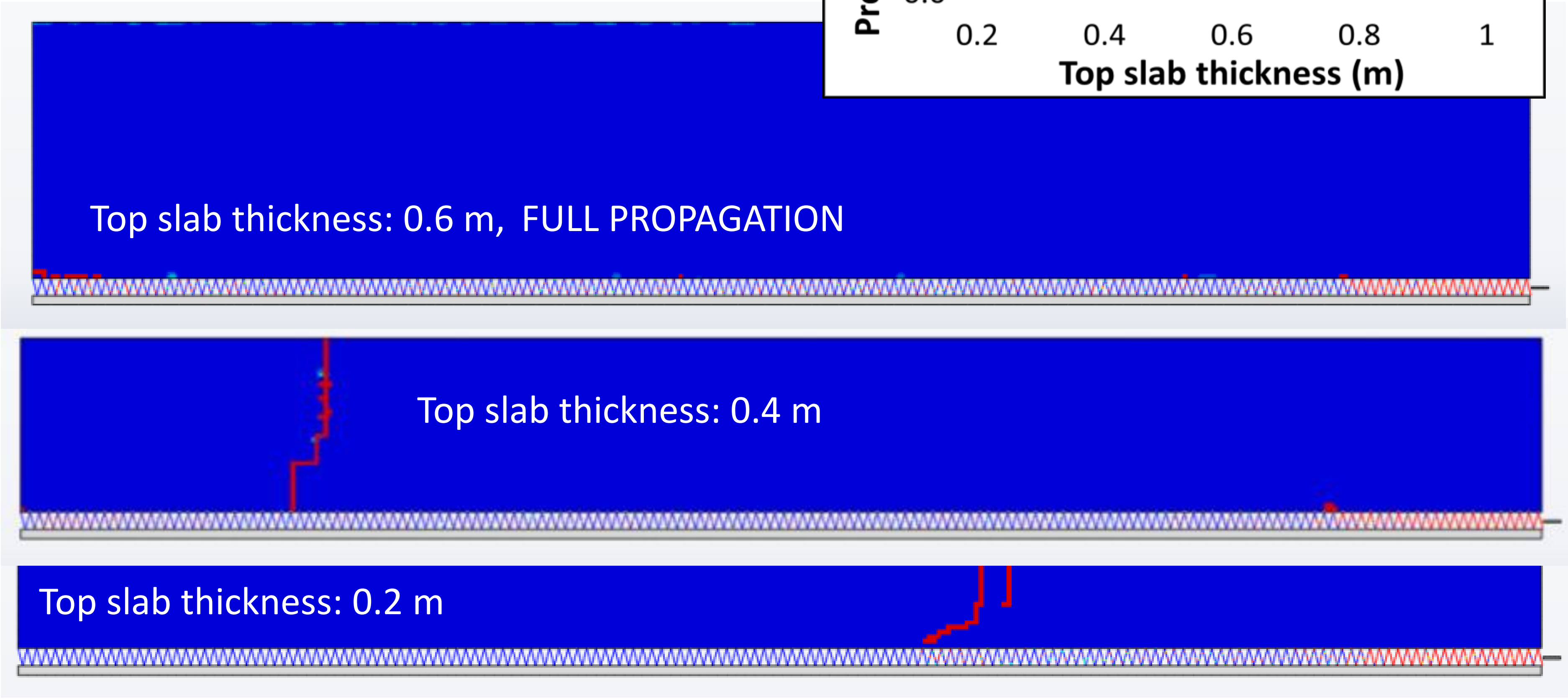
- For densities higher than 150 Kg/m^3 fracture in the slab starts from the top surface
- Propagation length increases with density as Strength is density dependent



Results: Variation of propagation length in top slab with thickness

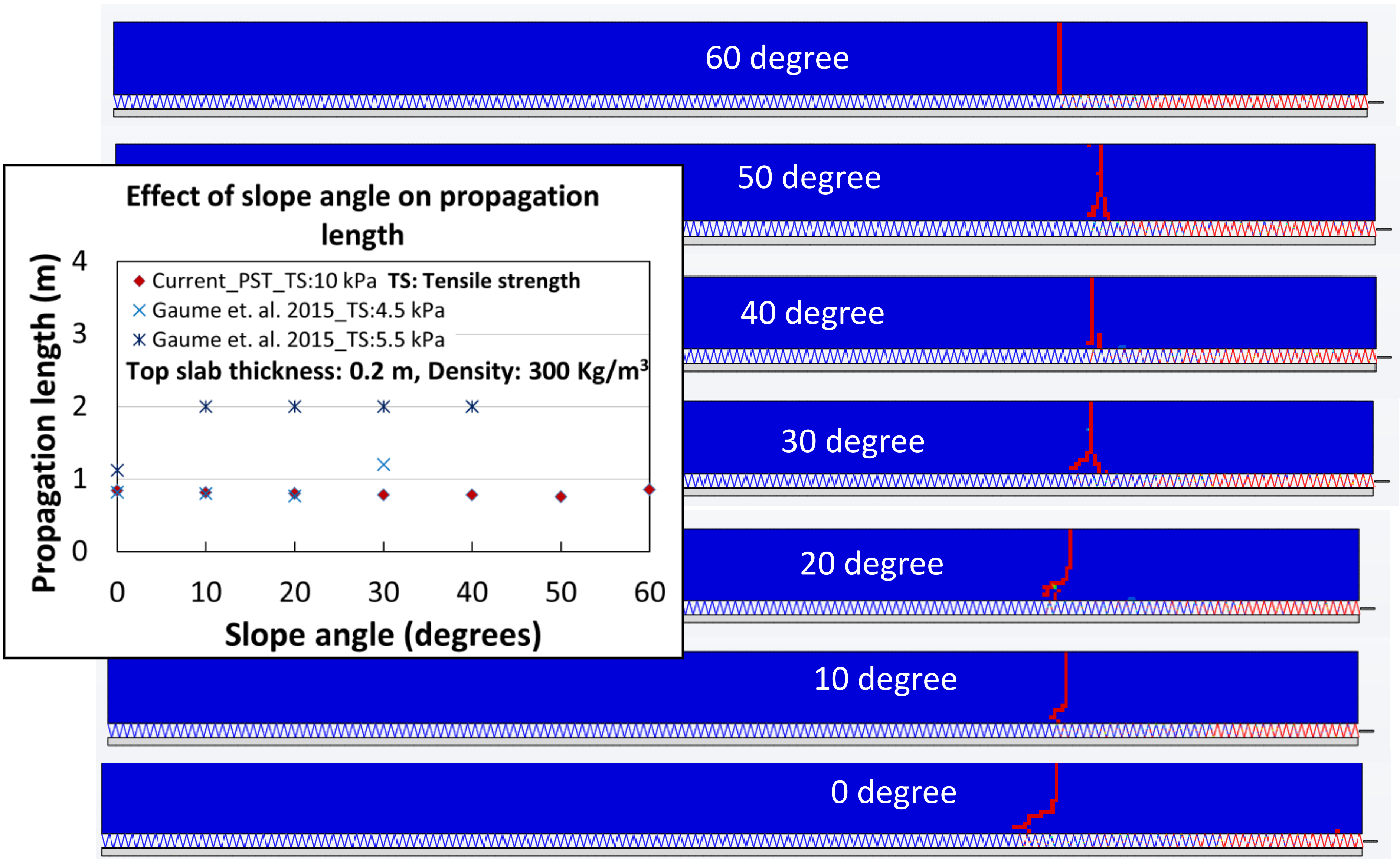
- Propagation length increases with top slab thickness
- Trend of variation is similar to the one reported by Gaume et. al. 2015 in their DEM model





Results: Variation of propagation length in top slab with slope angle

No major influence of slope angle on propagation length in top slab is observed



Conclusions

- **The proposed model for snow was used successfully used for modelling fracture of overlying slab in numerical Propagation saw test**
- Propagation length was found to increase with top slab density and thickness whereas no major influence of slope angle is observed
- **For snow with densities greater than 150 Kg/m^3 fracture in the slab starts from the upper surface**
- The modelling approach used seems promising and can be extended for snow slab failure modelling in multi layer snow cover with varying densities

Thank You