Some models for numerical simulations of brittle failure

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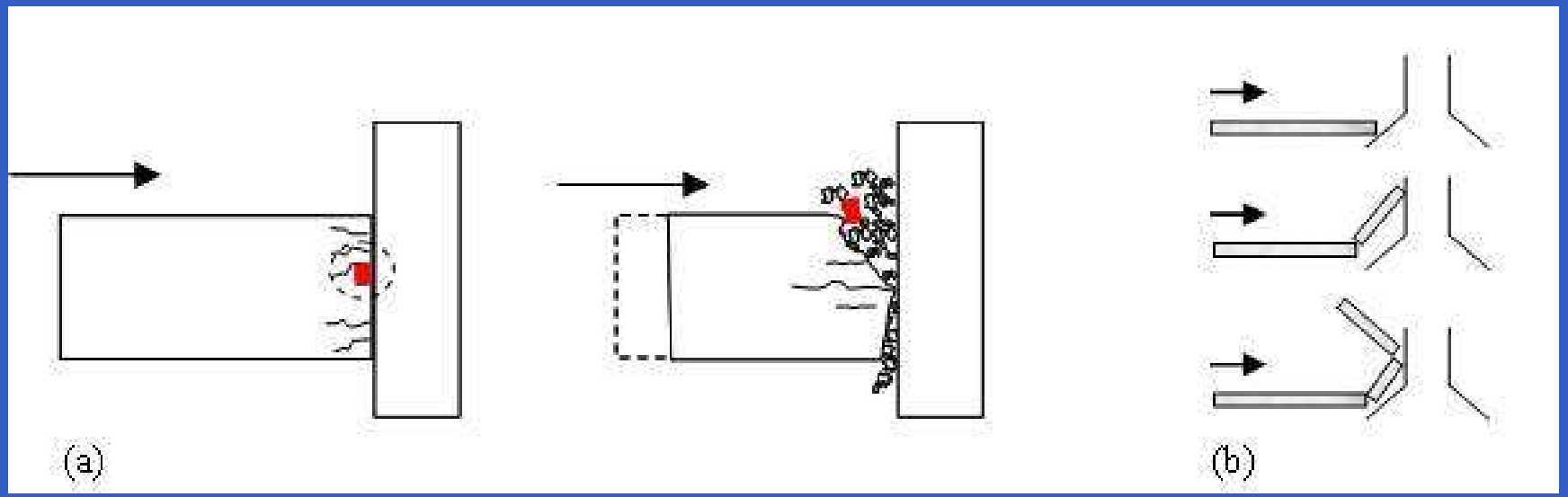
OUTLINE

- Motivation and materials
- Numerical model
  - Constitutive models
  - Finite element procedures
- Example simulations
  - Tensile test
  - Bending failure

MOTIVATION AND MATERIALS

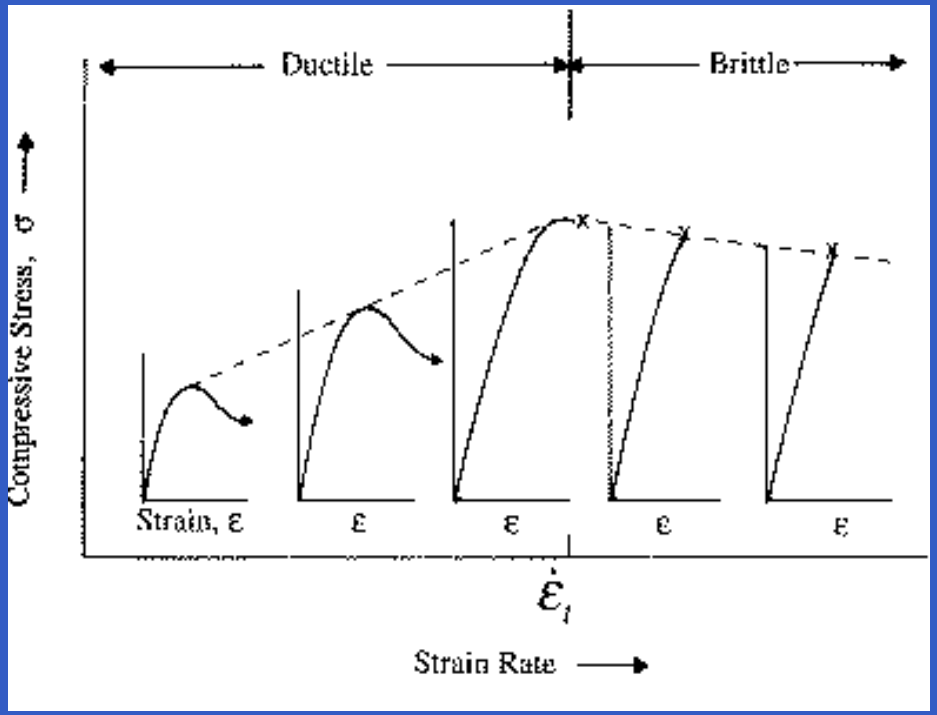
Ice-structure interaction
transition from continuous to discontinuous

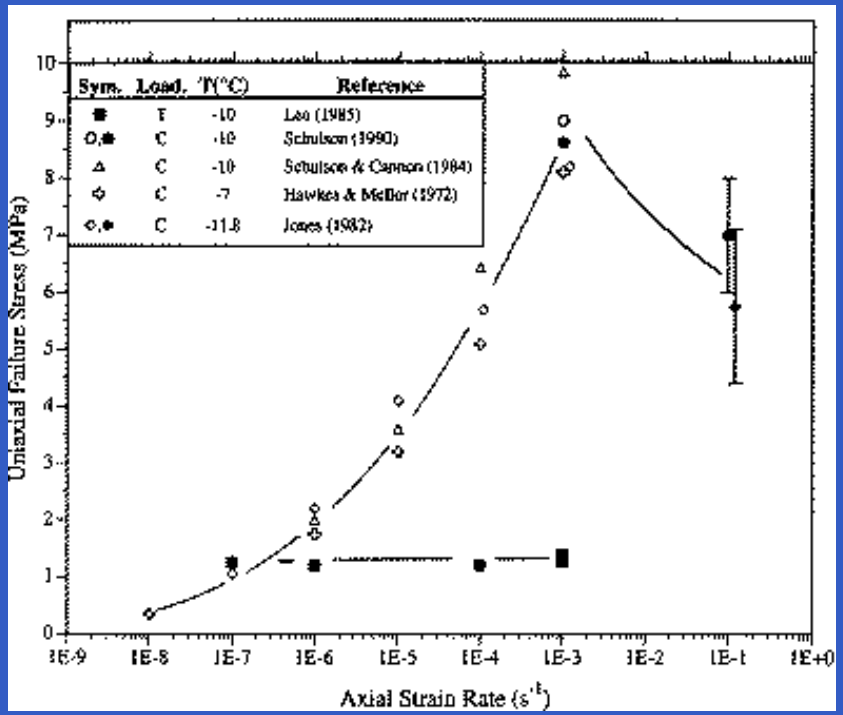


(a) crushing (b) bending

MOTIVATION AND MATERIALS

Ductile-to-brittle transition





E. M. Schulson: Brittle failure of ice, *Engineering Fracture Mechanics* **68** (2001) 1839–1887.

MOTIVATION AND MATERIALS

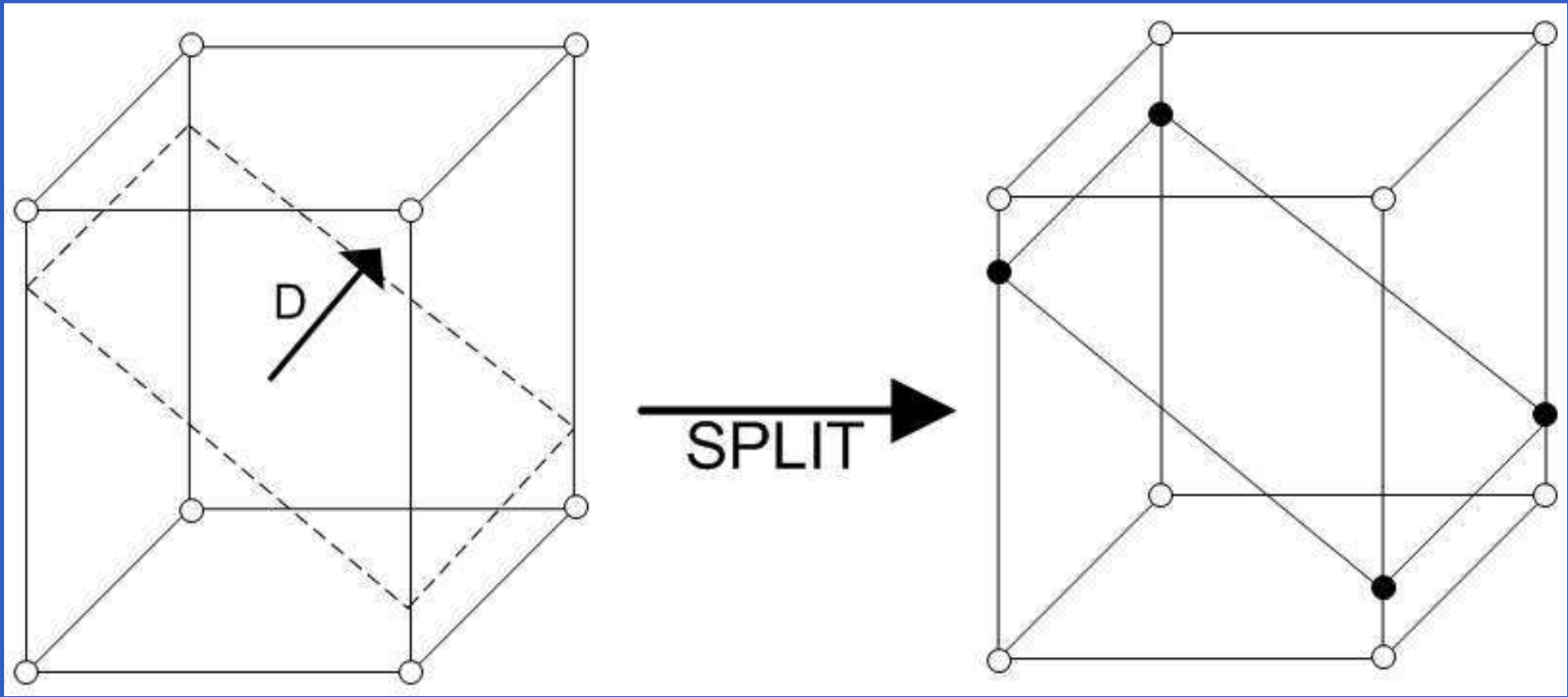
Ice crushing against the lighthouse Norrströmsgrund

NUMERICAL MODEL

- Implemented in commercial code (Abaqus/Explicit)
- Model update strategy
- CDM-model for brittle failure
- Model for ductile-to-brittle transition

Model update strategy

Element split based on damage vector

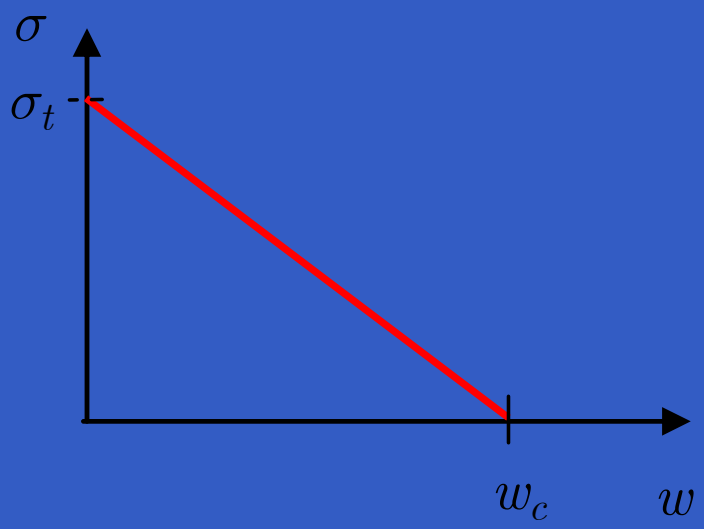


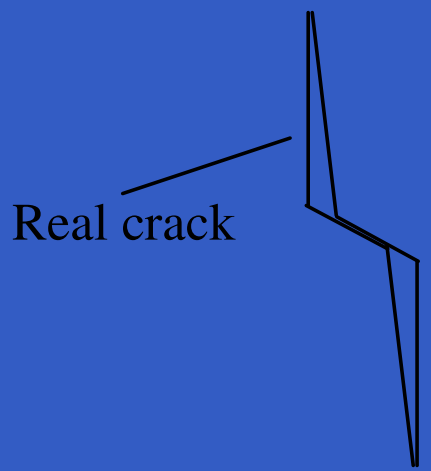
Several advantages over element deletion process

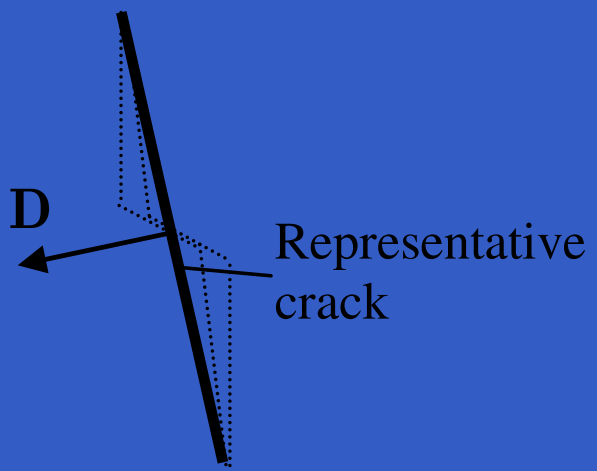
CDM-model for brittle behaviour

- Vectorial damage model (Kolari 2007)
- Crack-surface friction neglected
- Stiffness recovery due to crack closure is taken into account
- Softening by fictitious crack approac (Hillerborg et al. 1976)
- Damage criterion

$$F = \eta_1 \varepsilon^{\mathrm{e}}_{ii} + \eta_2 \varepsilon^{\mathrm{e}}_{ii} \varepsilon^{\mathrm{e}}_{jj} + \varepsilon^{\mathrm{e}}_{ij} \varepsilon^{\mathrm{e}}_{ij} - B_0 - h(w_c, H)\kappa = 0$$



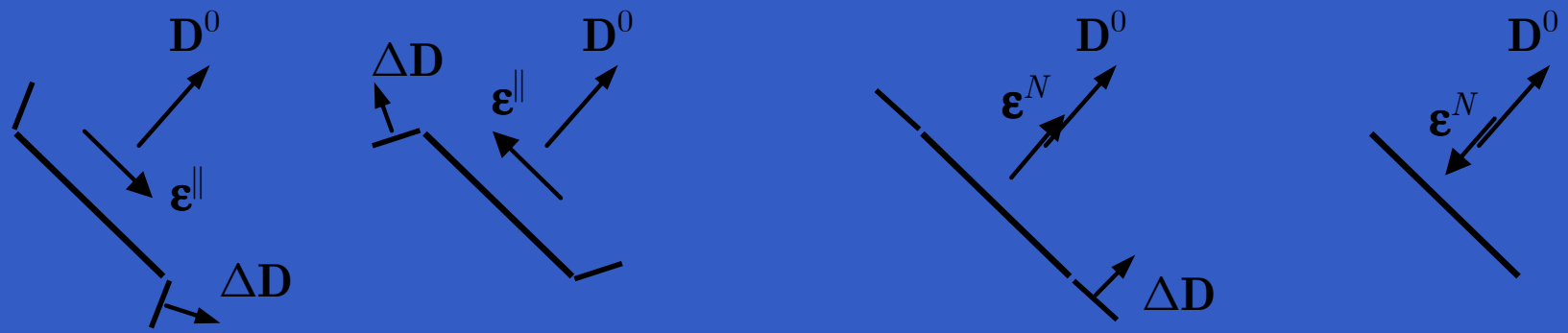




CDM-model for brittle behaviour

Damage evolution

$$\dot{D}_i = \dot{\lambda} \left(H(\varepsilon^N)\varepsilon^N + \sqrt{\varepsilon_i^{\parallel}\varepsilon_i^{\parallel}} \right) n_i + \varepsilon_i^{\parallel}$$

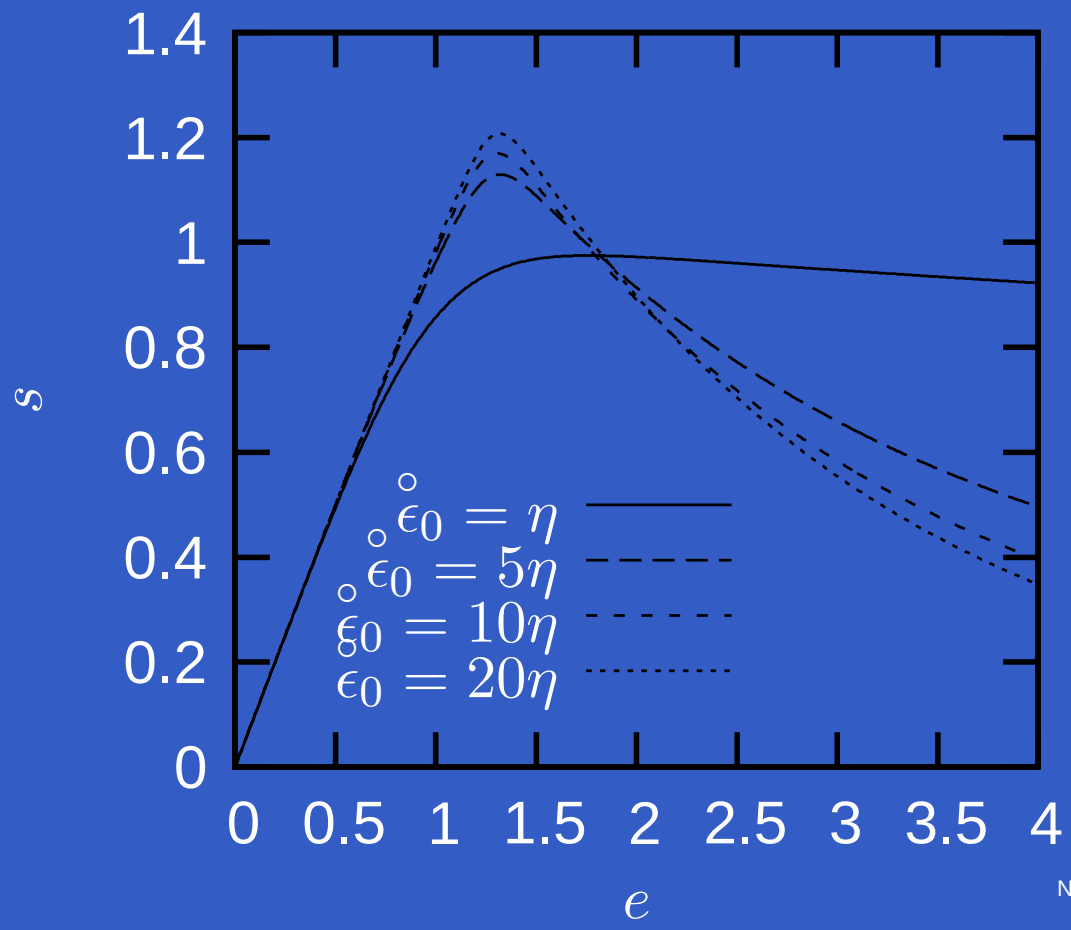


Ductile-to-brittle transition

Dissipation potential

$$\varphi(\sigma, Y) = \varphi_{\mathrm{d}}(Y)\varphi_{\mathrm{tr}}(\sigma) + \varphi_{\mathrm{vp}}(\sigma)$$

$\varphi_{\mathrm{tr}} \geq 0 \quad \varphi_{\mathrm{tr}} \approx 0$ when $\|\dot{\epsilon}_{\mathrm{i}}\| < \eta$ and $\varphi_{\mathrm{tr}} > 1$ when $\|\dot{\epsilon}_{\mathrm{i}}\| > \eta$



NUMERICAL SIMULATIONS

Tensile test simulation

- Velocity (3 mm/s) controlled loading
- C3D8R elements. Two elements in thickness direction (total 612 elements at initial stage)

Animation

NUMERICAL SIMULATIONS

Bending failure with inclined structure

- Level ice 30 cm thick
- Initially 792 C3D8R elements

Animation