Snow storm damage in Denmark 22 February 2007

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Incidents investigated

Building usage

- Arenas
- Factory buildings
- Farm buildings
- Shopping centre

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Failed structural material

- Steel
- Glulam
- Timber
- Concrete
- Masonry

Examples of failure

Sports arena with low extension at west gable


odde
materieludlejning

Stable placed on west-side of a (later) barn

Arena with failed secondary beam

Characteristics of failed buildings

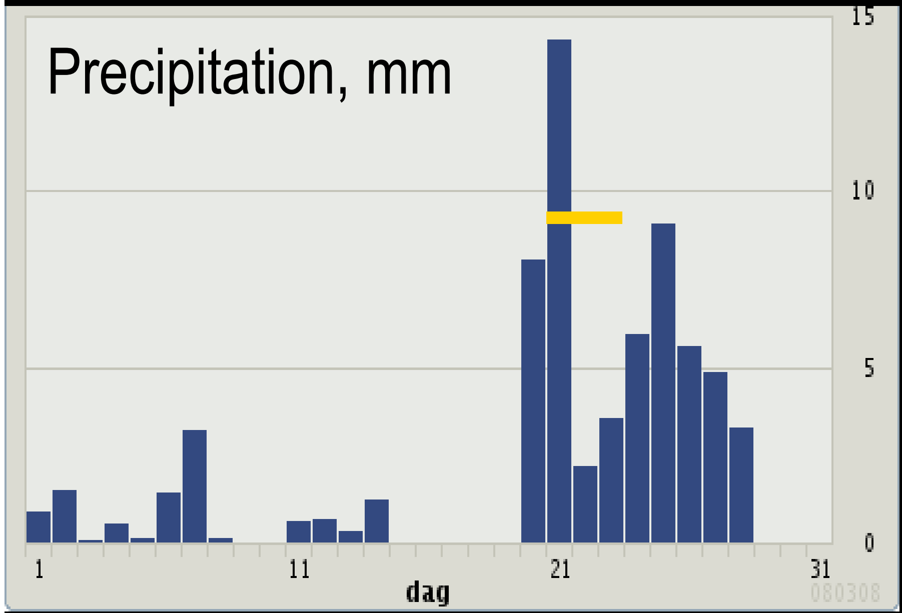
- Low building on west-side of a higher building
  or
- Large span buildings

Possible causes of failure

- Extreme snow load or drifting
- Inadequate code
- Structural flaws during design or construction
- Insufficient maintenance

Actual snow load

The weather in February 2007



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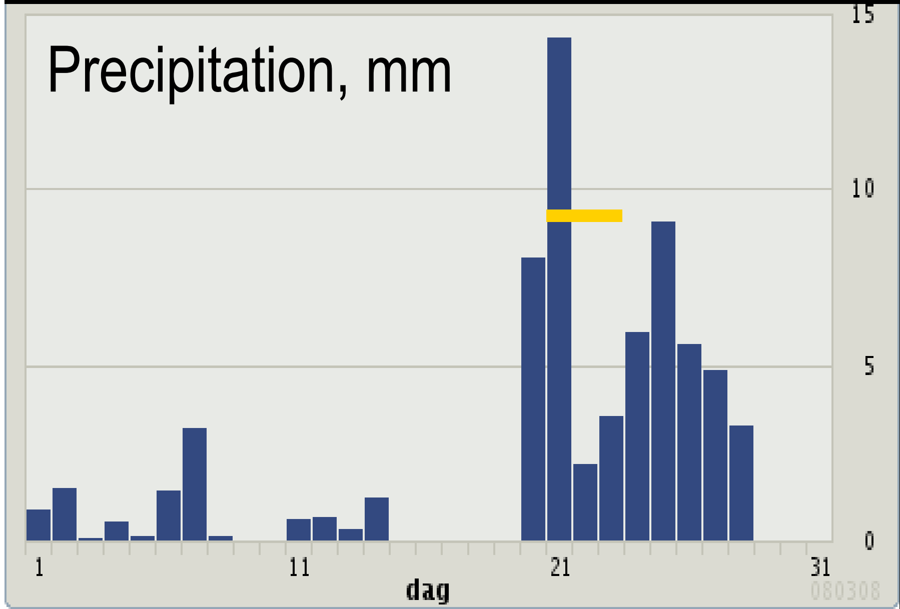

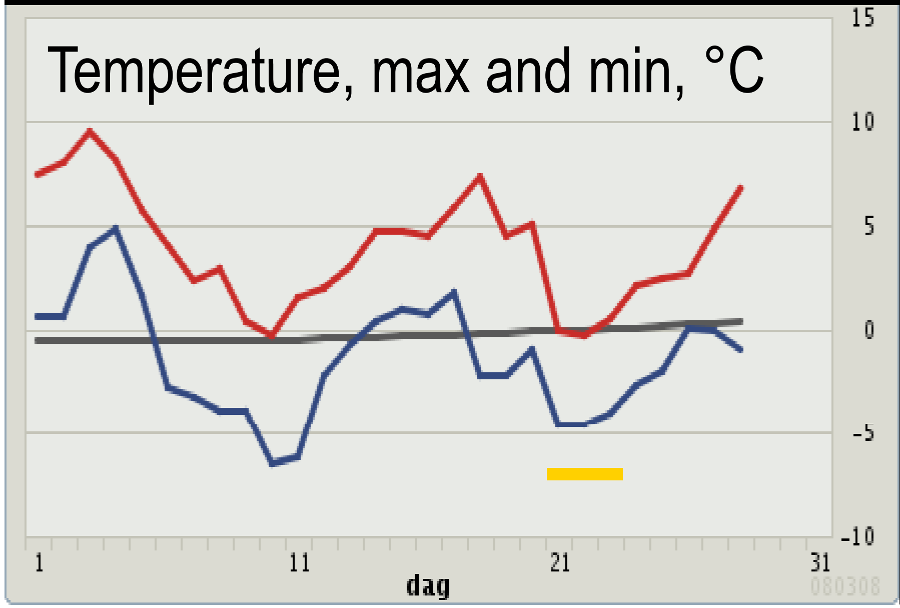

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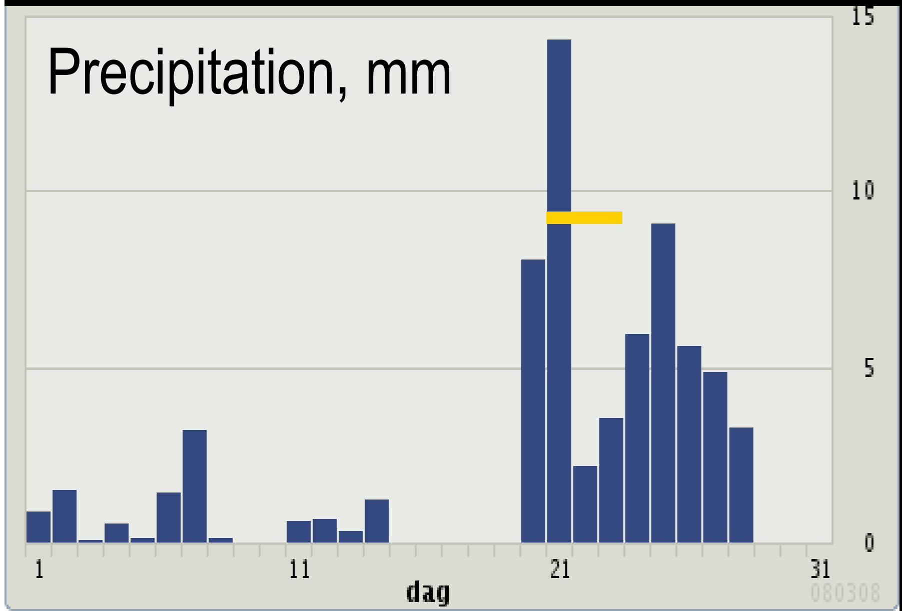

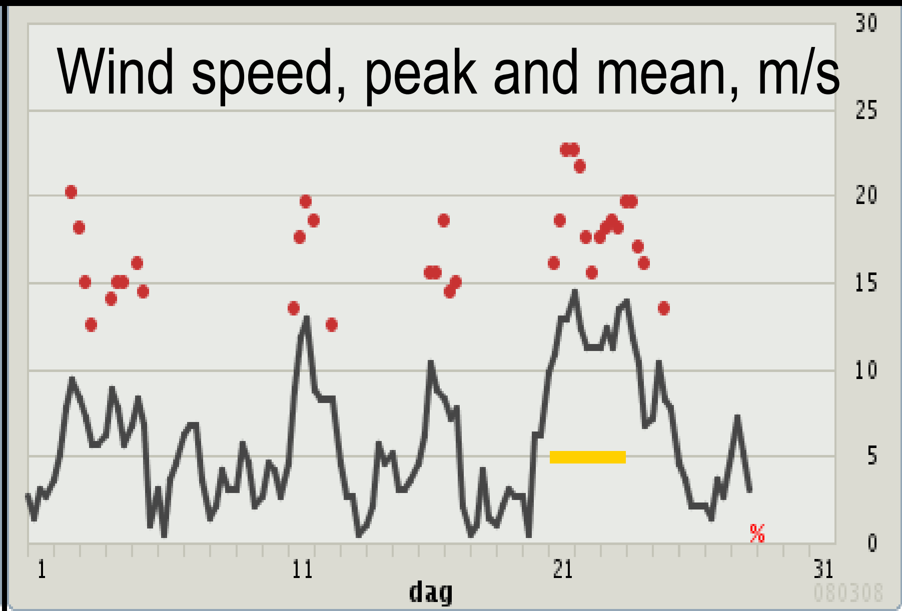

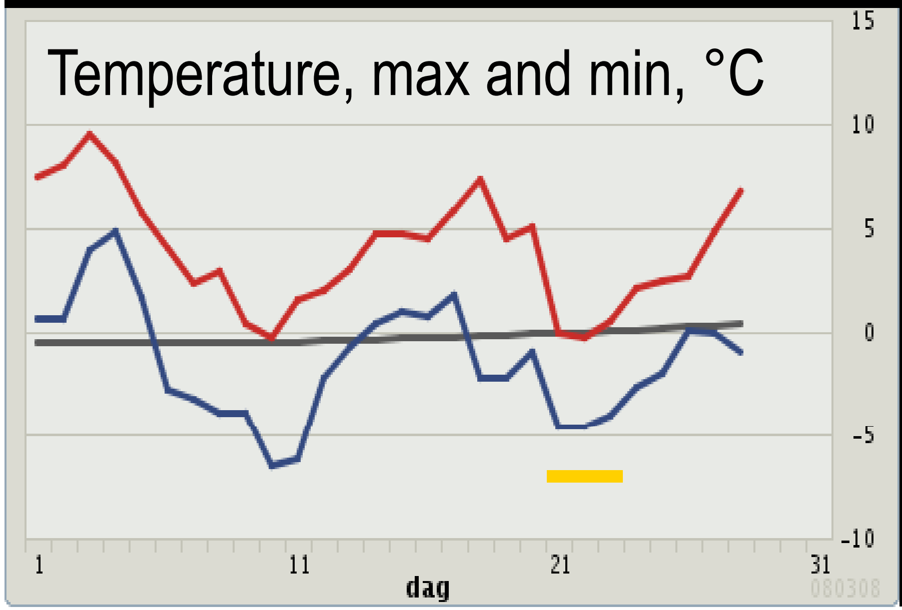

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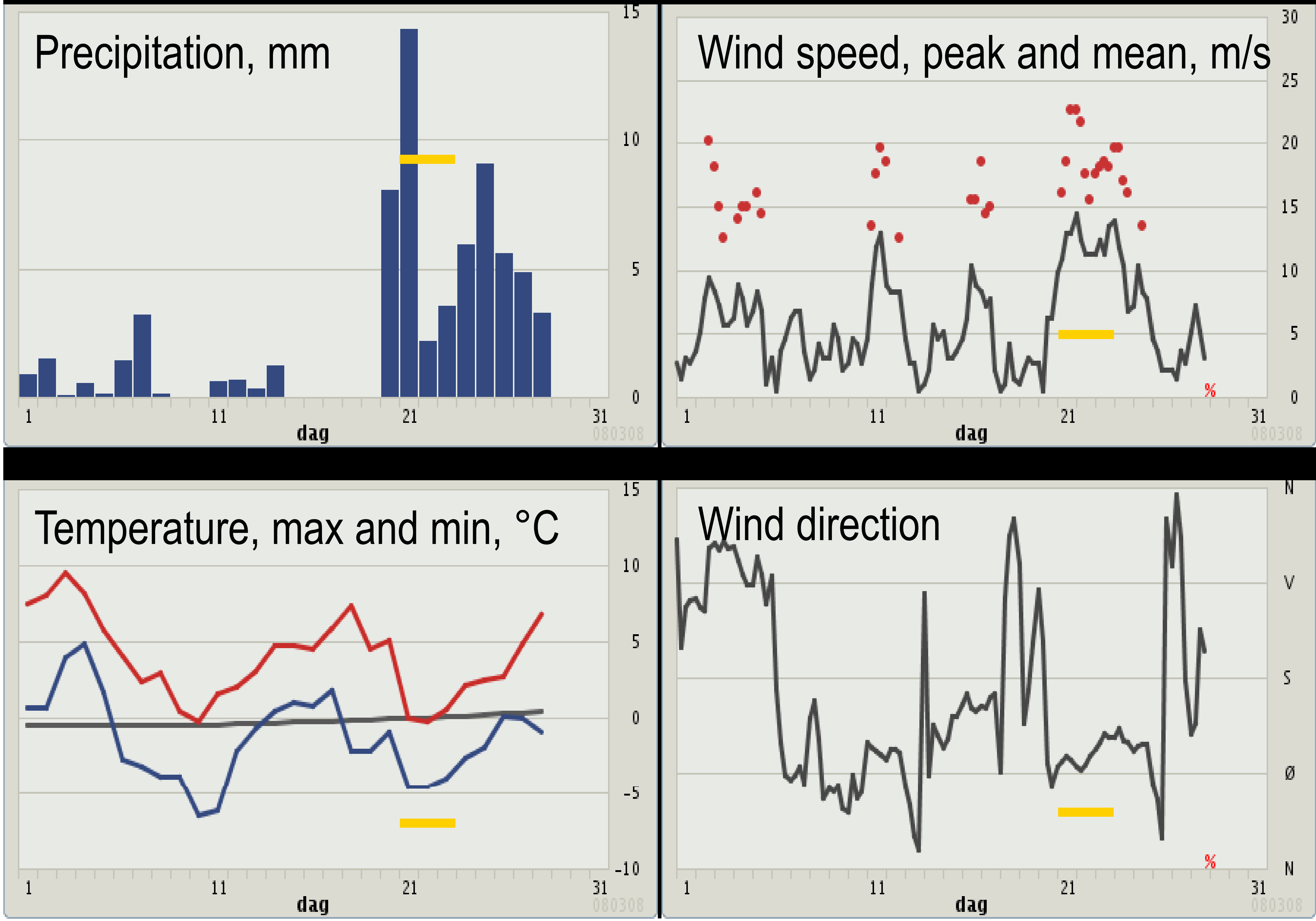

Characteristics of normal snow storm

- Wind always from east (Siberia)
- Cold air passing the sea picks up water
- Water temperature usually a few °C
- Air temperature -8 to -10 °C
- Snow density about 100 kg/m^3

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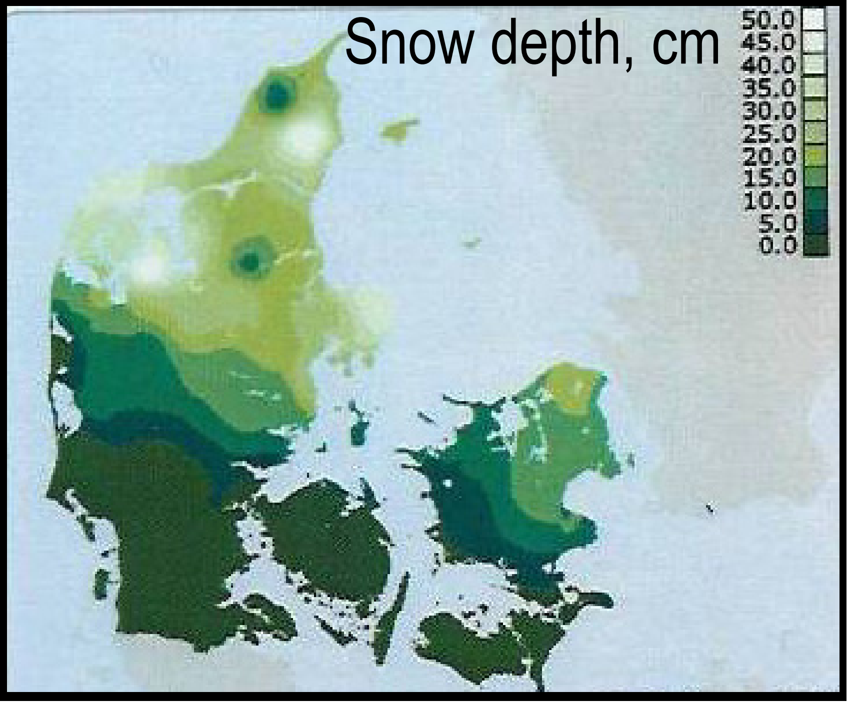
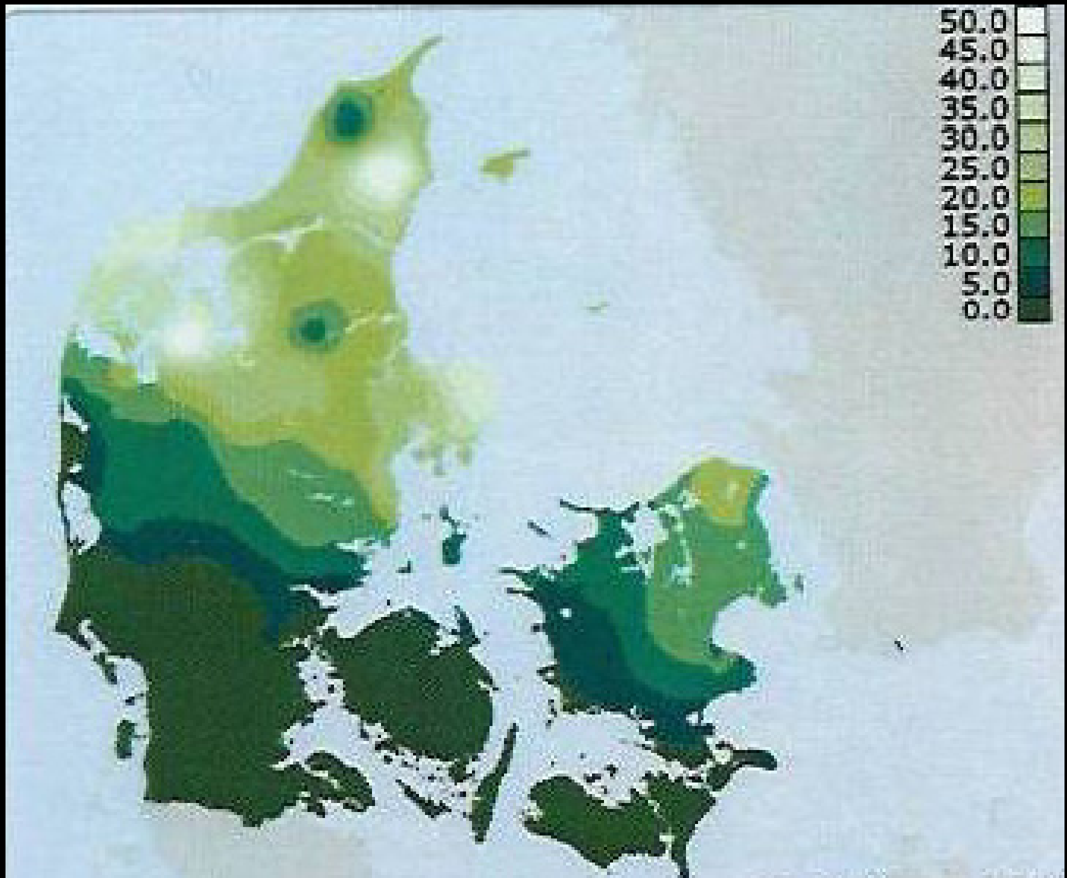
Warm snow storm

- Water temperature about 6 °C
- Air temperature just below 0 °C
- Snow density about 200 kg/m^3
- Constant conditions for 3 days
- Happened last 1979 in SE



Snow load - summary

- Characteristic ground snow load in code, 0.9 kN/m^2, might have been slightly exceeded in some places



50 cm x 200 kg/m^3
~ 1 kN/m^2

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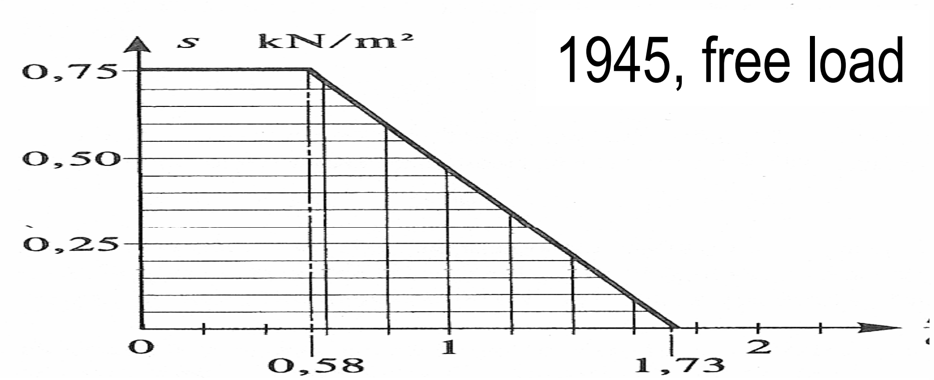
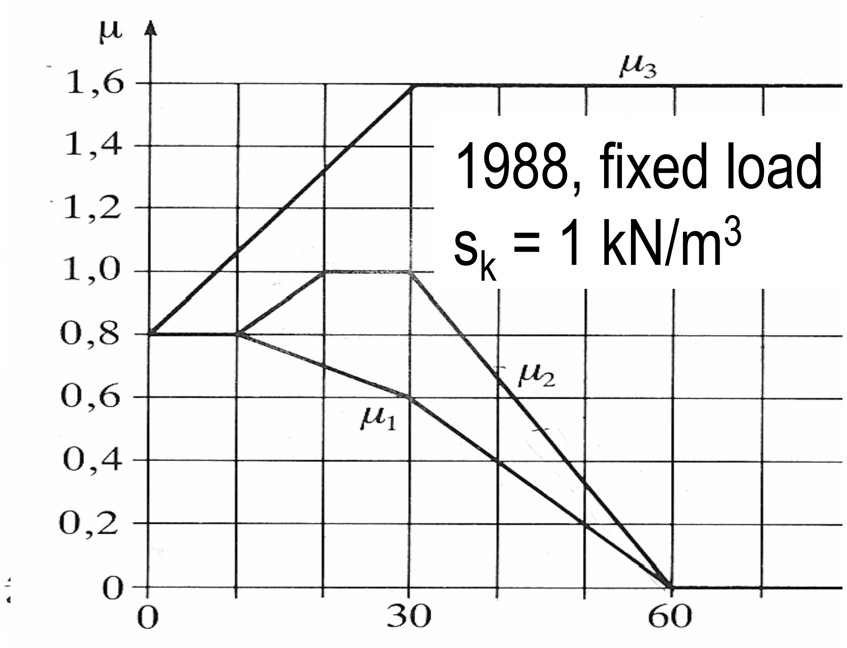
- Actual loads on roofs not measured
- Local snow depth on roof of 3 m or more reported

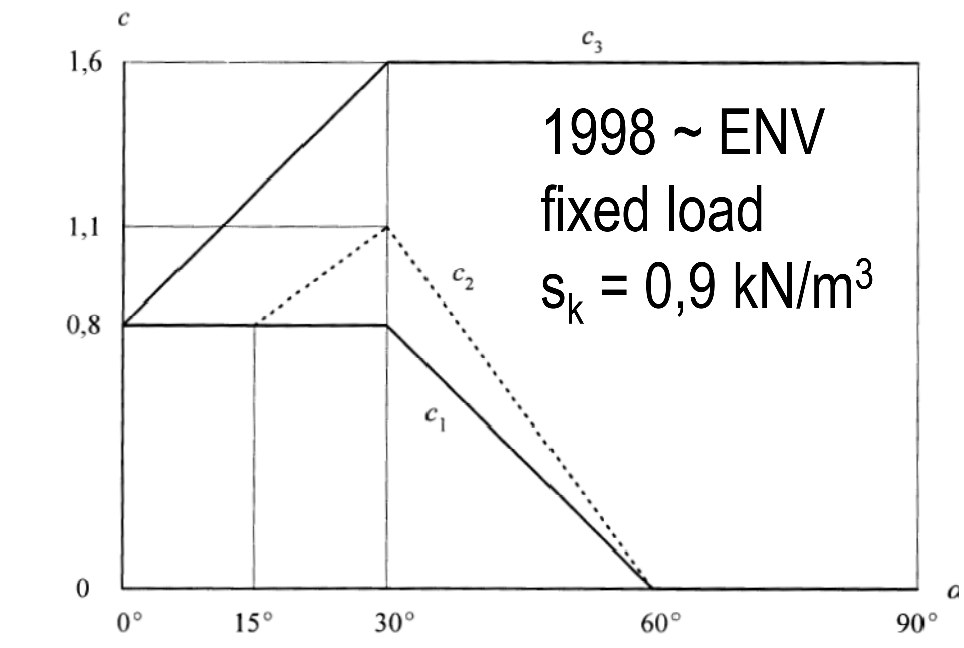
- Warm snow storm more likely due to climate change

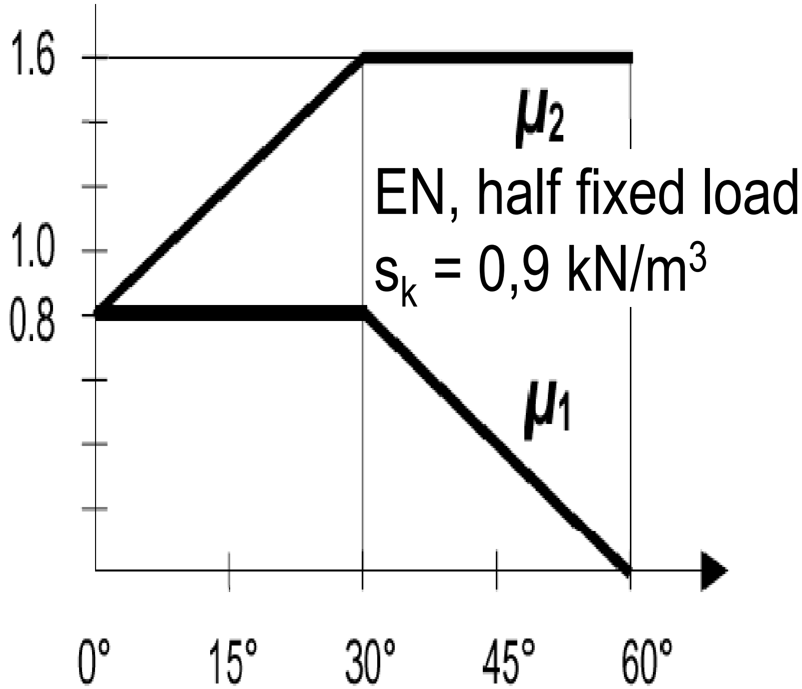
Code loads

History of code rules
Duo-pitch roof



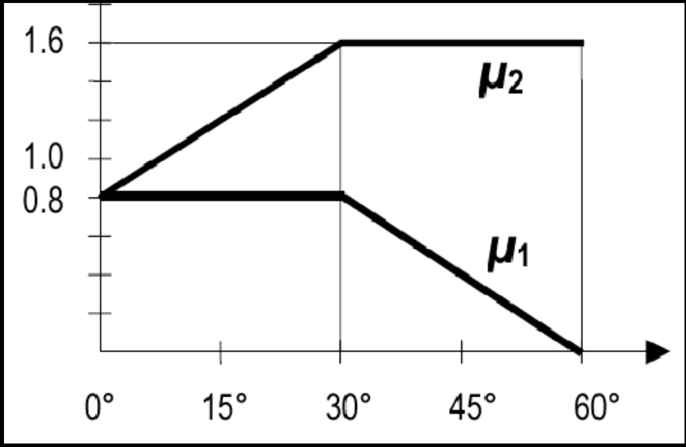


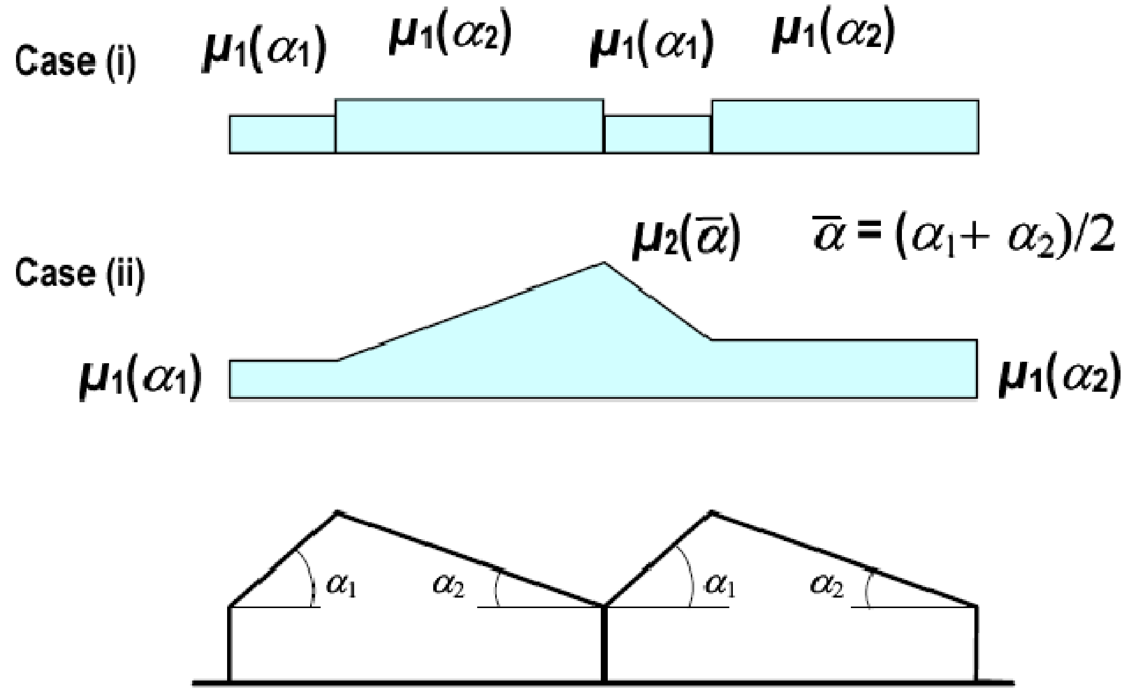




Multi-span roofs with valleys

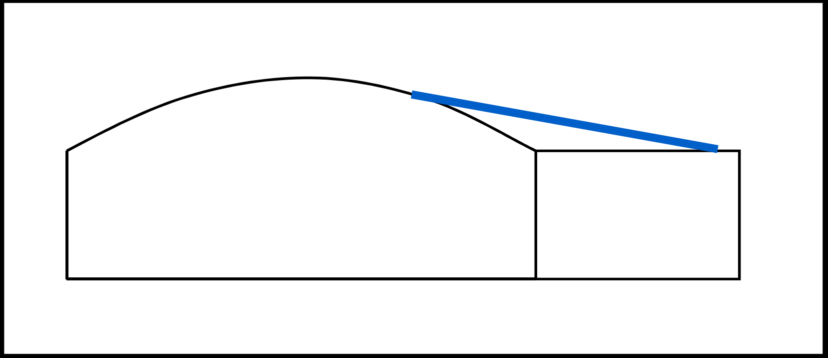
- Rules since 1945
- Peak load mostly about 1,5 kN/m^2
- (EC: max 1,6 x 0,9 = 1,44 kN/m^2)
- No damage observed

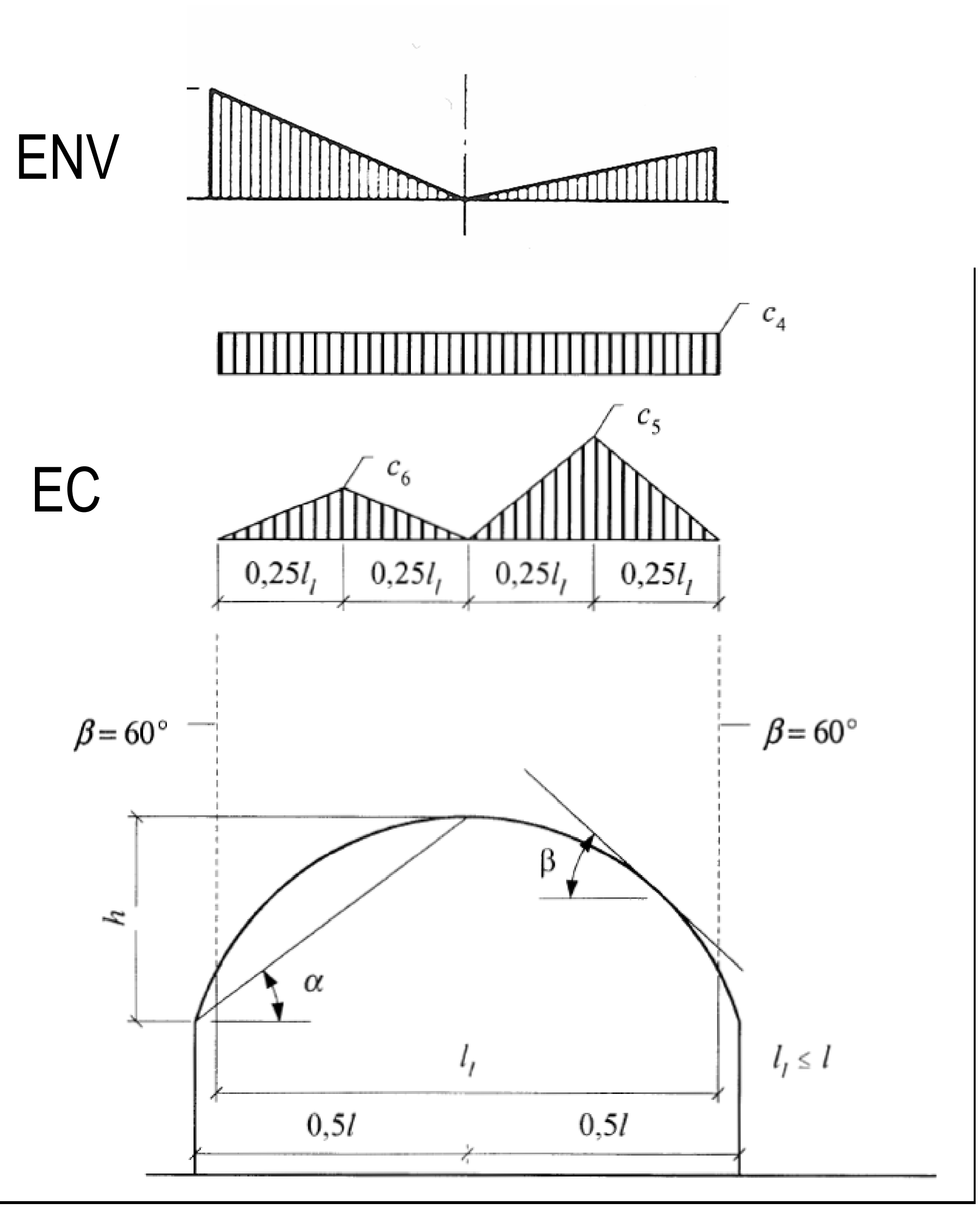




Cylindrical roofs

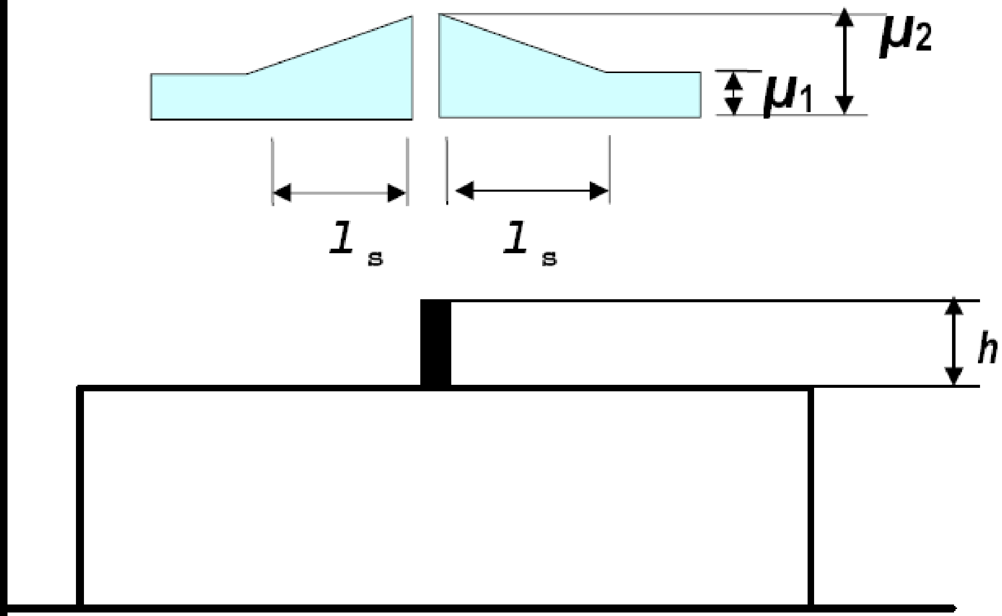
- Peak moved from edge to middle in EC
- DK recommends to use both

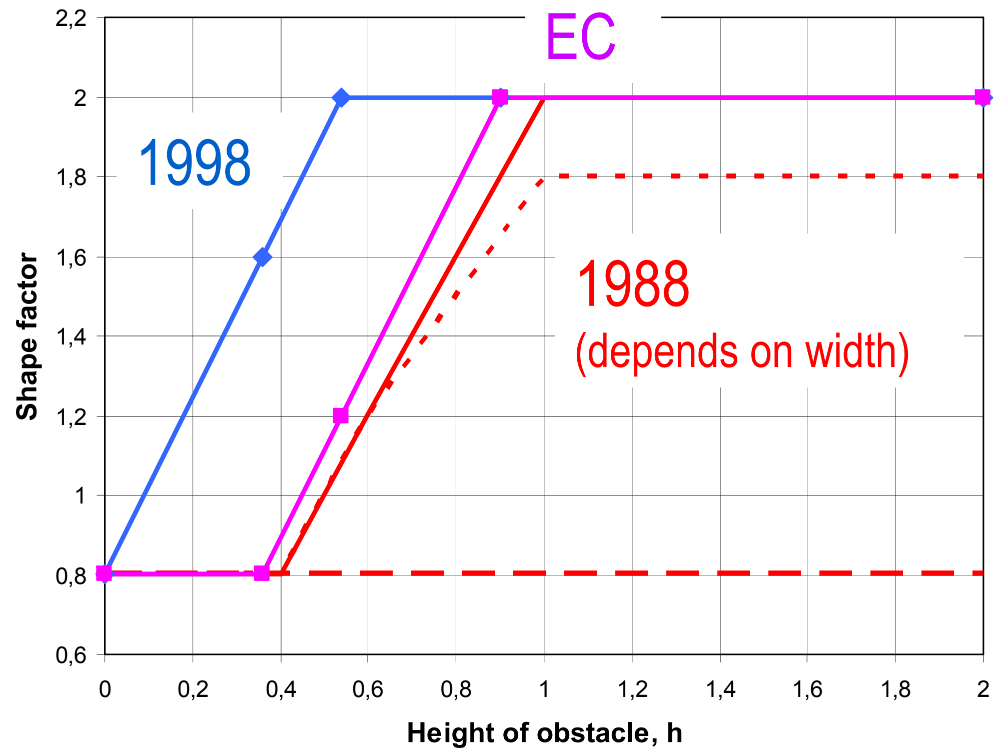




Drifting at obstacles

- First rules in 1988
- μ_2 and l_s defines load
- Various dependency on height and length of obstruction
- Max μ_2 =2 at all times
- l_s = 2 h
- Max l_s = 15 m at all times
- Min l_s = 5 m since 1998

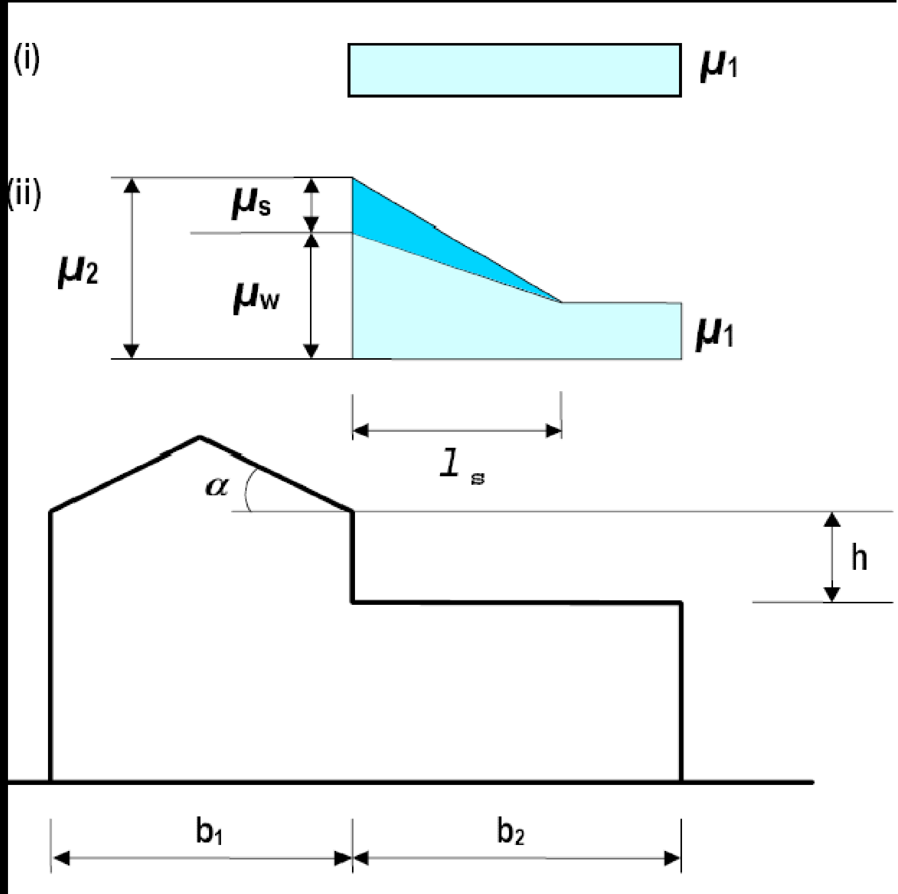




Low roof next to a higher building in EC

2 contributions:

- Sliding from high roof to low (μ_s)
- Shelter effect when drifting (μ_w)



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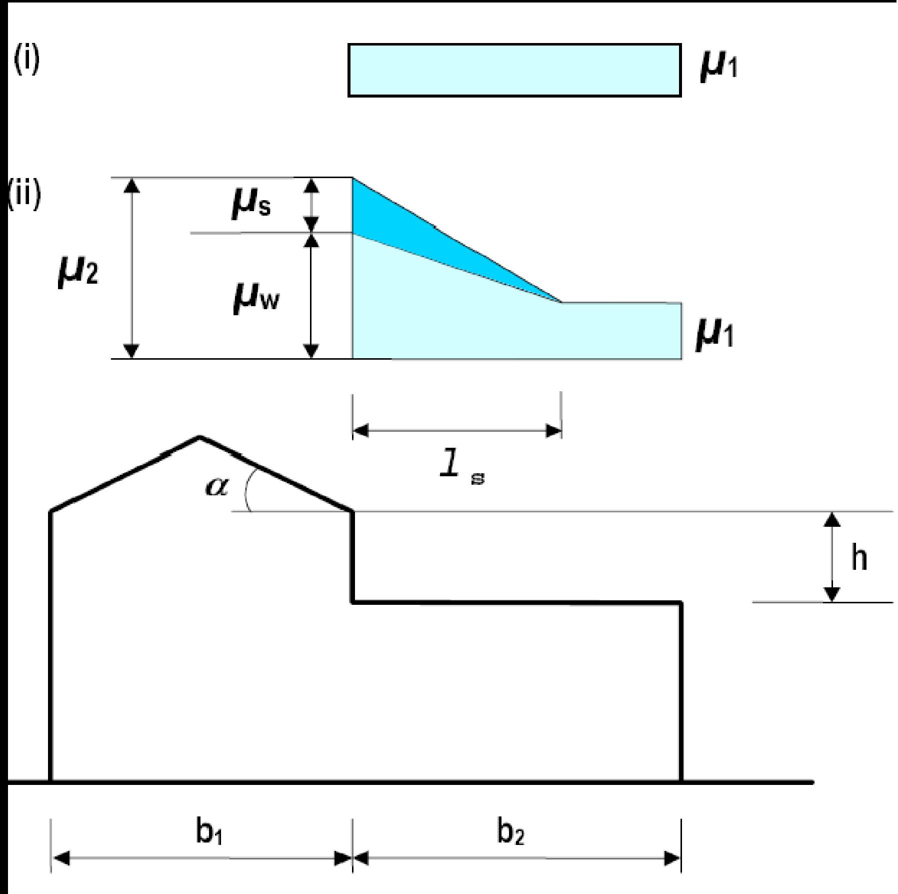

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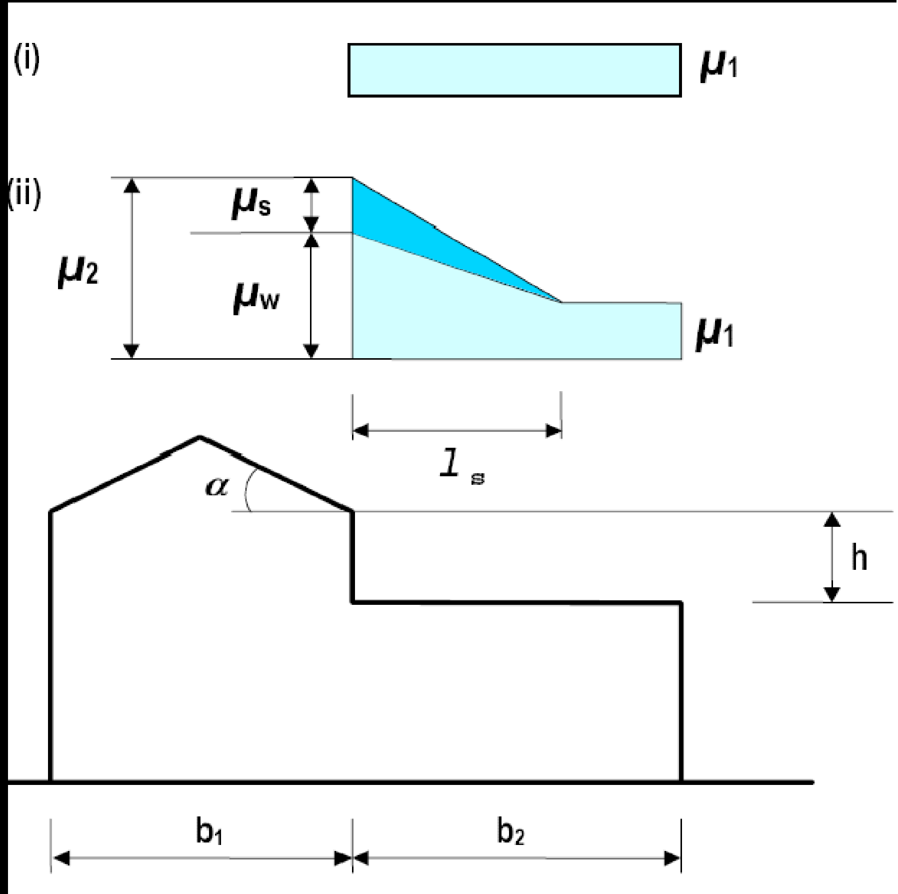

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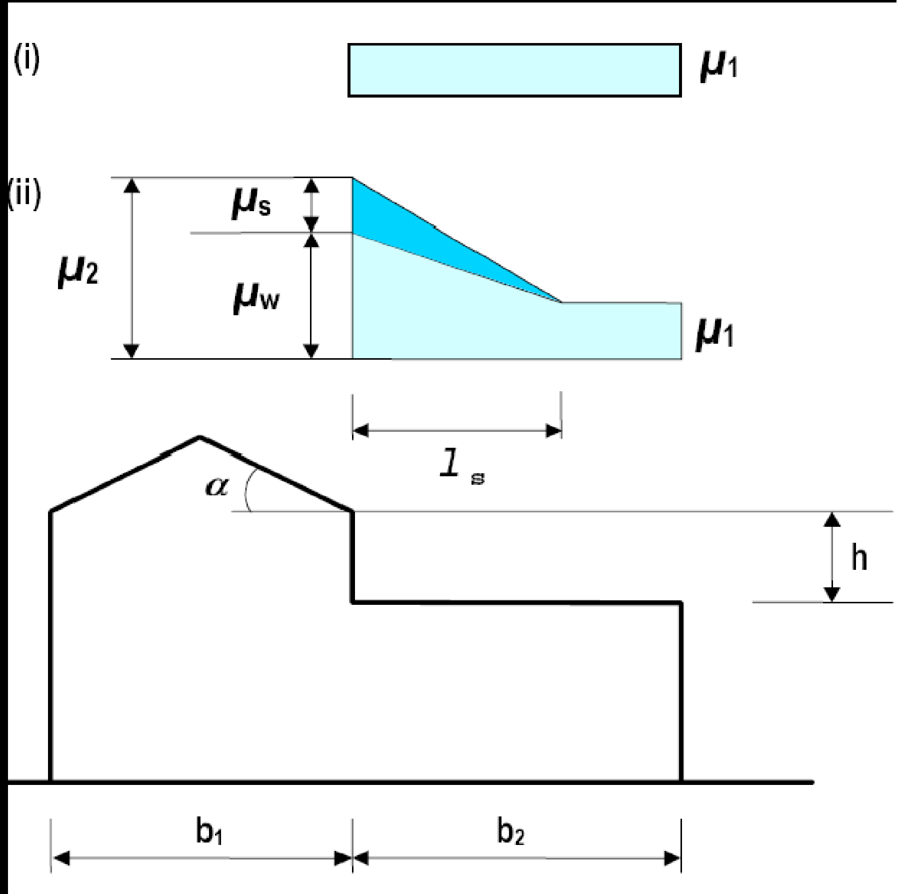
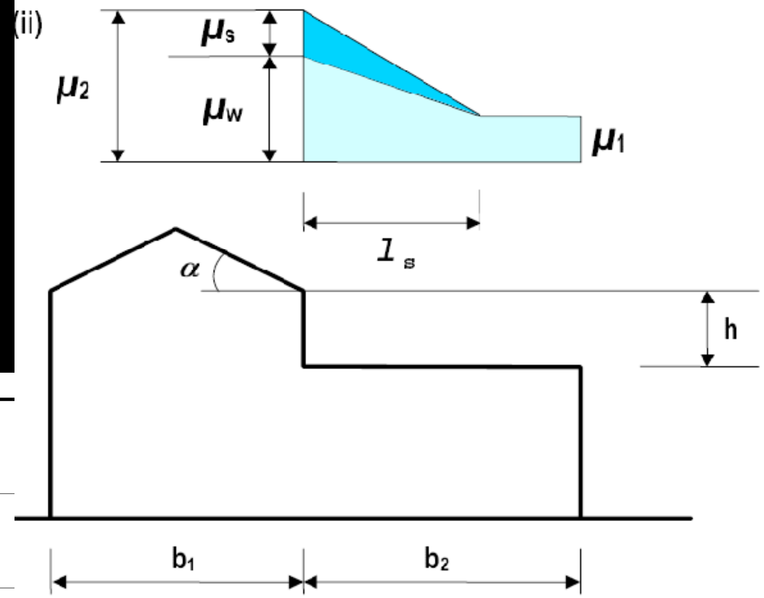
Shelter effect:

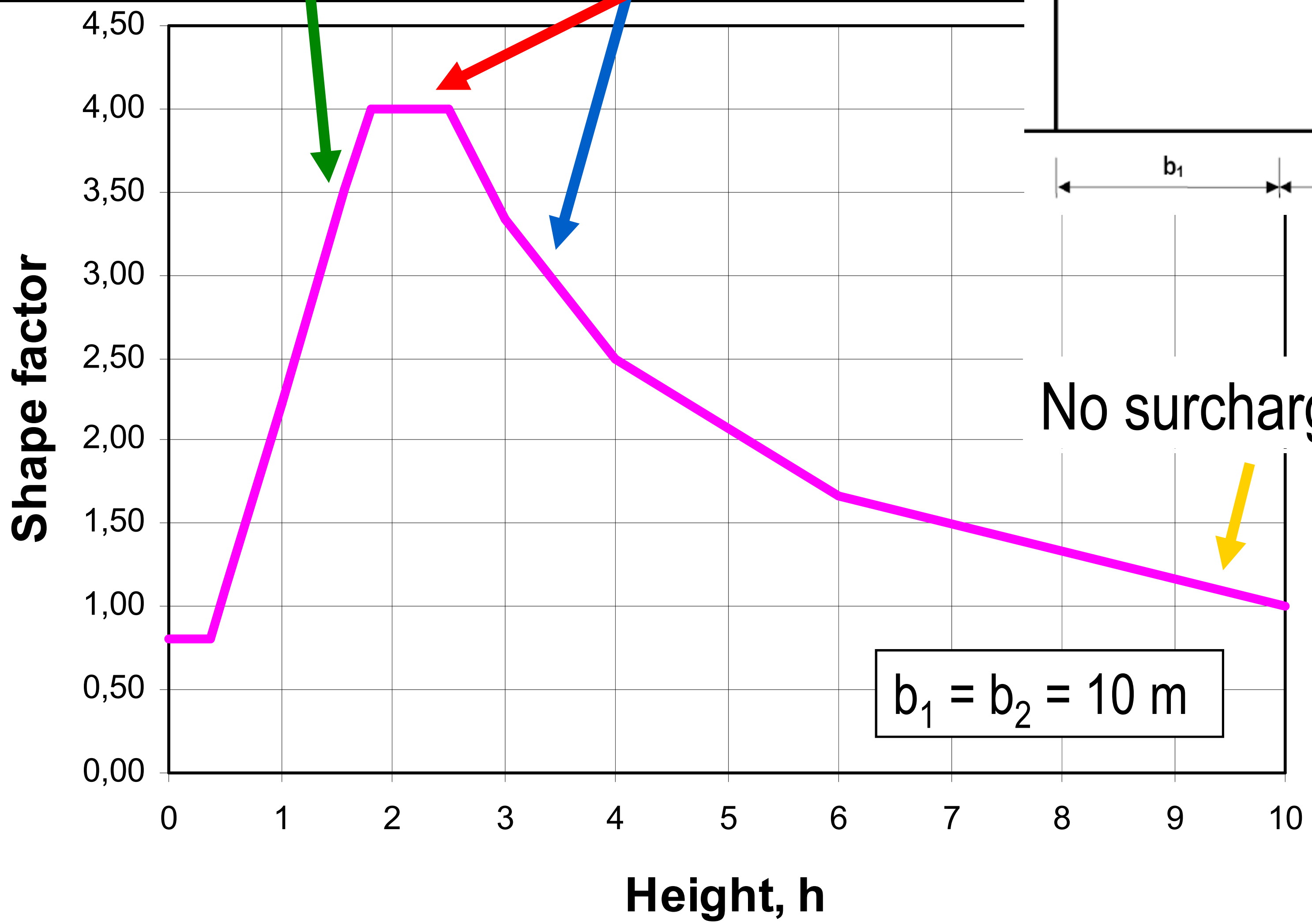
- μ_w= min[$\gamma_s h / s_k$; (b1+b2) / 2h; 4], γ_s = 2 kN/m^3



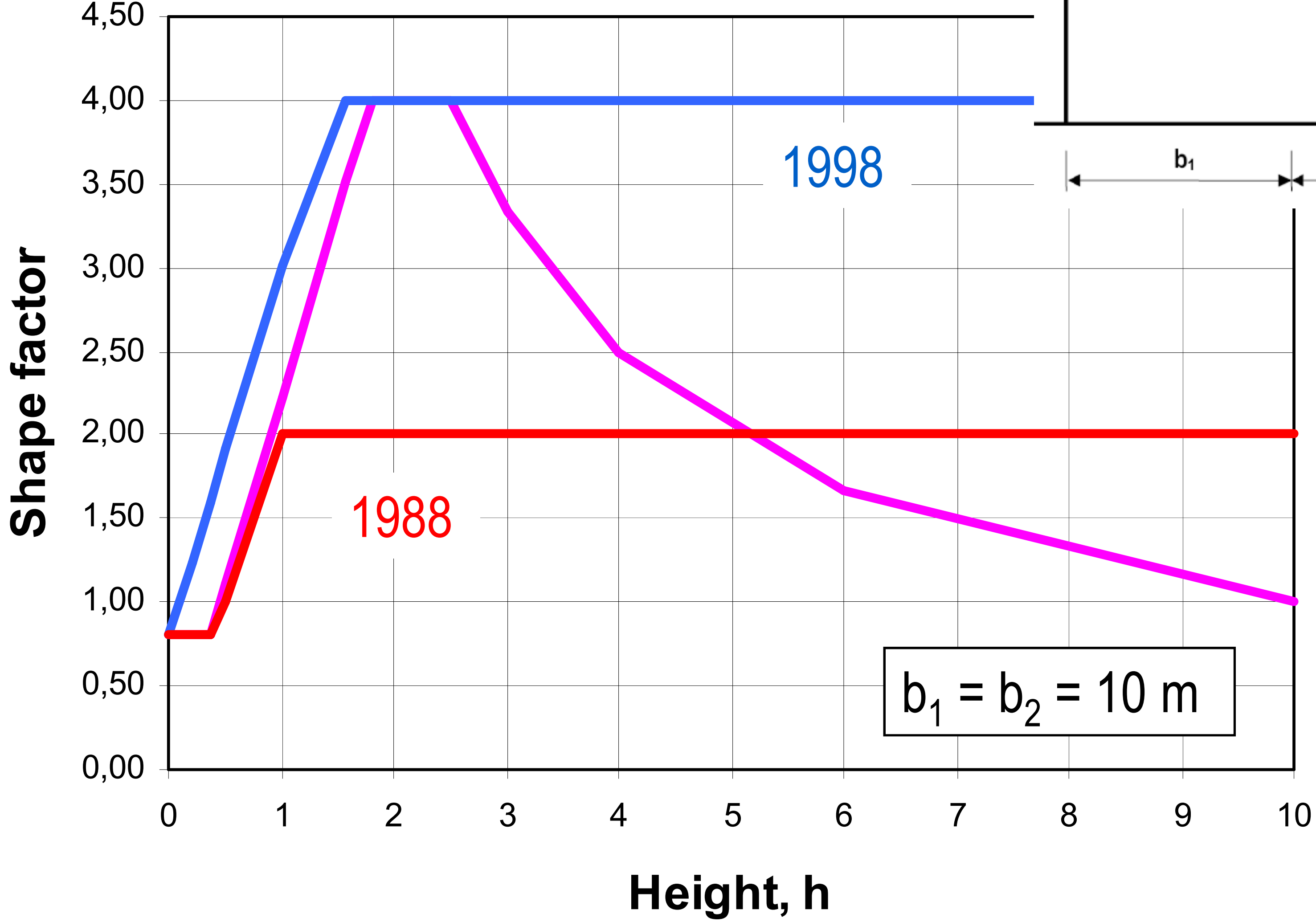
Shelter effect (α = 0)

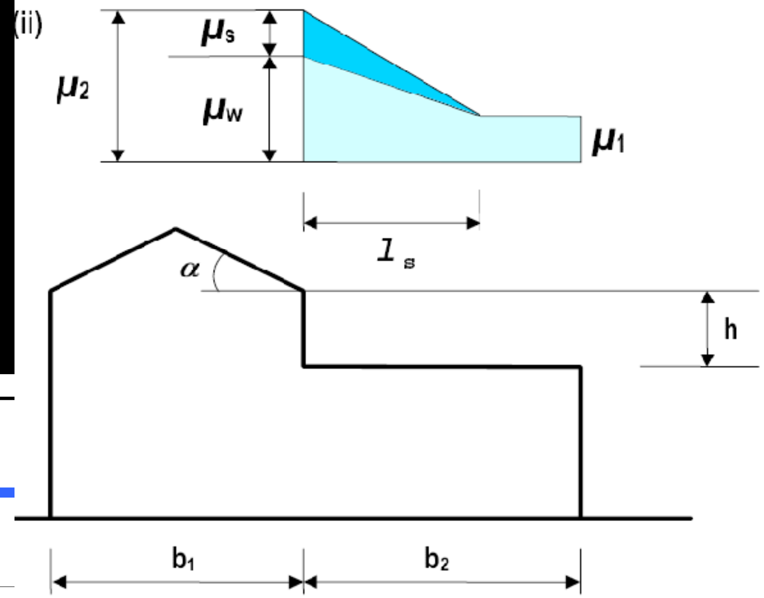
$$\mu_w = \min[\ \gamma_s h / s_k;\ (b1+b2) / 2h;\ 4\ ]$$



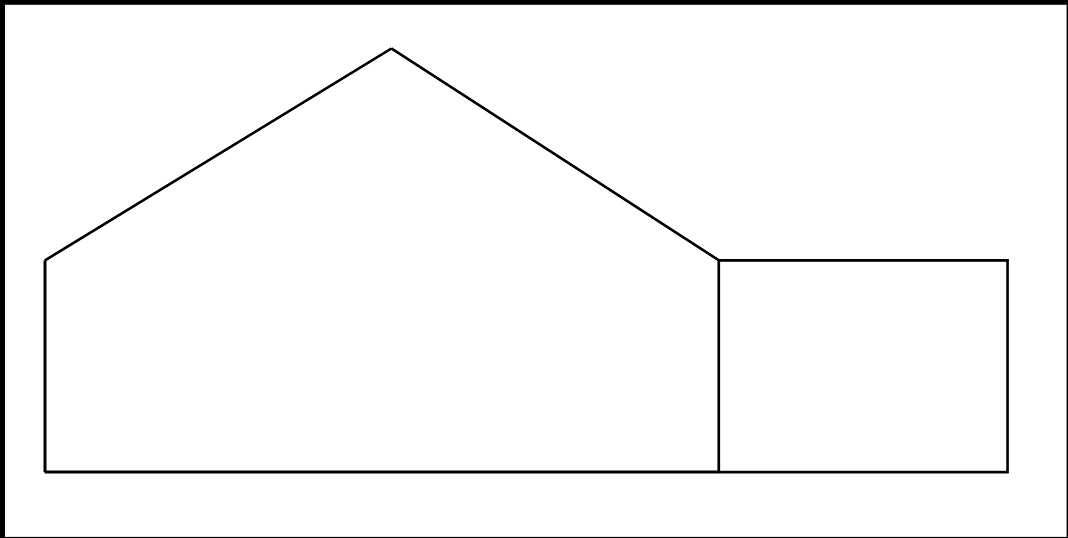


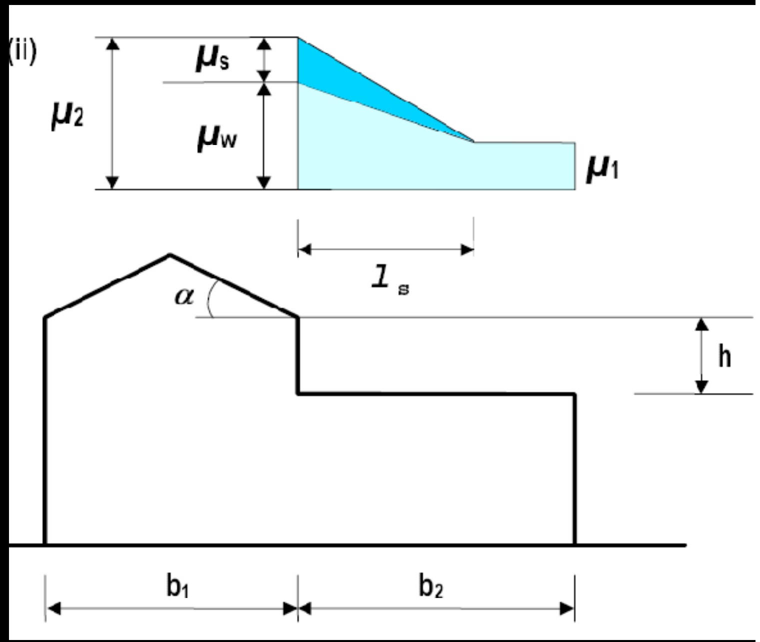
EC compared with DK codes





h = 0 and α > 0





- Ridge height has no influence
- h = 0 => no surcharge on either roof from drifting

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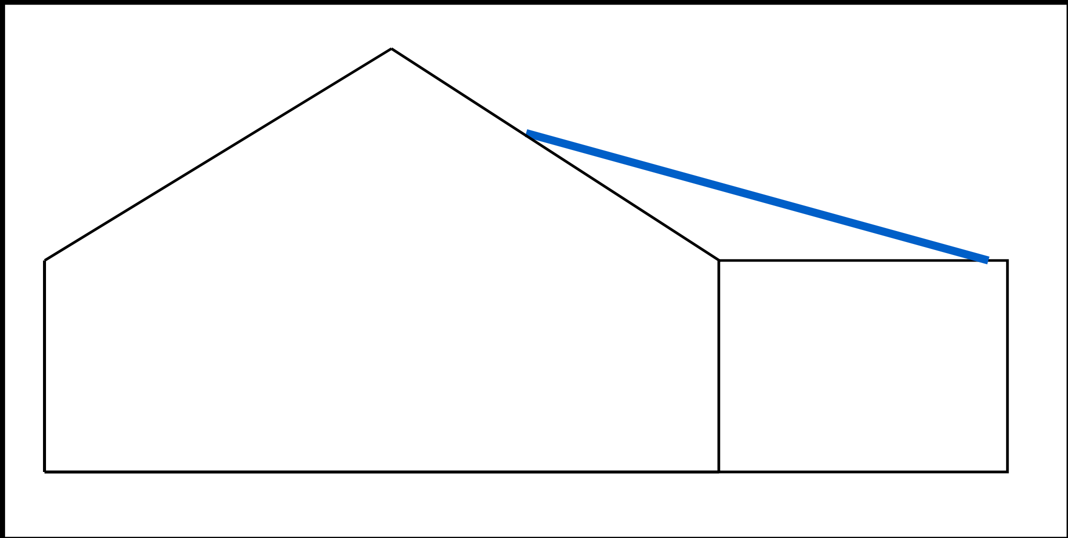

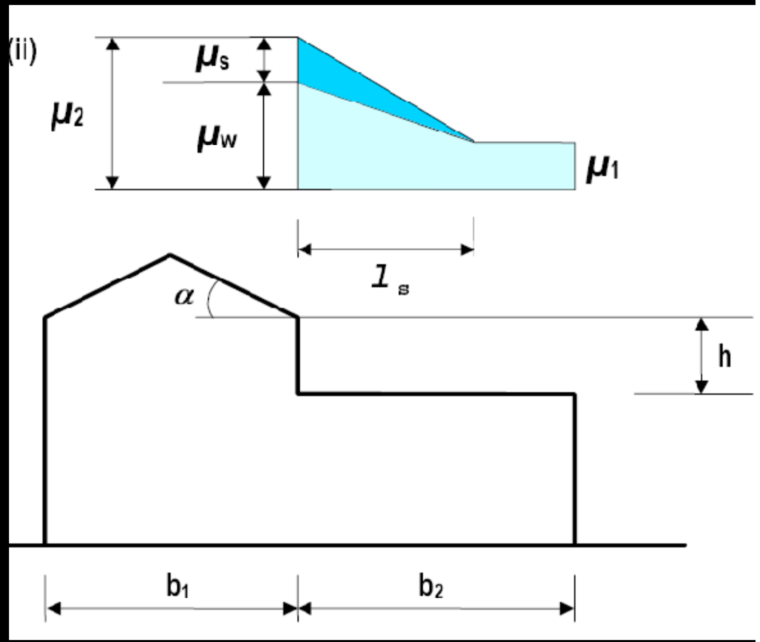

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- Reality: significant surcharge depending on ridge height

Code loads - summary

- Older codes inadequate for drifting
- EC seems unsafe for h = 0 (where roof slope decrease)
- EC seem unsafe for low buildings next to much higher buildings

Structural flaws and maintenance

Structural flaws

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Maintenance

- Insufficient maintenance only accounted for one failure, an old stable

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- Weaknesses of present codes not the only cause for any failure – always structural flaws as well
- EC not good for h = 0 and for large h

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- Weaknesses of present codes not the only cause for any failure – always structural flaws as well
- EC not good for h = 0 and for large h
- Recommendation for checking large span buildings
- If flaws observed possible actions are
  - Strengthening,
  - Evacuation plan or
  - Removal of snow

Recent storm damage to roof

Roof of steel plates

- 300 m^2 blew off
- Wind speed far from characteristic
- Other part of the roof blew off 3 years ago
- No strengthening considered!

Cause

- Battens fastened with smooth nails (square and rusty)