Moisture induced stresses Discussion

- what is its role on the occurred failures
- how to consider moisture induced stresses in practice

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Business from technology

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Design of safe timber structures –
How can we learn from structural failures in concrete, steel and timber?

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Table 8. Failure cases according to countries.

Country	Number of cases	Percentage of cases
Sweden	31	24
Finland	30	23
Norway	16	13
Germany	33	26
United States	13	10
Denmark	2	2
Czech Republic	1	< 1
Great Britain	1	< 1
Total	127	100

Failure analysis on timber structures in Germany

A contribution to COST Action E55

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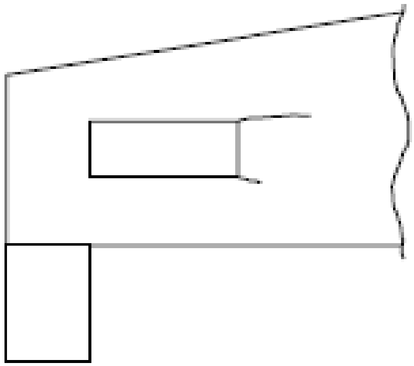
Fig. 9. Longitudinal through crack in glulam roof girder due to shrinkage effects. Hot water piping in the vicinity of the girder contributed to fast drying. Source: Ref. [7].



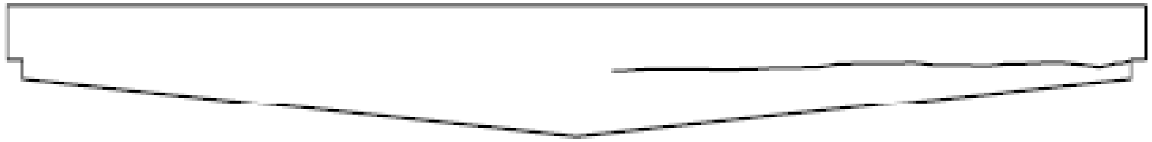


Figure 18. Schematic illustrations of perpendicular to grain failures in connection with holes and notches in large glulam beams.

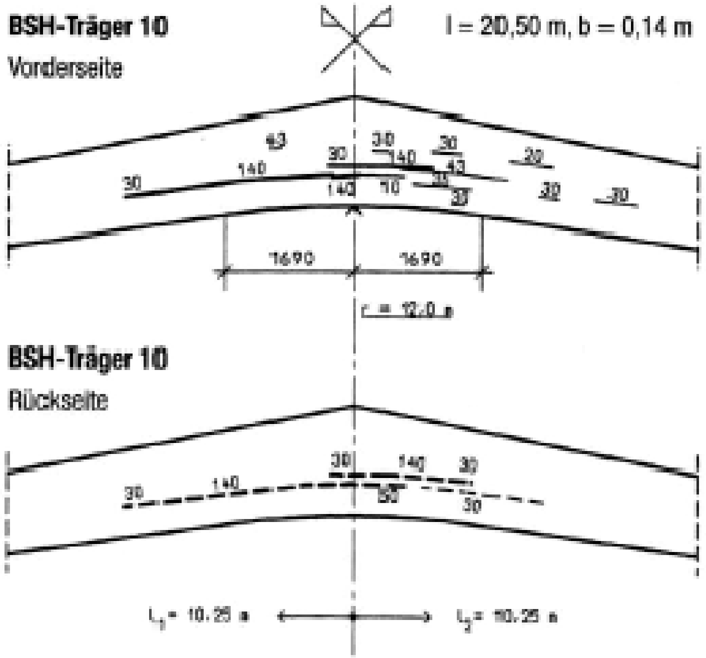


Figure 20. Cracks in pitched cambered roof beams due to restrained shrinkage. Views of both sides of a beam. Source: Ref. [7].

Figure 115-1. Arched column with steel parts (in white).

Figure 115-2. Crack at column fitting to the steel part.

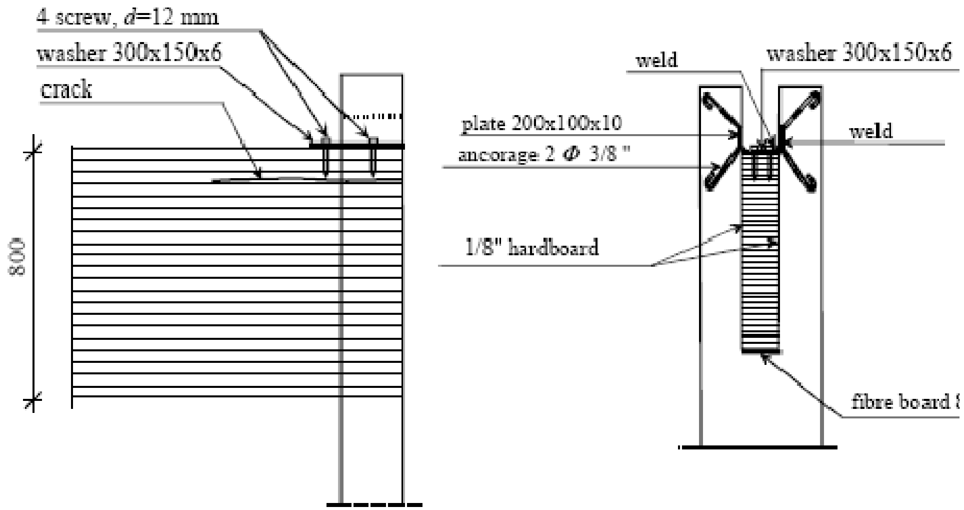


Figure 94-1: Support connection of glulam beam to concrete column.

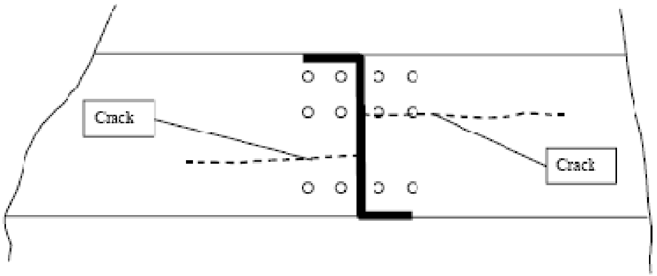


Figure 109-2 Scematic of beam connection and cracks found

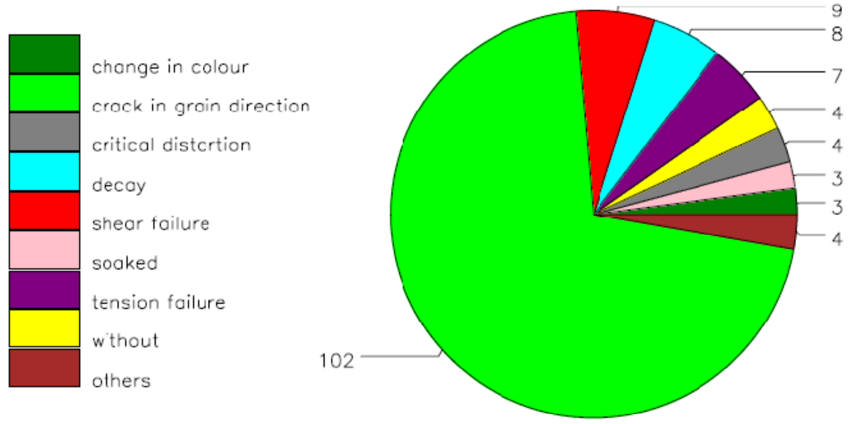


Fig. 8 Primary damage distribution

Table 15. Failure modes.

Failure mode	Percentage of cases
Instability	30
Bending failure	15
Tension failure perpendicular to grain	11
Shear failure	9
Drying cracks	9
Excessive deflection	7
Tension failure	5
Corrosion of fasteners / decay	4
Withdrawal of fasteners	3
Compression	2
Other / unknown	21

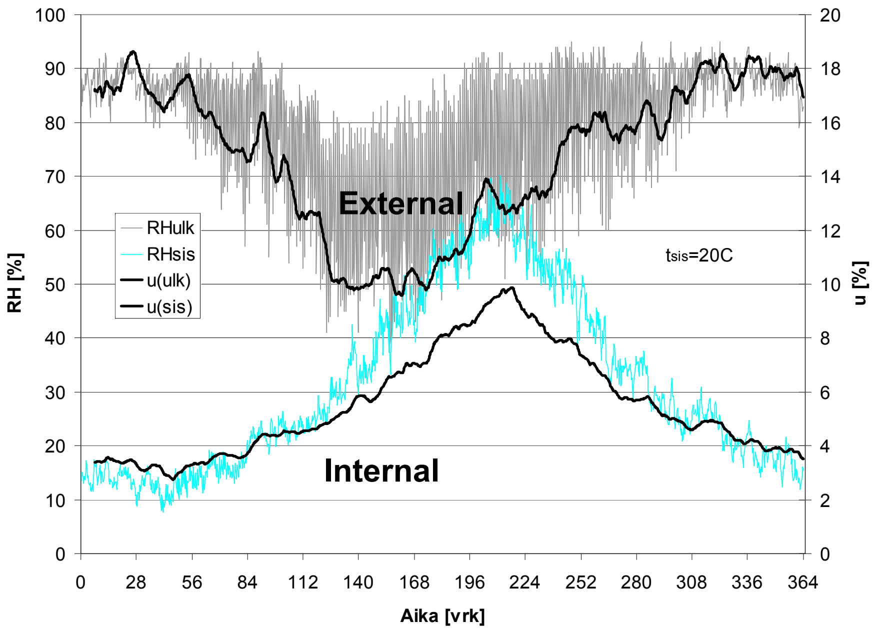
Influence of moisture on the failure modes

Table 15. Failure modes.

Failure mode	Percentage of cases	
Instability	30	Likely
Bending failure	15	Possible
Tension failure perpendicular to grain	11	Yes, moisture stresses
Shear failure	9	Likely
Drying cracks	9	Yes, moisture stresses
Excessive deflection	7	Yes
Tension failure	5	Possible
Corrosion of fasteners / decay	4	Yes
Withdrawal of fasteners	3	Possible
Compression	2	Possible
Other / unknown	21	

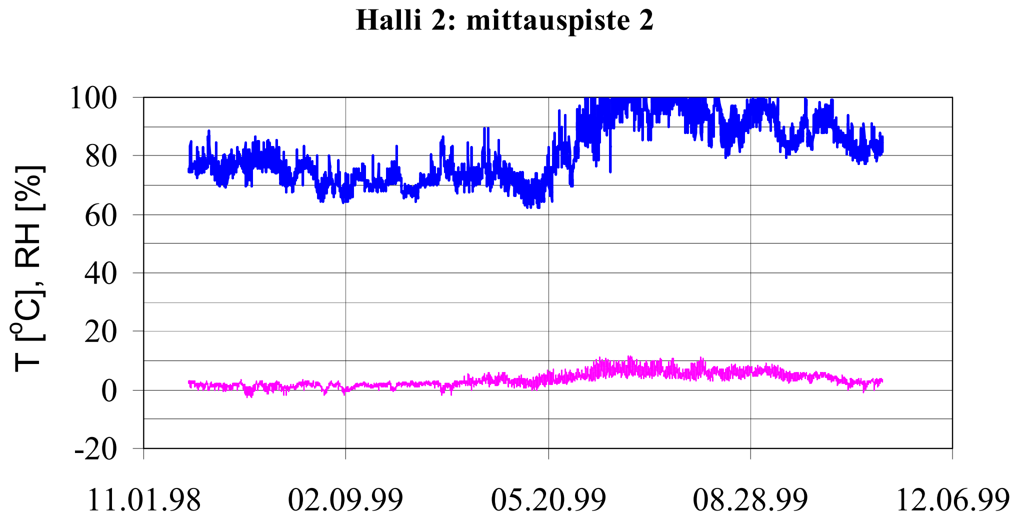
Humidity environments

Sibelius hall

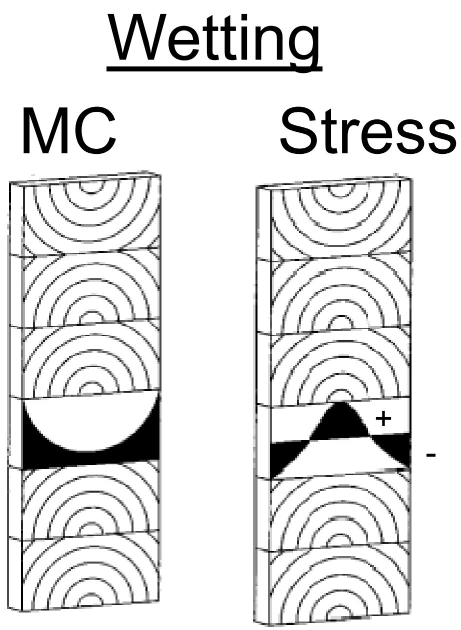


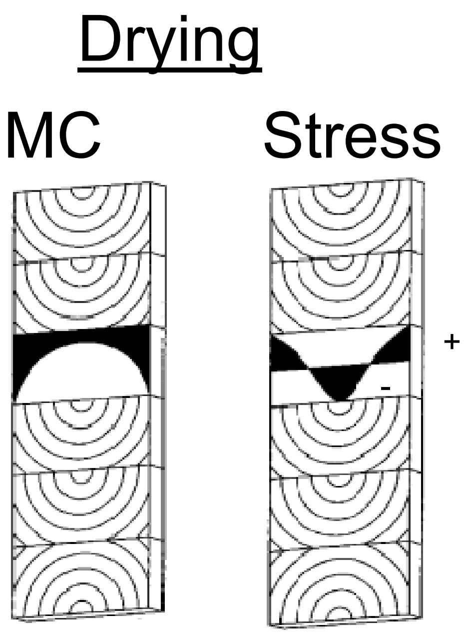
Ref: Koponen, 2002

Ice skating hall



Ref: Kevarinmäki et al., 2000





Previous studies have shown:
- Wetting causes a decrease in tension strength perp to grain
- Drying does not cause strength losses
- Duration of load effect is small

reference: Duration of load project 1992-1997, Jönsson[2003]

Originalarbeiten · Originals

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The effect of moisture gradients on tensile strength perpendicular to grain in glulam

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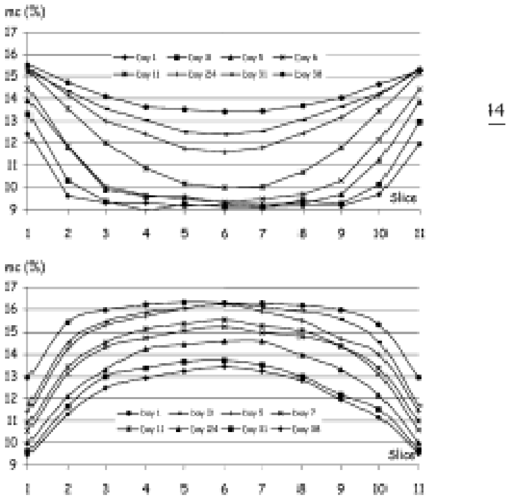

Fig. 4. Moisture distribution for wetting and drying specim
between RH 40 and 80%
Abb. 4. Feuchteverteilung für befeuchtete und trocknende Proben zwischen 40 und 80% rel. Feuchte

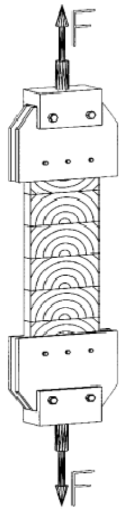

Fig. 2. Test arrangement
Abb. 2. Testanordnung

Wetting:

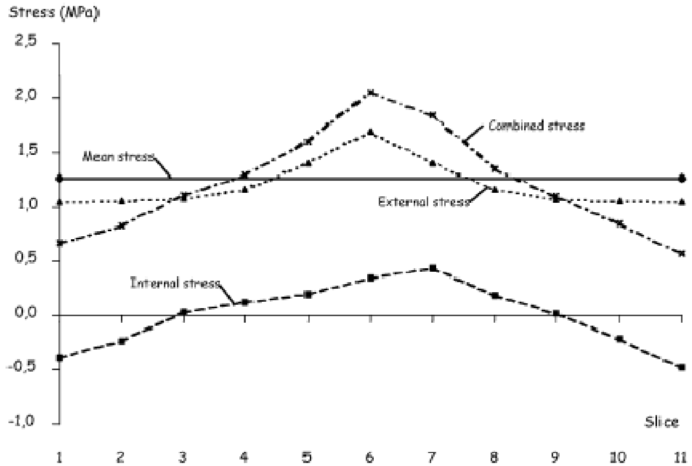

Fig. 14. The combination between internal and external stress for specimens under wetting, day 5

Drying:

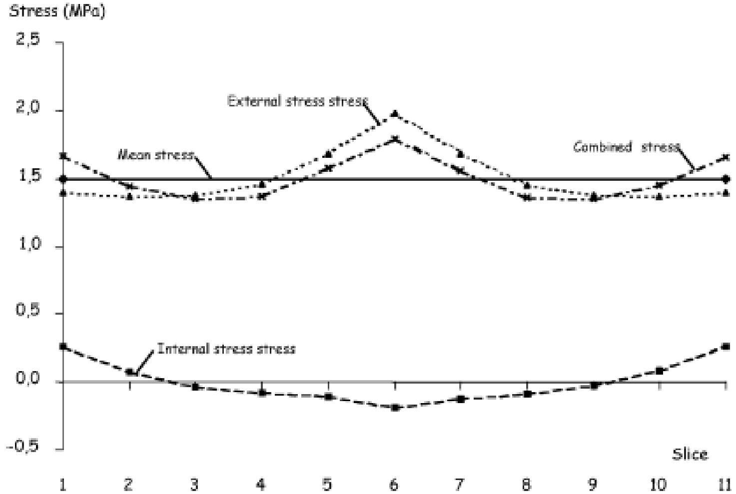

Fig. 15. The combination between internal and external stress for specimen under drying, day 5
Abb. 15. Die Kombination zwischen interner und externer Spannung bei Proben unter Trocknung, Tag 5

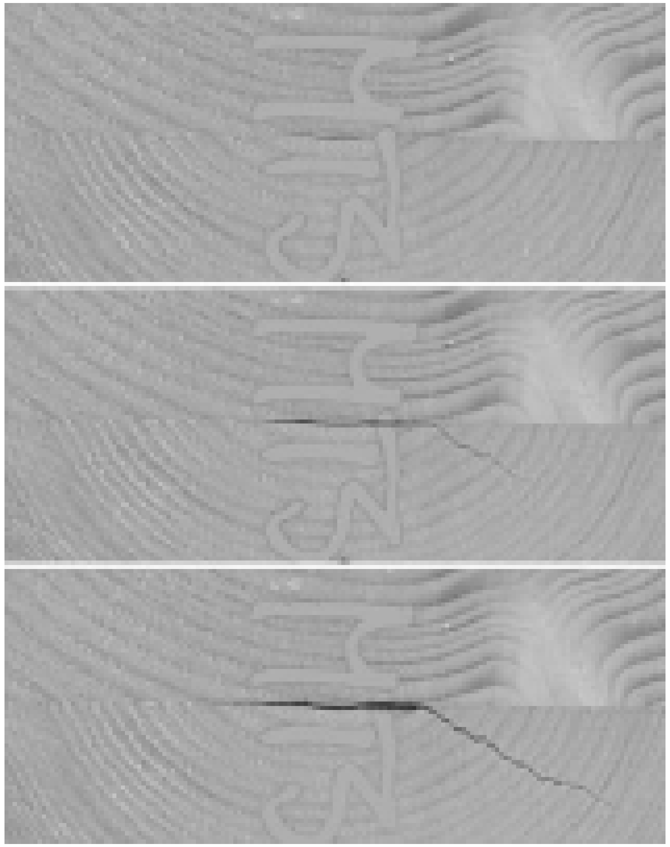

Fig. 8. Crack propagation in gradient specimens, RH 40 to 80%, tested at day 5

Moisture induced mechanical effects: Classes 1, 2, 3, 4

Classification

1. Restrained shrinkage is a problem in joint design and detailing
2. Fast drying is a problem in areas with surface peak perp stresses (holes, notches)
3. Long wetting is a problem where wood is under tension perp load (tapered beams)
4. Longitudinal stresses, continuous humidity cycles more important than single moisture changes. (beams, shear ?)

Conclusions from previous research

Classes 1–3 →

- **Moisture induced stresses is primary reason of failure**
- **Number of cycles or duration of load not important**
- **Stress analysis shows similar stress fields in successive cycles**

Class 4 →

- **Strength is reduced in high humidities and still more reduced in cyclic humidities, duration of load is important**

How to deal with moisture stresses

Moisture induced mechanical effects Classes 1, 2, 3, 4

Perpendicular stress

1. Restrained shrinkage is a problem in joint design and detailing
2. Fast drying is a problem in areas with surface peak perp stresses (holes, notches)
3. Long wetting is a problem where wood is under tension perp load (tapered beams)

Longitudinal stress

4. Continuous humidity cycles more important than single moisture changes. (beams, shear ?)

Proposal on how to treat in Codes

For cases 1,2,3,4

Specific instructions on:

a) Dowel max spacing perp to grain,
b) Permissible wood moisture contents: initial, during building and in-service
c) Development of coatings

For cases 2,3

Additional moisture load:

Ranta-Maunus proposed adding a moisture stress of σ_Q = 0,25 MPa for uncoated and 0,1 MPa for coated wood members.

For case 4

Apply the k_{mod} factor

$$\gamma_G \sigma_G + \gamma_Q (\sigma_{Q1} + \psi \sigma_{Q2}) \leq k_{\text{mod}} \frac{f}{\gamma_M}$$