Moisture induced stresses in glulam components

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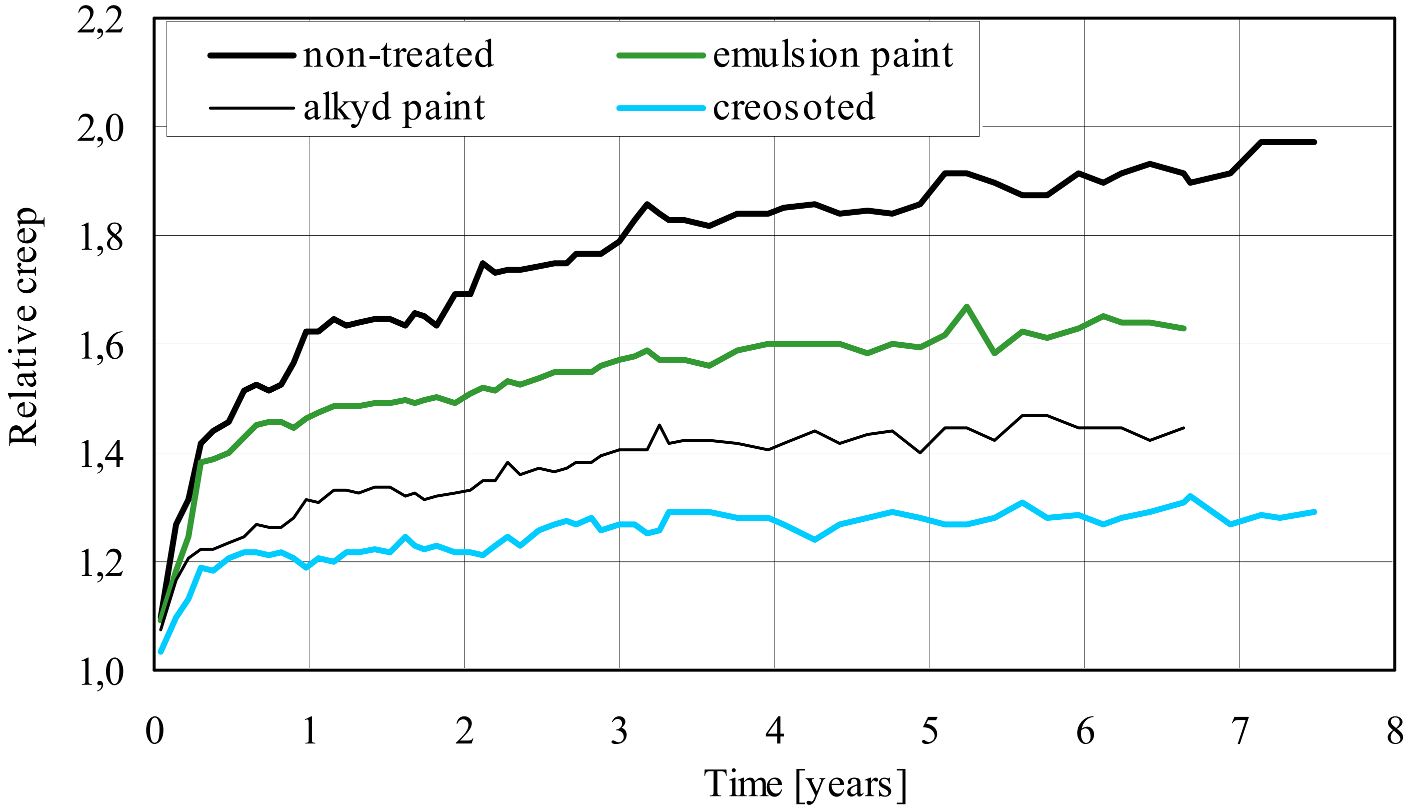
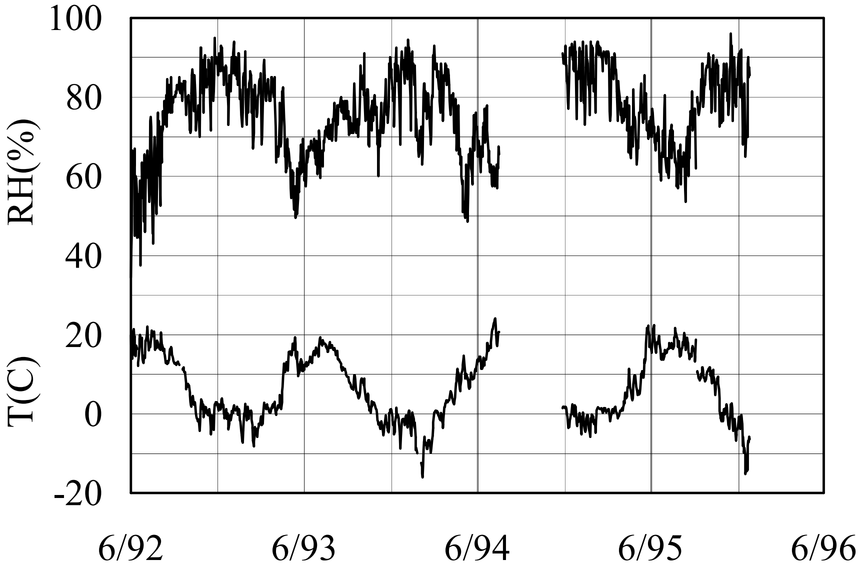
- Experimental evidence of phenomenon
- “Duration of load”- project 1996-
- Methods and results of analysis of strength reduction due to moisture gradients

Effect of treatment on creep in sheltered environment

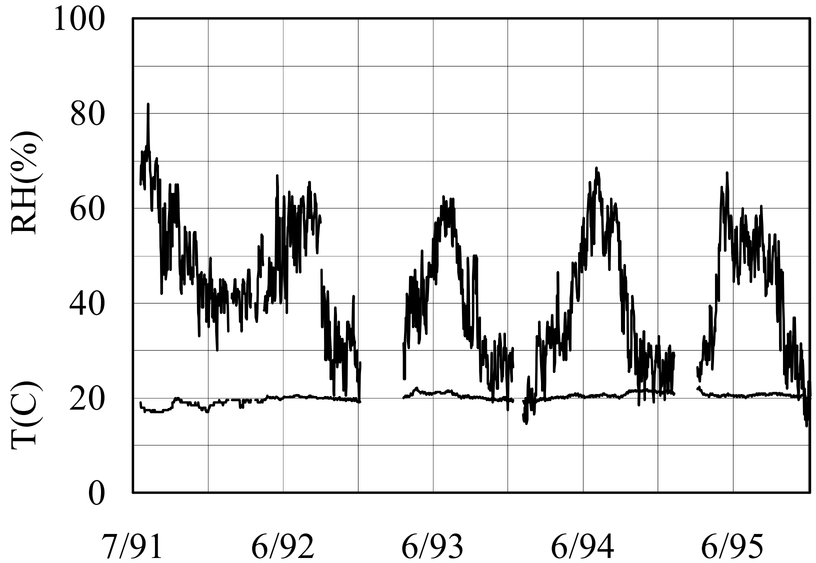


Relative humidity in Finland

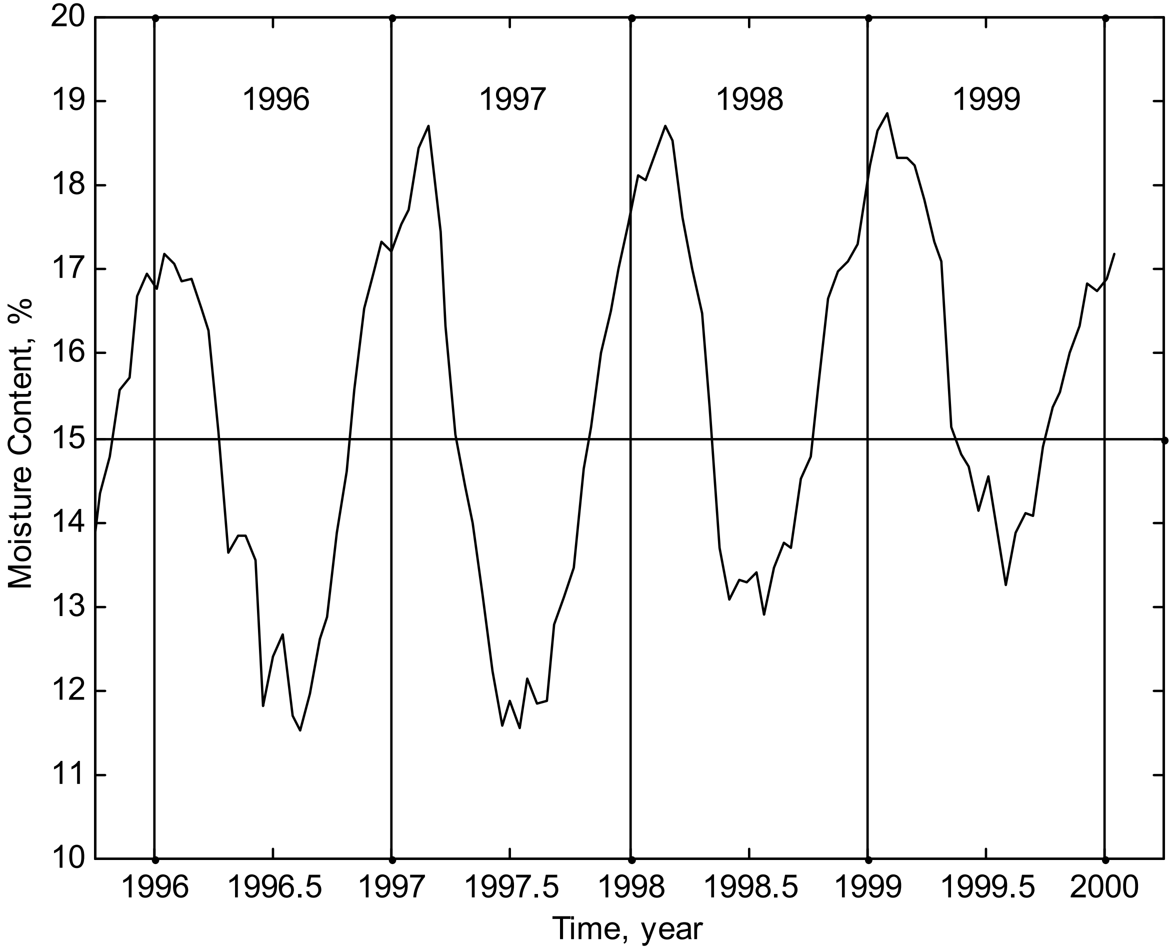
sheltered



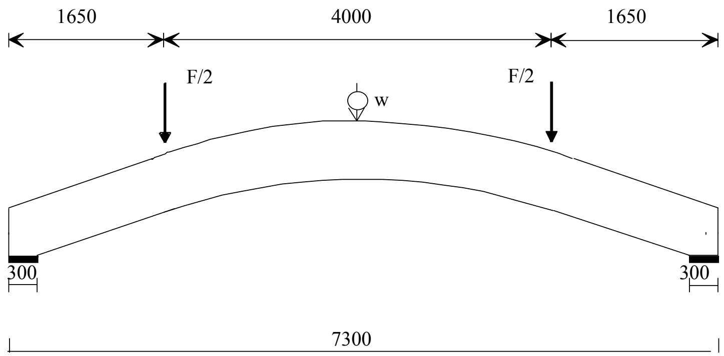
indoors



Moisture content variation of wood in southern Sweden



Experimental evidence: Long term experiments with curved beams



	painted			
RH cycle (%)	40 <-> 85	40 <-> 85	55 <-> 90	55 <-> 90
Width (mm)	90	90	90	140
Time to failure (days)	13	20	28	17
k_{DOL}	0.76	0.55	0.60	0.66

k_{DOL} at constant humidity = 0.8
for 2 to 4 week load duration

Moisture calculation

Moisture transport in wood

$$\frac{\partial}{\partial t}\int_V u dV = \oint_{\partial V} D_{eff} \frac{\partial u}{\partial x} dS$$

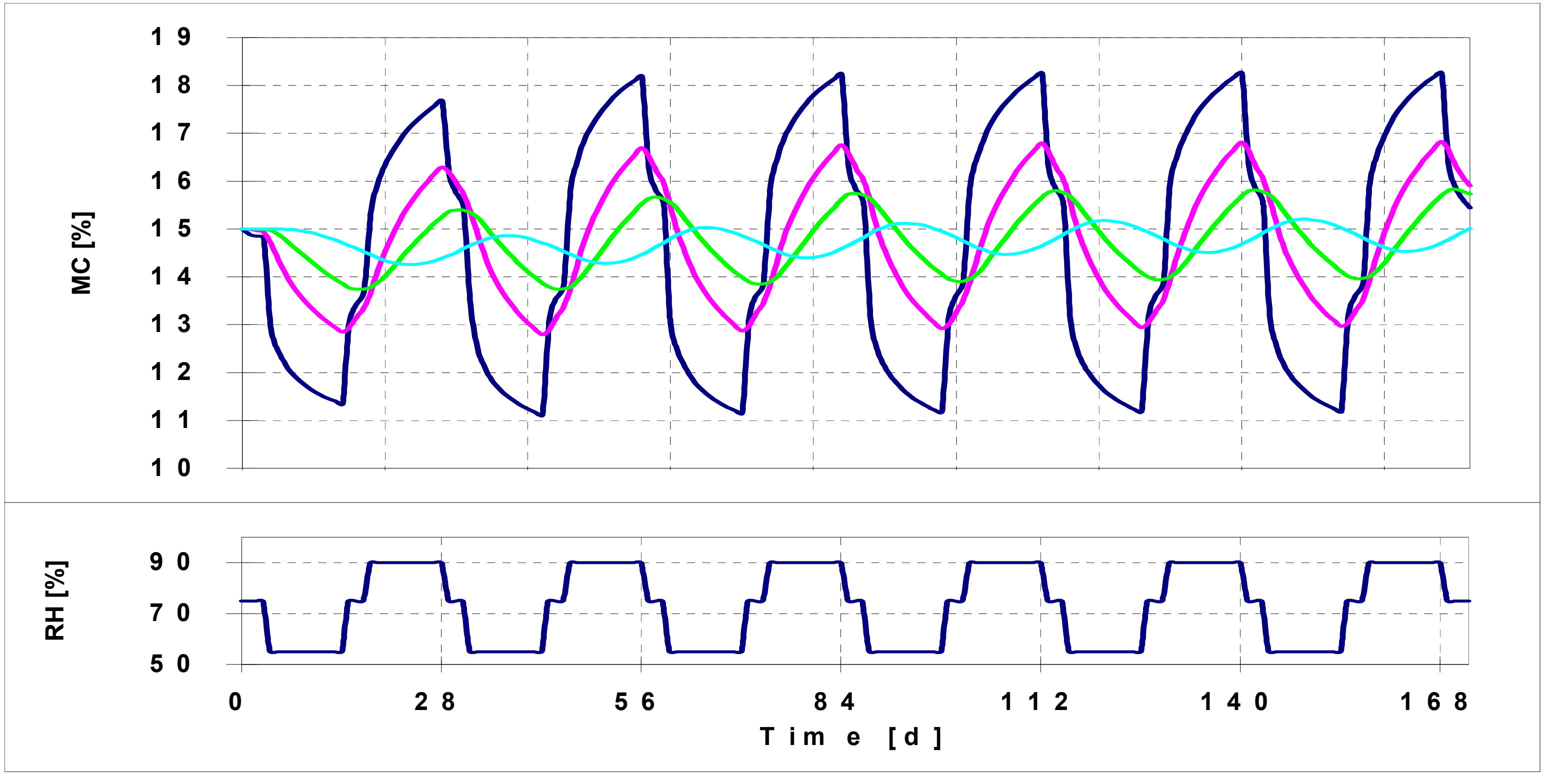
The mass flux density at the wood boundary:

$$F_u = k_{pa\,\mathrm{int}} \beta_l (p_v^* - p_v) \frac{\beta_w}{\beta_l}$$

where p_v^* is vapour pressure outside wood,

β_l is the mass transfer coefficient from liquid water.

Moisture is changing in wood



MC at depths of

0 mm

10 mm

20 mm

45 mm

Beam thickness 90 mm

Stress calculation

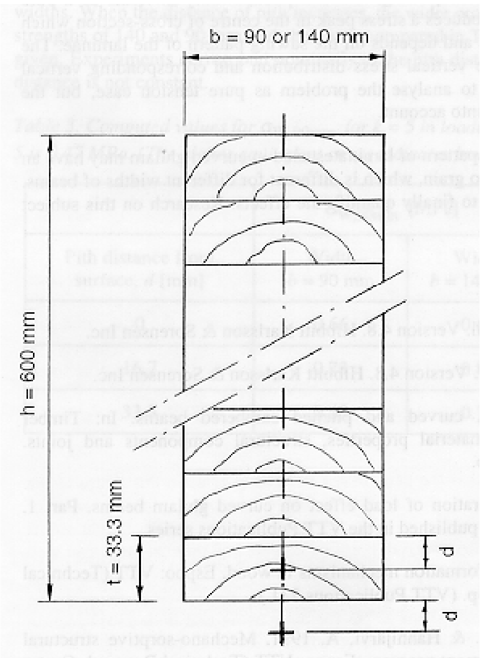
Constitutive model including shrinkage, elastic, viscoelastic and mechano-sorptive strain component:

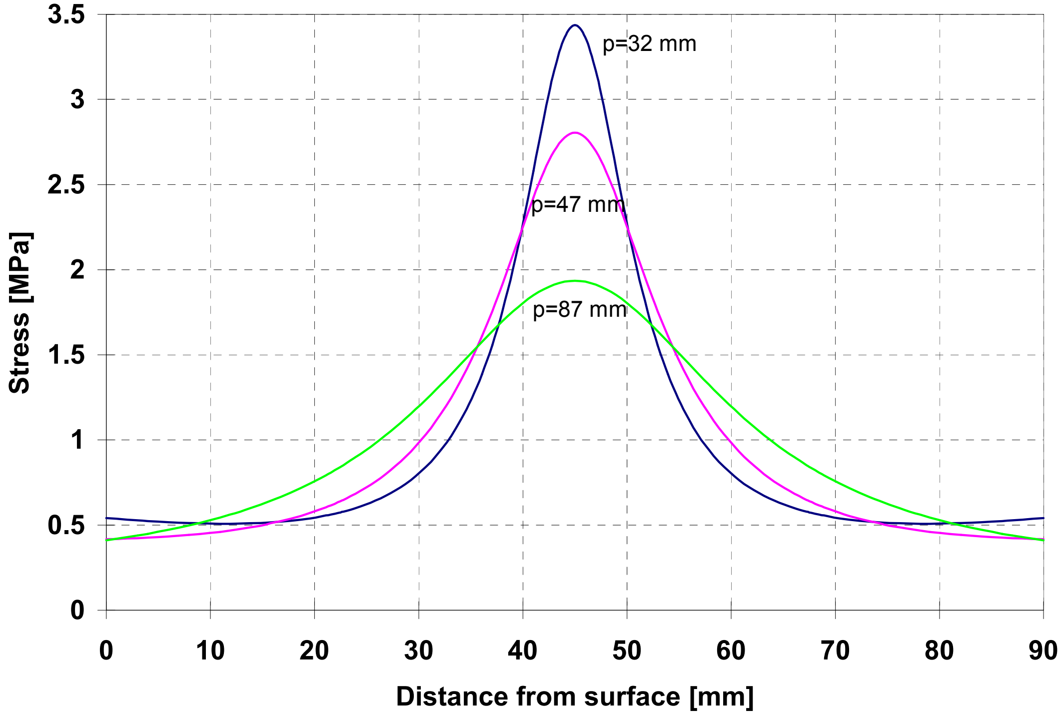
$$\varepsilon_{tot} = J_0 \cdot \sigma + \varepsilon_{ve} + \varepsilon_{ms} + \varepsilon_s$$

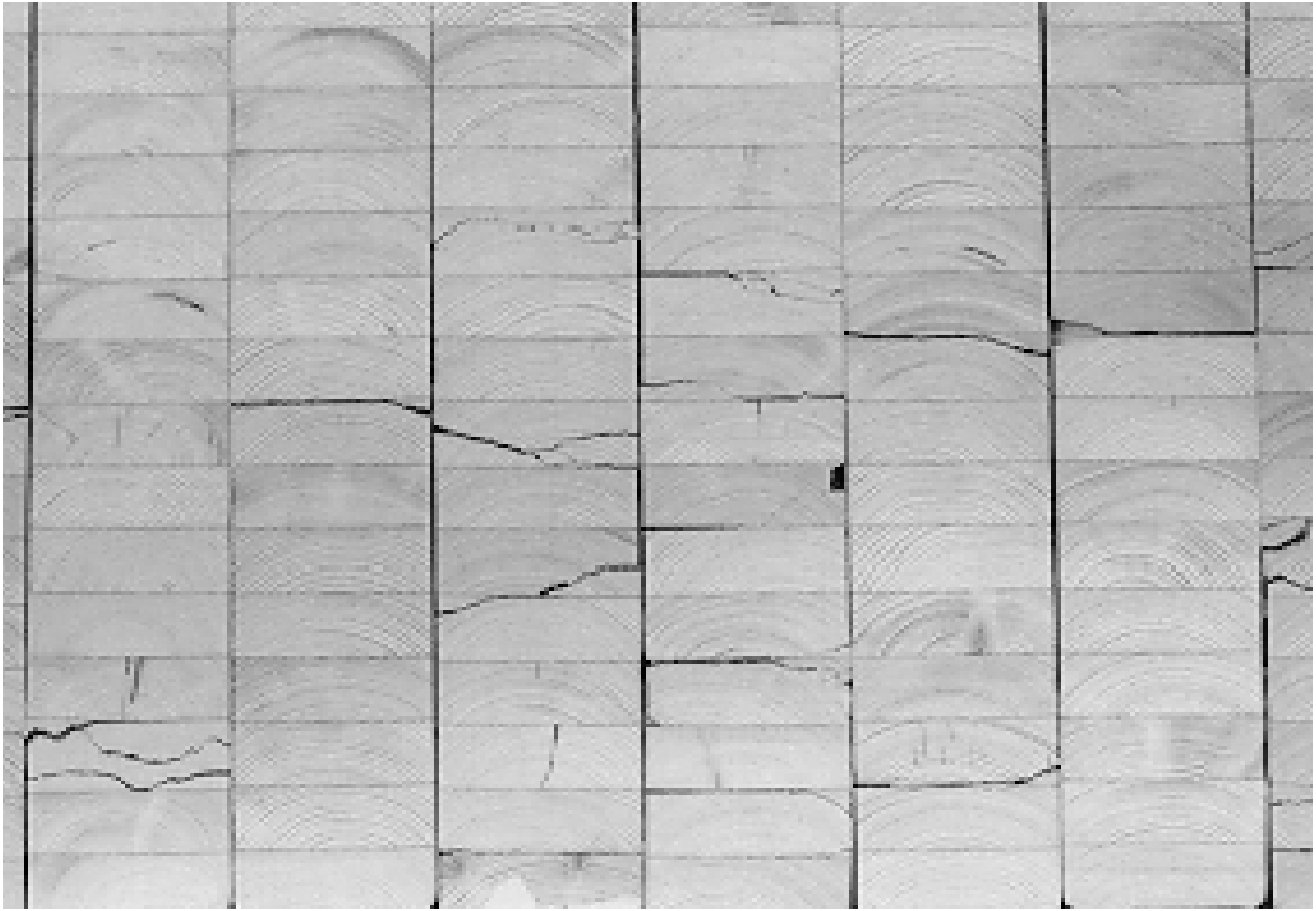
Two kind of calculations were made:
- considering wood as cylindricaly orthotropic material or
- isotropic material in RT-plane with variable E.

Tension stresses in a cross-section with variable E in thickness direction

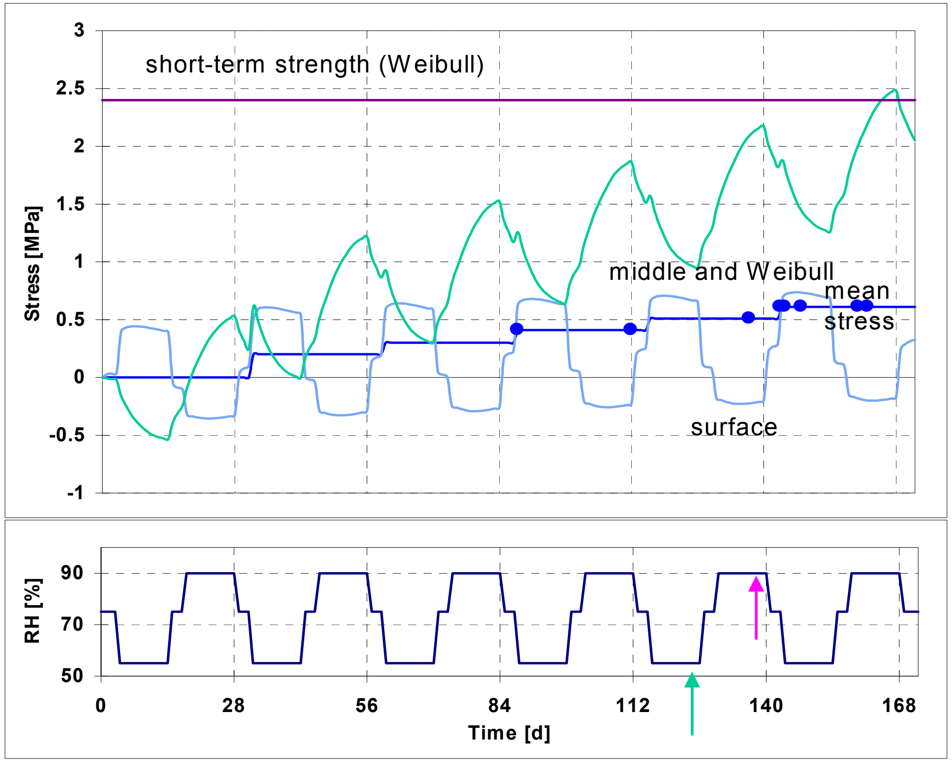
$$\frac{1}{E_\alpha} = \frac{\sin^2\alpha\cos^2\alpha}{G_{RT}} + \frac{\sin^4\alpha}{E_T} + \frac{\cos^2\alpha(\cos^2\alpha - \sin^2\alpha)}{E_R}$$

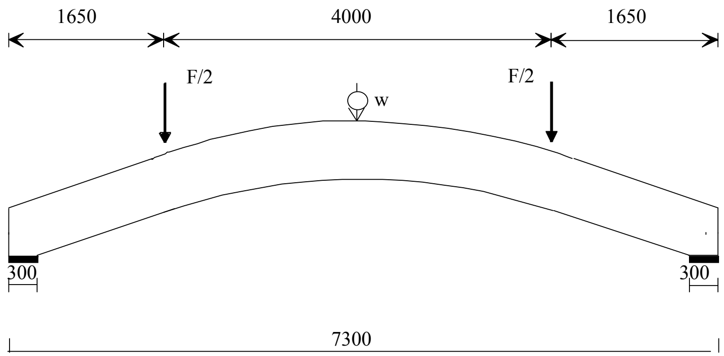


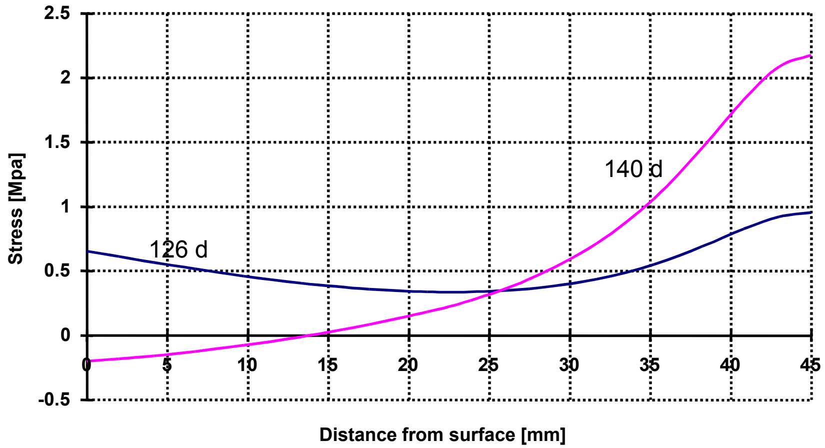




Stresses in wood perpendicular to grain







$$\sigma_W = \left(\frac{1}{V_{\text{ref}}} \int_V \sigma_{t,90}{}^k dV \right)^{1/k}$$

Calculated equivalent (mean) stresses for combined moisture and mechanical action for 90 mm thick glulam

Mean stress from external load = **0.20 MPa**

RH cycle	Equivalent stress
65 -> 90 %	**0.52 MPa**
75 -> 90 %	**0.40 MPa**
55 <-> 90 %	**0.45 MPa**
40 <-> 85 %	**0.35 MPa**
40 <-> 85 %	**0.25 MPa surface coated**

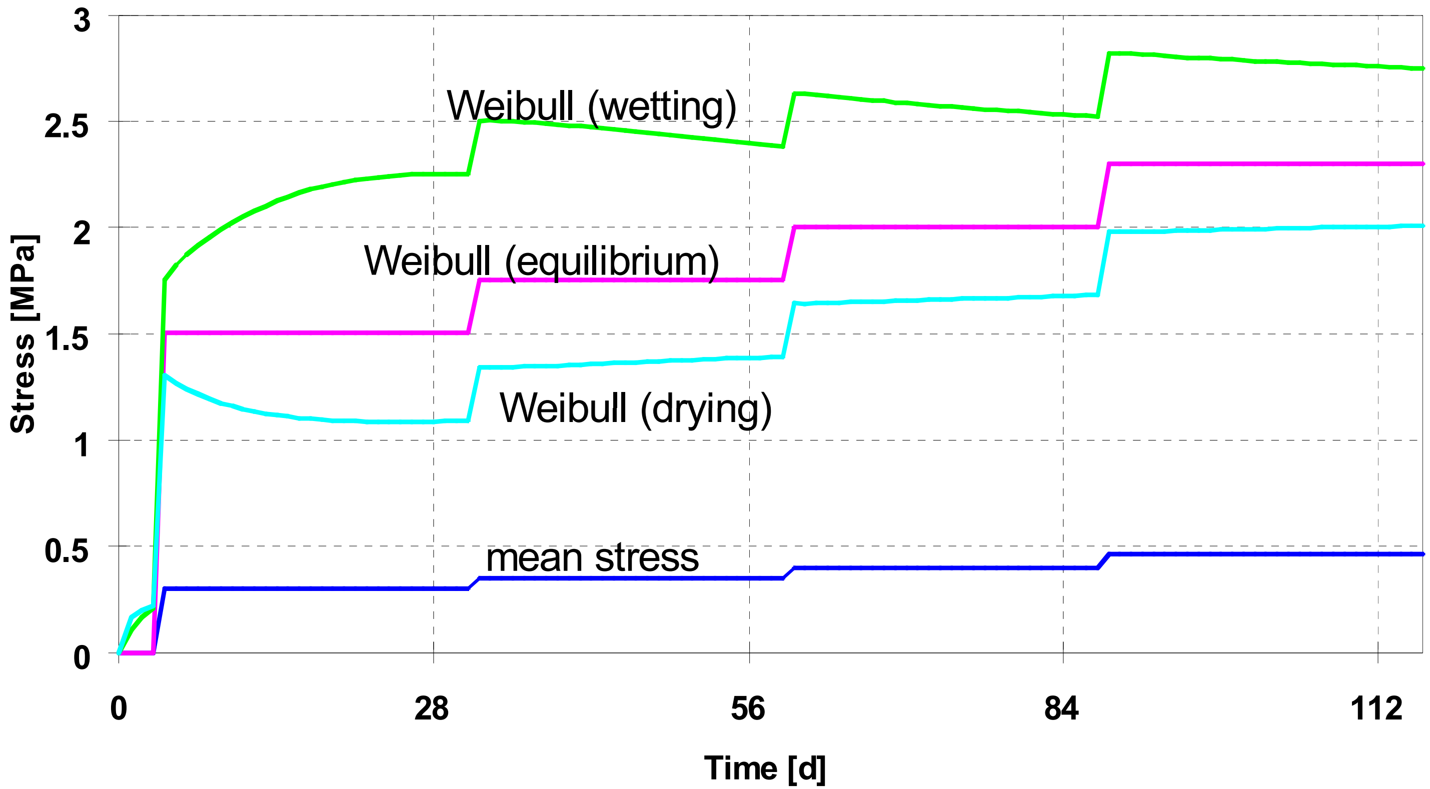


Figure 6.1 Calculated Weibull stresses in 140 mm wide test beams when pre-test conditioning moisture content is the same as during the test or 3% EMC lower or higher (Fig. 57, Gowda et al 1998)

Consideration of moisture gradients in structural design

- It is suggested that transient moisture conditions resulting in tensile stress perpendicular to grain should be considered as a load case instead of strength reducing factor
- The design equation for multiple loads is expressed in design codes in principle as follows:

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

Summary

- annual moisture cycling may cause cracking
- moisture cycling combined with other loads such as tension perp. or shear may cause collapse of structures
- high permanent load (shear, tension perp) is a risk because moisture gradients will occur simultaneously, soon or later