Cost Action E55 – Meeting in Zagreb

Working group 2 – Moisture induced stresses

Can moisture be considered as an action for the design of timber and composite structures?

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BACKGROUND:

- Eurocode 5 considers the influence of moisture on strength and deflection through the coefficients k_{mod} and k_{ser}, respectively

k_{ser} – deflection (SLS)

k_{mod} – strength (ULS)

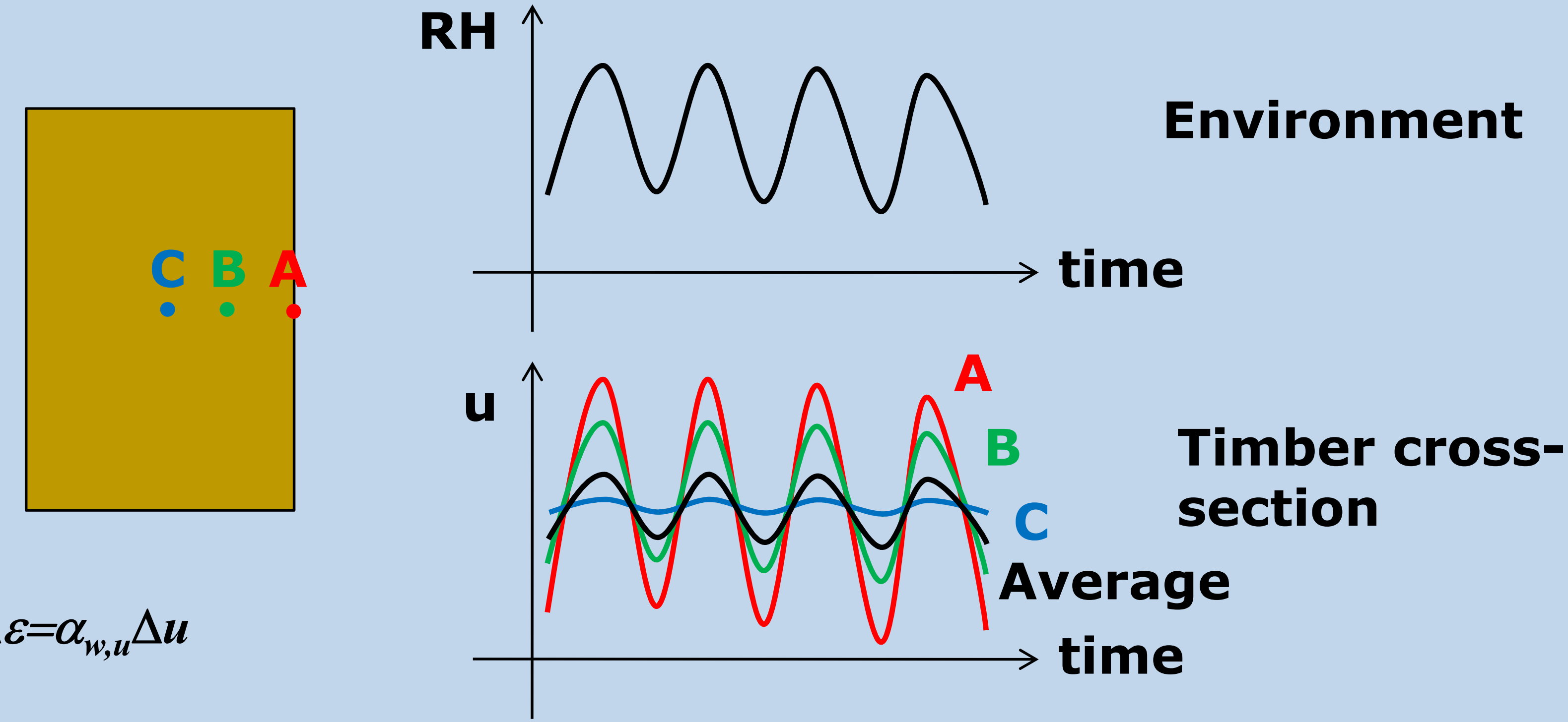
Load duration classes

k_{ser} – deflection (SLS)	k_{mod} – strength (ULS)
Creep	Creep rupture

Service classes

k_{ser} – deflection (SLS)	k_{mod} – strength (ULS)
Mechano-sorption	Mechano-sorption rupture
Increase in deflection for higher moisture u	Dependency of strength on moisture u

EFFECT OF MOISTURE:



$\Delta\varepsilon=\alpha_{w,u}\Delta u$

The different moisture content variations over the cross-section cause inelastic strains and, therefore, eigenstresses and deflections, both parallel and perpendicular to grain.

EFFECT OF MOISTURE || GRAIN:

Statically determinate structures:

- **Eigenstresses and deflections due to Δu negligible**

- **Moisture u and Δu increases deflection due to creep and mechano-sorption, *but only when an external load is applied*.**

- ***Moisture* u and Δu *cannot be considered only as a load for statically determinate structures parallel to the grain*: k_{ser} and k_{mod}, or an alternative approach, need to be used.**

EFFECT OF MOISTURE || GRAIN:

Statically indeterm. and composite structures:

- **k_{mod}, k_{ser} or an alternative approach to be used**
- **Eigenstresses and deflections due to Δu and any other inelastic strain (ΔT, concrete shrinkage ε_{cs}) no longer negligible**

- ***Moisture and temperature variations should be considered as additional loads* ΔU and ΔT:**

? ? ?

$$F_U = \gamma_G G + \gamma_Q Q + \gamma_s \varepsilon_{cs} + \gamma_U \Delta U + \gamma_T \Delta T \qquad \textbf{for ULS}$$

$$F_S = G + \psi_2 Q + \varepsilon_{cs} + \Delta U + \Delta T \qquad \textbf{for SLS}$$

(γ_s=1 in DIN Fachbericht 104 for steel-concrete composite beams)

LOAD EQUIVALENT TO MOISTURE AND TEMPERATURE:

A proposal for a new code of practice:

• select a number of yearly history RH=RH(t) for:

- different countries (e.g. Sweden, Germany, Italy)

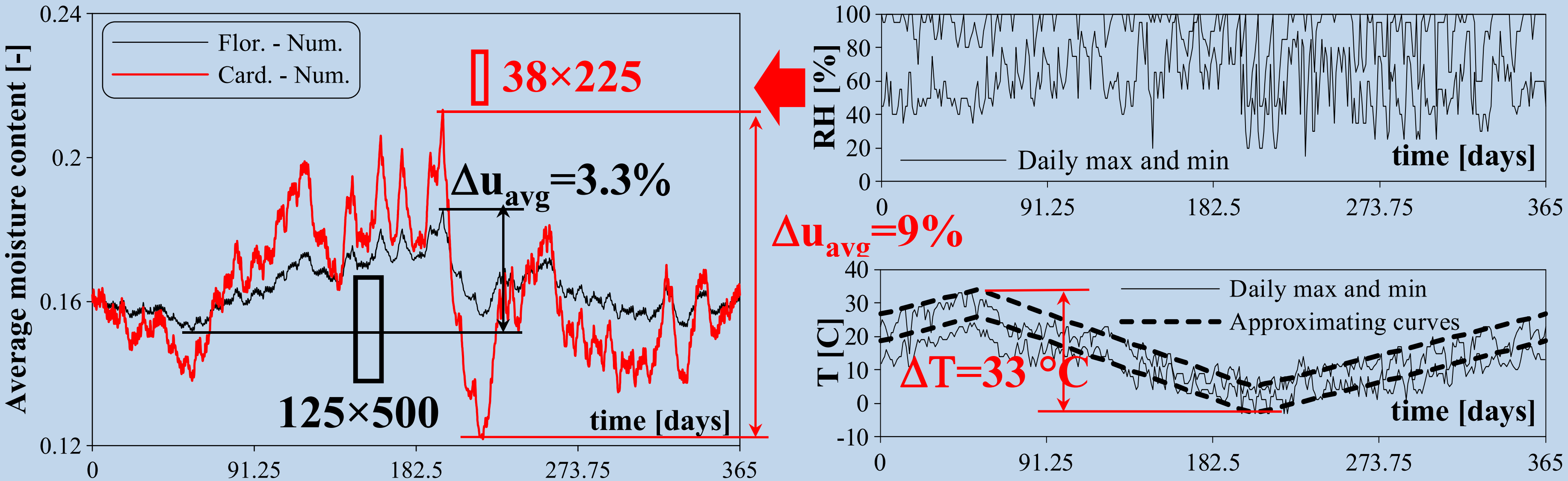
- different member exposure (outdoor unprotected by the rain, outdoor protected, indoor unheated, indoor heated)

• for all those cases, select a maximum yearly variation of temperature $\Delta T=T_{max}-T_{min}$

• select a number of cross-sections: e.g. large (160×230), medium (90×230) and small (38×225)

LOAD EQUIVALENT TO MOISTURE AND TEMPERATURE:

- **calculate the history of average moisture content $u_{avg}=u_{avg}(t)$ over the section and the max. yearly variation Δu_{avg}, by solving the diffusion problem:**



LOAD EQUIVALENT TO MOISTURE AND TEMPERATURE:

- the max yearly moisture Δu_{avg} and temperature variations ΔT could then be provided in tabular format for the different climate regions, exposure, and size of the cross-section

- question: how to calculate the moisture content variation for timber members in outdoor conditions exposed to the rain? In that case, diffusion of moisture and water penetration in the timber should be considered in some way.

LOAD EQUIVALENT TO MOISTURE AND TEMPERATURE:

- **a u.d.l. equivalent to moisture and temperature variations, p_{SLS}, can then be calculated for timber-concrete composite beams:**

$$p_{sls} = C_{p,sls} \cdot \Delta\varepsilon \qquad C_{p,SLS} = \pi^2 \cdot \frac{E_1 \cdot A_1 \cdot E_2 \cdot A_2 \cdot z \cdot \gamma_1}{\left(E_1 \cdot A_1 + E_2 \cdot A_2\right) \cdot L^2}$$

$$\Delta\varepsilon = \Delta\varepsilon_{timber} - \Delta\varepsilon_{concrete}$$

$$\Delta\varepsilon_{timber} = \alpha_{w,u} \Delta u_{avg} + \alpha_{w,T} \Delta T \qquad \Delta\varepsilon_{concrete} = \alpha_{c,T} \Delta T + \varepsilon_{c,s}$$

ANALYTICAL-NUMERICAL COMPARISON:

Dead load

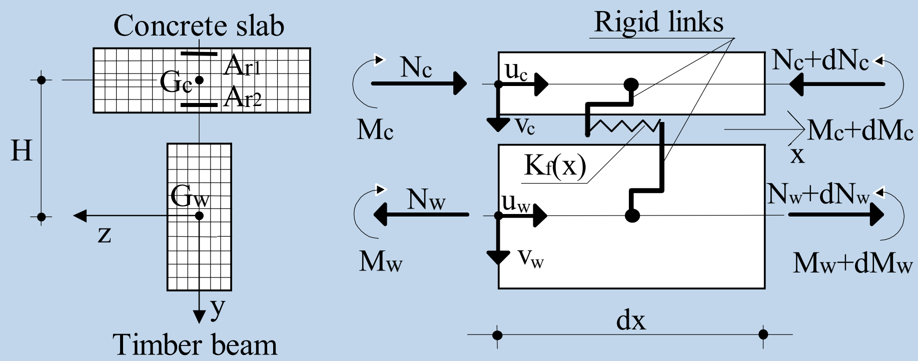
Current approach: $$S = \boxed{S(g_1) + S(g_2)} + \boxed{S(\psi_2 q)}$$ Live load

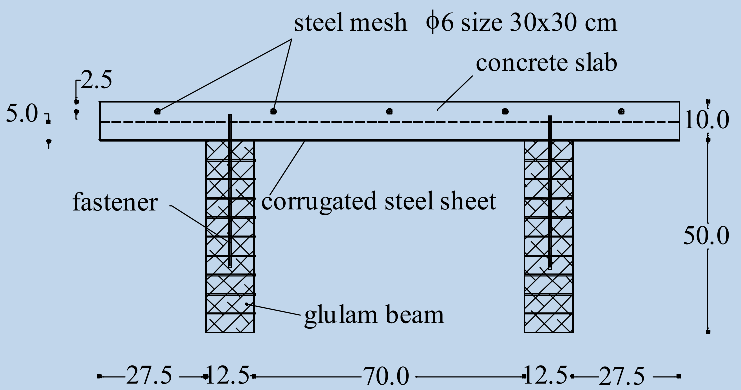
Concrete shrinkage

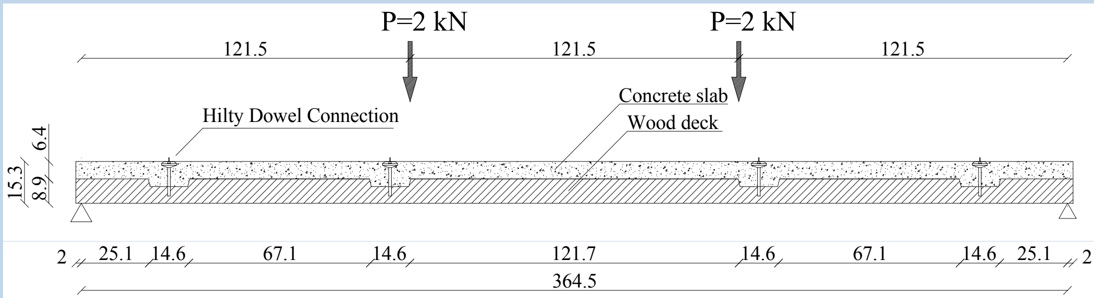
Environmental loading

New proposal: $$S = S(g_1) + S(g_2) + S(\psi_2 q) + \boxed{S(\varepsilon_{cs})} + \boxed{S(\Delta\varepsilon_y) + S(\Delta\varepsilon_d)}$$

FE model (rigorous solution):





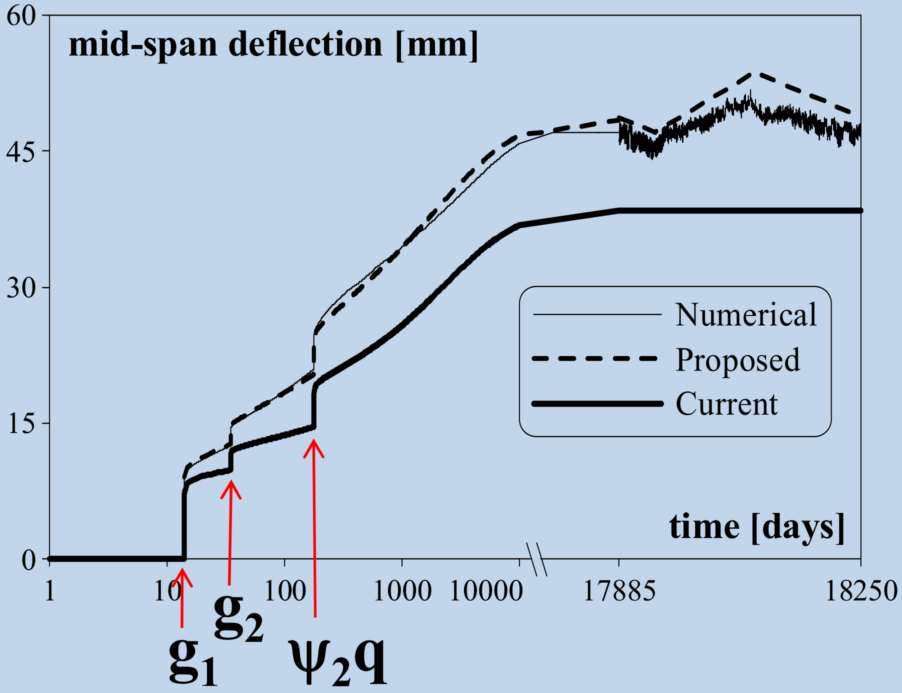


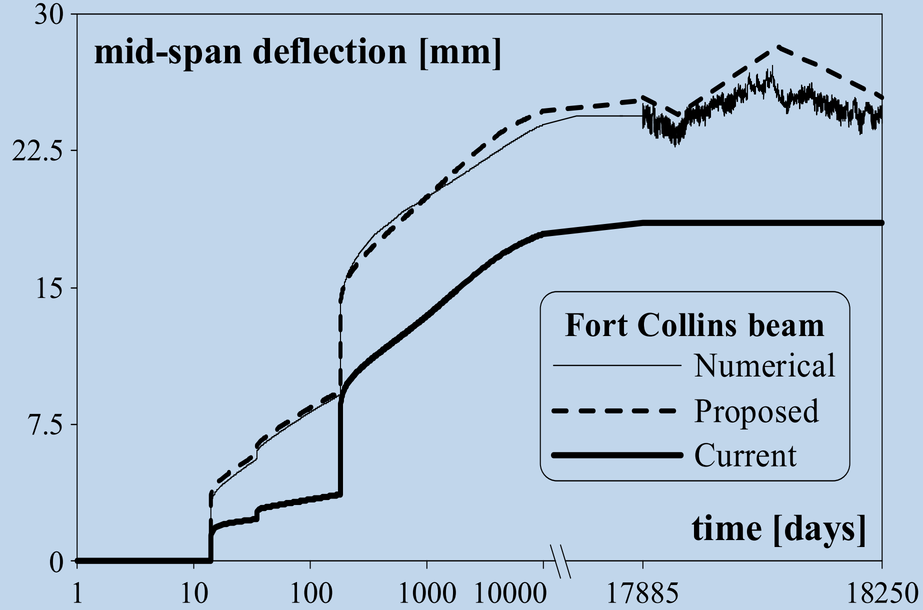
Florence beam, L=10 m

Fort Collins floor/deck system, L=3.6 m

ANALYTICAL-NUMERICAL COMPARISON:

All beams are propped until t_s=14 days





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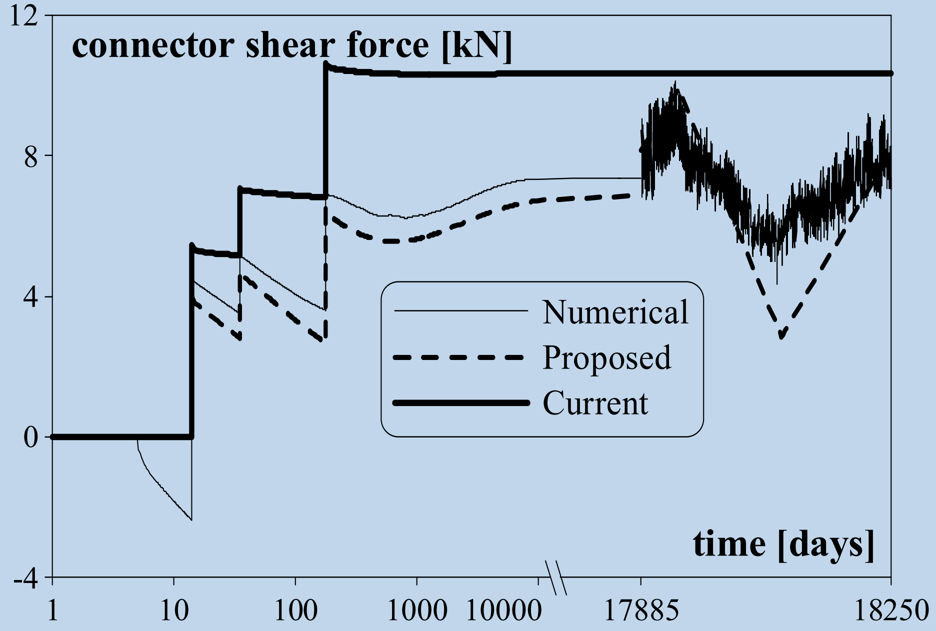
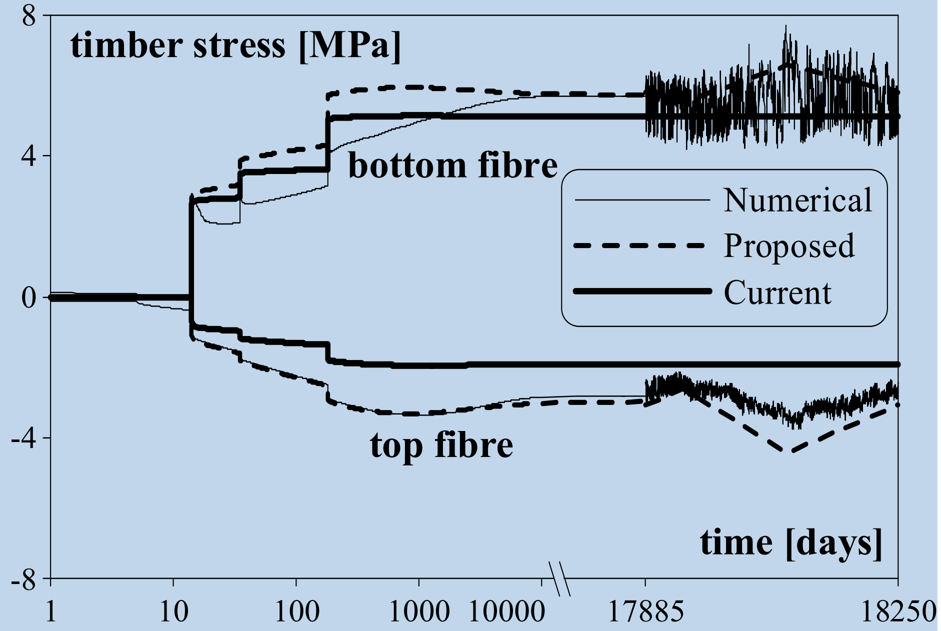




Florence beam, L=10 m

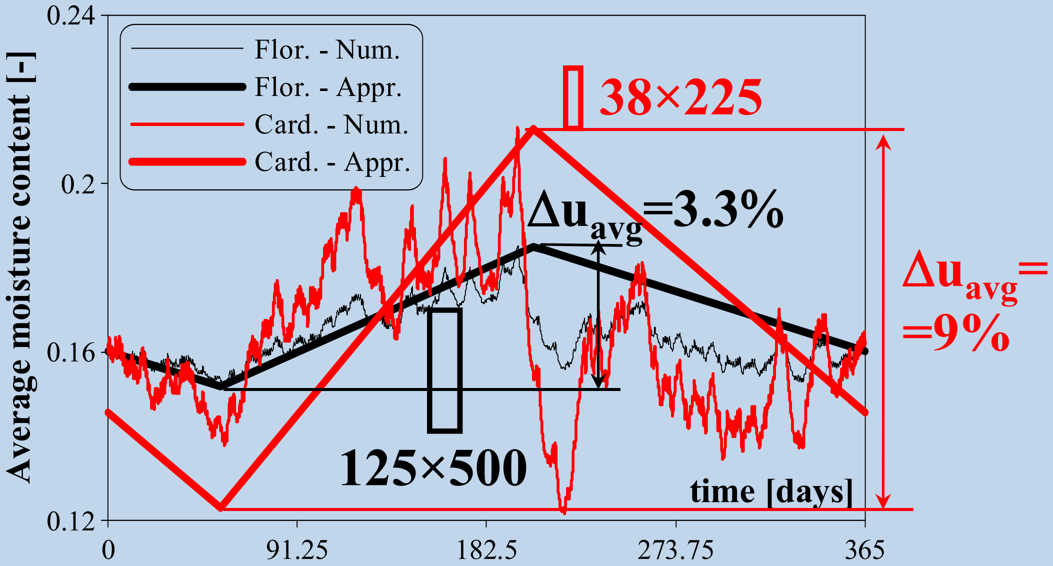
Florence beam, L=10 m

EFFECT OF MOISTURE ON MATERIAL PROPERTIES:

A proposal to explicitly take into account the influence of moisture on the material properties is described herein after, as a more accurate alternative to the use of k_{ser} and k_{mod} factors

The actual history of average moisture content computed by solving the diffusion process for the type of environment, exposure and cross-section is approximated by a piecewise-linear:

EFFECT OF MOISTURE ON MATERIAL PROPERTIES:



A rheological model is selected for the creep coefficient: e.g. if the Toratti's model is used:

$$\varepsilon(t)=\int_{t_0}^{t} J_0(u(\tau))\,d\sigma(\tau)+\int_{t_0}^{t} J_c(t-\tau)\,d\sigma(\tau)+\cancel{\int_{t_0}^{t} \sigma(\tau)\,dJ_0(u(\tau))}+$$

$$+J^{\infty}\int_{t_0}^{t}\left\{1-e^{\left[-c\int_{\tau}^{t}\left|du(\tau_1)\right|\right]}\right\}d\sigma(\tau)-\cancel{\int_{t_0}^{t} b\varepsilon(\tau)\,du(\tau)}+\cancel{\int_{t_0}^{t} \alpha_u\,du(\tau)}+\cancel{\int_{t_0}^{t} \alpha_T\,dT(\tau)}$$

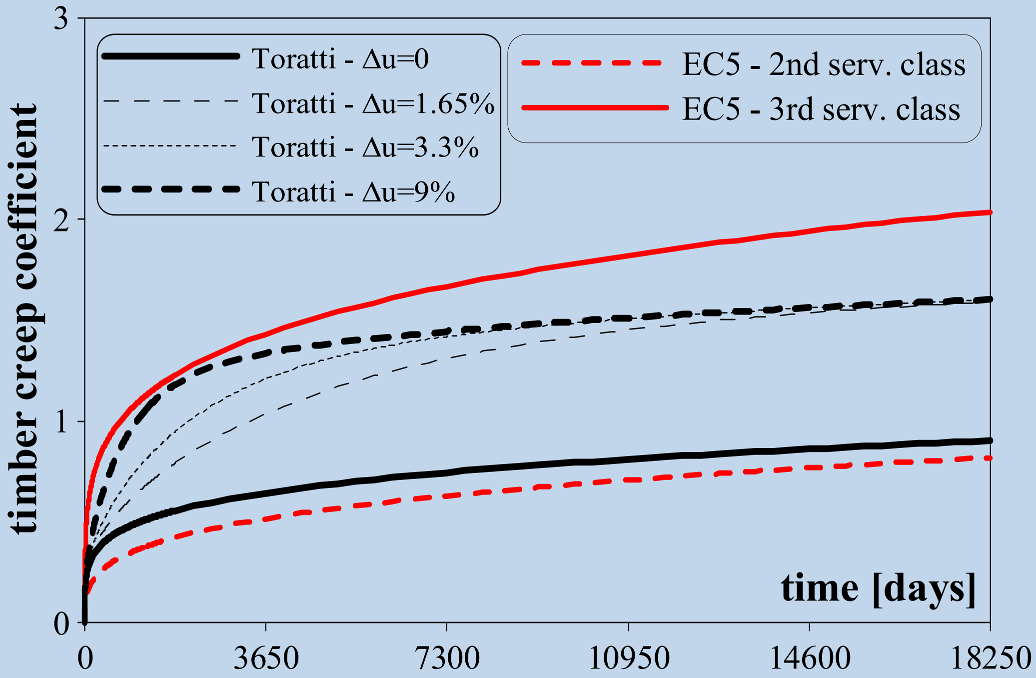
"pure creep" **"mechano-sorption"**

$$\phi_t(t)=\phi_{tc}+\phi_{tms}=\underbrace{\left(\frac{t}{t_d}\right)^{m}}_{\text{pure creep}}+\underbrace{\phi^{\infty}\left[1-e^{-c\frac{2\Delta u}{100\Delta t}t}\right]}_{\text{mechano-sorption}}$$

EFFECT OF MOISTURE ON MATERIAL PROPERTIES:

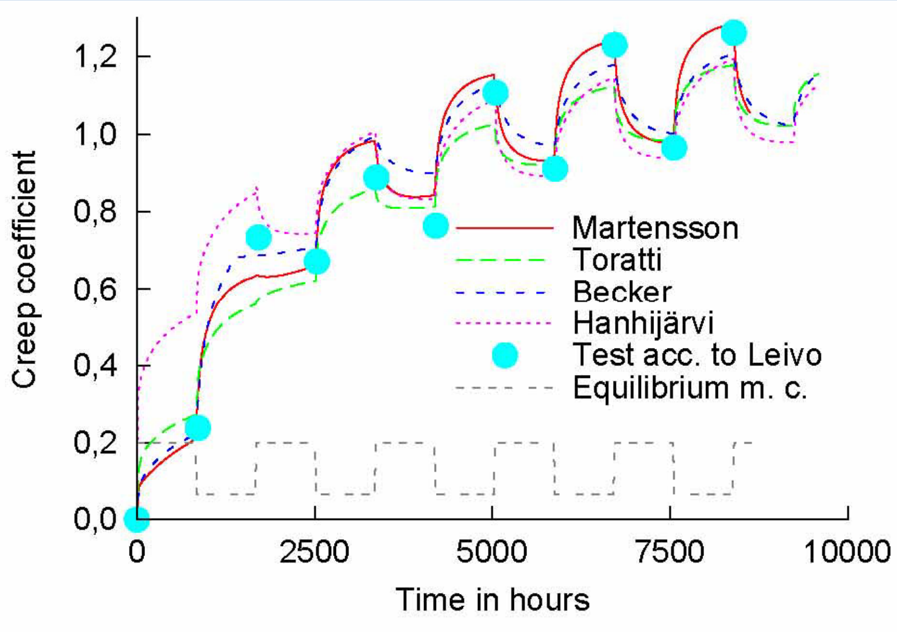
The total creep coefficient $\phi_t(t)$ can be used instead of k_{def}. In addition, tabular values of $\phi_t(t_\infty)$ could be provided in the code of practice.

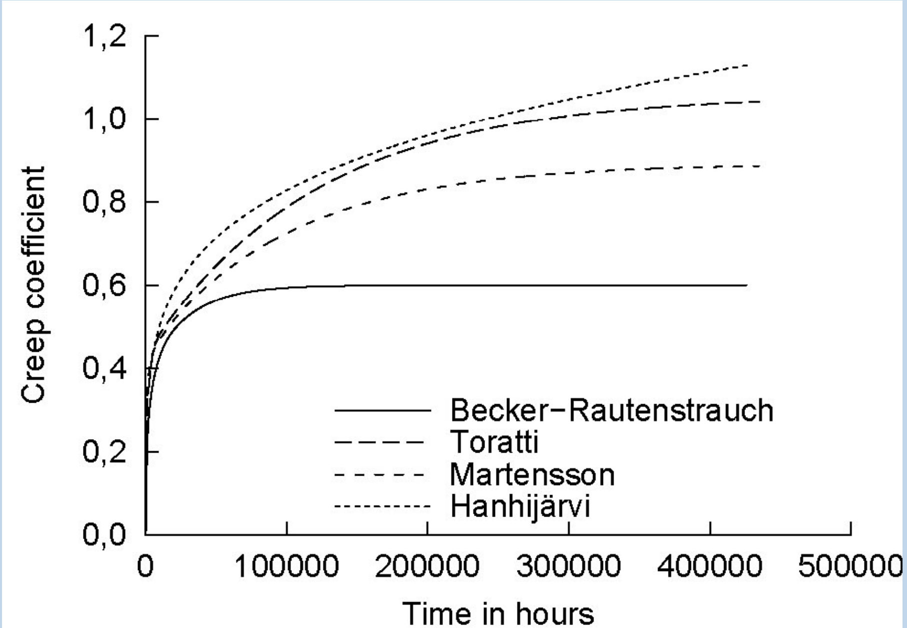
The proposal is based on approximating the different histories of moisture content over the cross-section with the average history of moisture



EFFECT OF MOISTURE ON MATERIAL PROPERTIES:

Which rheological model to choose among the many proposed?

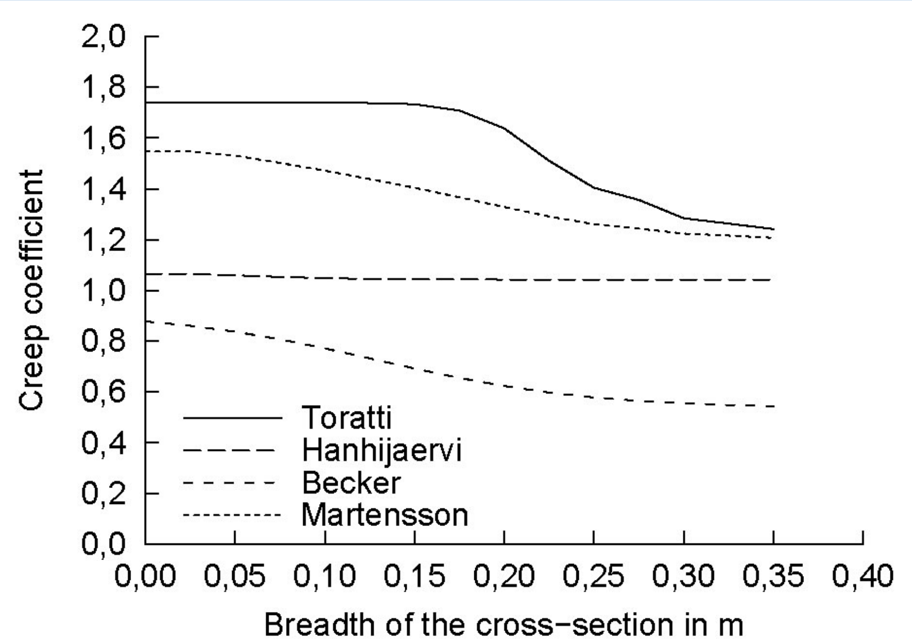


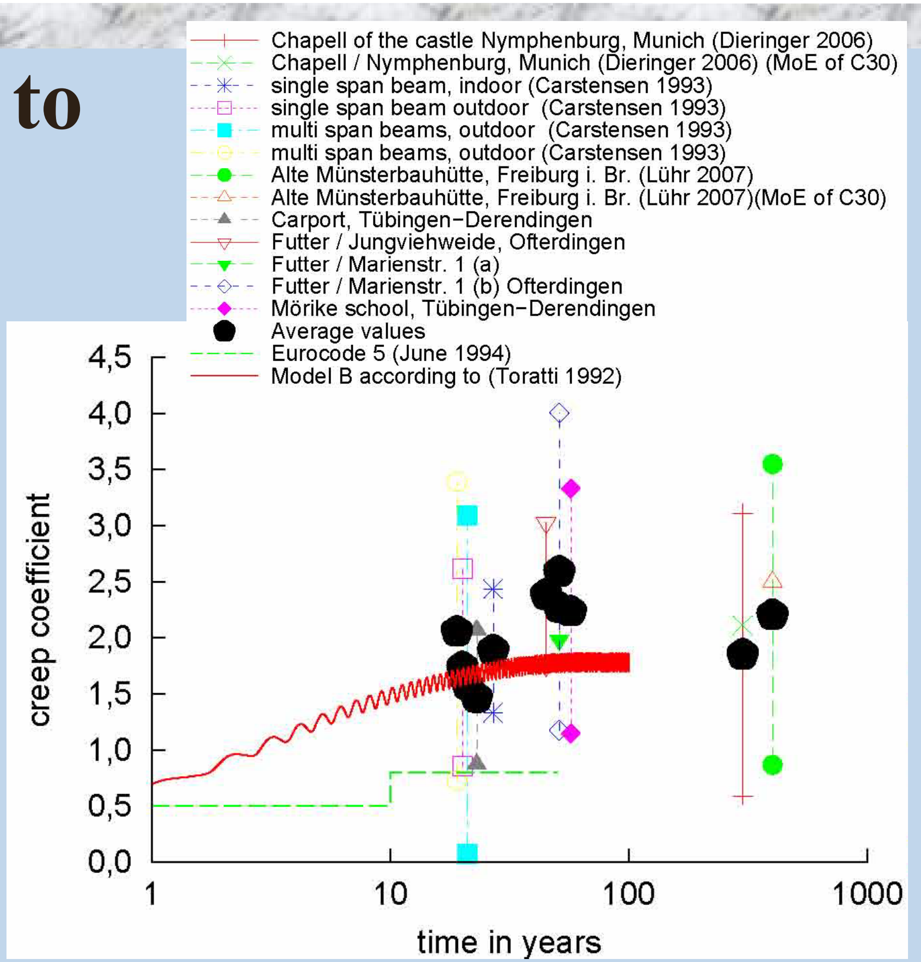


Constant relative humidity

EFFECT OF MOISTURE ON MATERIAL PROPERTIES:

Which rheological model to choose?





Variable relative humidity (RH_{avg}= 65%, annual ΔRH=15%)

EFFECT OF MOISTURE ON MATERIAL PROPERTIES:

The first comparisons with deflections of real structures in Tübingen, South Germany, suggests that the best approximation can be achieved using the Toratti's B model.

The Toratti's B model could be recalibrated in order to obtain the best fit with the real deflections:

element	1	2	3	4	5	6
τ_i	0,01	0,1	1	10	193,23	11079,51
J_i	0,0686	-0,0056	0,0716	0,0409	0,2201	1,8052

However, more comparisons should be performed!

EFFECT OF MOISTURE ON MATERIAL PROPERTIES:

A rheological model for creep and mechano-sorption rupture should also be provided in order to explicitly calculate the strength reduction coefficient k_{mod}':

$$k_{\mathrm{mod}}' = \frac{f\left(t, u, \sum \Delta u\right)}{f_0} \qquad k_{\mathrm{mod}}' = k_1(u)\left[1 - k_1(t) - k_2\left(\sum \Delta u\right)\right]$$

In addition, the code of practice could provide some tabular values of k_{mod}' for different climatic regions, exposure, and size of the timber cross-section.

INFLUENCE OF ENVIRONMENTAL COND.:

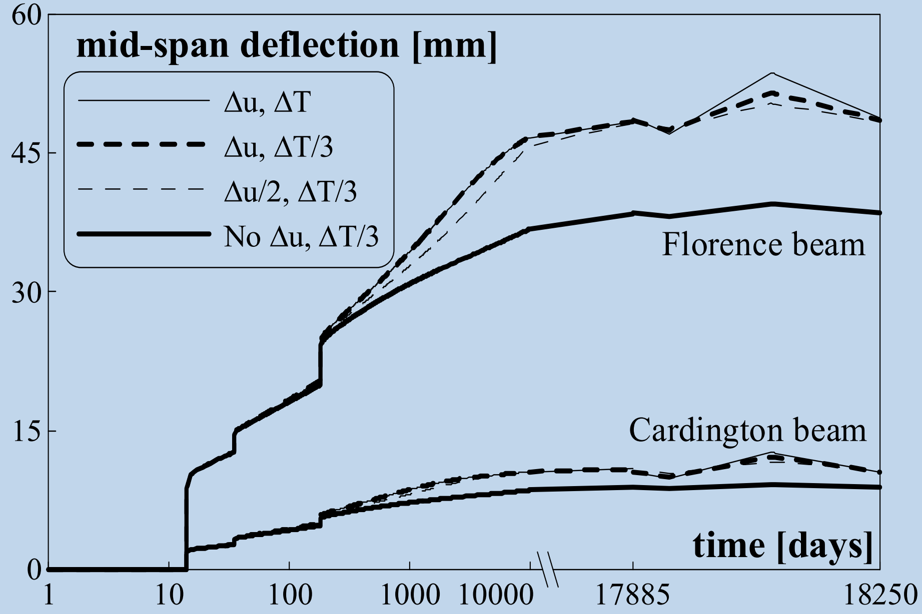
Florence beam 125×500 mm Cardington beam 38×225 mm

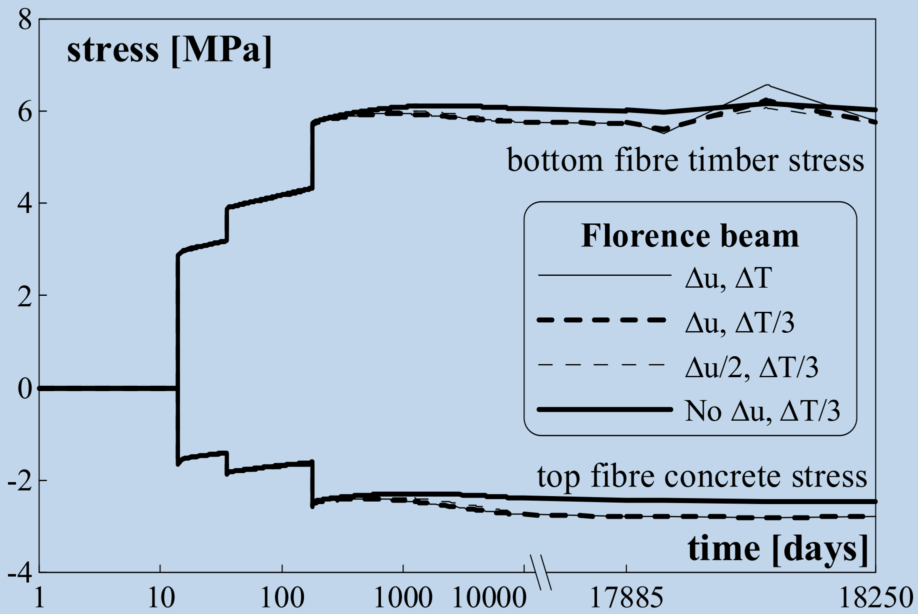
Outdoor, protected conditions: ΔT, Δu (3.3% - 9%)

Heated indoor conditions: ΔT/3, Δu or ΔT/3, Δu/2

Limit case: ΔT/3, Δu=0 (no mechano-sorption)

Häglund and Thelandersson 2005 Limträhandbook 2001





CONCLUSIONS:

Can moisture content be considered as an action?

- **Yes, moisture content and temperature variations should be considered as an action for the design parallel to the grain of statically indeterminate and timber-concrete composite beam (they cause eigenstresses and deflection)**
- **However this equivalent load cannot replace the dependency of the deflection and strength on the moisture due to the creep and mechano-sorption (k_{def} and k_{mod} coefficients)**

CONCLUSIONS:

- A procedure for the evaluation of the load equivalent to moisture has been proposed. The procedure can be implemented in codes of practice.
- A more accurate procedure for the evaluation of the coefficients k_{def} and k_{mod} has been proposed. Some investigations are still needed in order to choose the best rheological model.

COMMENTS, PLEASE

Thank you!