Creep of timber parallel to grain

J. Schänzlin* / M. Fragiacomo**

*Institute of Structural Design
University of Stuttgart
**University of Sassari

Trondheim, COST E55 WG 2

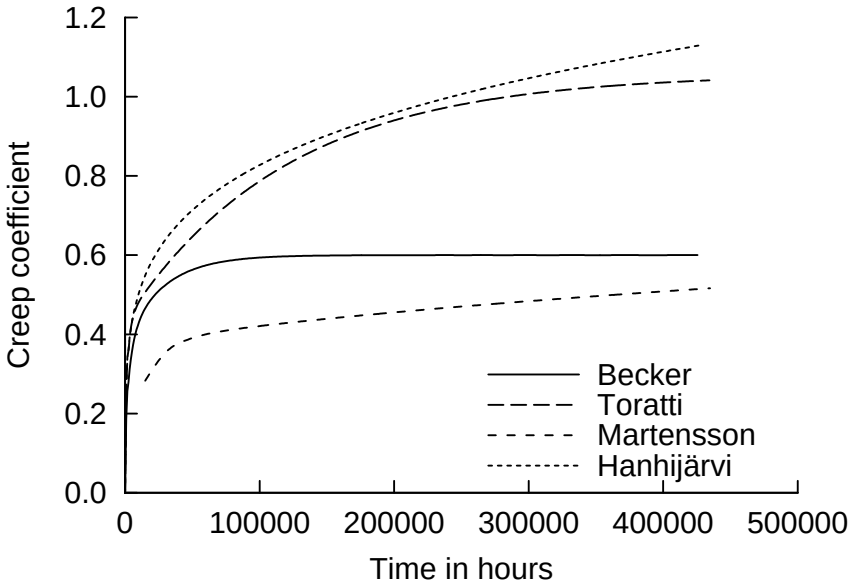
Motivation: Creep coefficients

- Creep dependent on
  - time ($\rightarrow$ "normal creep")
  - moisture variations ($\rightarrow$ "mechano-sorptive creep")
- Influence of creep in the ULS, e.g.
  - load capacity of columns,
  - composite systems, e.g. timber-concrete-composite
  - user modification in order to re-ensure serviceability

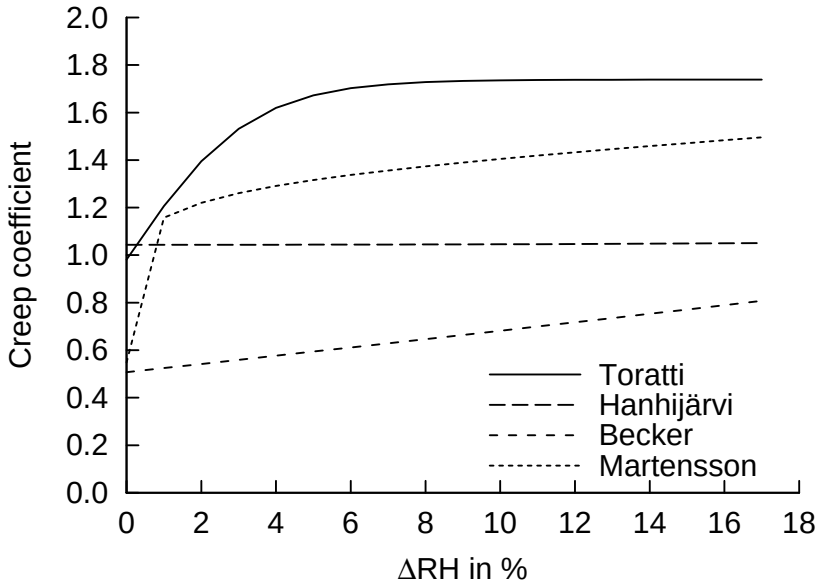
Motivation: Creep coefficients

- Creep dependent on
  - time ($\longrightarrow$ "normal creep")
  - moisture variations ($\longrightarrow$ "mechano-sorptive creep")
- Influence of creep in the ULS
- consideration in the design by creep coefficients
  - large variability of values given in the standards
  - more detailed prediction by use of rheological models taken from literature
    - Toratti [51]
    - Hanhijärvi [22]
    - Becker [2]
    - Mårtensson [38]

Comparison of the evaluated creep coefficients



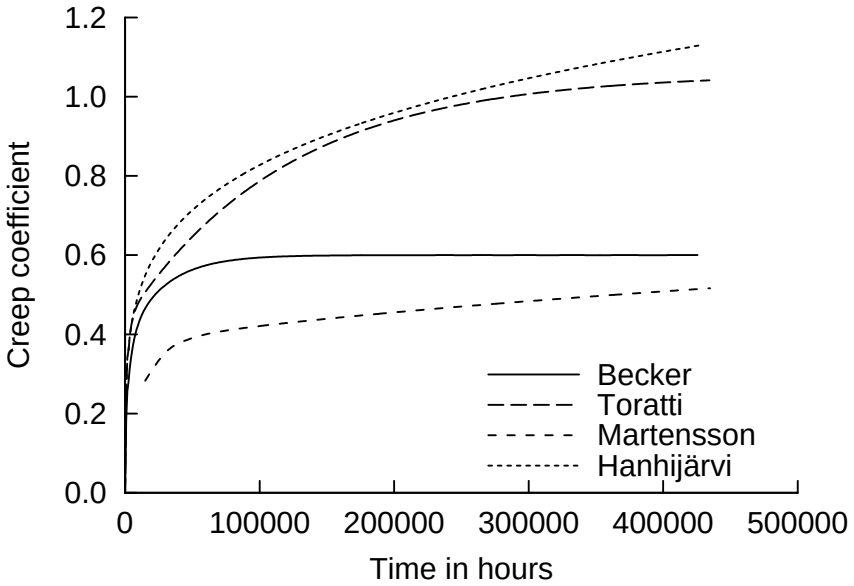
(a) Constant relative humidity & temperature



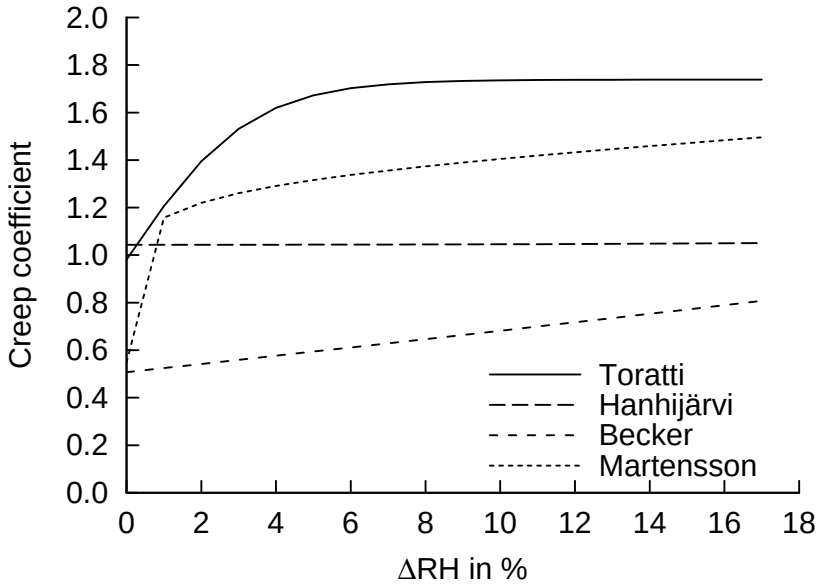
(b) Variable climate: influence of the amplitude of the relative humidity (RH= 65%); t=50 years

Figure: Comparison of the evaluated creep coefficients

Comparison of the evaluated creep coefficients



(a) Constant relative humidity & temperature

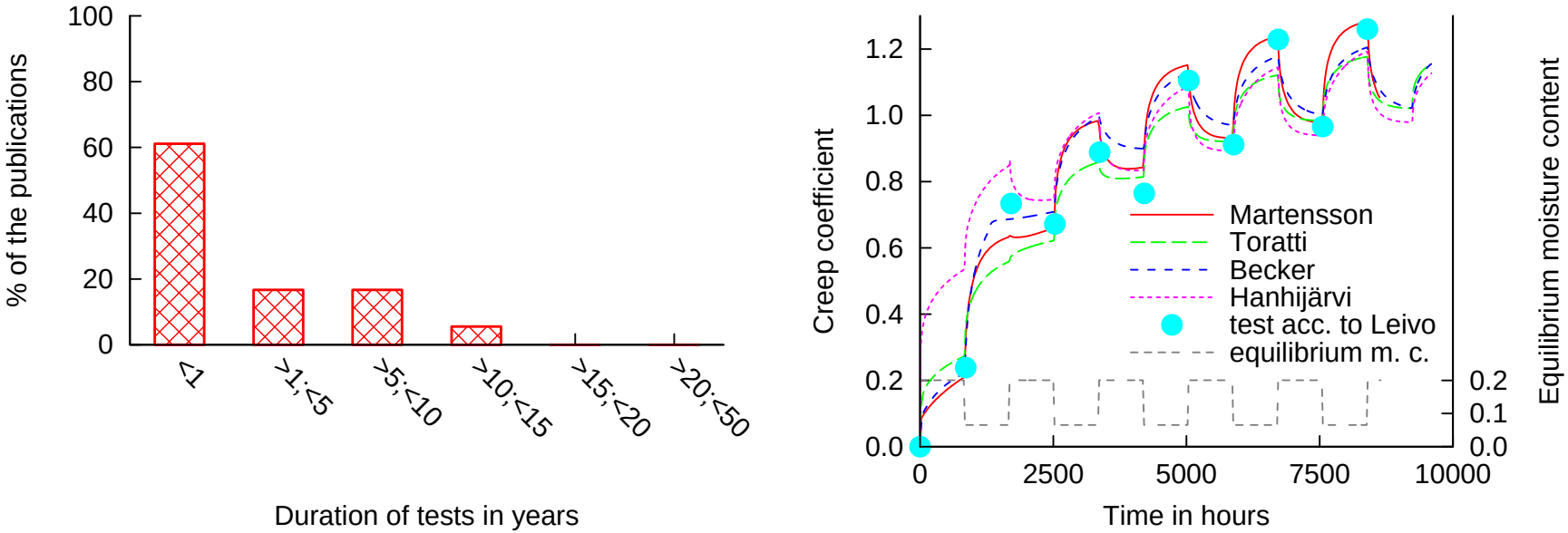


(b) Variable climate: influence of the amplitude of the relative humidity (RH= 65%); t=50 years

Figure: Comparison of the evaluated creep coefficients

$\longrightarrow$ quantitative as well as qualitative differences

One possible reason for the differences

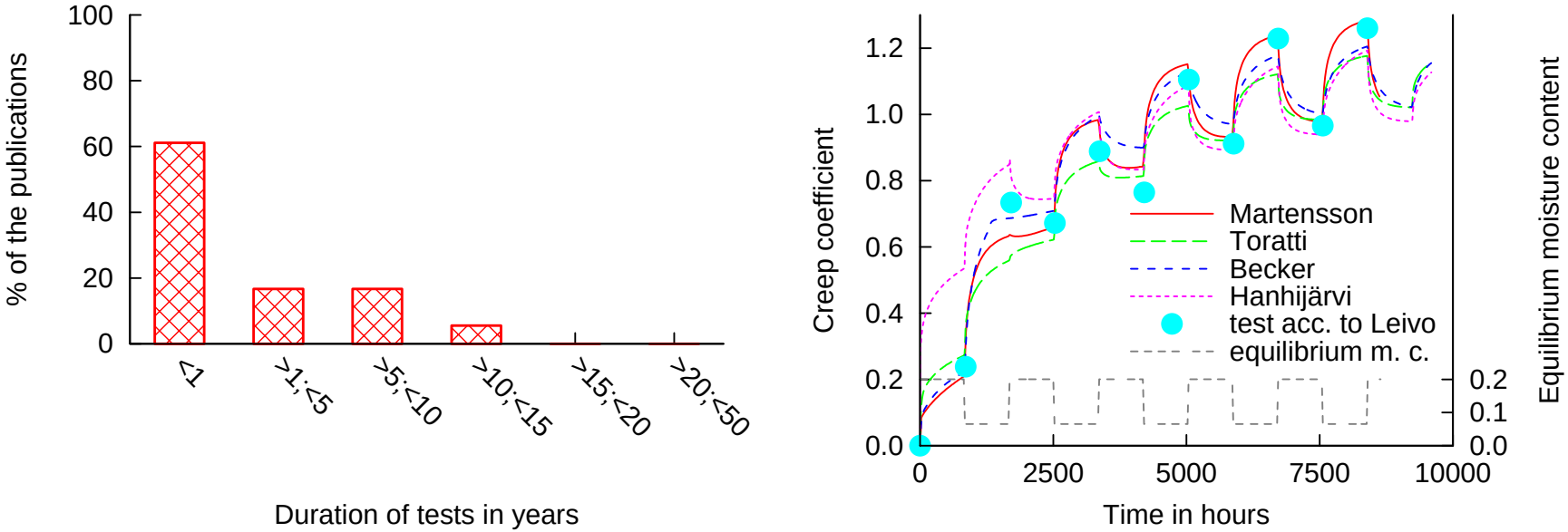


(a) Duration of test in dependence of the numbers of publication (extracted from the data given in Becker [2])

(b) Comparison of the models to the test by Leivo [35]

Figure:

One possible reason for the differences



(a) Duration of test in dependence of the numbers of publication (extracted from the data given in Becker [2])

(b) Comparison of the models to the test by Leivo [35]

Figure:

→ Models valid in the validated period of time

→ Which models should be used for the prediction of 50 years?

→ Required duration of tests = 50 years

Modified model

- Existing roof structures $\longrightarrow$ effective creep coefficient
  - measurement of the existing deflection
  - loading of the elements for the determination of the integral stiffness of the beam
  - evaluation of the elastic deflection using the dead load and the integral stiffness

$$\varphi = \frac{w_{measured} - w_{elastic,evaluated}(EJ_{loading})}{w_{elastic,evaluated}(EJ_{loading})}$$

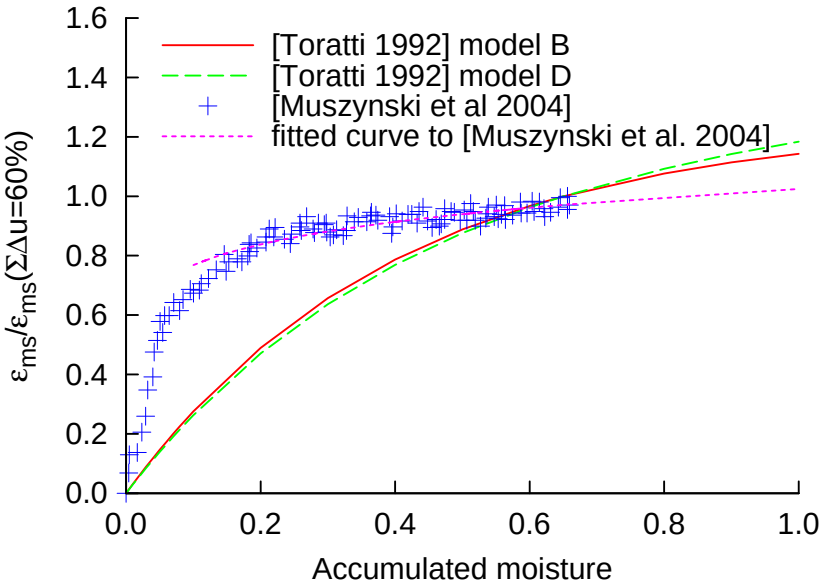
Modified model

- Existing roof structures $\longrightarrow$ effective creep coefficient
- Difference between measurement and evaluation with the models

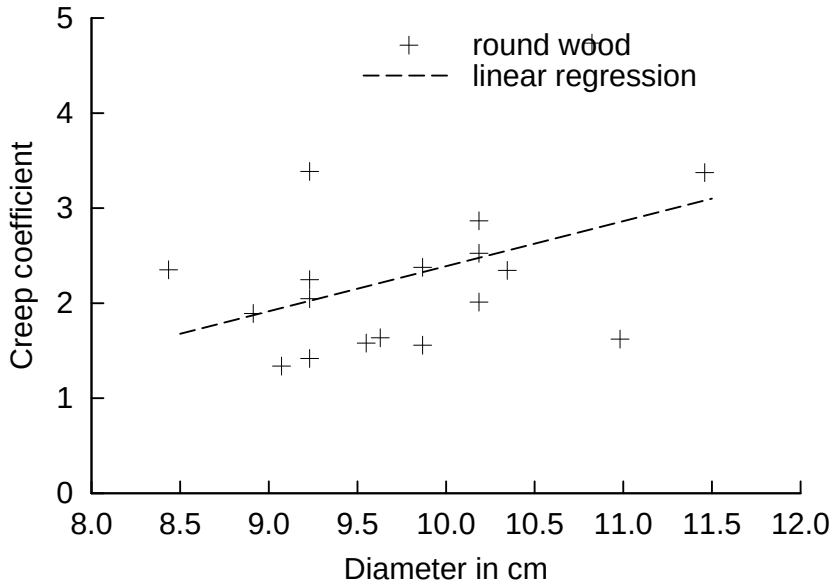
	average creep coefficient
measurements	2.3
evaluation by models	$\approx 0.8 - \approx \underbrace{1.8}_{\text{Toratti [51]}}$

Modified model

- Existing roof structures $\longrightarrow$ effective creep coefficient
- Difference between measurement and evaluation with the models
- Assumption: Differences caused by normal creep since
  - Mechano-sorptive creep limit of tests data according to Muszynski et al. [42]
    Creep limit comparable to ms-creep of the model B according to Toratti [51]
  - No decrease of the creep coefficient with increasing diameter



mechano-sorptive creep limit (?)

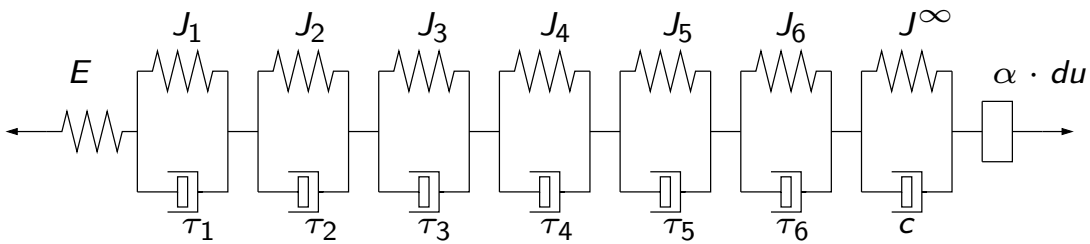


influence of the diameter

Modified model

- Existing roof structures $\longrightarrow$ effective creep coefficient
- Difference between measurement and evaluation with the models
- Assumption: Differences caused by normal creep since
  - Mechano-sorptive creep limit of tests data according to Muszynski et al. [42]
    Creep limit comparable to ms-creep of the model B according to Toratti [51]
  - No decrease of the creep coefficient with increasing diameter

$\longrightarrow$ Modification of the normal creep



Original values						
element	1	2	3	4	5	6
τ_i	0.01	0.1	1	10	100	5000
J_i	0.0686	-0.0056	0.0716	0.0404	0.2073	0.5503

Modified values						
element	1	2	3	4	5	6
τ_i	0.01	0.1	1	10	193.23	11078.51
J_i	0.0686	-0.0056	0.0716	0.0409	0.2201	1.8052

Modified model

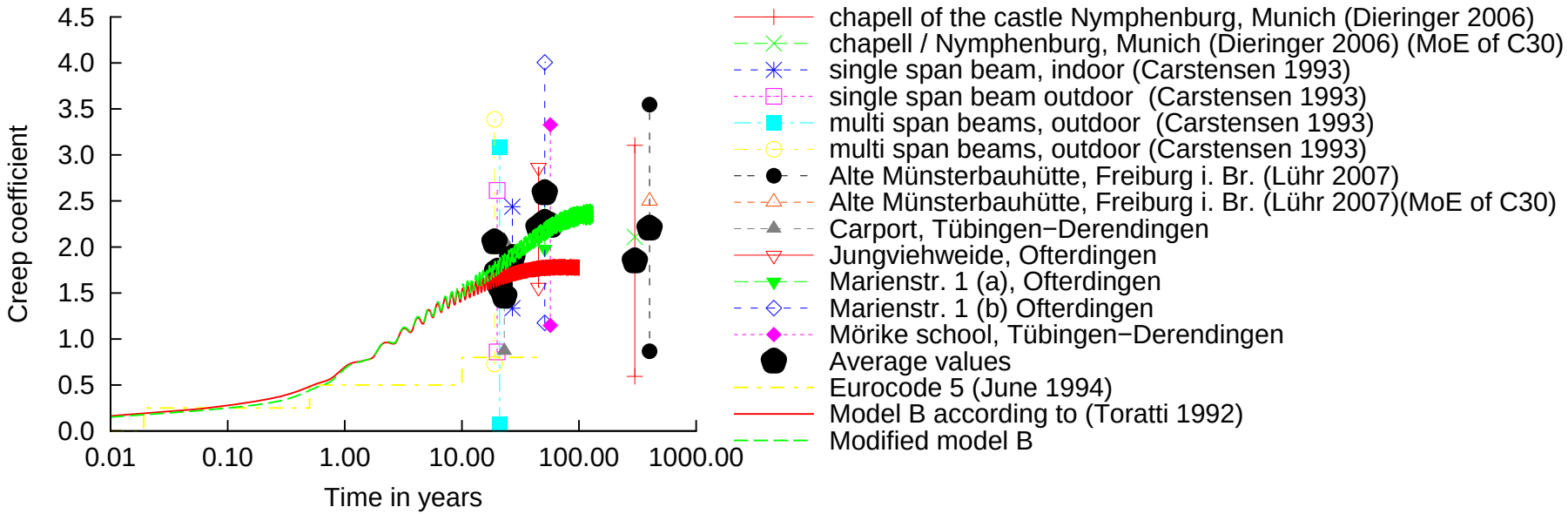


Figure: Comparison of the modified model B according to Toratti [51] to the measured creep coefficients

Modified model

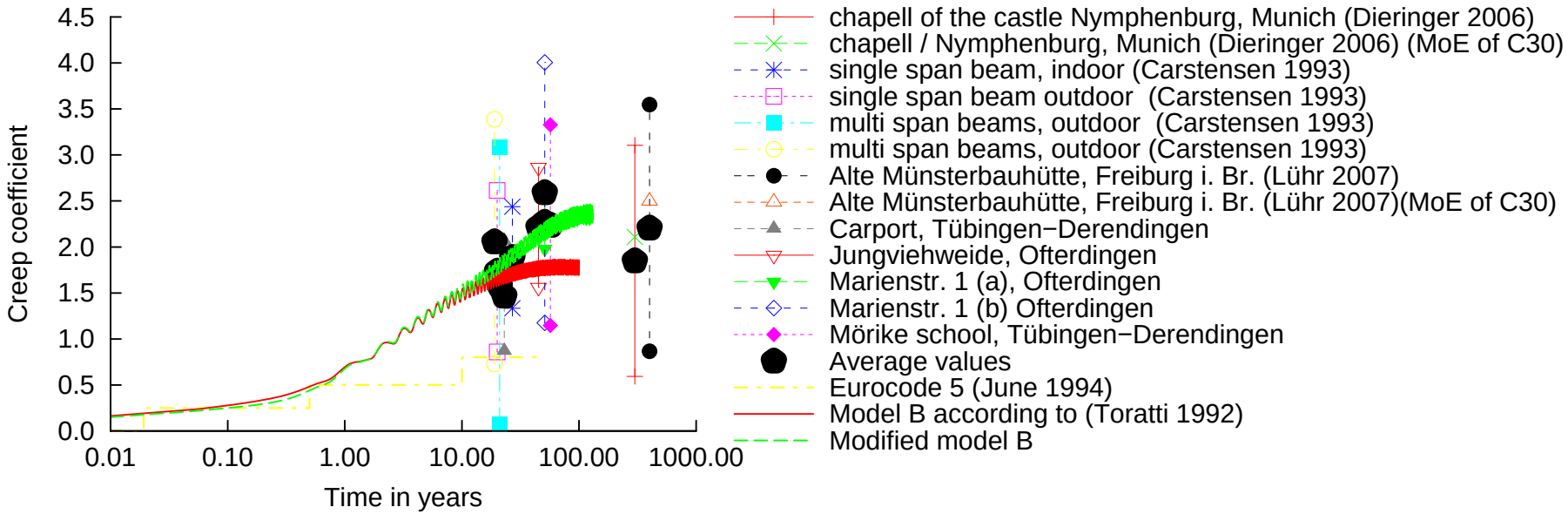
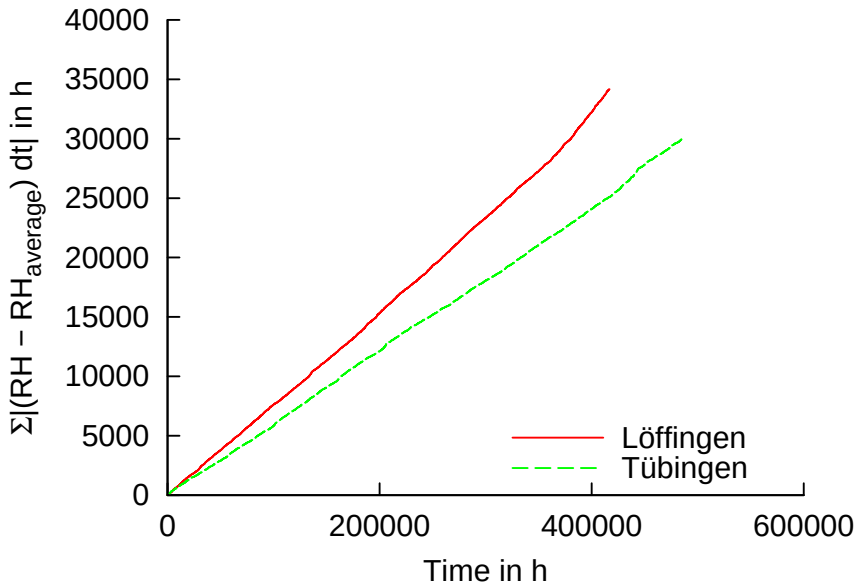


Figure: Comparison of the modified model B according to Toratti [51] to the measured creep coefficients

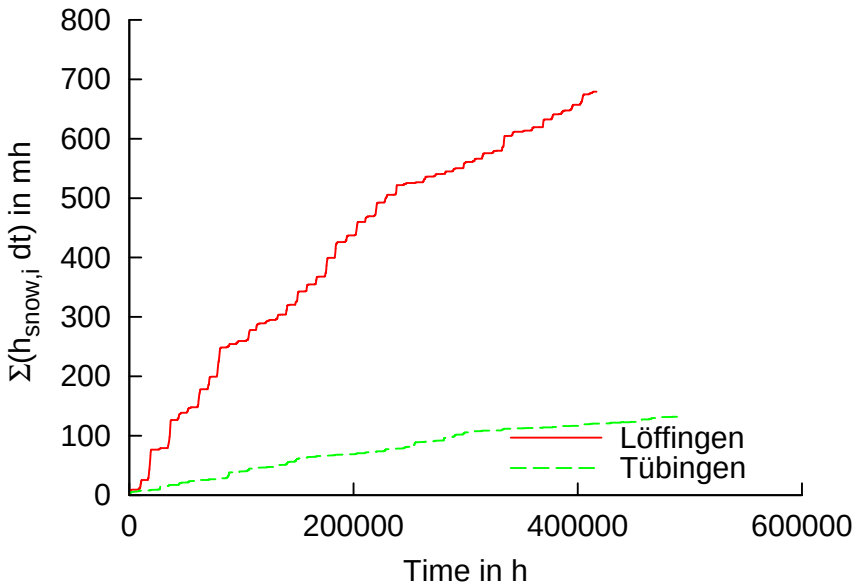
- acceptable differences between modified model and measurements
- hardly differences between the model B and modified model B within the first 10 years
  → validation of model B for t< 10 years transferable to modified model
- additional verification to measurements in the region of Löffingen, Breisgau-Hochschwarzwald, Baden-Württemberg
  altitude above sea level ≈ 800 m

Climate

- modified model B applicable if climate is comparable to the climate in the regions of Tübingen and Breisgau-Hochschwarzwald.



(a) Accumulated relative humidity

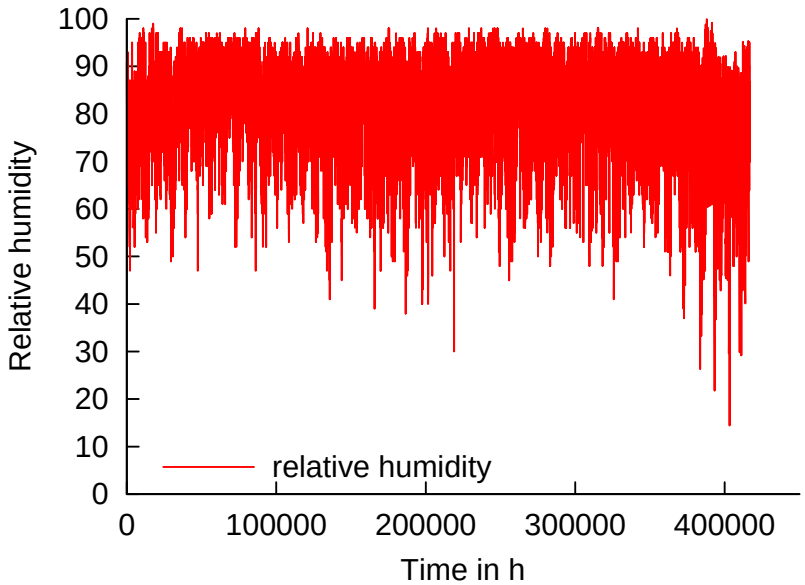


(b) Accumulated snow height

Figure: Accumulated relative humidity and accumulated snow height in the region of Tübingen and Breisgau-Hochschwarzwald

Open questions, part I

- How to define a comparable climate?
- How to approximate the surrounding conditions?



- daily fluctuation or annual fluctuation
- $\longrightarrow$ set of Fourier-series?

Open questions, part I

- How to define a comparable climate?
- How to approximate the surrounding conditions?
- Limits of application of the modified model?

	Test by Mohager [39]	Measurements	Tests by Hoyle et al. [28]
Accu. moisture	≈ 20	$>> 20$	0.5
duration	1200 days	$\approx$ 18250 days	1000 days
nominal stress	$10 N/mm^2$	$\approx$ 1-2 N/mm^2	$13.2 N/mm^2$
creep coefficient	≈ 3	≈ 2.3	≈ 0.7

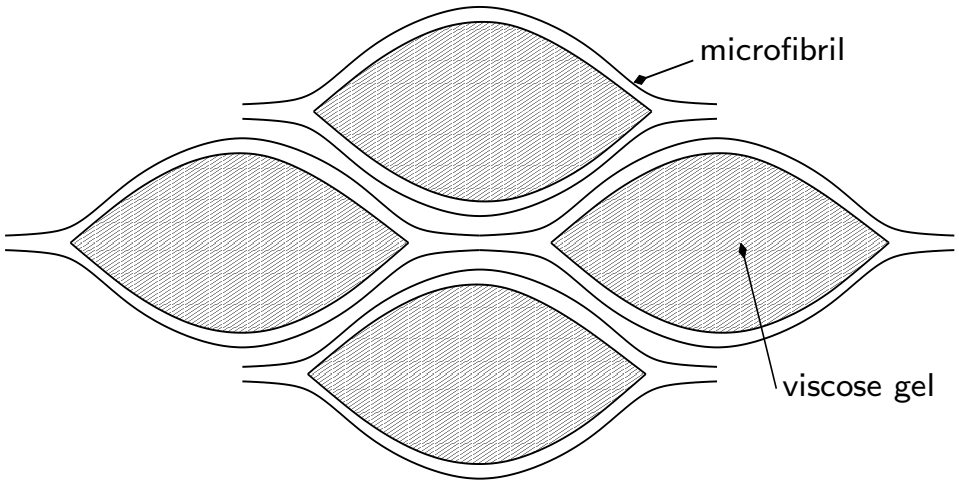
  - lower duration, lower moisture accumulation but higher stress level $\rightarrow$ higher creep coefficient (?)
  - no general tendency

$\Rightarrow$ How to improve the modified model B?

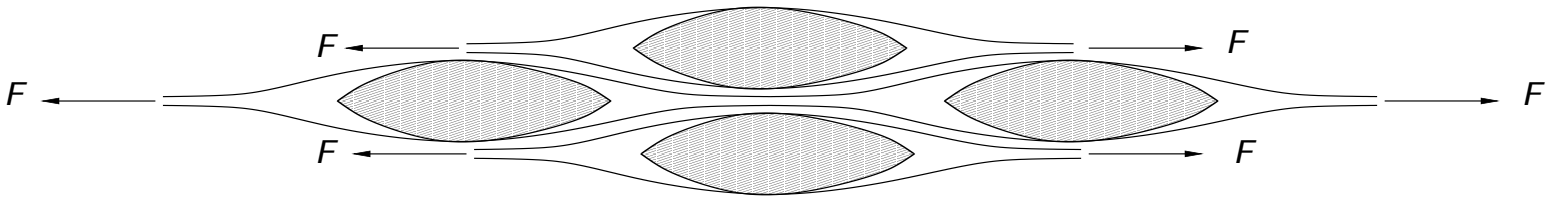
Proposal: Development of yet another rheological model (YaRM)

Hypothesis: Boyd [4]'s explanatory model for creep and mechano-sorptive creep is valid and modified respectively.

- cell-wall: microfibrils & interlayered gel
- shrinkage/swelling only of the interlayered gel
- creep of microfibril and gel
- only consideration of layer S_2 of the cell-wall

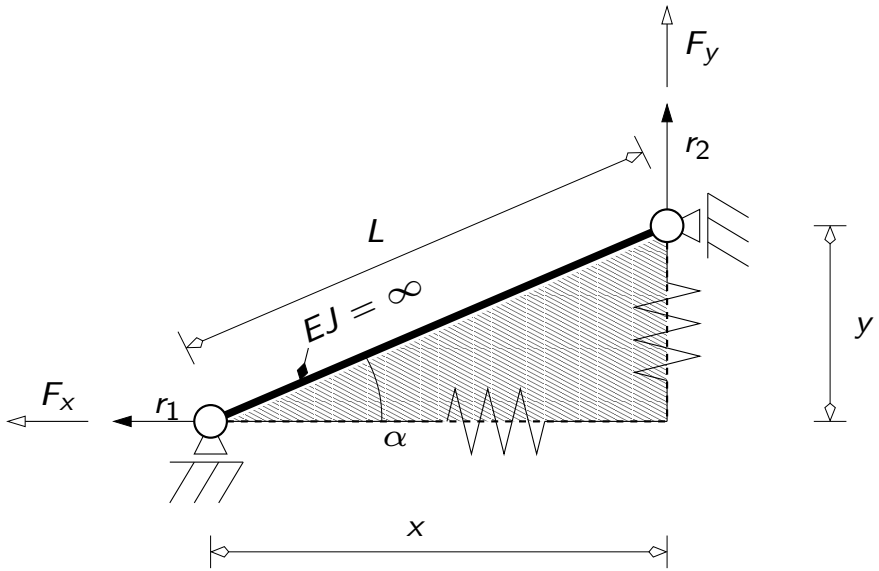


(a) microfibrils



(b) creep and mechano-sorptive creep

Structural system



- unknown parameters:
  - length L and breadth b
  - inclination of the microfibril α
  - stiffness of the microfibril EA_{fib} and the gel E_{Gel} resp.
- external parameters:
  - MoE parallel to the grain
  - Poisson's ratio
  - ratio $\varepsilon_{\perp}(\Delta u)/\varepsilon_{||}(\Delta u)$

$\longrightarrow$ 5 unknown parameters but 3 boundary conditions

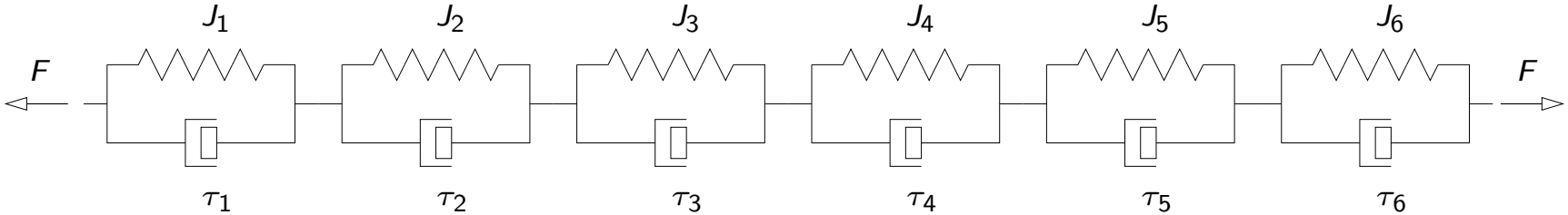
$\longrightarrow$ length and breadth are chosen, other parameters evaluated based on the values given in Neuhaus [43] in dependence on the moisture content

Creep deformation

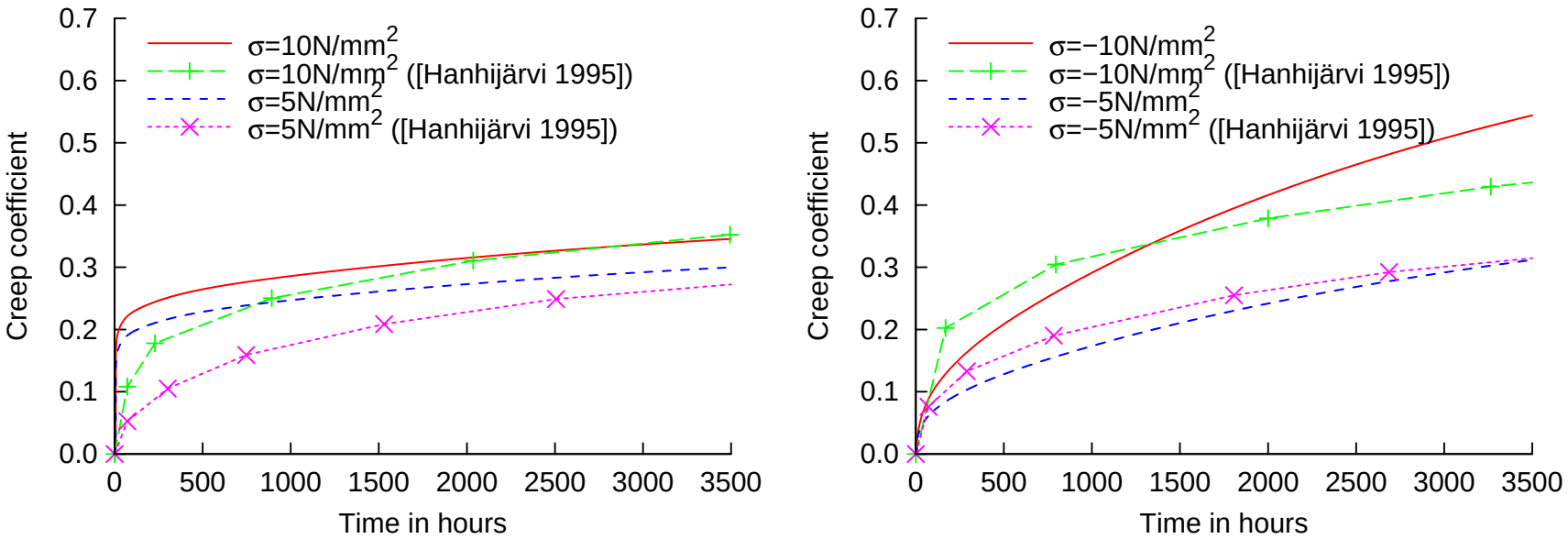
- assumed dependence of the creep strain on the stress level

$$\varepsilon_{cr}(t) = \frac{\sigma}{E} \cdot cosh\,(m \cdot \sigma) \cdot a \cdot t^{b}$$

- rheological model of the microfibril & the gel



Comparison of the model in constant climate to the model according to Hanhijärvi [22]



(a) tension (b) compression

Figure: Creep coefficients of axially loaded elements given by Hanhijärvi [22] and evaluated by YaRM

→ acceptable differences between model according to Hanhijärvi [22] and YaRM

Variable climate

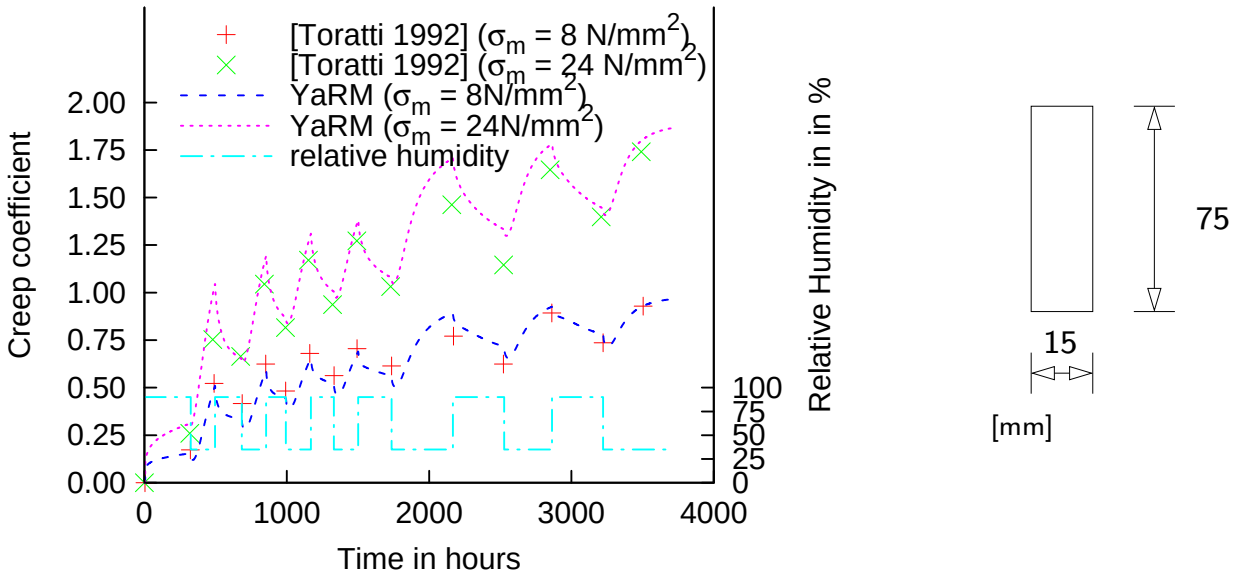
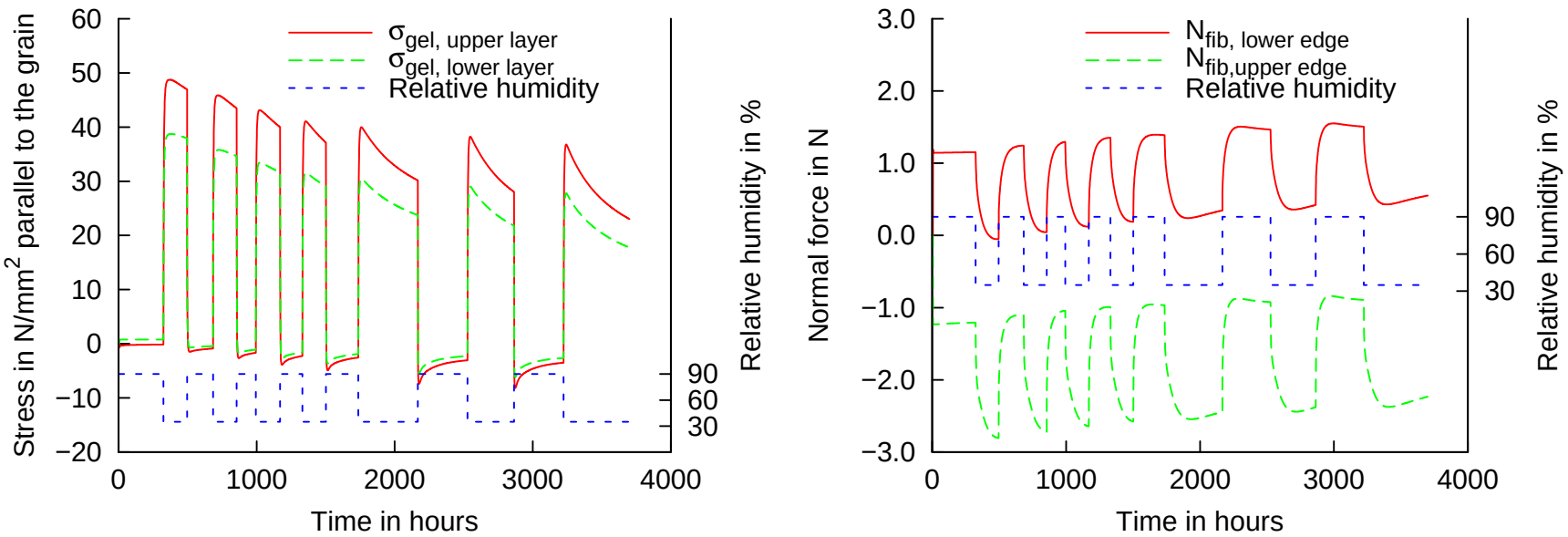


Figure: Comparison between the tests according to Toratti [51] (see Hanhijärvi [22]) and the results of YaRM

$\longrightarrow$ acceptable differences between test results and YaRM

Internal stresses and forces



(a) gel (b) microfibril

Figure: Stresses in the components of the model

→ Mechano-sorptive creep = reaction of the cell-wall on moisture induced eigenstresses(?)

Open questions, part II

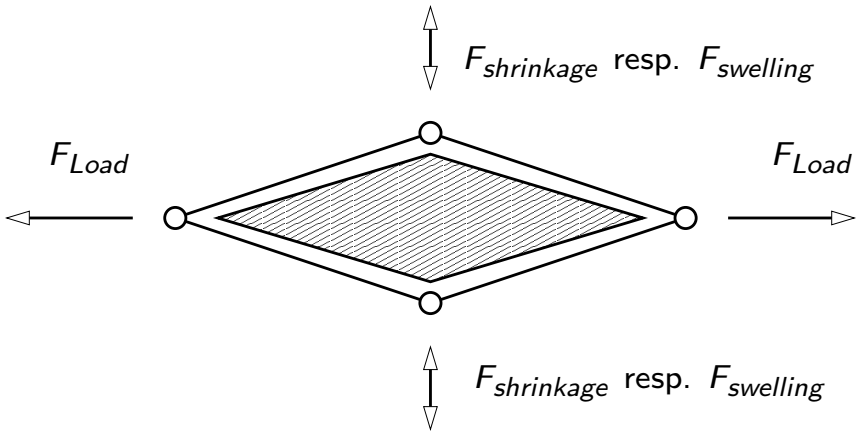
→ Mechano-sorptive creep = reaction of the cell-wall on moisture induced eigenstresses(?)

- Theory also valid for other test configurations?

Open questions, part II

→ Mechano-sorptive creep = reaction of the cell-wall on moisture induced eigenstresses(?)

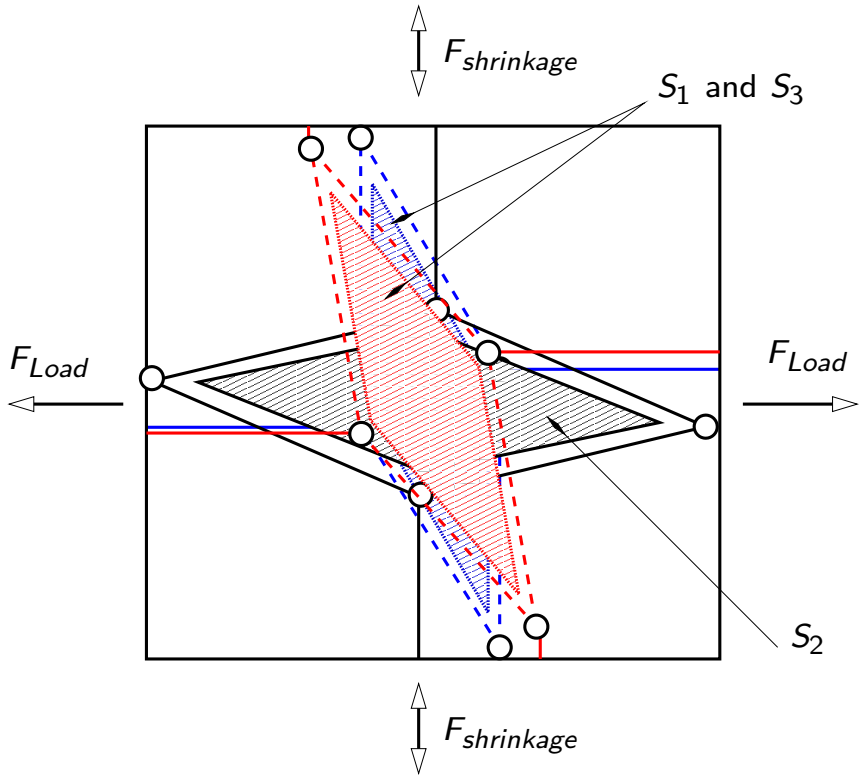
- Theory also valid for other test configurations?
- Influence of the neglect of the stresses perpendicular to grain due to swelling/shrinkage



Open questions, part II

→ Mechano-sorptive creep = reaction of the cell-wall on moisture induced eigenstresses(?)

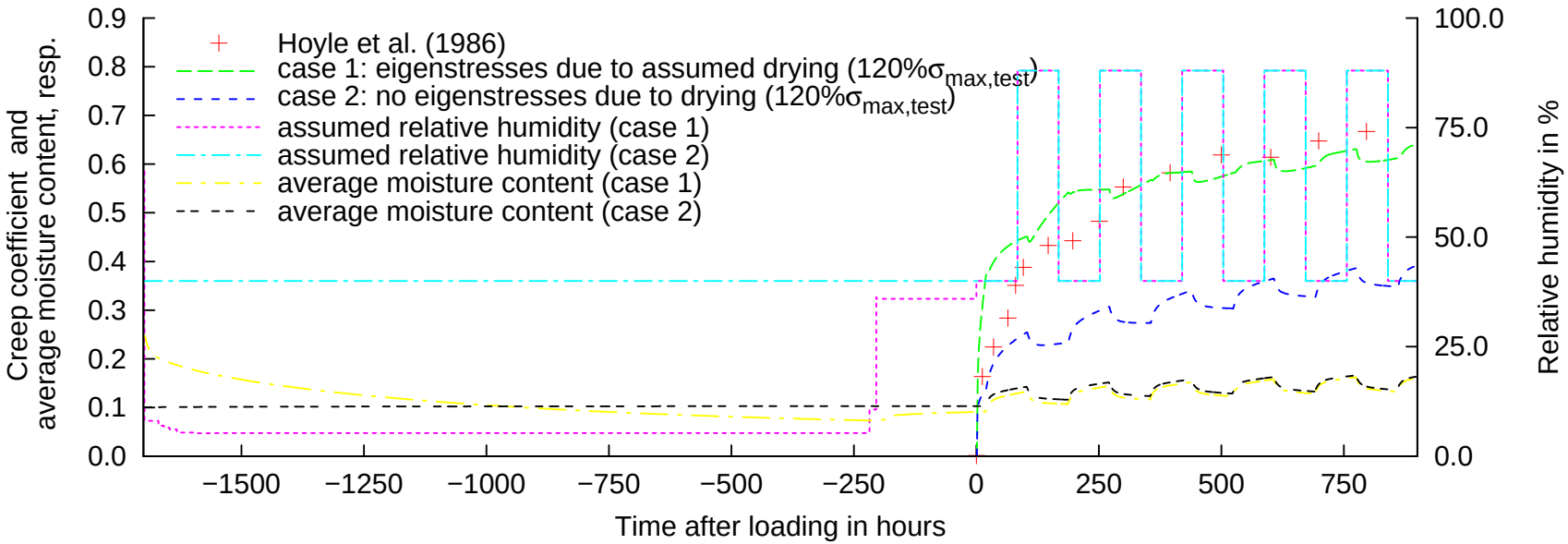
- Theory also valid for other test configurations?
- Influence of the neglect of the stresses perpendicular to grain due to swelling/shrinkage
- Up-to-now only consideration of the layer S_2 of the cell wall, assuming the microfibrils being parallel to the grain



Open questions, part II

→ Mechano-sorptive creep = reaction of the cell-wall on moisture induced eigenstresses(?)

- Theory also valid for other test configurations?
- Influence of the neglect of the stresses perpendicular to grain due to swelling/shrinkage
- Up-to-now only consideration of the layer S_2 of the cell wall, assuming the microfibrils being parallel to the grain
- Influence of the drying procedure



Open questions, part II

$\longrightarrow$ Mechano-sorptive creep = reaction of the cell-wall on moisture induced eigenstresses(?)

- Theory also valid for other test configurations?
- Influence of the neglect of the stresses perpendicular to grain due to swelling/shrinkage
- Up-to-now only consideration of the layer S_2 of the cell wall, assuming the microfibrils being parallel to the grain
- Influence of the drying procedure
- $\varepsilon_{cr} = f(cosh(\sigma))$

References

[1] J. Arfvidsson. Computer model for two-dimensional moisture transport. Manual for jam-2, Lund, 1989.

[2] P. Becker. *Modellierung des zeit- und feuchteabhängigen Materialverhaltens zur Untersuchung des Langzeitverhaltens von Druckstäben aus Holz*. PhD-thesis, Bauhaus-Universität Weimar, January 2002.

[3] E. Bou Saïd. *Contribution à la modelisation des effets différes du bois et du béton sous conditions climatiques variables. Application aux structures mixtes bois-béton*. PhD-thesis, 2003.

[4] J. D. Boyd. An anatomical explanation for visco-elastic and mechano-sorptive creep in wood and effects of loading rate on strength. In P. Baas, (Hrsg.), *New perspectives in wood anatomy*, pages 171–222. The Hague: Martinus Nijhoff and Dr. W. Junk Publishers, 1982.

[5] J. Carstensen. *Beiträge zum Biegekriechverhalten von Großquerschnitten unter baupraktischen Bedingungen*. PhD-thesis, Universität Hannover, IBH, 1993.

[6] Deutscher Wetterdienst. kl_dat_abgabe325_08. Technical report.

[7] F. Dieringer. *Dachsanierung des Kapellenbaus am Schloss Nymphenburg*. Diploma thesis, HTWG Konstanz, Prof. Dr.-Ing. W. Francke & Dr.-Ing. J. Schänzlin, January 2007.

[8] DIN 1052. *Holzbauwerke T.1. Berechnung und Ausführung und T. 2. Mechanische Verbindungsmittel mit Ergänzungen A1 und A2 (1996)*. 1988.

[9] DIN 1052. *Entwurf, Berechnung und Bemessung von Holzbauwerken - Allgemeine Bemessungsregeln für den Hochbau*. August 2004.

[10] DIN 1055. *Einwirkungen auf Tragwerke*. March 2001.

[11] DIN 1074. *Holzbrücken*. 1989.

[12] DIN 4074. *Sortierung von Nadelholz nach der Tragfähigkeit*. 2003.

[13] Eurocode 2. *DIN V ENV 1992 Eurocode 2: Planung von Stahlbeton- und Spannbetontragwerken; Teil 1: Grundlagen und Anwendungsregeln für den Hochbau*. June 1992.

[14] Eurocode 5. *DIN V ENV 1995 Eurocode 5: Entwurf, Berechnung und Bemessung von Holzbauwerken; Teil 1-1: Allgemeine Bemessungsregeln, Bemessungsregeln für den Hochbau*. June 1994.

[15] M. Fragiacomo. *Comportamento a lungo termine di travi composte legno-calcestruzzo*. PhD-thesis, Universität Trieste, 2000.

[16] M. Fragiacomo and J. Schänzlin. Modelling of timber-concrete floor structures. In A. Cecotti and S. Thelandersson, (Hrsg.), *Timber constructions in the new millenium*. Cost E5, September 2000.

[17] P. Gressel. Kriechverhalten von Holz und Holzwerkstoffen. *bauen mit holz*, pages 216–223, 1984.

[18] M. Grosse, R. Hartnack, S. Lehmann and K. Rautenstrauch. Modellierung von diskontinuierlich verbundenen Holz-Beton-Verbundkonstruktionen. *Bautechnik*, 80: S.534 – 541 und 693 – 701, 2003.

[19] P. U. A. Grossmann. Mechano sorptive behaviour. In B. A. Boyd, J. A. Johnson and R. W. Perkins, (Hrsg.), *General constitutive relations of wood and wood-based materials*, pages 313–325, July 1978.

[20] M. Gutenkunst. *Bestimmung von effektiven Kriechbeiwerten durch Messungen an bestehenden Bauwerken*. Bachelor-thesis, HTWG Konstanz, Prof. Dr.-Ing. W. Francke & Dr.-Ing. J. Schänzlin, August 2008.

[21] M. Häglund. On moisture induced stresses in timber structural elements. COST E55 Meeting in Helsinki, March 2008.

[22] A. Hanhijärvi. *Modelling of creep deformation mechanisms in wood*. PhD-thesis, Helsinki University of Technology. Technical Research Centre of Finland. VTT Publications. Espoo (SF), 1995.

[23] A. Hanhijärvi. *Perpendicular-to-grain creep of Finnish softwoods in high temperature drying conditions – experiment and modelling in temperature range 95-125 °C*. Vtt publications 301, VTT Building Technology, 1997.

[24] R. Hartnack. *Langzeitverhalten von druckbeanspruchten Bauteilen aus Holz*. PhD-thesis, Bauhaus-Universität Weimar, April 2005.

[25] P. Hoffmeyer and R.W. Davidson. Mechano-sorptive creep mechanism of wood in compression and bending. *Wood Science and Technology*, 23: S.215–227, 1989.

[26] R. Hofmann. *Erfassung des Langzeitverhaltens von schlanken Brettschichtholzträgern beim Stabilitätsnachweis "Kippen"*. PhD thesis, Institut für Konstruktion und Entwurf, Universität Stuttgart, 2012.

[27] Holzbautaschenbuch. *Holzbautaschenbuch*, volume 9. R. v. Haslasz; C. Scheer, 1995.

[28] R. J. Hoyle, R. Y. Hani and J. J. Eckhard. Creep of Douglas-fir beams due to cyclic humidity fluctuations. *Wood and Fibre Science*, 18: S.468–477, 1986.

[29] D. G. Hunt. Linearity and non-linearity in mechano-sorptive creep in softwood in compression and bending. *Journals of material science*, 21: S.2088–2096, 1986.

[30] Joint Committee on Structural Safety. *Probabilistic Model Code*. www.jcss.ethz.ch/, 2001.

[31] A. Kenel and U. Meierhofer. *Holz / Beton-Verbund unter langfristiger Beanspruchung*. Forschungs- und Arbeitsbericht 115/39. EMPA Dübendorf (CH), Abteilung Holz, 1998.

[32] H. Kreuzinger. *Verbundkonstruktionen Holz / Beton*. 1994.

[33] U. Kuhlmann and R. Hofmann. Erfassung des Langzeitverhaltens von schlanken Brettschichtholzträgern beim Stabilitätsnachweis "Kippen". research report of dfg-project 542091, Institut für Konstruktion und Entwurf, Universität Stuttgart, 2009.

[34] U. Kuhlmann and G. Teichmann. Influence of creep on lateral torsional buckling of glued laminated timber beams. In *Proceedings of the 9th World Conference on Timber Engineering, WCTE 2006, Portland, OR, USA, August 6-10, 2006*, 2006.

[35] M. Leivo. *On stiffness changes in nail plate trusses*. PhD thesis, Espoo, Finland, 1991.

[36] A. Lühr. *Dachtragwerk der Münsterbauhütte Freiburg*. Bachelor-thesis, HTWG Konstanz, Prof. Dr.-Ing. W. Francke & Dr.-Ing. J. Schänzlin, August 2007.

[37] maps.google.de. Google Maps Deutschland. webpage, http://maps.google.de/maps?hl=de&tab=wl, 2008.

[38] A. Mårtensson. *Mechanical behaviour of wood exposed to humidity variations*. PhD-thesis, 1992.

[39] S. Mohager. *Studier av krypning hos trä*. KTH Stockholm, 1987.

[40] W. Moorkamp. *Zum Kriechverhalten hölzerner Biegeträger und Druckstäbe im Wechselklima*. PhD thesis, Universität Hannover, 2002.

[41] P. Morlier and L.C. Palka. Creep in Timber Structures. volume 8 of *Rilem Report*, pages 9 – 42. Rilem Publications, 1994.

[42] L. Muszynski, R. Lagana and S. M. Shaler. Characterization of hygro-mechanical properties of solid wood on the material level. In *Proceedings of the 8th World Conference on Timber Engineering, WCTE 2004, June 14-17, Lahti, Finland*, volume 2, pages 161–166, 2004.

[43] F.-H. Neuhaus. *Elastizitätszahlen von Fichtenholz in Abhängigkeit von der Holzfeuchtigkeit*. Phd thesis, Institut für konstruktiven Ingenieurbau Ruhr-Universität Bochum, 1981.

[44] P. Niemz. *Physik des Holzes*. 2004.

[45] Österreichische Bergrettung. *Schnee- und Lawinenkunde*. Österreichische Bergrettung, Land Vorarlberg, www.bergrettung-koetschach.com/pdf/schnee_lawinenkunde.pdf, 11 2006.

[46] K. Rautenstrauch. *Untersuchungen zur Beurteilung des Kriechverhaltens von holzbiegeträgern*. PhD-thesis, Universität Hannover, IBH, 1989.

[47] H. Ruesch and D. Jungwirth. *Stahlbeton, Spannbeton - Berücksichtigung der Einflüsse von Kriechen und Schwinden auf das Verhalten der Tragwerke*, volume 2. Werner-Verlag, 1976.

[48] J. Schänzlin. *Zum Langzeitverhalten von Brettstapel-Beton-Verbunddecken*. PhD-thesis, Institut für Konstruktion und Entwurf, Universität Stuttgart, 2003.

[49] J. Schänzlin and M. Fragciacomo. Extension of EC5 Annex B formulas for the design of timber-concrete composite structures. CIB-40-10-1, International council for research and innovation in building and construction – working commission W18 - timber structures (CIB-W18), Meeting 40, Bled, Slovenija, http://www.rz.uni-karlsruhe.de/ gc20/IHB/cib.htm, August 2007.

[50] G. D. Taylor, D. J. West and B. O. Holsion. Creep of glued laminated timber under conditions of varying humidity. In *International timber engineering conference, London*, 1991.

[51] T. Toratti. *Creep of timber beams in variable environment*. PhD-thesis, Helsinki University of Technology, Laboratory of Structural Enginieering and Building Physics, 1992.

[52] P. Tukiainen and M. Hughes. Fracture of spruce and birch in the RT crack propagation direction. In *Proceedings of the 10th World Conference on Timber Engineering, WCTE 2008, Miyazaki, Japan, June 2-5, 2008*, 2008.

[53] wetter-online.de. Stuttgart-Echterdingen. webpage, http://www.wetteronline.de/cgi-bin/regframe?3&LANG=de&PLZ=70771&PLZN=-Leinfelden-Echterdingen&PROG=citybild&PRG=citybild, 2008.

[54] wikipedia.de. Wikipedia. webpage, http://www.wikipedia.de/, 2008.

[55] Q. Wu and M. R. Milota. Rheological behaviour of douglas-fir perpendicular to the grain at elevated temperature. *Wood and Wood Fibre Science*, 27(3): S.285–295, 1995.