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AN ENHANCED BEAM MODEL FOR GLUED LAMINATED STRUCTURES THAT TAKES MOISTURE, MECHANO-SORPTION AND TIME EFFECTS INTO ACCOUNT

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ABSTRACT: There is a need of more advanced analysis for studying how the long-term behaviour of glued laminated timber structures is affected by creep and by cyclic variations in climate. A beam theory is presented able to simulate the overall hygro-mechanical and visco-elastic behaviour of (inhomogeneous) glulam structures. Two frame structures subjected to both mechanical and cyclic environmental loading are analysed to illustrate the advantages the model involved can provide. The results indicate clearly both the (discontinuous) inhomogeneity of the glulam products and the variable moisture-load action that occurs to have a significant effect on deformations, section forces and stress distributions within the frame structures that were studied.

KEYWORDS: Wood, moisture-related stresses, mechano-sorption, creep, FE-simulation, beam element

1 INTRODUCTION

Wood is a non-isotropic and inhomogeneous material concerning both modulus of elasticity and shrinkage properties. It is also a hygroscopic and moisture-sensitive material. In stress calculations associated with timber designs even of ordinary types, these matters are often not dealt with properly, primarily because of the stress distributions encountered in inhomogeneous glulam structures exposed to mechanical actions of different sorts, together with the climatic conditions that are present, being extremely difficult to predict by any simple means. Accordingly, advanced numerical simulations are often needed in studying cyclic climate related stresses in glulam structures. An incremental beam model able to predict the stress history as a whole at an arbitrary location within the beam is employed. The model and the extended beam theory associated with it, dealing with the elastic, the shrinkage, the mechano-sorption and the visco-elastic behaviour of the material involved, were implemented here in the finite element program CALFEM (2004). For a more detailed account then provided here of the theory and of the implementation procedure employed, see [1] and [2].

2 MOISTURE VARIATION IN TIMBER STRUCTURES

In the Nordic countries, RH values typically vary from about 90% in the winter to about 65% in the summer each year. When a timber structure is exposed to natural climatic variations, the question arises of the extent to which moisture changes and moisture gradients will be generated in the wood material. In order to gain insight into this, a transient moisture flow simulation was performed for a glued laminated cross section having dimensions 100x300 mm; see Fig. 1.

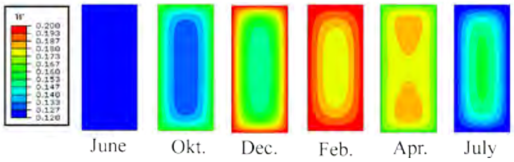

Figure 1: *Moisture-content profiles for a timber cross section having dimensions of 100x300 mm.*

In timber structures exposed to moisture gradients such as shown in Fig.1 considerable stresses both longitudinal and perpendicular to the grain direction will occur.

3 NUMERICAL EXAMPLES

A rather simple beam-column structure was employed for studying how different parameters affect the hygro-mechanical long-term deformations and stresses that develop. Figure 2 shows the structure in question.

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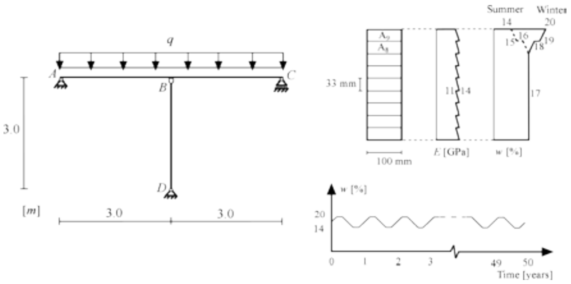

Figure 2: *The geometry of the structure, variations found in the E-modulus and in the moisture content over the beam cross section, and moisture history on the upper surface.*

The figures that follows illustrates how the presence of a dominant mechanical load *q*, together with a cyclically varying moisture load shown in Fig. 2, affects the deformations and the stresses in the structure. Figures 3 and 4 show how the displacement varies along the beam and how the normal stress varies over a cross section.

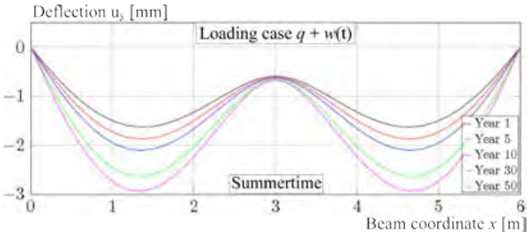

Figure 3: *Deflections of the beam A-B-C.*

The deflection increases markedly over time due both to creep and to the mechano-sorption phenomenon. The maximum degree of deflection occurs during the summers, its increasing from 1.6 to 2.9 mm during years 1-50.

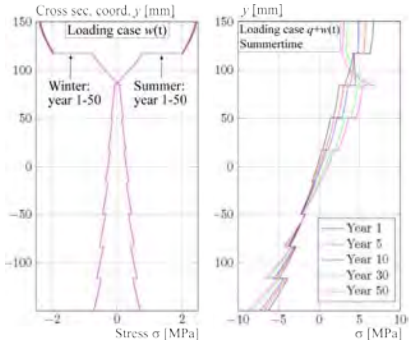

Figure 4: *Variations in stress over the cross section at point B for (a) pure climate loading and (b) combined mechanical and climate loading during the summertime.*

It can be clearly seen in Fig. 4 that the stresses caused by the combination of mechanical and climate loading vary markedly, both over a given year and over time, whereas the moisture-related stresses are practically independent of time. The second numerical example is a large arch structure shown in Fig. 5. It is composed of two slightly curved beams, there being a number of vertical columns connecting the upper and the bottom chords.

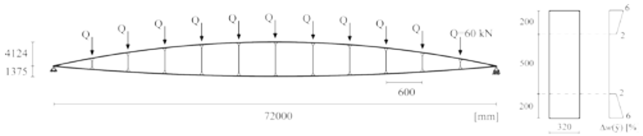

Figure 5: *Structural geometry and mechanical and moisture loading acting on the upper chord.*

The structure is subjected here to both mechanical and climate loading. Figure 6 shows displacement and stress curves both for separate moisture and snow loads and for combinations of these.

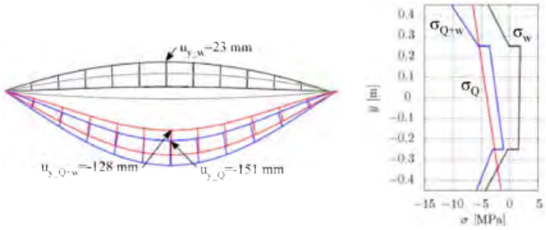

Figure 6: *Deformation of the arch structure and stress profiles for the centre cross section of the upper chord.*

Figure 6 (left) shows the structure in a deformed state, the largest deflection being in the centre of the structure. For pure moisture loading, the centre of the structure was found to bend upwards by about 23 mm. When the snow load acted alone, there was a maximum downward deflection of 151 mm. The figure also shows there to be normal stress variations in the cross section in the centre of the upper chord where the moisture loading has a relatively strong effect on the normal stress that develops. The changes in moisture content have an unfavourable effect on the strongest stresses found in the cross section, the compression stress increasing from about 7 to 10 MPa at the top edge of the upper chord.

4 CONCLUSIONS

The major conclusion to be drawn on the basis of the simulation results is that the moisture loading (either cyclic or constant) had a strong effect on the deformations and the stresses found in the timber structures that were studied. A final conclusion that can be drawn is that climate loading should best be treated as a separate load case in connection with future design codes for timber structures that are exposed to natural variations in climate.

REFERENCES

[1] Ormarsson S, Dahlblom O.: Finite element modelling of moisture related and visco-elastic deformations in timber beams. Engineering Structures 49:182-189, 2013.

[2] Steinnes J. R.: Finite element modelling of a special designed beam element for simulation of lateral buckling driven by mechanical and moisture related stresses. Master thesis, Technical University of Denmark, Department of Civil Engineering, 2014.