A critical discussion on the application of the Finite Element Method in design and verification of timber structures

Robert Jockwer †*

† Chalmers University of Technology, Division of Structural Engineering, robert.jockwer@chalmers.se

Structural models based on Finite Element Method are widely established in engineering practice e.g. for the determination of the distribution of forces and stresses in and deformations of structures or for evaluating their dynamic response. Some of the reasons for choosing FEM instead of hand-calculation are the easy possibility to evaluate statically indeterminate structures, structures of complex geometry (e.g. Free-Form structures) and those deviating from beam theory (glulam beams of small length to height ratio), or plate and shell type elements (e.g. CLT panels with large openings, windows and doors). For the realistic representation of timber structures by means of models, the particular characteristics of wood and the material behaviour of timber pose a challenge to the engineer.

Traditionally the design of timber structures according to EN 1995-1-1 (EC5) [1] is based on an element by element approach, in which the individual elements often can be verified by hand-calculation. An example is the single supported beam loaded primarily in bending: In the verification the linear distribution of stresses according to linear-elastic beam theory is used; the characteristic values of bending strength given in the material product standards associated to EC5 are based on simple bending tests of beams with certain geometry as specified in the related test standards; the related partial safety factors for the ultimate limit state (ULS) of a beam in bending were calibrated with the two above assumptions. When deviating from these assumptions and prerequisites the design rules and recommendations given in EC5 and related standards do not apply any more. This can be illustrated with the example of a beam with shorter span and greater height: the highly non-linear distribution of shear stresses in the region of beam supports and the interaction of shear and compression perpendicular to the grain stresses are not reflected in detail in the design according to EC5.

For the estimation of the expected deformation of timber structures by means of FEM the models can be based on the mean material stiffness properties that can be found to some extent in the product standards related to EC5. The model based on these mean values of properties can be used for the validation of the structural behaviour in the serviceability limit state. However, when it comes to the evaluation of the behaviour of structurally indeterminate timber structures in ULS, the variability of the material properties has to be accounted for. Information on the variability of the material strength and stiffness properties can be found in JCSS Probabilistic Model Code [2], detailed information on the distribution characteristics of stiffness and load-carrying capacity of connections is much harder to find in literature. System effects in structurally indeterminate timber structures with parallel or serial arrangement of elements make it impossible to simply rely on conservative, characteristic values but may require a probabilistic evaluation of the structural reliability.

In the contribution the various parameters and characteristics of timber and timber structures with relevance to the modelling by FEM for design and verification are discussed, amongst others the following:

- The relatively high variability in material strength and stiffness properties of timber together with the brittleness of failure mechanism in tension and shear may requires Monte-Carlo or other probabilistic methods in order to determine the relevant design situation.
- The non-linear load-deformation behaviour in connections requires good knowledge of the adequate analytical or tabulated representation of this behaviour. Especially modern, high performance fasteners and connections are not be represented adequately by the equations and recommendations given in EC5 for traditional connections. The potential load-redistribution between different fasteners and connections due to different ductility, stiffness and yield load requires variation of these parameters in the models.
- The size dependency of the material wood requires an exact evaluation of the stresses volume. Especially when being loaded in tension perpendicular to the grain and in shear the effective strength may be impacted by local defects in the stresses volume due to the weakest link effect.
- Stress singularities, that occur in the vicinity of cracks, cuts or abrupt changes in cross-section of elements (e.g. notches or holes), are highly dependent on the choice of element type and element size in the model. Material property values in product standards are commonly determined for situations without stress singularities.

References

[1] EN 1995 1 1:2004. Eurocode 5: Design of timber structures – Part 1-1: General – Common rules and rules for buildings. (2004). European Committee for Standardization (CEN), Brussels, 123.

[2] JCSS. Probabilistic model code. Joint Committee on Structural Safety; 2001. http://www.jcss.byg.dtu.dk/ .

ISBN: 978-91-88898-64-7