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Finite element analysis of timber containing branches – An approach to model the grain course and the influence on the structural behaviour

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ABSTRACT

Wood, as a naturally grown material, is affected by growth inhomogeneities like branches. Especially in solid timber or glulam beams, knots lead to a decrease in stiffness and strength. In this contribution, approaches to model knots and the grain course in an FE-simulation are presented. Based on these methods, the influence of knots is evaluated by structural analyses. For validation, the numerical results are compared to experimental data. Since knots often initiate damage in structural timber parts, a failure criterion is applied in the area of the knots.

1. Introduction

Recently, different numerical models to analyze wooden structures by means of an FE-analysis have been developed and published. These methods include material models on different length scales to simulate damage and failure as well as to capture the hygro-mechanical behaviour, see e.g. [1]. Most of the models are restricted to perfect timber and wood products free of inhomogeneities.

To analyze timber structures made of solid or sawn timber, the existing models need to be enhanced in order to capture growth inhomogeneities like branches or knots (as branches are called in construction timber). Besides, even wood products like glue-laminated timber are affected by branches since every layer is made of sawn timber containing knots. Regarding glue-laminated girders, layers in the tensile zone are most likely to fail outgoing from knots. Fig. 1 shows failure in timber boards evolving from knots. Thus, the main objective of the work at hand is the combination of material models for timber with approaches to describe branches and knots in an FE-analysis.

Several methods to capture inhomogeneities like branches in a structural analysis are already known. As a simple option, knots can be considered by means of reduced mechanical material parameters, e.g. the longitudinal elasticity modulus, due to a knottiness factor. According to [2], knottiness can be determined mechanically or visually [3]. By knottiness, strength classes and related material parameters are defined for a structural part made of timber.

To capture local differences within a component of timber, the total knot area ratio (TKAR [4]) might be applied, whereas knottiness is determined section-wise. In [4], boards are divided into knot and clear wood sections based on the TKAR to determine a distribution of material parameters like the longitudinal elasticity modulus along the board length. The direct modelling of knots and grain deviation in an FE-analysis is even more detailed. Studies of single knots are documented e.g. in [5,6]. An approach to capture arbitrary knots is presented e.g. in [7].

Here, a method to capture an arbitrary number of knots varying in position and shape in structural members made of timber is presented, whereas each knot is described in particular in the FE-model. Moreover, a geometrical description and methods to numerically determine the grain course in the area of branches are introduced. The models are applied to analyze the mechanical behaviour of timber boards from [8].

2. Geometrical and FE-modelling of timber and branches

2.1. Description of branches

2.1.1. Geometrical model

The naturally grown shape of branches needs to be modelled and idealized, respectively, by means of geometric shapes to

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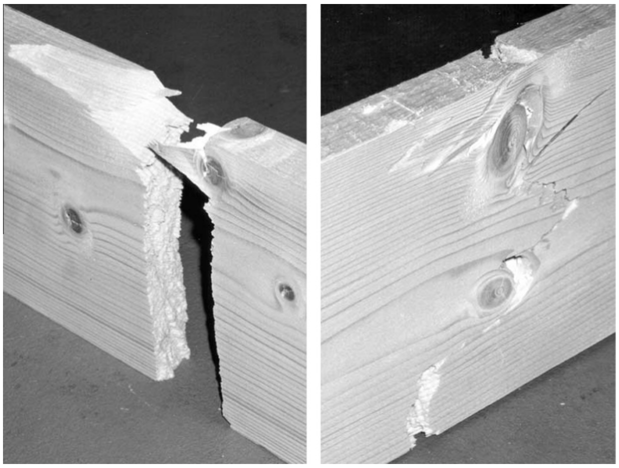

Fig. 1. Failure in boards at tensile loading initiated by knots [8].

include knots in an FE-model. Considering Norway Spruce (*Piceas abies*), branches are growing at the whole stem until an age of about 20 years. Then, the typical crown evolves and the growth of branches below the crown reduces and stops, respectively. Related to these periods of living, branches can be represented by cones for the growth in the crown (living), frustums for the reduced growth between crown and first living branch (dying) and cylinders for the stopped growth of branches below the crown. Since a branch can pass through each period of living, the geometrical model can be composed of each geometric shape according to Fig. 2(a).

To describe the growth of Norway Spruce, several growth functions have been developed in the past, e.g. in [9,10]. Based on these functions, a growth description, which provides a fully three-dimensional geometrical model of a randomly generated tree including branches, has been developed [11]. From such a virtual tree, arbitrary structural members can be cut, see Fig. 2(b). Depending on the position of the part in the tree, knots are modelled by means of the three described geometric shapes. The growth model was used to study the influence of knots on the load-bearing behaviour of timber in numerical parameter studies, e.g. in [11–14].

However, the methods to capture knots in an FE-analysis need to be validated by experimental data, i.e. the knot shapes inside real structural parts need to be determined. In [15], several options to investigate the inside of timber by digital radiography are discussed. To obtain a three-dimensional view inside timber, computed tomography might be applied [16]. In Fig. 3(a), a radiography of a timber component [15] and a possible geometrical model are shown. The model is obtained by measuring the dimensions of each branch and the position of the heartwood and the pith, respectively. The latter is always needed to determine the three shapes, since it defines the position of the investigated part in a tree. Thus, a tree model equivalent to the tree model derived by the growth model is obtained and the branches are described in this virtual tree.

Of course, radiography and computed tomography are very complex and costly. In most cases, knots are only documented in position and size on the surface of a structural part, e.g. in [4,8]. Due to the lack of information for the inside of the structural parts, an interpolation of this surface data is appropriate, especially for thin boards. By means of the location of the pith and the position and shape on the entering and exit surface, a tree model can be obtained and each branch is described. In Fig. 3(b), information on the location and size of knots on each wide side of a board taken from [8] is depicted. Below, a possible geometrical model is shown. A detailed description of the geometrical modelling for this example is given in Section 4.

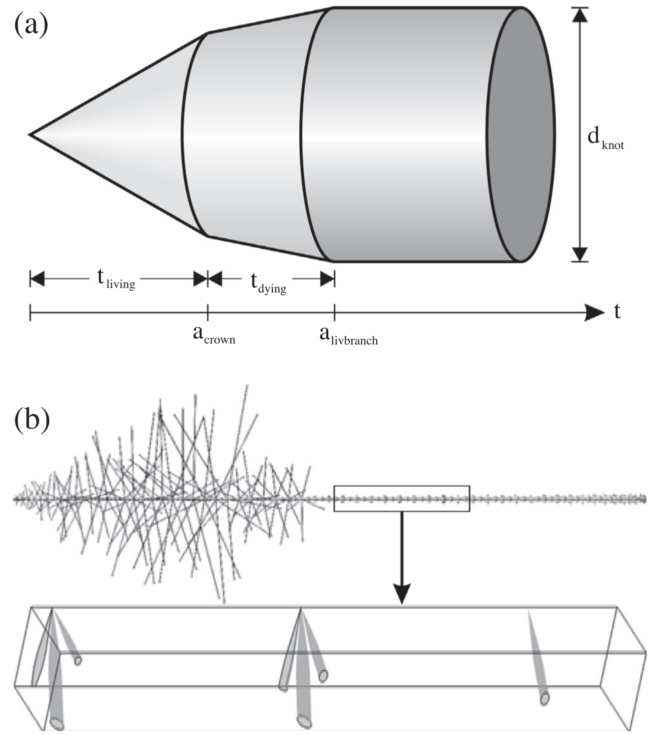

Fig. 2. Modelling of branches: (a) geometrical idealization and (b) growth model.

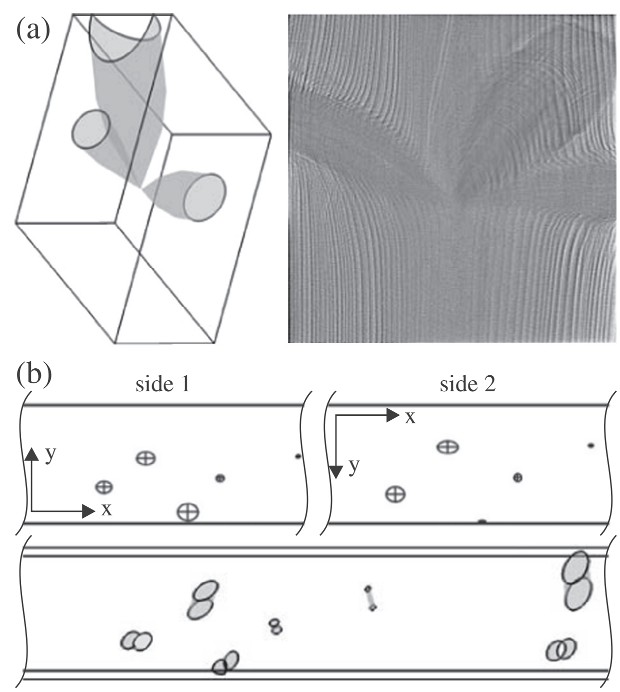

Fig. 3. Modelling of branches by information (a) inside timber [15] and (b) on the surface [8].

Independent of its origin, either the growth model or real data, the geometrical model provides the information “knot” or “not-knot” for every point in a structural part by means of geometrical functions.

2.1.2. FE-model

In the next step, the geometrical model is transferred into an FE-model. Therefore, each knot could be meshed individually, e.g. by using hexahedral or tetrahedral elements. Thus, the knots are described directly by the mesh geometry and the boundaries