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LOAD CARRYING CAPACITY OF NAIL-LAMINATED TIMBER UNDER CONCENTRATED LOADS

by

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1 Introduction

A laminated timber element is a plane structural component composed of single, edgewise-oriented lamellas. These lamellas are mechanically jointed usually by nails, alternatively by dowels made of hardwood. In the following, only nail-laminated timber elements are considered, which are mechanically jointed by nails and loaded by central concentrated loads.

The aim of a research project was to derive design-equations for the effective bending stiffness, for the resulting bending stresses, and for the nail loads. It would have been quite expensive to obtain the design-equations by running a large number of tests. This is why the tests were simulated on the computer. For the simulations, the parameters ℓ/h (span / height of the element), the nail diameter, and the nail spacing were varied. The simulations were conducted on the basis of realistic stiffness-values of the lamellas and of the nails. The lamellas were generated on the basis of Görlacher [1], the nails on the basis of the deformation characteristics given in EC5 [2]. To guarantee statistically reliable results, 36 different systems of nail-laminated timber elements were simulated. Each system of the nail-laminated timber elements was simulated 500 times. The design equations were derived from the results of these 18,000 simulations.

The results of the design equations show a good agreement with the results of 6 tests.

2 Basis of the Simulations

2.1 Lamellas

The strength and stiffness properties of the lamellas were simulated on the basis of the work of Görlacher and Colling [3]. Investigations of lamellas used in glued laminated timber served as a basis for these simulations. A virtual lamella (l = 4.5m) is subdivided into 30 segments with a length of 15 cm each. The values of MOE, the Knot Area Ratio (KAR) and the density are assigned to each single segment. The distribution of the MOE-values within a simulated lamella is shown as an example in figure 1.

According to Glos [4], the values of the simulated lamellas correspond to strength class C24 [5].

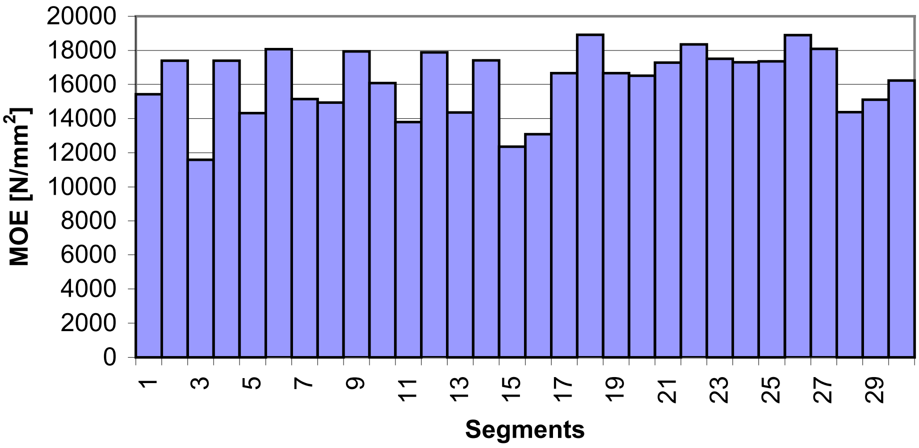

Figure 1 Example of the simulated within member variability of a lamella (MOE_{mean} = 15959 N/mm^2)

2.2 Dimensions of the nail-laminated timber elements

The nail-laminated timber elements (NLTE) were simulated as simply supported beams (see figure 2). The span (ℓ) of the NLTE was kept constant at 3.6 m. The depth (h) of the lamellas was varied in the range of 140, 160 and 180 mm. Consequently, the ℓ/h-ratios ranged from 20 up to 25.7, which are close to the ratios used for floors [6]. The width (t) of the lamellas was varied in the range of 30 mm, 35 mm, and 40 mm.

To keep the computing time at a reasonable level, each virtual NLTE consisted of 30 lamellas.

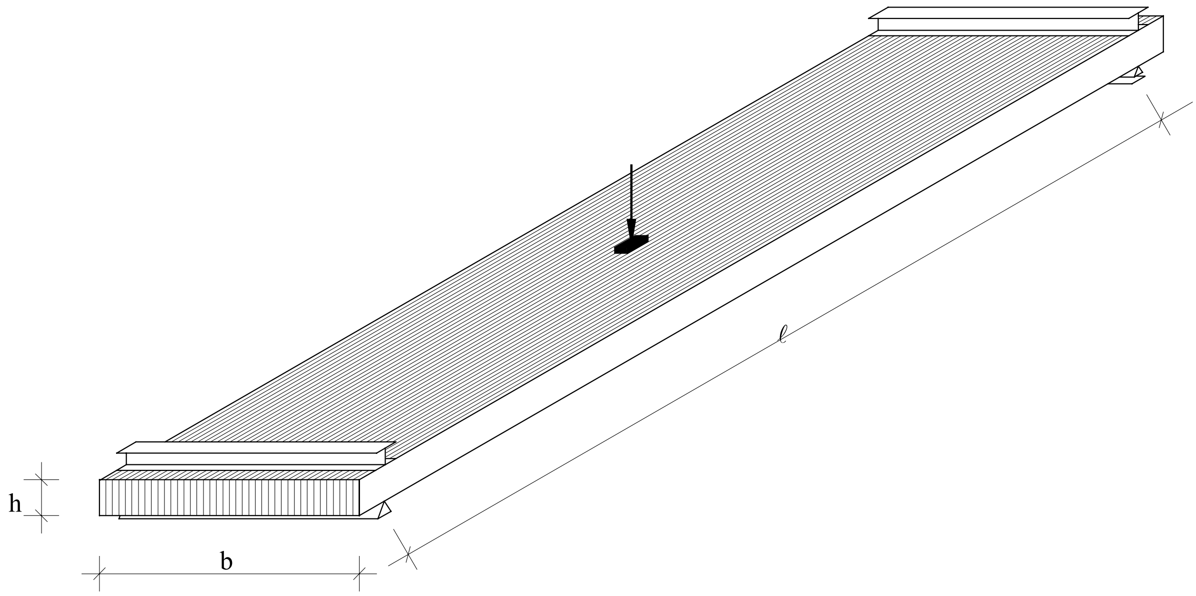

Figure 2 Nail-laminated timber element

2.3 Nails

The simulation of the nails was conducted on the basis of a nailed double shear timber to timber connection. The nail length consequently resulted as three times the lamella width. With the available smooth nails commonly used, the nail diameter (d_N) then depends on the width (t) of the lamella. The dimension of the nails corresponded to dimensions given in DIN 1151 [7] and in DIN 1143 [8]. For example, for t = 30 mm the nail 3.4 x 90 mm is used. The nails are assumed to be arranged in a zigzag pattern, as shown in figure 3.

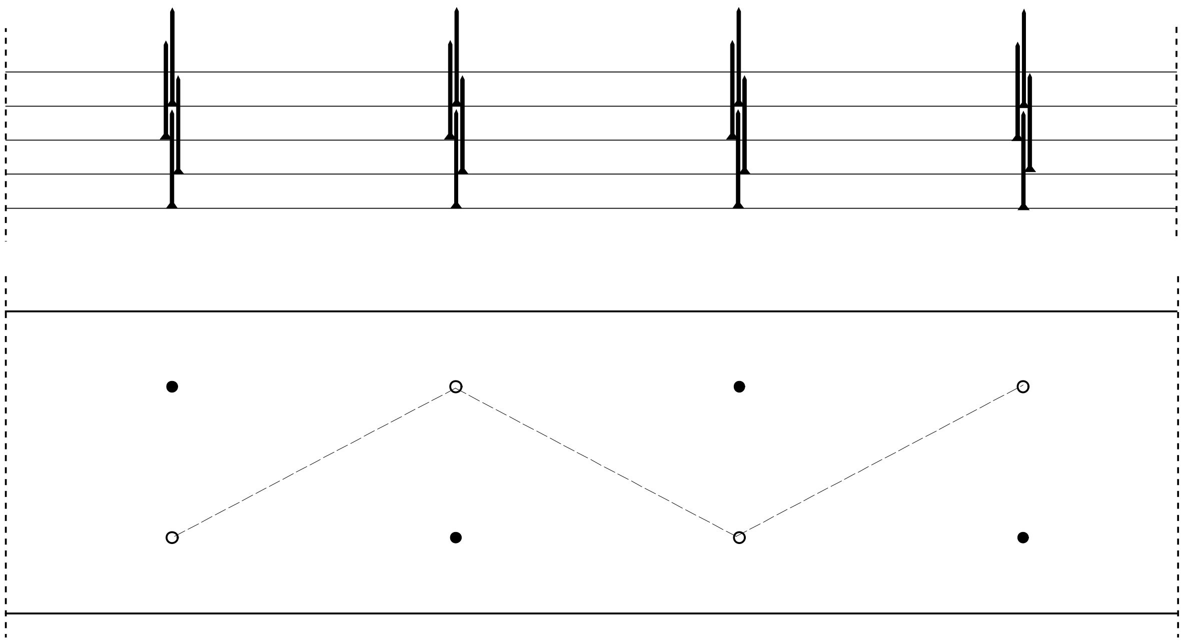

Figure 3 Nail arrangement

3 Finite Element Model

A grid was chosen as the mechanical model of the NLTE. The girders in longitudinal direction represent the lamellas. The shear stiffness of the nails was modelled by the bending stiffness of the girders in transverse direction. The lamellas of the NLTE are supported in x-, y-, and z-direction (left end) and in y-, and z-direction (right end).

The NLTE‘s were loaded with a single load of 1.0 kN. To simulate the spatial distribution of a single load (approximately 5cm/5cm), the single load was subdivided into 6 parts. The assembly of the mechanical model of the NLTE is shown in figure 4.

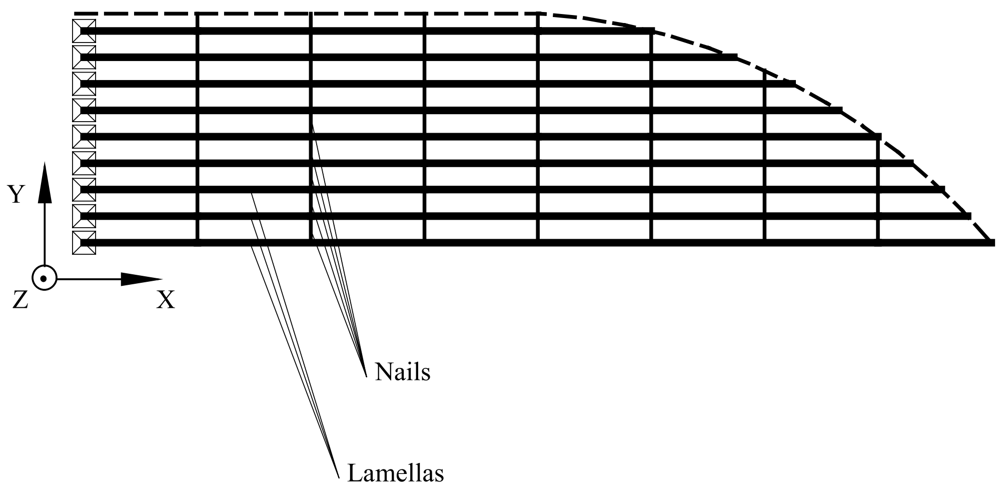

Figure 4 Mechanical model of the NLTE

3.1 Simulation of the NLTE

First, the files with the material properties of the lamellas and of the nails were generated. The files for the FE-calculation were generated on the basis of these material properties and on chosen geometric values of the NLTE. The calculations were performed with the FE- program ANSYS. Due to the fact that the calculations were linear-elastic, the results could be linearly extrapolated. Table 1 shows the parameters of 36 different simulated NLTE-systems [9]. 500 simulations were calculated and evaluated for each of the 36 NLTE-systems.

Table 1 Simulation table

No.	Spacing (Nail) a1 [mm]	Heigth (Lam.) h [mm]	Width (Lam.) t [mm]	Diameter (Nail) d [mm]
1	75	140	30	3,4
2	75	140	35	3,8
3	75	140	40	4,2
4	75	160	30	3,4
5	75	160	35	3,8
6	75	160	40	4,2
7	75	180	30	3,4
8	75	180	35	3,8
9	75	180	40	4,2
10	150	140	30	3,4
11	150	140	35	3,8
12	150	140	40	4,2
13	150	160	30	3,4
14	150	160	35	3,8
15	150	160	40	4,2
16	150	180	30	3,4
17	150	180	35	3,8
18	150	180	40	4,2
19	225	140	30	3,4
20	225	140	35	3,8
21	225	140	40	4,2
22	225	160	30	3,4
23	225	160	35	3,8
24	225	160	40	4,2
25	225	180	30	3,4
26	225	180	35	3,8
27	225	180	40	4,2
28	300	140	30	3,4
29	300	140	35	3,8
30	300	140	40	4,2
31	300	160	30	3,4
32	300	160	35	3,8
33	300	160	40	4,2
34	300	180	30	3,4
35	300	180	35	3,8
36	300	180	40	4,2

4 Evaluation of the Simulations

For each of the 36 NLTE's the 95%-fractile-values of the bending stresses of the lamellas and of the nail loads and the mean-values of the deformations were determined. The design equations were derived from these 95%-fractile- and mean-values.

4.1 Bending stresses of the lamellas

The maximum bending stress of lamellas in a NLTE under a centric single load can be calculated using equation 1:

$$\sigma_B = \frac{M}{W_{ef}} \text{ [N/mm}^2\text{]} \quad (1)$$

The bending moment is calculated according to equation 2:

$$M = \frac{F \cdot \ell}{4} \text{ [Nmm]} \tag{2}$$

where F is the concentrated load in midspan and ℓ is the span of the NLTE.

The effective section modulus W_{ef} resulted as:

$$W_{ef} = \frac{t \cdot h \cdot \ell}{4{,}5 \cdot a_1^{0{,}3}} \tag{3}$$

where t and h are the width and the depth of the lamellas [mm]

ℓ is the span of the NLTE [mm]

a_1 is the nail spacing [mm]

4.2 Nail loads

The nail loads depend on the parameters ℓ/h and a_1. Thus, the equation to calculate the nail loads are given as:

$$F_{Na} = F \cdot \frac{\left(\frac{\ell}{h}\right)^{2/3} \cdot a_1^{0{,}8}}{8{,}5} \text{ [N]} \tag{4}$$

where

F	is the concentrated load [kN]
ℓ	is the span of the NLTE [mm]
h	is the depth of the lamellas [mm]
a_1	is the nail spacing [mm]

4.3 Deformation of the NLTE

The elastic displacement of the NLTE under a concentrated load is calculated with equation 5:

$$v = \frac{F \cdot \ell^3}{48 \cdot E \cdot I_{ef}} \text{ [mm]} \tag{5}$$

The modulus of elasticity is assumed as the mean value of the simulated MOE-values and resulted as 12600 N/mm^2. The effective second moment of area of the NLTE cross section I_{ef} was determined as:

$$I_{ef} = \frac{t \cdot h^2 \cdot \ell^{0,86}}{0,9 \cdot a_1^{0,4}} \tag{6}$$

where

ℓ is the span of the NLTE [mm]

t/h are the width and the depth of the lamellas [mm]

a_1 is the nail spacing [mm]

5 Validating tests

A total of 6 tests were conducted to validate the simulation results. The test parameters are shown in table 2.

Table 2 Test Parameters

Test No.	Span (Element) ℓ [m]	Spacing (Nail) a_1 [mm]	Depth (Lam.) h [mm]	Width (Lam.) t [mm]	Diameter (Nail) d [mm]
1	3,75	150	190	35	3,8
2	4,50	150	155	28	3,1
3	4,50	150	140	30	3,4
4	3,75	75	180	28	3,1
5	3,75	150	180	28	3,1
6	3,60	225	180	28	3,1

The material properties (density, MOE, KAR and moisture content) of 248 lamellas were determined and used for simulating the tests in advance. Thus, the position and the material properties of each lamella in the NLTE were known.

Figure 5 shows the comparison of 248 values of MOE (lamellas) with 248 simulated mean values of MOE.

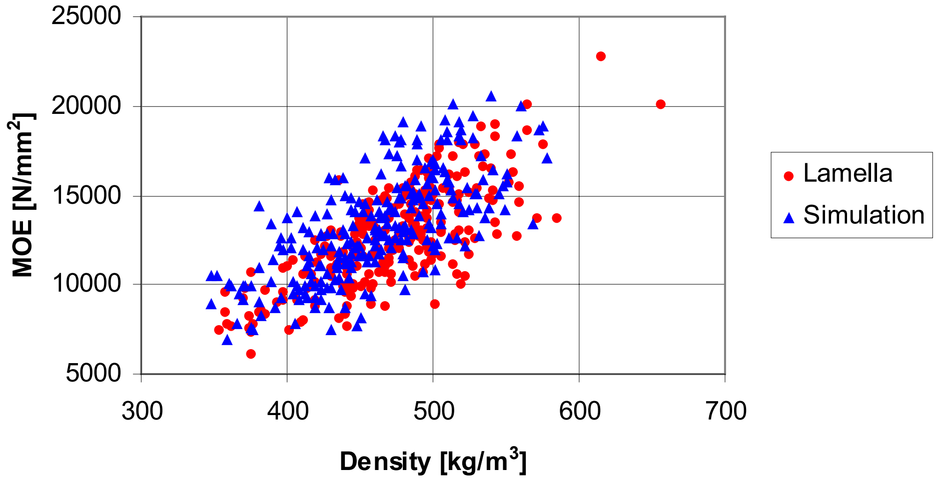

Figure 5 Comparison of measured and simulated values of MOE versus density

The test results agreed with the results of the simulations. The comparison of the test results, the simulations result, and the results of the design equations for the vertical displacement under a load of 5.0 kN is shown in figure 6.

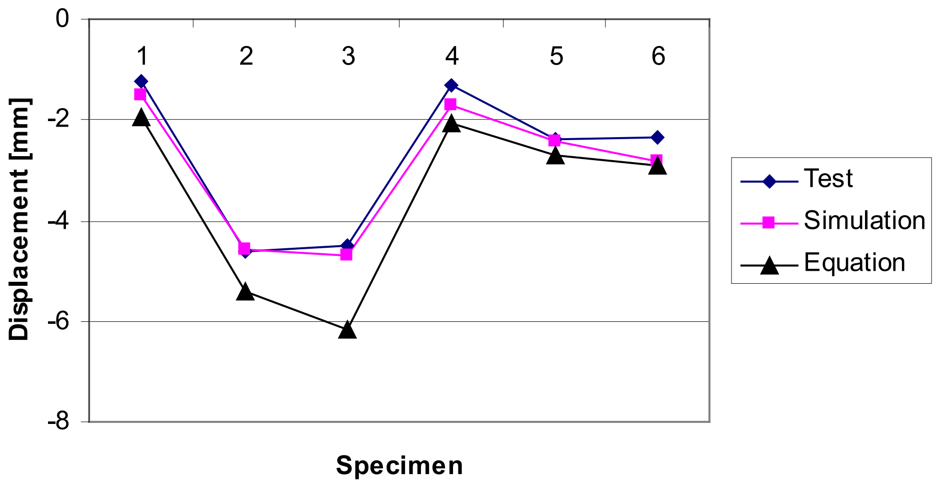

Figure 6 Comparison of the results of the tests, simulation, and equation

6 Summary

A mechanically laminated timber element (NLTE) is a plane structural component which is made of single, edgewise-oriented lamellas. The lamellas are mostly jointed by nails.

The aim of a research project was to derive design-equations for the bending stiffness, for the bending stresses of the lamellas, and for the action effects of the nails. The design-equations were derived from the simulation of thousands of nail-laminated timber elements. In these simulations, the parameters ℓ/h (span / height of the element), the diameter of the nails, and the nail spacing were varied. The simulations were conducted on the basis of realistic stiffness-values of the lamellas and the nails. The lamellas were generated on the basis of the work of Görlacher, the nails on the basis of the slip moduli given in EC5. To guarantee statistically reliable results, 36 different systems of nail laminated timber elements were simulated. Each system of nail-laminated timber elements was simulated 500 times. The design equations were derived from the 95%-fractile-values and from the mean-values of 18,000 simulations.

The results of the design equations were compared with the test results and demonstrated good agreement with each other.

7 References

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