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BENDING STRENGTH OF GLULAM BEAMS

-A DESIGN PROPOSAL-

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The scope of a current research project[1] is the investigation of the bending strength of glulam beams aiming at the development of design proposals. The "Karlsruhe calculation model" (Ehlbeck et al 1985a, Colling 1988) - a finite element model calculating the strength of glulam beams by means of Monte Carlo simulations - was thought to achieve this purpose.

The simulations showed, however, that the strength of glulam beams is a very complex field and that it is very difficult to describe the influence of one single parameter. The "Karlsruhe calculation model" takes into account every possible tendency, but the problem was to describe these tendencies mathematically.

Therefore, a statistical model (Colling 1990) was developed, which devides the totality of glulam beams into two groups: beams with wood failure (knots) and beams failing due to finger joints. On the basis of the "true" strength distributions of these two groups, it is possible to calculate the strength characteristics of the resultant glulam beams.

According to this model, the strength distribution of the final product glulam orientates itself very strongly by the lower of these two strength distributions and the characteristic bending strength of glulam beams is governed by the lower 5th-percentile of this group ("weaker material").

In *fig. 1* the characteristic bending strength (5th-percentile) depending on KAR, ovendry density and MOE of the laminations is shown for beams with finger joint failure ($x^0_{5,fj}$) and wood failure ($x^0_{5,wood}$). The index "0" indicates, that the strength values are valid for a standard beam with a depth of 300 mm (see *fig. 2*). Based on these calculation results, beams with finger joint failure were found to be the "weaker material" having the lower 5th-percentile. This tendency even increases with increasing beam dimensions, because size

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[1] Ehlbeck, J.; Colling, F.: Biegefestigkeit von Brettschichtholzträgern in Abhängigkeit von den Eigenschaften der Brettlamellen im Hinblick auf Normungsvorschläge

effects are more pronounced in case of beams with finger joint failure than in case of beams with wood failure. This may be explained by the higher variability of strength data in case of beams with failure due to finger joints .

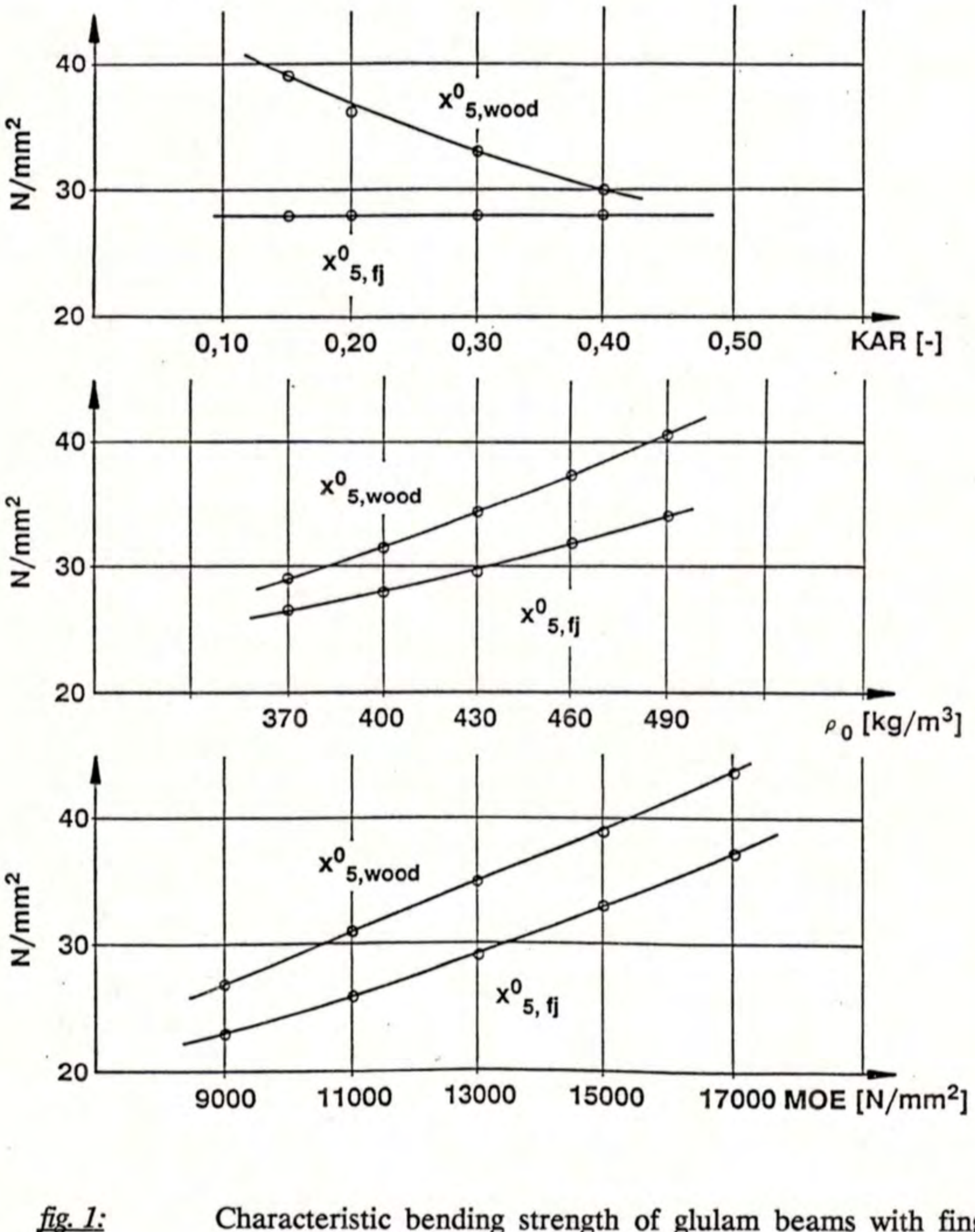

fig. 1: Characteristic bending strength of glulam beams with finger joint failure ($x^0_{5,fj}$) and wood failure ($x^0_{5,wood}$)

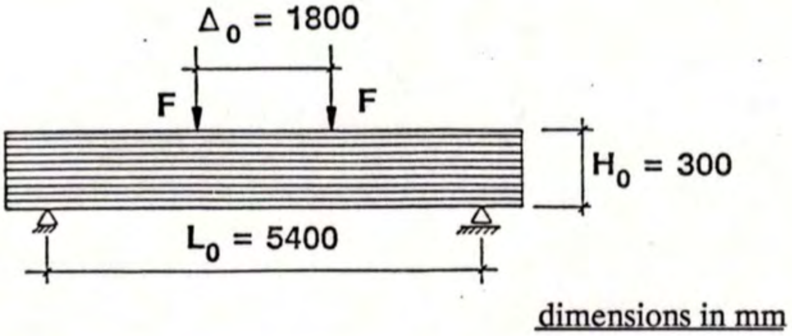

fig. 2: Standard beam

The reliability of the statistical model and of calculation results was verified by beam tests. A total of 42 bending tests were performed. Test set-up and beam dimensions are given in *fig. 3*.

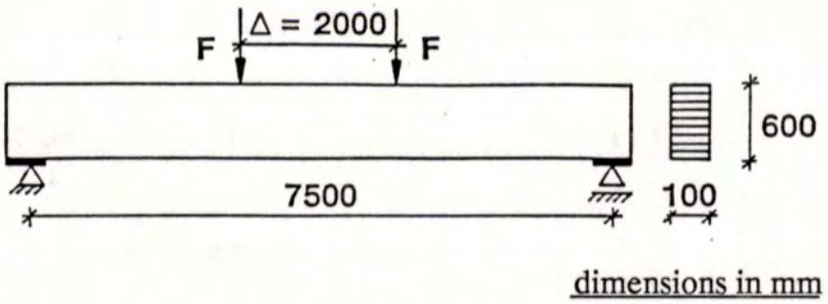

fig. 3: Test set-up and beam dimensions

Six test series with seven replications were performed. The three outer laminations of the beams had to meet the requirements given in *table 1*.

A comparison between test results and calculation results proved very good agreement (see *fig. 4*).

Contrary to the test results, calculation results allowed some statements concerning the expected characteristic strength values and it was shown that the 5th-percentile of the bending srength of $f_{m,k}$ glulam beams is almost equal to the 5th-percentile of those beams with failure due to finger joints.

In case of the standard beam of *fig. 2*, this strength value $f^0_{m,k}$ was found to be 20% higher than the characteristic tensile strength $f_{t,0,k,fj}$ of the occuring finger joints. Hence it may be written:

$$f^0_{m,k} = 1.20 \cdot f_{t,0,k,fj} \tag{1}$$

where

$f^0_{m,k}$ = characteristic bending strength of the standard beam,
$f_{t,0,k,fj}$ = characteristic tensile strength of the finger joints.

But as tensile strength can hardly be controlled by glulam factories during current quality control, the desired strength value $f_{t,0,k,fj}$ should be estimated by the corresponding bending strength value $f_{m,k,fj}$: knowing the ratio of tensile/bending strength of finger joints, it is possible to estimate the tensile strength by means of bending tests.

On the basis of numerous tests with finger joints (Ehlbeck et al. 1985b, Ehlbeck et al 1989) a ratio of

$$f_{t,0,k,fj}/f_{m,k,fj} = 23{,}4/36{,}3 = 0{,}64$$

may be expected. The ratio of the corresponding mean values was found to be

$$f_{t,0,fj}/f_{m,fj} = 35{,}0/50{,}6 = 0{,}69.$$

Tests of Radovic/Rohlfing 1986 with finger jointed laminated veneer lumber (LVL) however showed ratios of

$$f_{t,0,fj}/f_{m,fj} = 0{,}72 - 0{,}79.$$

These values correspond well to those found by Johansson (1983 and 1986):

$$f_{t,0,fj}/f_{m,fj} = 0{,}70 - 0{,}79.$$

The ratio of tensile/bending strength of finger joints is systematically investigated in a current research project in Karlsruhe, so that definitive values will be available within one year.

The following assumptions seem to be reasonable:

$$f_{t,0,k,fj}/f_{m,k,fj} \approx 0{,}70 \tag{2}$$

and

$$f_{t,0,fj}/f_{m,fj} \approx 0{,}75.$$

With *eq(2)*, *eq(1)* may be written as:

$$f^0_{m,k} = 0{,}84 \cdot f_{m,k,fj} \tag{3}$$

This relationship is valid for the standard beam, shown in *fig. 2*. The characteristic bending strength $f_{m,k}$ of any given beam may then be calculated as follows:

$$f_{m,k} = k_L \cdot k_H \cdot k_F \cdot f^0_{m,k} \tag{4}$$

where

k_L, k_H, k_F = factors taking into account the effects of length L, depth H and load configuration F

According to Colling 1990, these factors may be calculated according to Weibull's theory of brittle fracture as:

$$k_L = \left(\frac{L}{L_0} \cdot \frac{BL_0}{BL} \right)^{-0{,}15} \tag{5}$$

and

$$k_H = \left(\frac{H}{H_0} \right)^{-0{,}15} \tag{6}$$

L and H are the actual dimensions of the beam, whereas L_0 (=5400 mm) and H_0 (=300 mm) are the dimensions of the standard beam. BL and BL_0 (=4 m) are the average lengths of the boards used.

Assuming a mean value of board length of about 4 m, *eq(5)* may be reduced to:

$$k_L = \left(\frac{L}{L_0} \right)^{-0{,}15} \tag{7}$$

The load configuration factor k_F may be determined according to Colling (1986). In case of a beam with uniformly distributed load, a value of

$$k_F = 1{,}04 \tag{8}$$

may be assumed.

Based on *eq(3)*, the characteristic bending strength of the standard beam with constant loading may then be calculated as:

$$\begin{aligned} f^0_{m,k} &= 1{,}04 \cdot 0{,}84 \cdot f_{m,k,fj} \\ &= 0{,}874 \cdot f_{m,k,fj} \qquad (9) \end{aligned}$$

From this equation can be derived that the characteristic bending strength of finger joints must be 15% (1/0,874 = 1,144) higher than the characteristic bending strength to be achieved for the final glulam beam.

Thus, the following proposal for the design of glulam beams may be established:

Based on the characteristic bending strength $f^0_{m,k}$ of a standard beam under constant loading, the characteristic bending strength $f_{m,k}$ of any glulam beam may be calculated as

$$f_{m,k} = \left(\frac{L}{5400} \cdot \frac{H}{300}\right)^{-0{,}15} \cdot k_F \cdot f^0_{m,k} \qquad (10)$$

with

L and H = length and depth of the beam in mm,
k_F = load configuration factor (=1 in case of a single span beam with uniformly distributed load).

The finger joints in the beam have to meet the following requirement:

$$f_{m,k,fj} \geq 1.15 \cdot f^0_{m,k}. \qquad (11)$$

It is essential to point out that in case of beams, systematically built up with laminations having significantly different MOE-values, the ultimate bending stress (in the outermost lamination) must be calculated according to the theory of transformed sections.

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