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DESIGN OF TIMBER COLUMNS

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1 INTRODUCTION

The design of timber columns in the draft Eurocode 5 (1986) and in the CIB Structural timber design code (1983) is based on the elastic theory with a linear failure criterion of the cross section: collapse of the column occurs when in the critical cross section an elastic limit stress is reached.

Some research results during the last years |1, 2| show that this is a conservative failure criterion. Taking into account the plastic deformations of the timber when subjected to compression parallel to grain, the ultimate loads of timber compression members are considerably higher than under assumption of the elastic theory.

It is the objective of this paper to provide approximate functions for the characteristic strength of centrically and eccentrically loaded timber columns.

2 STRENGTH MODEL

A computer model for calculating the ultimate loads of glued laminated columns was presented in |3| and is used to determine characteristic values of the load-carrying capacity of timber compression members. Monte-Carlo-simulations are used for calculating the ultimate load by a second order plastic analysis.

The principal run of the stress-strain-diagram (fig. 1) applies to both glued laminated and solid timber columns. In case of glulam columns the stress-strain-relationship of the cross section of each lamination with a length of 150 mm may be verified by using the following decisive structural attributes: density, knot area ratio, moisture content, portion of compression wood and finger-joint. Such detailed relations are unknown for timber sections in structural sizes. A great number of test results concerning the material properties of timber are, however, available. GLOS |4| presented for European softwood under normal climate (20/65) conditions statistic distribution functions of the elastic and the strength properties and their mutual correlations. The results of this study are based on values summarized in table 1 and 2. For the so-called asymptotic compressive strength $f_{c,a}$ and the ultimate compressive strain at failure $\varepsilon_{c,u}$ the following approximate values are assumed:

$$f_{c,a} = 0,85 \cdot f_{c,u} \qquad |N/mm^2| \qquad (1)$$

$$\varepsilon_{c,u} = 1250 \cdot f_{c,u}/E_{o,c} \qquad |‰| \qquad (2)$$

The influence of the moisture content ω on the stress-strain behaviour is taken into account by modifying the characteristic values of the stress-strain-relationship corresponding to table 3.

Based on these material data it is possible to simulate the stress-strain-relationship of solid timber members and to use this relationship in a realistic mechanical model.

The stochastic model of the glulam column includes the statistic distribution functions of the prevailing structural properties i.e. the density, the knot area ratio, the moisture content, the portion of compression wood and the finger joints. These structural properties determine the stress-strain curve of lamination sections. Furthermore, the geometric imperfections, such as curvature of the member axis and deviations of the cross-sectional dimensions from the nominal values, are included in the stochastic model. Simulating the structural properties in each lamination at an equal distance of 150 mm leads to elements with changing properties in longitudinal and transverse direction. The corresponding ultimate loads are a sample of the resistance of the element.

The basic variables of the stochastic model of the solid timber column are the elastic and the strength properties under normal climate (20/65) conditions as well as the moisture content. The probabilistic density of the moisture content of timber columns was determined in situ in a measuring series |5|. Furthermore, the statistic distribution functions of the geometric imperfections are used in the stochastic model of the solid timber columns. The resulting material properties within the timber column are, in analogy to |1|, assumed to be constant. The ultimate loads of a great number of members simulated in this way provide the resistance of European softwood timber columns. Fig. 2 shows the flow diagram of the simulation calculations for glulam and solid timber columns.

3 BUCKLING CURVES FOR CENTRICALLY LOADED COLUMNS

The evaluation of the calculation of the ultimate load is shown in Fig. 3 to 5. The 3-parameter Weibull distribution, fitted to the samples, is used to calculate the characteristic values of the failure stress, $f_{c,u}$, i.e. the buckling strength. The sample size amounts to 400 for high slenderness ratios and up to 1000 for low slenderness ratios. The simulation calculation for the glulam columns was realized with members of seven laminations.

Fig. 3 presents the characteristic values of the buckling strength depending on the slenderness ratio for glulam columns made from laminations of quality grade II according to the german standard DIN 4074. The single points represent the 5-percentiles resulting from the Monte-Carlo-simulations, the solid line describes a fitting approximate function. The approximating curve depends on the characteristic compressive strength $f_{c,o,k}$ and on the ratio $E_{o,k} / f_{c,o,k}$. Equation (3) is the function of the approximate curve:

$$g_c (f_{c,o,k}, E_{o,k}) = \varkappa \cdot f_{c,o,k} \qquad (3)$$

with

$$\varkappa = \begin{cases} 1 & \text{for } \bar{\lambda} \leq 0,5 \\ \dfrac{1}{k + \sqrt{k^2 + \bar{\lambda}^2}} & \text{for } \bar{\lambda} > 0,5 \end{cases}$$

$$k = 0,5\,(1 + 0,13\,(\bar{\lambda} - 0,5) + \bar{\lambda}^2)$$

$$\bar{\lambda} = \lambda / \lambda_f$$

$$\lambda_f = \sqrt{\frac{E_{o,k}}{f_{c,o,k}}} \cdot \pi$$

Fig. 3a belongs to glulam columns with an equilibrium moisture content for normal climate conditions, whereas Fig. 3b was calculated on the basis of a moisture content distribution, which was determined in buildings with a mean value of 14,8 % and a standard deviation of 1,2 %.

Due to a low moisture content the buckling strength of columns with low slenderness increases more than that of high slender columns. This may be explained by the distinct influence of the moisture content on the compressive strength, whereas the moisture content is of less influence on the modulus of elasticity.

Fig. 4 gives the characteristic buckling strengths for glulam columns from laminations of quality grade I (DIN 4074). Differences between the grades I and II are only based on different knot area ratios, as long as the laminations are graded only visually. COLLING and DINORT |7| found, however, that there are only small differences between the knot area ratios of the two quality classes. This explains the fact, that there is nearly no difference between the buckling strength of columns grade I and II (see Fig. 3b and 4b). A significant increase of the buckling strength is possible when an additional machine grading is applied, e.g. for density grading. Fig. 4a was calculated for glulam columns of grade I with an additional assumption of a minimum oven-dry density of 420 kg/m³. This leads to an increase of the characteristic values of about 15 % for all slenderness ratios.

The buckling strengths of solid timber columns, quality grade II, as shown in Fig. 5, are considerably lower than the corresponding data for glulam columns. This can be explained by the considerable higher variation of the material properties of solid timber compared to those of glulam as well as the higher moisture content of solid timber columns in situ (mean = 17,6 %, standard deviation = 3,0 %), the greater inital curvature of the member axis and the more unfavourable ratio of existing to nominal cross section area.

4 MOMENT-NORMAL FORCE-INTERACTION

The results of ultimate load calculations for eccentrically loaded columns are described as moment-normal force-interaction diagrams for glulam columns grade II (DIN 4074). The curves shown in Fig. 6 were computed for columns with different end eccentricities and slenderness ratios between $\lambda = 10$ and $\lambda = 200$. The values on the abscissa represent the end moments of the columns, i.e. the first order moments. The values on the normal force axis for $M/M_u = 0$ correspond to the buckling stresses for centrically loaded columns.

5 DESIGN PROPOSAL

For the design of timber and glulam columns the following design method is proposed:

Approximated curves for centrically loaded columns are shown in Figs. 3 to 5, whereas approximations for the moment-normal force-interaction are given as dashed lines in Fig. 7 for the slenderness ratios λ = 10, 60 and 120.

For columns the stresses should satisfy the following condition:

$$\left(\frac{\sigma_{c,o,d}}{\varkappa \cdot f_{c,o,d}}\right)^{m} + \frac{\sigma_{m,d}}{f_{m,d}} \leq 1 \qquad (4)$$

$\sigma_{m,d}$ is the bending stress caused by the first order bending moments.

$$\varkappa = \begin{cases} 1 & \text{for } \bar{\lambda} \leq 0,5 \\ \dfrac{1}{k + \sqrt{k^2 - \bar{\lambda}^2}} & \text{for } \bar{\lambda} > 0,5 \end{cases}$$

$$m = \begin{cases} 2 & \text{for } \bar{\lambda} \leq 0,5 \\ 1 & \text{for } \bar{\lambda} > 0,5 \end{cases}$$

with k and $\bar{\lambda}$ as defined in equation (3).

Using equation (4) the design of columns on the basis of a second order plastic analysis is reduced to a simple function depending only on the compressive strength $f_{c,o,k}$ and the modulus of elasticity $E_{o,k}$ of the timber used. The approximate equation (4) contains the influence of all structural and geometric imperfections, such as the initial curvature of the member axis.

Creep effects are not yet taken into account, but the influence of long duration loads is being investigated with a sophisticated computer program.

6 SUMMARY

For the design of timber compression members a new method is submitted, based on a non linear moment - normal force - interaction of the cross section. The method is derived from the results of extensive simulation calculations and applies to European spruce glulam and to European softwood timber columns. The material behaviour is taken into account better than in former methods. Whith this method a more economic design of columns is possible. The influence of moisture content and grading is shown for centrically loaded columns.

7 LITERATURE CITED

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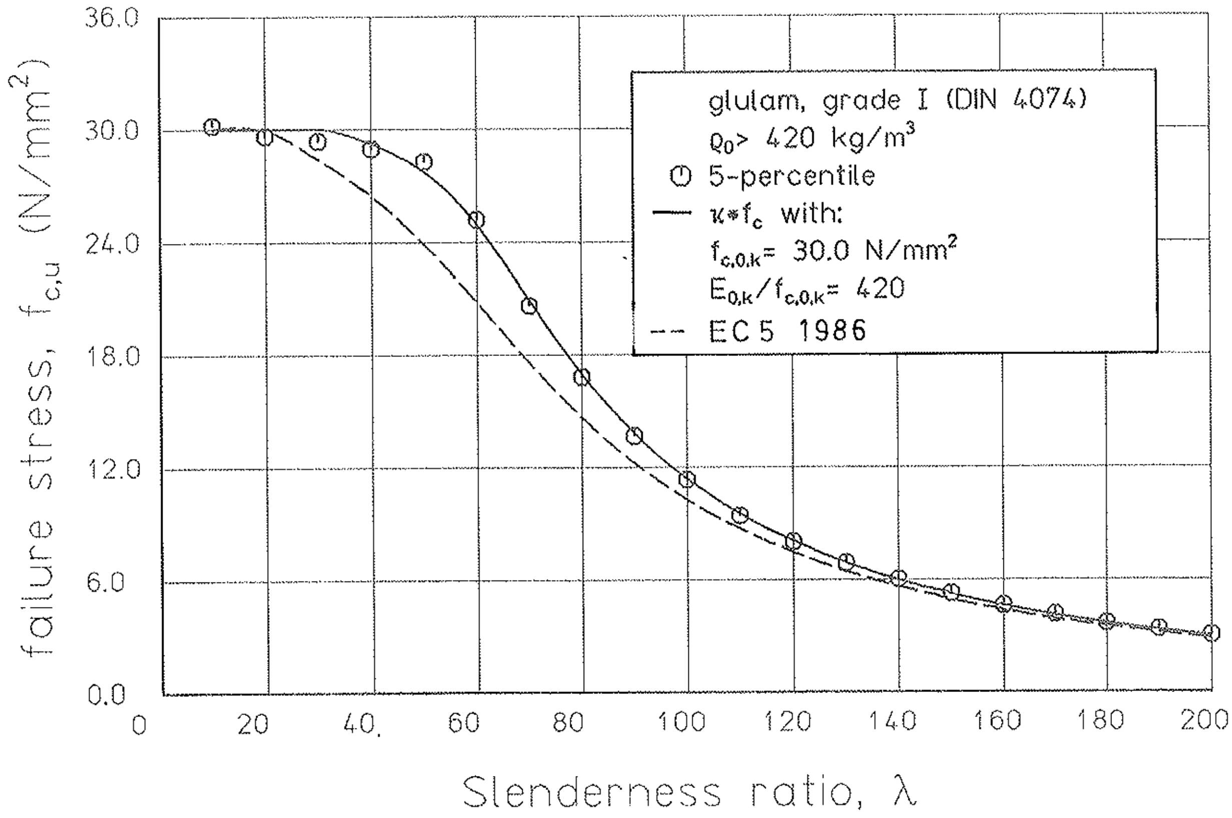
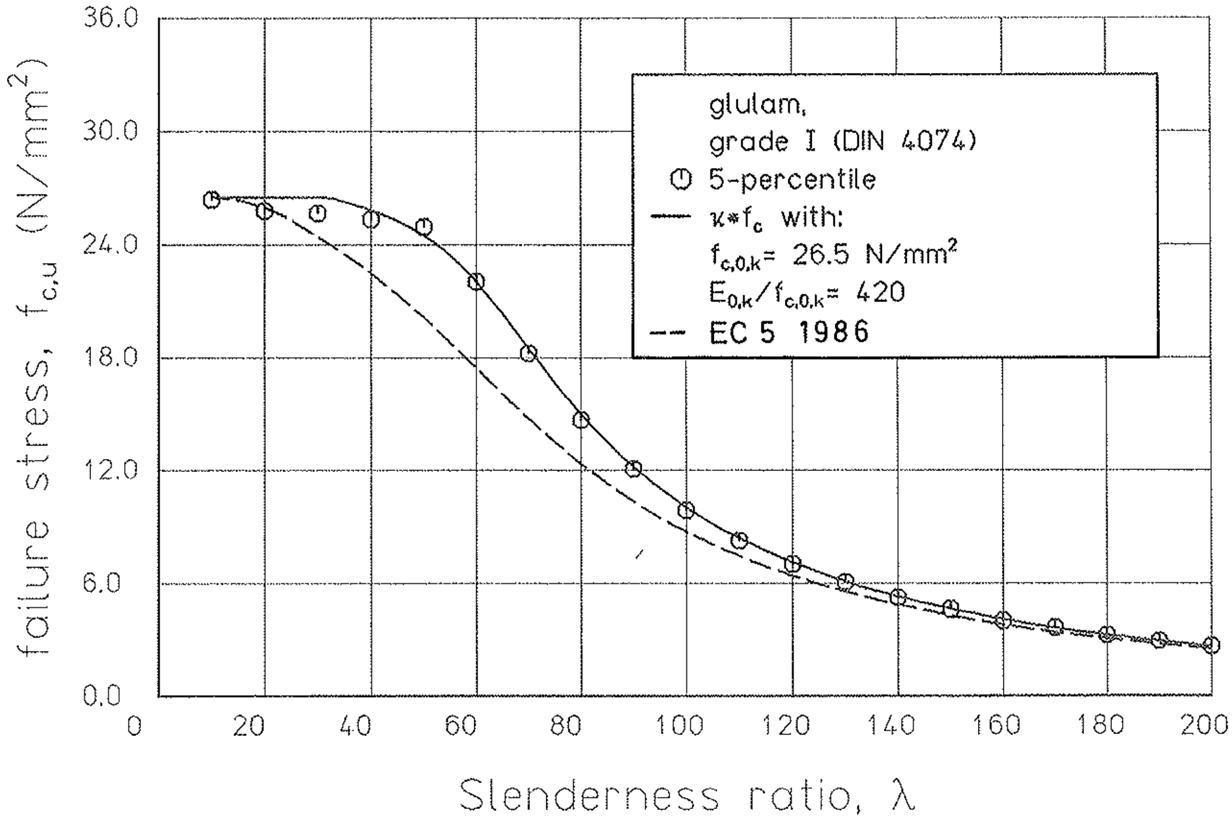


a) Compressive strength $f_{c,o,k}$ = 30,0 N/mm²



b) Compressive strength $f_{c,o,k}$ = 26,5 N/mm²

Fig. 4 Characteristic buckling strengths (failure stresses) for glulam columns grade I (DIN 4074) assuming different compressive strengths

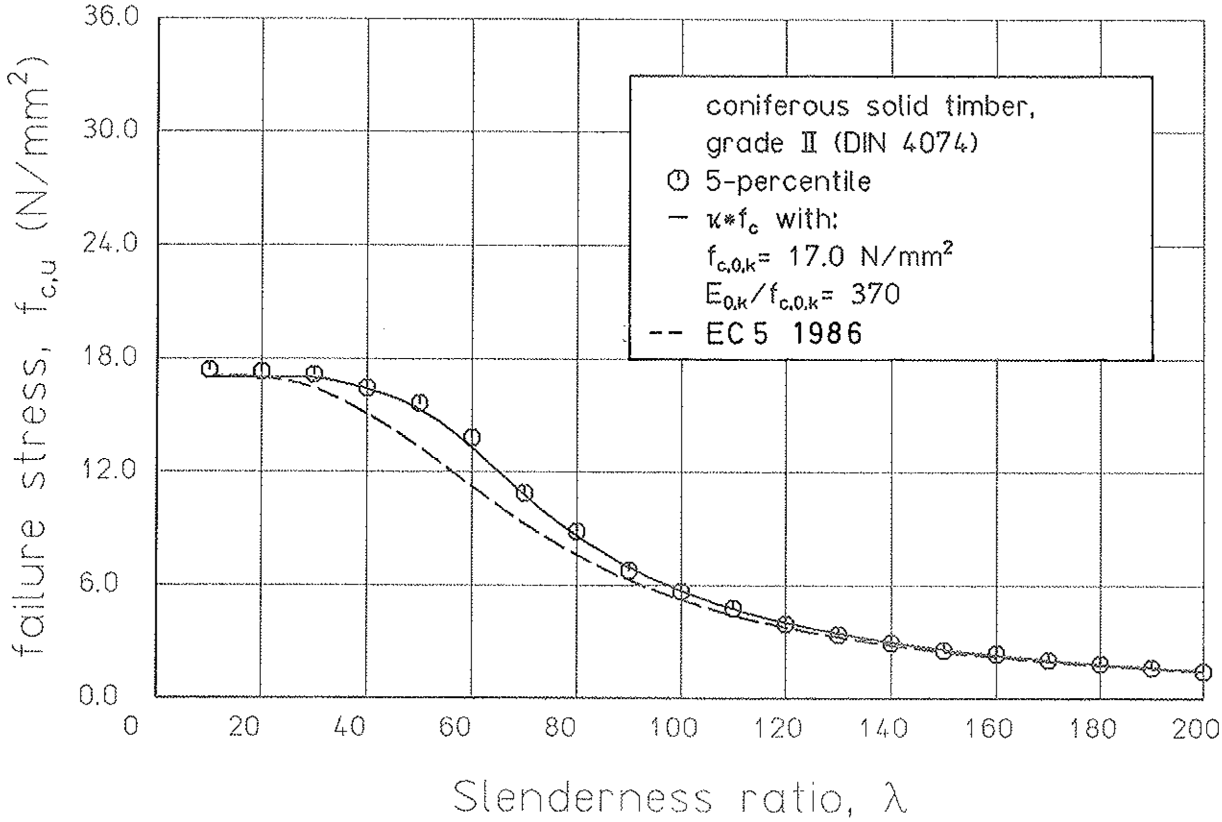


Fig. 5 Characteristic buckling strengths (failure stresses) for solid timber columns

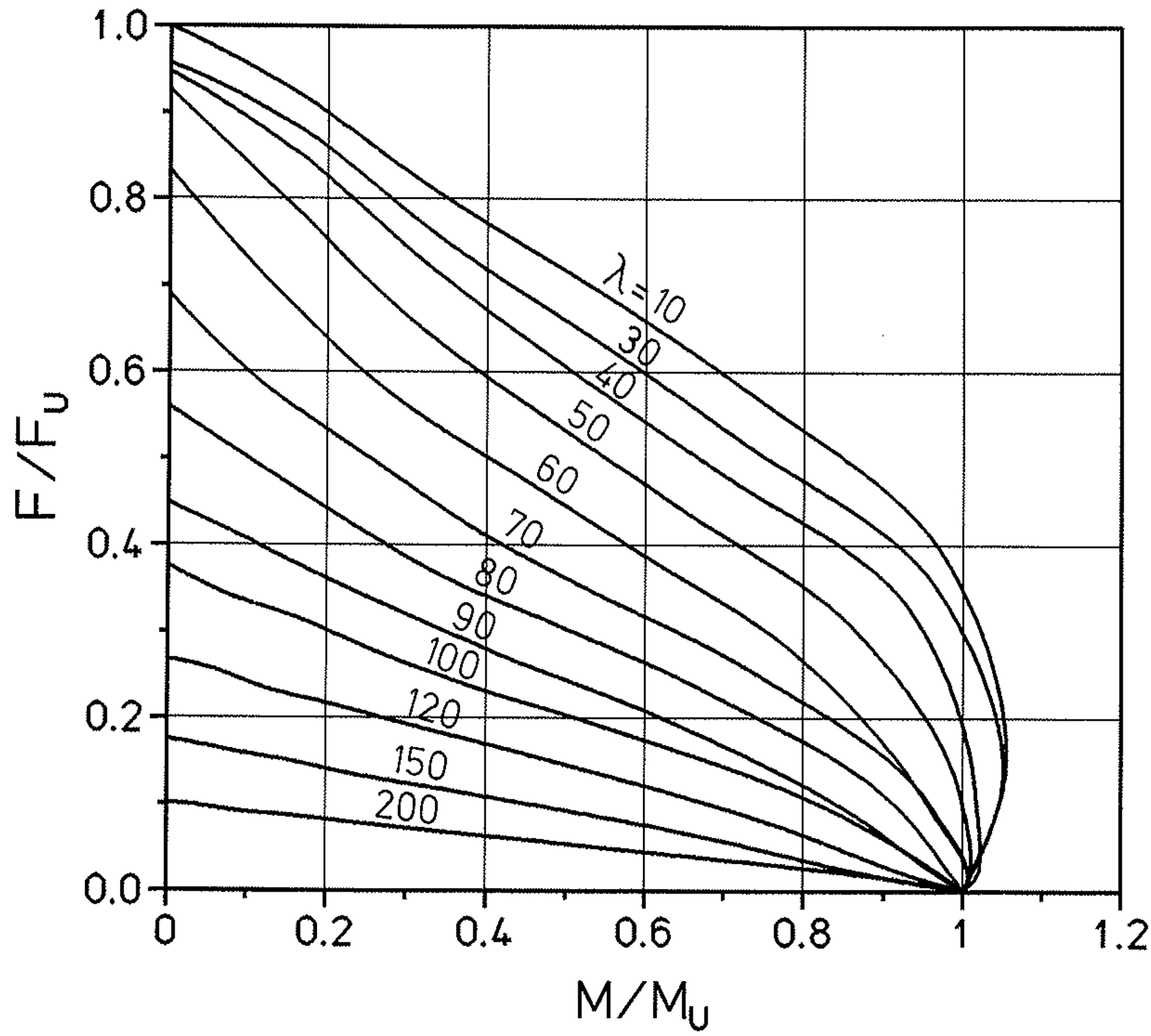


Fig. 6 Moment - normal force - interaction for glulam columns grade II

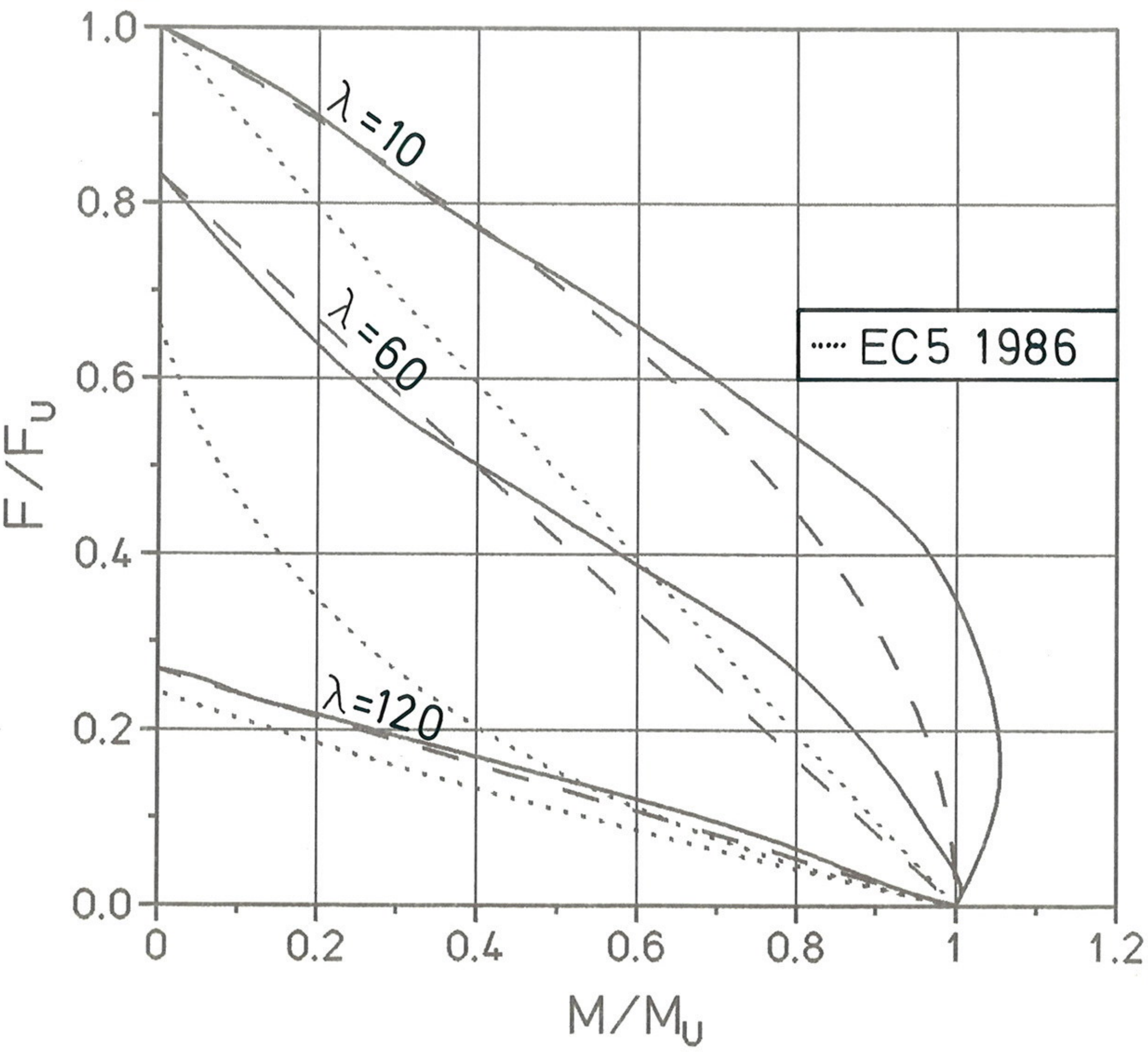


Fig. 7 Approximations for eccentrically loaded columns as basis for a new column design proposal

Table 1: Elastic and strength properties in Mpa and parameters of the 3-parameter Weibull distribution of European softwood in normal climate according to GLOS |4|

	compressive strength	bending strength	modulus of elasticity
Mean |Mpa|	32	37	11500
Coefficient of Variation	0,18	0,27	0,22
5-percentile |Mpa|	21	24	7000
Parameters of the 3-parameter Weibull distribution			
location |Mpa|	14	15	3500
Scale |Mpa|	20	26	9000
shape	2,6	2,5	3,1

Table 2: Relationship between compressive strength, bending strength and modulus of elasticity according to GLOS |4|

	compressive strength	bending strength	modulus of elasticity
compressive strength	1	0,8	0,75
bending strength	0,8	1	0,75
modulus of elasticity	0,75	0,75	1

Table 3: Modification of timber properties in % related to change of moisture content of $\Delta\omega$ = 1 %, based on ω = 12 % and applicable in the range of ω from 5 to 25 %, according to GLOS |4|

timber quality	compressive strength	bending strength	modulus of elasticity
low (5 percentile)	- 1	0	- 1
mean (50 percentile)	- 4	- 2	- 2
high (95 percentile)	- 6	- 3,5	- 3,5