CIB-W18A/21-102-1

INTERNATIONAL COUNCIL FOR BUILDING RESEARCH STUDIES AND DOCUMENTATION

WORKING COMMISSION W18A - TIMBER STRUCTURES

# RESEARCH ACTIVITIES TOWARDS A NEW GDR TIMBER DESIGN CODE BASED ON LIMIT STATES DESIGN

by

W Rug and M Badstube
Institute for Industrial Buildings
Academy of Building of the GDR
German Democratic Republic

MEETING TWENTY-ONE
PARKSVILLE, VANCOUVER ISLAND
CANADA
SEPTEMBER 1988

# Research Activities Towards A New GDR Timber Design Code Based On Limit States Design

By W. Rug and M. Badstube
Academy of Building of the GDR,
Institute for Industrial Buildings

Berlin, 1988

## Table of Contents

## 1. Status of research work

Recent basic research activities have resulted in further deepening the hitherto available state of knowledge, know-how and information included in the bibliographical references /1/, /2/ and /3/ as listed at the end of this paper.

In 1987, investigations have been accomplished in the GDR concerning the adaptation factors /4/, as to checking the load-bearing capacity of connecting means (timber fasteners) /8/, for acquiring basic values with nailed connections /17/, as to designing (dimensioning) compressed members /9/, /14/, /22/, concerning the compressive strength of structural timber /15/, as to the creep behaviour of structural timber /16/, and concerning the adaptation factors as to "aggressive media" /11/, /13/.

Furthermore, the latest publications were reviewed and evaluated and investigations into the material factor, into the standard values of the flexural strength of glued laminated timber, into the influence of the key-dovetail skew notch on the flexural strength of glued laminated timber, and into the tensile strength of key-dovetailed layers of timber boards have been performed. The results and findings of said investigations including a summary of all other results and findings are provided in reference /5/.

The hitherto existing draft code /1/ has been further improved.

A comparison of the improved draft code with the international trend shows that it complies widely with the ISO draft specification /23/ concerning the designations, the grades of moisture, the grades of load duration and with regard to the conditions prevailing for the experimental determination of the strength parameters of structural timber, glued laminated timber and connections (fasteners).

The great number of tests and experiments performed with a view to scientifically establishing and consolidating the new timber design code was effected in accordance with the standard recommendations as prepared by RILEM/CIB concerning the testing of structural timber and connections.

With the standard values of the design strength and of the magnitude of the material factor, in the main the Eurocode /25/ was followed. The adaptation factor as to "long-term behaviour" has been determined in accordance with the factors applied by the ISO Code and the Eurocode /25/, with the influence of the moisture on the strength as included in said factor being derived from the results of our own tests and experiments performed with beams when subjected to bending /2/.

The adaptation factors as to "cross-sectional height" and "curvature of timber" were obtained in accordance with the Swiss Code. In spite of the fact that the results and findings of our own tests and experiments performed with glued laminated timber beams with depths ranging between 192 mm and 900 mm - as related to the 5 % quantile - did not show any decrease in strength /3/, for the time being the proposed adaptation factor for the cross-sectional height will not be changed.

The adaptation factor for aggressive media considers mainly results and findings obtained from comprehensive investigations performed in the GDR.

In addition, investigations have been initiated with a view to preparing a special standard specification (code) concerning the analysis of the structural state of repair, the calculation (design) and restoration of historical timber structures /6/. Essential fundamentals for such a code are included in the papers as mentioned under /11/ to /13/ and /18/ to /21/.

## 2. Draft code

### 2.1. Basic values of the design strength and of the moduli of elasticity

The basic values of the design strength and of the moduli of elasticity are being obtained from the 5 % quantiles according to the formulae (1) and (2) as follows :-

$$R^{o} = \frac{R_{5\%} \cdot k_t}{\gamma_{m,o}} \qquad (1)$$

$$E^{o} = \frac{E_{5\%} \cdot k_t}{\gamma_{m,o}} \qquad (2)$$

$k_t$ = time factor = 0.75 with tension across the grain, shear stress in the limit state of the loadbearing capacity for structural timber and glued laminated timber

$k_t$ = time factor = 0.85 with bending and compressive stress and strain (across and parallel to the grain), tensile stress and strain parallel to the grain in the limit state of the loadbearing capacity for structural timber and glued laminated timber

$\gamma_{m,o}$ = 1.3 with bending and tensile stress and strain (across and parallel to the grain, shear stress and strain for structural timber and glued laminated timber

$\gamma_{m,o}$ = 1.1 with compressive stress and strain parallel to and across the strain in the limit state of the loadbearing capacity for structural timber and glued laminated timber

Since our own investigations into the influence of the load duration on the strength of structural timber and glued laminated timber are not yet completed, the time factor $k_t$ was determined in accordance with the reviewed and evaluated international status. In this connection, mainly the standard recommendations included in /23/ and /24/ have been followed.

The material factor was obtained from a comparison with the method of permissible stresses and in accordance with the reviewed international publications. Additional investigations to be performed on a probabilistic basis are planned.

The calculated basic values as included in table 1 are based on the standard values as indicated in /2/.

## 2.2. Adaptation factor as to "long-term behaviour" $\gamma_{m,1}$

$\gamma_{m,1}$ covers the influence of the magnitude of loading, duration of loading, moisture of timber and temperature. As compared with /1/, the number of time grades has been increased from 3 to 4 (with time grade D applying to instantaneous load action - see table 2 b). The grouping into time grades subject to the possible load combinations is represented in table 2 c. The tables 2 d and 2 e are indicating the values of $\gamma_{m,1}$ for the limit state of the loadbearing capacity and for the limit state of the usability.

## 2.3. Adaptation factor as to "cross-sectional height" $\gamma_{m,2}$

$\gamma_{m,2}$ is included in table 3 which has not been changed as compared with /1/.

## 2.4. Adaptation factâr as to "curvature of timber" $\gamma_{m,3}$

$\gamma_{m,3}$ is included in table 4 which has not been changed as compared with /1/.

## 2.5. Adaptation factor as to "aggressive media" $\gamma_{m,4}$

Investigations recently performed by Erler as indicated in /11/ and /13/ resulted in an improvement of the recommendation included in /1/. $\gamma_{m,4}$ is given in the tables 5a to 5e subject to 3 stress degrees and to the cross-sectional size. The stress degrees are obtained from the grouping of available aggressive media (gases, solutions and solids) into ranges of aggressivity. With gases and solids, the grade of moisture must be considered when grouping them.

# 3. Results and findings of special investigations

## 3.1. Strength of key-dovetailed connections

When producing glued laminated timber, individual uniformly distributed layers of timber boards have been sampled from which test specimens subjected to tensile stress and strain (sized 10 by 70 by 550 mm - see figure 1) with and without key-dovetailing were manufactured.

With mechanically sorted layers of timber boards, 6 tests have been performed covering 20 to 68 specimens each (see tables 6a to 6d). Visually sorted layers of boards representing the quality grades I to III according to /26/ were subjected to 3 tests covering 21 to 96 specimens each (see tables 7a and 7b).

The tests have been accomolished in the standard condition as follows :-

- temperature of 20°C,
- moisture of timber from 8 to 13 %,
- test duration from 3 to 5 minutes.

The standard values are the 5 % quantiles of the three-parametric Weibull distribution according to /27/. The results and findings are shown in the tables 6a, 6c and 7a.

To an extent of 78 % of the test specimens with key-dovetailing, the failure occurred within the zone of the key-dovetailed connection whereas the specimens without key-dovetailing failed in the cross sections with large knot areas.

Layers of timber boards without key-dovetailing have a tensile strength being in part very much higher than that of key-dovetailed layers of boards. In addition, the tensile strength of mechanically sorted layers of boards (without key-dovetailing)considerably exceeds the values obtained for visually sorted layers of timber boards. Analogous results are achieved with regard to the moduli of elasticity of layers of boards without any key-dovetailing. The values for the tensile strength of key-dovetailed layers of boards correspond to international values stated by Larsen /28/, Ehlbeck and others /29/.

## 3.2. Influence of the key-dovetailed connection on the flexural strength of glued laminated timber

Girders of glued laminated timber (hereinafter sometimes referred to as GLT in English or as BSH when abbreviated in German within figures and/or tables) are being produced the layers of boards of which were sorted mechanically (see figure 2). The GLT (or BSH, respectively) cross sections correspond to those included as BSH 4 and BSH 6 in table 8. The bottom layer within the test zone - abbreviated in German as PB (see figure 3, layer 1) - was provided both with and without key-dovetailing (abbreviated in Herman as KZ). The key-dovetail skew notching (abbreviated in German as KZV) between the first and second layer amounts to 250 mm whereas with all other layers it is at choice. The key-dovetail length (abbreviated in German as KZL) amounts to 50 mm with these connections. With a view to providing a zone being free from transverse forces, a four-point loading has been selected for the test design and arrangement of the GLT girders. In order to avoid shear (diagonal tension) failures, an analysis of investigations performed by means of structural timber results in obtaining a ratio of 22 concerning the bending stress to shear stress, and in obtaining a ratio of 15 concerning the effective span to test-specimen height for a shear influence of about 6 per cent. Thus, the length of the test zone is obtained as 4 h (see figure 3).

By comparing the tests accomplished with and without key-dovetailing in layer 1, statements can be made concerning the effect of the key-dovetailing on the flexural strength of glued laminated timber (see table 9; comparison of test B1 with B2 and B3 with B4). Among other data, average values, 5 % quantile values and 1 % quantile minimum values of the flexural strength and of the modulus of elasticity in bending for the GLT girders are being indicated. The values are derived from three-parametric Weibull distributions. The results and findings one can state are as follows :-

1. As to their magnitude, the minimum values of the flexural strength and of the modulus of elasticity in bending correspond to the 5 % quantiles (see table 9; comparison of $R_{m,min}$ with $R_{m,5\%}$ and of $E_{m,min}$ with $E'_{m,5\%}$).

2. Flexural strength and modulus of elasticity in bending are increasing with an improving quality of glued laminated timber (see table 9: B4 compared with B2; B3 compared with B1). Thus, the amounts of the increase in strength for the standard value of $R_m^n = R_{m,5\%}$ are with: BSH 6 (test B4) as compared with BSH 4 (test B2) equal to 43 %; BSH 6 (test B3) as compared with BSH 4 (test B1) equal to 42 %. The amounts of the increase in the modulus of elasticity in bending for the standard value of $E_m^n = \overline{E}_m$ are with: BSH 6 (B4) as compared with BSH 4 (B2) equal to 16 %; BSH 6 (B3) as compared

with BSH 4 (B1) equal to 16 %. One can see that the amounts of the increase in flexural strength and modulus of elasticity in bending with an improving quality of GLT in case of the girders without any key-dovetailing (tests B4 and B2) are nearly equal to those prevailing in case of the girders with key-dovetailing (tests B3 and B1).

3. The tests performed by means of BSH 4 without key-dovetailing in layer 1 of the test zone (see table 9: test B2) result in increased strength values being higher by 12 % for $R_{m,5\%}$ as compared with those tests accomplished by means of GLT with key-dovetailing (see table 9: test B1). The tests performed by means of BSH 6 without key-dovetailing (table 9: B4) result in increased strength values being higher by 11 % for $R_{m,5\%}$ as compared with those tests accomplished by means of GLT with key-dovetailing (table 9: B3). Thus, the key-dovetailing has adverse effects on the flexural strength of GLT (BSH) girders.

4. The failure of the GLT girders is initiated by the rupture of the first layer in the key-dovetailing area to an extent of about 80 % and in the layer cross section with larg knots to an extent of about 20 % only.

## 3.3. Influence of the key-dovetail skew notch on the flexural strength of glued laminated timber

14 GLT girders have been selected the key-dovetail skew notching of which between the first and second layer (when counted from the bottom) amounted to 0 up to 800 mm; during the tests, the failure occurred always in the key-dovetailing of the first layer. The influence of the key-dovetail skew notch on the flexural strength $R_m$ should be determined by means of a regression analysis. The regression analysis yields the regression equations with the appropriate correlation coefficients as indicated in table 10. The highest correlation coefficient amounting to r = 0.473 is provided by equation 4. However, the connection is weak (see reference /31/, page 85). The reason for this must be sought in the fact that the scattering or deviation due to the effect of

influencing factors other than key-dovetail skew notching is considerable.

With r = 0,473, $R_m$ is equal to 32.71 $(KZV)^{0.0066}$ $(\frac{N}{mm^2})$. Measured values and functional values of the equation 4 are plotted in figure 4. As for a deviation of 1 % of the flexural strength with KZV = 800 mm, the result will be a minimum key-dovetail skew notch (min.KZV) between the first and second layer amounting to 150 mm.

## 3.4. Influence of the key-dovetail length

(a) Influence of the key-dovetail length on the flexural strength of glued laminated timber girders

GLT girders of the production A having a key-dovetail length (abbreviated in German as KZL) of 50 mm the failure of which during the tests occurred always in the key-dovetailing (abbreviated in German as KZ) are being selected and compared with GLT girders of the production B having a key-dovetail length of 20 mm.

The GLT girders consist of visually sorted layers of timber boards of grade II coniferous sawn timber (abbreviated in German as NSH II). The results of the tests are indicated in table 11 from Weibull distributions. When comparing the 5 % quantiles of the flexural strength, one will find out that glued laminated timber having a key-dovetail length of 20 mm (KZL 20) has an increased strength being by 23 % higher than that of glued laminated timber having a key-dovetail length of 50 mm (KZL 50).

The reasons for the increased strength values may be not only the key-dovetail lengths but also the different level of wear and tear (deterioration) of the technologies concerned (see table 11). Thus, for instance, the key-dovetailing press employed in case of production A is obsolete as compared with that employed in case of production B.

(b) Influence of the key-dovetail length on the tensile strength of key-dovetailed layers of timber boards

The tensile strengths obtained as a result of tests performed by means of visually sorted key-dovetailed layers of timber boards (see table 7a) are being indicated in table 12. The test specimens are sampled from the productions A and B. When comparing the 5 % quantiles of the tensile strength (see table 12), one will find out that glued laminated timber of production B having a key-dovetail length of 20 mm (KZL 20) has an increased tensile strength being by 24 % higher than that of glued laminated timber of production A having a key-dovetail length of 50 mm (KZL 50). However, production B is also provided with a technology being better than that of production A. When comparing the 5 % quantiles of the flexural strength with those of the tensile strength (i.e. a comparison of table 11 with table 12), one will find out that the value of the flexural strength amounts to 1.7 times the value of the tensile strength in case of both the productions A and B.

## 4. Summary - Problems to be solved in future

The hitherto available draft code /1/ was further improved by making use of the latest knowledge, know-how and information. Changes and modifications occurred concerning the grades of load duration and with regard to the adaptation factor as to "aggressive media". The basic values of the design strength for structural timber and glued laminated timber were defined. A comparison of the tensile strength of key-dovetailed layers of timber boards with that of layers of boards without any key-dovetailing results in determining a decrease in strength by 38 % for key-dovetailed layers of timber boards.

The tensile strength of mechanically sorted layers of timber boards without any key-dovetailing is considerably higher than that of visually sorted layers. Glued laminated timber girders without any key-dovetailing have an increased flexural strength (being higher by 11 to 16 %) - when related to the 5 % quantile - as compared with girders with key-dovetailing in the test zone.

The research activities to be performed in future shall be orientated towards investigations into the following problems :-

1. The possibility of increasing the strength of glued laminated timber girders.

2. The loadbearing capacity of glued laminated timber girders subjected to a long-term loading (stress and strain).

3. Fundamentals required for the restoration of historical timber structures.

4. Fundamentals required for preparing a separate code applying to timber-based engineering material structures.

5. Fundamentals required for improving the methods and procedures of sorting.

## 5. Bibliographical references

(Note: The references marked (x) are indicating publications or papers in German!)

/1/ Rug, W.; Badstube, M.
New Developments of Limit States Design for the New GDR Timber Design Code
Academy of Building of the GDR, CIB-W18-Paper 19-102-4, Florence, 1986.

/2/ Rug, W.; Badstube, M.
Development of a GDR Limit States Design Code for Timber Structures
Academy of Building of the GDR, Institute for Industrial Buildings. CIB-W18-Paper 20-102-1; Dublin, 1987.

/3/ Badstube, M.; Rug, W. (x)
Forschungsarbeiten auf dem Gebiet der Bemessung nach Grenzzuständen in Vorbereitung auf den neuen DDR-Standard Holzbau (Research activities in the field of limit states design in preparing the new GDR Timber Design Code).
Published in: Holztechnologie, Leipzig 22 (1986):281-336; Bauforschung-Baupraxis Heft 205, Berlin 1988

/4/ Zimmer, K.-H. (x)
Anpassungsfaktoren für die Bemessung nach Grenzzuständen im Holzbau (Adaptation factors for limit states design in timber construction).
Published in: Bauforschung-Baupraxis Heft 205, Berlin 1988

/5/ Badstube, M.; Rug, W. (x)
Berechnung nach Grenzzuständen im Holzbau, Teilthema: Grundlagen, Berechnung und Konstruktion von Holzkonstruktionen (Limit states design in timber construction; Partial theme: Fundamentals, design and construction of timber structures). Academy of Building of the GDR, Institute for Industrial Buildings; Research report; Berlin, 1987.

/6/ Rug, W. (x)
Berechnung nach Grenzzuständen im Holzbau, Teilthema: Grundlagen, Berechnung und Instandsetzung von historischen Holzkonstruktionen (Limit states design in timber construction; Partial theme: Fundamentals, design and repair of historical timber structures).
Academy of Building of the GDR, Institute for Industrial Buildings; Research report; Berlin, 1987.

/7/ Rug, W. (x)
Internationaler Trend in der Normung
Mitteilung 1/88 des Fachausschusses Ingenieurholzbau und des Instituts für Industriebau, Berlin 1988 (in Vorbereitung).
(International trend in standardization - Information 1/88 of the Special Committee on Engineering Timber Construction and of the Institute for Industrial Buildings; Berlin, 1988 (under preparation)).

/8/ Zimmer, K.-H.; Lißner, K. (x)
Zum Nachweis der Tragfähigkeit von Verbindungsmitteln nach Grenzzuständen im Holzbau.
Mitteilung 1/88 ... Berlin 1988 (in Vorbereitung).
(On the check of the loadbearing capacity of fasteners by adopting limit states in timber construction - Information 1/88 ...as above...Berlin, 1988 (under preparation)).

/9/ Kaiser, K. (x)
Zur Bemessung schlanker Holzdruckstäbe nach Theorie II. Ordnung - Mitteilung 1/88 ... Berlin 1988 (in Vorbereitung).
(On the design of slender compressed timber members by adopting the second-order theory - Information 1/88 ... as above...Berlin, 1988 (under preparation)).

/10/ Badstube, M. (x)
Rechenbeispiele zum 3. Entwurf des DDR-Fachbereichsstandards "Holzbau / Tragwerke / Teil 1". - Mitteilung 1/88 ... Berlin 1988 (in Vorbereitung).
(Calculation examples for the 3rd draft of the Special GDR Branch Code "Timber construction / Loadbearing systems / Part 1". - Information 1/88 ...as above...Berlin, 1988 (under preparation)).

/11/ Erler, K. (x)
Bauzustandsanalyse und Beurteilung der Tragfähigkeit von Holzkonstruktionen unter besonderer Berücksichtigung der Korrosion des Holzes (Analysis of the structural state of repair and evaluation of the loadbearing capacity of timber structures with particular consideration of the corrosion of timber).
Dissertation B (thesis); Wismar Engineering College, 1988.

/12/ Kothe, E. (x)
Grundlagen für die Berechnung und Instandsetzung alter Holztragwerke; Teilthema: Methode zur Bestimmung der Festigkeit von alten Holzkonstruktionen (Fundamentals for the design and repair of old timber loadbearing members; Partial theme: Method for determining the strength

of old timber structures).
Dresden University of Technology, Construction Engineering Department; Research report; Dresden, 1987

/13/ Erler, K. (x)
Berechnung nach Grenzzuständen im Holzbau
Teilthema: Anpassungsfaktor "Aggressive Medien" von Bau- und Brettschichtholz (Limit states design in timber construction - Partial theme: Adaptation factor as to "aggressive media" for structural timber and glued laminated timber).
Wismar Engineering College, Dept. for Technology in Construction; Research report; Wismar, 1987.

/14/ Kaiser, K. (x)
Berechnung nach Grenzzuständen im Holzbau
Teilthema: Beitrag zur Bemessung knickgefährdeter Holzbauteile nach der Methode der Grenzzustände (Limit states design in timber construction - Partial theme: Contribution to the dimensioning of timber components subjected to a risk of buckling by adopting the limit states method). Wismar Eng. Coll.; Research report; Wismar, 1987.

/15/ Kiesel, . (x)
Berechnung nach Grenzzuständen im Holzbau
Teilthema: Beitrag zur Ermittlung der Verteilungsfunktion der Festigkeitseigenschaften des Bauholzes unter besonderer Berücksichtigung des Festigkeitsverhaltens bei der Druckbeanspruchung für eine Bemessung nach der Methode der Grenzzustände (Limit states design in timber construction - Partial theme: Contribution to the determination of the distribution function of the strength properties of structural timber with particular consideration of the strength behaviour under compressive stress for a dimensioning by adopting the limit states method).
Wismar Eng. Coll.; Research report; Wismar, 1987.

/16/ Karstadt, M. (x)
Bemessung nach Grenzzuständen im Holzbau
Teilthema: Vorschlag für Anpassungsfaktoren zum Langzeitverhalten biegebeanspruchter Vollholzquerschnitte (Limit states design in timber construction - Partial theme: Proposal for adaptation factors as to long-term behaviour of solid timber cross sections subjected to bending stress).
Wismar Eng. Coll.; Research report; Wismar, 1987.

/17/ Lißner, K. (x)
Bemessung nach Grenzzuständen im Holzbau
Teilthema: Experimentelle Ermittlung der Rechengrundwerte der Tragfähigkeit von Nagelverbindungen
(Limit states design in timber construction - Partial theme: Experimental determination of the basic design values of the loadbearing capacity of nailed connections)
Dresden University of Technology; Construction Engineering Dept.; Research report; Dresden, 1987.

/18/ Erler, K. (x)
Grundlagen zur Rekonstruktion von Holzkonstruktionen
(Fundamentals for the restoration of timber structures).
Wismar Eng. Coll.; Research report (not published);
Wismar, 1984.

/19/ Erler, K. (x)
Bauzustandsanalyse, Instandsetzung und Rekonstruktion
von Holzkonstruktionen
Entwurf einer Richtlinie; Mitteilung 1/85 des Fachausschusses Ingenieurholzbau und des Instituts für Industriebau, Berlin 1986
(Analysis of the structural state of repair, repair and restoration of timber structures; - Draft guideline specification - Information No. 1/85 of the Special Committee on Engineering Timber Construction and of the Institute for Industrial Buildings; Berlin, 1986).

/20/ Seemann, A. (x)
Durchführung von Versuchen zur Feststellung der Tragfähigkeit von eingebautem (alten) Bauholz und Auswertung der dazu vorhandenen Literatur
(Implementation of tests for determining the loadbearing capacity of built-in (old) structural timber and review of the available publications).
Weimar College of Architecture and Construction; University graduation paper; Weimar, 1988.

/21/ Mönck, W. (x)
Schäden an Holzkonstruktionen - Analyse und Behebung
(Damages done to timber structures - Analysis and repair).
1st edition; Berlin, 1987.

/22/ Duy, W. (x)
Ebenes Spannungsproblem im Holzbau, Berechnungsgrundlage
(Plane stress problem in timber construction; Design basis)
Published in: Bauforschung-Baupraxis, Heft 210; Berlin, 1987.

/23/ ISO-TC-165-N, 1983-05-11
Timber Structures, Design, First Working Draft; June, 1983; ISO, Technical Committee 165.

/24/ CIB-W18-Code
CIB - Structural Timber Design Code, Sixth Draft; January, 1983; CIB Report 1983, Publication G6, Working group W18, Timber Structures.

/25/ Larsen, H.-J.
Eurocode 5, Timber Structures
CIB-W18-Paper 18-1-2, Orew 1980.

/26/ DDR-Norm: (x)
TGL 117-0767, 1963. Bauschnittholz, Gütebedingungen
(GDR Code ... Sawn Timber - Quality Conditions).

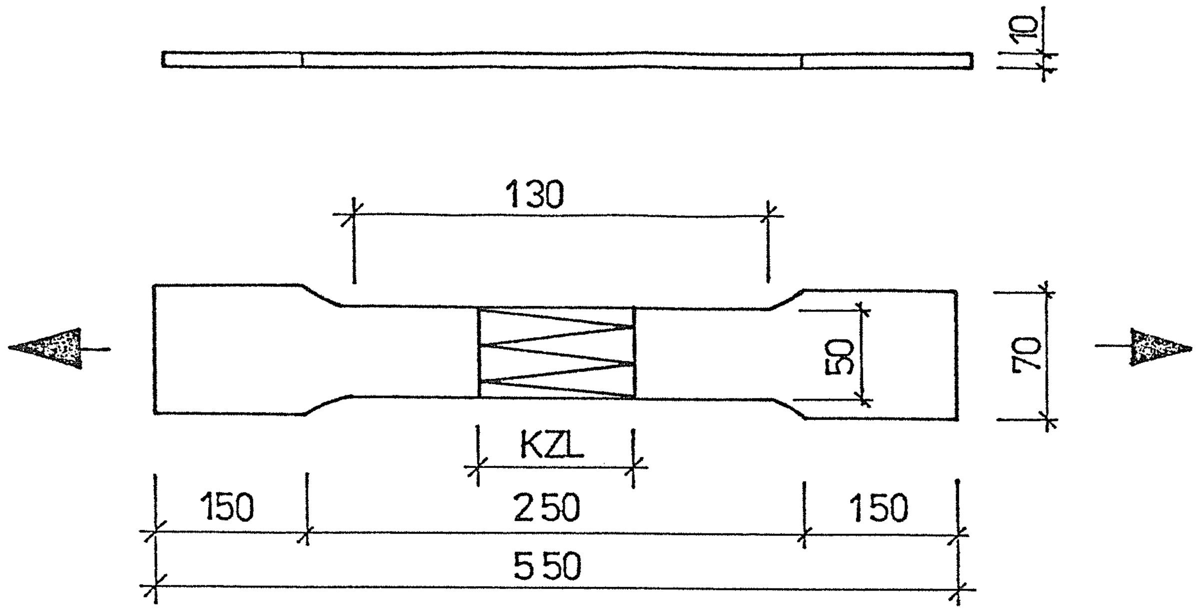
/27/ RGW-Norm: (x)
ST-RGW 877-78; DDR-Norm TGL 38791/03
Angewandte Statistik, Bestimmung der Schätzwerte und Konfidenzgrenzen für Parameter der Weibull-Verteilungen
(CMEA Code ... ; GDR Code ... - Applied Statistics; Determination of Estimated Values and Confidence Limits for Parameters of the Weibull Distributions).

/28/ Larsen, H.-J. (x)
Die Festigkeit von Brettschichtholz
In: Ingenieurholzbau in Forschung und Praxis
(The Strength of Glued Laminated Timber - Published in: ...as above...)
Karlsruhe, 1982.

/29/ Ehlbeck, J.; Colling, F.; Görlacher, R. (x)
Einfluß der Keilzinkenlamellen auf die Biegefestigkeit von Brettschichtholzträgern (Influence of the key-dovetailed lamellae on the flexural strength of glued laminated timber girders).
In (published in): Holz als Roh- und Werkstoff 43 (1985): 333-337; 43 (1985):369-373; 43 (1985):439-442.

/30/ Apitz, R. (x)
"Ermittlung von Festigkeitswerten für Vollholz bei der Beanspruchungsart Biegung durch Versuche"
(Determination of strength values for solid timber subjected to the bending type of stress and strain by means of tests)
Wismar Engineering College; Research report; Wismar, 1982.

/31/ Schindowski, Schürz (x)
"Statistische Qualitätskontrolle"
(Statistical Quality Control).
7th edition; Publishers: VEB Verlag Technik, Berlin.




quality grade II sawn coniferous timber

key-dovetail length of 50mm with production A
key-dovetail length of 20mm with production B

Figure 1: Tensile test with key-dovetailing

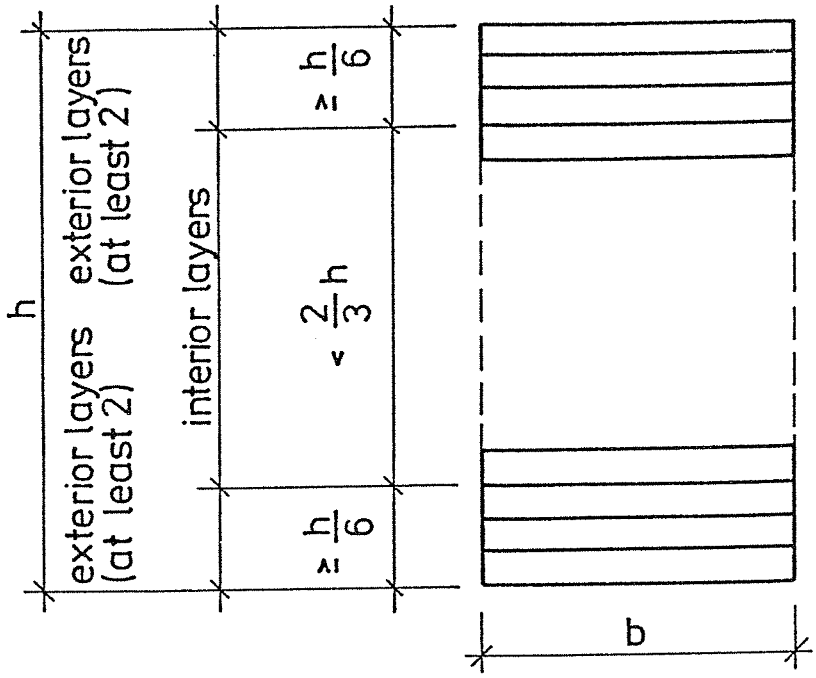
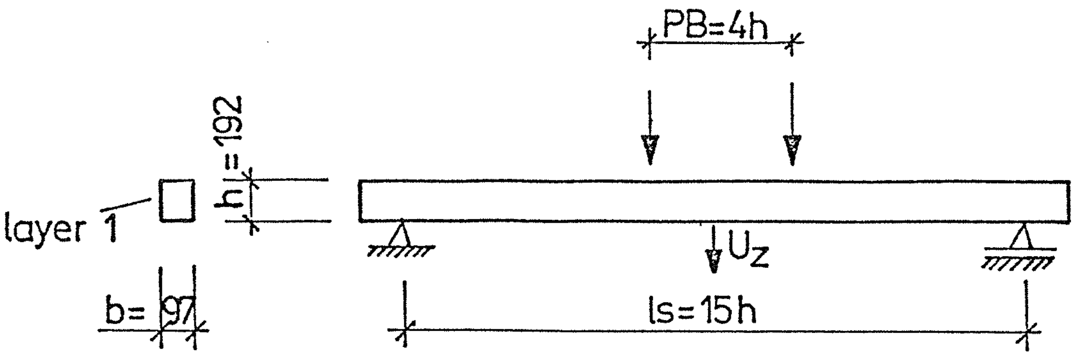



Figure 2: Design of glued laminated timber




12 test specimens for each test

Designations:

PB = test zone
BSH = glued laminated timber
F = strength grade
KZ = key-dovetailing

Figure 3: Test arrangement

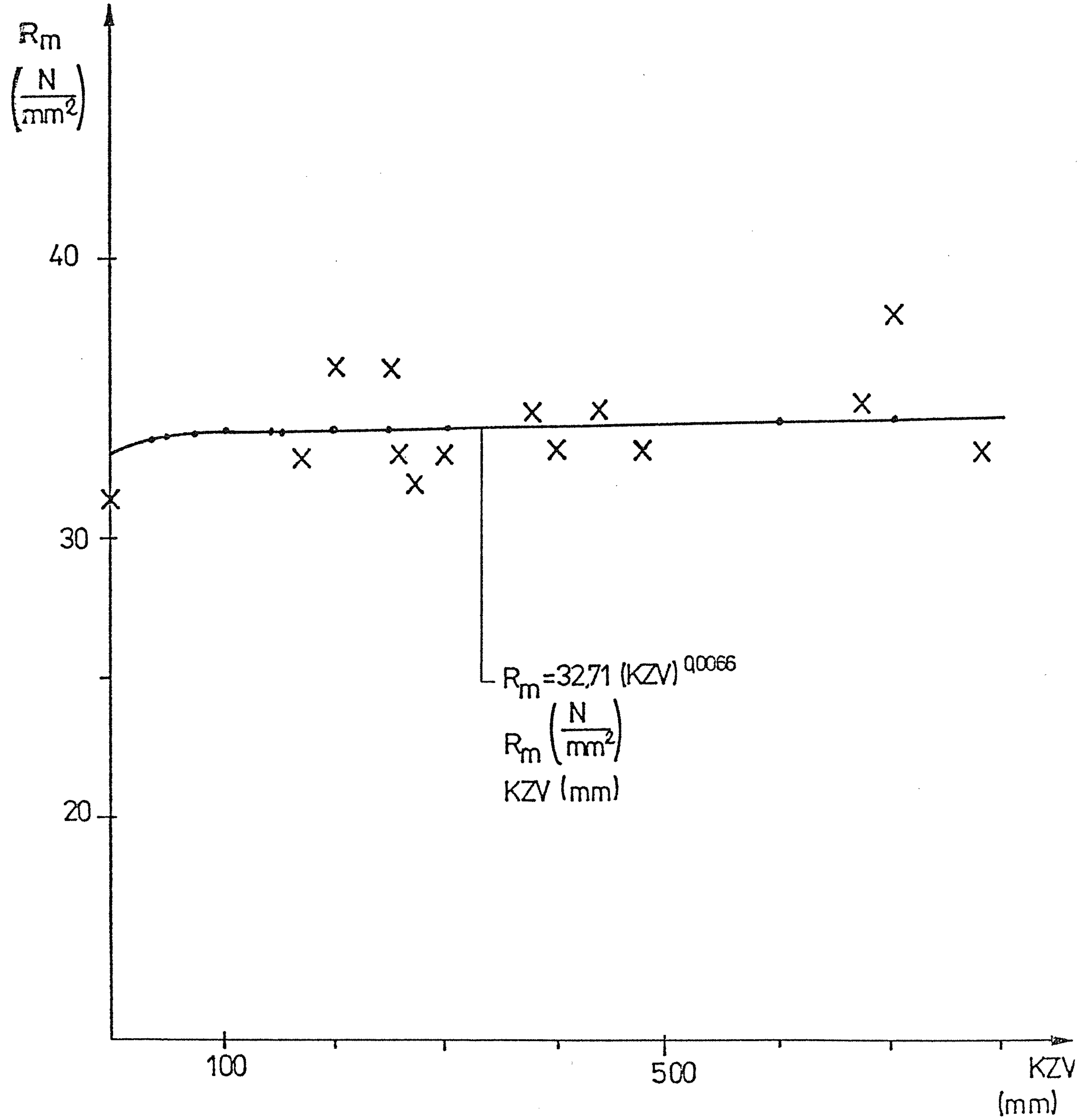



Figure 4: Behaviour of $R_m(KZV)$

KZV=key -dovetail skew notching

Table 1: Basic values of the design strength, standard and basic values of the elastic moduli (E) and shearing moduli (G), in $\frac{N}{mm^2}$

| | | softwood | | | | | | | | | | | | | hardwood |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | sawn timber | | | | | | glued laminated timber | | | | | | round timber | |
| | | quality grade | | | strength grade | | | grade | | | | | | | |
| | | I | II | III | I | II | III | 1 | 2 | 3 | 4 | 5 | 6 | | |
| bending | $R^o_m$ | 18,6 | 15,7 | 14,1 | 24,9 | 18,6 | 14,1 | 18,6 | 15,7 | 14,1 | 19,6 | 18,6 | 15,7 | 15,7 | 19,6 |
| tension | $R^o_{t,o}$ | 11,8 | 8,5 | 4,9 | 15,7 | 11,8 | 7,2 | 8,5 | 6,2 | 8,5 | 9,5 | 10,1 | 8,8 | 8,5 | 13,1 |
| | $R^o_{t,90}$ | 0,3 | 0,25 | 0,1 | 0,35 | 0,3 | 0,15 | 0,25 | 0,2 | 0,25 | 0,25 | 0,3 | 0,25 | 0,25 | 0,3 |
| compression | $R^o_{c,o}$ | 20,1 | 16,2 | 14,7 | 23,2 | 20,1 | 14,7 | 16,2 | 15,1 | 16,2 | 13,5 | 20,1 | 13,5 | 16,2 | 20,1 |
| | $R^o_{c,90}$ | 6,2 | 5,8 | 5,4 | 8,5 | 6,2 | 5,4 | 5,8 | 5,4 | 5,8 | 5,8 | 6,2 | 5,8 | 5,8 | 6,2 |
| shearing-off ll to the grain | $R^o_{\upsilon,o}$ | 1,3 | 1,2 | 1 | 1,7 | 1,3 | 1 | 1,3 | 1,2 | 1 | 1,4 | 1,3 | 1,2 | 1,2 | 1,7 |
| shear from transv. force | $R^o_{\upsilon}$ | 1,7 | 1,6 | 1,4 | 2,2 | 1,7 | 1,4 | 1,7 | 1,6 | 1,4 | 1,8 | 1,7 | 1,5 | 1,6 | 1,7 |
| moduli | $E^n_o$ | 12 000 | 11 000 | 10 000 | 13 500 | 12 000 | 10 000 | 12 000 | 11000 | 10 000 | 12 500 | 12 000 | 11 000 | 11 000 | 12 500 |
| | $E^n_{90}$ | 400 | 350 | 300 | 450 | 400 | 300 | 400 | 350 | 300 | 400 | 400 | 350 | 350 | 400 |
| | $G^n_{90}$ | 750 | 700 | 600 | 850 | 750 | 600 | 750 | 700 | 600 | 800 | 750 | 700 | 700 | 800 |
| | $E^o_o$ | 5600 | 4900 | 4600 | 6200 | 5600 | 4600 | 5600 | 4900 | 4600 | 5900 | 5600 | 4900 | 4900 | 5900 |
| | $E^o_{90}$ | 170 | 140 | 120 | 190 | 170 | 120 | 170 | 140 | 120 | 170 | 170 | 140 | 140 | 170 |
| | $G^o$ | 310 | 290 | 250 | 350 | 310 | 250 | 310 | 290 | 250 | 330 | 310 | 290 | 290 | 330 |

Table 2 a: Moisture grades

| Moisture grade (FK) | Relative air humidity $\varphi$ (%) | Moisture of timber u (%) | Case of application / Category of structure |
|---|---|---|---|
| FK 1 | $< 65$ | $\leq 18$ | Enclosed buildings/structures with and without heating; enclosed and ventilated animal shelter buildings without heating; open and partially open roofed-over buildings |
| FK 2 | $65 \leq \varphi \leq 85$ | >18 to 24 | Free-standing loadbearing systems/members without any protection against climatic influences; industrial buildings with corresponding technologies; wet rooms |
| FK 3 | $> 85$ | $> 24$ | Structures subjected to the immediate influence of water |

Table 2 b: Time grades

| Time grade | Duration of the load action |
|---|---|
| A | Permanently and/or for a long period (e.g. dead load, live load) |
| B | For a short period (e.g. live load, snow) |
| C | For a very short period (e.g. wind) |
| D | Suddenly (e.g. impact, earthquake) |

Table 2 c: Load combinations; grouping into time grades

| Load combination | Time grade | | | |
|---|---|---|---|---|
| | A | B | C | D |
| A + B | LA $\geq$ 85% | LA $<$ 85% | - | - |
| A + C | LA $\geq$ 85% | - | LA $<$ 85% | - |
| A + B + C | LA $\geq$ 85% | LC $\leq$ 15% | LC $<$ 15% | - |
| A + B + C + D | LA $\geq$ 85% | LD $\leq$ 15%<br>LA $\leq$ 85% | -<br>- | LD $>$ 15 %<br>- |

LA (etc.) means load percentage of time grade A (etc.) of the total load

e.g. $LA = \frac{A}{A+B}$

| Table 2 d: Adaptation factor $\gamma_{m,1}$ as to "long-term behaviour" for the limit state of the loadbearing capacity (GZT) | | | | | | |
|---|---|---|---|---|---|---|
| Time grade | M o i s t u r e g r a d e (FK) | | | | | |
| | FK 1 | | FK 2 | | FK 3 | |
| | BH | BSH | BH | BSH | BH | BSH |
| A | 0.85 | 0.8 | 0.75 | 0.66 | 0.65 | 0.4 |
| B | 1 | 1 | 0.85 | 0.83 | 0.75 | 0.5 |
| C | 1.2 | 1.2 | 1 | 1 | 0.9 | 0.6 |
| D | 1.3 | 1.3 | 1.2 | 1.16 | 1.05 | 0.7 |

BH means structural timber; BSH means glued laminated timber
For air temperatures of $40^{o}C \leq T \leq 70^{o}C$ and FK 1, $\gamma_{m,1}$ shall be multiplied by 0.85.

| Table 2 e: Adaptation factor $\gamma_{m,1}$ as to "long-term behaviour" for the limit state of the usability (GZN) | | | | | | |
|---|---|---|---|---|---|---|
| Time grade | M o i s t u r e g r a d e (FK) | | | | | |
| | FK 1 | | FK 2 | | FK 3 | |
| | BH | BSH | BH | BSH | BH | BSH |
| A | 0.65 | 0.8 | 0.4 | 0.5 | - | - |
| B | 0.75 | 0.85 | 0.5 | 0.6 | - | - |

| Table 3: Adaptation factor $\gamma_{m,2}$ as to "cross-sectional height" for the GZT limit state | | |
|---|---|---|
| Cross-sectional height h (mm) | Structural timber | Glued laminated timber |
| $\leq 200$ | 1 | 1.00 |
| $200 \leq h < 300$ | 0.95 | 1.00 |
| $300 \leq h < 500$ | - | 0.95 |
| $500 \leq h < 800$ | - | 0.9 |
| $800 \leq h < 1500$ | - | 0.85 |
| $\geq 1500$ | - | 0.8 |

| Table 4: Adaptation factor $\gamma_{m,3}$ as to "curvature of timber" for the GZT limit state | | | | | | |
|---|---|---|---|---|---|---|
| $\frac{t}{r}$ | 0 | $2 \cdot 10^{-3}$ | $4 \cdot 10^{-3}$ | $6 \cdot 10^{-3}$ | $8 \cdot 10^{-3}$ | $10^{-2}$ |
| $\gamma_{m,3}$ | 1 | 0.92 | 0.83 | 0.76 | 0.68 | 0.6 |

r is the radius of curvature of the curved timber.

t is the thickness of the curved timber or - with glued laminated timber - the thickness of one curved layer.

**Table 5: Adaptation factor $\gamma_{m,4}$ as to "aggressive media" for the GZT and GZN limit states for BH and BSH**

The kind of the media is grouped into gases, solutions and solids. By considering the criteria as to concentration of the medium concerned and the grade of moisture, the stress degrees (BG) I, II, III are obtained:

| Stress degree (BG) | Explanation |
|---|---|
| BG I | Not or slightly aggressive |
| BG II | Moderately aggressive |
| BG III | Heavily aggressive |

Upon grouping the medium concerned into a specific range of aggressivity, the stress degree (BG) can be determined by means of the tables following hereinafter. Depending on the cross-sectional size of the timber components concerned, the adaptation factor $\gamma_{m,4}$ for aggressive media can be drawn from table 5e with the stress degree concerned.

Ranges of aggressivity and stress degrees for gases

Table 5 a: Ranges of aggressivity for gases

| Gas, increasing aggressivity | Gas group with a concentration ($mg/m^3$) of: A 1 | A 2 | A 3 |
|---|---|---|---|
| 1. $CH_2O$ (formaldehyde) | 1 ... 200 | - | - |
| 2. $NH_3$ (ammonia) | 0.5... 20 | - | - |
| 3. $SO_2$ (sulphur dioxide) | 0.2... 10 | 10...200 | - |
| 4. $NO_2$ (nitric oxide) | 0.1... 5 | 5... 25 | above 25 |
| 5. HCl (hydrogen chloride) | 0.05... 1 | 1... 10 | above 10 |
| 6. $Cl_2$ (chlorine) | 0.02... 1 | 1... 5 | above 5 |

| Table 5 b: Stress degrees for gases | | | |
|---|---|---|---|
| Range of aggressivity | Moisture grade | | |
| | FK 1 | FK 2 | FK 3 |
| A 1 | I | I | I |
| A 2 | I | II | II |
| A 3 | II | II | II |

Table 5 c: Stress degrees for solutions

| Group | Solution | pH-value | Concentration of the solution | Degree of dissociation | Stress degree |
|---|---|---|---|---|---|
| Acids | nitric acid $HNO_3$ | below 2 | up to 5<br>above 5 | high | III<br>III |
| | hydrochloric acid HCl | | up to 5<br>above 5 | high | III<br>III |
| | sulphuric acid $H_2SO_4$ | | up to 5<br>above 5 /<br>above 15 | medium | I<br>II/III |
| | acetic acid $C_2H_4O_2$ | 4 | above 15 | low | I |
| Bases | soda lye NaOH | above 13 | up to 2<br>above 2 | high | II<br>III |
| | potash lye KOH | | up to 2<br>above 2 | high | II<br>III |
| | ammonium hydroxide $NH_4OH$ | | up to 5<br>above 5 | low | I<br>II |
| Salt solutions | chlorid solutions KCl, NaCl | 7 | up to 10<br>above 10 | medium | I<br>II |
| | sulphate solutions: $Na_2SO_4$ (Glauber's salt) | | up to 10<br>above 10 | medium | I<br>II |
| | $(NH_4)\ SO_4$ (ammonium sulphate) | 5 | up to 40 | | I |
| (Organic compound) | urea $CO\ (NH_2)_2$ | 2 | up to 40 | | II |

| Table 5 d: Stress degrees for solid media | | | | | | |
|---|---|---|---|---|---|---|
| Solid medium | pH-value | Solubility in water | Hygroscopicity | Stress degree (BG) with FK1 | FK2 | FK3 |
| potash fertilizer | 8 | good (up to 20 %) | good | I | II | II |
| urea | 9 | good (up to 40 %) | high | I | II | II |
| superphosphate | 3 | (up to 5%) | good | I | I | II |
| sodium chloride | 7 | good | good | I | I | II |
| ammonium sulphate | 5 | good (up to 40 %) | low | I | I | I |

Table 5 e: Adaptation factors $\gamma_{m,4}$ for aggressive media subject to the timber cross-sectional size

Note: Minimum dimension of the timber component with stress degrees BG II and BG III: 40 mm
Minimum cross-sectional area: 4000 $mm^2$

| Stress degree (BG) | Cross-sectional size ($10^3$ $mm^2$) | Factor $\gamma_{m,4}$ |
|---|---|---|
| BG I | | 1.0 |
| BG II | < 9<br>< 30<br>≥ 30 | 0.75<br>0.85<br>0.95 |
| BG III | < 9<br>< 30<br>≥ 30 | 0.65<br>0.75<br>0.85 |

Table 6a: Tensile strengths of mechanically sorted layers of boards (values of tests after 3 to 5 minutes; Weibull distributions, production A, KZL 50)

| test | sample | n<br>(-) | $\bar{\rho}$<br>$\left(\frac{kg}{m^3}\right)$ | $\bar{u}$<br>(%) | $\bar{R}t$<br>$\left(\frac{N}{mm^2}\right)$ | $V_R$<br>(%) | Rt 5%<br>$\left(\frac{N}{mm^2}\right)$ | Rt 1%<br>$\left(\frac{N}{mm^2}\right)$ | Rt min<br>$\left(\frac{N}{mm^2}\right)$ |
|---|---|---|---|---|---|---|---|---|---|
| Z 1 | FI without KZ | 35 | 582 | 6,0 | 67,4 | 23,8 | 41,6 | 33,9 | 29,7 |
| Z 2 | FI with KZ | 20 | 548 | 5,4 | 32,1 | 26,1 | 18,5 | 14,1 | 15 |
| Z 3 | FII without KZ | 38 | 537 | 5,8 | 52,5 | 31,9 | 25,5 | 17,4 | 18,8 |
| Z 4 | FII with KZ | 39 | 538 | 5,6 | 27,4 | 26,3 | 15,7 | 12,1 | 10,8 |
| Z 5 | FIII without KZ | 68 | 461 | 5,6 | 34,1 | 40,0 | 11,3 | 3,3 | 7,7 |
| Z 6 | FIII with KZ | 37 | 459 | 5,6 | 21,0 | 26,1 | 12,6 | 10,7 | 12,1 |

F = strength grade
KZ = key-dovetailing
KZL 50 = key-dovetail length of 50mm

Table 6b: Moduli of elasticity in tension for mechanically sorted layers of boards (values of tests after 3 to 5 minutes; Weibull distributions; production A, KZL 50)

| test | sample | n | $\rho$ | u | $E_t$ | $V_E$ | $E_{t,5\%}$ | $E_{t,1\%}$ | $E_{t,min}$ |
|---|---|---|---|---|---|---|---|---|---|
| | | (-) | $\frac{kg}{m^3}$ | (%) | $\frac{N}{mm^2}$ | (%) | $\frac{N}{mm^2}$ | $\frac{N}{mm^2}$ | $\frac{N}{mm^2}$ |
| Z 1 | F I without KZ | 7 | 536 | 9,0 | 14 071 | 14 | 12 252 | 12 181 | 12 470 |
| Z 2 | F I with KZ | — | — | — | — | — | — | — | — |
| Z 3 | F II without KZ | 17 | 499 | 9,0 | 11 475 | 12,1 | 9 569 | 9 249 | 9 590 |
| Z 4 | F II with KZ | — | — | — | — | — | — | — | — |
| Z 5 | F III without KZ | 23 | 476 | 9,0 | 8 949 | 19,1 | 6 533 | 6 077 | 6 490 |
| Z 6 | F III with KZ | 21 | 481 | — | 5 408 | 20,7 | 3 691 | 3 257 | 3 560 |

F =strength grade
KZ =key -dovetailing
KZL50=key-dovetail length of 50 mm

Table 6c: Tensile strengths of mechanically sorted layers of boards (values of tests after 3 to 5 minutes; Weibull distributions, production B, KZL 20)

| test | sample | n | $\bar{\varrho}$ | $\bar{u}$ | $\bar{R}_t$ | $V_R$ | $R_{t,5\%}$ | $R_{t,1\%}$ | $R_{t,min}$ |
|---|---|---|---|---|---|---|---|---|---|
| | | (-) | $\frac{kg}{m^3}$ | (%) | $\frac{N}{mm^2}$ | (%) | $\frac{N}{mm^2}$ | $\frac{N}{mm^2}$ | $\frac{N}{mm^2}$ |
| Z 1 | F I without KZ | 16 | 456 | 8,7 | 56,8 | 15,7 | 41,1 | 34,7 | 42,3 |
| Z 2 | F I with KZ | — | — | — | — | — | — | — | — |
| Z 3 | F II without KZ | 40 | 441 | 6,6 | 45,6 | 25,6 | 24,9 | 15,7 | 16,2 |
| Z 4 | F II with KZ | 7 | 434 | — | 28,4 | 18,7 | 19,8 | 15,2 | 19,2 |
| Z 5 | F III without KZ | 13,7 | 413 | 9,1 | 30,4 | 38,7 | 11,8 | 6,6 | 6,1 |
| Z 6 | F III with KZ | 93 | 420 | — | 26 | 28,3 | 15;2 | 13,0 | 11,0 |

F = strength grade
KZ = key-dovetailing
KZL50 = key-dovetail length of 50 mm

Table 6d: Moduli of elasticity in tension for mechanically sorted layers of boards (values of tests after 3 to 5 minutes; Weibull distributions, production B, KZL 20)

| test | sample | n<br>(-) | $\rho$<br>$\frac{kg}{m^3}$ | u<br>(%) | $E_t$<br>$\frac{N}{mm^2}$ | $V_E$<br>(%) | $E_{t,5\%}$<br>$\frac{N}{mm^2}$ | $E_{t,1\%}$<br>$\frac{N}{mm^2}$ | $E_{t,min}$<br>$\frac{N}{mm^2}$ |
|---|---|---|---|---|---|---|---|---|---|
| Z 1 | F I without KZ | 12 | 448 | 9,0 | 13 963 | 10,9 | 11 778 | 11 343 | 12 030 |
| Z 2 | F I with KZ | — | — | — | — | — | — | — | — |
| Z 3 | F II without KZ | 20 | 428 | 8,7 | 11 394 | 10,8 | 9 407 | 8 800 | 6 570 |
| Z 4 | F II with KZ | — | — | — | — | — | — | — | — |
| Z 5 | F III without KZ | 15 | 416 | 9,0 | 9 072 | 28,1 | 7 001 | 6 952 | 6 950 |
| Z 6 | F III with KZ | 31 | 435 | — | 6 101 | 23,6 | 3 740 | 2 973 | 3 340 |

F = strength grade
KZ = key-dovetailing
KZ 20 = key-dovetail length of 20 mm

Table 7a: Tensile strengths of visually sorted layers of boards (values of tests after 3 to 5 minutes; Weibull distributions, production A, KZL 50)

| test | sample | n | $\bar{\rho}$ | $\bar{u}$ | $\bar{R}_t$ | $V_R$ | $R_{t\,5\%}$ | $R_{t,1\%}$ | $R_{t,min}$ |
|---|---|---|---|---|---|---|---|---|---|
| | | (–) | $\frac{kg}{m^3}$ | (%) | $\frac{N}{mm^2}$ | (%) | $\frac{N}{mm^2}$ | $\frac{N}{mm^2}$ | $\frac{N}{mm^2}$ |
| Z 7 | GK I without KZ | 96 | 523 | 5,7 | 54 | 36,3 | 22,7 | 13,4 | 7,7 |
| Z 8 | GK II without KZ | 23 | 512 | 5,8 | 39,2 | 39,6 | 13,1 | 3,0 | 11,2 |
| Z 9 | GK III without KZ | 21 | 497 | 5,8 | 27,2 | 45,5 | 7,5 | 1,8 | 7,7 |

GK = quality grade
KZ = key-dovetailing
KZL 50 = key-dovetail length of 50 mm

| test | sample | n | $\bar{\varrho}$ | u | $E_t$ | $V_E$ | $E_{t,5\%}$ | $E_{t,1\%}$ | $E_{t,min}$ |
|---|---|---|---|---|---|---|---|---|---|
| | | (-) | $\frac{kg}{m^3}$ | (%) | $\frac{N}{mm^2}$ | (%) | $\frac{N}{mm^2}$ | $\frac{N}{mm^3}$ | $\frac{N}{mm^2}$ |
| Z 7 | GK I without KZ | 17 | 514 | 8,9 | 11 760 | 21,9 | 8 317 | 7 791 | 8 390 |
| Z 8 | GK II without KZ | 12 | 438 | 8,9 | 11 236 | 18,6 | 7 441 | 5 433 | 6 960 |
| Z 9 | GK II without KZ | 18 | 478 | 9,1 | 9 148 | 20,3 | 6 327 | 5 638 | 6 490 |

GK = quality grade
KZ = key-dovetailing
KZL 50 = key-dovetail length of 50 mm

Table 7b: Moduli of elasticity in tension for visually sorted layers of boards (values of tests after 3 to 5 minutes; Weibull distributions, production A, KZL 50)

Table 8: Design of the grades of glued laminated timber

| BSH - grade | | BSH 1 | BSH 2 | BSH 3 | BSH 4 | BSH 5 | BSH 6 |
|---|---|---|---|---|---|---|---|
| sorting of the layers | | visually | visually | visually | mechani-cally | mechani-cally | mechani-cally |
| exterior layers | kind of timber | NSH GkII | NSH GkII | NSH GkII | NSH F I | NSH F II | NSH F II |
| | KZV (mm) | ≥ 250 | ≥ 250 | ≥ 0 | ≥ 250 | ≥ 250 | ≥ 250 |
| interior layers | kind of timber | NSH GkII | NSH GkIII | NSH GkII | NSH FIII | NSH FII | NSH FIII |
| | KZV (mm) | ≥ 250 | ≥ 0 | ≥ 0 | ≥ 0 | ≥ 0 | ≥ 0 |

Designations:

BSH = glued laminated timber
NSH = sawn coniferous timber
KZV = key - dovetail skew notching
GK = quality grade acc. to /10/
F = strength grade acc. to /1/

Table 9: Results of the bending tests concerning mechanically sorted glued laminated timber

| test | test specimen | $\varrho$ $\left(\frac{kg}{m^3}\right)$ | $\bar{u}$ (%) | $\bar{R}_m$ $\left(\frac{N}{mm^2}\right)$ | $s_R$ $\left(\frac{N}{mm^2}\right)$ | $v_R = \frac{s_R}{R_m}$ (%) | $R_{m5\%}$ $\left(\frac{N}{mm^2}\right)$ | $R_{m1\%}$ $\left(\frac{N}{mm^2}\right)$ | $R_{m,min}$ $\left(\frac{N}{mm^2}\right)$ | $E_m$ $\left(\frac{N}{mm^2}\right)$ | $s_E$ $\left(\frac{N}{mm^2}\right)$ | $v_E = \frac{s_E}{E_m}$ (%) | $E_{m5\%}$ $\left(\frac{N}{mm^2}\right)$ | $E_{m1\%}$ $\left(\frac{N}{mm^2}\right)$ | $E_{m,min}$ $\left(\frac{N}{mm^2}\right)$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B 1 | BSH 4 +KZ 1) | 502 | 10,8 | 40,4 | 4,0 | 9,8 | 36,1 | 35,8 | 35,9 | 12646 | 904 | 7,2 | 11155 | 10661 | 11050 |
| B 2 | BSH 4 o. KZ 2) | 525 | 11,1 | 54,6 | 7,9 | 14,5 | 40,6 | 34,2 | 38,3 | 13818 | 1054 | 7,6 | 11879 | 10752 | 12040 |
| B 3 | BSH 6 + KZ | 504 | 11,2 | 33,3 | 5,3 | 15,8 | 25,5 | 23,9 | 25,1 | 10909 | 968 | 8,9 | 9563 | 9320 | 9700 |
| B 4 | BSH 6 o. KZ | 515 | 10,2 | 45,1 | 9,4 | 20,8 | 28,3 | 20,2 | 30,3 | 11876 | 1228 | 10,3 | 9915 | 9342 | 10054 |

Designations: $\varrho$ = density; u = moisture of timber; $R_m$ = flexural strength; $E_m$ = modulus of elasticity in bending; s = standard deviation; v = variation coeffizient

1) BSH + KZ = glued laminated timber with key-dovetailing
2) BSH o. KZ = glued laminated timber without key-dovetailing

Table 10: Regression analysis of $R_m$ (KZV)

| | $R_m$ $\left(\frac{N}{mm^2}\right)$ | r (-) | r (-) |
|---|---|---|---|
| 1 | 32,87 + 0,003 (KZV)<br>KZV in mm | 0,123 | 0,351 |
| 2 | 32,47 + 0,2648 ln(KZV) | 0,212 | 0,460 |
| 3 | $32{,}8 \cdot 0^{7{,}729 \cdot 10^{-5} (KZV)}$ | 0,128 | 0,358 |
| 4 | $32{,}71 (KZV)^{0{,}0066}$ | 0,224 | 0,473 |
| 5 | 32,04 + 0,008 (KZV) $- 0{,}457 \cdot 10^{-6} (KZV)^2$ | 0,165 | 0,41 |

14 glued laminated timber girders; b=97mm, h=288, $l_s$=4 320 mm
layers sorted visually, at least grade II sawn coniferous timber
key-dovetailing (KZ) in the test zone (PB)
key-dovetail length (KZL) of 20 mm
moisture of timber u=8,1 to 11.7%
failure in the key-dovetailing, 1st layer
KZV=key-dovetail skew notching

Table 11: Flexural strengths of visually sorted glued laminated timber with key-dovetail skew notching of 50 and 20 mm

| | | |
|---|---|---|
| KZL=key-dovetail length (mm) | 50 | 20 |
| production | A | B |
| technology | planing of the glued laminated timber immediately after the curing of the glue | planing of the glued laminated timber immediately after the pressing |
| glued laminated timber girders | b=97; h=288<br>$l_s$=4 450 mm | b=97; h=288<br>$l_s$=4 450 mm |
| sawn coniferous timber layers | at least quality grade II | at least quality grade II |
| sorting | visually | visually |
| failure | in key-dovetailing, test zone, layer 1 | in key-dovetailing, test zone, layer 1 |
| moisture of timber u | 6 - 11,6 % | 7,4 - 13,9% |
| key-dovetail skew notching layers 1-2 | ≥ 250 mm | ≥ 250 mm |
| number of griders n | 16 | 19 |
| $R_m$ $\left(\frac{N}{mm^2}\right)$ | 35 | 34,3 |
| $V_R$ (%) | 17,1 | 9,4 |
| $R_{m,5\%}$ $\left(\frac{N}{mm^2}\right)$ | 24,7 | 30,5 |
| $R_{m,1\%}$ $\left(\frac{N}{mm^2}\right)$ | 20,7 | 30,1 |
| $R_{m,min}$ $\left(\frac{N}{mm^2}\right)$ | 24,9 | 30 |

Table 12: Tensile strengths of visually sorted key-dovetailed layers of timber boards with key-dovetail skew notching of 20 and 50mm (values of tests after 3 to 5 minutes; Weibull distribution)

| KZL=key-dovetail length (mm) | 50 | 20 |
|---|---|---|
| production | A | B |
| technology | planing of the glued laminated timber after the curing of the glue at 20°C | planing of the glued laminated timber immediately after the pressing |
| $R_t$ $\left(\frac{N}{mm^2}\right)$ | 27,8 | 31,2 |
| $V_R$ (%) | 28,6 | 26,9 |
| $R_{t,5\%}$ $\left(\frac{N}{mm^2}\right)$ | 14,4 | 17,8 |
| $R_{t,1\%}$ $\left(\frac{N}{mm^2}\right)$ | 9,5 | 13,9 |
| $R_{t,min}$ $\left(\frac{N}{mm^2}\right)$ | 9,0 | 14,4 |

90 specimens each, made of quality grade II sawn coniferous timber
u= 6 to 12%, failure in the key-dovetailing

INTERNATIONAL COUNCIL FOR BUILDING RESEARCH STUDIES AND DOCUMENTATION

WORKING COMMISSION W18A - TIMBER STRUCTURES

# CIB - W18 A

MEETING TWENTY - ONE

PARKSVILLE, VANCOUVER ISLAND

CANADA

SEPTEMBER 1988