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ACCEPTANCE CRITERIA FOR STRUCTURAL BAMBOO

AC162

March 2000

(Effective April 1, 2000)

PREFACE

Evaluation reports issued by ICBO Evaluation Service, Inc. (ICBO ES), are based upon performance features of the Uniform family of codes and the International family of codes. Section 104.2.8 of the *Uniform Building Code*™ (UBC), Section 104.11 of the *International Building Code*® (IBC) and Section R104.11 of the *International Residential Code*™ (IRC) are the primary charging sections upon which evaluation reports are issued. Section 104.2.8 of the UBC reads as follows:

> The provisions of this code are not intended to prevent the use of any material, alternate design or method of construction not specifically prescribed by this code, provided any alternate has been approved and its use authorized by the building official.
>
> The building official may approve any such alternate, provided the building official finds that the proposed design is satisfactory and complies with the provisions of this code and that the material, method or work offered is, for the purpose intended, at least the equivalent of that prescribed in this code in suitability, strength, effectiveness, fire resistance, durability, safety and sanitation.
>
> The building official shall require that sufficient evidence or proof be submitted to substantiate any claims that may be made regarding its use. The details of any action granting approval of an alternate shall be recorded and entered in the files of the code enforcement agency.

Similar provisions are contained in Sections 104.11 and R104.11 of the IBC and IRC, respectively.

The attached acceptance criteria has been issued to provide all interested parties with guidelines on implementing performance features of the applicable code(s) referenced in the acceptance criteria. The criteria was developed and adopted following public hearings conducted by the Evaluation Committee and is effective on the date shown above. All reports issued or reissued on or after the effective date must comply with this criteria, while reports issued prior to this date may be in compliance with this criteria or with the previous edition. If the criteria is an updated version from a previous edition, solid vertical lines (▌) in the outer margin within the criteria indicate a technical change or addition from the previous edition. Deletion indicators (➧) are provided in the outer margins where a paragraph or item has been deleted if the deletion resulted from a technical change. This criteria may be further revised as the need dictates.

ICBO ES may consider alternate criteria, provided the proponent submits valid data demonstrating that the alternate criteria are at least equivalent to the attached criteria and otherwise meet the applicable performance requirements of the codes. Notwithstanding that a material, type or method of construction, or equipment, meets the attached acceptance criteria, or that it can be demonstrated that valid alternate criteria are equivalent and otherwise meet the applicable performance requirements of the codes, if the material, product, system or equipment is such that either unusual care in its installation or use must be exercised for satisfactory performance, or malfunctioning is apt to cause unreasonable property damage or personal injury or sickness relative to the benefits to be achieved by the use thereof, ICBO ES retains the right to refuse to issue or renew an evaluation report.

Published by

ICBO Evaluation Service, Inc.

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ACCEPTANCE CRITERIA FOR STRUCTURAL BAMBOO

1.0 INTRODUCTION

1.1 Scope: This acceptance criteria establishes minimum requirements for recognition of structural bamboo in an ICBO ES evaluation report under Section 104.2.8 of the 1997 *Uniform Building Code*™ (UBC), Section 104.11 of the 2000 *International Building Code*® (IBC) and Section R104.11 of the 2000 *International Residential Code*™ (IRC).

1.2 References:

1.2.1 1997 UBC.

1.2.2 Proposed *International Model Building Code for Bamboo*.*

1.2.3 Proposed INBAR Standard for Determination of Physical and Mechanical Properties of Bamboo*, dated January 2000. (Reproduced in Appendix A.)

1.2.4 ASTM D 5456-98, "Standard Specification for Evaluation of Structural Composite Lumber Products."

1.2.5 ASTM D 1761-88, "Standard Test Method for Mechanical Fasteners in Wood."

1.2.6 ASTM D 2915-94, "Standard Practice for Evaluating Allowable Properties for Grades of Structural Lumber."

1.2.7 ASTM D 4933, "Standard Guide for Moisture Conditioning of Wood and Wood-Based Materials."

1.2.8 2000 IBC.

1.2.9 2000 IRC.

2.0 BASIC INFORMATION AND REPORTS OF TESTS

2.1 Testing: An ICBO ES accredited testing laboratory, complying with the ICBO ES Acceptance Criteria for Laboratory Accreditation (AC89), must conduct the tests or witness the testing as outlined in this criteria.

Testing must be conducted in accordance with the appropriate sections of the INBAR document (Appendix A), unless modified by details noted in Section 2.2.

2.2 Test Reports: All test reports must be written by an ICBO ES accredited testing laboratory and comply with the ICBO ES Acceptance Criteria for Test Reports and Product Sampling (AC85), and must comply with the requirements outlined in Sections 2.2.1 through 2.2.8 of this criteria.

2.2.1 Test Location: The location of testing must be identified (the test agency's facility or other appropriate location; see Section 1 of AC89).

2.2.2 Specimen Sampling Methods: Specimen sampling methods must comply with AC85 and with Section 1.6.1 of the INBAR document (Appendix A). Sampling of the test material must be done in accordance with applicable portions of Section 3, Statistical Methodology, of ASTM D 2915. Statements are needed indicating whether specimens were produced in accordance with the minimum requirements of the approved quality control manual.

2.2.3 Specimen Description: Measured dimensions must be recorded, for each specimen, to the degree of accuracy specified in Section 1.5.2 of the INBAR document (Appendix A).

2.2.4 Specimen Conditioning Methods: The method of conditioning the test specimens must be described. Section 1.5.3 and other appropriate sections of the INBAR document (Appendix A) must be used as a guide.

Bamboo used in qualification testing must be brought to moisture equilibrium in a conditioned environment of 80°F ± 4°F (27°C ± 2°C) and 70 percent ± 5 percent relative humidity. Methods for determining completion of conditioning are given in ASTM D 4933.

Also see Section 3.1 of this criteria for conditioning requirements.

2.2.5 Test Methods: Details describing the test setup, test methods and test procedures, including load application rate, time to failure, support details and lateral supports, must be described. Any deviations from the test procedures or test methods described in Sections 2 through 8, inclusive, of the INBAR document (Appendix A) must be documented and justification provided for the deviation. Deviations must be discussed with ICBO ES staff prior to commencement of the test program.

2.2.6 Test Results: The failure mode for each specimen must be described and/or illustrated, in addition to the test results described as noted in appropriate sections of the INBAR document (Appendix A).

2.2.7 Test Conclusions: Test results must be limited to the species, location where the specimens are grown, and the selection process described in Section 1.6.2 of the INBAR document (Appendix A), unless additional data that justify extrapolation of test results to a wider range is submitted.

2.2.8 Authorization: The test report must bear the signature of a representative of the testing agency.

3.0 TESTING AND ANALYSIS OF DATA

3.1 General: Testing and analysis of data must be in accordance with this section and appropriate sections of the INBAR document (Appendix A), to determine design values for bending strength, modulus of elasticity, tensile strength parallel to the grain, compressive strength parallel to the grain, and shear strength. Moisture content, shrinkage and mass per volume must also be determined in accordance with the appropriate sections of the INBAR document (Appendix A).

Design stress, except for modulus of elasticity, must be based on the fifth percentile tolerance limit.

The confidence level for calculating tolerance limits and confidence intervals must be 75 percent.

The minimum sample size for calculating tolerance limits on fifth percentiles must be 53.

The calculated fifth percentile parametric tolerance limits (PTL) must have a standard error no greater than 5 percent of the PTL, when evaluated in accordance with Section 3.4.3.2 of ASTM D 2915. When necessary, the sample size must be increased beyond the minimum of 53 to meet this requirement.

Moisture content and mass per volume must be measured and reported for each specimen tested in the qualification program. Measurement for moisture content must be in accordance with the test method described in Section 2 of the INBAR document (Appendix A), and measurement of mass per unit volume must be in accordance with the test method described in Section 3 of the INBAR document.

The effect of length and changes in diameter of the bamboo product, and duration of load, also need to be considered in the test program and design analysis. A discussion with ICBO ES staff, prior to the commencement of testing, is required. Also see Section 3.2.7.

Final test results and design values must be expressed in both English and SI units.

3.2 Mechanical Properties: The properties that must be evaluated by qualification testing include, but are not limited

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to: bending strength, modulus of elasticity, tensile strength parallel to the grain, compressive strength parallel to the grain, shear strength and shrinkage.

3.2.1 Bending: The ultimate bending strength and modulus of elasticity must be determined in accordance with the principles of Section 6 of the INBAR document (Appendix A). The cross section of the specimen must not be less than the minimum anticipated structural size.

When the qualification specimens differ in either size or moisture content, or both, from specimens to be tested in quality control, bending tests must also be conducted on specimens of the size and moisture content that will prevail at the time of routine quality control testing. The specimens representing the quality control conditions must be matched with those to be conditioned. The ratio of the means of both strength and stiffness shall be used to adjust quality control test results to the qualification level, for use in the confirmation tests required by the quality control manual.

3.2.2 Tension: The ultimate tensile strength parallel to grain must be determined in accordance with the principles described in Section 8 of the INBAR document (Appendix A). Specimen cross section must not be less than the minimum anticipated structural size.

When the qualification specimens differ in either size or moisture content, or both, from specimens to be tested in quality control, tension tests must also be conducted on specimens of the size and moisture content that will prevail at the time of routine quality control testing. The specimens representing the quality control conditions must be matched with those to be conditioned. The ratio of the mean of strength shall be used to adjust quality control test results to the qualification level, for use in the confirmation required in the quality control manual.

3.2.3 Compression: The ultimate compressive strength parallel to the grain must be determined in accordance with the principles described in Section 5 of the INBAR document (Appendix A).

3.2.4 Shear: The ultimate shear strength must be determined in accordance with the principles described in Section 7 of the INBAR document (Appendix A).

3.2.5 Shrinkage: Shrinkage must be determined in accordance with the principles described in Section 4 of the INBAR document (Appendix A).

3.2.6 Connection: Connection tests must be conducted in accordance with the following:

Tests on full-scale joints or on components must be carried out in accordance with the principles of ASTM D 1761, Standard Test Methods for Mechanical Fasteners in Wood. Other types of joint test methods may be considered. Alternative test methods must be discussed with the ICBO ES staff prior to commencement the tests.

3.2.7 Volume Effect: Volume effects shall be determined either by testing a range of sizes, or from prescribed theoretical relationships. See Section 6.4.1 in ASTM D 5456 for clarifying details.

3.3 Determination of Allowable Stresses: Allowable stress design values developed in this section are consistent with standard engineering practice in building construction. Design stresses are determined in a manner similar to that for structural composite lumber.

3.3.1 Characteristic Value: In the derivation of the characteristic value, the procedures of Section 3 and 4 of ASTM D 2915 must be followed, except that provisions of this section govern where differences occur.

The fifth percentile tolerance limit (TL) with 75 percent confidence, of the results of tests noted in Section 3.2, must be the characteristic value for strengths in bending strength, tension parallel to the grain, compression parallel to grain, and shear.

Parametric or nonparametric analysis must be performed to obtain a fifth percentile tolerance limit.

For parametric analysis, either the normal or lognormal distribution must be used to establish a fifth percentile tolerance limit with 75 percent confidence. The distribution selection must be based on standard statistical goodness of fit tests. At a minimum, the fit selection must include:

1. Visual inspection of cumulative frequency plots of the fitted distributions with the data.
2. The lesser of standard errors of the estimate from the two distributions fitted by the method of least squares.

The average value for apparent modulus of elasticity from testing in accordance with Section 3.2.1 must be the characteristic value for modulus of elasticity.

3.3.2 Design: Design stresses must be calculated using the characteristic value in the following formula:

$$S = \frac{B}{C_a} \quad (1)$$

where:

S = Design stress.

B = Characteristic value = $(m - Ks) \cdot DOL$.

- m = Average ultimate strength.
- K = Factor from Table 3, ASTM D 2915.
- s = Standard deviation.
- DOL = Duration of load.
  - 1.0 for permanent load.
  - 1.25 for normal duration of load (less than 10 years).
  - 1.5 for wind and seismic.

C_a = Adjustment factor from Table 1.

TABLE 1—C_a ADJUSTMENT FACTORS

PROPERTY	C_a ADJUSTMENT FACTOR
Modulus of elasticity	1.00
Bending strength	2.25
Tensile strength parallel to grain	2.25
Compressive strength parallel to grain	2.25
Shear strength	2.25

From the characteristic value, a design value must be derived, applying a safety factor, a modification factor, etc., in accordance with this section.

3.3.3 Allowable Design Stress: Design stresses must be modified by factors that consider the conditions and end-use applications as follows:

$$F_a = C_e S \quad (2)$$

where:

F_a = Allowable design stress.

C_e = Product of end-use (K) factors.

S = Design stress.
Factors common to all members are detailed in this section.

K_g = Modification for the difference between laboratory results and actual field use: default value is 0.5.

K_d and K_L (bending and tension volume effect factors to be determined)

Additional K factors may be needed. Further discussion with ICBO ES staff is necessary.

3.4 Strength of Connections: Adjustment and end-use factors applied to connection tests must be consistent with those noted in Section 3.3.3 for structural bamboo members.

Adjustment and end-use factor values can vary depending on the test method and number of tests.

Load-deformation diagrams, obtained from physical tests on joints, must be used in analyzing the joint capacity, with the following also taken into account:

- The capacity of a multiple-fastener joint will frequently be less than the sum of the individual fastener capacities.
- The effect of different fastener properties must be taken into account if more than one type of fastener is being used in a joint.
- The possibility of reversal of load.

3.5 Other Considerations: Allowable design stresses and connection strengths developed using this criteria are for use under dry conditions as defined in Section 1.4 of ASTM D 5456-98. If use under other moisture conditions is intended, a documented test-based investigation leading to appropriate adjustments of properties must be carried out. Information regarding the durability of the bamboo product and any preservative treatment required must be provided.

The effect that preservative treatment and other chemical treatments have on the physical and mechanical properties of the bamboo elements and bamboo connectors must be investigated.

4.0 DESIGN CONSIDERATIONS

4.1 General: Design and construction practices must take the following into account:

1. It must be shown that the dimensional stability and environmental behavior (i.e., temperature and relative humidity) are satisfactory for the intended purposes.
2. Any plastic behavior of the joints must be provided for.
3. The structure must be designed so that the structural members and joints have adequate strength for the linear lateral force response caused by seismic motions. The damping of joints must be taken into account accordingly, using available experimental evidence. Ductility of joints must not be expected, unless ductility is demonstrated by direct testing.
4. A design for lateral bracing to resist wind and seismic forces must be provided.
5. Bamboo construction design concepts must be based on calculations that verify that relevant permissible stress values are not exceeded.
6. The structural behavior must be assessed by calculating the action effects using a linear material model (elastic behavior).
7. The effect of shrinkage must be taken into account in the design of structural members, and in the design of the structure as a whole.
8. The effects of long-term loading (creep) need to be considered in the design of structural members, and in the design of the structure as a whole. Test methods and analytical approaches should be discussed with the ICBO ES staff prior to submittal of data.

4.2 Bamboo Element:

4.2.1 General: Typically, designs using bamboo as the structural material involve the following:

1. It is assumed that bamboo retains its elastic behavior, until failure (plastic behavior is considered to be not significant).
2. Bamboo culms are analyzed as variable thickness hollow tube structures.
3. Bamboo culms are analyzed as not perfectly straight members.
4. Bamboo culms are analyzed as tapered.
5. Design of structural bamboo members is done in accordance with the following:
   a. Conventional structural analysis methods are used, with definitions of the initial curvature, the diameter and the wall thickness.
   b. Any bamboo joint or support must be considered to act as a hinge, unless substantiating data are submitted to justify consideration as a semi-rigid or a rigid joint.
   c. Bernouilli's theorem (flat cross sections remain flat) is valid for bamboo.

4.2.2 Beams (predominantly loaded in bending): Design of beams must be based on calculation. Calculations must be based on the following items, provided the load is symmetrical (for asymmetrical loads, applied stresses at critical points must be calculated):

1. The moment of inertia, *I*, shall be determined as follows:

   The outside diameter and the wall thickness must be measured at both ends, in accordance with Section 1.5.2 of the INBAR document (Appendix A). With these values, the mean diameter and the mean wall thickness for the middle of the beam must be calculated and the moment of inertia, *I*, must be calculated with these mean values.
2. The maximum design stress must be calculated, and compared with the allowable stress.
3. The deflection must be calculated, and compared with the allowable deflection. The initial curvature must be considered in the calculation of the deflection.
4. If the length of the beam is less than 25 times the diameter at the small end, the shear stress in the neutral layer at that end must be checked.
5. Forces acting on a beam (loads or reaction forces at supports) must act at nodes or as near to nodes as possible, preferably not exceeding 4 inches from the nodes.
6. For beams in which combined axial and bending loads occur, the interaction of applied stresses must be considered.

4.2.3 Columns: Design of columns must be based on one of the following:

1. Compression buckling tests on full-size specimens of the same species, size and other relevant variables.
2. Calculations, which must be based on the following items:
   a. The moment of inertia (*I*) is determined in accordance with Section 6.6.1 of the INBAR document (Appendix A).
   b. The bending stresses due to initial curvature, eccentricities and induced deflection are taken into account.
   c. Buckling calculation is in accordance with the Euler equation, using a reduction to 90 percent of the moment of inertia. [This reduction to 90 percent takes into account the effect of the taper, provided the taper (defined as the ratio of the difference between the minimum and maximum outer diameters to the length) is less than 1:170.]

Note: Combined bending and compression in predominantly axially loaded members is outside the scope of this criteria.

4.3 Connections:

4.3.1 Connections must be designed to achieve structural continuity between elements. This includes:

1. Force transmission in accordance with a prescribed manner.
2. Deflections that can be predicted and kept within acceptable limits.

4.3.2 Connection designs must be based on complete joint tests for a given load and geometry. This includes fastening elements and location.

5.0 INDEPENDENT INSPECTION

A qualified agency must be employed by the bamboo supplier for the purpose of monitoring the quality assurance and production process on a random, unannounced basis. The qualified independent agency must establish, approve and monitor procedures for quality assurance. (A qualified agency is defined as one that is an ICBO ES accredited quality control agency and that holds a current ICBO ES certificate.)

6.0 QUALITY CONTROL

Quality control must comply with the requirements noted in Section 9 of ASTM D 5456-98. Additionally, quality control inspections must be performed by an independent quality control agency accredited by ICBO ES. A quality control manual, developed jointly by the bamboo supplier, the evaluation report applicant and the quality control agency, and complying with the ICBO ES Acceptance Criteria for Quality Control Manuals (AC10), must also be submitted.

7.0 IDENTIFICATION

Product identification must include the name of the bamboo supplier, the name of the evaluation report applicant, the name or logo of the quality assurance agency, and the ICBO ES evaluation report number for the product. Additional information needs to be provided regarding any treatment, such as preservative treatment, or fire-retardant treatment that the product has undergone.

APPENDIX A

PROPOSED INBAR Standard for Determination of Physical and Mechanical Properties of Bamboo

Revised Edition dated January 2000

Determination of physical and mechanical properties of bamboo.

Fourth draft, January 2000

The first three drafts have been published under the title “INBAR standard for determination of physical and mechanical properties of bamboo”. The title has been changed following the suggestions of ISO-TC 165 in Harbin, September 1999.

Edited by Dr. Jules J.A. Janssen

on behalf of

Inbar

the International Network on

Bamboo and Rattan

1. General

1.1 Foreword

INBAR expresses the need for a bamboo-standard as follows.
“In these days of heightened quality consciousness, quality standards are a must for the successful development and marketing of any product. It is even mandatory, in the form of building codes, when it comes to materials for structural applications. Although the absence of standards or building codes has not hindered the construction of bamboo houses at low-income levels, it has certainly impeded the wider acceptance of bamboo as a wood substitute of choice. On another plane, the lack of codes and standards has kept architects and designers away from bamboo, even from expressing their requirements for bamboo as a building material.” (INBAR Newsletter, 1997)

“Engineers and architects prefer to work with the determinacy of a well known system or material, supported by solid knowledge of its properties, backed by the existence of a minimum code of specifications on which they can base their judgement and design decisions” (Arce 1993)

The next quotation from IS 6874 is valid for this standard: “In order to ascertain the suitability of bamboos for various structural purposes their physical properties are required to be tested. Standard method of tests have been developed for the purpose and the same are described in this standard. The data obtained by these methods may be made use of with confidence where strength factors are involved”.

1.2 Content

Each of the chapters 2 to 8 contains the following paragraphs:

- Scope and field of application.
- References.
- Principle.
- Apparatus.
- Preparation of test pieces.
- Procedure.
- Calculation and expression of results.
- Test report.

1.3 Scope

This standard covers tests on specimens of bamboo that are conducted to obtain data, which can be used to establish characteristic strength functions and to arrive at the allowable stresses. The data can also be used to establish the relationship between mechanical properties and factors such as moisture content, mass per volume, growth site, position along the culm, presence of node and internode, etc., all for quality control functions.

This publication lays down methods of tests for bamboo for evaluating the following characteristic physical and strength properties:

moisture content,
mass per volume, and
shrinkage,
compression,
bending,
shear,
tension.

1.4 Terminology, units and symbols.
The following symbols, units, and definition shall apply.

Sym-bol	Unit	Terminology	Definition.
-	-	Bamboo culm	*A single shoot of bamboo usually hollow except at nodes which are often swollen.*
-	-	Bamboo clump	*A cluster of bamboo culms emanating from two or more rhizomes in the same place.*
A	mm^2	Cross sectional area	*Calculated as $(\pi/4)*\{D^2-(D-t^2)\}$; this is the area of the section perpendicular to the direction of the principal fibres and vessels.*
D	mm	Outer diameter	*Diameter of a cross section of a piece of bamboo measured from two opposite points on the outer surface.*
E	MPa	Modulus of elasticity	*Note: 1 MPa = 1 N/mm^2*
F	N	Load	
G	MPa	Shear modulus	
I	mm^4	Moment of inertia	
L	mm	-	*Full span in bending; length of test piece in com pression, shear and tension.*
m	g	Mass	kg *is also allowed as unit.*
MC	%	Moisture content	*Percentage of water related to ovendry weight.*
t	mm	Wall thickness	*Thickness of wall of a piece of bamboo.*
V	mm^3	Volume	*Normally: of test piece.*
W	mm^3	Section modulus	
δ	mm	Deflection or deformation	*Pronounce "delta"*
π			*usually taken as 3.14.*
ρ	kg/m^3	Mass by volume	*(pronounce "rho")*
σ	MPa	Stress	*(pronounce "sigma").*
τ	Mpa	shear stress	*(pronounce "tau")*
*			*symbol for multiplication*

Suffices:

ult	-	Ultimate	*(used for strength at failure)*

1.5 Organisation and use of this standard

1.5.1 Introduction

This standard is organised to provide clear requirements for standard tests to be carried out to determine the properties of bamboo as a building or engineering material. Complementary to this is the manual for laboratory-staff, prepared by the same working-group of INBAR, and published by INBAR under the title "LABORATORY MANUAL ON TESTING METHODS FOR DETERMINATION OF PHYSICAL AND MECHANICAL PROPERTIES OF BAMBOO"
This system allows for a more formal content of this standard, and a practical and informal guide (a "how to do it") in the manual.

General procedures.

1.5.2 Measurement and weight.

Prior to each test, the dimensions of each specimen shall be measured correct to:
- 10 mm for the length of the culm,
- 1 mm for the length or height of a specimen, parallel to the axis of the culm,
- 1 mm for the diameter of the culm; for each cross-section the diameter shall be taken twice, in directions perpendicular to each other.
- and 0.1 mm for the wall-thickness; in each cross-section the wall-thickness shall be taken four times, in the same places as the diameter has been taken (twice).

The specimen shall be weighed correct to:
- 10 g for a culm,
- 1 g for a specimen of more than 100 g,
- and 0.1 g for a specimen of less than 100 g.

1.5.3 Temperature and humidity.

To avoid significant changes in strength properties, the standard will be that all test specimens shall be tested within the temperature range of 27° C ± 2° degrees centigrade, and the relative air humidity range of 70 ± 5 percent. This allows for comparison of test results all over the world, and reproducible tests.
However, if tests are meant for local use of the results in the region itself, or if the laboratory is unable to follow the standard, ambient temperature and relative humidity can be followed. The exact values of the temperature and the relative humidity of the air shall be recorded, and mentioned in the test report.

1.5.4 Rate of loading.

The rate of loading of the testing machine shall not vary by more than ± 20 % from the specified speed for a given test. The load shall be applied continuously without interruption at the required speed throughout the test. The rate of traverse of the movable head of the testing machine shall mean the free running or no load speed of the head in the mechanical drive type of machine, and the loaded head speed for testing machines of the hydraulic loading type.

1.5.5 Calibration.

All apparatus and testing equipment used in obtaining data shall be calibrated at sufficiently frequent intervals to ensure accuracy.

1.6. Sampling and storage of specimens

1.6.1 Sampling.

Material for any particular species shall be taken:
- in the case of tests on properties for commercial purposes: from a number of different localities, representative of different growth conditions throughout the geographical range of the species;
- in the case of scientific research: from localities determined by the purpose of the research, and mentioned in the design-report of the tests.

From each locality the selection, marking, etc., of the different consignments, and all the details of the various clumps and culms, shall be reported.

1.6.2 Selection.

- Bamboo culms shall be selected from various clumps in the standing condition, by a qualified person who can identify the species and understand the various implications involved in conversion and testing. Whenever necessary and convenient, the testing authority shall inspect the locality before felling.
- For scientific research, the culms selected for testing shall be sound and free from any defects, and shall be representative of average dominant bamboo culms of the locality. For commercial tests, they must fairly represent the total population that is to be used for construction purposes, even if the entire population has its drawbacks. Broken, damaged and discoloured bamboo's shall be discarded.
- The required number of culms shall be randomly selected from different clumps, blocks and compartments. For commercial tests they shall be of the same mature age group.
- Immediately after selection, the bamboo may be marked "T" in the standing condition, at breast height, and the testing authority shall be informed of the locality, so that further special instructions, if any, may be considered.

1.6.3 Felling, marking and conversion.

- Before felling, one ring shall be marked at a height of one meter from the ground with white or black paint, and the next data shall be recorded:
- the name of the species (botanical and local),
- the name of the locality,
- the number of clumps and culms selected,
- the age of the culms,
- details about the marks on the culms,
- number of nodes between ground level and the ring of paint,
- date of felling and of despatch,
- signature.
- Also before felling, each culm shall be marked at a distance of about 0.25 m above the ring of paint; if digits 6 or 9 are used, these shall be underlined.
- The culms shall be felled according to good local practice, but the ring of paint shall be kept in the culm. In horizontal position the culm shall be divided into parts to be used for tests or to be thrown away. The parts to be used shall be marked with a ring at the lower end, and the mark of the culm shall be repeated on each part, and a mark re. the position in the culm shall be added, indicating "bottom", "middle" or "top", each being 1/3 of usable part of culm. The height of these parts in the culm shall be recorded in metres from the level where the culm has been felled. Only then the culm shall be divided into parts.

1.6.4 Despatch.

- Material should be despatched as early as possible, preferably within two weeks after felling. In case it is not possible to send the material immediately, the material shall be stored in a shady place, protected from rain, and free of contact with the soil. If a risk of cracking exists, the ends can be covered with coaltar, paraffin wax or varnish, or any other appropriate cover.
- If the tests are meant for commercial purposes, specimens shall be tested in air dry condition; in case of scientific research, tests might be done on green specimens, in which case the specimens shall be despatched immediately. As bamboo is highly susceptible to the attack by destroying agents in many countries, it may need prophylactic treatment to keep intact during despatch, transit and storage.

- All the various details of a particular consignment shall be rechecked and signed and dated by the despatcher. The details shall be sent along with the documents of the consignments.

1.6.5 Receipt and storage of the bamboo culms.
- On receipt of the material by the testing authority, the particulars of identification of the various culms shall be checked, and a proper record shall be kept.
- The bamboo culms shall be stored for, as short a duration as possible, in such a way that no deterioration shall take place.

1.6.6 Marking and conversion into test specimens.
- Specimens shall be cut for the various tests, and suitable markings (like project number, consignment number, culm number, etc.) shall be made for complete identification of each specimen.
- The sequence of tests shall be such as to eliminate as far as possible, changes due to storage and weather conditions, which might affect comparison of results.
- The number of specimens in each test shall be not less than twelve.

1.6.7 Test report.
The test report shall include:
- the name and address of the laboratory, the date, name of the responsible researcher,
- a reference to this standard, and to applicable national standards,
- details of the test specimens, as mentioned sub 1.6.3.,
- temperature and air humidity in the laboratory,
- equipment used, and any other information which may influence the use of the test results,
- the test results, including, the values of moisture content and the mass per volume, the actual dimensions, moduli and/or strength values, mode of failure, and any other information which may influence the use of the test results, (e.g. position along the culm),
- details about the statistical treatment of the test results, including the methods used and the results obtained; the accuracy of a mean value shall be half the standard deviation, and the accuracy of a standard deviation shall be half its own standard deviation.
- data about the adjustment to a 12 percent moisture content, if applicable.

2 MOISTURE CONTENT

2.1 Scope and field of application

This paragraph specifies a method for determining the moisture content of bamboo for physical and mechanical tests.

2.2 References

- Indian Standard I.S. 6874, 1973, Method of tests for round bamboos, par. 6.
- ISO 3130, Wood – Determination of moisture content for physical and mechanical tests.

2.3 Principle

Determination, by weighing, of the loss in mass of the test piece on drying to constant mass. Calculation of the loss in mass as a percentage of the mass of the test piece after drying.

2.4 Apparatus

- Balance with an accuracy of 0.01 g.
- Equipment capable of drying bamboo to absolute dry condition, e.g. an electric oven.
- Equipment to ensure the retention of moisture in the test pieces, e.g. flasks with ground glass necks, and stoppers.

2.5 Preparation of test specimen

Test pieces for determination of moisture content shall be prepared immediately after each mechanical test. The number of test pieces shall be equal to the number of test pieces for the physical or mechanical test. The form shall be like a prism, approximately 25 mm wide, 25 mm high and as thick as the wall-thickness. The test pieces shall be taken near to the place of failure, and stored under conditions which ensure that the moisture content remains unchanged.

2.6 Procedure

- The test pieces shall be weighed to an accuracy of 0.01 g, and then dried in an oven at a temperature of 103 ± 2 °C.
- After 24 hours the mass shall be recorded at regular intervals of not less than 2 hours. Great care shall be taken to prevent any change in moisture content between the removing from the oven and subsequent weighings.
- The drying shall be considered to be complete when the difference between the successive weighings does not exceed 0.01 g.

2.7 Calculation and expression of results

The moisture content of each test piece shall be calculated as the loss in mass, expressed as a percentage of the oven dry mass, according to the next formula:

$MC = \{(m - m_o) / m_o \} * 100$ in which

m = the mass of the test piece before drying,
m_o = the same after drying,
each with an accuracy of 0.01 g.

The MC shall be calculated to an accuracy of one tenth of a percent. This MC shall be taken as representative for the MC of the tested specimen as a whole. The arithmetic mean of the results obtained from the individual test pieces shall be reported as the mean value for the moisture content of the test pieces.

2.8 Tests report

The outcome shall be mentioned in the test report according to 1.6.7

3 MASS BY VOLUME

3.1 Scope and field of application

This paragraph specifies a method for determining the mass by volume of bamboo for physical and mechanical tests. For accurate comparison between reported values, the basic mass by volume ρ is the most appropriate one, for the determination of which oven-dry mass and green volume will be used because these will not change irrespective of weather conditions. If the mass by volume is to be reported at the moisture content of the test sample, the mass is taken as the oven-dry mass and only the volume is taken at the MC of the sample. The symbol is ρ_o.

3.2 References

- ISO 3131, Wood – Determination of density for physical and mechanical tests
- Indian Standard 6874, 1973, Method of tests for round bamboos, par. 6

3.3 Principle

Determination of the mass of the test piece by weighing, and of its volume by measurement of its dimensions or by another method. Calculation of the mass of a unit volume of the bamboo.

3.4 Apparatus

- measuring instrument capable of determining the dimensions of the test pieces to an accuracy of 0.1 mm,
- balance capable of weighing to an accuracy of 0.01 g,
- equipment for the determination of the moisture content in accordance with par. 6.

3.5 Preparation of test pieces.

Completely as described in **2.5**. For the determination of the mass per volume, it is also permitted to prepare the test piece from a full cross-section of a culm, provided the volume can be measured easily.

3.6 Procedure

- Measure the dimensions of the test pieces to the nearest 0.1 mm, and calculate the volume, or determine the volume by a suitable method (e.g. immersion) to an accuracy of 10 mm^3. Do this in green condition or at the MC during the mechanical test, as required. In the last case, determine the MC as in **2**.
- Dry the test pieces to constant mass (see **2.6**), but do this gradually to minimise their deformation and splitting.
- Carry out the weighing operations immediately after drying.
- Determine the mass of the test pieces to an accuracy of 0.01 g.

3.7 Calculations and expressions of results.

The oven-dry mass by volume of each test piece is given by the next formula:

$\rho = (m / V) * 10^6$ in which:
ρ = the mass by volume in kg/m^3,
m = the mass in g of the test piece, oven-dry,
V = the green volume of the test piece in mm^3.

Express the result to the nearest kg/m^3.
The mass per volume ρ_o of each test piece in the condition as during the test, is given by the same formula with m oven-dry and V in the condition during the test.
Calculate to an accuracy of 10 kg/m^3 the arithmetic mean of the results obtained for the individual test pieces, and report this as the average value for the mass per volume of the test pieces.

3.8 Test report

The test report shall be in accordance with 1.6.7

4 SHRINKAGE

4.1 Scope and field of application.
This paragraph specifies a method to determine the shrinkage of full bamboo culms.

4.2 References.
- Indian Standard 6874, 1973, Method of tests for round bamboos, par. 7

4.3 Principle
The determination of the shrinkage of an internode section of a bamboo culm, by measuring the outside diameter, wall thickness and height, before and after drying.

4.4 Apparatus
- Measuring equipment as in **1.5.2**, (a micrometer),
- Equipment capable of drying bamboo to absolute dry condition, e.g. an electric oven.

4.5 Preparation of test specimens
Specimens shall be prepared from full bamboo culms, internode sections, with a height of 100 mm. In case of tests on compression, shear and tension, they shall be taken as near to these test pieces as possible; in case of bending tests they shall be taken as near to the place of failure as possible. In any case they shall be free from any initial cracks. If shrinkage tests are done independent from any other test, specimens shall be taken from the lowest section of the culm.

4.6 Procedure.
4.6.1 Shrinkage shall be observed in the outer diameter D, in the wall thickness t and also in the length L of the specimen.
4.6.2 Suitable markings shall be done on the specimen, to facilitate taking of observations every time at the same place. On each specimen, 4 diameters, 4 wall-thicknesses (two on either end) and 2 lengths shall be measured. The specimen shall be allowed to dry slowly under gradually decreasing humidity and increasing temperature. Masses and dimensions shall be recorded regularly, until the dimensions are constant or one complete weather cycle is over.
4.6.3 The specimens shall finally be put into an oven at about 103 ±- 2 °C temperature, so that the specimens shall become completely dry (as in **2.6**), after which the dimensions shall be taken for the last time.

4.7 Calculation and expression of results
Shrinkage percentage from initial condition to dry condition, correct to one place of decimal, shall be calculated by the following formula:
{ (I - F) / I} * 100 percent, in which:
I = initial reading,
F = final reading, each of these being the average value for diameter, wall thickness or length, with an accuracy as in **1.5.2**

4.8 Test report.
The test report shall be in acordance with par. 1.6.7; it shall contain the initial and the final dimensions and MC, a description of defects developed in the specimen during shrinkage, and the results from the calculation.

5. COMPRESSION

5.1 Scope and field of application.
This paragraph specifies a method for compression parallel-to-the-axis tests on specimens from bamboo culms.

5.2 References.
- Indian Standard IS 6874, Method of tests for round bamboos.
- ISO 3787, Wood – Test methods – Determination of ultimate stress in compression parallel to grain.

5.3 Principle.
The determination of:
- the ultimate compressive stress of specimens from culms,
- the nominal modulus of elasticity.

5.4 Apparatus.
- The tests shall be carried out on a suitable testing machine. At least one platen of the testing machine shall be equiped with a hemi-spherical bearing to obtain uniform distribution of load over the ends of the specimen. In between both the steel platens of the machine and both the ends of the specimen, an intermediate layer shall be applied to reduce friction to a minimum.

5.5 Preparation of tests specimens.
5.5.1 Specimens shall be taken from the bottom part, middle part and top part of each culm. These specimens shall be marked with the letters B, M and T respectively.
5.5.2 Compression tests parallel to the axis shall be made on specimens without any node, and the length of the specimen shall be taken equal to the outer diameter; however if this is 20 mm or less, the height shall be twice the outer diameter. These limitations are valid in the case of testing for commercial purposes; in the case of scientific research tests one is free to determine otherwise.
5.5.3 The end planes of the specimen shall be perfectly at right angles to the length of the specimen; the end planes shall be flat, with a maximum deviation of 0.2 mm
5.5.4 To determine the modulus of elasticity E, strain gauges shall be applied, minimum two per specimen, each one of them at the opposite side of the specimen.

5.6 Procedure.
5.6.1 The specimen shall be placed so that the centre of the movable head is vertically above the centre of the cross-section of the specimen, and a small load of not more than 1 kN is initially applied to set the specimen.
5.6.2 The load shall be applied continuously during the test to cause the movable head of the testing machine to travel at a constant rate of 0.01 mm per second.
5.6.3 If applicable, the strain gauges shall be read a sufficient number of times to be able to plot a sufficiently accurate load-deformation diagram form which E is to be determined.
5.6.4.The final reading of the maximum load, at which the specimen fails, shall be recorded.

5.7 Calculation and expression of results.

5.7.1 The maximum compressive stress shall be determined by the following formula:
$\sigma_{ultt} = F_{ult} / A$, in Mpa (or N/mm^2), in which:
σ_{ult} = the ultimate compression stress, rounded off to the nearest 0.5 Mpa,
F_{ult} = the maximum load at which the specimen fails, in N,
A = the cross sectional area as in **1.4**.
5.7.2 The modulus of elasticity E shall be calculated from the mean of the readings of the strain gauges, as a linear relationship between stress and strain between 20 % and 80 % of F_{ult}.
5.7.3 The mean ultimate stress of the tested specimens shall be calculated to the nearest 0.5 MPa as the arithmetic mean of the test results of the individual test specimens.

5.8 Test report.

The test report shall be in accordance with **1.6.7**; the MC and the mass per volume shall be determined according to **6** and **7**.

6 BENDING

6.1 Scope and field of application.
This paragraph specifies a method for bending tests on bamboo culms.

6.2 References.
- ISO 3133, Wood – Determination of ultimate strength in static bending.
- ISO 3349, Wood – Determination of modulus of elasticity in static bending.

6.3 Principle.
The determination of:
- the bending capacity of culms as from a four point bending test, as described below,
- the load versus vertical deflection curve,
- the nominal modulus of elasticity of the culm.

6.4 Apparatus.
6.4.1 A testing machine capable of measuring load to the nearest 1 %, and the deflection to the nearest mm.
6.4.2 A device capable of ensuring bending of the culm by applying a load midway between the centres of the device supports. The test shall be a four-point bending test. The load shall be divided into two halves by means of an appropriate beam. To avoid crushing of the culm, the halve loads and the reaction forces at the supports shall be applied to the nodes by means of appropriate devices. At the supports the bamboo culm shall be allowed to rotate freely.

6.5 Preparation of test culms.
Test culms shall be without visually apparent defects. In order to obtain a failure in bending, the free span shall be at least 30 * D, in which D is the outside diameter as in **1.5.2.**
The full length of the culm shall at least this free length plus at each end a half internode-length.

6.6 Procedure
6.6.1 Determine the mean value of outer diameter D and wall thickness as in **1.5.2** Calculate the moment of inertia:
$I = (\pi/64) * \{D^4 - (D - 2t)^4\}$
This value of I is being used to predict the behaviour during the test.
6.6.2 Put the culm in its place in the bending machine, resting on two devices at the two supports, allowing the culm to find its own position. Next put the two devices and the beam (which divides the load) on top of the culm, and allow the culm again to find its position and align the culm, the four devices, the load and the supports visually in one vertical plane.
6.6.3 The loading of the culm shall be carried out uniformly at constant speed. The speed of testing (preferably at constant rate of movement of the loading head of the machine, otherwise at constant rate of loading) shall be 0.5 mm/s. The maximum load shall be determined with an accuracy as in **6.4.1**. Observe the cracks and describe the form of the failure. Plot a load-deflection diagram.
6.6.4 After the test, determine the outer diameter D and the wall thickness t again, as close to the points of load as possible. The average of the diameters and wall thicknesses shall be used to calculate I, with the formula in **6.6.1**.
6.6.5 Determine the moisture content in accordance with the text in **3** with a sample from near the point of failure.

6.7 Calculation and expression of results
6.7.1 The ultimate strength σ_{ult} in static bending at the moisture content at the time of the test is given by the formula:
$\sigma_{ult} = F * L * (D/2) / 6 * I$ in N/mm^2, in which:

F = the applied maximum load in N, (the total load applied in the two points of load),
L = the free span in mm, (or clear span),
D = the outside diameter in mm as in **6.6.4,**

I = the moment of inertia in mm^4 as in **6.6.4**,
Express the result to an accuracy of 1 Mpa (or N/mm^2).

6.7.2 The modulus of elasticity (Young's modulus) is given by the slope of a linear part of the load-deformation diagram.

The modulus of elasticity E is calculated with the formula:
$E = 23 * F * L^3 / 1296 * \delta * I$ N/mm^2, in which:
F, L and I are as in **6.7.1**,
δ = the deflection mid-span in mm.
Plot a load-deflection diagram.

6.7.3 If enough data (about the relationship between mechanical properties and moisture content) are available, the ultimate strength in static bending shall be adjusted to a 12 % moisture content to an accuracy of 1 Mpa.
6.7.4 The mean ultimate strength of the sample and its standard deviation shall be calculated to an accuracy of 1 MPa from the results of the individual culms of the sample.

6.8 Test report
The test report shall be in accordance with **1.6.7.**
This report shall include also:
- the test results as calculated in **6.7,**
- dimensions of the culms, and the free span,
- the load-deflection diagrams,
- the values for σ_{ult} and E for each culm.

The MC and the mass per volume shall be determined according to **2** and **3**.

7 SHEAR

7.1 Scope and field of application

This paragraph specifies a method for shear tests on specimens from bamboo culms, parallel to the fibres.

7.2 References

none

7.3 Principle

The determination of the ultimate shear strength of specimens from culms.

7.4 Apparatus

- The tests shall be carried out in a compression machine like in **5**, without the intermediate layers from **5.4**. Instead of these, the specimen shall be supported at the lower end over two quarters, opposite one another; and loaded at the upper end over the two quarters which are not supported; see Fig. 7.1. This way to support and to load the specimen results in four shear areas.

7.5 Preparation of test specimens

7.5.1 (same text as **5.5.1**.) Specimens shall be taken from the bottom part, middle part and top part of each culm. These specimens shall be marked with the letters B, M and T respectively.
7.5.2 (same text as **5.5.2**., except node-internode) Shear tests parallel to fibre shall be made on specimens, 50 percent with a node and 50 percent without, and the length of the specimen shall be taken equal to the diameter. These limitations are valid in the case of testing for commercial purposes; in the case of scientific research one is free to determine otherwise.
7.5.3 (less strict than **5.5.3**.) The end planes of the specimen shall be at right angles to the length of the specimen; the end planes shall be flat.
7.5.4. The wall-thickness t and the height L of the specimen shall be taken at all four shear areas.

7.6 Procedure

7.6.1 The specimen shall be placed so that the centre of the movable head is vertically above the centre of the cross-section of the specimen. The specimen shall also be centered with regard to the supporting and loading quarters. A small load of not more than 1 kN is initially applied to set the specimen.
7.6.2 The load shall be applied continuously during the test to cause the movable head of the testing machine to travel at a constant rate of 0.01 mm per second.
7.6.4 The final reading of the maximum load, at which the specimen fails, and the number of areas that fail, shall be recorded.

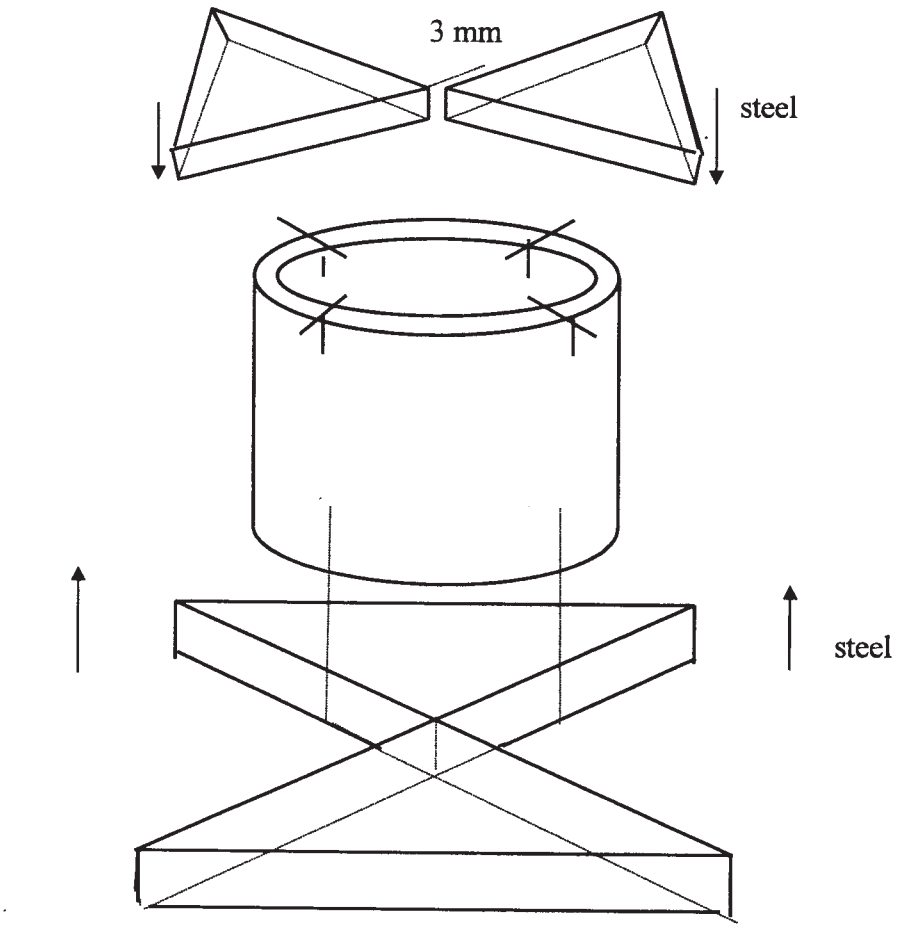
7.7 Calculation and expression of results

The ultimate shear strength shall be calculated according to the following formula:
$\tau_{ult} = F_{ult} / \Sigma(t * L)$ in N/mm^2, in which:
- τ_{ult} = the ultimate shear strength, rounded off to the nearest 0.1 Mpa,
- F_{ult} = the maximum load at which the specimen fails, in N,
- $\Sigma (t * L)$ = the sum of the four products of t and L.

7.8 Test report

The test report shall be in accordance with **1.6.7**; the MC and the mass per volume shall be determined according to **2** and **3**.

Figure 7.1 shear test. (from Janssen's thesis, p. 131)



8 TENSION

8.1 Scope and field of application.

This paragraph specifies a method for tension parallel-to-the-fibres tests on strips made from bamboo culms.

8.2 References.

- ISO 3345, Wood – Determination of ultimate tensile tress parallel to grain.

8.3 Principle.

The determination of the ultimate tensile strength parallel to the fibre by application of a gradually increasing load to a test piece.

8.4 Apparatus.

8.4.1 The grips of the tension machine shall ensure that the load is applied along the longitudinal axis of the test piece, and shall prevent longitudinal twisting of the test piece. The grips shall press the test piece perpendicular to the fibres and in radial direction.
8.4.2 The load shall be applied continuously throughout the test at a rate of motion of the movable crosshead of 0.01 mm/per second The load shall be measured to 1 percent.
8.4.3 The cross-sectional dimensions of the gauge portion of the test piece shall be measured to an accuracy of 0.1 mm.

8.5 Preparation of test specimens

8.5.1 (as **5.5.1**) Specimens shall be taken from the bottom part, middle part and top part of each culm. These specimens shall be marked with the letters B, M and T .
8.5.2 (as **5.5.2**, except for the nodes) Tension tests parallel to fibre shall be made on specimens with one node, which shall be in the gauge section. This limitation is valid in the case of testing for commercial purposes; in the case of scientific research one is free to determine otherwise.
8.5.3 The general direction of the fibres shall be parallel to the longitudinal axis of the gauge portion of the test piece. The gauge portion shall have a rectangular cross-section, with dimensions of the wall-thickness or less in the radial direction, and of 10 to 20 mm in the tangential direction. The gauge length shall be from 50 to 100 mm.
8.5.4 The ends of the test pieces shall be so shaped as to ensure that the failure occurs within in the gauge portion, and to minimize stress concentration in the transition area. It is permitted to use test pieces with laminated ends.
8.5.5 (as **5.5.4**) To determine the modulus of elasticity E, strain gauges shall be applied, two per test piece, each one of them at the opposite side of the test piece.

8.6 Procedure

8.6.1 Measure the cross-sectional dimensions of the gauge portion of the test piece to an accuracy of 0.1 mm, at three places in the gauge portion, and calculate the mean value.
8.6.2 Clamp the ends of the test piece between the grips of the testing machine, at a safe distance from the gauge portion. Load the test piece at a constant rate. Read the maximum load. Discard results obtained on test pieces which fail outside the gauge portion. After the test, determine the MC.
8.6.3 If applicable, the strain gauges shall be read a sufficient number of times to be able to plot an accurate load-deformation diagram from which E is to be calculated. .

8.7 Calculation and expression of results

8.7.1 The ultimate tensile strength shall be determined by the following formula:
$\sigma_{ult} = F_{ult} / A$ in N/mm^2, in which:
- σ_{ult} = the ultimate tensile strength, rounded off to the nearest whole Mpa,
- F_{ult} = the maximum load at which the piece fails, in N.
- A is the mean cross-sectional area of the gauge portion in mm^2.

8.7.2 (as **5.7.2**) The modulus of elasticity E shall be calculated from the mean of the readings of the strain gauges, as a linear relationship between stress and strain between 20 % and 80 % of F_{ult} .

8.8 Test report
The test report shall be in accordance with **1.6.7**; the MC and the mass per volume shall be determined from the gauge portion, and in accordance with **2** and **3**.

9. References

Arce (1993), Fundamentals of the design of bamboo structures. Thesis Eindhoven University.

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