Performance of joints in bamboo structures

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ISO standards on bamboo

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- ISO recommendation for bamboo structures
- ISO recommendation for testing specimen

ISO recommendations

ISO recommendations

Draft documents

ISO/TC 165/ N313

Bamboo Structural Design

Bambou – design pour usage structurel

ISO/TC 165/ N314

Determination of physical and mechanical properties of bamboo

Détermination des propriétés physiques et mécaniques du bambou

ISO/TC 165/ N315

Laboratory Manual on Testing Methods for determination of physical and mechanical properties of bamboo

Rapport Laboratoire d'Essai pour détermination des propriétés physiques et mécaniques du bambou

ISO recommendations

Final documents

ISO/TR 22157-1:2004

Bamboo:
Determination of physical and mechanical properties

Part 1: Requirements

ISO/TR 22157-2:2004

Bamboo:
Determination of physical and mechanical properties

Part 2: Laboratory manual

Bamboo: structural design

ISO/TC 165/ N313

6 Design concepts

6.2.1

Experience from previous generations, well preserved in a local tradition, and carefully transmitted to people living today. This expertise can be considered as an informal, non-codified "standard".

Criteria for the reliability are:

- *The content shall be generally known and accepted,*
- *It shall be considered as old and pure tradition, as general wisdom,*
- *The community shall be characterised by an undisturbed social structure, with a well-recognised social pattern.*

Limitations are:

- *The content is only applicable in similar situations,*
- *After migration the presence of this tradition is no longer self-evident.*

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6 Design concepts

6.2.2

Reports based on evaluations made after disasters like earthquakes and hurricanes. If these reports contain descriptions about structures, which did survive a quantitatively described disaster, similar structures shall be considered as adequate for similar disasters in the future.

Criteria for the reliability are:

- The report shall be composed by acknowledged engineers, with adequate experience in the field,
- The report shall be accepted by the international technical community and/or proven by referees,
- The report shall give full details and full information, with which one can build similar structures.

Limitations are:

- The report is only applicable in similar situations.

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7.2 Material properties

7.2.1

A material property is represented by a 5 percentile property, estimated from test results, obtained as in N314 "Determination of physical and mechanical properties of bamboo ", with 75 % confidence that it represents the population. This is called the characteristic value.

It can be obtained with this formula:

$$R_k = R_{0.05}\left(1 - \frac{2{,}7\frac{s}{m}}{\sqrt{n}}\right)$$

in which:

- R_k = the characteristic value,
- $R_{0.05}$ = the 5 percentile from the test data,
- m = the mean value from the test data,
- s = the standard deviation from the test data,
- n = the number of tests (at least 10).

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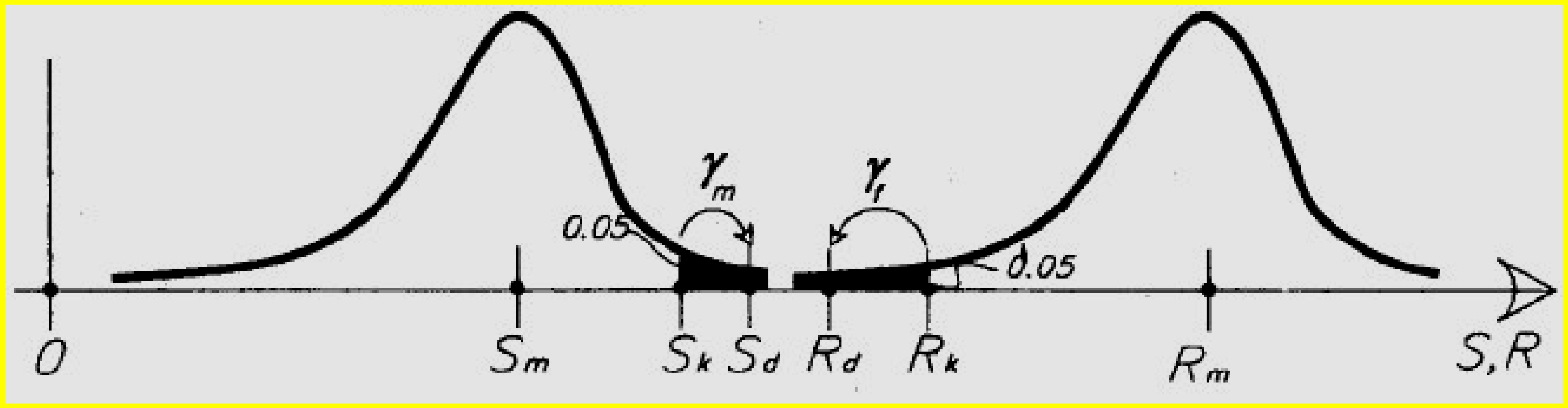
7.2 Material properties



$$S\left(\sum_i \gamma_i \cdot \psi_i \cdot Q_{ik}\right) = S_d \leq R_d = R\left(\frac{R_k}{\gamma_m}\right)$$

The 5 percentile property, is the value presenting an overpassing probability equal to 95% (1-0.05=0.95).

It represents the "characteristic value" of the resistance (R) to be used in the design of a structure, to be compared with the 95 percentile of the corresponding action (S).

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7.2 Material properties

7.2.2.5

The structural behaviour shall generally be assessed by calculating the action effects with a linear material model (elastic behaviour)

7.2.2.7

Design stresses shall be determined in a similar way as for timber structures

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7.3 Design requirements

7.3.2

Calculations shall be performed using appropriate design models (supplemented, if necessary, by tests) involving all relevant variables. The models shall be sufficiently precise to predict the structural behaviour, commensurate with the standard of workmanship (of the labour-force) likely to be achieved, and with the reliability of the information on which the design is based.

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7.4 Allowable stresses

Instead of the limit state design procedure, allowable stress design can be adopted. Allowable stresses can be derived from test results with the next formula.

$$\sigma_{all} = R_k \times G \times D / S$$

where:

σ_{all}	*is the allowable stress in N/mm^2 ,*
R_k	*is the characteristic value,*
G	*is the modification for the difference between laboratory quality and practice; default value 0.5,*
D	*is the modification value for duration of load:* *- 1.0 for permanent load,* *- 1,25 for permanent plus temporary load,* *- 1,5 for the above plus windload.*
S	*is the factor of safety, default value 2,25.*

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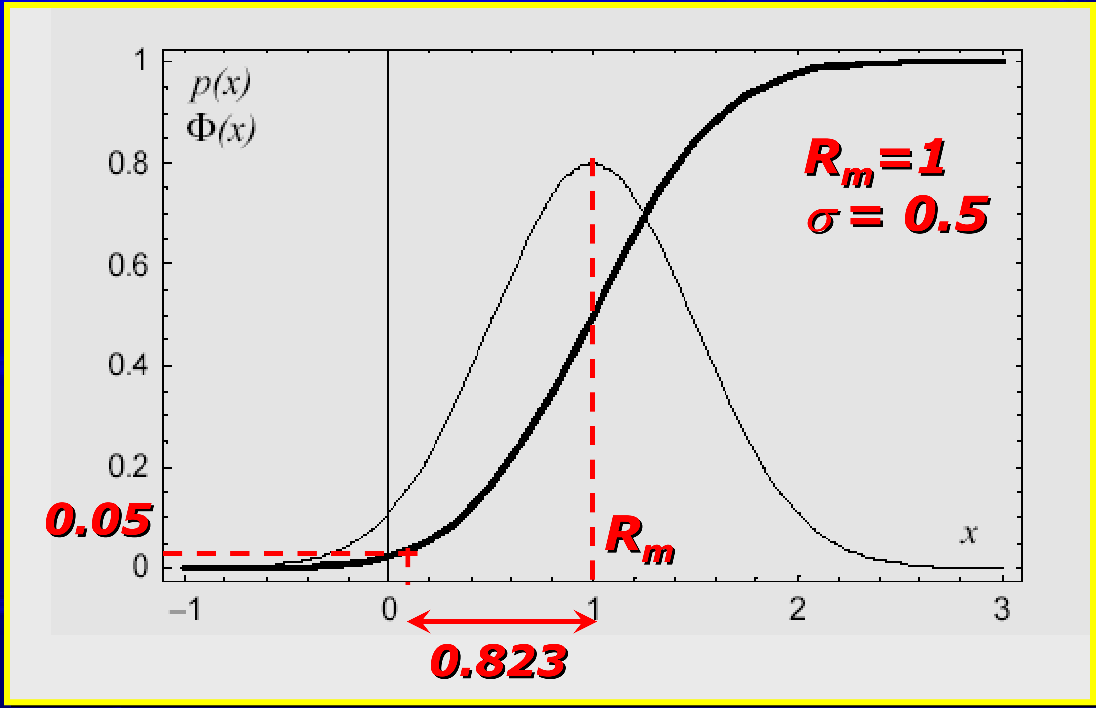
7.4 Allowable stresses

NOTE: with a standard deviation of 15% and for permanent load, <u>the allowable stress is 1/7 of the mean ultimate strength</u>.

For a Gaussian distribution, the 5% percentile is equal to

$$R_{0,05} \approx R_m - 1,645 \times \sigma$$



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7.4 Allowable stresses

NOTE: with a standard deviation of 15% and for permanent load, the allowable stress is 1/7 of the mean ultimate strength.

For a Gaussian distribution, the 5% percentile is equal to

$$R_{0,05} \approx R_m - 1,645 \times \sigma$$

then if

$$\sigma / R_m = 0,15$$

$$R_{0,05} = R_m \times (1 - 1,645 \times \sigma / R_m) \approx 0,75 \times R_m$$

hence

$$R_k = R_{0,05} \times (1 - 2,7 \times 0,15 / \sqrt{10}) \approx 0,87 \times R_{0,05}$$

and then

$$R_k = 0,87 \times R_{0,05} = 0,87 \times 0,75 \times R_m = 0,65 \times R_m$$

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7.4 Allowable stresses

NOTE: with a standard deviation of 15% and for permanent load, the allowable stress is 1/7 of the mean ultimate strength.

As a consequence, the allowable stress is equal to:

$$\sigma_{all} = R_k \times G \times D / S =$$

$$0{,}65 \times R_m \times 0{,}5 \times 1{,}0 / 2.25 =$$

$$0{,}145 \times R_m \approx R_m/7$$

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8 Schematisation

8.1

The elastic behaviour of bamboo, till failure; as the plastic behaviour is considered to be not significant.

8.2

Bamboo culms are analysed as hollow tube structures with variable thickness

8.3

Bamboo culms are analysed as not perfectly straight members

8.4

Bamboo culms are analysed as tapered

8.7

Any bamboo joint or support shall be considered to act as a hinge, unless substantiating data are submitted to justify a spring or a fixed joint

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9 Beams

9.2

The moment of inertia I shall be determined as follows.

- The outside diameter and the wall-thickness shall be measured at both ends, according to N314 "Determination of physical and mechanical properties of bamboo”.
- With these values the mean diameter and the mean wall-thickness for the middle of the beam shall be calculated.
- The moment of inertia I shall be calculated with these mean values for diameter and wall- thickness.

NOTE: This method is on the conservative side. Another way is to calculate the I at both ends and take the mean value of these two I’s, this gives a bigger value. Therefore this calculation is not applied in this standard.

9.6

Forces acting on a beam, being loads or reaction forces at supports, shall act in nodes or as near to nodes as by any means possible

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11 Joints

11.1.1

Joints shall be designed to achieve structural continuity between elements, which includes:

- *Force transmission according to a prescribed manner,*
- *Deflections which can be predicted and which should be kept within acceptable limits.*

Bamboo joint design concepts shall be based on calculations, which shall be based on one of the alternatives in 11.1.3, 11.1.4 or 11.1.5.

11.1.2

Bamboo joint design concepts are deemed to comply, provided the concepts are based on one of the items 6.2.1 or 6.2.2.

11 Joints (calculations alternatives)

11.1.3

Complete joint alternative.

In this alternative, the complete joint for a given load and geometry is fully specified for members of a particular size. This includes the description of all fastening element sizes and locations.

11.1.4

Component capacities alternative.

This allows a joint to be designed for a given load using the capacity of each of the components of the joint. The capacity of each component shall relate to a specific geometry and load direction. Data about this capacity shall be based on full-scale tests.

NOTE: capacities are the numerical strength of a component, e.g. a compression member will have a capacity in kN; nailed joints in timber structures are often designed this way: nails have given allowable loads, so that by combining an appropriate number of nails in a certain geometry, an efficient joint can be relatively easily designed.

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11 Joints (calculations alternatives – cont'd)

11.1.5

Design principles alternative.

Here the basic mechanics of joints and their materials shall be specified in a way that will enable designers to design safe and efficient joints of varying geometries and load directions.

NOTE: principles give the requirements that must be in place for the capacities to be valid. These are frequently non-numerical details, e.g. end connections for a compression member to give the appropriate effective length for the capacity to be valid. Other common examples include the spacing and connections between elements in a built-up column member, or the required rigidity for buckling restraints.

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11 Joints (good design practice)

11.4.1

Care shall be taken regarding the joints between structural components since damage in bamboo structures, caused by typhoons and earthquakes, have been found to be initiated by structural failure of the joints.

11.4.2

The structure shall be designed so that the structural members and joints have adequate strength for the linear lateral force response caused by the severe earthquake motions. The damping of joints is taken into account accordingly, with available experimental evidence.

11.4.3

Ductility of joints shall not be expected, unless shown otherwise by direct testing.

11.4.4

Solid walls or bracing in walls shall be considered for resisting in-plane shear.

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12 Global analysis

12.2.4

In view of the fact that a stress-strain diagram for bamboo is linear until very near failure, only linear analysis shall be carried out.

12.2.5

Joints may be generally assumed to be rotationally pinned.

12.2.6

Slip at the joints has to be taken into account for the strength verification, unless the influence on the distribution of internal forces and moments can be assumed to be negligible.

12.2.7

Joints may be assumed to be rotationally stiff, if their deformation would have no significant effect upon the distribution of member forces and moments.

Tests on bamboo specimen

ISO/TC 165/ N314

9 Compression

9.3 Apparatus

The tests shall be carried out on a suitable testing machine. At least one platen of the testing machine shall be equipped with a hemi-spherical bearing to obtain uniform distribution of load over the ends of the specimen, as in figure 1. 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.

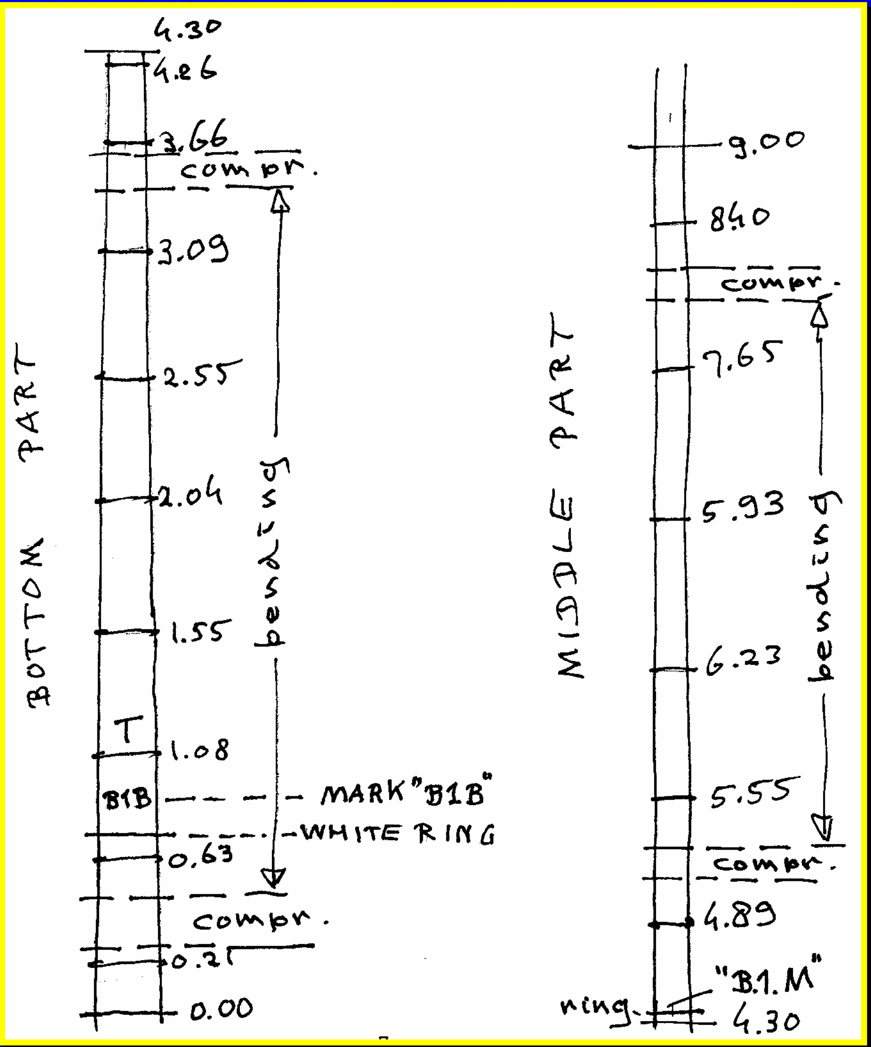
9.4.1

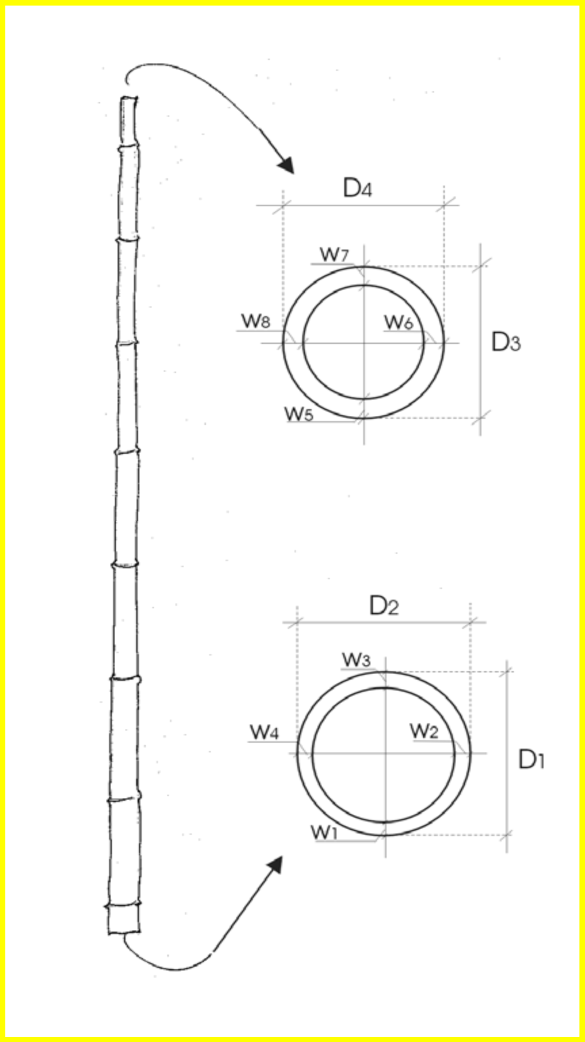
Specimens shall be taken from the bottom part, middle part and top part of each culm. These specimens shall be marked with the letters B, M and T respectively.

9.4.2

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.

from ISO/TC 165/ N315





Bottom and the middle part of a culm; from each part two samples will be tested in compression and one in bending, provided the length is sufficient.

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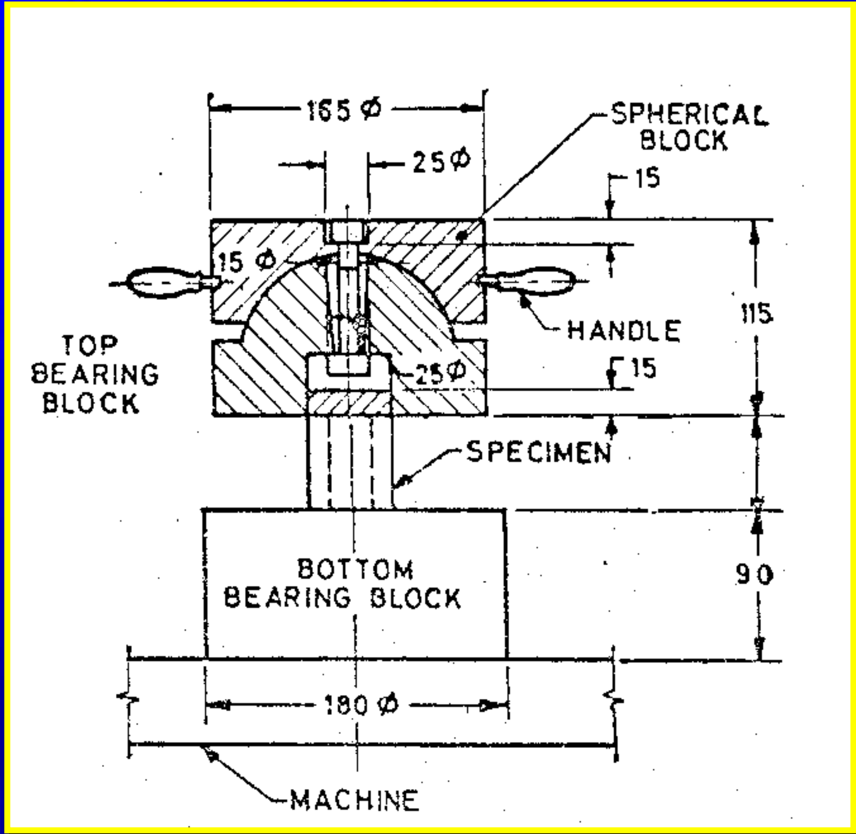
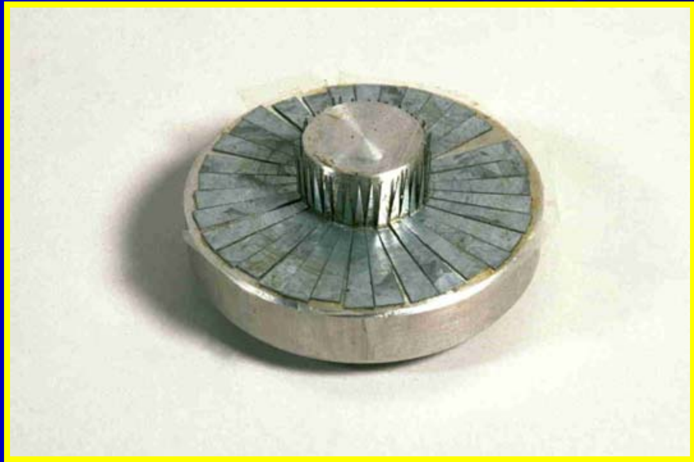
9 Compression (cont'd)





Intermediate layer

lead has been used to reduce friction between bamboo and steel platens

ISO/TC 165/ N314

10 Bending

10.3 Apparatus

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

10.4 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 $\times$ D, in which D is the outside diameter.

The full length of the culm shall be at least this free length plus at each end a half internode-length.

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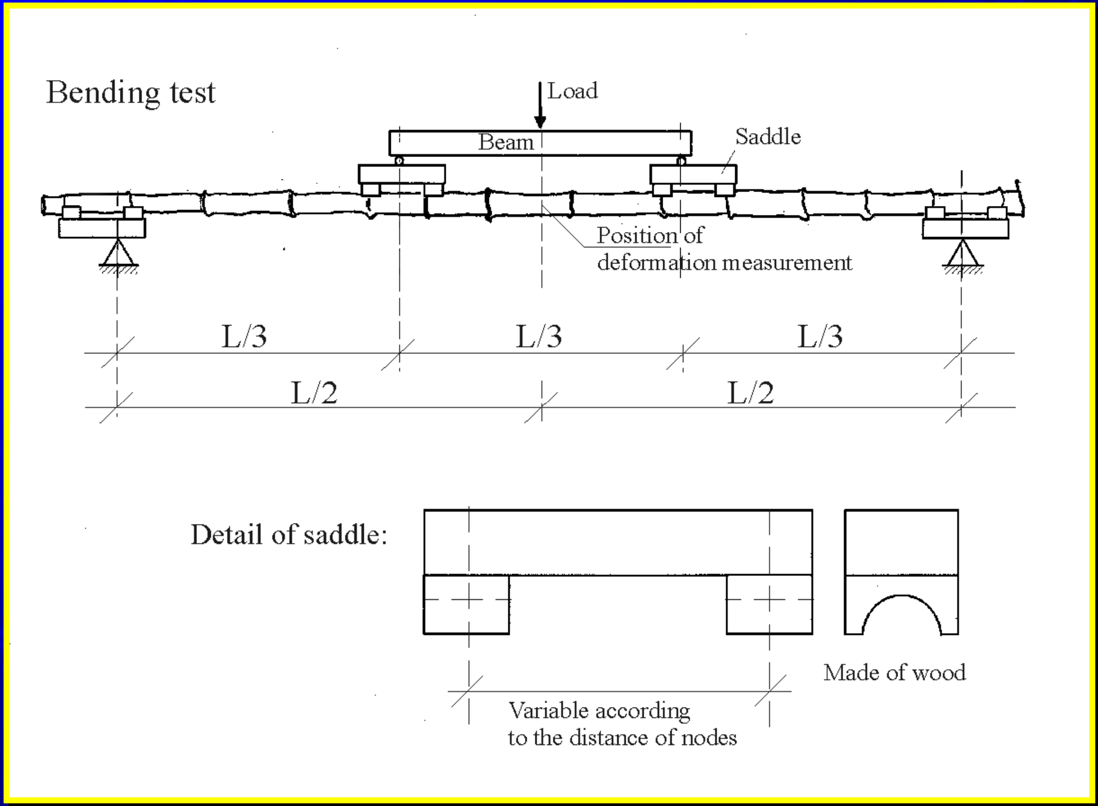
10 Bending (cont'd)



Tests will be executed as "four-point tests", because it is more reliable than the simplest "three-point tests"

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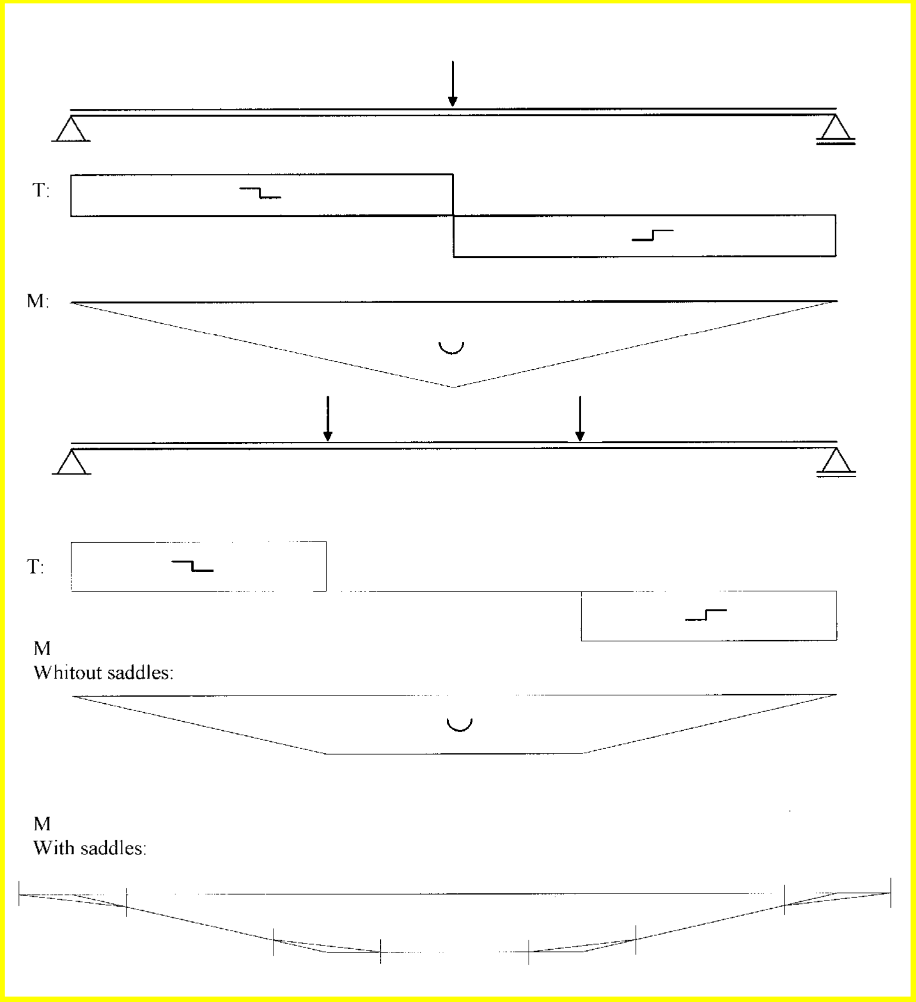
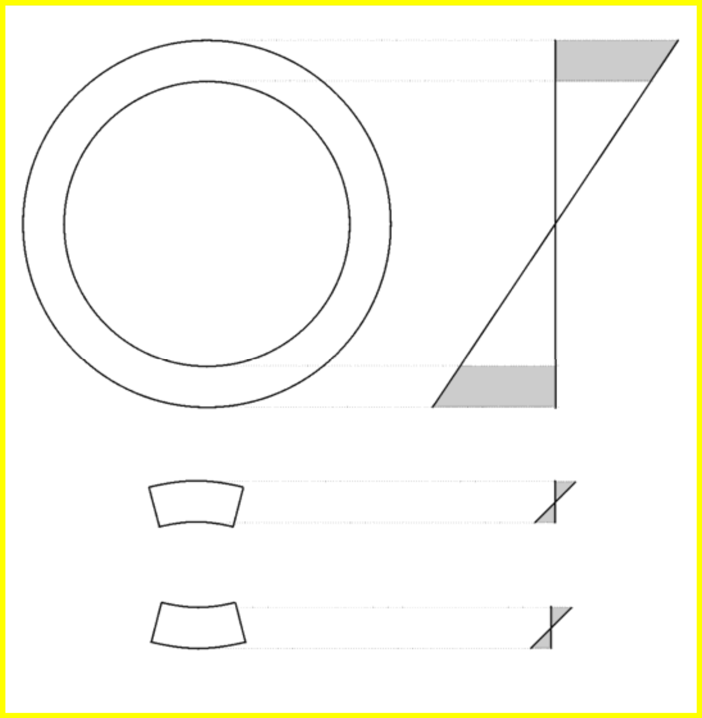
10 Bending (cont'd)





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11 Shear

11.4.1

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.

11.4.2

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.

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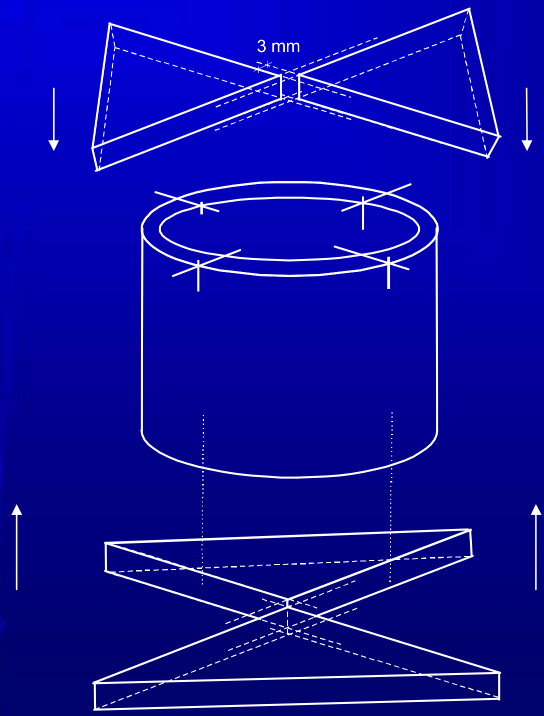
11 Shear (cont'd)

11.3 Apparatus

The tests shall be carried out in a compression machine like in bending tests, without the intermediate layers. 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.



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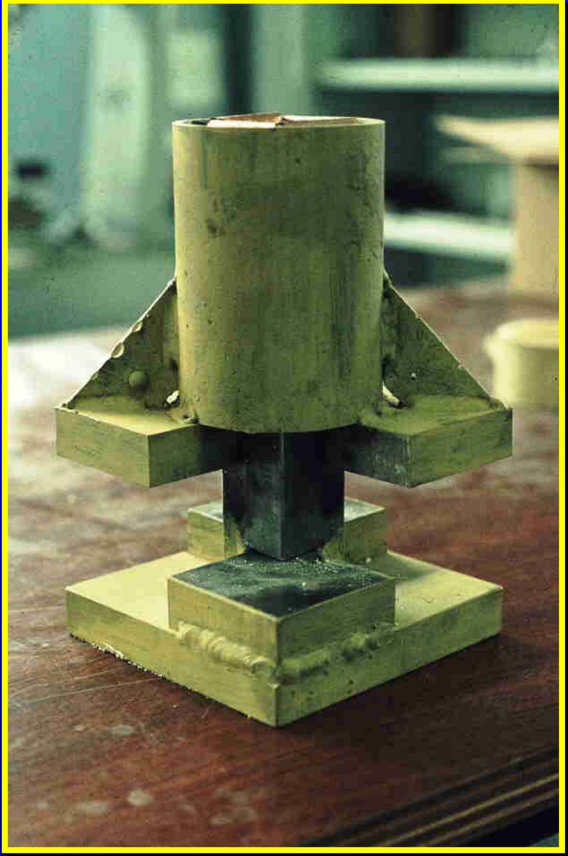
11 Shear (cont'd)



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12 Tension

12.4.1

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.

12.4.2

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.

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12 Tension (cont'd)

From ISO/TC 165/ N315

12.4.4 Form of the specimens

Three examples are given:

- *a wedge-shaped test piece, in use in many laboratories; many problems with failure in shear are known. (Zhou Fangchun 1981)*
- *a test piece with glued wooden pieces on both ends. The length of these is determined by the allowable shear stress in this glue joint. (Arce 1993).*
- *a test piece being used in Japan (courtesy Prof. Inoue). NOTE: this one prefers not to have a node in the test area! (contrary to N314)*

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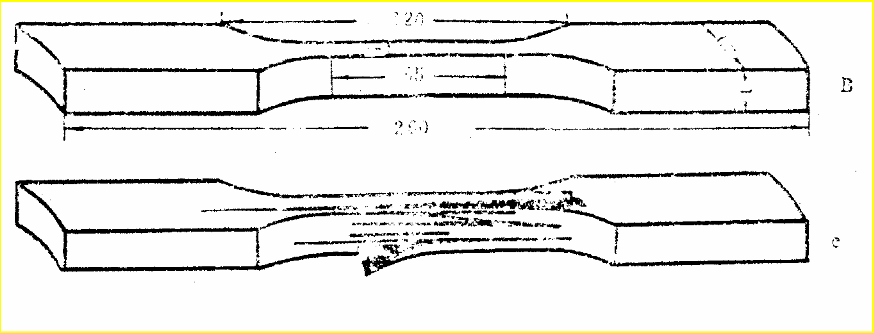
12 Tension (cont'd)



wedge-shaped test piece

From ISO/TC 165/ N315

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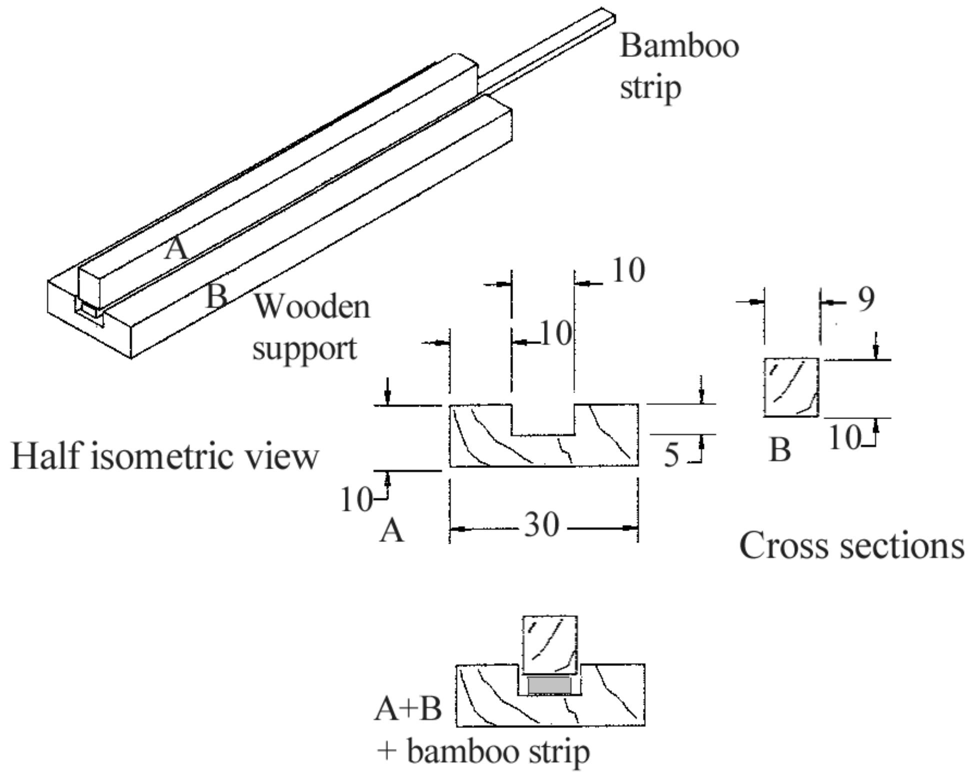
12 Tension (cont'd)



tensile test piece with wooden ends

From ISO/TC 165/ N315

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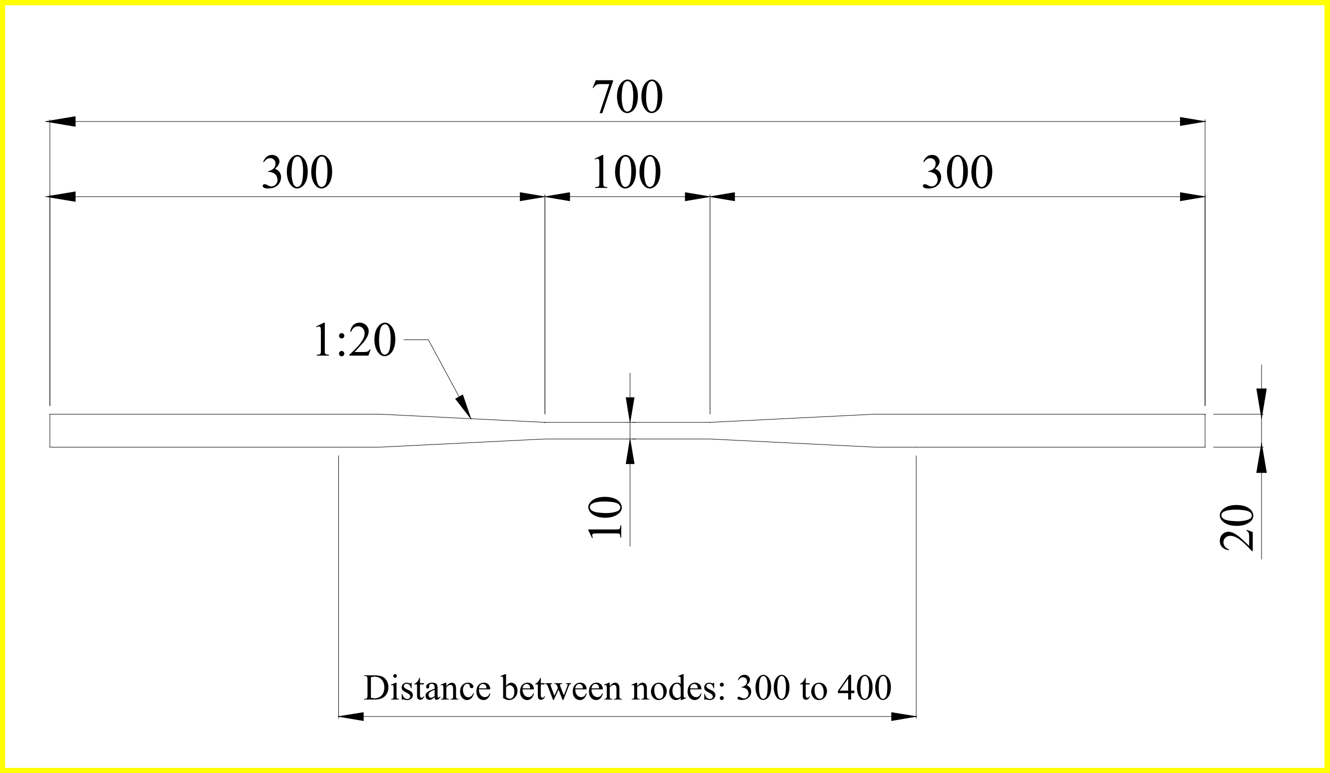
12 Tension (cont'd)



test piece for tension tests

From ISO/TC 165/ N315