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Bamboo — Structural design

Bambou — Conception des structures

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 22156 was prepared by Technical Committee ISO/TC 165, *Timber structures*.

Bamboo — Structural design

1 Scope

This International Standard applies to the use of bamboo structures, i.e. structures made of bamboo (round bamboo, split bamboo, glued laminated bamboo) or bamboo-based panels joined together with adhesives or mechanical fasteners.

This International Standard is based on limit-state design, and on the performance of the structure; see also 7.1. It is only concerned with the requirements for mechanical resistance, serviceability and durability of structures.

Other requirements, e.g. concerning thermal or sound insulation, are not considered. Bamboo used as a composite structure may require additional considerations beyond this International Standard. Execution (work on-site, and fabrication of components off-site, and their erection on-site) is covered to the extent that is necessary to indicate the quality of construction materials and products which should be used and the standard of workmanship on-site needed to comply with the assumptions of the design rules.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 6891, *Timber structures — Joints made with mechanical fasteners — General principles for the determination of strength and deformation characteristics*

ISO 16670, *Timber structures — Joints made with mechanical fasteners — Quasi-static reversed-cyclic test method*

ISO 22157-1, *Bamboo — Determination of physical and mechanical properties — Part 1: Requirements*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1

joint

connection between two or more bamboo structural elements

3.2

node

place in a bamboo culm where branches sprout and where a diaphragm is inside the culm

4 Symbols and abbreviated terms

σ_{all} the allowable stress, in N/mm^2

I_B the second moment of area, in mm^4

5 Basic requirements

5.1 General

A structure shall be designed and constructed in such a way that

— with acceptable probability, it will remain fit for the use for which it is required, having due regard to its intended life and costs, and

— with appropriate degrees of reliability, it will sustain all actions and influences likely to occur during execution and use and have adequate durability in relation to maintenance costs.

NOTE See also informative Annex B.

5.2 Exceptional events

A structure shall also be designed in such a way that it will not be damaged by events like explosions, impact or consequences of human errors, to an extent disproportionate to the original cause.

5.3 Potential damage

The potential damage should be limited or avoided by the appropriate choice of one or more of the following:

— avoiding, eliminating or reducing the hazards which the structure is to sustain;

— selecting a structural form that has low sensitivity to the hazards considered;

— selecting a structural form and design that can survive adequately the accidental removal of an individual element;

— selecting a structural form and design which provides sufficient continuity between individual elements.

5.4 Choice of materials

The above requirements shall be met by the choice of suitable materials, by appropriate design and detailing and by specifying control procedures for production, construction and use as relevant for the particular project.

5.5 Exception

All bamboo constructions shall comply with this International Standard completely; as an exception, constructions complying only with 6.2.2 and/or 6.2.3 are deemed to comply with the requirements of this standard.

The purpose of this exception is that building processes in the informal sector need a long period of teaching and training in order to support self-help building to the full, and also to promote the self-reliance of lower income groups. National Building Codes should specify step-wise processes starting from zero, until the said assumptions can be reached in the future.

6 Design concepts

6.1 Concepts based on calculations

Bamboo construction design concepts shall be based on calculations, verifying that no relevant limit state or no relevant permissible stress is exceeded (see Clause 7), except as noted in 6.2.

6.2 Concepts based otherwise

6.2.1 General

Bamboo construction design concepts are deemed to comply, provided the concepts are based on one of the items in 6.2.2 or 6.2.3.

6.2.2 Experience from previous generations

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

Criteria for reliability are:

— the content shall be generally known and accepted;

— it shall be considered as an 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.

6.2.3 Reports on evaluations

These reports are based on evaluations made after disasters like earthquakes and hurricanes. If these reports contain descriptions cf 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 written 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 provide full details and full information, with which one can build similar structures.

Limitations are:

— the report is only applicable in similar situations.

6.3 Alternative design

It is permissible to use alternative design rules which differ from this International Standard, provided that it is shown that the alternative rules comply with relevant principles and are at least equivalent with regard to the strength, serviceability and durability achieved for the structure with this International Standard.

7 Structural design

7.1 Limit states

NOTE For allowable stress design, see 7.4.

Limit states are states beyond which the structure no longer satisfies the design performance requirements. Limit states are classified into ultimate limit states, and serviceability limit states.

Ultimate limit states are those associated with collapse, or with other forms of structural failure which may endanger the safety of people. States prior to structural collapse which, for simplicity, are considered in place of the collapse itself, are also classified and treated as ultimate limit states. Ultimate limit states, which may require consideration, include

— loss of equilibrium of the structure or any part of it, and

— failure by excessive deformation or excessive forces, causing rupture or loss of stability of the structure or of any part of it, including supports and foundations.

Serviceability limit states correspond to states beyond which specified service criteria are no longer met. Serviceability limit states, which may require consideration, include

— deformations or deflections which affect the appearance or effective use of the structure (including the malfunction of machines or services) or cause damage to finishes or non-structural elements, and

— vibration which causes discomfort to people, damage to the building or its contents, or which limits its functional effectiveness.

7.2 Material properties

7.2.1 Characteristic value

A material property is represented by a 5 percentile property, estimated from test results, obtained as in ISO 22157-1, with 75 % confidence that it represents the population. This is called the characteristic value. It can be obtained with this formula:

$$R_{\mathrm{k}} = R_{0,05}\left(1 - \frac{2{,}7\,\frac{s}{m}}{\sqrt{n}}\right)$$

where

R_{k} is the characteristic value;

$R_{0,05}$ is the 5 percentile from the test data;

m is the mean value from the test data;

s is the standard deviation from the test data;

n is the number of tests (at least 10).

7.2.2 Design stresses

For the derivation of design stresses from the characteristic value, the following rules shall be applied.

Strength and stiffness parameters shall be determined on the basis of tests for the types of action effects to which the material will be subjected in the structure, or on the basis of comparisons with similar bamboo species or bamboo-based materials or on well-established relations between the different properties.

It shall be shown that the dimensional stability and environmental behaviour are satisfactory for the intended purposes.

Special attention shall be given to differences between material originating from different localities.

Since the characteristic values are determined on the assumption of a linear relation between stress and strain until failure, the strength verification of individual members shall also be based on such a linear relation.

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

Service classes shall be defined according to the temperatures and relative humidity occurring in the regions.

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

7.3 Design requirements

It shall be verified that no relevant limit state is exceeded. All relevant design situations and load cases shall be considered. Possible deviations from the assumed directions or positions of actions shall be considered.

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.

The verification of limit states, and the partial safety factors, shall be in accordance with relevant National Standards.

The loads and actions, to be considered in the calculations, shall be in accordance with relevant National Standards.

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 following formula:

$$\sigma_{\text{all}} = R_{\text{k}} \times G \times \frac{D}{S}$$

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 wind-load;

S is the factor of safety, default value 2,25.

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

7.5 Sound construction practices

The designer shall ensure that sound construction practices are taken into account, according to this subclause.

The use of air-dry bamboo, and of details which ensure that bamboo in buildings shall remain air-dry, and which ensure that bamboo, once it has become wet, shall have the opportunity to dry again before the material can deteriorate due to the moisture content. (For durability and preservation, see Clause 15.)

The permeability of walls, floors and roofs made from bamboo, causing internal pressures, which change the net wind-load acting on the roof, wall and floor.

Special attention shall be given to check whether the workmanship of the labour force, in the factory and on the building site, is according to the assumptions.

Other similar relevant items.

8 Schematisation

This is the process of “translating” the physical reality of a building structure towards a schematised system of symbols to be used during the calculation process. The schematisation is based on the theory of applied mechanics. Typically, bamboo schematisation involves the following assumptions.

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

Bamboo culms are analysed as hollow-tube structures with variable thickness.

Bamboo culms are analysed as not perfectly straight members.

Bamboo culms are analysed as tapered.

Nodes do not occur at constant intervals, which is a problem in practice because joints or supports are preferably located near nodes.

Conventional structural-analysis methods are used with definitions of the initial curvature, the diameter and the wall thickness.

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.

Bernoulli's theorem (flat cross-sections remain flat) is valid for bamboo.

9 Beams (predominantly loaded in bending)

The design of beams shall be based on calculation. Calculation shall be based on the following items, provided the load is symmetrical. For asymmetrical loads, applied stresses at critical points shall be calculated.

The second moment of area I_B shall be determined as follows.

— The outside diameter and the wall thickness shall be measured at both ends, in accordance with ISO 22157-1.

— With these values, the mean diameter and the mean wall thickness for the middle of the beam shall be calculated.

— The second moment of area I_B shall be calculated with these mean values for diameter and wall thickness.

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

The maximum bending stress shall be calculated, and compared with the limit state or the allowable stress, using the loads prescribed in the National Building Code.

The deflection shall be calculated, and compared with the allowable deflection according to National Standards. The initial curvature shall be considered in the calculation of the deflection.

The shear stress in the neutral layer at the small end shall be checked, if the length of the beam is less than 25 times the diameter at that end.

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.

For beams where combined axial and bending loads occur, the interaction of applied stresses shall be considered.

10 Columns (predominantly loaded in an axial direction)

For bamboo columns, the best available straight bamboo culms shall be selected.

The design of columns shall be based on one of the following two items.

— Full-scale buckling tests on the same species, size and other relevant variables,

— Calculations, which shall be based on the following paragraphs.

The second moment of area shall be determined in accordance with Clause 9.

The bending stresses due to initial curvature, eccentricities and induced deflection shall be taken into account, in addition to those due to any lateral load.

Buckling calculation shall be according to Euler, with a reduction to 90 % of the second moment of area I_B. This reduction to 90 % takes into account the effect of the taper. The taper is defined as the ratio of difference between minimum and maximum outer diameter to length. The taper shall be less than 1 to 170; otherwise this paragraph is not applicable.

Combined bending and compression in predominantly axially loaded members needs special consideration.

11 Joints

11.1 General

11.1.1 Based on calculations

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

— force transmission according to a prescribed manner, and

— 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 Based otherwise

Bamboo joint design concepts are deemed to comply, provided the concepts are based on one of the items in 6.2.2 or 6.2.3.