INTERNATIONAL STANDARD

ISO 19624

First edition
2018-09

Bamboo structures — Grading of bamboo culms — Basic principles and procedures

Structures en bambou — Classement des tiges de bambou

Reference number
ISO 19624:2018(E)

Contents

Page

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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by ISO Technical Committee 165, *Timber structures*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The general principle of this document is that any type of grading procedure is acceptable, provided it is defined, controlled, and documented to the extent required to achieve the degree of reliability intended for the structural application of the product. This document specifies procedures that conform to this principle. The grading procedures outlined in this document require visual, dimensional and mechanical stages to ensure conformity.

Annex A provides an example conformance standard reflecting the requirements of this document.

Bamboo structures — Grading of bamboo culms — Basic principles and procedures

1 Scope

This document specifies grading procedures for visually and mechanically sorting round, or pole, bamboo for structural applications using such fundamental elements. Visual sorting is based on observable characteristics of the piece(s). Mechanical sorting is based on non-destructive measurement of properties known to correlate to characteristic values defining a grade.

The grading procedures in this document can be used in a quality acceptance regime, although this document does not define or address acceptance criteria.

This document is applicable only for bamboo that is graded in the seasoned state.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 22156, *Bamboo — Structural design*

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

ISO 12122-1, *Timber structures — Determination of characteristic values — Part 1: Basic requirements*

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
bamboo culm
single shoot of bamboo

Note 1 to entry: A culm is comprised of the entire unaltered bamboo cross section and is usually a hollow cylinder except at nodes.

3.2
bow
measure of variation of culm from straight condition, reported as the ratio of greatest transverse variation to reference length of culm

3.3
dry bamboo
seasoned bamboo
bamboo that has been subjected to a drying process and with moisture content of 19 % or less

3.4
fissure
longitudinally oriented separation or split of the bamboo wall running parallel to the fibres at the end of a culm or at any internode of the piece that may or may not penetrate through the entire wall thickness

Note 1 to entry: An example of a fissure is shown in Figure 1.

3.5
geometric property
measurable dimensional property of bamboo piece, generally used in reference to diameter, wall thickness, length and internode length

3.6
grade-determining property
GDP
mechanical, geometric or physical property for which a particular value should be achieved for the material to be assigned to that grade

3.7
indicating property
IP
measurement or combination of measurements made during grading, which are related to one or more of the grade-determining properties

3.8
initial evaluation
process prior to grading during which the geometric, physical and mechanical properties for bamboo originating from a source region will be assessed with the aim of developing reliable selection criteria

3.9
internode
usually hollow region of bamboo culm between two nodes at which diameter and wall thickness are defined

3.10
longitudinal indentation
longitudinal depression running parallel to the fibres that may indicate the presence of an internal fissure that is not visible externally

Note 1 to entry: An example of a longitudinal indentation is shown in Figure 2.

3.11
mechanical property
measurable property of bamboo associated with both culm geometry and bamboo material properties that describes behaviour under the effects of applied load or stress, generally used in reference to member or section strength or stiffness

3.12
moisture content
portion of culm weight consisting of water expressed as percentage of oven-dry weight

3.13
node
transverse diaphragm region located along length of culm separating adjacent internodes

Note 1 to entry: The separation between nodes varies along the culm. When alive, nodes are locations of leaf and branch growth.

3.14
ovality
degree of variation of culm cross section from circular, reported as the ratio of the greatest to least diametric measurement at a specific location

3.15
physical property
measureable or observable property of bamboo that describes its behaviour to external influences other than stress or strain, generally used in reference to density, moisture content, etc.

3.16
producer
supplier
organization responsible for the grading process, which usually would be the same organization responsible for drying and preserving the bamboo culms

3.17
proof testing
non-destructive structural testing protocol involving loading the culm (or structural assembly) to a predetermined value to assess its ability to carry this load

Note 1 to entry: Not addressed by this document.

3.18
source region
geographical location from which the bamboo resource originates

3.19
structural capacity
load carrying capacity of a culm which is a function of mechanical, geometric and physical properties of the culm

Note 1 to entry: Usually expressed in kiloNewtons (force) or kiloNewtons-metre (moment).

3.20
taper
degree of change of outer diameter (external taper), internal diameter (internal taper), section area (areal taper) or other geometric property along length of culm, expressed as percentage of the length of the culm

3.22
unseasoned bamboo
bamboo with moisture content greater than 19 %

3.23
grading rules
visual set of criteria used to sort bamboo pieces during visual grading

Note 1 to entry: Grading rules should have a demonstrated link to the grades sought.

3.24
visual override
process by which bamboo pieces are excluded from machine grading, because they do not meet criteria known to be important to grading and that cannot be sensed by the machine

4 Symbols

b_{max} maximum perpendicular distance from the centre of the culm section to the chord drawn from the centres of either end of the piece of bamboo, expressed in millimetres

b_o bow of a piece of bamboo

D external diameter of the bamboo culm, expressed in millimetres

D_b external diameter at the base of a piece of bamboo

D_{max} maximum external diameter at a given location on a piece of bamboo

D_{min} minimum external diameter at a given location on a piece of bamboo

D_t external diameter at the top of a piece of bamboo

L length of a piece of bamboo, expressed in millimetres

L_{in} internode length, expressed in millimetres

L_{ref} reference length of a piece over which the bow of a piece of bamboo is assessed, expressed in millimetres

δ culm wall thickness, expressed in millimetres

α_e external taper, expressed as a percentage

α_i internal taper, expressed as a percentage

5 General

5.1 Grading

Grading is the process of sorting every piece of bamboo in a sample into grades according to defined selection criteria. The criteria identify dimensional, visual, geometric, mechanical and/or physical properties that reflect the bamboo's mechanical strength or structural capacity and may affect the utility of the product.

Each grade is associated with a range of mechanical, geometric, physical and/or structural properties derived from testing. The selection criteria are based on non-destructive observations and measurements that have been established to be useful to the grading process.

Grading provides a statistically significant prediction of the mechanical, geometric and/or physical properties of the population within a grade, but does not provide the properties of each individual piece.

Grading is not proof testing. Proof testing can be carried out to increase confidence in selected material, if desired. Proof testing is beyond the scope of this document.

5.2 Grades

The sorting criteria for a given grade should reliably infer the properties selected as the basis of the grading process. A grade can be set to correspond to a particular bamboo resource in order to make optimum use of the resource. Alternatively, a grade can be set to meet the requirements of a particular end use or specification.

5.3 Graded bamboo culms

Graded bamboo culms are dry (or seasoned) lengths of bamboo in their round form that have been subjected to a grading process. It should not be assumed that products derived from graded bamboo culms, such as strips or laminates, are also graded; such products would need to be subjected to a separate grading process beyond the scope of this document.

5.4 Grading operations

Bamboo shall be visually graded according to Clause 6, and/or machine-graded according to Clause 7.

The grading operation shall be comprised of a visual grader and/or machine(s) sorting an input resource into output grades. If some of the bamboo does not meet the requirements of the minimum grade, it is rejected.

5.5 Secondary properties

Secondary properties are physical or mechanical properties for a given grade that are neither measured nor inferred directly from the grading process. Secondary properties should not be critical to the end application of the culms. These properties are usually estimated from the grade-determining properties on the basis of previously derived correlations that are valid for the specific species.

6 Visual grading

6.1 General

Visual grading is understood to be the process of sorting material according to visually measureable characteristics known to affect the mechanical or structural properties of bamboo culms. Visual grading can be assisted by machines.

Visual grading operations shall be carried out by a grader that has received appropriate training to perform this task.

The sorting criteria for visual grading shall be referred to as grading rules, and based on characteristics known to affect the strength or structural capacity of bamboo culms. These characteristics can be divided into:

— condition properties;

— geometric properties.

It is permissible to verify the visual grade of a piece by applying the same grading rules.

Re-grading with different grading rules, or visually grading bamboo rejected by machine grading, is not permitted.

It is possible to supplement the visual grading process by non-destructively assessing properties that are known to correlate to strength or structural capacity.

6.2 Visual grading requirements

6.2.1 General

Most grading rules can be adapted to suit a particular species and source region, provided they are developed in accordance with 8.2. The following requirements shall be observed when setting grading rules or visual override criteria.

6.2.2 Condition properties

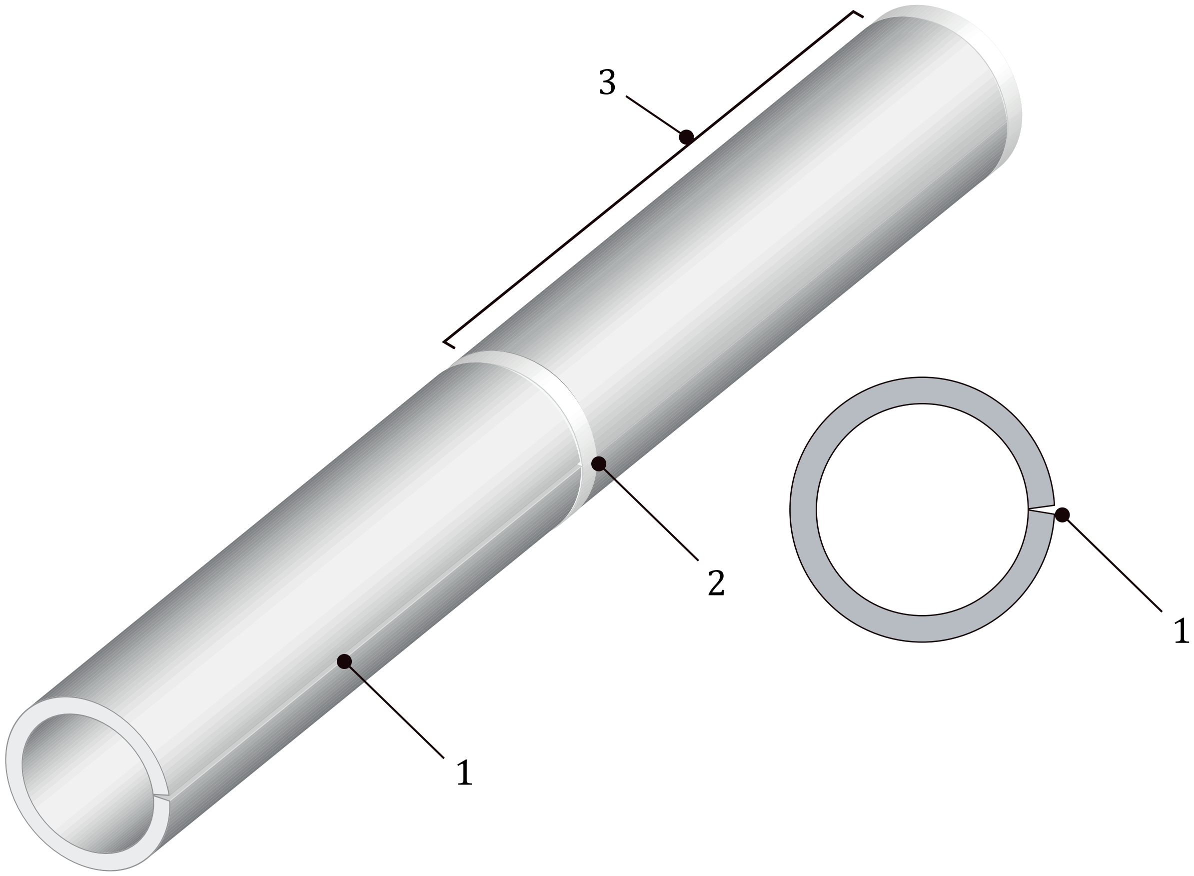
Condition properties refer to the state of the material in terms of insect and/or fungal damage, and defects such as fissures and longitudinal indentation. Visual grading rules shall be based on any combination of the following observable condition requirements.

6.2.2.1 Insect and fungal damage

Pieces showing evidence of rot or insect damage should normally be rejected.

6.2.2.2 Fissures and longitudinal indentation

Fissures present at the outer surface of any internode, shall be reported and considered in the grading process. Grading rules should consider the depth, length, location and number of fissures on a given piece. Figure 1 provides an example of a fissure.



Key

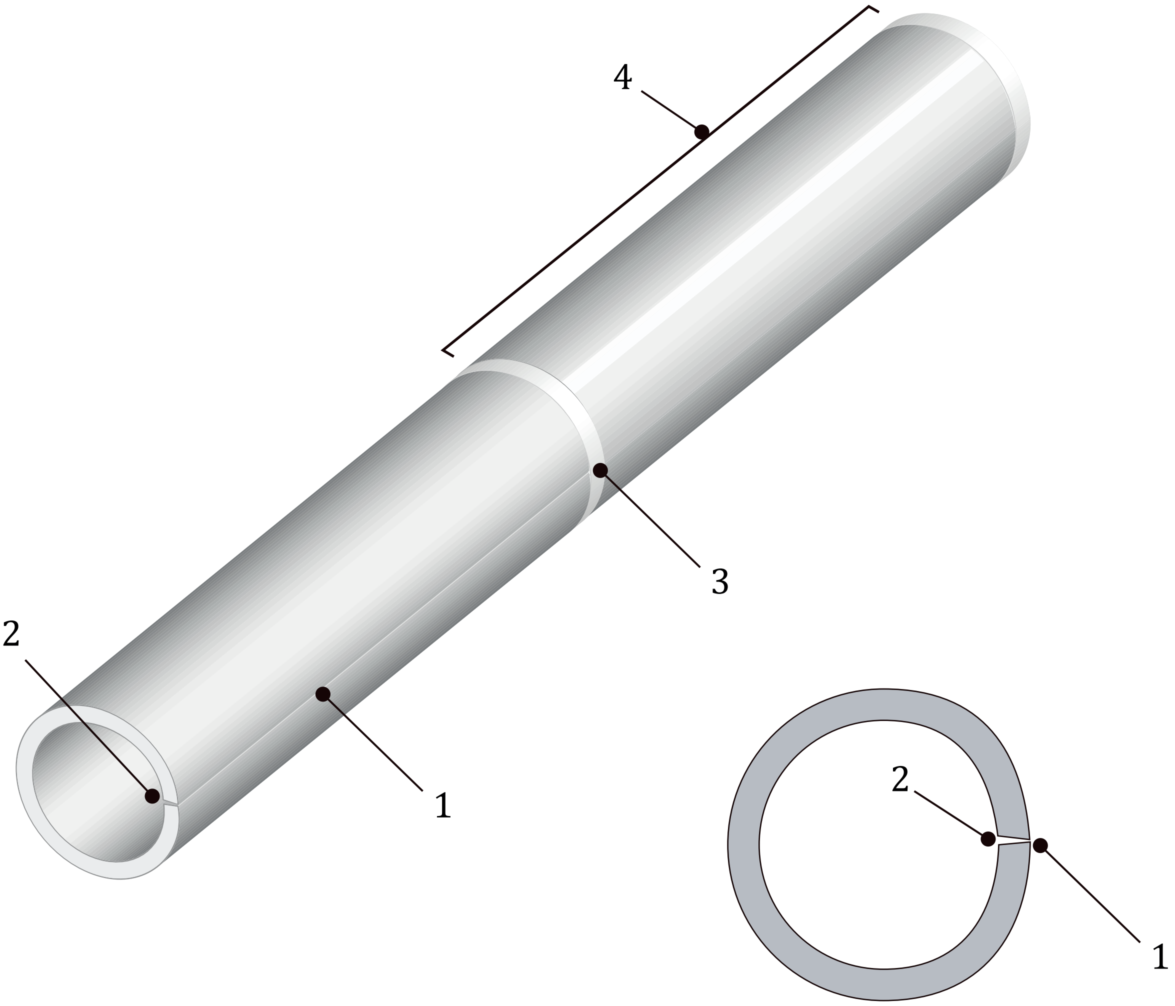
1 fissure

2 node

3 internode

Figure 1 — Manifestation of fissure on surface of culm and cross-section through fissure

Longitudinal indentations present at any internode, shall be reported and considered in the grading process. Longitudinal indentations can result from internal fissures (Figure 2) or be a natural manifestation of culm growth. It is permissible to assess the source of the indentations; only manifestations of internal fissures are reported as condition requirements. Grading rules should consider the depth, length, location and number of longitudinal indentations.



Key

1 longitudinal indentation

2 internal fissure

3 node

4 internode

Figure 2 — Manifestation of longitudinal indentation and cross-section through internal fissure and associated indentation

6.2.3 Geometric properties

Geometric properties refers to the directly measurable dimensions of a piece, such as diameter, wall thickness, internodal length and culm length; as well as properties that represent a deviation from a straight, hollow cylinder and that require some calculation, such as bow, taper and ovality. Visual grading shall be made based on any combination of the following measurable dimensional requirements.

6.2.3.1 Diameter

Diameter, D, should normally be considered as a visual grading criteria, as it is significantly affects the structural capacity of a section.

The diameter is measured at the centre of an internode region.

The diameter can be controlled during grading by any of the following methods:

6.2.3.1.1 Average diameter over culm length

The average of perpendicular measurements made across opposite points on the outer surface at both ends of the piece. Only this method should be used for initial evaluation.

6.2.3.1.2 Smallest average diameter

The smallest average diameter is the average value of two perpendicular measurements made across opposite points on the outer surface at the narrowest internode on the piece.

6.2.3.1.3 Smallest absolute diameter

The smallest absolute diameter is the smallest measurement made across opposite points on the outer surface at the narrowest internode on the piece.

6.2.3.2 Wall thickness

The wall thickness, δ, should normally be considered as a visual grading criteria, but may be inferred if species-specific diameter-to-thickness relationships are known, or calculated from the mass of the piece and density of the material.

The wall thickness is usually measured at the centre of an internode region.

When directly measured, the wall thickness can be controlled during grading by any of the following methods.

6.2.3.2.1 Average wall thickness over culm length

The average wall thickness over culm length is the average value of four measurements taken around the circumference of the culm, at angular spacings of 90° at both ends of the piece. Only this method should be used for initial evaluation.

6.2.3.2.2 Smallest average wall thickness

The smallest average wall thickness is the average value of four measurements taken around the circumference of the culm at angular spacings of 90° at the internode with the thinnest walls on the piece.

6.2.3.3 Internode length

For some applications and for some species, it can be desirable to consider internode lengths, L_{in}, during grading.

When directly measured, the internode length can be controlled during grading by any of the following methods.

6.2.3.3.1 Average of all internode lengths

The average of all internode lengths is the average value of all internode lengths along the piece.

6.2.3.3.2 Average of top and bottom internode lengths

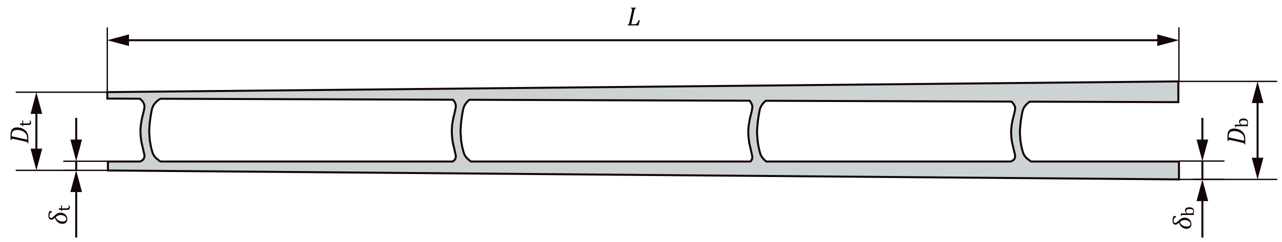
It is the average of the internode lengths of the top- and bottom-most internodes of the piece.

6.2.3.4 Length

Since bamboo properties vary along the culm, the length, L, of pieces during grading should be consistent with the lengths studied during the initial evaluation.

6.2.3.5 External taper

The external taper can significantly reduce the bending and compression capacity of a culm. The external taper should be reported and considered in the grading process.



Key

D_b diameter at the base of the piece

D_t diameter at the top of the piece

L length of the piece

δ_b wall thickness at the base of the piece

δ_t wall thickness at the top of the piece

Figure 3 — Longitudinal section of bamboo culm showing external and internal taper

The external taper, α_e, is determined from Formula (1), refer also to Figure 3.

$$\alpha_e = \frac{D_b - D_t}{L} \tag{1}$$

Control for external taper should be considered during grading if the method outlined in 6.2.3.1.1 is used for assessing external diameter.

6.2.3.6 Internal taper

The internal taper can significantly reduce the bending and compression capacity of a culm. The internal taper should be reported and considered in the grading process.

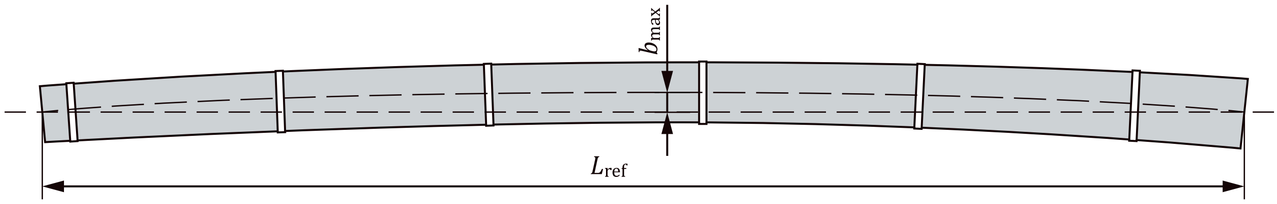
The internal taper, α_i, is determined from Formula (2), refer also to Figure 3.

$$\alpha_i = \frac{D_b - D_t - 2(\delta_b - \delta_t)}{L} \tag{2}$$

Control for internal taper should be considered during grading if the methods outlined in 6.2.3.1.1 and 6.2.3.2.1 are used for assessing external diameter and wall thickness, respectively.

6.2.3.7 Bow

Bow should be reported and considered in the grading process (see Figure 4).



Key

b_{max} maximum perpendicular distance from the centre of the culm section to the chord drawn from the centres of either end of the piece

L_{ref} reference length of the piece

Figure 4 — Elevation of a bamboo culm showing bow

The bow, b_o, is determined from Formula (3)

$$b_o = b_{max} / L_{ref} \quad (3)$$

The reference length shall be selected to be appropriate for both the intended use of the bamboo and the species characteristics. Examples of the definition of reference length may include: a) the length of the graded piece; b) the typical length of the structural member; c) a specified number of internodes greater than three; or, d) a specified number of culm diameters greater than 30.

6.2.3.8 Ovality

The ovality, d_o, is determined from Formula (4)

$$d_o = 2 \cdot (D_{max} - D_{min}) / (D_{max} + D_{min}) \quad (4)$$

where D_{max} and D_{min} are the diameters measured across the largest and smallest principle axes of the piece where D_{max} / D_{min} is greatest.

The ovality value should be reported and considered in the grading process. It is unnecessary to control for ovality during grading if the method outlined in 6.2.3.1.3 is used for assessing external diameter.

6.3 Other requirements for visual grading

6.3.1 Moisture content

The moisture content shall be determined and recorded using a method described in ISO 22157-1. Grading should normally be done on seasoned bamboo. Grading of unseasoned bamboo is possible, but provision should be made for checking for splits and fissures after drying.

6.3.2 Age at harvesting

The maturity of the culm is known to affect the mechanical properties of bamboo and it may be included as a grading requirement for some species. However, if maturity can only be controlled at the plantation, this requirement is not strictly part of the grading process. Where controlling for age is not possible, practical or enforceable, properties derived during the initial evaluation should not be derived using a sample consisting only of mature culms, as this would bias the strength properties. Instead, the sample used during initial evaluation should contain a range of levels of maturity consistent with those that would be used during production in accordance with 8.2.

6.4 Check on visual grading process

During each production shift, a check shall be made to assess the accuracy of the visual grading process. This shall be done by regrading a sample of graded bamboo. The acceptance criterion shall be that not more than 5 % of the verified pieces fall below the visual grading rules.

If the checks indicate that the process is inadequate, then appropriate measures shall be undertaken to modify the process.

7 Machine grading

7.1 General

Machine grading will be understood to be the process of sorting material by means of measuring one or more indicating properties known to correlate to grade-determining properties. After the machine grading operation takes place, a visual override can be required to inspect the bamboo for structural capacity-reducing defects that cannot be identified by the machine.

A grading machine comprises one or more devices that can measure physical or mechanical properties in any of the following manners:

— At several locations along the length of a piece of bamboo as it passes through the machine;

— Properties are measured, that relate to the piece of bamboo considered as a single unit;

— Discrete measurements are taken at a minimum of two locations, which can be considered to be representative of the whole piece.

7.2 Machine grading process requirements

The machine grading process shall specify, at regular intervals, checks to ensure:

a) Repeatability – Within prescribed limits, the machine shall provide the same readings for repeated passes of the same piece of bamboo.

b) Calibration – Within prescribed limits, machines shall reproduce the original readings made on special pieces of bamboo set aside for calibration purposes or on non-bamboo calibration pieces.

In addition to verification of the calibration of the machine, all machine checks specified by the machine manufacturer shall be undertaken.

7.3 Indicating properties

Indicating properties are those directly measured from the grading process and that are relatable to the grade-determining properties.

EXAMPLES

— force to cause specified bending deformation (stiffness);

— deflection caused by specified load (flexibility);

— linear mass;

— wall thickness;

— diameter.

7.4 Grade-determining properties

The grade-determining properties may be measured directly, as indicating properties, calculated from indicating properties, or inferred, non-destructively, during grading. Indicating properties can also be grade-determining properties.

EXAMPLES

— bending strength (i.e. extreme fibre stress or "modulus of rupture");

— flexural capacity (i.e. bending moment);

— modulus of elasticity;

— flexural stiffness (i.e., EI);

— density;

— linear mass;

— wall thickness;

— external diameter.

The grade-determining properties are selected on the basis of their importance to structural design.

Grade-determining properties are initially established from the provisions laid out in 8.2.2, and are generally expressed as characteristic values, with the exception of stiffness values (modulus of elasticity or bending stiffness), which are generally expressed as mean values. Derivation of characteristic values from experimental data shall be in compliance with ISO 22156 or ISO 12122-1.

Secondary properties for a given grade may be derived from the indicative or grade-determining properties, if correlations have been determined.

For an example of grade-determining properties, refer to Table A.7.

7.5 Visual override

Visual sorting criteria contained in 6.2.2 and 6.2.3 should be considered as the basis for a visual override for a machine grading process.

7.6 Hybrid grading methods

Methods combining aspects of visual grading with machine measurements are permitted. These grading methods shall use grading rules for the determination of most structural properties, but can rely on indicating properties to infer one or more grade-determining properties. The determination of the indicating properties will be in accordance with 8.2.2 and 8.2.5.

8 Structural properties of graded bamboo

8.1 General

The mechanical or physical properties for any given structural grade or class shall be as defined and measured in accordance with the test methods contained in ISO 22157-1.

8.2 Initial evaluation

Once a grading operation has been selected, evidence shall be provided that the resulting output grades have the structural properties stated for the material and grade. The evidence may be linked to other producers carrying out equivalent or similar grading procedures, provided the material is the same species and originating from the same source region. For cases where such evidence is not available, or it is not appropriate to link the evidence to other producers, an initial evaluation of properties should be specified in accordance with 8.2.1 or 8.2.2, depending on the selected grading operation. It is not appropriate to link the evidence to other producers, if a new procedure is to be adopted.

8.2.1 Developing visual grading rules

The process of developing grading rules for one or more grades shall follow the following procedure:

1. Obtain a bamboo sample in accordance with 8.2.3 and 8.2.4.

2. Apply proposed grading rules and assign bamboo to grade(s).

3. Test sample destructively in accordance with ISO 22157-1. All physical and mechanical tests contained in ISO 22157-1 need to be undertaken, unless it is possible to link the grade to known secondary properties for the species in accordance with 8.4.

4. Evaluate the characteristic values of the structural properties in accordance with ISO 22156 or ISO 12122-1.

5. Declare the structural properties for the grade. Table A.1 provides an example of how values can be declared for three grades of a bamboo species.

8.2.2 Developing grading settings for machine grading

The process of developing grading rules for one or more grades shall follow the following procedure:

1. Obtain a bamboo sample in accordance with 8.2.3 and 8.2.5.

2. Subject sample to visual grading in accordance with the visual override criteria that is to be used.

3. Pass bamboo sample through machine to be used during grading for which settings are being developed.

4. Test sample destructively in accordance with ISO 22157-1. All physical and mechanical tests contained in ISO 22157-1 need to be undertaken, unless it is possible to link the grade to known secondary properties for the species in accordance with 8.4.

5. Formulate useful indicating property (or properties) and relate these to critical grade-determining property (or properties).

6. Derive indicating property thresholds that satisfy the requirements of the grades to ensure robust grading.

7. Verify settings.

8.2.3 Sampling

When determining a sample for initial evaluation, the main requirement is that the sample be representative of the material that is to be graded during production. Consideration should be made to the following:

1. The sample should originate from the same source region that is to be used during production. Grading cannot be applied to material originating from outside the source region used in the initial evaluation.

2. The sample should be similar to the production material in terms of variability of material originating from the source region. If, within the source region, particularly large or small specimens are known to occur, these are to be included in the sample, otherwise the grading process may be restricted to a range of properties established in the initial evaluation. If zones within the region are known to produce material of lower quality, and are to be exploited during production, these should be included.

3. If control for age at plantation is not possible or practical to implement, the sample should contain specimens of a range of ages. If, for a species or plantation, it is not possible to determine or infer the age of the culms, it may be assumed that the sample inherently contains a range of ages.

4. Samples that would fail the visual override, are not to be used in the development of grading settings for machine grading.

8.2.4 Sample size for initial evaluation

Table 1 provides guidance for minimum sample sizes to be used in the development of visual grading rules. Consideration should be given to the size of the growth area and variation of quality within it.

Table 1 — Minimum sample sizes to be used in the development of visual grading rules.

	Physical properties	Mechanical properties	Geometric properties
	e.g. density, moisture content, linear mass	e.g. bending, shear, compression, tension	e.g. diameter, wall thickness, internode length
New species	The sample should comply with ISO 12122-1:2014, 6.2, with a minimum size of 30 specimens per test per grade.		
Previously studied species, originating from different source region	As above	As above *or* A reduced test programme may be adopted as indicated in 8.4	As above

Development of machine settings can require very large sample sizes. The sample size should be consistent with that required for development of machine settings for timber grading.

8.2.5 Other considerations during initial evaluation testing

1. External diameter should be evaluated as the average diameter over the culm length in accordance with 6.2.3.1.1.

2. Wall thickness should be evaluated as the average wall thickness over the culm length in accordance with 6.2.3.2.1.

3. When bending properties are determined in accordance with ISO 22157-1, taper of the specimen results in an underestimation of the real bending properties of the section. Bending tests should be conducted with specimens having minimal taper. When evaluating bending properties, sections with large ovality can result in an overestimation of the usable bending properties of the section. Bending tests should be conducted with flexure about the weak axis of the specimen.

4. If diameter is used as a grading criteria, specimens exceeding the upper limit of the upper grade (where applicable), should not be included during initial evaluation, even if they are accepted during grading.

5. During the development of initial grading, it should be ensured that wall thickness and internode lengths are representative of the grade.

8.3 Periodic evaluation

The structural properties derived from initial evaluation should be routinely evaluated to ensure they remain consistent. The size of sample required during periodic evaluation should be at least half of that required in 8.2.4 and 8.2.5. Evaluation of grading procedures and processes should take place at least every two years or 60 000 m of graded culms. Where there is indication that properties vary periodically, properties shall be evaluated at each harvest.

If it is found during the periodic evaluation that the characteristic values are less than those declared, it is possible to retest these up to a maximum of four times. If the results are still less than those declared, the sample size of the last test shall be increased so that the sample size requirements contained in 8.2.4 and 8.2.5 are met. The values obtained from the enlarged fourth test shall be used for a new declaration of properties.

8.4 Reduced test programmes and secondary properties

It is recommended that a full test programme be undertaken for any new bamboo species or source region of a known species. If a species has been extensively studied, some secondary properties may be adopted in lieu of experimentally derived properties.

9 Product identification

A product identification mark on the bamboo shall be specified to indicate the standard on which the sorting is based, the grade, the date of grading (expressed to within one month) and the producer responsible. The product identification mark may include other information deemed important such as the population characteristic values or the grade characteristic values.

10 Documentation

Documentation shall include:

a) the standard on which the grading process is based;

b) specifications for the bamboo grade criteria;

c) specifications and control checks of the resource input where applicable to machine control operations;

d) specifications and control checks for the machine grade sorting process;

e) where applicable, specifications and control checks for the visual requirements;

f) specifications and control checks of the structural properties;

g) specifications for the identification of the product;

h) methods for assigning and confirming a grade; and

i) any other specifications or materials deemed to be important.

Annex A
(informative)

Example of application of clauses in this document to a visual grading standard for bamboo culms based on external diameter and flexural properties

A.1 General

This Annex provides an illustrative example of grading procedures for producing visually sorted, capacity graded bamboo culms for structural applications.

For the purposes of this Annex, all normative references, terms and definitions given in ISO 22157-1 and this document apply.

A.1.1 Hypothetical example

This hypothetical example uses external diameter as the primary grading criteria, and assumes that flexural properties are deemed the most critical to design. Values and equations presented should be interpreted as being for illustrative purposes only.

A.2 Symbols

A.2.1 General notation

For the purposes of this Annex, the symbols and abbreviated terms given in ISO 22157-1, and in the main body of this document apply. Additionally, the following symbols apply.

EI_m apparent flexural stiffness of section parallel to direction of fibres, expressed in Newtons per square millimetre (N/mm^2)

M_0 flexural, or bending, capacity of the section parallel to the direction of the fibres, expressed in Newton millimetres (Nmm)

$N_{c,0}$ compressive capacity of the section parallel to the direction of the fibres, expressed in Newtons (N)

$N_{t,0}$ tensile capacity of the section parallel to the direction of the fibres, expressed in Newtons (N)

V_k shear capacity of the section, expressed in Newtons (N)

A.2.2 Subscripts

0,05 5-percentile value

0,25 25-percentile value

k characteristic value

mean mean value

A.2.3 Grades

The output grades proposed in this Annex are based on external culm diameter. Flexural properties are assumed as the most critical properties to design. Table A.1 presents the output grades. Pieces with an external diameter greater than 120 mm may be treated as belonging to ϕ110, provided they comply with wall thickness requirements and their inclusion does not affect the utility of grade ϕ110. Pieces with an external diameter less than 70 mm are rejected.

Table A.1 — Example of output grades based on external diameter

Grade	ϕ70	ϕ80	ϕ90	ϕ100	ϕ110
Range of average external diameter, *D*	≥70 mm <80 mm	≥80 mm <90 mm	≥90 mm <100 mm	≥100 mm <110 mm	≥110 mm <120 mm

A.2.4 Graded bamboo culms

Graded bamboo culms are seasoned lengths of bamboo in their round form that have been subjected to a grading process, such as that indicated in Figure A.1.

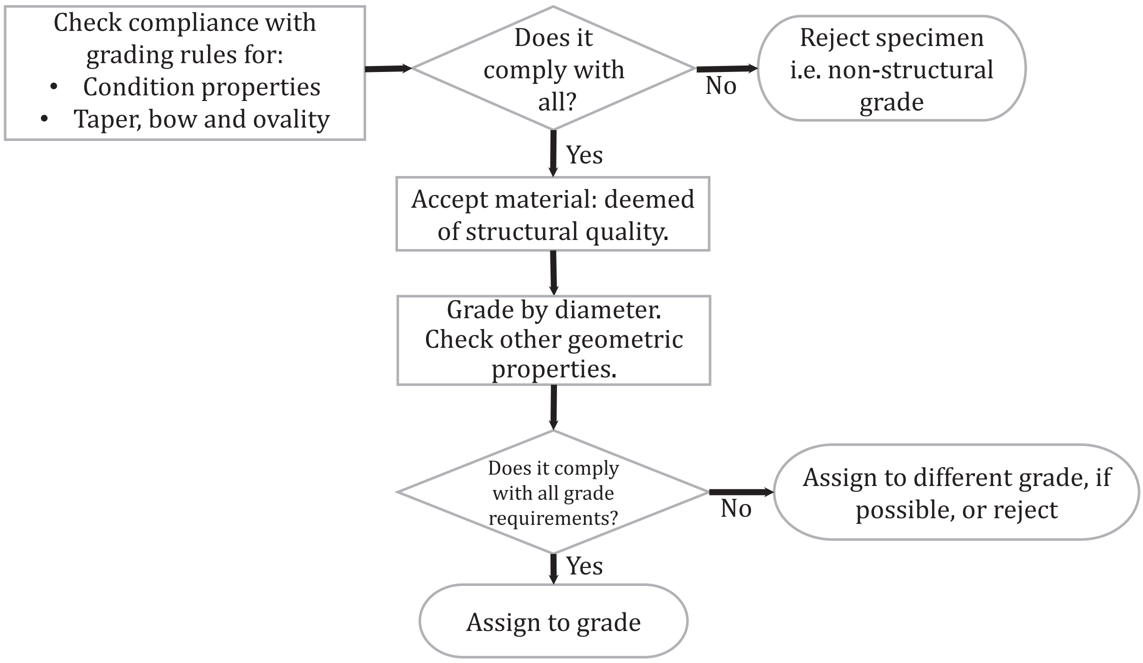


Figure A.1 — Grading of bamboo culms by external diameter

A.2.5 Secondary properties

Secondary properties are physical or mechanical properties for a given grade that are neither measured nor inferred directly from the grading process. Secondary properties should not be critical to the end application of the culms. These properties are usually estimated from the grade-determining properties on the basis of previously derived correlations that are valid for the species. Table A.2 provides examples of secondary properties determined from two different grade-determining properties valid for a hypothetical species of bamboo considered in this Annex.

Table A.2 — Example of secondary properties derived from the grade-determining properties a) characteristic bending strength, $f_{m,0,k}$, of the population; and b) characteristic density, ρ_k, of the population

		Grade-determining property	
		Characteristic bending strength, $f_{m,0,k}$	Characteristic density, ρ_k
Secondary mechanical property	Symbol	Formula	Formula (ρ_k in kg/m^3)
Characteristic compression strength parallel to fibres (N/mm^2)	$f_{c,0,k}$	$= f_{m,0,k} / 2$	$= 0{,}04\ \rho_k$
Characteristic tension strength parallel to fibres (N/mm^2)	$f_{t,0,k}$	$= f_{m,0,k}$	$= 0{,}08\ \rho_k$
Characteristic shear strength (N/mm^2)	$f_{v,k}$	$= f_{m,0,k} / 15$	$= 0{,}005\ \rho_k$

A.2.5.1 Fissures and longitudinal indentation

Fissures present at the outer surface of any internode shall be reported and considered in the grading process. Pieces exceeding the guidelines for fissures contained in Table A.3 shall be deemed “non-structural”.

Table A.3 — Example of limits to fissures and longitudinal indentations

	Fissures	Longitudinal indentation
Width permitted	≤1 mm	≤2 mm (when it can be assessed)
Length permitted	Sum of the lengths of all fissures ≤20 % length of piece	Sum of the lengths of all longitudinal indentations ≤20 % length of piece
The following will not be permitted:	Continuous fissures extending over three or more internodes, regardless of width	Continuous longitudinal indentations extending over three or more internodes, regardless of width

A.2.5.2 Wall thickness

The wall thickness, δ, should normally be considered as a visual grading criteria, but may be inferred if species-specific diameter-to-thickness relationships are known, or calculated from the mass of the piece and density of the material. Table A.4 provides an example of equations used to infer wall thickness from the mean linear mass of a given population of bamboo. Formula (A.1) provides an example of a minimum diameter-to-thickness ratio appropriate for a species of bamboo.

$$\delta_{0,25} = \frac{D}{10{,}5} \qquad \text{(A.1)}$$

where $\delta_{0,25}$ is the 25th percentile inferred wall thickness

Table A.4 — Wall thickness properties inferred from the mean linear mass, q_{mean}

Mean wall thickness	δ_{mean}	$3{,}93 \times q_{mean} + 3{,}32$
Characteristic wall thickness	$\delta_{0,25}$	$3{,}93 \times q_{mean} + 1{,}41$

NOTE The examples provided in Table A.4 and Formula (A.1) use 25th percentile wall thickness in lieu of characteristic wall thickness.

A.2.5.3 External taper and internal taper

Table A.5 provides example limits to external, α_e, and internal taper, α_i appropriate for a hypothetical species of bamboo.

Table A.5 — Limits to internal taper

Level of external taper, α_e	Range of external taper, α_e	Permitted range of internal taper, α_i
Moderate	0 % ≤ α_e <0,1 %	−0,17 % ≤ α_i <0,09 %
High	0,1 % ≤ α_e ≤0,5 %	0,09 % ≤ α_i <0,43 %

External tapers, α_e, greater than 0,5 % are not permitted.

A.2.5.4 Bow

Bow should be calculated using a reference length, L_{ref}, equal to the length of the graded member (not less than 3 m) and should be limited to $L/150$.

A.2.5.5 Ovality

Ovality should be limited to 1/10.

A.2.6 Indicating properties

Indicating properties are those directly measured from the grading process and that are relatable to the grade-determining properties. Tables A.4 and A.7 provide examples of how linear mass, q_{12}, may be used as an indicating property.

A.2.7 Grade-determining properties

The grade-determining properties may be measured directly, as indicating properties, calculated from indicating properties, or inferred, non-destructively, during grading. Indicating properties can also be grade-determining properties. Table A.7 provides an example of grade-determining properties derived from linear mass using the formulae shown.

Grade-determining properties are initially established from 8.2.2, and are generally to be expressed as characteristic values, with the exception of stiffness values (modulus of elasticity or bending stiffness), which are expressed as mean values. Derivation of characteristic values from experimental data shall be done to comply with ISO 22156.

A.2.8 Hybrid grading methods

Methods combining aspects of visual grading with machine measurements are permitted. These grading methods should use grading rules for the determination of most structural properties, but may rely on indicating properties to infer one or more grade-determining properties. The determination of the indicating properties shall be in accordance with 8.2.2 and 8.2.4. Figure A.2 provides an example of a hybrid process combining elements of visual grading with machine grading, using linear mass as the indicating property. The linear mass needs to be non-destructively assessed in accordance with ISO 22157-1 and normalized to 12 % moisture content. A.2.8.2 provides an example of values declared for an unspecified species of bamboo.

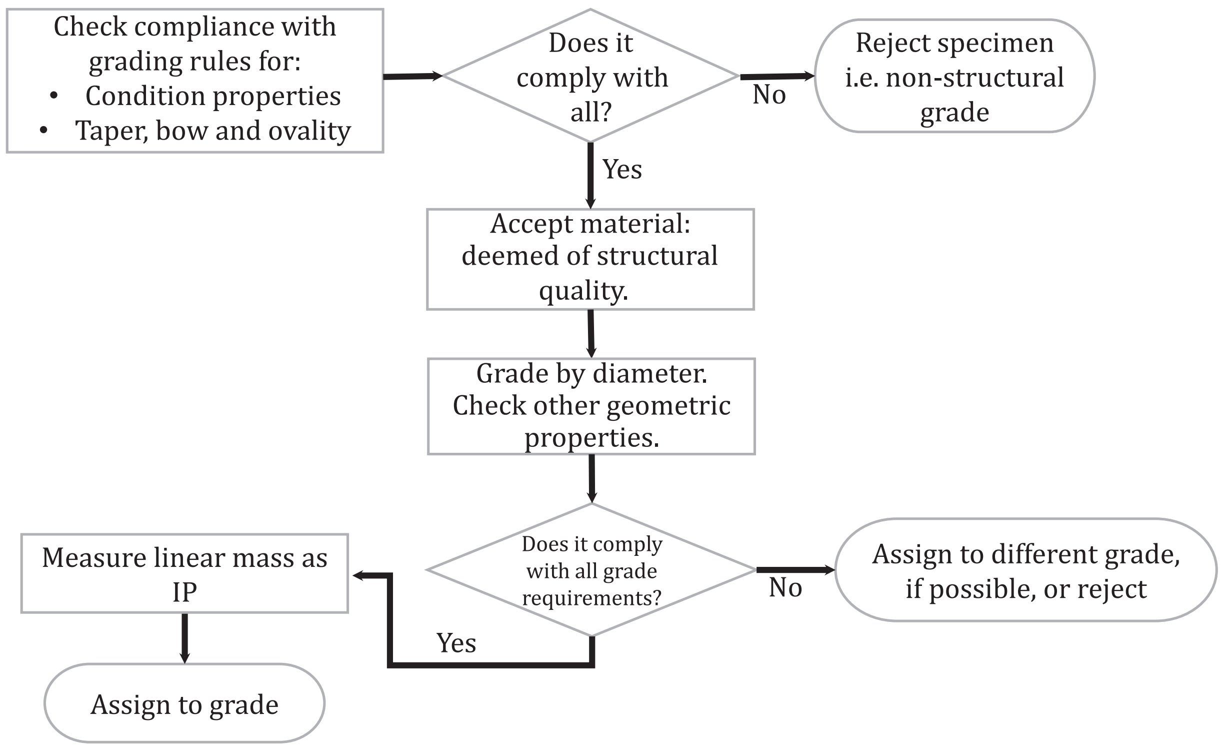


Figure A.2 — Flowchart of a diameter-based visual grading combined a machine graded process using linear mass as an IP

A.2.8.1 Developing visual grading rules

Table A.6 provides an example of a declaration of properties derived from an initial evaluation appropriate to a visual grading process.

Table A.6 — Design values for diameter-based grades for the example hypothetical species

	Property	Units	Grade			
			ϕ80	**ϕ90**	**ϕ100**	**ϕ110**
Range of external diameter	D	mm	≥80 mm <90 mm	≥ 90 mm <100 mm	≥100 mm <110 mm	≥110 mm <120 mm
Experimentally determined properties	$EI_{m,mean}$	$GNmm^2$	32,9	49,8	69,6	96,0
	$EI_{m,0,05}$		21,9	32,7	46,8	68,7
	$M_{0,k}$	kNm	1,47	2,79	3,90	4,75
	q_{mean}	kg/m	1,56	1,97	2,46	3,07
	q_k	kg/m	1,09	1,48	1,83	2,19
	$\delta_{0,25}$	mm	7,9	7,9	9,8	11,9
Secondary properties	$N_{t,0,k}$	kN	88	142	203	272
	$N_{c,0,k}$	kN	44	71	101	136
	V_k	kN	1,4	1,7	2,2	2,8

NOTE All characteristic values were derived in accordance with ISO 22156:2004, Clause 7. Secondary properties are based on the equations contained in Table A.2.

A.2.8.2 Developing grading settings for machine and hybrid grading

Table A.7 provides an example of a declaration of properties derived from an initial evaluation appropriate to a hybrid grading process. The inferred grade-determining properties were obtained using the formulae contained in Table A.7 and Table A.4.

Table A.7 — Design values for diameter-based grades, supported by machine grading for the example hypothetical species

		Property	Units	Grade				
				ϕ70	**ϕ80**	**ϕ90**	**ϕ100**	**ϕ110**
Grade-determining properties (GDPs)	Range of external diameter	D	mm	≥70 mm <80 mm	≥80 mm <90 mm	≥90 mm <100 mm	≥100 mm <110 mm	≥110 mm <120 mm
	Indicating properties (IP)	q_{mean}	kg/m	1,22	1,56	1,97	2,46	3,07
		q_k		0,88	1,09	1,48	1,83	2,19
	Grade-determining properties (GDP) inferred from IP	$EI_{m,mean} = 17{,}8 \times q_{mean}^{1{,}46}$	GNmm2	23,9	35,6	51,9	71,7	96,1
		$EI_{m,0,05} = 17{,}8 \times q_{0,05}^{1{,}46}$		18,2	26,0	36,5	50,6	69,9
		$M_{0,k} = 3{,}17 \times q_{mean} - 3{,}4$	kNm	0,48	1,56	2,85	4,42	6,36
		$\delta_{0,25} = 3{,}93 \times q_{mean} - 1{,}41$	mm	6,2	7,5	9,2	11,1	13,5
Secondary properties		$N_{t,0,k}$	kN	32	91	151	216	288
		$N_{c,0,k}$	kN	16	46	76	108	144
		V_k	kN	1,0	1,4	1,7	2,2	2,8

NOTE Grade-determining properties are based on the formulae contained in Table A.4. Secondary properties are based on the formulae contained in Table A.2.

Bibliography

[1] ISO 9709, *Structural timber — Visual strength grading — Basic principles*

[2] ISO 13912, *Structural timber — Machine strength grading — Basic principles*

[3] Bahtiar E.T., Nugroho N., Surjokusumo S., Karlinasari L. 2013) Eccentricity Effect on Bamboo's Flexural Properties. *Journal of Biological Sciences*, **13**(2), p. 82

[4] Harries K., Bumstead J., Richard M., Moran R., Trujillo D. 2017) Geometric and Material Effects on Bamboo Buckling Behaviour, Structures and Building – Proceedings of the Institution of Civil Engineers The institution of Civil Engineers, London Vol. 170, No. 4. pp 236-249

[5] Nugroho N., & Bahtiar E.T. 2013). Bamboo taper effect on third point loading bending test. *International Journal of Engineering and Technology*, **5**(3), pp. 2379-2384

[6] Trujillo D., Jangra S., Gibson J. 2017). Flexural properties as a basis for bamboo strength grading, Structures and Building - Proceedings of the Institution of Civil Engineers The institution of Civil Engineers, London 170, No. 4. pp 284-294

[7] Trujillo D., & Jangra S. 2016) Grading of Bamboo – INBAR Working Paper 79. International Network for Bamboo and Rattan, Beijing

[8] Yu W.K., Chung K.F., Chan S.L. 2003) Column buckling of structural bamboo. *Engineering Structures*, **25**(6), pp. 755-768

ICS 91.080.20

Price based on 22 pages