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Bamboo — Structural design

Bambou — Conception des structures

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Contents

Foreword

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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 Technical Committee ISO/TC 165, *Timber Structures*.

This second edition cancels and replaces the first edition (ISO 22156:2004), which has been technically revised.

The main changes compared to the previous edition are as follows:

— adoption of design equations for material or component capacities for both members and joints

— adoption of service classes and specific consideration of susceptibility to splitting

— addition of Light Cement Bamboo Frame (LCBF) construction

— addition of informative Annexes addressing durability and representative details for connections and LCBF construction

— removal of use of bamboo for reinforcing concrete or soil

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

This standard provides a means of structural design for one- and two-storey building structures using full-culm round bamboo poles as the primary vertical and horizontal structural load resisting systems. This standard addresses connection design, light cement bamboo frame shear panel design, and addresses issues of durability. Informative Annexes provide means of achieving design and performance goals in these areas.

Bamboo — Structural Design

1 Scope

This International Standard applies to the design of bamboo structures whose primary load bearing structure is made of round bamboo or shear panel systems in which the framing members are made from round bamboo (**12**).

Except as indicated in **12**, this International Standard applies to one- and two-storey residential, small commercial or institutional and light industrial buildings not exceeding 7 m in height.

This International Standard is concerned only with requirements for mechanical resistance, serviceability and durability of bamboo structures.

This International Standard permits an allowable load-bearing capacity design (ACD) and/or allowable stress design (ASD) approach for the design of bamboo structures. Allowable load-bearing capacity and allowable stress approaches may be used in combination in the same structure.

This International Standard additionally recognises design approaches based on partial safety factor design (PSFD) and/or load and resistance factor design (LRFD) methods (**5.11.1**), previous established experience (**5.11.2**), or documented 'design by testing' approaches (**5.11.3**).

Other requirements, such as those concerning thermal or sound insulation, are not considered. Bamboo structures may require consideration of additional requirements beyond the scope of this International Standard. Execution is covered to the extent that it impacts the quality of construction materials and products required to comply with the design requirements contained herein.

This International Standard provides a number of modification factors, designated C_i. These are empirically derived factors, based on best available engineering judgement, that are believed to be universally applicable to bamboo materials that are appropriate for building construction. Parameters affecting bamboo material performance are many and are addressed explicitly through the use of experimentally determined characteristic values of strength and stiffness. **Annex A** provides a summary of the bases upon which the provisions of this International Standard were developed.

1.1 Exceptions

This International Standard does not apply to

- structures made of engineered bamboo products such as glue-laminated bamboo, cross-laminated bamboo, oriented strand, or densified bamboo materials;

- bamboo-reinforced materials where bamboo is not the primary load-bearing constituent. This includes bamboo-reinforced concrete, masonry and soil; or,

- scaffold structures constructed with bamboo.

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.

EN 350:2016 Durability of wood and wood-based products. Testing and classification of the durability to biological agents of wood and wood-based materials

ISO 2394 General principles on reliability for structures

ISO 6891 Timber Structures – Joints made with mechanical fasteners – General principles for the determination of strength and deformation characteristics

ISO 12122-1 Timber structures – Determination of characteristic values – Part 1: Basic requirements.

ISO 12122-5 Timber structures – Determination of characteristic values – Part 5: Connections

ISO 12122-6 Timber structures -- Determination of characteristic values -- Part 6: Large components and assemblies

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

ISO 19624 Bamboo structures — Grading of bamboo culms — Basic principles and procedures.

ISO 21581 Timber structures - Static and cyclic lateral load test methods for shear walls

ISO 21887 Durability of wood and wood-based products – Use classes

ISO 22157 Bamboo structures – Determination of physical and mechanical properties of bamboo culms –Test methods.

PD ISO/TR 21141 Timber structures - Timber connections and assemblages - Yield and ultimate characteristics and ductility from test data

3 Terms and Definitions

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

Assembly also **Multiple-Culm Assembly**: a structural member comprised of more than one bamboo culm constructed in such a fashion that the multiple culms together serve as a single structural member.

Bamboo culm also **Bamboo pole:** A single shoot of bamboo. A culm is comprised of the entire unaltered bamboo cross section and is usually a hollow cylinder except at nodes.

Bamboo Strip: bamboo piece with outer and inner layers intact, made by cutting bamboo culm in longitudinal direction.

Cross sectional area (*A*): The area of the section perpendicular to the direction of the longitudinal axis of the culm.

Ductility (μ): The ratio of the experimentally determined ultimate displacement to the yield displacement determined in accordance to PD/ISO TR 21141 for joints.

Equilibrium moisture content (EMC): Moisture content at which bamboo is neither gaining moisture from, nor losing moisture to, the environment.

Fibre Saturation Point (FSP): Moisture content below which only water bound in the cell walls remains; i.e., condition in which there is no free water in the cell cavities.

Flattened bamboo also **Esterilla**: element obtained by opening the bamboo culm and making longitudinal cuts (scores) partially through the culm wall to make a flat member.

Hygrothermal [Environment]: pertaining to both temperature and humidity.

Internode: Typically hollow region of bamboo culm between two nodes.

Joint: Connection of two or more bamboo members.

Lashing: Means of connecting bamboo culms by continuous wrapping of material around culm and joint region.

Light Cement Bamboo Frame (LCBF) also **Engineered Bahareque:** Improved vernacular construction technique originating in Latin America utilising shear walls constituted from a cement mortar render applied onto strip, flattened or small diameter bamboo, which are fixed onto bamboo and/or timber studs or framing. The cement mortar render is reinforced by a small-gauge metal mesh such as “chicken wire”. An alternative technique in which the cement mortar render is applied directly onto expanded metal lath sheets, which are in turn fixed onto the frame, is also accepted. The system is also known as *bahareque encementado*.

Moisture content (MC): Portion of culm weight consisting of water expressed as percentage of oven-dry weight.

Node: Transverse diaphragm region located along length of culm separating adjacent internodes.

Non-redundant: A structural member is non-redundant if there is no alternative and sufficient load path in the structure to transmit the load carried by the member in the event of its removal (member failure) from the load path. Failure of a non-redundant member leads to failure of the load path in which it is a part.

Outer diameter (*D*): Diameter of the cross section of a piece of bamboo taken as the average of two perpendicular measurements made across opposite points on the outer surface or calculated from a measurement of the perimeter. Measurement is typically made near the centre of an internode.

Point of contraflexure also **Point of inflection:** In a flexural member, the location of zero moment where the curvature of the member is zero.

Shear span: In a flexural member, the distance between the maximum moment and the nearest point of contraflexure (zero moment). Shear span is conventionally assumed to be equal to half the span for a uniformly loaded simple beam and half the column height for a column resisting lateral load.

Splice: Connection of two bamboo culms along their common longitudinal axis; used to extend the length of a structural member beyond the length of an individual culm.

[Culm] Wall thickness (*δ*): Thickness of wall of bamboo culm taken as the average of four measurements taken around the circumference of the culm at angular spacings of 90 degrees. Measurement is typically made near the centre of an internode.

Working point: In a structural assemblage – most often a truss – the location were the resultants of axial loads carried by members of connecting members intersect.

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/

4 Symbols and Abbreviated Terms

a length of the shear span of a member

A cross sectional area of a single culm

A_{min} minimum cross sectional area of the individual culms comprising the member

B moment amplification factor

b length of LCBF panel

b_{max} maximum perpendicular distance from the centre of the culm cross section to the chord drawn from the centres of the ends of the piece of bamboo

b_o maximum measured bow at midheight of culm comprising compression member

c calibration parameter for column interaction equation

C compression force in end member of LCBF resisting overturning moment

C_{bow} reduction factor to account for an initial bow in culms comprising a compression member

C_{DE} modification factor for Service Class and load duration for modulus

C_{DF} modification factor for Service Class and load duration for capacity and strength

C_{EB} modification factor for end bearing condition

C_R member redundancy factor

C_T modification factor for elevated temperature

C_v modification factor accounting for shear deformations

C_θ correction factor accounting for the angle of loading relative to the longitudinal axis of the culm

D nominal culm diameter

d overall depth of a flexural member

d_{dowel} diameter of dowel

D_u ultimate joint displacement

D_y yield joint displacement

E_d modulus of elasticity used in design

E_k mean characteristic compressive modulus of elasticity with 75% confidence determined from ISO 22157

$(EI)_d$ component flexural stiffness used in design

$(EI)_k$ mean characteristic component flexural stiffness with 75% confidence

F applied horizontal force (from wind or seismic analysis) to LCBF

F_b allowable bearing stress under a dowel

f_c compression strength parallel to fibres determined from ISO 22157

f_i generic nomenclature indicating allowable design strength of bamboo

f_{ik} 5th percentile characteristic strength with 75% confidence

f_m bending strength parallel to fibres determined from ISO 22157

f_{m90} bending strength perpendicular to fibres determined from ISO 22157

F_{resf} restraint force oriented perpendicular to the principal axis of an axial load carrying or flexural member

FS_c component factor of safety

FS_j joint factor of safety

FS_m material factor of safety

f_t tension strength parallel to fibres determined from ISO 22157

f_{t90} tension strength perpendicular to fibres determined from ISO 22157

f_v shear strength determined from ISO 22157

F_y joint capacity

F_{yk} 5th percentile characteristic capacity of joint with 75% confidence

h height of LCBF panel

I moment of inertia of a single culm

I_{min} minimum moment of inertia of the individual culms comprising a member

K effective length coefficient

K_e stiffness of joint

K_{ek} mean characteristic joint stiffness with 75% confidence

K_M factor used in circumferential bearing calculation

KL effective compression member length

L_{cir} length along the culm of the region of circumferential bearing

L length of member

L working length of axial load carrying member between points of lateral restraint

LCBF light cement bamboo frame

M bending capacity of a single culm or a multiple culm component bent about its principal axis

M_{cd} design moment

M_r moment capacity of a single or multiple culm member

M_u maximum moment resisted by a flexural member

MC moisture content of bamboo

MC_{FSP} moisture content of bamboo at fibre saturation point

MC_m moisture content at the time of testing

n number of culms comprising a member

N_c compression capacity parallel to the fibres of a single culm or a multiple culm component

N_{cd} design compression force

N_{cr} compressive load applied to an axial load carrying member

N_t tension capacity parallel to the fibres of a single culm

N_{td} design tensile force

N_{tr} tensile load applied to an axial load carrying member

P_b end bearing capacity of unfilled bamboo culms

P_c crushing strength of a compression member

p_{cir} circumferential bearing pressure;

P_{cir} circumferential bearing capacity of an unfilled bamboo culm

P_e buckling capacity of a compression member

P_u maximum axial load resisted by a compression member

s least spacing between adjacent dowels located along the same longitudinal gauge line, or the distance from the dowel to the nearest node or end of the culm in the direction of loading

S elastic section modulus of a single culm

T tensile force in end member of LCBF resisting overturning moment

V shear capacity of a single culm or a multiple culm component subject to flexure about its principal axis

V_b base shear force resisting applied horizontal force in LCBF

V_r shear capacity of a single or multiple culm member

X_i generic nomenclature indicating allowable design capacity of bamboo member

X_{ik} 5th percentile characteristic component capacity with 75% confidence

β central angle describing portion of circumference over which bearing pressure is applied

δ nominal culm wall thickness

θ angle of load applied to dowel connector relative the longitudinal axis of the culm

μ joint ductility

ψ central angle between adjacent gauge lines of dowel connectors

5 Basic Requirements of Design

5.1 General

This International Standard is based on an allowable load-bearing capacity design (ACD) or allowable stress design (ASD) approach to ensuring the safety and performance of the structure.

A structure shall be designed and constructed such that

- with acceptable probability, it will remain fit for its intended use, having due regard to its intended life and costs;

- with appropriate reliability, it will resist all actions and influences likely to occur during its intended use over its intended life, and have adequate durability in relation to maintenance requirements; and,

- it will not represent a hazard to human life by exceptional events such as explosion, impact or consequence of human error, to an extent disproportional to the magnitude of the exceptional event.

5.2 Design Methodology

Bamboo structures shall be designed based on calculations, verifying that no relevant allowable load-bearing capacity or stress is exceeded. The following are assumed:

- structures are designed by appropriately qualified and experienced design professionals;

- structures are constructed by personnel having appropriate skills and experience;

- adequate supervision and quality control are provided in factories, plants and on site;

- construction materials and products are used as specified in this International Standard or in the relevant material or product specifications;

- structures are adequately maintained; and,

- structures will be used in accordance with their intended occupancy and design.

5.3 Susceptibility to Splitting

Bamboo culms are susceptible to longitudinal splitting. Splitting is commonly related to changes in moisture content of the culm in service. The susceptibility to splitting can lead to non-redundant members (**5.4.1**) and may necessitate replacement of culms in a member or structure (**5.9**).