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Bamboo structures — Bamboo culms — Structural design

Structures en bambou — Tiges de 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.

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).

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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 document 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 document 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 structures — Bamboo culms — Structural design

1 Scope

This document 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.

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

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

This document 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 document 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 document. 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 document 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 document were developed.

This document 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.

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

ISO 12122-5, *Timber structures — Determination of characteristic values — Part 5: Mechanical 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 21581:2010, *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*

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
assembly
multiple-culm assembly
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

3.2
bamboo culm
bamboo pole
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.

3.3
cross sectional area
A
area of the section perpendicular to the direction of the longitudinal axis of the culm

3.4
ductility
μ
ratio of the experimentally determined ultimate displacement to the yield displacement

Note 1 to entry: The ratio is determined according to ISO/CD TR 21141[1)] for joints.

3.5
equilibrium moisture content
w_{EMC}
moisture content at which bamboo is neither gaining moisture from, nor losing moisture to, the environment

3.6
fibre saturation point
w_{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

1) In preparation. Stage at the time of publication ISO/CD TR 21141:2021.

3.7
flattened bamboo
element obtained by opening the bamboo culm and making longitudinal cuts (scores) partially through the culm wall to make a flat member

Note 1 to entry: Flattened bamboo is often referred to as “esterilla”.

3.8
internode
typically hollow region of bamboo culm between two nodes

3.9
joint
connection of two or more bamboo members

3.10
lashing
means of connecting bamboo culms by continuous wrapping of material around culm and joint region

3.11
light cement bamboo frame
LCBF
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

Note 1 to entry: 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" and composite bamboo shear walls.

3.12
moisture content
w
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

3.14
non-redundant
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

Note 1 to entry: Failure of a non-redundant member leads to failure of the load path in which it is a part.

3.15
outer diameter
D
diameter of the cross section of a piece of bamboo, typically made near the centre of an internode, taken as the average of two perpendicular measurements made across opposite points on the outer surface or calculated from a measurement of the perimeter

3.16
point of contraflexure
point of inflection
<flexural member> location of zero moment where the curvature of the member is zero

3.17
shear span
<flexural member> distance between the maximum moment and the nearest *point of contraflexure* (3.16)

Note 1 to entry: 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.

3.18
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

3.19
bamboo strip
bamboo piece with outer and inner layers intact, made by cutting bamboo culm in longitudinal direction

3.20
[culm] wall thickness
δ
thickness of wall of bamboo culm, typically made near the centre of an internode, taken as the average of four measurements taken around the circumference of the culm at angular spacings of 90°

3.21
working point
<structural assemblage (most often a truss)> location where the resultants of axial loads carried by connecting members intersect

4 Symbols and abbreviated terms

A	cross sectional area of a single culm
A_{min}	minimum cross sectional area of the individual culms comprising the member
a	length of the shear span of a 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	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
c	calibration parameter for column interaction equation
D	nominal culm diameter
D_{dowel}	diameter of dowel
d	overall depth of a flexural member

Δ_u	ultimate joint displacement
Δ_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_{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_y	joint capacity
F_{yk}	5th percentile characteristic capacity of joint with 75 % confidence
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_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
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
w	moisture content of bamboo
w_{EMC}	equilibrium moisture content
w_{FSP}	moisture content of bamboo at fibre saturation point
w_M	moisture content at the time of testing

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
n	number of culms comprising a member
P_b	end bearing capacity of unfilled bamboo culms
P_c	crushing strength of a compression member
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
p_{cir}	circumferential bearing pressure;
S	elastic section modulus of a single culm
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
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 document is based on an allowable load-bearing capacity design (ACD) or allowable stress design (ASD) approach to ensure 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 resulting from 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 document or in the relevant material or product specifications;

— structures are adequately maintained;

— 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).

The effects of splitting in design may be investigated using a notional approach in which a single notional split is assumed to occur at the least favourable location in a member or joint. In this state, the member or joint shall be shown to retain at least 75 % of its capacity. If at least 75 % of the capacity is not retained, the member or joint shall be designed assuming that the notional split will occur and a reduced capacity shall be used in design.

The effects of splitting may be partially mitigated using radial clamping described in 10.7.1.

5.4 Redundancy

To the extent possible, non-redundant structures and/or structural members or components should not be used.

The member redundancy factor, C_R, shall be defined by Table 1.

Table 1 — Member redundancy factor, C_R

redundancy of member in structure	C_R
non-redundant as defined in 5.4.1	0,90
redundant as defined in 5.4.2	1,10
all other structures	1,00

5.4.1 Non-redundant structural members

Non-redundant structural members shall be those satisfying the following criteria.

— load-bearing members whose removal from the structure or load path result in failure of the structure, or

— load-bearing members made of multiple culms for which the removal of any single culm from the multiple culm assembly results in failure of the member.

5.4.2 Redundant structural members

Redundant structural members shall be those satisfying the following criteria.

Where four or more structural members of the same stiffness are connected to a continuous load distribution path (such as may be the case with floor joists, rafters, purlins and trusses) and, in addition, either

— the continuous load distribution path is capable of redistribution of loads, or

— the structural members are no more than 600 mm apart, the load distribution members are continuous over at least two spans, and any joints in the load distribution members are staggered.

5.5 Serviceability considerations

Deflections of the structure or its components likely to affect use or occupancy of the structure or damage finishes or non-structural components shall be considered.

5.6 Service classes

Members in a bamboo structure shall be assigned to one of the service classes given by 5.6.1, 5.6.2, or 5.6.3 based on the environment to which the bamboo is exposed. These service classes are related to the mechanical performance of the bamboo. Use classes associated with durability performance are prescribed in 5.7.1. Different elements or members in the same structure may have different service classes.

5.6.1 Service class 1

Service Class 1 is characterised by an equilibrium moisture content in the bamboo not exceeding 12 %.

NOTE Service Class 1 is representative of indoor air-conditioned or heated environments in which relative humidity is maintained below 65 % and will generally correspond to ISO 21887 Use Class 1 (see 5.7.1).

5.6.2 Service class 2

Service class 2 is characterised by an equilibrium moisture content in the bamboo not exceeding 20 %.

NOTE Service Class 2 is representative of indoor unheated or uncooled environments in most locations except those with relative humidity regularly or for prolonged periods exceeding 85 % and will generally correspond to ISO 21887 use class 2 or 3.1 (see 5.7.1).

5.6.3 Service class 3

Service class 3 is characterised by ambient or climatic conditions leading to higher moisture content in the bamboo than experienced in Service Class 2.

Load duration factors (C_{DF} and C_{DE}) and elevated service temperature factor (C_T) for Service Class 3 shall be determined experimentally (5.11.3)

5.7 Durability

Provision shall be made in the design of bamboo structures to ensure durability of the structure.

Durability is the ability of bamboo to resist degradation of geometric, physical or mechanical properties when subject to an intended service environment for an intended service life. Effects of fire are addressed in Clause 13.

No species of bamboo is known to have significant natural resistance to biological attack. Bamboo shall be considered “non-durable”, requiring preservation, in terms of its resistance to the following:

— fungal attack;

— attack by wood boring insects and termites; and,

— marine borers for bamboo exposed to a marine environment.

Treatment shall be either demonstrated to not affect bamboo mechanical properties (strength and stiffness) or, more typically, mechanical properties defined in Clause 6 shall be determined for treated bamboo.

The following general considerations for durable structures are required:

— construct only with bamboo that has achieved its equilibrium moisture content, w_{EMC}, for the location of the building. Moisture content, w, shall never exceed the fibre saturation point, w_{FSP}, which, if unknown may be assumed to be w_{FSP} = 30 %;

— building details shall be such that the bamboo shall remain air-dry by ventilation and ensure that if the bamboo does become temporarily wet, it will dry before material deterioration can occur; and,

— building envelope permeability shall be such that negative pressure resulting from heating, ventilation and/or air conditioning, likely to draw water or moisture into the bamboo, is mitigated.

Annex B provides additional recommendations for designing durable bamboo structures.

5.7.1 Use classes

Bamboo within a structure shall be assigned to one of the use classes defined by ISO 21887 based on the environment to which the bamboo is exposed. Table 2 summarises Use classes and basic durability considerations.

Bamboo should not be used in use class 3.2 except for structures having a design life of less than 5 years. Bamboo shall not be used in use classes 4 or 5.

Table 2 — Use classes, durability considerations and appropriate preservation techniques

Use class	service conditions	typical uses	Protection against biological agents		
			fungal	insects	termites
1	interior, dry	framing, pitched roof members	-	yes	yes
2	interior, occasional damp (possibility of condensation)	framing, roof members, ground floor joists, framing built into exterior walls	yes	yes	yes
3.1	exterior, above ground protected from driving rain and UV radiation	protected exterior joinery and framing	yes	yes	yes
3.2[a]	exterior, above ground not protected from weathering	unprotected exterior framing and joinery including cladding, vertical load bearing members, exposed unprotected culm ends	yes	yes	yes
4.1[b]	in contact with ground or in-ground	sole plates or columns at ground, columns built into ground, piles	yes	yes	yes
4.2[b]	in-ground severe, fresh water	piles	yes	yes	yes
5[b]	marine or brackish water	marine piles including splash zone	yes		

[a] Bamboo should not be used in use class 3.2 except for structures having a design life of less than 5 years.

[b] Bamboo shall not be used in this use class.