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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).

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 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}	5^{th} 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}	5^{th} 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}	5^{th} 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.

5.7.2 Resistance to corrosion of metallic elements

Metal fasteners and other structural connections shall be either inherently corrosion resistant or protected from corrosion.

5.8 Effects of elevated temperature

When heated, the strength and stiffness of bamboo decrease. The effects of elevated temperature are immediate and their magnitude varies depending on the moisture content of the bamboo. Up to 65 °C, the immediate effect is reversible upon return to normal ambient temperature. Prolonged exposure to temperature greater than 65 °C can cause permanent loss of strength and stiffness in bamboo culms. As bamboo is cooled below normal ambient temperatures, its strength increases.

It is appropriate to use the reference design values of this document for ordinary temperature fluctuations and occasional short term heating to temperatures no greater than 65 °C.

Bamboo shall not be used for structures experiencing prolonged exposure to temperatures greater than 50 °C or short term exposure to temperatures greater than 65 °C.

5.9 Maintenance, inspectability and replacement considerations

For a variety of reasons, bamboo culms may split longitudinally or be otherwise damaged when in service.

To the extent possible, provision should be made to permit maintenance and inspection of bamboo load-bearing members; particularly members forming part of a non-redundant load path.

To the extent possible, consideration of the future need to replace individual culms in a member or structure should be made.

5.10 Seismic force reduction factor for bamboo structures

The development of seismic force reduction factors must be calibrated with appropriate National Building or National Seismic standards. C.2 provides guidance – based on this document – for selecting seismic force reduction factors for bamboo structures.

5.11 Alternate design methodologies

It is permissible to use alternative design methodologies differing from this document, provided that it is shown that the alternative methodology complies with the general design requirements of 5.1.

Alternative bamboo construction design methodologies are deemed to comply with this document provided they are based on one of 5.11.1, 5.11.2 or 5.11.3.

5.11.1 Partial safety factor design (PSFD) or load and resistance factor design (LRFD) methodology

C.3 provides guidance – based on this document – for design of bamboo structures using PSFD or LRFD methodologies in instances where National Building or Construction Standards permit these approaches for bamboo.

5.11.2 Experience from Previous Generations

Experience from previous generations (i.e., vernacular construction) that is well preserved in local tradition and dutifully transmitted to people living today can be considered to be an informal, non-codified “standard” provided all of the following criteria are met:

— the content shall be known and accepted to result in adequate or acceptable structural performance;

— the content shall be considered as an “old and pure tradition” or as “general wisdom”;

— the community shall be characterised by a relatively undisturbed social structure having a recognised social pattern; and,

— the community understands the construction technique and are aware of and prepared to conduct required maintenance, which may be more significant than with other building materials.

The application of experience from previous generations is limited as follows:

— the content is only applicable to similar scenarios;

— the content is not extrapolated in terms of dimensional scale; and,

— after migration, the presence of this tradition is no longer self-evident.

5.11.3 Design by testing

Where the composition or configuration of structural members or systems is such that design by analysis cannot be performed in accordance with the provisions of this document, their structural performance and conformity with the intent of this document (5.1) shall be established from test results that are evaluated in accordance with the following:

— tests shall be full-scale and use bamboo culms representative – preferably of the same grade – as those to be used in the designed structure;

— tests shall be conducted to failure and the mode of failure reported in addition to all necessary applied forces, deformations and stresses; therefore “proof-testing” does not satisfy the requirements of this Section;

— evaluation of predicted capacity shall be made on the basis of the 10^{th} percentile value of tests of at least ten (10) identical specimens; this value shall be the characteristic value, X_{ik} defined in 6.2. No test result shall be eliminated without a written rationale; and,

— The testing shall be presented in a report suitable for peer-review. The report shall provide sufficient detail to permit the testing to be repeated.

For joints, the requirements of 10.2 shall supersede those of this Section.

6 Member component and material properties

6.1 General

Member component and/or material properties of bamboo used for structural load-carrying applications should be determined by grading in accordance with 14.

Component and material properties are determined at bamboo moisture contents representative the anticipated Service Class in which the bamboo is used.

Component properties are those which the determined property is a component capacity or stiffness. Component capacities may be determined for a single culm or a multiple-culm assembly intended for use as a structural member. Component capacities may be inferred from grading.

Material properties are those obtained from material tests described in ISO 22157. The material property is multiplied by a geometric parameter to give a component capacity or stiffness.

NOTE Examples of material properties are stress to cause failure and modulus of elasticity. Multiplying compression stress (f_c) by cross section area (A) results in the component property bearing capacity (Af_c). Similarly, multiplying modulus of elasticity (E) by moment of inertia (I) results in the component property flexural stiffness (EI).

6.2 Characteristic material and component properties

Characteristic values of component or material properties should be inferred by Grade determined using a grading procedure in accordance with Clause 14.

If not graded in accordance with Clause 14, characteristic values of component or material properties shall be determined in accordance with ISO 12122-1.

6.3 Allowable member design capacity

The allowable member design load-bearing capacity shall be determined by applying all relevant adjustment factors to the calculated characteristic component strength determined in accordance with 6.2 as given by Formula (1):

$$X_i = X_{ik} \times C_R \times C_{DF} \times C_T \times (1/FS_c) \quad (1)$$

where

X_i is the design capacity.

X_{ik} is the 5th percentile characteristic member capacity with 75 % confidence (6.2). In ISO 12122-1, the value is denoted $X_{i,0,05,0,75}$.

The designation X_i is as follows:

- N_t is the tension capacity parallel to the fibres of a single culm or a multiple culm component.
- M is the bending capacity of a single culm or a multiple culm component bent about its principal axis.
- V is the shear capacity of a single culm or a multiple culm component subject to flexure about its principal axis.

C_R is the member redundancy factor given in 5.4.

C_{DF} is the modification factor for service class and load duration given in Table 3. The duration factor selected for load combinations shall be that for the component of the combination having the shortest duration.

Table 3 — Load duration factor for capacity and strength, C_{DF}

load duration	Service Class defined in 5.6		
	1	2	3
permanent and long term applied load	0,60	0,55	see 5.6.3
transient loads	0,75	0,65	
instantaneous loads (wind and seismic)	1,00	0,85	

C_T is the modification factor for service temperature given in Table 4. For structural members that will experience sustained exposure to elevated temperatures up to 65 °C this factor shall be applied. The factor is not required for transient elevated temperature exposure less than 3 hours.

Table 4 — Elevated service temperature factor, C_T

	Service class defined in 5.6		
	1	2	3
$T \leq 38$ °C	1,00	1,00	see 5.6.3
38 °C < $T \leq 52$ °C	0,90	0,90	
52 °C < $T \leq 65$ °C	0,80	0,80	

FS_c is the component factor of safety given in Table 5.

Table 5 — Component factor of safety, FS_c

	N_c	N_t	M	V
FS_c	2,0	2,0	2,0	4,0

NOTE 1 Since axial load capacity is dependent on many factors and affected by buckling instability, a component compressive capacity cannot be determined.

NOTE 2 FS_c for shear is twice that for flexure in order to enforce 'flexure critical' behaviour in members subject to bending which helps to mitigate splitting behaviour (5.3).

Bamboo culms or multiple-culm members shall be designed such that they are not subject to torsion.

6.4 Allowable design strength

The allowable design strength shall be determined by applying all relevant adjustment factors to the calculated characteristic material strength determined in accordance with 6.2 as given by Formula (2):

$$f_i = f_{ik} \times C_R \times C_{DF} \times C_T \,(1/FS_m) \tag{2}$$

where

f_i is the allowable design strength.

f_{ik} is the 5th percentile characteristic strength with 75 % confidence (6.2). In ISO 12122-1, the value is denoted $f_{i,0,05,0,75}$.

The designation f_i is as follows:

f_c is the compression strength parallel to fibres determined from ISO 22157.

f_t is the tension strength parallel to fibres determined from ISO 22157.

f_m is the bending strength parallel to fibres determined from ISO 22157.

f_v is the shear strength determined from ISO 22157.

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

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

C_R is the member redundancy factor given in 5.4.

C_{DF} is the modification factor for service class and load duration given in Table 3. The duration factor selected for load combinations shall be that for the component of the combination having the shortest duration.

C_T is the modification factor for service temperature given in Table 4. For structural members that will experience sustained exposure to elevated temperatures up to 65 °C this factor shall be applied. The factor is not required for transient elevated temperature exposure less than 24 h.

FS_m is the material factor of safety given in Table 6.

Table 6 — Material factor of safety, FS_m

	f_c	f_t	f_m	f_v	f_{t90}	f_{m90}
FS_m	2,0	2,0	2,0	4,0	4,0	2,0

NOTE FS_m for shear is twice that for flexure in order to enforce 'flexure critical' behaviour in members subject to bending which helps to mitigate splitting behaviour (5.3). Similar to shear, tension failure perpendicular to fibre, f_{t90} is very brittle, warranting a higher factor of safety.

Bamboo culms or multiple-culm members shall be designed such that they are not subject to torsion.

6.4.1 Culm geometry for use with allowable design strength

When applying allowable design strengths (6.4) to determine component capacity, geometric properties of culms shall be determined as follows:

D is the nominal culm diameter determined from a grading procedure in accordance with 14; otherwise, for culms having a variation in diameter over their length of less than 10 %, D is the culm diameter determined as the average of diameters measured at each end of the culm. For culms having a variation in diameter over their length greater than 10 %, D is the minimum culm diameter determined over the length of the culm.

δ is the nominal culm wall thickness determined from a grading procedure in accordance with 14; otherwise, for culms having a difference in wall thickness from one end of the culm to the other of less than 10 %, δ is determined as the average of wall thicknesses measured at each end of the culm. For culms having a difference in wall thickness from one end of the culm to the other greater than 10 %, δ is the minimum culm wall thickness determined at each end of the culm.

Cross sectional area of a single culm shall be calculated by Formula (3):

$$A = (\pi/4) \times [D^2 - (D - 2\delta)^2] \quad (3)$$

The moment of inertia of a single culm shall be calculated by Formula (4):

$$I = (\pi/64) \times [D^4 - (D - 2\delta)^4] \quad (4)$$

The elastic section modulus of a single culm shall be calculated by Formula (5):

$$S = (\pi/32D) \times [D^4 - (D - 2\delta)^4] \quad (5)$$

6.5 Component flexural stiffness

The component flexural stiffness used in design, $(EI)_d$ shall be determined by Formula (6):

$$(EI)_d = (EI)_k \times C_{DE} \times C_T \tag{6}$$

where

$(EI)_k$ is the mean characteristic component flexural stiffness with 75 % confidence (6.2). In ISO 12122-1, the value is denoted $(EI)_{mean,0,75}$.

C_{DE} is the modification factor for service class and load duration given in Table 7.

Table 7 — Load duration factor for modulus, C_{DE}

load duration	Service class defined in 5.6		
	1	2	3
permanent and long term applied load	0,50	0,45	see 5.6.3
transient loads	1,00	0,95	
instantaneous loads (wind and seismic)	1,00	1,00	

C_T is the modification factor for service temperature given in Table 4. For structural members that will experience sustained exposure to elevated temperatures up to 65 °C this factor shall be applied. The factor is not required for transient elevated temperature exposure less than 24 h.

6.6 Modulus of elasticity

The modulus of elasticity used in design, E_d, shall be determined by Formula (7):

$$E_d = E_k \times C_{DE} \times C_T \tag{7}$$

where

E_k is the mean characteristic compressive modulus of elasticity with 75 % confidence (6.2) determined from ISO 22157. In ISO 12122-1, the value is denoted $E_{mean,0,75}$.

C_{DE} is the modification factor for service class and load duration given in Table 7.

C_T is the modification factor for service temperature given in Table 4. For structural members that will experience sustained exposure to elevated temperatures up to 65 °C this factor shall be applied. The factor is not required for transient elevated temperature exposure less than 24 h.

7 Structural modelling bamboo structures

Structural modelling is the process of 'translating' the physical reality of a building structure into a mathematical model from which necessary design calculations may be carried out.

Required load-bearing or stress demands shall be calculated at critical locations as determined from loads or load combinations corresponding to those required by the applicable national building code.

Design of bamboo members and structures shall be based on calculation applying the principles of fundamental applied mechanics. Typically, models of bamboo structures will make the following assumptions:

— bamboo is modelled as a linear elastic material through the allowable stress;

— bamboo culms are modelled such that they satisfy Bernoulli beam theory (i.e., plane sections remain plane);

— bamboo culms are conservatively modelled as hollow tubes having cross section dimensions equal to the smallest dimension of the culm;

NOTE For most applications, using average cross section dimensions is adequate and appropriate for modelling.

— bamboo culms may be more accurately modelled accounting for diameter and wall-thickness taper provided such information is reliably available;

— second order effects resulting from imperfect (not straight) members shall be considered; because elastic properties are assumed, moment and/or axial load amplification factors (such as B defined in 9.5) based on prescribed imperfections may be adopted;

— joints in bamboo structures shall be assumed to be pinned (hinged) unless otherwise permitted or substantiated by experimental data justifying the use of a finite stiffness (spring) or fixed joint. Joint or connection stiffness are defined in 10.5;

— in analyses in which joint stiffness is included, the deformation or slip of the joint shall be accounted for in analysis;

— when determining loads in statically indeterminate bamboo frames, variation in the load path resulting from variations in stiffness of the connections and members shall be considered. This is best accomplished by performing a sensitivity analysis of the structural load path; varying member and connection stiffness parameters within bounds established by grading protocols or other rational assessment of how these parameters may be expected to vary in the structure; and,

— when determining the period of bamboo structures, variations in stiffness of the connections and members shall be considered, as these can vary significantly affecting the calculated period of the structure.

8 Flexural members (beams)

8.1 General

The moment resisted by a flexural member shall be equal to or less than the moment capacity, M_r, of the member defined by 8.3.1 or 8.3.2.

The shear force resisted by a flexural member shall be equal to or less than the shear capacity, V_r, of the member defined by 8.3.1.1 or 8.3.2.1.

To the extent possible, design capacity of members subject to flexure shall not be governed by shear-dominated failure modes.

8.2 Multiple culm flexural members

Multiple culm flexural members shall be symmetric about the axis perpendicular to the axis of bending and shall have an overall depth-to-width ratio no greater than 3. Members having a depth-to-width ratio greater than 1,5 shall meet the lateral bracing requirements of 8.2.1.

Multiple culm flexural members arranged into a triangular bundle shall have one side of the triangle oriented along the compression face of the member.

Culms in multiple culm flexural members should be in contact to the extent possible. In no case shall culms be separated by more than a clear distance equal to the average culm diameter in the member.

Multiple culm flexural members shall be assembled such that the sum of geometric properties do not vary by more than 10 % from one end to the other; typically, such members will be assembled with culm top and bottoms alternating at each end.

Connections between adjacent culms in multiple culm flexural members shall be provided at the ends of all unbraced lengths and between adjacent culms at a spacing no greater than ten times the [smaller] culm diameter. Connections shall be designed based on the requirements of 10 to adequately transfer a minimum force of 1 500 N/m between adjacent culms in all three principal axes of the member.

8.2.1 Bracing requirements for multiple culm flexural members

Where a multiple culm flexural member is bent about its major axis and the member depth-to-width ratio exceeds 1,5, lateral bracing is required that satisfies the following:

— the compression region of the member is laterally restrained at intervals not exceeding 10 times the width of the member.

— both the compression and tension regions of the member are laterally restrained at all supports.

— lateral restraints shall provide sufficient restraint and stiffness to inhibit lateral movement of the restraint point. The sum of all restraints provided to a member shall be capable of resisting a total force ΣF_{resf} oriented perpendicular to the principal axis of the flexural member of not less than that given by Formula (8):

$$\Sigma F_{resf} \geq (M_u/d) \times 0{,}04 \tag{8}$$

— individual lateral restraints shall be capable of resisting a force $F_{resf,}$ oriented perpendicular to the principal axis of the flexural member of not less than that given by Formula (9):

$$F_{resf} \geq (M_u/d) \times 0{,}015 \tag{9}$$

where

M_u is the maximum moment resisted by the flexural member; and,

d is the overall depth of the flexural member.

— the total restraint force, ΣF_{resf}, shall be divided between the intermediate lateral restraints in proportion to their spacing.

— the lateral restraint shall be connected to an appropriate system of bracing capable of transferring the restraint force to the effective points of support of the member, or else connected to an independent part of the structure capable of fulfilling a similar function. Where two or more parallel members require intermediate lateral restraint, it is not adequate to connect the members together such that they become mutually dependent.

8.3 Flexural member capacity

The use of summations of culm capacity or geometric properties in this clause allow for use of multiple culm members.

8.3.1 Flexural capacity determined from component capacity

The moment capacity of a member defined from component capacity shall be given by Formula (10):

$$M_r = M \tag{10}$$

where

$M = \Sigma M_i$ is the sum of the allowable flexural design capacity of the single culms, M_i, comprising the member defined in 6.3; or,

M is the allowable flexural design capacity explicitly determined for a multiple culm member defined in 6.3.

8.3.1.1 Shear capacity of flexural members determined from single culm component capacity

The shear capacity of a member defined from component capacity shall be given by Formula (11):

$$V_r = V \tag{11}$$

where

$V = \Sigma V_i$ is the sum of the allowable shear design capacity of the single culms, V_i, comprising the member defined in 6.3; or,

V is the allowable flexural design capacity explicitly determined for a multiple culm member defined in 6.3.

8.3.2 Flexural capacity determined from bending strength

The moment capacity of a member determined from allowable bending strength and culm geometry shall be given by Formula (12):

$$M_r = f_m \times \Sigma S \tag{12}$$

where

f_m is the allowable bending strength parallel to fibres given in 6.4;

ΣS is the sum of the elastic section moduli, defined in 6.4.1, of the individual culms comprising the member.

8.3.2.1 Shear capacity in multiple culm flexural members determined from shear strength

The shear capacity of a member determined from allowable shear strength and culm geometry shall be given by Formula (13):

$$V_r = f_v \times \Sigma \frac{3\pi\delta}{8} \frac{D^4 - (D-2\delta)^4}{D^3 - (D-2\delta)^3} \tag{13}$$

where

f_v is the allowable shear strength parallel to fibres given in 6.4;

The second term in the equation is calculated as the sum of the geometric properties of the individual culms comprising the multiple culm member; and,

D and δ are defined in 6.4.1.

8.4 Calculation of deflection

Deflections shall be calculated using elastic section properties. For calculating deflections to be compared with National Building Code-prescribed serviceability deflection limits, the elastic flexural stiffness may be determined as given in 8.4.1 or 8.4.2.

8.4.1 Flexural stiffness determined from component properties

The flexural stiffness, EI, determined from component properties for the calculation of deflections shall be given by Formula (14):

$$EI = (EI)_d \times C_v \tag{14}$$

where

$(EI)_d = \underline{\Sigma(EI)}_{di}$ is the sum of $(EI)_{di}$ determined for single culms (6.5), comprising a multiple culm member; or,

$(EI)_d$ is determined explicitly for multiple culm members as defined in 6.5.

C_v is the modification factor accounting for shear deformations given by Formula (15):

$$C_v = 0{,}5 + 0{,}05 \times (a/D) \le 1{,}00 \tag{15}$$

where

a is the length of the shear span of the member; and,

D is defined in 6.4.1.

8.4.2 Flexural stiffness determined from material and geometric properties

The flexural stiffness, EI, determined from materials and geometric properties for the calculation of deflections shall be given by Formula (16):

$$EI = E_d \times \Sigma I \times C_v \tag{16}$$

where

E_d is the modulus of elasticity used in design defined in 6.6;

ΣI is the sum of the moments of inertia, defined in 6.4.1, of the individual culms comprising the member; and,

C_v is the modification factor accounting for shear deformations defined in 8.4.1.

8.4.3 Long term deflections

Total long term deflections shall be calculated applying appropriately determined values of $(EI)_d$ or E_d (6.5 or 6.6, respectively) separately to permanent and transient component of applied loads and summing the components of deflection together.

9 Axial load carrying members

9.1 General

The compressive load applied to an axial load carrying member shall be equal to or less than the compressive capacity, N_{cr}, of the member defined by 9.3.1.

The tensile load applied to an axial load carrying member shall be equal to or less than the tension capacity, N_{tr}, of the member defined by 9.4.1 or 9.4.2.

Multiple culm axial load carrying members shall be arranged such that they are

— symmetric about two principle axes;

— radially symmetric; or,

— arranged in a triangular arrangement having an equal number of culms on each side.

Single culm axial load carrying members are permitted; such members shall be considered to be non-redundant as defined in 5.4.1.

Culms in multiple culm axial load carrying members shall be separated by no more than a clear distance equal to the average culm diameter in the member.

Connections between adjacent culms in multiple culm members shall be provided at the ends of all unbraced lengths and between adjacent culms at a spacing no greater than ten times the [smaller] culm diameter. Connections shall be designed based on the requirements of 10 to adequately transfer a minimum force of 1 500 N/m between adjacent culms in all three principal axes of the member.

When required, lateral bracing requirements for compression members shall be determined by 9.2.1.

Bamboo culms comprising an axial-load carrying member shall not have a bow exceeding the limit set in a grading protocol in accordance to ISO 19624. Bow shall not exceed $L/50$, where L is the unbraced length of the member.

Axial load carrying members having eccentrically applied loads with an eccentricity exceeding $d/4$, where d is the smallest overall dimension of the member shall be designed for combined axial and flexural loads as defined in 9.5.

9.2 Compression member effective length

The effective of length of compression load carrying members shall be determined as the working length of the member between points of lateral restraint, L multiplied by the recommended effective length coefficient for bamboo members, K given in Table 8. For multiple culm members, the effective length may be different about the two principal axes of the member.

Table 8 — Effective length coefficient, *K*

	compression member end conditions			truss element
	pin-pin	pin-fixed	fixed-fixed	(see Clause 11)
laterally restrained	1,10	0,80	0,65	1,00
no lateral restraint	2,40	2,10	1,20	not permitted

9.2.1 Lateral restraint of compression members

Lateral restraints shall provide sufficient restraint and stiffness to inhibit lateral movement of the restraint point. Restraints shall be capable of resisting a force F_{resc}, given by Formula (17), oriented perpendicular to the principal axis of the member about which restraint is being calculated.

$$F_{resc} \geq (P_u / C_{bow}) \times 0{,}01 \qquad (17)$$

where

P_u is the maximum axial load resisted by the compression member;

C_{bow} is a reduction factor to account for an initial bow in the culms comprising the compression member given by Formula (18):

$$C_{bow} = 1 - (b_o/0{,}02) \tag{18}$$

where

b_o is the maximum bow at midheight of any culm comprising a compression load bearing member given by Formula (19); b_o shall not exceed the limit given in 9.1.

$$b_o = b_{max}/L < 0{,}02 \tag{19}$$

b_{max} is 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.

L is the length of the member.

The lateral restraint shall be connected to an appropriate system of bracing capable of transferring the restraint force to the effective points of support of the member, or else connected to an independent part of the structure capable of fulfilling a similar function. Where two or more parallel members require intermediate lateral restraint, it is not adequate merely to connect the members together such that they become mutually dependent.

9.3 Compression capacity

The use of summations of culm capacities and geometric properties in this clause allow for use of multiple culm members including those comprised of different sized culms.

9.3.1 Compression capacity from geometric and material properties

The compression capacity of a member is determined shall be given by Formula (20)[15]:

$$N_{cr} = \frac{P_c + P_e}{2c} - \sqrt{\left(\frac{P_c + P_e}{2c}\right)^2 - \frac{P_c P_e}{c}} \tag{20}$$

where

P_c is the crushing capacity defined in 9.3.2;

P_e is the buckling capacity defined in 9.3.3; and,

$c = 0{,}80$[17]

9.3.2 Crushing capacity

Crushing strength of a compression member, P_c, shall be determined from strength and geometry shall be given by Formula (21)

$$P_c = f_c \times \Sigma A \tag{21}$$

where

f_c is the allowable compression strength parallel to fibres given in 6.4; and,

ΣA is the sum of the cross sectional areas, defined in 6.4.1, of the individual culms comprising the member.

9.3.3 Buckling capacity

Buckling capacity of a compression member, P_e shall be given by Formulae (22) or (23):

$$P_e = \frac{n\pi^2 E_d I_{min} C_{bow}}{(KL)^2} \quad (22)$$

or

$$P_e = \frac{n\pi^2 (EI)_{d,min} C_{bow}}{(KL)^2} \quad (23)$$

where

n is the number of culms comprising the member;

E_d is the design modulus of elasticity given in 6.6;

I_{min} is the minimum moment of inertia, defined in 6.4.1, of the individual culms comprising the member;

$(EI)_{d,min}$ is the minimum flexural stiffness, defined in 6.5, of the individual culms comprising the member;

C_{bow} is a reduction factor to account for an initial bow in the culms comprising the compression member defined in 9.2.1; and,

KL is the effective compression member length defined in 9.2.

NOTE Since buckling capacity is dependent on many factors, a component buckling capacity cannot be determined.

9.4 Tension capacity

The use of summations of geometric properties in this clause allow for use of multiple culm members comprised of different sized culms. For the design of single culm members, the summation symbol is neglected and the calculation made for the single culm.

It is very rare for axial tension to govern the design or behaviour of a member. Special attention shall be paid to connections imparting a tensile load to a member.

9.4.1 Tension capacity from component capacity

The tension capacity of member defined from component capacity shall be given by Formula (24):

$$N_{tr} = N_t \quad (24)$$

where

$N = \Sigma N_{ti}$ is the sum of the allowable tension design capacity of the single culms, N_{ti}, comprising the member defined in 6.3; or,

N_t is the allowable tension design capacity explicitly determined for a multiple culm member defined in 6.3.

9.4.2 Tension capacity from geometric and material properties

The tension capacity of a member determined from geometric and material properties shall be given by Formula (25):

$$N_{tr} = n \times f_t \times A_{min} \tag{25}$$

where

n is the number of culms comprising the member;

f_t is the allowable tensile strength parallel to fibres given in 6.4; and,

A_{min} is minimum cross sectional area, defined in 6.4.1, of the individual culms comprising the member.

9.5 Combined axial and flexural loads

For members subject to combined axial load and moment including those having initial eccentricities (including National Code-prescribed accidental eccentricities) exceeding the limits given in 9, the failure criteria given by Formulae (26) and (27) shall be applied.

For net axial compression:

$$N_{cd}/N_{cr} + BM_{cd}/M_r \leq 1{,}0 \tag{26}$$

For net axial tension:

$$N_{td}/N_{tr} + M_{cd}/M_r \leq 1{,}0 \tag{27}$$

where

N_{cd} is the design compression force;

N_{cr} is the compression resistance defined in 9.3;

N_{td} is the design tensile force;

N_{tr} is the tensile resistance defined in 9.4;

M_{cd} is the design moment;

M_r is the moment resistance defined in 8.3; and,

B is the moment amplification factor given by Formula (28):

$$B = [1 - N_{cd}/P_e]^{-1} \tag{28}$$

P_e is the buckling capacity defined in 9.3.3.

10 Joints and splices

10.1 General

A joint shall comprise a means of transferring design forces between two or more individual culms or structural members.

Joints shall have predictable deformation characteristics consistent with a) their use; and b) the analytical methods used to determine their design forces.

Joints shall be designed to have appropriate capacity, stiffness, ductility and robustness against bamboo culm splitting. Yield load (F_y; see 10.4), elastic stiffness (K_e; see 10.5) and ductility (μ) are defined in accordance to ISO/TR 21141. The static (monotonic) characteristic design properties for a joint may be determined from either 10.2 or 10.3. Seismic capacities of a joint shall be determined from 10.2. All joints shall satisfy the requirements of 10.6 and 10.7. Culm splices shall satisfy the requirements of 10.8. Connection hardware, ancillary components and/or appurtenances shall conform to the requirements of 10.9 as appropriate.

To the extent possible, the longitudinal axes of all culms connecting in a joint should intersect at a single working point. If this is not possible, the resulting eccentricity of culm loads shall be considered on the design of the joint and connected members.

Component capacities (10.3) and detailing requirements of some well-established joint types are provided in 10.10 through 10.12. A non-exhaustive list and qualitative description of joint types is provided in Annex D.

10.2 Design properties by complete joint testing

Design properties shall be established based on full-scale complete joint assemblages having the same geometry, fastener elements and details, and connected member properties and/or grades as the joint being designed. Tests shall be carried out in accordance with ISO 16670 and joint properties determined in accordance with ISO/TR 21141. Determination of characteristic values shall be made in accordance to ISO 12122-5 or ISO 12122-6 as appropriate.

So as to produce the correct moment-to-shear ratios, joint assemblies designed to resist moments shall be tested in assemblies for which the connected bamboo members are loaded at their points of contraflexure.

10.3 Design properties by component capacities

This approach shall only be used when the failure mode of a joint type is well understood and can be reliably predicted. This approach should be validated by complete-joint testing (10.2).

Joint capacity is determined as the least capacity of each component of the joint. To ensure expected behaviour, all other components of the joint shall have a capacity at least 1,25 times that of the critical component of the joint.

Joint capacity shall not be based on a brittle failure mode ($\mu \leq 1,25$) or a failure mode characterised by longitudinal splitting of the bamboo culm (10.7). Such failure modes shall have a capacity at least 1,25 times that of the critical component of the joint.

Component capacity shall be determined from appropriate test standards and/or methods and characteristic capacities determined in accordance with ISO 12122-5.

Expected component capacities and detailing requirements of some well-established joint types are provided in 10.10 to 10.12.

10.4 Allowable joint design capacity

The allowable joint design load-bearing capacity shall be determined by applying all relevant adjustment factors to the calculated characteristic joint strength determined in accordance with 10.2 or 10.3 as given by Formula (29):

$$F_{\mathrm{y}} = F_{yk} \times C_{DF} \times (1/FS_{\mathrm{j}}) \tag{29}$$

where

F_y is the joint design capacity.

F_{yk} is the 5th percentile characteristic joint capacity determined in accordance with 10.2 or 10.3 with 75 % confidence. In ISO 12122, this value is denoted $F_{y,0,05,0,75}$.

C_{DF} is the modification factor for service class and load duration given in Table 3. The duration factor selected for load combinations shall be that for the component of the combination having the shortest duration.

FS_j is the joint factor of safety given in Table 9

Table 9 — Joint factor of safety, FS_j

	μ < 1,5	1,5 ≤ μ < 4,0	μ ≥ 4
FS_j	3,0	2,5	2,0

where μ is the ductility defined in 10.6. If ductility is unknown, a value μ = 1,25 shall be assumed.

10.5 Joint stiffness

The joint flexural stiffness used in design, K_e shall be determined by Formula (30)

$$K_e = K_{ek} \times C_{DE} \tag{30}$$

where

K_{ek} is the mean characteristic joint stiffness with 75 % confidence (6.2). In ISO 12122 this value is denoted $K_{e,mean,0,75}$.

C_{DE} is the modification factor for service slass and load duration given in Table 7. The duration factor selected for load combinations shall be that for the component of the combination having the shortest duration.

10.6 Ductility of joints

Ductility, μ, is determined in accordance with ISO/TR 21141 as the ratio of the experimentally determined ultimate displacement, Δ_u, to the yield displacement, Δ_y.

Joints having μ < 1,25 shall not be used in load bearing structures.

Joints having μ ≤ 2,00 shall not be used in moment resisting connections in statically indeterminate frames.

Joints having μ ≤ 2,5 shall not be used in the main seismic force resisting system of a structure.

10.7 Robustness against culm splitting

Joints shall be designed to mitigate the risk of longitudinal culm splitting as described in 5.3.

To mitigate splitting at joints near the ends of culms, to the extent possible, at least one node should be located between a joint and the end of a culm.

10.7.1 Radial clamping to resist splitting

Radial clamping of individual culms may be utilised to resist the effects of culm splitting. Testing in accordance with 10.2 is required to establish residual capacity of a joint in the presence of notional splitting required by 5.3.

Straps used to provide radial clamping force shall provide uniform bearing of the strap around the circumference of the culm and shall not result in damage to culm wall when tightened.

All components of metallic clamping straps shall be appropriately protected from corrosion based on their environmental exposure (5.7.2).

NOTE Examples of radial clamping straps include: metallic pipe clamps, plastic ("zip") ties and prestressed lashing (10.9.3).

10.8 Splices joints

Splice joints are a class of joints intended to connect two culms along their longitudinal axes. Examples of splice geometries are provided in Annex D.

Lap splices connect two members along parallel axes separated by the diameter of the culms being spliced. Lap splices shall be designed considering the effects of moment arising from the eccentricity of culm axes.

To the extent possible, splices shall be located away from other connections.

To the extent possible, splices located in a moment resisting member shall be located at the location of least moment (optimally, at the point of contraflexure).

The presence of a splice will typically reduce the capacity of the member in which the splice is located. The capacity of spliced members shall be determined from 8 or 9 including the presence of the splice.

10.9 Requirements for non-bamboo components of joints

10.9.1 Metallic components of joints

All metallic components of joints shall be appropriately protected from corrosion based on their environmental exposure (see 5.7.2). Components having multiple metallic components in contact shall be of the same material to eliminate the possibility of galvanic corrosion.

10.9.2 Joints utilising flowable infill material (grouted joints)

Flowable infill material may be used in the internode regions of a joint or connection for the following reasons:

— provide anchorage for embedded components of the joint or connection; or,

— enhance bearing capacity of an internode region.

When used, flowable infill material shall:

— be compatible with bamboo and shall have no deleterious effects on the material or geometric properties of the bamboo culm;

— be sufficiently flowable to reliably and completely fill the intended infill region; and,

— shall not exhibit either significant shrinkage or swelling resulting from its cure.

The bamboo to be infilled shall have reached its equilibrium moisture content (EMC) at the time of infilling.

10.9.3 Lashing

Lashed connections take two forms:

— connections in which the lashing is the primary means of force transfer in the joint. The geometry and method of executing such a lashed connection will typically be based on acceptable methods as described in 5.11.2 and will typically be prestressed in some manner.

— connections in which the lashing supplements or augments another connection type. In such joints, the contribution of the lashing can be established by testing (10.2 or 5.11.3) and should not be critical to the ultimate performance of the joint.

Lashing may also be used as a means to mitigate culm splitting (10.7.1).

Lashing shall be made of a material not expected to degrade in the environment in which the connection is located and whose expected performance in fire is not worse than the bamboo culm itself.

10.9.4 Mechanical and proprietary joint systems

There are a variety of proprietary mechanical joints used to connect individual culms; these interface with the bamboo culms in a variety of ways and are often used to erect space frames.

Mechanical joints shall be prequalified using the method of 10.2 by demonstrating their ability to resist at least 1,25 times the allowable design capacity of connected components with acceptable deformations.

10.10 End bearing capacity of bamboo culms

The end bearing capacity of unfilled bamboo culms including the 'mouth' portion of fish-mouth connections shall be determined by Formula (31):

$$P_b = C_{EB} \times f_c \times A \tag{31}$$

where

f_c is the allowable compression strength parallel to fibres given in 6.4; and,

A is the cross sectional area of the culm given in 6.4.1.

C_{EB} = 0,80 for straight cuts bearing onto a flat surface

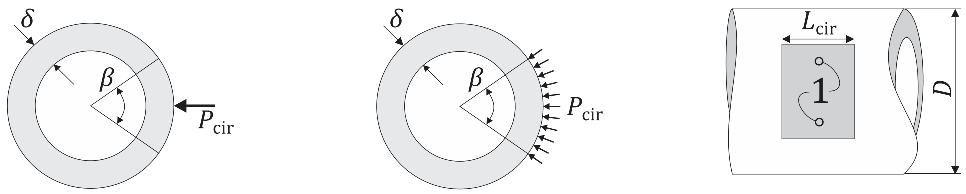
C_{EB} = 0,40 for fish-mouth connections bearing onto another piece of bamboo

The end bearing capacity of filled culms shall be established by 10.2.

End bearing loads shall be distributed uniformly over the entire cross section of the culm.

10.11 Circumferential bearing capacity of bamboo culms

Joints involving hollow bamboo culms shall be designed such that circumferential bearing on the culm engages at least one eighth of the culm circumference (i.e. engaging a central angle of at least β = 45°). See Figure 1.



a) Resultant circumferential bearing force **b) Circumferential bearing pressure** **c) Region of culm subject to bearing**

Key

1 bearing area

Figure 1 — Geometry of circumferential bearing connections

The circumferential bearing capacity of an unfilled bamboo culm shall be determined by Formula (32):

$$P_{cir} = p_{cir} \sin\left(\frac{\beta}{2}\right) D L_{cir} \leq \frac{2 f_{m90} L_{cir}^2 \delta^2 \sin\left(\frac{\beta}{2}\right)}{3 D K_M} \tag{32}$$

where

P_{cir} is the resultant circumferential bearing force;

p_{cir} is the circumferential bearing pressure;

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

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

L_{cir} is the length along the culm over which bearing pressure is applied; and,

D and δ are defined in 6.4.1.

K_M is given in Table 10

Table 10 — Values of factor K_M[16]

β	45°	60°	75°	90°	105°	120°	135°	150°	165°	180°
K_M	0,067	0,112	0,164	0,220	0,277	0,333	0,386	0,432	0,471	0,500
NOTE $K_M = (1/\pi) \times [(\pi - \beta/2)\cos(\pi - \beta/2) + (\pi - \beta/2)]$; β expressed in radians.										

The circumferential bearing capacity of an unfilled bamboo culm shall not exceed that given by Formula (33):

$$P_{cir} \leq 0{,}5 \times L \times \delta \times f_c \tag{33}$$

Where f_c is the compression strength parallel to fibres determined from ISO 22157.

To mitigate culm splitting associated with circumferential bearing, the bearing region shall be at least two culm diameters (2D) from the end of a culm and, to the extent possible, at least one node should be located between the bearing region and the end of a culm.

Circumferential bearing loads shall be distributed uniformly over the bearing area. Care should be taken to ensure that sharp corners at the ends of the bearing region do not damage the culm wall.

The circumferential bearing capacity of filled culms shall be established by 10.2.

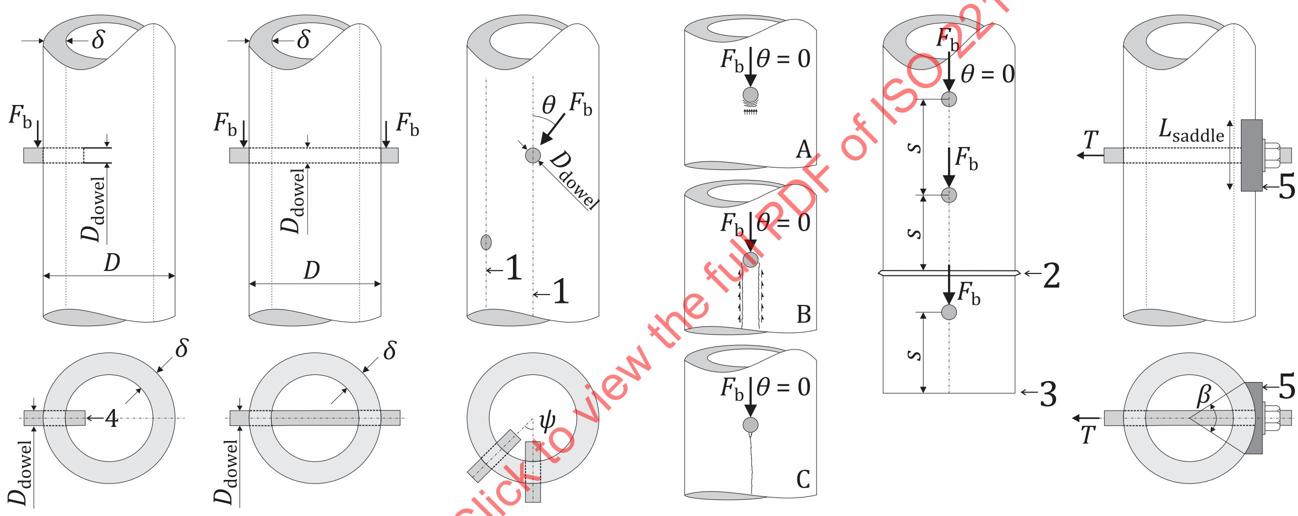
10.12 Joints having through culm wall dowels

Connections intended to transmit shear force involving pins, dowels, bolts, wood screws or other similar anchors (collectively called dowels) that penetrate the culm wall or pass diametrically through the culm engaging two culm walls [Figures 2 a) and 2 b), respectively] shall be designed such that the least capacity of the connection is bearing failure under the dowel.

Shear and combined loading capacity of the dowel itself shall exceed the design capacity determined by this section. Dowel and loading geometry will impact resulting dowel capacity.

For culms loaded such that the angle of applied load relative the longitudinal axis of the culm, $0° < \theta \leq 5°$, to the extent possible, dowel locations within one internode should not be aligned along a single longitudinal gauge line but rather their locations distributed around the circumference of the culm.

To the extent possible, parallel gauge lines shall have a radial spacing no less than $\psi = (115 \times D_{dowel}/D)$ degrees [Figure 2 c)].



a) Dowel engaging single culm wall **b) Symmetrically loaded dowel engaging both culm walls** **c) Radial spacing of gauge lines** **d) Failure modes** **e) Dowel spacing along single gauge line** **f) Means of resisting perpendicular tension** (10.12.3)

Key

1 gauge line
2 node
3 end of culm
4 full diameter of dowel engaged
5 saddle
A bearing
B shear tear out
C cleavage

Figure 2 — Geometry of dowel connections

10.12.1 Capacity of single dowel

The provisions of this section address the capacity of a dowel penetrating a single culm wall. For a single continuous dowel passing diametrically through an entire culm, F_b is doubled.

For connections containing multiple dowels in a single culm it is not permissible to sum the capacities of the individual dowels; tests according to 10.2 are necessary to establish reduction factors for multiple-dowel connections.

Allowable bearing capacity under a dowel, F_b, shall be determined by Formula (34):

$$F_b = D_{dowel} \times \delta \times f_c \times C_\theta \tag{34}$$

where

D_{dowel} is the diameter of the dowel; for screws, D_{dowel} is 1,1 times the root diameter of the screw.

δ is the culm wall thickness defined in 6.4.1;

f_c is the compression strength parallel to fibres determined from ISO 22157;

C_θ is a correction factor accounting for the angle of loading relative to the longitudinal axis (0°) of the culm given in Table 11.

NOTE It is intended that F_b be applied at the outer culm wall as shown in Figure 2. The eccentricity of the load F_b should be no more than one culm wall thickness or the thickness of an attached gusset plate.

Table 11 — Values of factor C_θ

dowel load condition	angle of loading relative to the longitudinal axis (0°) of the culm	
	$0° < \theta \leq 5°$	$\theta > 5°$
dowel engaging single culm wall only (Figure 2 a) or asymmetrically loaded dowel engaging both culm walls	0,3	0,2
symmetrically loaded dowel engaging both culm walls (Figure 2 b)	0,7	0,4

The allowable bearing capacity determined for cases in which $0° < \theta \leq 5°$, F_b, shall not exceed the shear tear-out capacity (Figure 2 d (B)) given by Formula (35):

$$F_b \leq 1{,}6 \times s \times \delta \times f_v \tag{35}$$

where

s is the 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 (see Figure 2 e);

δ is the culm wall thickness defined in 6.4.1 and,

f_v is the shear strength determined from ISO 22157.

Additionally, the allowable bearing capacity determined for cases in which $0° < \theta \leq 5°$, F_b, shall not exceed the cleavage capacity (Figure 2 d (C)) given by Formula (36):

$$F_b \leq \frac{\pi \delta D_{dowel} f_{t90}}{2(1 - D_{dowel}/D)^2} \tag{36}$$

where

D_{dowel} is the diameter of the dowel; for screws, D_{dowel} is 1.1 times the root diameter of the screw.

D and δ are defined in 6.4.1; and,

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

NOTE Both the shear tear-out and cleavage limits for F_b include an additional factor of 1,25 intended to provide a factor of safety against the limit states of shear-out and bearing-induced splitting, respectively.

10.12.2 Requirements for dowels

Dowels, other than wood screws, shall be inserted through predrilled holes having a diameter not greater than 110 percent of the inserted dowel diameter and not less than the inserted dowel diameter except as required for press fit dowels described below. The dowel diameter shall not exceed $D/8$.

Wood screws or sheet metal screws, with the exception of self-tapping screws shall be inserted in predrilled holes having a diameter between one quarter and one half the nominal screw diameter. Self-tapping screws and auger-tip wood screws are permitted to be installed without predrilling.

Driven nails or staples shall not be used to connect structural bamboo members except as permitted in E.2.

Dowels shall fully penetrate the culm wall and engage the culm wall with their full diameter at all locations (Figure 2 a).

NOTE In order for screws to engage their full diameter through the culm wall, the tapered screw tip must pass fully into the interior of the culm.

Bolt, or threaded-rod dowels shall be secured with washers and nuts. Nuts shall not be tightened more than “finger tight”. For applications in which vibration is likely, lock washers or some other means of ensuring the nut does not loosen shall be provided.

Press-fit dowels (e.g. drift pins, key wedges, etc.) are inserted through predrilled/precut holes having a dimension equal to or marginally less than the dowel dimension. The force or effort required to fit the dowels shall not damage the culm wall.

Design of press-fit dowels shall use materials having a modulus similar to bamboo and shall account for possible shrinkage or swelling of the dowel.

10.12.3 Tension forces on dowel joints

With the following exceptions, dowels shall not be designed to resist tension perpendicular to the culm wall (i.e., a dowel withdrawal force).

Through-culm bolts or threaded rods may be designed to resist tension only in a manner shown in Figure 2 f). In such a case, a bearing saddle conforming to the bamboo diameter shall be used. The bearing capacity of the saddle shall be designed based on the requirements of 10.11 taking the bearing length as the saddle length minus the dowel hole diameter.

11 Trusses

Trusses are assemblies of pin-connected members. Trusses may be planar (2D) or space truss (3D) structures. Multiple culm members are permitted. In planar trusses all members and connection points shall be symmetric about the plane of the truss. In space trusses all members at a connection shall be arranged such that their lines of action are collinear with the working point of the connection.

Members shall be designed to resist axial compression and tension as specified in 9. For compression members, the length of a member, L, shall be taken as that between points of restraint in the axis of member buckling and the effective length factor shall be $K = 1$ (9.2). Members shall be designed to resist flexure (8) as required.

Trusses shall be supported against out-of-plane buckling and lateral deformation at every joint along the compression chord. Lateral restraints shall provide sufficient restraint and stiffness to inhibit lateral movement of the restraint point. Restraints shall be capable of resisting a force F_{resc}, determined as given in 9.2.1, oriented perpendicular to the plane of the truss.

To the extent possible, tension and compression chords shall be continuous over at least the shear span of a truss. Spliced members are permitted. Splices shall be designed based on the requirements of 10.

Joints in trusses shall be designed such that they provide minimal rotational restraint and are generally not capable of imparting moments into the members they connect; i.e., they are “pinned” connections. Truss joints shall be designed based on the requirements of 10 to resist the design forces determined from analysis compliant with 7.

Analysis of trusses shall include deformation of joints.

Potential buckling of joint components shall be considered when applicable.

12 Shear panels (walls)

12.1 General

In the context of this document, light cement bamboo frame (LCBF) construction is a modern technique utilising composite shear panels constituted of a wall matrix of bamboo or metal lath fixed onto a bamboo or sawn timber framing system, plastered with cement or lime mortar render. Panels shall have a height-to-length ratio no greater than 3,0. LCBF panels or walls resist short-term lateral forces from wind, impact or seismic action as described in 12.2.1 and 12.2.2. Panels will typically resist tributary gravity loads as described in 12.2.3. Design strength shall be that defined in 12.3.

The bamboo elements of a LCBF shall meet the requirements of this document. The design of sawn timber elements shall meet the requirements of the applicable timber design standard and the intent of this section.

The LCBF frame arrangement may be braced or unbraced. Braced LCBF systems shall not exceed three storeys and 9 m in height. Unbraced LCBF systems shall not exceed two storeys and 7 m in height.

The LCBF panel may be single skin (matrix applied to one side only) or double skin (matrix applied to both sides). The mortar render may be applied to one or both sides of the matrix. This document does not cover systems where the wall matrix is placed in the centreline of the bamboo framing, such that the matrix is not continuous across adjacent panels. Figure 3 shows examples of a single and double skin LCBF.

Example prescriptive details for elements of LCBF systems are described in Annex E.

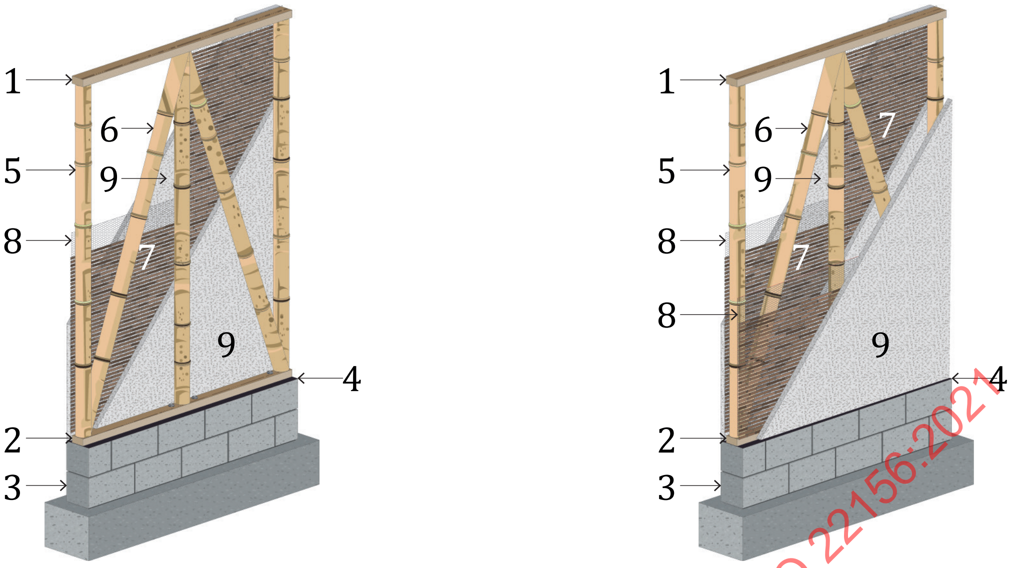
12.1.1 Openings in panels

Windows or other openings in panels are permitted to be included in LCBF wall systems provided the following requirements are met:

— LCBF panel capacity determined in accordance with 12.3 is determined with opening framing included in the panels.

— openings are framed on all four sides.

In cases where opening dimensions exceed one third of either the length or height of a LCBF panel, the panel shall be considered as two separate panels located to either side of the opening. In this case end panel elements and associated tie downs are required to frame the opening. No contribution from the panel region directly above or below such an opening shall be included in overall wall capacity calculations.



a) **Single skin system** b) **Double skin system**

Key

1 head plate; typically timber

2 sole plate; typically timber

3 upstand on concrete or masonry

4 damp-proof membrane

5 bamboo studs (timber can be used)

6 bamboo bracing (timber can be used)

7 wall matrix may consist of strip bamboo, flattened bamboo, small-diameter bamboo or cane, or galvanised metal lath

8 galvanised wire mesh nailed or stapled to matrix

9 cement mortar or lime cement mortar render

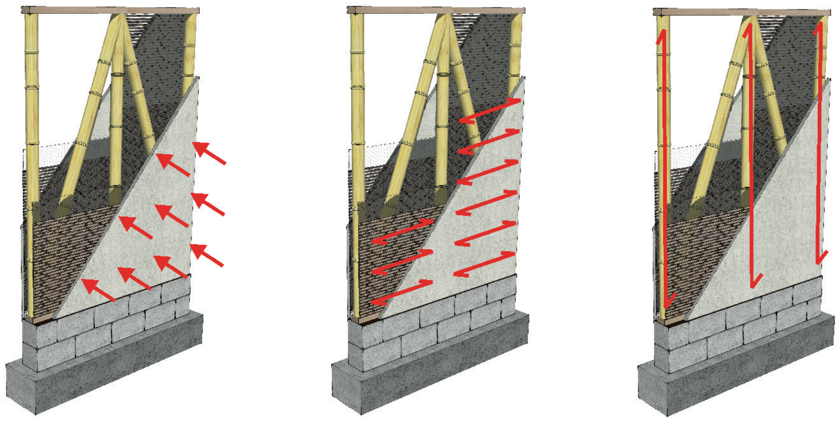
Figure 3 — Examples of light cement bamboo frame (LCBF) construction

12.2 Loads

LCBF shall be capable of resisting applicable national building code-prescribed loads and load combinations and consist of load paths described in 12.2.1, 12.2.2 and 12.2.3.

12.2.1 Out-of-plane loads

Out-of-plane loads originating from wind, impact or seismic action induce flexure in the panels spanning vertically between their head and sole plates and horizontally between vertical members. Figure 4 shows how the LCBF wall matrix spans horizontally between bamboo studs, and how the bamboo studs span vertically between head and sole plates.



a) Out-of-plane loads b) Matrix spanning horizontally between vertical studs c) Studs spanning vertically between sole and head plates

Figure 4 — Mechanisms of out-of-plane load resistance in LCBF construction

The flexural resistance to out-of-plane loads of the vertically spanning elements (studs) of the LCBF panels, shall be determined from 8. No contribution from the mortar or wall matrix shall be assumed. The connection between vertically spanning members and head or sole plates shall be determined from 10.

The flexural resistance to out-of-plane loads of the horizontally spanning wall matrix shall be determined experimentally or analytically, unless the recommended minimum wall matrix properties of E.2.1 are met. The connection between the horizontally spanning wall matrix and vertically spanning members shall be determined in accordance with 10.

12.2.2 In-plane loads

In-plane, LCBF panels or walls shall be designed as vertical cantilevers (see Figure 5). Panel shear capacity, compression capacity and tension capacity at the extreme framing members, as well as overturning and sliding failure at the wall connections shall be considered.

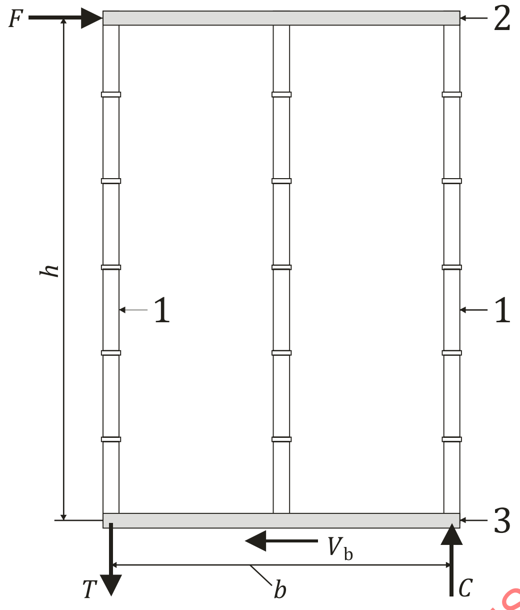
In order to adequately resist in-plane loads, LCBF systems shall be designed and detailed such that the following flow of forces is reliably established:

— shear from upper storeys and/or roof, return walls and the floor diaphragm is transferred to the continuous head plate.

— the head plate transfers shear into the LCBF bamboo frame elements and the composite mortar and wall matrix which transfer shear to the sole plate. The composite mortar and wall matrix combined with in-plane diagonal bracing, if provided, shall be assumed to resist 100 % of the in-plane shear force.

— axial forces (compression and tension) generated due to overturning shall be resisted by the vertical framing members at the ends of the LCBF panel only. The capacities of these members and their connections shall be determined from 9 and 10. Framing members can be assumed to be restrained against buckling in the plane of the wall. Intermediate framing members in a LCBF panel shall not be assumed to contribute to resisting forces resulting from overturning.

— the axial load paths shall be established to the foundation of the structure through appropriate connection between framing elements and head and sole plates



Key

1 framing members at ends of LCBF panel
2 head plate
3 sole plate
F applied horizontal force (from wind or seismic analysis)
V_b base shear force resisting F
T tensile force in end member resisting overturning moment; $T = (F \times h)/b$
C compression force in end member resisting overturning moment; $C = (F \times h)/b$
h height of LCBF panel
b length of LCBF panel

Figure 5 — LCBF panel acting as a cantilever
(effects of gravity load shall be superimposed on the effects of lateral load shown)

12.2.3 Gravity loads

LCBF panels are permitted to resist the effects of gravity loads, provided that the vertical frame elements spanning between head and sole plates resist the loads directly and solely. The compression capacities of these members shall be determined from 9. No contribution from the composite mortar and wall matrix shall be assumed, although vertical framing members can be assumed to be restrained against buckling in the plane of the wall.

12.3 Determination of design strengths

LCBF shear wall or panel capacity shall be determined in accordance with ISO 21581. Wind, seismic and impact load resistance shall be determined by the method of either ISO 21581:2010, 6.1 or 6.2.

Interpretation of test results shall be in accordance with ISO/TR 21141. Determination of characteristic values shall be in accordance with ISO 12122-6. The characteristic lateral stiffness of the complete wall panel assembly shall be used in analyses to ensure horizontal displacements remain within limits prescribed in relevant National Codes.

In-plane design shall assume that wall panels remain elastic in the design earthquake (i.e. a ductility factor of 1 is assumed).

13 Fire resistance

Bamboo shall be assumed to have very little fire resistance by itself. If a national regulation requires bamboo to perform in fire, some form of fire protection or treatment will be required.

Fire resistance ratings for bamboo structural assemblies (e.g., wall panels) shall be determined in accordance with applicable national standards for fire testing.

14 Structural grading

Bamboo should be graded in accordance with ISO 19624 from which component or material properties shall be inferred. Grading shall be adopted for single projects exceeding 10,000 linear metres of bamboo.

If a grading protocol in accordance with ISO 19624 is not adopted, the following streamlined grading procedure shall be adopted:

— the bamboo resource shall be subjected to a visual selection process that includes all of the condition and geometric properties listed in ISO 19624:2018, Clause 6.

— The characteristic mechanical, physical and geometrical properties relevant to design shall be determined in accordance with ISO 19624:2018, 8.2.

— the component bending stiffness or modulus of elasticity and shear strength shall be assessed routinely not exceeding every 2 000 linear metres of bamboo used. If mean values of these parameters are more than 10 % lower than those values used in design, a full assessment of all characteristic properties is required.

Methods of bamboo selection that meet the criteria of 5.11.2 are permitted.

15 Quality assessment and control

Quality assessment and control is beyond the scope of this document. Nonetheless, appropriate quality assessment and control of materials, workmanship and construction methods should be specified. The adoption of a verifiable grading protocol (see Clause 14) is evidence of appropriate quality control of bamboo culms supplied to a project.

Annex A
(informative)

Bases of provisions in this document

A.1 General

There exist over 1 600 species of bamboo. Perhaps 100 of these may be suitable for load-bearing structural applications. Nonetheless, the inter- and intra-species variability of bamboo is significant. This document is based on peer-reviewed research and established bamboo construction norms. There are some implicit limitations of this basis that should be considered by the designer when applying the provisions of this document.

A.2 Bamboo species

The majority of available data on bamboo material properties is based on study of relatively few species. These include the following genus and species

genus *Guadua*:	*G. Angustofolia Kunth, G. Aculeata*
genus *Phyllostachys*:	*P. edulis, P. meyeri, P. nigra, P. bambusoides*
genus *Dendrocalamus*:	*D. giganteus, D.asper, D. strictus, D. barbatus*
genus *Gigantochloa*:	*G. apus, G. atter, G. atroviolacea*
genus *Bambusa*:	*B. blumeana, B. stenostachya, B. oldhami*

A.3 Culm dimensions

The majority of available data on bamboo in load bearing structural applications is based on culms having a diameter, D, greater than 50 mm. Exceptions may be in bundled compressive load carrying members such as columns or truss chords. Appropriate determination of characteristic material properties for culms smaller than D = 50 mm may be impractical and only component properties may be determined.

Full culm bamboo used in load bearing structural applications will typically have a diameter-to-wall thickness ratio (D/δ) less than 12. Above this threshold, local buckling of the culm wall becomes a concern.

Annex B
(informative)

Durability and preservation recommendations

B.1 General

Bamboo is susceptible to a variety of biological agents:

Bamboo will rot (fungal attack) if its moisture content exceeds 20 % for an extended period of time.

Insects that can attack bamboo are endemic to most countries in the world. Typical bamboo-attacking insects are termites and various species of beetles. The prevalence of individual species varies according to country, climate, soil, temperature and altitude, among other factors. Unless it is categorically known that insects which attack bamboo do not live in a specific region because they cannot survive there, it should be assumed that there is a risk of insect attack of bamboo. If national standards do not specify the risks of insect attack, local or national experts should be consulted for advice on the risk of insect attack and appropriate measures of treatment or protection.

Bamboo exposed to a marine environment may be subject to attack from marine borers.

B.2 Recommendations for designing durable bamboo structures

General recommendations for designing durable bamboo structures are as follows:

After harvesting, keep bamboo protected from rain and moisture; allow the bamboo to breathe (air flow around culms) in storage while it is still green.

Only dry bamboo should be used in construction.

Structural details (particularly connections) should be designed to ensure standing water is unlikely to accumulate or enter the inside of the culm.

Bamboo shall not be used in conditions in which it is in contact with standing water or soil.

In a structure, to the extent possible, bamboo should be protected from water and rain (i.e., “protection by design”):

— elevate bamboo above the ground level on a plinth or upstand, isolating the bamboo from the plinth or foundation with a damp-proof membrane.

— use water-proof roof coverings.

— use of long roof overhangs or verandas to protect bamboo members from driven rain

— use of durable and water-proof finishes

— expose bamboo to the extent possible in the interior of the structure to permit drying should it get wet.

Where there is a risk of subterranean insect attack (such as termites), bamboo should be elevated on a solid plinth or upstand, such that ground-based insects need to build visible shelter tubes to access the bamboo; these can be destroyed when they are found.

A bamboo structure requires maintenance through its life, in particular reinstating any water-proof finishes periodically.

