



भारतीय मानक ब्यूरो

(उपभोक्ता मामले, खाद्य एवं सार्वजनिक वितरण मंत्रालय, भारत सरकार)

BUREAU OF INDIAN STANDARDS

(Ministry of Consumer Affairs, Food & Public Distribution, Govt. of India)

मानक भवन, 9, बहादुर शाह ज़फ़र मार्ग, नई दिल्ली - 110002

Manak Bhawan, 9, Bahadur Shah Zafar Marg, New Delhi - 110002

Mob.: 7071963270, Phones: 011-23608594, Extn: 8594

Website: www.bis.org.in, www.bis.gov.in

व्यापक परिचालन मसौदा

हमारा संदर्भ: सीईडी 46 /टी-8

25 फ़रवरी 2025

तकनीकी समिति: भारत की राष्ट्रीय भवन निर्माण विषय समिति, सीईडी 46
प्राप्तकर्ता :

1. सिविल अभियांत्रिकी विभाग परिषद, सीईडीसी के सभी सदस्य
2. राष्ट्रीय भवन निर्माण संहिता विषय समिति, सीईडी 46 के सभी सदस्य
3. सीईडी 46 की पैनल और अन्य कार्यदल के सभी सदस्य
4. रुचि रखने वाले अन्य निकाय।

महोदय/महोदया,

निम्नलिखित मानक का मसौदा संलग्न है:

प्रलेख संख्या	शीर्षक
सीईडी 46 (26947) WC	भारत की राष्ट्रीय भवन निर्माण संहिता भाग 6 संरचनात्मक डिजाइन अनुभाग 3 इमारती लकड़ी तथा बाँस 3B बाँस [SP7(भाग 6, अनुभाग 3, 3बी) का चौथा पुनरीक्षण] (आई सी एस नंबर: 01.120: 91.040.01)

कृपया इस मसौदे का अवलोकन करें और अपनी सम्मतियाँ यह बताते हुए भेजे कि यह मसौदा प्रकाशित हो तो इस पर अमल करने में आपको व्यवसाय अथवा कारोबार में क्या कठिनाइयाँ आ सकती हैं।

सम्मतियाँ भेजने की अंतिम तिथि: 27 मार्च 2025

सम्मति यदि कोई हो तो कृपया अधोहस्ताक्षरी को ई-मेल द्वारा ced46@bis.gov.in पर या उपरलिखित पते पर, संलग्न फ़ॉर्मेट में भेजें। सम्मतियाँ बीआईएस ई-गवर्नेंस पोर्टल, www.manakonline.in के माध्यम से ऑनलाइन भी भेजी जा सकती हैं।

यदि कोई सम्मति प्राप्त नहीं होती है अथवा सम्मति में केवल भाषा संबंधी त्रुटि हुई तो उपरोक्त प्रलेख को यथावत अंतिम रूप दे दिया जाएगा। यदि सम्मति तकनीकी प्रकृति की हुई तो विषय समिति के अध्यक्ष के परामर्श से अथवा उनकी इच्छा पर आगे की कार्यवाही के लिए विषय समिति को भेजे जाने के बाद प्रलेख को अंतिम रूप दे दिया जाएगा।

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धन्यवाद।

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(द्वैपायन भद्र)

वैज्ञानिक 'ई' एवं प्रमुख (सिविल अभियांत्रिकी विभाग)

संलग्न: उपरलिखित



भारतीय मानक ब्यूरो

(उपभोक्ता मामले, खाद्य एवं सार्वजनिक वितरण मंत्रालय, भारत सरकार)
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WIDE CIRCULATION DRAFT

Our Reference: CED 46/T-8

25 February 2025

National Building Code of India Sectional Committee, CED 46

ADDRESSED TO:

1. All Members of Civil Engineering Division Council, CEDC
2. All Members of the National Building Code Sectional Committee, CED 46
3. All Members of Panels and Working Groups under CED 46
4. All others interested

Dear Sir/Madam,

Please find enclosed the following draft:

Doc No.	Title
CED 46 (26947) WC	National Building Code of India Part 6 Structural Design Section 3 Timber and Bamboo: 3B Bamboo [Fourth Revision of SP 7 (Part 6 Section 3, 3B)] (ICS No. 01.120: 91.040.01)

Kindly examine the attached draft and forward your views stating any difficulties which you are likely to experience in your business or profession, if this is finally adopted as National Standard.

Last Date for comments: 27 March 2025

Comments if any, may please be made in the enclosed format and emailed at ced46@bis.gov.in or sent at the above address. Additionally, comments may be sent online through the BIS e-governance portal, www.manakonline.in.

In case no comments are received or comments received are of editorial nature, kindly permit us to presume your approval for the above document as finalized. However, in case comments, technical in nature are received, then it may be finalized either in consultation with the Chairman, Sectional Committee or referred to the Sectional Committee for further necessary action if so desired by the Chairman, Sectional Committee.

The document is also hosted on BIS website www.bis.gov.in.

Thanking you,

Yours faithfully,

Sd/-
(Dwaipayan Bhadra)
Scientist 'E' / Director & Head
(Civil Engineering Department)

Encl: As above

BUREAU OF INDIAN STANDARDS

DRAFT FOR COMMENTS ONLY

(Not to be reproduced without the permission of BIS or used as a Standard)

Draft Indian Standard

National Building Code of India

Part 6 Structural Design
Section 3 Timber and Bamboo: 3B Bamboo

[Fourth Revision of SP 7 (Part 6 Section 3, 3B)]

(ICS No. 01.120: 91.040.01)

Technical Committee

Last Date for Comments:

National Building Code, CED 46

27 March 2025

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National Building Code Sectional Committee, CED 46

FOREWORD

This Code (Part 6/Subsection 3B) covers the general principles involved in the design of structural bamboo in buildings with regard to mechanical resistance and durability of structures. Design of both bamboo (round bamboo, split bamboo, glued laminated bamboo) and bamboo-based panels joined together with adhesives or mechanical fasteners are covered in this Subsection. It also covers minimum strength data, dimensional stability, grading requirements and traditional bamboo joints for quality assurance. Constructional aspects using bamboo, such as, work on site, fabrication of components off-site and their erection on site is also covered to the extent necessary to indicate and ensure the quality of material and standard of workmanship to comply with the assumptions of the design rules and the limitations.

Bamboo is a versatile resource possessing high strength-to-weight ratio and cost ratio and offers considerable ease in working with simpler tools. It has a long and well established tradition as a building material. The application of bamboo as a constructional material is largely based on established traditions and intuitions of forefathers throughout the tropical and sub-tropical regions.

Resilience coupled with light weight makes bamboo an ideal material for housing in disaster prone/earthquake prone areas. It has the capacity to withstand repetitive loadings and absorb more energy and show larger deflections before collapse and as such is safer under earth tremors. As the design guidelines were inadequate, the application of bamboo as an engineering material was largely based on practical and engineering experience. A need was therefore felt to develop a Code for design and construction with bamboo so as to cater to a number of social and trade advantages, engineering recognition and the improved status of bamboo as an engineering material. This was achieved by adding a new chapter in the last revision of the Code, covering structural design with bamboo. Forest Research Institute, Dehradun and some other organizations were engaged in bamboo research to establish its silviculture, botanical, entomological and pathological aspects besides creating a utilization base. All these works were utilized in the preparation of the last version of this Subsection of the Code.

Some of the suitable species grown in India and neighbouring countries are enlisted in Annex A along with their local names and source, for general information.

The bamboo culm has a tubular structure consisting essentially of nodes and inter-nodes. In the inter-nodes the cells are axially oriented while the nodes provide the transverse inter-connection. The disposition of the nodes and the wall thickness are significant in imparting strength to bamboo against bending and crushing. In a circular cross-section, bamboo is generally hollow and for structural purposes this form is quite effective and advantageous. Each of the species of bamboo has widely different characteristics

affecting its usefulness as constructional material. The strength of bamboo culms, their straightness, lightness combined with hardness, range and size of hollowness make them potentially suitable for a variety of applications both structural and non-structural. With good physical and mechanical properties, low shrinkage and good average density, bamboo is well suited to replace wood in several applications, especially in slats and panel form. Mass production of bamboo components, if required, may be integrated with treatment facilities near to the site of plantation or site of construction, for speed and economy in construction.

The Section on structural design with bamboo was first published in 2005 as Subsection 3B of Part 6. In the 1983 version of the Code, timber was covered under Section 3 of Part 6 'Structural Design' under the title 'Wood', which did not cover bamboo. In the 2005 version of the code, the scope of Section 3 was enlarged as Section 3 'Timber and Bamboo', which was subdivided into Subsection 3A 'Timber' and Subsection 3B 'Bamboo'. This Subsection pertains to 3B 'Bamboo'.

Key changes to the 2016 version included: inclusion of provisions on construction practices using bamboo that was addressed erstwhile in Part 7; updated provisions for bamboo trusses, bamboo foundations; bamboo as reinforcement in concrete; introduction of the use of bamboo-based materials for walling, flooring, roofing, and in-fill panels, along with provisions for reconstituted wood from bamboo; and updates to the terms and definitions related to bamboo-based panel products.

With the standardization on design and construction aspects of bamboo in this Subsection of the Code, it was expected to ensure durable structures, however, some specific guidelines were required in the event of tropical cyclones in the sub-continent and the traditional non-engineered structures generally constructed. Keeping this in view, some recommendations are given in Annex B which may be followed in addition to provisions given in the main text of this Subsection.

As a result of experience gained in implementation of 2016 version of this Code and further research work done, feedback received as well as formulation of new standards in the field and revision/updation of some of the existing standards, a need to revise this Subsection was felt. This revision has, therefore, been brought out to take care of these aspects

The significant changes incorporated in this revision include the following:

- a) Bamboo is graded based on conditional, geometric, and dimensional properties for consistent quality assessment.
- b) Detailed guidelines for proper chemical treatment and storage methods to extend the lifespan of bamboo up to 20 to 25 years, in 4.5.2.3.
- c) New design considerations include elevated plinths, adequate drainage, and natural airflow for structural longevity, in 4.5.2.2.

- d) Enhanced fire retardant treatments to improve fire safety in bamboo constructions, in 4.5.1.
- e) Bamboo mat corrugated sheets (BMCS) are included, in 6.9.9, as a sustainable roofing material with high strength, resilience, and thermal resistance for diverse climates.
- f) Comprehensive life cycle assessment to evaluate environmental impacts from production to end-of-life of bamboo structures.
- g) References to all the concerned Indian Standards have been updated.

The information contained in this Subsection is largely based on the works carried out at Forest Research Institute, Dehradun; Institute of Wood Science and Technology, Bangalore; International Network for Bamboo and Rattan (INBAR) documents and Indian Standards given below. Assistance has also been derived from ISO 22156:2021 'Bamboo structures- Bamboo culms- Structural design', apart from the following:

- IS 9096 : 2006 Preservation of bamboo for structural purpose – Code of practice (*first revision*)
- IS 15912 : 2018 Structural design using bamboo – Code of practice (*first revision*)

All standards, whether given herein above or cross-referred to in the main text of this Subsection, are subject to revision. The parties to agreement based on this Subsection are encouraged to investigate the possibility of applying the most recent editions of the standards.

For the purpose of deciding whether a particular requirement of this Subsection is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 2022 'Rules for rounding off numerical values (*second revision*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this Subsection.

Code Users are requested to share their inputs/comments on the draft particularly based on the changes listed above in the foreword; and specially on those text highlighted in blue in this draft.

Important Explanatory Note for Users of the Code

In any Part/Section of this Code, where reference is made to **‘good practice’** in relation to **design, constructional procedures or other related information**, and where reference is made to **“accepted standard”** in relation to **material specification, testing, or other related information**, the Indian Standards listed at the end of the Part/Section shall be used as a guide to the interpretation.

At the time of publication, the editions indicated in the standards were valid. All standards are subject to revision and parties to agreements based on any Part/ Section are encouraged to investigate the possibility of applying the most recent editions of the standards.

In the list of standards given at the end of a Part/Section, the number appearing within parentheses in the first column indicates the number of the reference of the standard in the Part/Section. For example:

a) Good practices [6-3B(1)] refers to the Indian Standard(s) give at serial number (1) of the list of standards given at the end of this Part/Section, that is, IS 9096:2006, ‘Code of practice for preservation of bamboo for structural purposes (first revision)’

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Draft Indian Standard

National Building Code of India

Part 6 Structural Design
Section 3 Timber and Bamboo: 3B Bamboo

[Fourth Revision of SP 7 (Part 6 Section 3, 3B)]

(ICS No. 01.120: 91.040.01)

Technical Committee

Last Date for Comments:

National Building Code, CED 46

27 March 2025

1 SCOPE

1.1 This Code (Part 6/Subsection 3B) covers the general principles involved in the design of structural bamboo in buildings with regard to mechanical resistance and durability of structures. Design of both bamboo (round bamboo, split bamboo, glued laminated bamboo) and bamboo-based panels joined together with adhesives or mechanical fasteners are covered in this Subsection. It also covers minimum strength data, dimensional stability, grading requirements and traditional bamboo joints for quality assurance. Constructional aspects using bamboo, such as, work on site, fabrication of components off-site and their erection on site are also covered to the extent necessary to indicate and ensure the quality of material and standard of workmanship to comply with the assumptions of the design rules and the limitations.

1.2 This Subsection also covers precautions and design limitations on bamboo. The provisions relating to proper procurement and storage of bamboo are covered in Part 7 'Construction Management, Practices and Safety' of the Code.

1.3 The following aspects are not covered in this Subsection:

- a) Limit state design and performance of structures; and
- b) Scientific designing of bamboo joints and their fastenings.

2 TERMINOLOGY

For the purpose of this Subsection, the following definitions shall apply.

2.1 Anatomical Purpose Definitions

2.1.1 Bamboo – Tall perennial grasses found in tropical and sub-tropical regions. They belong to the family *Poaceae* and sub-family *Bambusoideae*.

2.1.2 Bamboo Culm – A single shoot of bamboo usually hollow except at nodes which are often swollen.

2.1.3 Bamboo Clump – A cluster of bamboo culms emanating from two or more rhizomes in the same place.

2.1.4 Cellulose – A carbohydrate, forming the fundamental material of all plants and a main source of the mechanical properties of biological materials.

2.1.5 Cell – A fundamental structural unit of plant and animal life, consisting of cytoplasm and usually enclosing a central nucleus and being surrounded by a membrane (animal) or a rigid cell wall (plant).

2.1.6 Cross Wall – A wall at the node closing the whole inside circumference and completely separating the hollow cavity below from that above (*Syn.* Diaphragm, that is, horizontal partition in a standing culm) (see also **2.2.17** and **2.2.30**).

2.1.7 Hemi Cellulose – The polysaccharides consisting of only 150 to 200 sugar molecules, also much less than the 10 000 of cellulose.

2.1.8 Lignin – A polymer of phenyl propane units, in its simple form ($C_6H_5CH_2CH_2CH_3$).

2.1.9 Sliver – Thin strips of bamboo processed from bamboo culm.

2.1.10 Tissue – Group of cells, which in higher plants consist of (a) Parenchyma – a soft cell of higher plants as found in stem pith or fruit pulp, (b) Epidermis – the outermost layer of cells covering the surface of a plant, when there are several layers of tissue.

2.2 Structural Purpose Definitions

2.2.1 Bamboo Mat Board – A board made of two or more bamboo mats bonded with an adhesive.

2.2.2 Bamboo Mat Corrugated Sheet – A sheet made up of adhesive soaked and coated mats assembled and pressed under specified temperature and pressure to obtain sinusoidal or other suitable corrugations.

2.2.3 Bamboo Mat Corrugated Sheets (BMCS) – Roofing sheets made from woven bamboo mats, treated and pressed with resin to form a durable, weather-resistant corrugated material.

2.2.4 Bamboo Mat Ridge Cap (BMRC) – It is a specially shaped bamboo composite designed to cover and seal the ridge line of BMCS roofs, providing a weatherproof finish to the roof structure.

2.2.5 Bamboo Mat Veneer Composite – Panel manufactured with a combination of bamboo mat and veneer. Bamboo mat can be either as outer skins or as core/cross-bands. However, the composite panel shall be balanced construction on either side of central ply.

2.2.6 Beam – A structural member which supports load primarily by its internal resistance to bending.

2.2.7 Breaking Strength – A term loosely applied to a given structural member with respect to the ultimate load it can sustain under a given set of conditions.

2.2.8 Bundle-Column – A column consisting of three or more number of culms bound as integrated unit with wire or strap type of fastenings.

NOTE – During bunching of beams/columns, binders (5 mm tie bar/wire and 15 mm bamboo dowel pins) may be carefully inserted after proper pre-drilling the holes throughout the assembly as per the requirements of structural design.

2.2.9 Centre Internode – A test specimen having its centre between two nodes.

2.2.10 Characteristic Load – The value of load which has a 95 percent probability of not exceeding during the life of the structure.

2.2.11 Characteristic Strength – The strength of the material below which not more than 5 percent of the test results are expected to fall.

2.2.12 Cleavability – The ease with which bamboo can be split along the longitudinal axis. The action of splitting is known as cleavage.

2.2.13 Column – A structural member which supports axial load primarily by inducing compressive stress along the fibres.

2.2.14 Common Rafter – A roof member which supports roof battens and roof coverings, such as boarding and sheeting.

2.2.15 Curvature – The deviation from the straightness of the culm.

2.2.16 Delamination – Separation of mats through failure of glue.

2.2.17 De-structured bamboo – Raw material (green bamboo) reduced partially to a condition, as far as practicable, in which the element fibres remain interlocked and in their highly aligned state and which with the help of binder can be reconstituted into a valuable product of a desirable size.

2.2.18 End Distance – The distance measured parallel to the fibres of the bamboo from the centre of the fastener to the closest end of the member.

2.2.19 Flattened Bamboo – Bamboo consisting of culms that have been cut and unfolded till it is flat. The culm thus is finally spread open, the diaphragms (cross walls) at nodes removed and pressed flat.

2.2.20 Full Culm – The naturally available circular section/shape.

2.2.21 Fundamental or Ultimate Stress – The stress which is determined on a specified type/size of culms of bamboo, in accordance with standard practice and does not take into account the effects of naturally occurring characteristics and other factors.

2.2.22 Inner Diameter – Diameter of internal cavity of a hollow piece of bamboo.

2.2.23 Inside Location – Position in buildings in which bamboo remains continuously dry or protected from weather.

2.2.24 Joint – A connection between two or more bamboo structural elements.

2.2.25 Joist – A small beam directly supporting floor, ceiling or roof of a structure.

2.2.26 Length of Internode – Distance between adjacent nodes.

2.2.27 Loaded End or Compression End Distance – The distance measured from the centre of the fastener to the end towards which the load induced by the fastener acts.

2.2.28 Machette – A light cutting and slashing tool in the form of a large knife.

2.2.29 Mat – A woven sheet made using thin slivers.

2.2.30 Mortise and Tenon – A joint in which the reduced end (tenon) of one member fits into the corresponding slot (mortise) of the other.

2.2.31 Net Section – Section obtained by deducting from the gross cross-section (A), the projected areas of all materials removed by boring, grooving or other means.

2.2.32 Node – The place in a bamboo culm where branches sprout and a diaphragm is inside the culm and the walls on both sides of node are thicker.

2.2.33 Outer Diameter – Diameter of a cross-section of a piece of bamboo measured from two opposite points on the outer surface.

2.2.33.1 Mean outer diameter – The diameter taken twice on the outer surface, in direction perpendicular to each other at each cross-section on both the ends. Thus, resulting in mean of four readings for the middle of culm.

2.2.34 Outside Location – Position in building in which bamboos are occasionally subjected to wetting and drying as in case of open sheds; and outdoor exposed structures.

2.2.35 Permissible Stress – Stress obtained after applying factor of safety to the ultimate stress. This is also the working stress unless adjusted to the particular structural form in design.

2.2.36 Principal Rafter – A roof member which supports purlins.

2.2.37 Purlins – A roof member directly supporting roof covering or common rafter and roof battens.

2.2.38 Roof Battens – A roof member directly supporting tiles, corrugated sheets, slates or other roofing materials.

2.2.39 Roof Skeleton – The skeleton consisting of bamboo truss or rafter over which solid bamboo purlins are laid and lashed to the rafter or top chord of a truss by means of galvanized iron wire, cane, grass, bamboo leaves, etc.

2.2.40 Slenderness Ratio – The ratio of the length of member to the least radius of gyration is known as slenderness ratio of member (the length of the member is the equivalent length due to end conditions).

2.2.41 Splits – The pieces made from quarters by dividing the quarters radially and cutting longitudinally.

2.2.42 Taper – The ratio of difference between minimum and maximum outer diameter to length.

2.2.43 Unloaded End Distance – The end distance opposite to the loaded end.

2.2.44 Wall Thickness – Half the difference between outer diameter and inner diameter of the piece at any cross section.

2.2.44.1 Mean wall thickness – The wall thickness taken four times in the same points as the diameter has been measured. Thus, resulting in mean of eight values for the middle of culm.

2.2.45 Wet Location – Position in buildings in which the bamboos are almost continuously damp, wet or in contact with earth or water, such as piles and bamboo foundations.

2.3 Definitions Relating to Defects

2.3.1 Bamboo Bore/GHOON Hole – The defect caused by bamboo ghoon beetle (*Dinoderus spp. Bostrichidae*), which attacks felled culms.

2.3.2 Crookedness – A localized deviation from the straightness in a piece of bamboo.

2.3.3 Discolouration – A change from the normal colour of the bamboo which does not impair the strength of bamboo or bamboo composite products.

2.4 Definition Relating to Drying Degraded

2.4.1 Collapse – The defect occurring on account of excessive shrinkage, particularly in thick walled immature bamboo. When the bamboo wall shrinks, the outer layers containing a larger concentration of strong fibro-vascular bundles set the weaker interior portion embedded in parenchyma in tension, causing the latter to develop cracks. The interior crack develops into a wide split resulting in a depression on the outer surface. This defect also reduces the structural strength of round bamboo.

2.4.2 End Splitting – A split at the end of a bamboo. This is not so common a defect as drying occurs both from outer and interior wall surfaces of bamboo as well as the end at the open ends.

2.4.3 Surface Cracking – Fine surface cracks not detrimental to strength. However, the cracking which occurs at the nodes reduces the structural strength.

2.4.4 Wrinkled and Deformed Surface – Deformation in cross section, during drying, which occurs in immature round bamboos of most species; in thick walled pieces, besides this deformation the outer surface becomes uneven and wrinkled. Very often the interior wall develops a crack below these wrinkles, running parallel to the axis.

3 SYMBOLS

For the purpose of this Subsection, the following letter symbols shall have the meaning indicated against each, unless otherwise stated:

A = cross-sectional area of bamboo (perpendicular to the direction of the principal fibres and vessels), mm²

$$= \frac{\pi}{4} [D^2 - (D - 2w)^2];$$

A_B = area of reinforcement in bamboo reinforced cement concrete, mm²;

D = mean outer diameter of bamboo culm, mm;

d = inner diameter, mm

	=	$(D - 2w)$;
E	=	modulus of elasticity (MOE) in bending, N/mm ² ;
f_c	=	calculated stress in axial compression, N/mm ² ;
f_{cp}	=	permissible stress in compression along the fibres, N/mm ² ;
I	=	moment of inertia (the second moment of area) of culm section, mm ⁴
	=	$\frac{\pi}{64} [D^4 - (D - 2w)^4]$;
l	=	unsupported length of column, mm;
m	=	moisture content, percent;
r	=	radius of gyration, mm
	=	$\sqrt{\frac{I}{A}}$;
R	=	modulus of rupture (MOR), N/mm ² ;
w	=	mean of wall thickness of bamboo culm, mm;
Z	=	section modulus, mm ³
	=	$\frac{\pi}{32} \left[\frac{D^4 - (D - 2w)^4}{D} \right]$; and
δ	=	deflection or deformation, mm.

4 MATERIALS

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

4.1 Species of Bamboo

More than 100 species of bamboo are native to India and a few of them are solid but most of them are hollow in structure. In all 20 species have been systematically tested so far. Sixteen species of bamboo are recommended for structural usages in round form. Some physical and mechanical properties of the same are given in Table 2 both for air-dry conditions and green conditions.

4.1.1 Matured bamboo of at least 4 years of age shall be used. The bamboo shall be used after at least six weeks of felling period.

4.1.2 Bamboo shall be properly treated in accordance with the good practice [6-3B(1)].

4.1.3 Solid bamboos or bamboos whose wall thickness is comparatively more and which are generally having nodes very closer are often considered good for structural purposes.

4.1.4 Broken, damaged or collapsed bamboo shall be rejected. Dead and immature bamboos, bore/*Ghoon* holes, decay, collapse, checks more than 3 mm in depth, shall be avoided.

4.2 Grouping

4.2.1 Sixteen species of bamboo recommended for structural applications are classified in three groups on the basis of their strength properties, namely, modulus of elasticity (E) in bending in green condition and modulus of rupture (R) (extreme fibre stress in bending). For structural use in piles and mines' components, an additional criterion of compressive strength is considered in classification. The limits in ultimate strength values of these groups shall be as given in Table 3 (these are corresponding to the spread of properties in structural timber).

4.2.2 Bamboo species may be identified using suitable methods.

NOTE – Methods of identification of bamboo through anatomical characters have not been perfected so far. Identification through morphological characters could be done only on full standing culm by experienced sorters.

4.2.3 Species of bamboo other than those listed in the Table 3 may be used, provided their strength characteristics are determined and found more than the limits specified in Table 4.

4.3 Moisture Content in Bamboo

Normally only dry or seasoned bamboo shall be used otherwise special attention shall be given to dimensional changes occurring during the drying process in the joints, assemblies.

With decrease of moisture content, the strength of bamboo increases exponentially and bamboo has an intersection point (fibre saturation point) at around 25 percent moisture content depending upon the species. A typical moisture strength relationship is given at Fig. 1. The moisture content of bamboo shall be determined in accordance with method given in the accepted standard [6-3B(2)]. Matured culms shall be seasoned to about 15 percent moisture content before use.

Freshly felled bamboo with shoots and leaves intact, dry fairly well in the open sun with lesser surface cracking, etc, and reduced starch contents. Rapid drying in the open can control degrades.

4.4 Grading of Structural Bamboo

Grading bamboo is a process that ensures its structural integrity, standardization, efficient use, and marketability. It plays a crucial role in enhancing trade and promoting sustainable harvesting by ensuring that bamboo meets the required specifications for various applications. This process is essential for ultimately producing safe and

economical structures, encouraging its use in mainstream construction and other industries.

4.4.1 Grading is sorting out bamboo on the basis of characteristics important for structural utilization as under:

- a) Diameter and length of culm;
- b) Taper of culm;
- c) Straightness of culm;
- d) Inter nodal length and distribution of nodes;
- e) Wall thickness;
- f) Density and strength; and
- g) Durability and seasoning.

One of the above characteristics or sometimes combination of two or three characteristics form the basis of grading. The culms shall be segregated species-wise.

4.4.2 Visual Grading of Bamboo

Visual grading involves the inspection of bamboo based on visible characteristics, which are divided into three primary categories: conditional properties, geometric properties, and dimensional properties. (see Table 1)

4.4.2.1 Conditional properties

These include:

- a) *Moisture content* – The state of bamboo in terms of moisture, age at the time of harvesting, insect or fungal damage, and other visible defects such as fissures.
- b) *Fissures* – Cracks or splits in the bamboo, typically developing during the drying process, which affect its load-bearing capacity.
- c) *Age at harvest* – While optimal ages for harvesting can impact bamboo strength, it is challenging to control at the grading stage.

4.4.2.2 Dimensional properties

These include:

- a) *Diameter* – Critical to the flexural capacity of the bamboo; methods for measuring the diameter include using rulers, vernier callipers, or diameter tapes.
- b) *Wall thickness* – Important for shear and tensile strength; it is measured at the middle of the internode.

- c) *Internode length* – Helps prevent splits and buckling, ensuring the structural integrity of the bamboo.

Table 1 Grading Criteria of Bamboo
(Clause 4.4.2)

SI No. (1)	Property Type (2)	Specifics (3)	Grading Methodology (4)
i)	Conditional properties	Insect/fungal damage, cracks, age at harvest	Visual inspection for defects; ensure dryness before grading.
ii)	Dimensional properties	Diameter, wall thickness, internode length	Use vernier callipers or diameter tape for precise measurement.
iii)	Geometrical properties	Taper, straightness, ovality	Ensure taper is within 1 percent range; assess straightness visually.

4.4.2.3 Geometrical properties

These include:

- a) *Taper* – The variation in diameter along the bamboo length, which affects load-bearing capacity.
- b) *Straightness* – Measures the curvature or bow of the bamboo, which is essential for compression elements.
- c) *Ovality* – Defined as the ratio between the smallest and largest diameters, affecting the uniformity of bamboo strength.

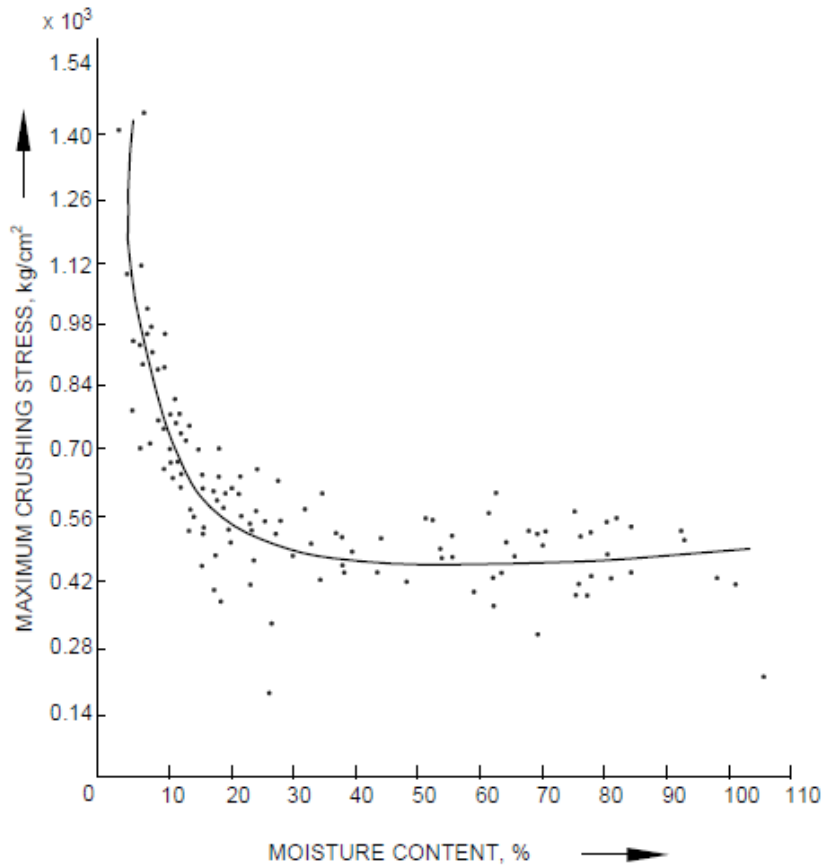


FIG. 1 MOISTURE STRENGTH RELATIONSHIP BAMBUSA NUTANS (BAMBOO)

4.4.3 Diameter and Length

4.4.3.1 Gradation according to the mean outer diameter

For structural Group A and Group B species, culms shall be segregated in steps of 10 mm of mean outer diameter as follows:

- a) Special grade 1 : $100 \text{ mm} < d < 130 \text{ mm}$
- b) Special grade 2 : $70 \text{ mm} < \text{Diameter} \leq 100 \text{ mm}$
- c) Grade I : $50 \text{ mm} < \text{Diameter} \leq 70 \text{ mm}$
- d) Grade II : $30 \text{ mm} < \text{Diameter} \leq 50 \text{ mm}$
- e) Grade III : $\text{Diameter} \leq 30 \text{ mm}$

For structural Group C species culms shall be segregated in steps of 20 mm of mean outer diameter as follows:

- a) Grade I : $80 \text{ mm} < \text{Diameter} \leq 100 \text{ mm}$
- b) Grade II : $60 \text{ mm} < \text{Diameter} \leq 80 \text{ mm}$
- c) Grade III : $\text{Diameter} \leq 60 \text{ mm}$

4.4.3.2 The minimum length of culms shall be preferably 4.5 m for facilitating close fittings at joints, etc.

4.4.4 Taper

The taper shall not be more than 5.8 mm per metre length (or 0.58 percent) (1 in 170) of bamboo in any grade of bamboo.

4.4.5 Curvature

The maximum curvature should not be more than 75 mm in a length of 6 m of any grade of bamboo.

NOTE – Due to the constraint of preferential selection of straighter material out of a lot, more bent material may be accommodated to avoid high cost. Following remedial options may be helpful:

- a) Adopt component assembly method to take care of some degree of curvature (bunching done after holding components straight).
- b) Cut longer bamboo components with less curvature out of taller bamboo and use cambered ones for shorter length components.

4.4.6 Wall Thickness

Preferably minimum wall thickness of 8 mm shall be used for load bearing members unless calculations and the availability dictate otherwise.

4.5 Durability and Treatability

4.5.1 Durability

The natural durability of bamboo is low and varies between 12 months and 36 months depending on the species and climatic conditions. In tropical countries the bio-deterioration is very severe. Bamboos are generally destroyed in about one to two years' time when used in the open and in contact with ground; while a service life of two to five years can be expected from bamboo when used under cover and out of contact with ground. The mechanical strength of bamboo deteriorates rapidly with the onset of fungal decay in the sclerenchymatous fibres. Split bamboo is more rapidly destroyed than round bamboo

To significantly enhance the lifespan of bamboo constructions, chemical treatments are essential. Proper preservative treatments can extend the life of bamboo structures to the order of 20 to 25 years. Treatment is most effective when performed while the bamboo is still green, using methods such as the Boucherie or modified Boucherie process. For making bamboo durable, suitable treatment for preserving bamboo shall be given in accordance with the good practice [6-3B(3)].

These are the key considerations for bamboo durability:

- a) *Storage* – Bamboo should be stored properly to prevent deterioration due to exposure to rain, sun, or moisture. Elevated storage (at least 150 mm above the ground) helps avoid bio-deterioration and fungal attacks.
- b) *Fire protection* – Proper precautions should be taken during storage to minimize fire hazards.
- c) *Prophylactic treatments* – Bamboo may require preventive treatments to avoid insect and fungal infestations during storage and use.
- d) *Site management* – Bamboo construction sites should be inspected for termite infestations, and the area should be cleared of any debris that may attract pests. Suitable insecticides should be used to treat the site.
- e) *End treatment* – The ends of bamboo culms should be sealed with coal tar or varnish to prevent cracking.
- f) *Fire retardant treatment* – Bamboo can be treated with a fire-resistant solution containing a mix of ammonium phosphate, boric acid, copper sulphate, zinc chloride, sodium dichromate, and water, with a drop of concentrated hydrochloric acid to dissolve any precipitated salts.

4.5.2 The effective treatment of bamboo is essential for enhancing its durability in construction. Treatment practices are guided by three key considerations: harvesting, construction design, and chemical treatment.

4.5.2.1 *Harvesting practices*

Proper harvesting practices are crucial for maximizing the strength and longevity of bamboo. These practices have been detailed in earlier sections and include guidelines on the timing of harvest and conditions that reduce pest attacks and structural deformities.

4.5.2.2 *Construction design considerations*

When using bamboo in construction, it shall be kept dry, out of ground contact, and in areas with good air circulation. This should be achieved through the following design features:

- a) *Drainage system* – Adequate drainage shall be provided to prevent water accumulation around bamboo structures.
- b) *Elevated plinth* – The base of bamboo structures should be elevated to avoid contact with the ground.

- c) *Natural airflow* – Proper air circulation shall be ensured to promote longevity and facilitate maintenance.

Additional protection measures include:

- 1) A termite protection sheet made of galvanized steel or aluminium shall be installed between the wall and foundation of the structure.
- 2) The use of cavity walls should be avoided to prevent moisture retention.
- 3) The open ends of bamboo culms shall be plugged with paraffin wax to protect against deterioration.

4.5.2.3 Chemical treatment for preservation

Chemical treatment methods shall be employed to protect bamboo from pests, fungi, and other forms of degradation. The following methods may be used, depending on the intended application and condition of the bamboo:

- a) *Chemical preservatives* – Preservatives shall be applied to protect bamboo from bio-deterioration.
- b) *Dip diffusion method* – Bamboo should be immersed in a chemical solution for diffusion into the fibres.
- c) *Boucherie process* – In the green state, bamboo shall be treated using the Boucherie or modified Boucherie process for effective sap displacement.
- d) *Internodal injection method* – Chemical preservatives may be injected directly into the internodes of the bamboo.
- e) *Hot and cold method* – This method may be used to treat bamboo by alternating between hot and cold conditions to facilitate chemical absorption.

By adhering to these guidelines for harvesting, construction design, and chemical treatment, the service life of bamboo structures shall be significantly enhanced, ensuring their durability in construction applications.

4.5.3 Fire safety of bamboo structures shall be ensured, for which the treatment prescribed in 7.3.4 may be followed.

5 PERMISSIBLE STRESSES

5.1 Ultimate stress values of different species and groups of bamboo shall be determined according to the accepted standard [6-3B(2)]. These values shall then be divided by

appropriate factors of safety to obtain permissible stresses to cover the effects of variability, long term loading, grade, location of use and expected dynamic loading.

NOTE – As an information, it may be noted that the method of test for split bamboos is covered in the accepted standard [6-3B(4)].

5.1.1 The strength factors for deriving safe working stresses of bamboo shall be as under:

Extreme fibre stress in beams	:	4
Modulus of elasticity	:	4.5
Maximum compressive stress parallel to grain/fibres	:	3.5

5.2 The available data for the safe working stresses for 16 species of bamboos are given in Table 4.

5.3 For change in duration of load other than continuous (long-term), the permissible stresses given in Table 4 shall be multiplied by the modification factors given below :

For permanent loads	:	1.0
For imposed or medium term loading (permanent + temporary load)	:	1.25
For short term loading (permanent + temporary load + wind load)	:	1.50

Table 2 Physical and Mechanical Properties of Indian Bamboos (in Round Form)
(Clause 4.1)

SI No.	Species	Properties							
		In Green Condition				In Air Dry Conditions			
		Density	Modulus of Rupture	Modulus of Elasticity	Maximum Compressive Strength	Density	Modulus of Rupture	Modulus of Elasticity	Maximum Compressive Strength
		kg/m ³	N/mm ²	x 10 ³ N/mm ²	N/mm ²	kg/m ³	N/mm ²	x 10 ³ N/mm ²	N/mm ²
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
i)	<i>Bambusa auriculata</i>	594	65.1	15.01	36.7	670	89.1	21.41	54.3
ii)	<i>B. balcooa</i>	783	65.4	7.31	46.7	–	–	–	60.6
iii)	<i>B. bambos</i> (Syn. <i>B. arundinacea</i>)	559	58.3	5.95	35.3	663	80.1	8.96	53.4
iv)	<i>B. burmanica</i>	570	59.7	11.01	39.9	672	105.0	17.81	65.2
v)	<i>B. glancescens</i> (Syn. <i>B. nana</i>)	691	82.8	14.77	53.9	–	–	–	–
vi)	<i>B. nutans</i>	603	52.9	6.62	45.6	673	52.4	10.72	47.9
vii)	<i>B. pallida</i>	731	55.2	12.90	54.0	–	–	–	–
viii)	<i>B. tulda</i>	658	51.1	7.98	40.7	722	66.7	10.07	68.0
ix)	<i>B. ventricosa</i>	626	34.1	3.38	36.1	–	–	–	–
x)	<i>B. vulgaris</i>	626	41.5	2.87	38.6	–	–	–	–
xi)	<i>Cephalostachyum pergracile</i>	601	52.6	11.16	36.7	640	71.3	19.22	49.4
xii)	<i>Dendrocalamus longispathus</i>	711	33.1	5.51	42.1	684	47.8	6.06	61.1
xiii)	<i>D. strictus</i>	631	73.4	11.98	35.9	728	119.1	15.00	69.1
xiv)	<i>Melocanna baccifera</i>	817	53.2	11.39	53.8	751	57.6	12.93	69.9

SI No.	Species	Properties							
		In Green Condition				In Air Dry Conditions			
(1)	(2)	Density	Modulus of Rupture	Modulus of Elasticity	Maximum Compressive Strength	Density	Modulus of Rupture	Modulus of Elasticity	Maximum Compressive Strength
		kg/m ³	N/mm ²	x 10 ³ N/mm ²	N/mm ²	kg/m ³	N/mm ²	x 10 ³ N/mm ²	N/mm ²
		(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
xv)	<i>Oxytenanthera abyssinicia</i>	688	83.6	14.96	46.6	–	–	–	–
xvi)	<i>Thyrsostachys oliveri</i>	733	61.9	9.72	46.9	758	90.0	12.15	58.0

NOTE – The values of stress in N/mm² have been obtained by converting the values in kgf/cm² by dividing the same by 10.

Table 3 Properties of Structural Bamboo
(Clauses 4.2.1 and 4.2.3)

SI No.	Group	Modulus of Rupture (R) N/mm ²	Modulus of Elasticity in Bending (E) x 10 ³ N/mm ²	Maximum Compressive Strength ($f_{c, \max}$) N/mm ²
(1)	(2)	(3)	(4)	(5)
i)	A	$R > 70$	$E > 9$	$MCS > 35$
ii)	B	$70 \geq R > 50$	$9 \geq E > 6$	$35 > MCS > 30$
iii)	C	$50 \geq R > 30$	$6 \geq E > 3$	$30 > MCS > 25$

Table 4 Safe Permissible Stresses of Bamboos for Structural Designing¹⁾
(Clauses 4.2.3, 5.2 and 5.3)

SI No.	Species	Extreme Fibre Stress in Bending N/mm ²	Modulus of Elasticity x 10 ³ N/mm ²	Allowable Compressive Stress N/mm ²
(1)	(2)	(3)	(4)	(5)
i)	Group A:			
	a) <i>Bambusa glancescens</i> (Syn. <i>B.nana</i>)	20.7	3.28	15.4
	b) <i>Dendrocalamus strictus</i>	18.4	2.66	10.3
	c) <i>Oxytenanthera abyssinicia</i>	20.9	3.31	13.3
ii)	Group B:			
	a) <i>Bambusa balcooa</i>	16.4	1.62	13.3
	b) <i>B.pallida</i>	13.8	2.87	15.4
	c) <i>B.nutans</i>	13.2	1.47	13.0
	d) <i>B.tulda</i>	12.8	1.77	11.6
	e) <i>B.auriculata</i>	16.3	3.34	10.5
	f) <i>B.burmanica</i>	14.9	2.45	11.4
	g) <i>Cephalostachyum pergracile</i>	13.2	2.48	10.5
	h) <i>Melocanna baccifera</i> (Syn. <i>M.bambusoides</i>)	13.3	2.53	15.4
	j) <i>Thyrsotachys oliveri</i>	15.5	2.16	13.4
iii)	Group C:			

SI No.	Species	Extreme Fibre Stress in Bending	Modulus of Elasticity	Allowable Compressive Stress
(1)	(2)	N/mm ² (3)	x 10 ³ N/mm ² (4)	N/mm ² (5)
a)	<i>Bambusa arundinacea</i> (Syn. <i>B.bambos</i>)	14.6	1.32	10.1
b)	<i>B.ventricosa</i>	8.5	0.75	10.3
c)	<i>B.vulgaris</i>	10.4	0.64	11.0
d)	<i>Dendrocalamus longispathus</i>	8.3	1.22	12.0

1) The values given pertain to testing of bamboo in green condition.

NOTE – The values of stress in N/mm² have been obtained by converting the values in kgf/cm² by dividing the same by 10.

NOTE – The above properties are based on the accepted standard [6-3B(2)].

6 DESIGN CONSIDERATIONS

6.1 Basic Requirements

A structure shall be designed and constructed by personnel having the appropriate skill and experience in such a way that,

- a) With acceptable probability, it will remain fit for the use for which it is required, having due regard to its intended life and costs;
- b) With appropriate degree of reliability, it will sustain all forces and effects likely to occur during execution and use and have adequate durability in relation to maintenance costs;
- c) The structure will be adequately maintained;
- d) The structure will be used in accordance with design limit briefs;
- e) All structural members, assemblies or framework in a building shall be capable of sustaining, without exceeding the limits of relevant stress specified, the worst combination of all loadings;
- f) A fundamental aspect of design will be to determine the forces to which the structure/structural element might be subjected to, starting from the roof and working down to the soil by transferring the forces through various components and connections;

- g) Accepted principles of mechanics for analysis and specified design procedures shall be applied (or) the design requirements may be satisfied by prototype testing;
- h) Loads shall be in accordance with Part 6 'Structural Design, Section 1 Loads, Forces and Effects' of the Code, keeping into consideration that permeability of walls, floors and roof made from bamboo cause internal pressure and can therefore affect the wind load factor; and
- j) The worst combination and location of loads shall be considered for design. Also, wind and seismic forces shall not be considered to act simultaneously.

6.2 Unlike timber, bamboo properties do not relate well to species, being dependent among other factors, on position of the culm, geographic location and age. The practice in timber engineering is to base designs on safe working stresses (see Note) and the same may be adopted to bamboo with the limitations that traditional experience rather than precise calculations generally govern the detailing.

NOTE – Limit states are states beyond which the structure no longer satisfies the design performance requirements. Limit states are classified into ultimate limit state relating to collapse mode and serviceability limit states associated with deformations, vibrations, etc. Design is usually based on ultimate stages with partial factors of safety.

6.3 Age old traditional experience of construction with bamboo is to be well preserved as non-standard practices for similar situations considered as an informal based on general social pattern and wisdom. Confirmation of such structures be based on reports after they have sustained the severity of earthquakes, cyclones, etc, as criteria for recommendations by the evaluation by competent engineer/builder with adequate experience in the field.

6.4 Net Section

It is determined by passing a plane or a series of connected planes transversely through the members. Least net sectional area is used for calculating load carrying capacity of a member. In the design of an intermediate or a long column, gross section shall be used in calculating load carrying capacity of column.

6.5 Structural Components

6.5.1 Main structural applications in bamboo may include roofing and flooring, shear walls, wall paneling, beams, piles, columns, arches, etc. Both from the point of view of capacity and deformation, trusses and framed skeletons are much better options in bamboo.

6.5.2 Peculiarity of Bamboo as a Design Material

This shall be based on the principles of applied mechanics involving the following assumptions:

- a) Elastic behaviour of bamboo, until failure (plastic behaviour being considered to be not significant);

- b) Bamboo culms are analyzed as hollow-tube structures (not perfectly straight) member on mean diameter and mean wall thickness basis. Designing as a variable thickness hollow-tube structure is a bit complex;
- c) Nodes do not occur at constant intervals;
- d) Structural elements of bamboo shall be appropriately supported near the nodes of culm as and where the structural system demands. The joints in the design shall be located near nodes;
- e) Bamboo structures are designed like any other conventional structural analysis taking care of details with regards to supports and joints; and the diameter, wall thickness and initial curvature; and
- f) Joints shall be considered to generally act as a hinge or as pinned, unless substantiating data justify a fixed joint.

6.6 Flexural Members

6.6.1 All flexural members may be designed using the principles of beam theory.

NOTE – The tendency of bamboo beams to acquire larger deflections under long continual loading (including creep) has to be taken care of either by giving a factor of safety to E or by considering double the design dead loading in calculation of deflections.

6.6.2 The moment of inertia, I shall be determined as follows:

- a) Outside diameter and the wall thickness shall be measured at both ends, correct up to 1 mm for diameter of culm and 0.1 mm for the wall thickness.
- b) With these values the mean diameter and the mean thickness for the middle of the beam shall be calculated and moment of inertia determined.

6.6.3 The maximum bending stress shall be calculated and should be within the allowable stress.

6.6.4 The deflection shall be within the prescribed limits. The initial curvature shall also be considered in the calculation of the deflection.

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

6.6.6 Forces acting on a beam, being loads or reaction forces at supports, shall act in nodes or as near to nodes as by any means possible.

6.7 Columns (Predominantly Loaded in Axial Direction)

6.7.1 Columns and struts are essential components sustaining compressive forces in a structure. They transfer load to the supporting media.

6.7.2 Design of columns shall be based on one of the following two criteria:

- a) Full scale buckling tests on the same species, size and other relevant variables.
- b) Calculations, based on the following:

- 1) Moment of inertia shall be determined as per **6.6.2**.
- 2) For bamboo columns the best available straight bamboo culms shall be selected.
- 3) Bending stresses due to initial curvature, eccentricities and induced deflection shall be taken into account, in addition to those due to any lateral load.

NOTE – Unlike timber, MOE has already been provided a factor of safety in case of bamboo. This is on the basis of studies on variability of MOR and MOE. In the case of timber, no factor of safety for MOE was used because there has been an understanding that there is no variability in MOE. Subsequently it was confirmed that MOE varies as the MOR and there is very strong, highly significant correlation between the two. In fact this correlation has formed the basis of development of machine grading of timber world-over. However, somehow the practice of not giving factor of safety to MOE continued in Indian Standard. Later on when the standard on structural use of bamboo was formulated, factor of safety was given both in MOR and MOE on the basis of latest variability studies on strength of bamboo.

6.7.3 Buckling calculation shall be according to Euler, with a reduction to 90 percent of moment of inertia, to take into account the effect of the taper which shall be less than 1:170.

6.7.4 For strength and stability, larger diameter thick walled sections of bamboo with closely spaced nodes shall be used. Alternatively, smaller sections may be tied together as a bundle-column.

6.8 A single bamboo culm is not an optimum component to structurally design different load bearing members. Bunching of bamboo is inevitable to fabricate beams, columns, etc. There is no end to the number of culms in bunching. However, different components pose manufacturing problems during assembly, which should be appropriately taken care of (see also Fig. 9D and Fig. 9E).

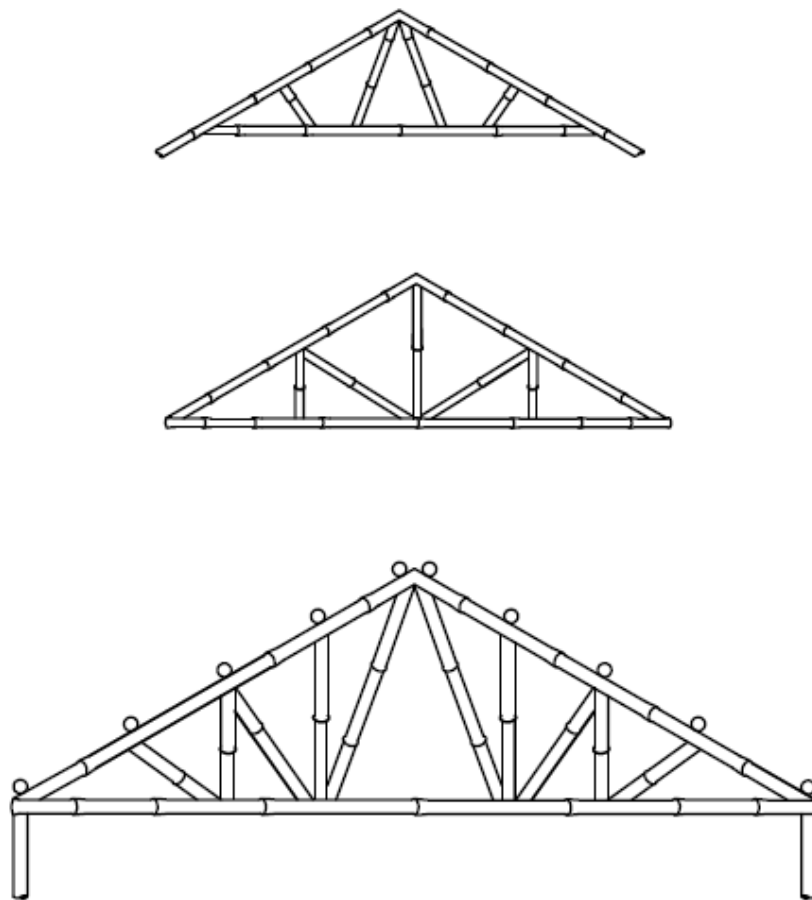
6.8.1 Following precautions shall be taken to avoid possible split/crack in walling of bamboo:

- a) Maintaining a minimum 100 mm distance of the drills from the end of the main bamboo culms drilled.
- b) Choosing drilling points preferably within 30 mm from node.
- c) Maintaining the interference fit between bamboo body and binders as under:
 - 1) For wall thickness ≥ 8 mm : 0.25 to 0.30 mm, and
 - 2) For wall thickness < 8 mm : 0.20 to 0.25 mm.
- d) The inserting ends of the dowel pins may be dressed as tapered (conical).

6.9 Assemblies and Roof Trusses

6.9.1 Elements in structure are generally built-up in the form of assembled members for which a triangle is a simple figure of stability. Besides sloped chords, parallel chord construction is also appropriate as external profile.

6.9.2 A truss is essentially a plane structure which is very stiff in the plane of the members, that is the plane in which it is expected to carry load, but very flexible in every other direction. Roof truss generally consists of a number of triangulated frames, the members of which are fastened at ends and the nature of stresses at joints is either tensile or compressive and designed as pin-ended joints (see Fig. 2A). Bamboo trusses may also be formed using bamboo mat board or bamboo mat-veneer composite or plywood gusset (see Fig. 2B).



2A PIN ENDED JOINT TRUSSES

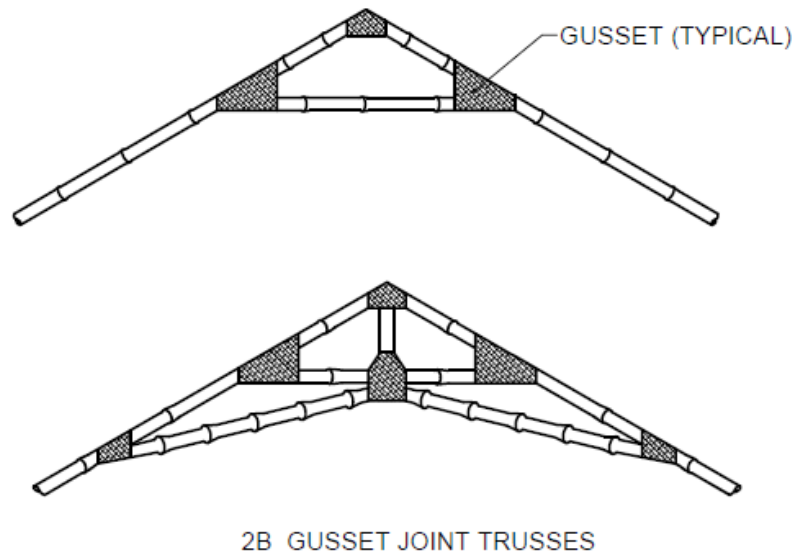


FIG. 2 SOME TYPICAL CONFIGURATIONS FOR SMALL AND LARGE TRUSSES IN BAMBOO

6.9.3 Trusses shall be analyzed for the determination of axial forces in members and the deformation of joints. For the influence of eccentricities, due allowance shall be made in design.

6.9.4 The truss height shall exceed 0.15 times the span in case of a triangular truss (pitched roofing) and 0.10 times the span in case of a rectangular (parallel) truss.

6.9.5 For members in compression, the effective length for in-plane strength verification shall be taken as the distance between two adjacent points of contraflexure. For fully triangulated trusses, effective length for simple span members without especially rigid end-connection shall be taken as the span length.

6.9.6 The spacing of trusses shall be consistent with use of bamboo purlins.

6.9.7 The ends in open beams, joists, rafters, purlins shall be suitably plugged. Bamboo roof coverings shall be considered as non-structural in function.

6.9.8 Bamboo trusses with wire bound joints using bamboo pins and/or wooden splice plates fastened with bamboo pins when tested at load for factor of safety of at least 5, result in deflection within permissible range at design load; good recovery but abnormal deflection beyond ultimate load without collapse was observed.

NOTE – This is based on the work done on prototypes of a few bamboo trusses (span 4 m) tested at Forest Research Institute, Dehradun.

6.9.9 Bamboo Mat Corrugated Sheets for Building Roofs

Bamboo mat corrugated sheets (BMCS) shall be used as a sustainable roofing material suitable for residential, commercial, and institutional buildings. BMCS are made from woven bamboo mats treated with phenolic resin and pressed under heat

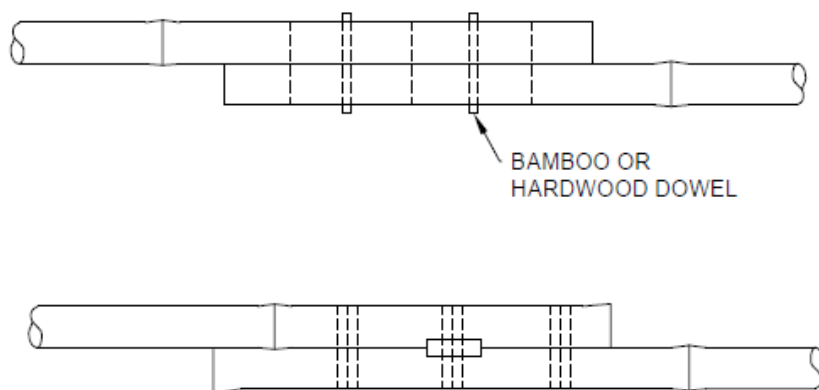
and pressure, these sheets offer a durable and eco-friendly alternative to traditional roofing materials. BMCS sheets shall provide high strength, resilience, and resistance to water, decay, and UV exposure, making them suitable for varied climates. These sheets should contribute to energy efficiency by offering thermal resistance and natural temperature regulation, especially in green buildings. BMCS shall comply with the accepted standard [6-3B(9)], meeting the necessary performance requirements for load-bearing capacity, impermeability, water absorption, and fire resistance.

6.9.10 Bamboo Mat Ridge Cap (BMRC)

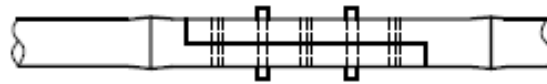
Bamboo mat ridge cap (BMRC) is a sustainable, lightweight, and eco-friendly roofing solution developed to complement bamboo mat corrugated sheets (BMCS) in green building construction. Produced from bamboo mats, BMRCs are designed to cover the ridge (top edges) of BMCS roofs, providing strong physical and mechanical properties suitable for roofing applications. BMRCs are energy-efficient and cost-effective, offering a high strength-to-weight ratio, low thermal conductivity, and an aesthetically pleasing appearance, making them an ideal choice for eco-conscious construction projects. These ridge caps are manufactured in alignment with industry standards for durability and performance.

7 DESIGN, TECHNIQUES OF JOINTS AND CONSTRUCTION PRACTICES

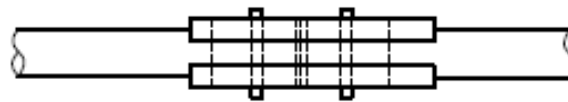
7.1 Connecting the load-bearing elements together for effective transfer of stress and to achieve continuity between elements with controlled displacements is one of the serious problem. As joints are a source of weakness in any bamboo structure, they have to be made as strong and rigid as possible. Joints are quite critical in assemblies, and these should be stable in relation to time. For general information, the diagrams of typical joints given in Figs. 3 to 7 may be used based on tests for adequacy of strength.



3A FULL LAPPED JOINT



3B HALF LAPPED JOINT
(REBATED/SPLAYED)



WITH SIDE PLATES OF BAMBOO



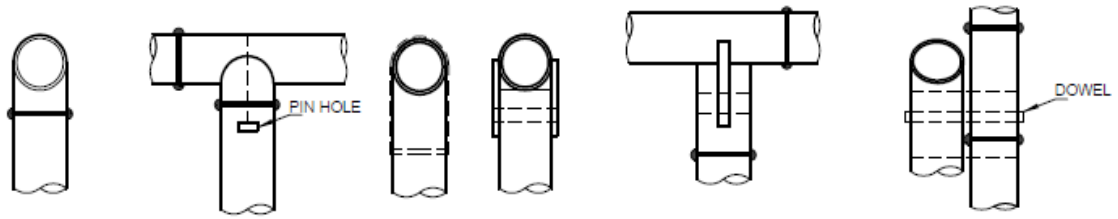
WITH INSERTS



WITH SLEEVE

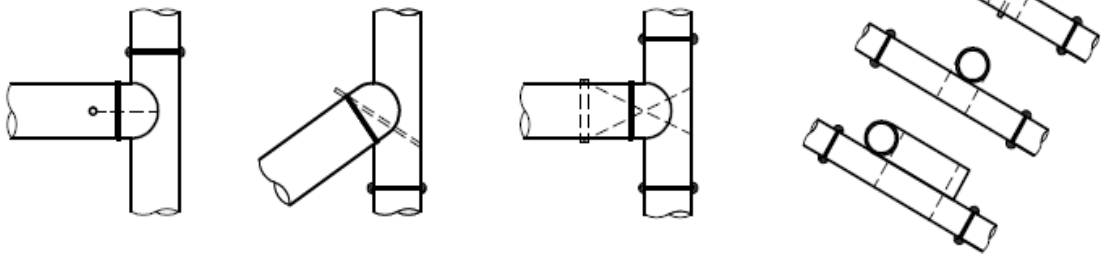
3C BUTT JOINT

FIG. 3 SPLICED JOINT



4A SADDLE JOINT WITH LASHING AND SIDE PLATES (or Seated Joints)

4B BEAM SUPPORTED ON INDEPENDENT SHORT CULM TIED TO THE POST



4C TIES PASSING THROUGH A PRE-DRILLED HOLE OR AROUND PEG

4D PEGGED AND TIED SYSTEM

4E DOWELLED AND TIED SYSTEM

4F PURLIN TIED TO RAFTER

FIG. 4 BEARING JOINTS

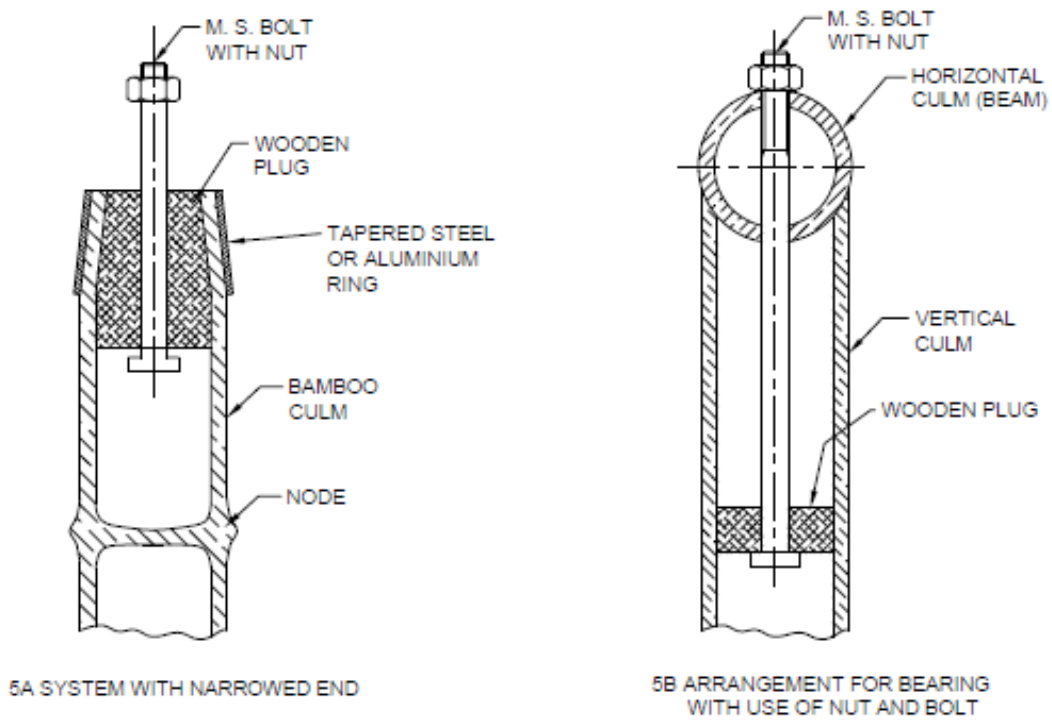


FIG. 5 SOME NUT BOLT JOINERY DETAILS

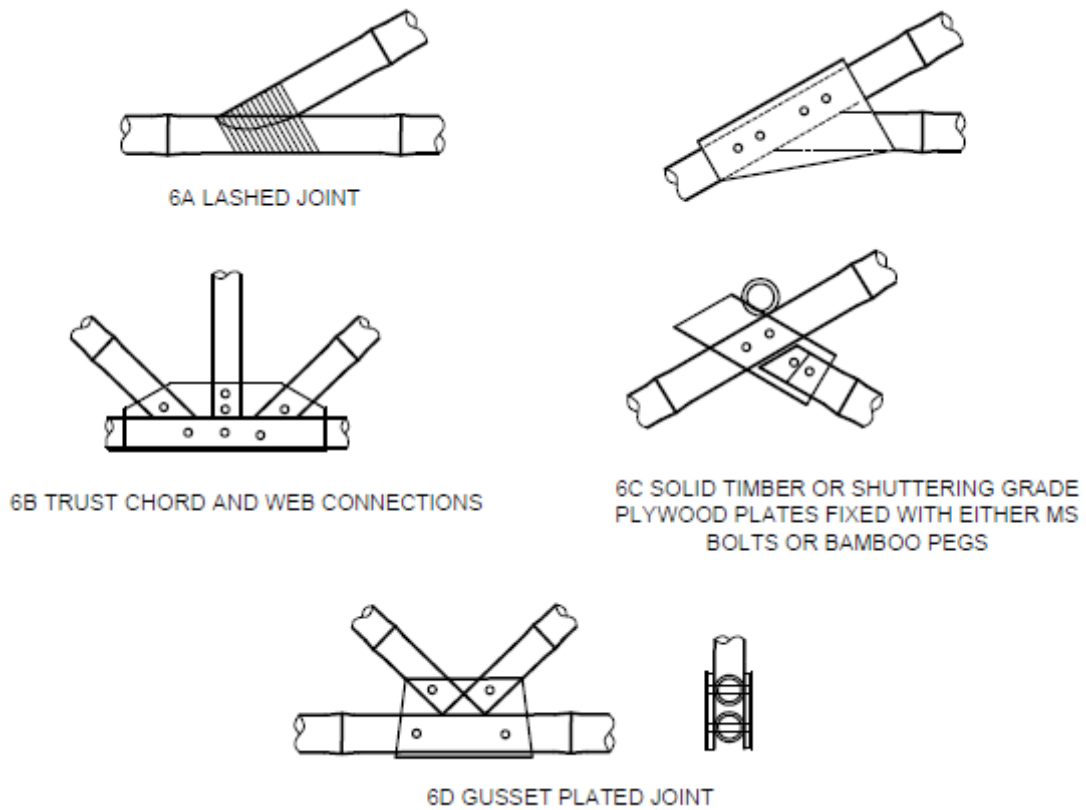
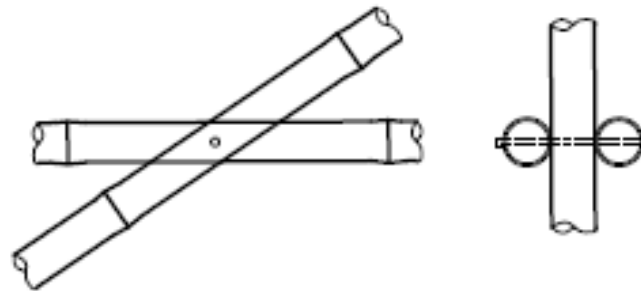
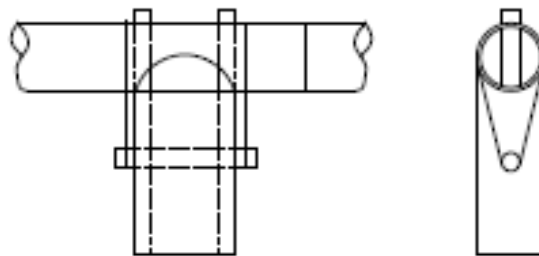


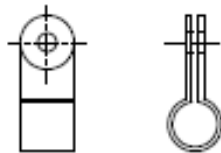
FIG. 6 GUSSET PLATED JOINTS



7A SIMPLY BOLTED CONNECTION WITH MS ARC WASHERS



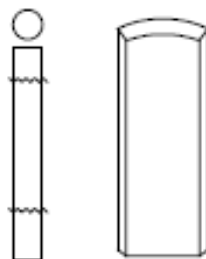
7B HORNED JOINT WITH PIN AND ROPE LASHING



7C STEEL BAND TO BE FITTED AROUND BAMBOO SECTION



7D HARDWOOD DOWEL (SQUARE OR CIRCULAR)



7E SOLID BAMBOO OR SPLIT BAMBOO PINS (WITH SKIN ON)

FIG. 7 OTHER JOINTS AND SECTIONS

7.2 Bamboo Joints

Susceptibility to crushing at the open ends, splitting tendency, variation in diameter, wall thickness and straightness are some of the associated issues which have to be taken care of while designing and detailing the connections with bamboo.

Joints shall be designed to include force transmissions in a required manner, predictable deformations to be within prescribed limits and specific geometry/load direction.

Tests on full scale joints or on components shall be carried out in accordance with the good practice [6-3B(5)] and the accepted standards [6-3B(6)] for nailed jointed timber structures.

7.2.1 Traditional Practices

Such joining methods revolve around lashing or tying by rope or string with or without pegs or dowels. Such joints lack stiffness and have low efficiency but have served the mankind for long in traditional bamboo construction.

7.2.1.1 Lengthening joints (end jointing) (see Fig. 3)

7.2.1.1.1 Lap joint

End of one piece of bamboo is made to lap over that of the other in line and the whole is suitably fastened. It may be full lapping or half lapping. Full section culms are overlapped by at least one internode and tied together in two or three places. Efficiency could be improved by using bamboo or hardwood dowels.

7.2.1.1.2 Butt joints

Culms of similar diameter are butted end to end, inter-connected by means of side plates made of quarter-round culm of slightly large diameter bamboo, for two or more internode lengths. Assembly shall be fixed and tied preferably with dowel pins.

7.2.1.1.3 Sleeves and inserts – Short length of bamboo of appropriate diameter may be used either externally or internally to join two culms together.

7.2.1.1.4 Scarf joints

A scarf joint is formed by cutting a sloping plane 1 in 4 to 1 in 6 on opposite sides from the ends of two similar diameter bamboo culms to be joined. They shall be lapped to form a continuous piece and the assembly suitably fastened by means of lashings or glued.

7.2.1.2 Bearing joints (see Fig. 4)

For members which either bear against the other or cross each other and transfer the loads at an angle other than parallel to the axis, bearing joints are formed.

7.2.1.2.1 Saddle joints

The simplest form consists of a horizontal member supported directly on top of a vertical member. The top of the post may be cut to form a saddle to ensure proper seating of beam for good load transfer. The saddle should be close to a node to reduce risk of splitting.

7.2.1.2.2 Angled joints

When two or more members meet or cross other than at right angles, angled joints are formed.

7.2.2 Improved Practices in Bamboo Jointing

7.2.2.1 Plywood or solid timber gusset plates may be used at joint assemblies of web and chord connection in a truss and fixed with bamboo pins or MS (mild steel) bolts. Hollow cavities of bamboo need to be stuffed with wooden plugs or otherwise by suitable means.

7.2.2.2 Use of wooden inserts to reinforce the ends of the bamboo before forming the joints. Alternatively, steel bands clamps with integral bolt/eye may be fitted around bamboo sections for jointing.

7.2.3 Fixing Methods and Fastening Devices

In case of butt joints the tie-wire may be passed through a pre-drilled hole or around hardwood or bamboo pegs or dowels inserted into preformed holes to act as horns. Pegs are driven from one side, usually at an angle to increase strength and dowels pass right through the member, usually at right angles. Normally 1.60 mm (16 SWG) diameter galvanized iron wire may be used for tight lashing.

NOTE – Drill size needs to be specified in order to avoid possible split/crack in walling of bamboo.

7.2.3.1 Wire bound joints with or without pins

Usually 2.00 mm (14 SWG) diameter galvanized iron wire is tightened around the joints by binding the respective pieces together. At least two holes are drilled in each piece and wire is passed through them for good results. Generally, 10 mm to 12 mm diameter bamboo pins are driven and fastened to culms.

7.2.3.2 Fish plates/Gusset plated joints (see Fig. 6)

At least 25 mm thick hardwood splice plate or 12 mm thick structural grade plywood are used. Solid bamboo pins help in fastening the assembly.

7.2.4 For any complete joint alternative for a given load and geometry, description of all fastening-elements, their sizes and location shall be indicated. Data shall be based on full scale tests.

7.2.5 Tests on full scale joints or on components shall be carried out in a recognized laboratory.

7.2.6 In case of high wind and seismic areas, good construction practices shall be followed taking care of joints, their damping and possible ductility. Bracings in walls shall be taken care of in bamboo structures.

7.2.7 Metal fasteners and other structural joints shall be made inherently corrosion resistant or be protected against corrosion, thereby making the joints more durable.

7.3 Construction Practices

7.3.1 Bamboo being a versatile resource characterized by high strength, low mass and ease of working with simple tools, it is desirable to increasingly make appropriate use of this material. Design of structures using bamboo shall be done in accordance with 6. It shall be ensured that the elements of structure satisfy the appropriate fire resistance requirements as specified in Part 4 ‘Fire and Life Safety’ of the Code, and quality of building materials/components used shall be in accordance with Part 5 ‘Building Materials’ of the Code. For construction using bamboo, some of the important constructional provisions given in **7.3.2** to **7.3.7** shall be followed.

7.3.2 The following sound construction practices shall be taken into account:

- a) Use of air dry bamboo; and ensure that bamboo in building remains air dry; and in case the bamboo has become wet, shall provide it the opportunity to dry again before the it deteriorates due to moisture.
- b) Permeability of walls, floors and roofs made from bamboo, cause internal pressure and can therefore change the net wind-load acting on the roof, wall and floor.
- c) Check whether the workmanship of the labour force is according to the assumptions.

7.3.3 Working Finishing

7.3.3.1 Bamboo can be cut and split easily with very simple hand tools. Immature bamboos are soft, pliable and can be moulded to desired shape. It takes polish and paint well.

7.3.3.2 While it is possible to work with bamboo simply using a machete, a few basic tools such as, machete, hack saw, axe, hatchet, sharpening tools, adze, chisel (20 mm), drill, wood rasps, steel rod, and pliers, will greatly increase the effectiveness of the construction process.

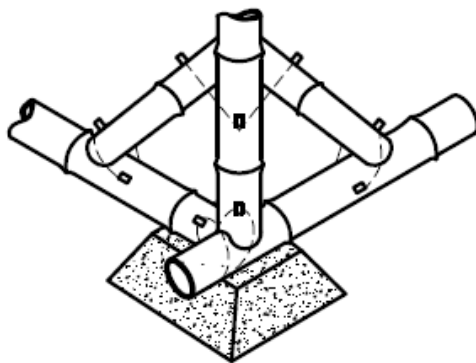
7.3.4 For providing safety to the structure against fire, bamboo may be given fire retardant treatment using following chemicals; a few drops of concentrated HCL shall be added to the solution to dissolve the precipitated salts:

Ammonium phosphate	:	3 parts
Boric acid	:	3 parts
Copper sulphate	:	1 part

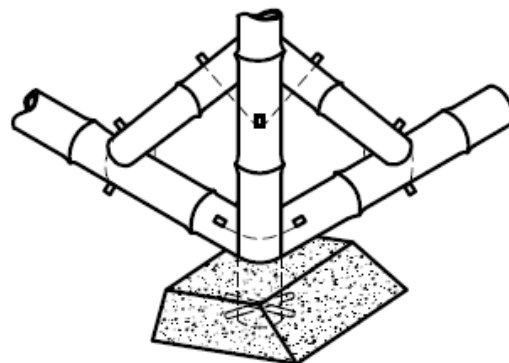
Zinc chloride	:	5 parts
Sodium dichromate	:	3 parts
Water	:	100 parts

7.3.5 Foundations

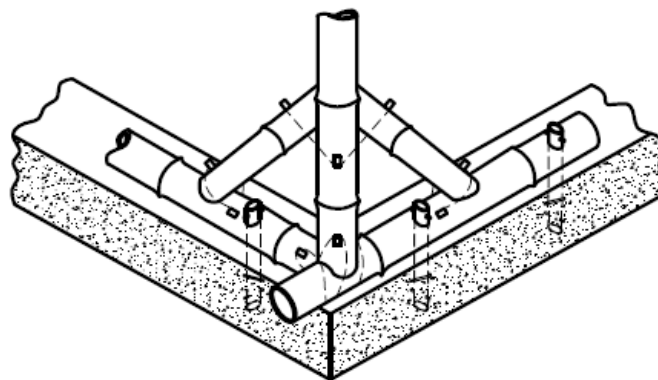
Bamboo in direct contact with ground, bamboo on rock or preformed concrete footing, bamboo incorporated into concrete, may form the foundation structure (see Fig. 8). Also, arrangements with use of metallic strap, C-clamp and bunched bamboo columns embedded in concrete may be used for foundation of bamboo structures (see Fig. 9).



8A BAMBOO ON PREFORMED CONCRETE FOOTINGS

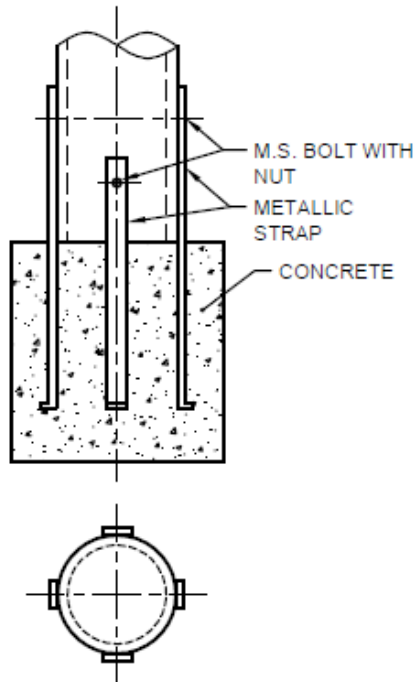


8B BAMBOO INCORPORATED INTO CONCRETE FOOTINGS (SINGLE POST FOOTING)



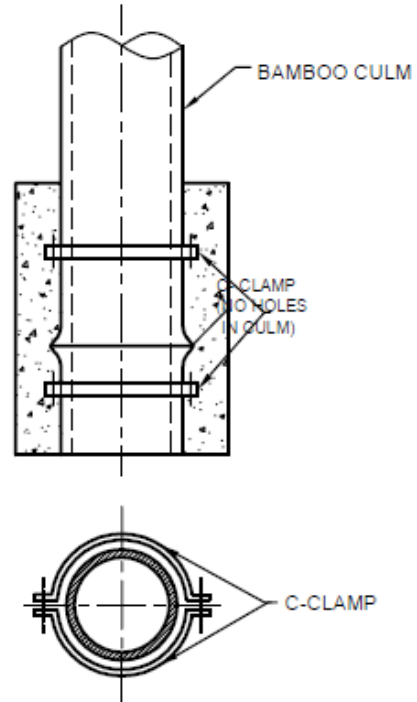
8C BAMBOO OUT OF GROUND CONTACT ON STRIP FOOTINGS OF CONCRETE (LARGE DIAMETER THICK WALLED BAMBOO WITH CLOSELY SPACED NODES TO BE USED)

FIG. 8 BAMBOO FOUNDATIONS

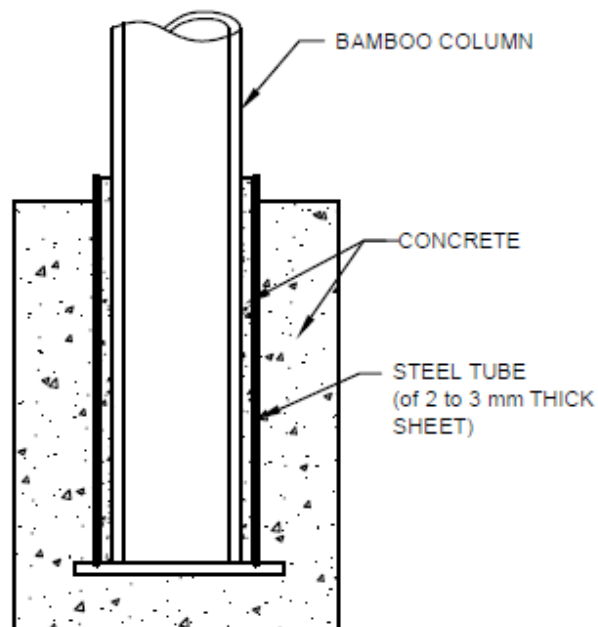


PREFER STAGGERED BOLT HOLES; LOWER PORTION OF BAMBOO-CULM HOT BITUMEN COATED FOR EMBEDMENT IN CONCRETE

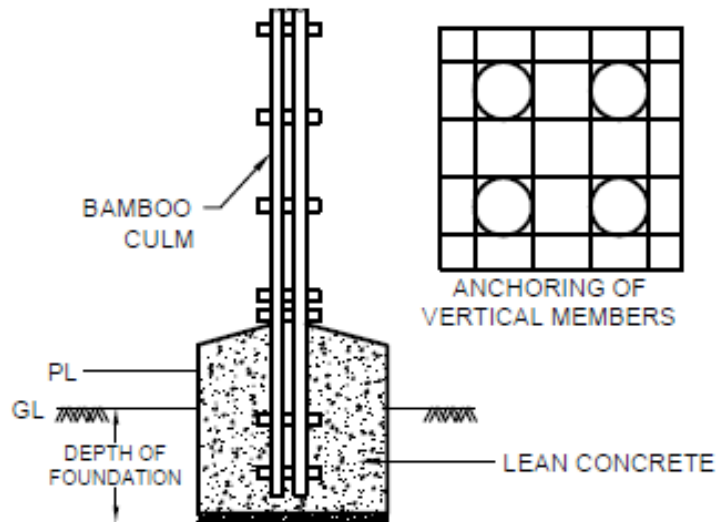
9A USING METALLIC STRAP



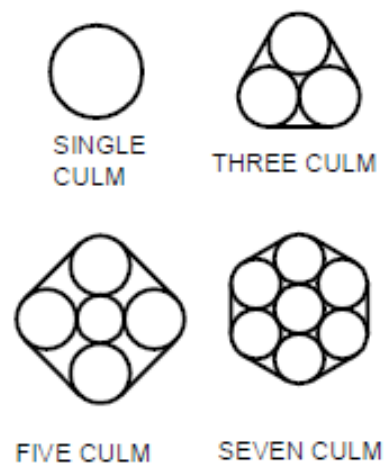
9B USING C-CLAMP



9C USING METAL TUBE



9D BUNCHED BAMBOO COLUMNS
EMBEDDED WITHIN CONCRETE



9E INTEGRATED BAMBOO FOR FORMING
BUNDLE COLUMNS AND THEIR FASTENING

FIG. 9 BAMBOO COLUMN IN CONCRETE

7.3.6 Floors

The floor of bamboo may be at ground level with covering of bamboo matting, etc. In elevated floors, bamboo members become an integral part of structural framework of building. The floor will comprise structural bamboo elements and bamboo decking.

7.3.7 Jointing Techniques

The jointing techniques in construction using bamboo shall be in accordance with 7.2.

8 BAMBOO AS REINFORCEMENT IN CONCRETE

8.1 Due to its fibrous texture, bamboo possesses high tensile strength. This can act as an alternate material for reinforcement in concrete within the limitations in design and construction. The ultimate strength of some of the species of bamboo in direct tension is nearly the same as that of steel at its yield point. On an average it varies from 1 400 to 2 000 kg/cm². The principles adopted for design of concrete structure with steel is also applicable for the concrete member with bamboo. Strength characteristics of steel, concrete and bamboo are indicated in Table 5 and the design data for balanced section in beams/slabs reinforcement is given in Table 6.

**Table 5 Strength Characteristics of Mild Steel, Bamboo and Concrete
(For Reinforcement Purposes)**
(Clause 8.1)

SI No.	Strength Characteristics kgf/cm ²			
		Mild Steel	Bamboo (Green)	Mass Concrete
(1)	(2)	(3)	(4)	(5)
i)	Modulus of elasticity	2.1× 10 ⁶	175 750 to 196 640 (for all locations)	–
ii)	Tensile stress	1 265.5 to 1 400	158, Bending- tension (all locations)	–
iii)	Compressive stress	–	105 (<i>D. strictus</i>)	500
iv)	Bond stress	–	3.5 (green) to 5.6 (dry) reported (likely to increase up to 10)	40-100
v)	Shear stress	–	115-180	50

Table 6 Design Data for Bamboo and Mild Steel Reinforced Cement Concrete for Balanced Section
(Clause 8.1)

Sl No.	Design Parameter	Design Data for Balanced Section M 15 (1:2:4) Bamboo and Mild Steel Reinforced Cement Concrete	
		Mild Steel	Bamboo
(1)	(2)	(3)	(4)
i)	Modular ratio	18	1 to 1.4
ii)	Position of neutral axis from the top	$0.4d$	$0.25d$ to $0.254d$
iii)	Lever arm of the resisting moment (MOR)	$0.87d$	$0.917d$ to $0.915d$
iv)	Constant for MOR (Q)	137	86
	where $Q = \text{Bending moment}/bd^2$, $d = \text{depth or thickness, and}$ $b = \text{width.}$		

8.2 The whole bamboo culms are halved longitudinally and again splitted into four and strips of the size of 20 to 25 mm width and 9 mm thickness are prepared for use as reinforcement. Bamboo strips with triangular lugs (formed at nodes) due to conversion of bamboo into strips improve the bond strength because of the protruding lugs beings gripped firmly in concrete. Strength properties of split bamboo out of a few species are given in Table 7.

8.3 Bamboo has a tendency to absorb water from concrete which results in initial swelling and subsequent shrinkage leading to cracks in concrete. Following processes are thus recommended as mandatory:

- a) Chemical treatment with preference for pressure impregnation (Full cell treatment with warm coal tar creosote is likely to preserve and at the same time act as water repellent).
- b) Treated strips be further given a water repellent treatment with a coating of very hot bitumen 80/100 grade, followed by a liberal coating of coarse sand. Water inhibitor will also help maintain dimensional stability of strips.

Table 7 Strength Properties of Split Bamboo in Green Condition¹⁾
(Clause 8.2)

SI No	Species	Static Bending			Compression Parallel (Without Node) Maximum Crushing Stress	Shear Parallel Maximum Shearing Stress
		Fibre Stress at Elastic Limit	Modulus of Rupture	Modulus of Elasticity		
(1)	(2)	kg/cm ²	kg/cm ²	x10 ³ kg/cm ²	kg/cm ²	kg/cm ²
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	<i>Bambusa pallida</i> ²⁾	378	605	32.5	595	97.7
ii)	<i>B. vulgaris</i>	464	885	52.3	403	94.4
iii)	<i>Dendrocalamus hamiltonii</i>	301	524	37.7	414	77.7
iv)	<i>D. giganteus</i>	472	848	50.7	360	88.5
v)	<i>Oxytenanthera abyssinica</i> ²⁾	450	831	33.6	377	112.0

¹⁾ average of bottom, middle and top portions of culms.

²⁾ average of bottom and middle portions only.

8.4 Techniques in Placing the Reinforcement (see also Fig. 10)

Reinforcement shall be placed in the following manner:

- Laid edge wise in sets of twin strips for main reinforcement.
- Laid flatwise with smooth surface and rough surface alternating as distribution or subsidiary reinforcement (wedge effects increased bond).
- For negative moments, bamboo strips of length equivalent to $\frac{\text{Span}}{6}$ laid flatwise in alternate rows of slab reinforcement.
- For beams and lintels, twin strips are arranged in tiers, placed one above the other depending upon requirement and held in position with the help of vertical strips.
- Split bamboo strip or preferably steel rod be used for diagonal tension to resist shear in beams, etc.
- Bind the reinforcement with the help of galvanized iron binding wire (or nylon thread/bamboo-cane string).

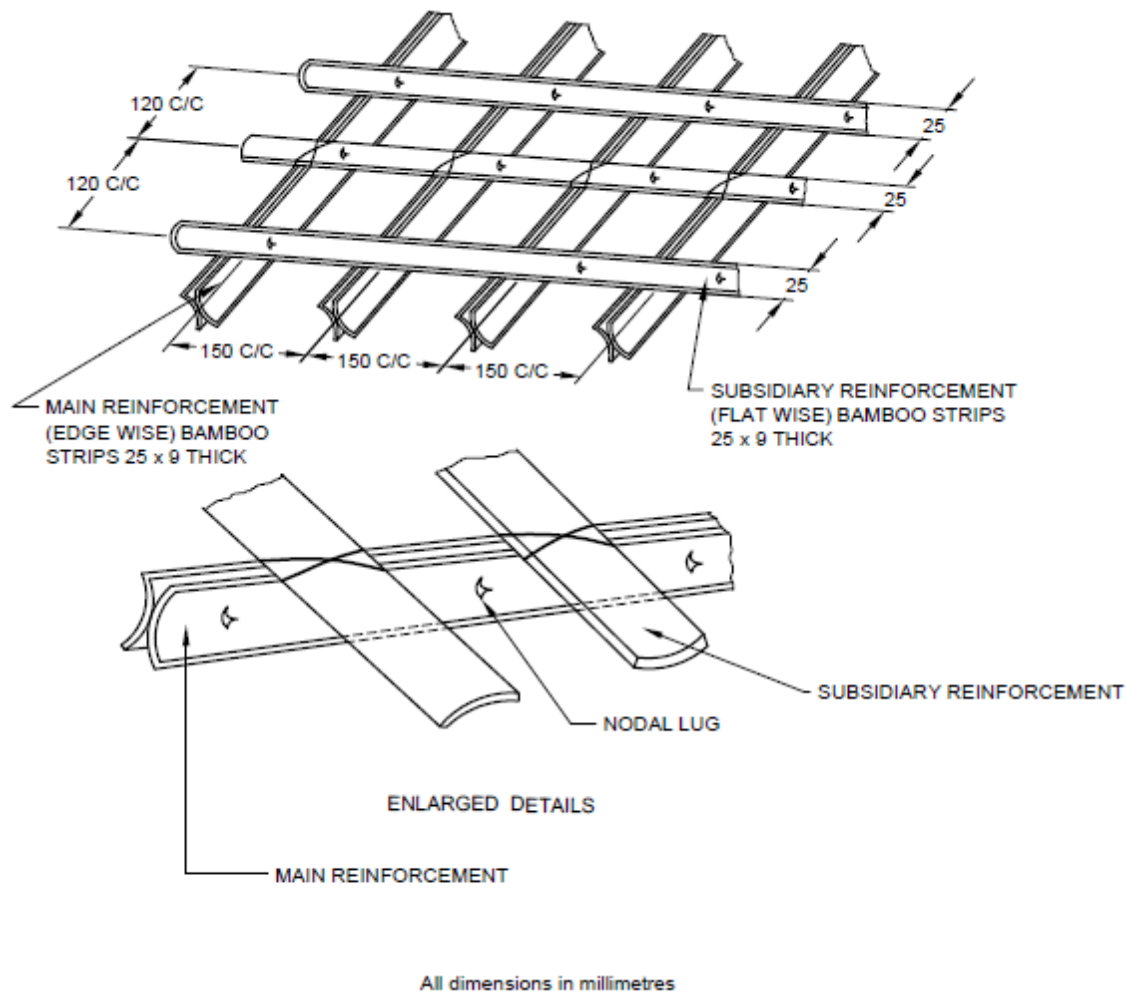


FIG. 10 GENERAL DETAILS OF BAMBOO REINFORCEMENT

9 WALLING, FLOORING, ROOFING, AND IN-FILL PANELS FOR WALL, AND COMMON ROOF COVERING/CLADDING

9.1 Materials

9.1.1 Bamboo Based Panel Products

The common roof covering and in-fill materials shall include bamboo mat board, bamboo mat veneer composite, bamboo mat corrugated sheet, bamboo tiles, plastered bamboo reeds, thatch, corrugated galvanized iron sheeting, asphaltic sheets, plain clay tiles, etc. The respective materials shall conform to the following:

- a) *Bamboo mat board* – These shall conform to the accepted standard [6-3B(7)].
- b) *Bamboo mat veneer composite* – These shall conform to the accepted standard [6-3B(8)].
- c) *Bamboo mat corrugated sheet and bamboo mat ridge cap* – These shall conform to the accepted standard [6-3B(9)].
- d) *Bamboo-jute composite corrugated and semi-corrugated sheets* – These shall conform to the accepted standard [6-3B(10)].

9.1.2 Reconstituted Wood from Deconstructed Bamboo

After lopping, bamboos are cross-cut into small lengths in the round and then split along the axis. The small cross-section strips are then passed between the counter revolving rollers till the material is fully deconstructed. This is then air dried and resin treated and suitably pressed without much disturbing the natural alignment of fibres thus retaining the directional properties of bamboo.

Some typical strength properties of reconstituted wood from deconstructed bamboo are given in Table 8. The reconstituted product from bamboo can be sawn, nailed, moulded, bored, screwed, polished and painted. Thus, it offers a good substitute of solid wood for structural uses.

NOTE — Reconstituted boards/wood from deconstructed bamboo when tested for physical and mechanical properties in accordance with the accepted standards [6-3B(11)] and [6-3B(12)] yielded encouraging results. Gist of mechanical properties of these boards is excellent when compared with *Dendrocalamus strictus* (bamboo), teak and sal.

Table 8 Gist of Mechanical Properties of Reconstituted Wood from Bamboo (*Dendrocalamus strictus*)
(Clause 9.1.2)

SI No.	Board Material			Density gm/cm ³	Modulus of Rupture kgf/cm ²	Tensile Strength Parallel to Grain kgf/cm ²	Compressive Strength Parallel to Grain kgf/cm ²	Izod Impact kgf/cm	Shear Strength kgf/cm ²	Modulus of Elasticity x 10 ³ kgf/cm ²	Screw Holding Power kgf
	Set	Resin Content Percent	Pressure kgf/cm ²								
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
i)	I	6 to 29	56	0.99 to 1.25	1 769 to 2 255	1 049 to 2 024	1 057 to 1 596	343 to 281	202 to 364	278 to 308	398 to 508
In the increasing order of resin percentage.											
ii)	II	9	21 to 28	0.62 to 0.93	1 062 to 1 615	6 99 to 1 210	675 to 1 030	186 to 202	128 to 247	155 to 232	361 to 486
Wood/Bamboo											
iii)	<i>Shorea robusta</i> (at 12 percent, dry moisture content)			0.749	1 249	–	685	124	110	152.8	369
iv)	<i>Tectona grandis</i> (at 12 percent, dry moisture content)			0.596	959	–	532	68	102	119.6	326
v)	<i>Dendrocalamus strictus</i>			0.757	1 310	–	624	–	–	180.3	–

9.1.3 Other Panel Products/Infill Materials

Other panel products/infill materials shall be in accordance with relevant Indian standards. These shall be such that they maintain their integrity and strength in the assigned service class throughout the expected life of the structure.

9.1.4 Adhesives

Adhesive shall maintain their integrity in accordance with the accepted standard [6-3B(13)].

9.2 Structural Usage of Bamboo Based Products

9.2.1 General

Bamboo mat board (BMB) and bamboo mat veneer composite (BMVC) have high in-plane rigidity and hence high racking strength and are more flexible than equivalent plywood. This property of BMB and BMVC can be advantageously used in many engineering applications such as wall panelling, composite beams, composite floor deck and stress skinned panels. Bamboo mat corrugated sheet (BMCS) is water proof and resistant to decay, termites/insects and fire. These sheets may be used as roofing material. Precast bamboo reinforced cement concrete and reconstituted wood from destructured bamboo can also be used in structural applications.

9.2.2 Bamboo Composites

Along with bamboo, bamboo composites such as bamboo mat board, bamboo mat veneer composite, may also be successfully used in combination with timber for making efficient structural components like web because where high shear strength of bamboo mat board and bamboo mat veneer composite can be utilized as web and timber flanges for transmitting tensile and compressive stress. PF, PRF adhesives are commonly used for gluing web and flanges as shown in Fig. 11. Beams can be straight, single tapered, double tapered, haunched, as shown.

Bamboo mat board and bamboo mat veneer composite can also be used for roof and wall sheathing (shear walls) and diaphragms, gussets, arch panels, barrel vaults, etc. It can also be used as skin material in sandwich construction.

Permissible safe working stresses are given in Table 9.

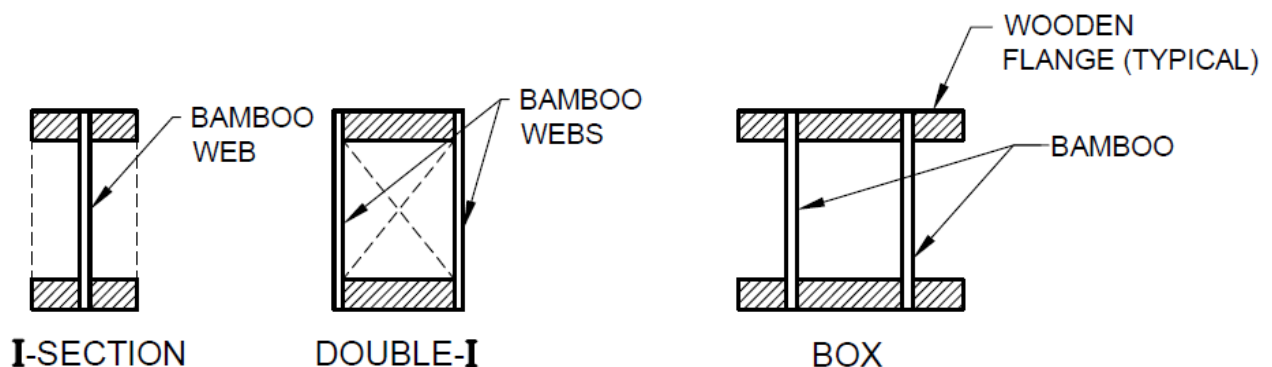


Fig. 11 A TYPICAL CROSS SECTION OF WEB BEAMS

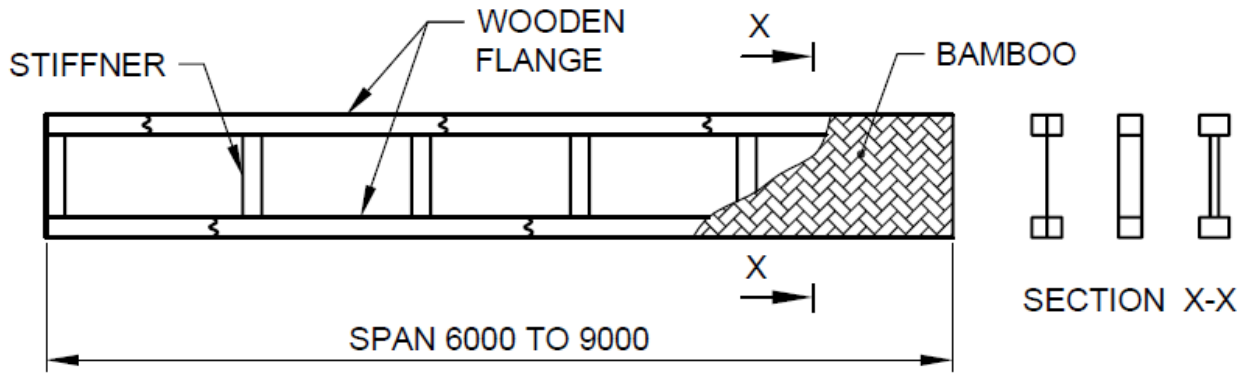


Fig. 11 B STRAIGHT

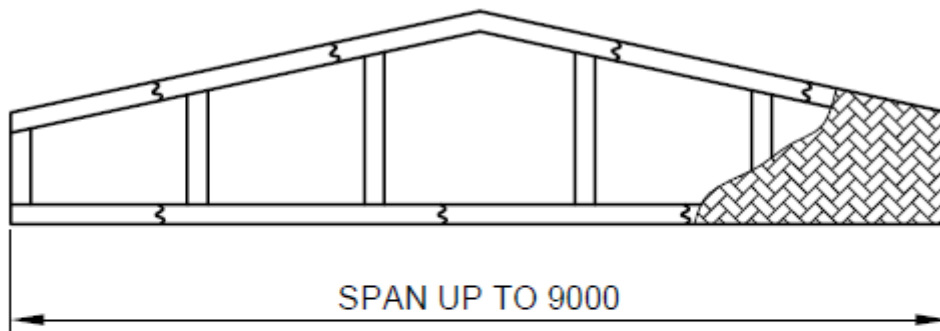


Fig. 11 C DOUBLE TAPERED

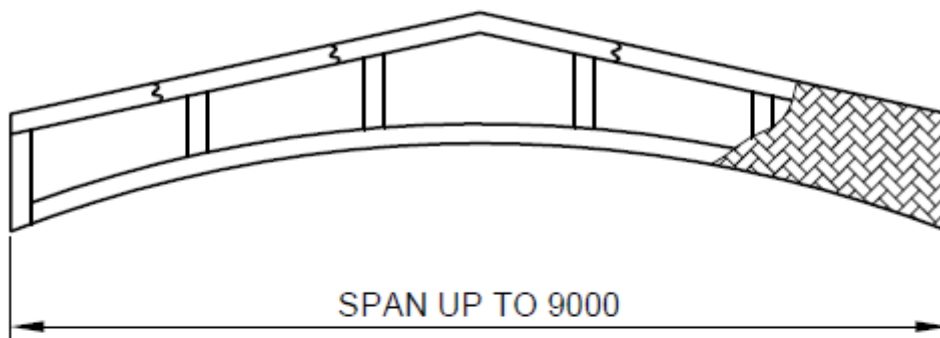


Fig. 11 D HAUNCHED

WEB BEAM CONFIGURATIONS

All dimensions in millimetres

FIG. 11 BAMBOO MAT BOARD WEB BEAMS

Table 9 Permissible Safe Working Stresses for Bamboo Mat Board and Bamboo Mat Veneer Composite
(Clause 9.2.2)

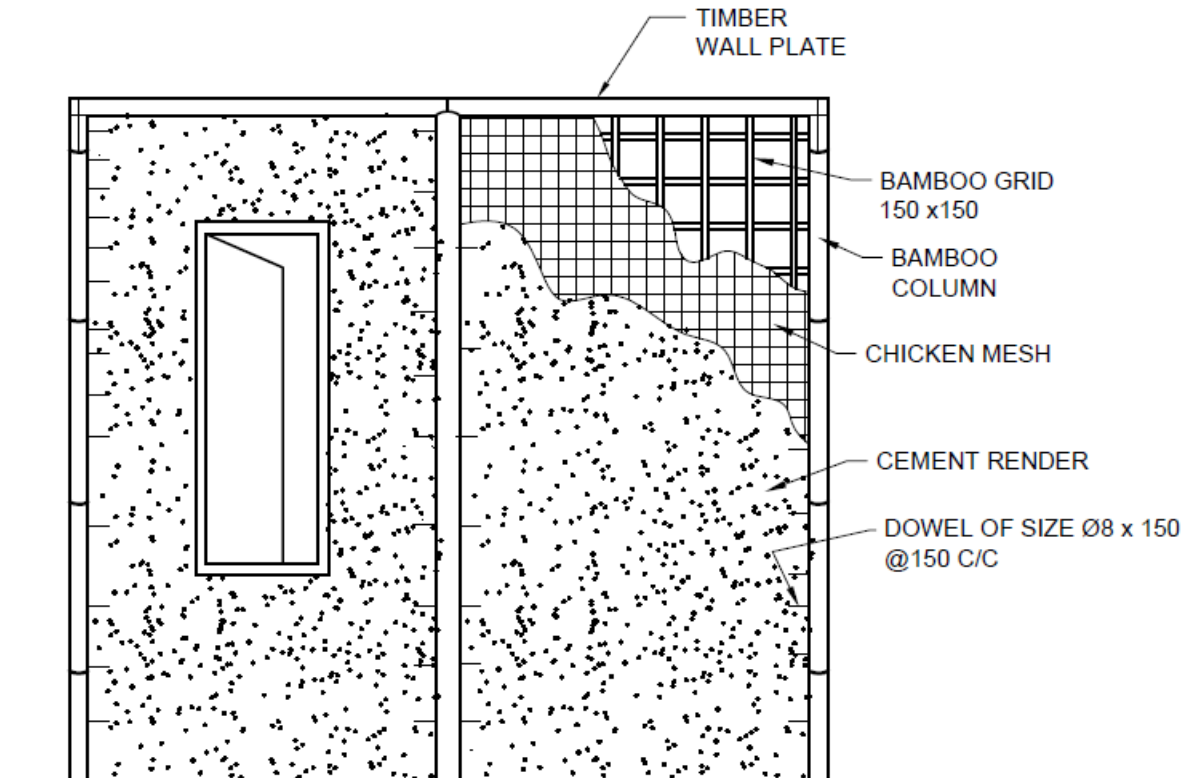
SI No.	Property	Bamboo Mat Board N/mm ²	Bamboo Mat Veneer Composite in Direction	
			Along N/mm ²	Across N/mm ²
(1)	(2)	(3)	(4)	(5)
i)	Tensile strength	8.5	10	10
ii)	Compressive strength	10.80	13	6.5
iii)	Modulus of rupture	19.00	19	10.5
iv)	Modulus of elasticity	3 200	4 600	–
v)	Modulus of rigidity	4 970	1 930	–

9.2.3 Precast Bamboo Reinforced Cement Concrete

Precast bamboo reinforced cement concrete panels of dimensions 600 mm × 300 mm × 40 mm can serve for walling, when laid one above the other in a suitably located wall in low cost construction, etc. Bamboo strips 20 mm × 8 mm splits duly processed should be placed at 90 mm centre-to-centre both ways in form work and concreted.

9.2.4 Wall Infill Panel

The wall is considered non-load bearing although connected to the framing elements. It comprises a grid of split bamboo (19 mm x 9 mm) tied together with MS binding wire to form a 150 mm x 150 mm grid. The grid is tied to steel dowels passing through the columns. Chicken wire mesh is fixed on the outside face of the grid. Cement mortar (in the proportion 1 : 3) is applied to both sides of the grid to a finished thickness of about 50 mm. Fly ash can be utilized as part replacement of cement up to 35 percent by mass. This is similar to conventional ferrocement-type construction. The same principle is extended to the construction of gable walls. Alternatively, gable walls may be formed with bamboo mat board. Figure 12 shows the typical cross section of the infill wall panel.

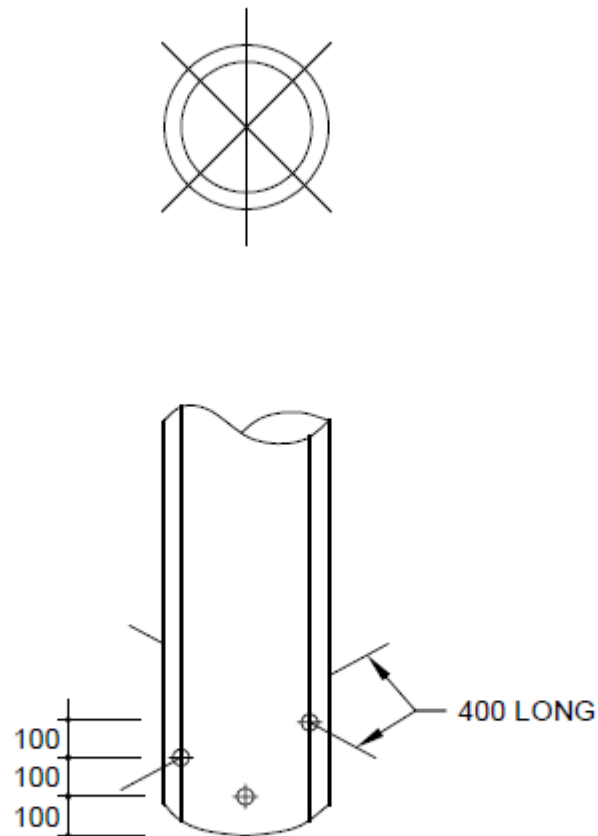


All dimensions in millimetres

FIG. 12 BAMBOO STRUCTURAL WALLING SYSTEM

9.2.4.1 Foundation detail

The columns pierced by steel dowels at 150 mm centre-to-centre provide connection to the bamboo grid infill. Fix 8 mm diameter MS rod of 400 mm length at 100 mm from one end of the column which has undergone treatment. For anchoring, fix two more MS rods of same diameter at 100 mm centre-to-centre starting from the first hole (see Fig. 13). Pour the concrete by giving temporary support. Foundation is limited to individual footings of size 400 mm x 400 mm x 600 mm deep for each bamboo column placed at 1 200 mm apart and two coarse concrete blocks or stone or other locally available material for infill wall foundation.



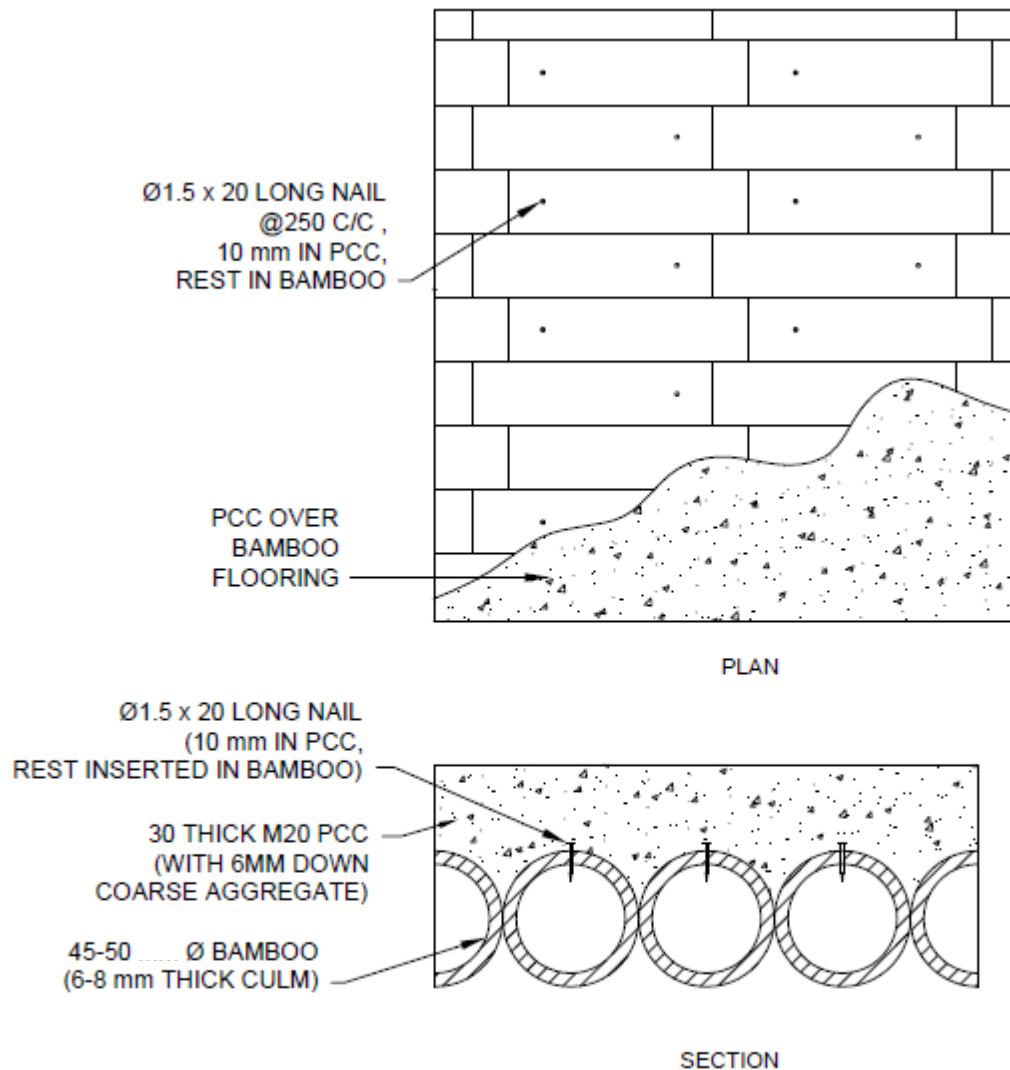
All dimensions in millimetres

FIG. 13 DETAILS OF BOTTOM OF BAMBOO COLUMN FOR ANCHORING IN CONCRETE FOR FOUNDATION

9.2.5 Bamboo Concrete Flooring Using Round Bamboo

Technology of such a flooring (for situations needing raised flooring) is based on the method of rigidly fixing round bamboo, where 30 mm thick M20 grade PCC (with 6 mm down coarse aggregate) is placed over 6 to 8 mm thick culm, that are arranged side by side to form bamboo flooring.

The rigid fixing is achieved by using shear connectors in the form of 1.5 mm dia. 20 mm long MS nails partially inserted into the bamboo flooring and balance length with the heads of the nails embedded in the PCC layer, holding the two components together. The sectional properties of the combination are calculated based on the concept of flitched beams for design (see Fig. 14).



All dimensions in millimetres

FIG. 14 DETAIL OF A TYPICAL BAMBOO CONCRETE FLOORING

9.2.6 Bamboo Concrete Walling Using Flat Bamboo

Loads on walls and roof do not generally justify use of round bamboo as such. So, flat or split bamboo is preferred for use in these cases. The flat bamboo works like a wire-net used conventionally to hold cement plaster in critical applications. Partial plastering is done during the first day ensuring entry of plastering material in the gaps of flat bamboo. This provides the base for cement plastering or PCC laying next day. About 5 mm gap is essential for entry of plastering material of sufficient sectional area to sustain shear force. The gaps are generated by inserting a small wedge of bamboo strip and pulling it out after a part of the gap is filled by plaster. Such gaps have to be discontinuous, to retain the character of a wire-net. About 25 percent width of the flat bamboo is assumed to be gaps, part of it is the organized gap of 5 mm width as described, at an interval of about 50 mm width, to sustain shear force and the balance

gap remains to be natural to flat bamboo. Minimum thickness of the flat bamboo is assumed to be 6 mm. Bamboo with thicker wall would be stronger.

Expected strength (using *Bambusa balcooa*) may be considered as follows:

- a) Walling of 6 mm bamboo with 18 mm thick cement sand plaster in 1:3 would be able to withstand wind pressure of 112 kgf/m² if used as wall, either supported continuously 1.5 m apart, or supported simply 1.25 m apart.
- b) As a roof, the wind suction load would be partly compensated by the dead load of the roof. The imposed load of a mason sitting at the centre of span needs to be considered. This load can be accommodated by use of 18 mm M 20 PCC with 6 mm flat bamboo, supported 1.0 m apart; neatly finished.

The engineered houses for application of the above bamboo concrete walling are designed with stiffeners and diagonals in all the three planes, keeping the deformation of walls along plane of walls almost nil and deflection of columns across the plane of wall at a minimum.

10 LIFE CYCLE ASSESSMENT OF BAMBOO FOR USE IN BUILDINGS

Bamboo used in building elements and structures shall undergo a comprehensive life cycle assessment (LCA) to evaluate its environmental impact. The LCA shall assess the environmental effects of bamboo throughout its entire lifecycle, from raw material extraction to disposal or recycling.

The assessment shall cover the following stages:

- a) *Production and Construction* – The energy and resources used for raw material extraction, transportation, and manufacturing of bamboo products, as well as construction-related activities.
- b) *Use Stage* – The environmental impacts during the building's lifespan, including maintenance, repair, and replacement of bamboo components.
- c) *End-of-Life* – The processes related to demolition, disposal, and recycling or reuse of bamboo materials.
- d) *Externalized Impacts Beyond System Boundaries* – The incidental effects of recycling, reuse, and recovery of water, energy, or materials beyond the system boundary.

10.1 Environmental Impact Categories

The LCA shall account for the following environmental impact categories, which may be assessed using appropriate LCA tools:

- a) Global warming potential
- b) Acidification potential
- c) Eutrophication potential
- d) Ozone depletion potential

e) Smog formation potential

10.2 Reporting

The results of the LCA shall be documented, including all assumptions, methodologies, and conclusions. Reports should be prepared in accordance with relevant standards, and may be used to guide sustainable building practices and decision-making in bamboo construction.

This clause shall be applicable to all bamboo building structures, ensuring environmental responsibility and promoting sustainable development.

11 BAMBOO SPECIES SUITABLE FOR CONSTRUCTION

Bamboo is known for its strength, flexibility, and eco-friendliness, making it an excellent construction material, especially in areas where it grows abundantly. However, not all bamboo species are equally suitable for structural purposes. Several factors, such as height, diameter, wall thickness, and internode length, play a significant role in determining the usability of bamboo for different construction needs. Table 10 showcases the most common bamboo species used for construction in India, along with their characteristics and distribution.

Table 10 Most Common Bamboo Species Used for Construction in India
(Clause 11)

Sl. No.	Bamboo Species	Height m	Diameter mm	Internode Length mm	Wall Thickness	Distribution
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	<i>Bambusa bambos</i> (Spiny Bamboo)	15-30	Up to 150	200-400	Thick-walled	E. Asia - Southern China, Indian Subcontinent, Myanmar, Thailand, Laos, Cambodia, Vietnam
ii)	<i>Dendrocalamus strictus</i> (Male Bamboo)	8-16	25-80	300-450	Thick-walled, often solid	Andaman Is., Assam, Bangladesh, China, East Himalayas, India, Myanmar, Nepal, Pakistan, Sri Lanka, Tibet, Vietnam
iii)	<i>Bambusa balcooa</i>	12-22	60-150	200-400	Thick-walled, up to 25 mm	Bangladesh, India (Assam, Bihar, Meghalaya, Nagaland, Tripura, West Bengal), Laos, Myanmar, Nepal, Vietnam

Sl. No.	Bamboo Species	Height m	Diameter mm	Internode Length mm	Wall Thickness	Distribution
(1)	(2)	(3)	(4)	(5)	(6)	(7)
iv)	<i>Bambusa tulda</i>	6-20	50-100	400-600	10-20 mm	Bangladesh, Bhutan, China, India, Laos, Myanmar, Nepal, Thailand, Vietnam
v)	<i>Dendrocalamus giganteus</i>	20-30	20-30	350-400	Thick-walled	India (Arunachal Pradesh, Assam, Karnataka, Maharashtra, Meghalaya, Mizoram, Nagaland, Uttarakhand, West Bengal), China, Myanmar, Indonesia, Nepal, Sri Lanka
vi)	<i>Dendrocalamus stocksii</i>	6-18	25-120	200-300	Thick-walled	South and Southeast Asia: India, Nepal, Bangladesh, Myanmar, Thailand
vii)	<i>Melocanna baccifera/Bambusoides</i>	10-20	50-90	300-600	Thick-walled	India (Assam, Karnataka, Maharashtra, Manipur, Meghalaya, Mizoram, Sikkim, Tripura, West Bengal), Bangladesh, China, Myanmar, Nepal
viii)	<i>Bambusa nutans</i>	6-15	50-100	350-450	Thick-walled	India (Orissa, West Bengal, Arunachal Pradesh, Assam, Bihar, Himachal Pradesh, Madhya Pradesh, Sikkim, Tripura, Uttar Pradesh, Uttarakhand), Bangladesh, Thailand

ANNEX A
(Foreword)

**SOURCE AND LOCAL NAMES OF SOME OF
THE SPECIES OF BAMBOO**

SI No. (1)	Species (2)	Source/Local Names (3)
i)	<i>Bambusa auriculata</i>	Assam, Bangladesh, Myanmar; introduced in Calcutta Botanical Garden.
ii)	<i>B. balcooa</i>	Asm- Baluka; Ben - Balku bans; Duars – Bora bans; Garo – Wamnah, beru; Tripura – Barak.
iii)	<i>B. bambos</i> (Syn. <i>B. arundinacea</i>)	Asm – Kotoba; Ben – Baroowa, behor, ketuas, ketwa; Manip – Saneibi; Mah – Katang bamboo, oowga; Oriya – Daba, katuig; Tel – Mulkasveduru, Mulluvedurn; English – Spiny bamboo.
iv)	<i>B. burmanica</i>	Asm – Thaikawa.
v)	<i>B. multiplex</i> <i>Syn. B. glanescens</i> (Syn. <i>B. nana</i>)	Sans – keu-fa; Burmese – Pa-lau-pinan-wa; Malay – Bamboo tjeenah; China - Bamboo hower tjeenah.
vi)	<i>B. nutans</i>	Asm – Deobans, jotia-makal; Asm – Bidhuli, mukial; Ben – Makia; Bhutia – Jiu; Hin – Malabans; Kangra – Nal; Khasi - Seringjai; Kuki – Wa malang; Lepcha – Malubans, mahlu, mallo; Oriya – Badia bansa; Sylhet (Bangladesh) – Peechli; Tripura – Kali.

SI No. (1)	Species (2)	Source/Local Names (3)
vii)	<i>B. pallida</i>	Asm – Bijli, jowa, makal, walkthai; Cachar – Bakhal, burwal; Khasi – Seskien, skhen, ineng, usker; Lepcha – Pashipo, pshi, pushee; Mikir – Loto; Naga – Tesero, watoi; Tripura – Makal.
viii)	<i>B. polymorpha</i>	Asm – Jama betwa, betwa; Ben – Batua, jaibarouwa, jama; Burma – Kyathaung-wa; MP-Korku – Narangi bhas; Tripura – Basi.
ix)	<i>B. tulda</i>	Asm – Wamunna, wagi, nal-bans; Ben – Tulda, jowa; Duars – Karanti, matela; Garo – Watti; Hin – Peka; Kamrup – Bijuli, jati, joo, ghora; Tripura – Miringa.
x)	<i>B. vulgaris</i>	Ben and Manipuri – Bakal; Oriya – Sunarkania bans.
xi)	<i>B. wamin</i> Syn. <i>B. ventricosa</i> (Syn. <i>B. vulgaris</i> var. <i>wamin</i>)	Common name – Pitcher bamboo.
xii)	<i>Cephalostachyum pergracile</i>	MP – Bhalan bans; Manip – Wootang; Naga – Latang; Oriya – Darrgi.
xiii)	<i>Dendrocalamus giganteous</i>	English – Giant Bamboo; Asm – Worra; Manip – Maroobeb.
xiv)	<i>D. hamiltonii</i>	Nep – Tamo; Asm – Kokwa; Tripura – Pecha.
xv)	<i>D. Longispathus</i>	Tripura – Rupai.
xvi)	<i>D. membranaceus</i>	Native of Myanmar; introduced in Kerala.

SI No. (1)	Species (2)	Source/Local Names (3)
xvii)	<i>D. strictus</i>	English – Male bamboo; Ben – Karail; Guj – Nakur bans; Kan – Kiri bidiru; Mah – Male bamboo, nanvel; Oriya – Salia; Tam – Kalmungil; Tel – Sadanapa vedur; Tripura – Lathi bans; Hin – Bans kaban, Nav bans;
xviii)	<i>Melocanna baccifera</i>	Asm – Tarai; Ben – Muli; Cachar – Wati; Garo – Watrai; Manip – Moubi; Mikir – Artem; Naga – Turiah.
xix)	<i>Oxytenanthera abyssinicia</i>	Native of tropical Africa; cultivated at FRI, Dehradun.
xx)	<i>Thyrsostachys oliveri</i>	Native of Myanmar; Planted in Haldwani (Uttaranchal), Arunachal Pradesh, Kerala and TamilNadu.

NOTES

- 1 The following abbreviations have been used in the above table:

Asm	Assam
Ben	Bengali
Guj	Gujarati
Hin	Hindi
Kan	Kannada
Mah	Maharashtra
Manip	Manipur
M.P.	Madhya Pradesh
Nep	Nepali
Sans	Sanskrit
Tam	Tamil
Tel	Telugu

- 2 The above table does not provide an exhaustive list. It only attempts to enlist some of the information readily available in regard to species of bamboo from India and some of the neighbouring countries, and some connected information.

ANNEX B (Foreword)

RECOMMENDATIONS FOR BAMBOO STRUCTURES IN HIGH WIND/CYCLONE PRONE AREAS

B-1 Given below are some recommendations for bamboo structures in high wind/cyclone prone areas, which are based on rapid visual screening (RVS) of the damages of past events:

- a) Prefer a square plan of the building symmetrical to the arrangement of partitions and openings for balanced distribution of forces within the structure. Window positioning be planned in such a way that wind entering through window could pass through similar opening on opposite wall in order to reduce built-up pressure, and incorporate ridge vents.
- b) A hip-shaped, pyramidal or a conical roofing be preferred to gable end or mono-pitch ones for least wind resistance.
- c) Wide mono-pitched *verandas* abutting the entrance to residence should be structurally separated from the main building.
- d) Roof overhangs be limited to 450 mm as they contribute to higher negative suction. Large overhangs should be properly tied back to wall frame-work.
- e) Roof structure shall be properly secured with vertical load-bearing members (wooden or bamboo columns, brick piers or walling) for eliminating the chances of being blown away from the building. A continuous beam connecting all the columns would increase the framing action.
- f) Roof cladding (G.I. sheets, clay tiles or thatch) be properly connected with holding down U-bolts, or sturdy anchorages to ensure safety. Thatch roof be tied by nylon ropes in diagonal pattern.
- g) Sufficient depth for anchorage be provided; columns be embedded in pits within the foundation and secured by poured concrete. Wetting of column base be checked by raising it from the floor level.
- h) Highest importance be given to strengthening the junctions between structural elements at different levels, that is, foundation, eaves and roof. Walls be linked together suitably by a continued collar beam at floor, sill, lintel and roof level.
- j) Fastening any two mutually perpendicular load bearing members should be done in accordance with good practice of spacing the connecting bolts with reference to loads direction and the centre of stiffness. This will increase the moment-resisting capacity of the joint and prevent hinge formation. A minimum of two bolts be provided to prevent rotation of members at a joint.

LIST OF STANDARDS

The following list records those standards which are acceptable as 'good practice' and 'accepted standards' in the fulfillment of the requirements of this Code. The latest version of the standard shall be adopted at the time of enforcement of the Code. The standards listed may be used by the Authority for conformance with the requirements of the referred clauses in the Code.

In the following list, the number appearing in the first column within parenthesis indicates the number of the reference in this Part/Section.

<i>IS No.</i>	<i>Title</i>
(1) 9096 : 2006	Code of practice for preservation of bamboo for structural purposes (<i>first revision</i>)
(2) 6874 : 2008	Method of tests for bamboo (<i>first revision</i>)
(3) 1902 : 2006	Code of practice for preservation of bamboo and cane for non-structural purposes (<i>second revision</i>)
(4) 8242 : 1976	Method of tests for split bamboo
(5) 2366 : 1983	Code of practice for nail-jointed timber construction (<i>first revision</i>)
(6) 4924	Method of test for nail-jointed timber trusses
(Part 1) : 1968	Destructive test
(Part 2) : 1968	Proof test
(7) 13958 : 1994	Specification for bamboo mat board for general purposes
(8) 14588 : 1999	Specification for bamboo mat veneer composite for general purposes
(9) 15476 : 2004	Specification for bamboo mat corrugated sheets
(10) 15972 : 2012	Specification for bamboo-jute composite corrugated and semi-corrugated sheets
(11) 1734 (Parts 1 to 20) : 1983	Methods of test for plywood (<i>second revision</i>)
(12) 1708 (Parts 1 to 18) : 1986	Methods of testing of small clear specimens of timber (<i>second revision</i>)
(13) 848 : 2006	Specification for synthetic resin adhesives for plywood (phenolic and aminoplastic) (<i>second revision</i>)
