भारतीय मानक ब्यूरो
BUREAU OF INDIAN STANDARDS

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WIDE CIRCULATION DRAFT

Ref	Date
CED 13/T-103	16 November 2009

Technical Committee: **Building Construction Practices Including Painting, Varnishing and Allied Finishes Sectional Committee, CED 13**

ADDRESSED TO:

1. **All Members of Civil Engineering Division Council, CEDC**
2. **All Members of CED 13**
3. **All other interests**

Dear Sir,

Please find enclosed the following document:

Doc. No.	Title
CED 13(7702)	**Structural Design using Bamboo - Code of Practice**

Kindly examine the enclosed 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 a National Standard.

Last date for comments: **15 January 2010**

Comments if any may please be made in the format as attached and mailed to the undersigned at the above address. You are requested to send your comments preferably through e-mail to **sak@bis.org.in**.

In case no comments are received or comments received are of editorial in nature, you may kindly permit us to presume your approval for the above document as finalized. However, in case of comments of technical 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 has also been hosted on BIS website **www.bis.org.in**.

Thanking you,

Yours faithfully,

(A.K. Saini)
Sc `F' & Head (Civil Engg)
Fax: 011 23235529

Encl: as above

FORMAT FOR SENDING COMMENTS ON BIS DOCUMENT

[Please use A4 size sheet of paper only and type within fields indicated. Information in column (3) should include reasons for comments, technical references and suggestions for modified wording of the clause when the existing text is found not acceptable. **Comments through e-mail (sak@bis.org.in) shall be appreciated**.]

Name of the Commentator/ Organization: _____

BIS Document No.:__CED 13(7702)WC____
Title:___*Draft* Indian Standard STRUCTURAL DESIGN USING BAMBOO – CODE OF PRACTICE____

BIS Letter Reference No._____CED 13/T-103_____**Dated**___16 November 2009___

Clause/ Table No.	**Comments/ Modified Wordings**	**Justification of Proposed Change**
(1)	**(2)**	**(3)**

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DRAFT FOR COMMENTS ONLY
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Draft **Indian Standard**

STRUCTURAL DESIGN USING BAMBOO – CODE OF PRACTICE

Building Construction Practices Including Painting, Varnishing and Allied Finishes Sectional Committee, CED 13

Last Date for Receipt of Comments is 15 January 2010

FOREWORD

(*Formal clause will be added later*)

Bamboo is a versatile resource possessing high strength-to-weight ratio and cost ratio and offers considerable ease in working with simpler tools. Resilience coupled with light weight makes bamboo an ideal material for housing in disaster-prone/earthquake prone areas. 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. A need is now felt for design and construction code for bamboo to cater to a number of social and trade advantages, engineering recognition and the improved status. Research Institutes of repute across the country have been engaged in bamboo research in the country to establish its silviculture, botanical, entomological and pathological aspects besides creating a utilization base.

The bamboo culm has a tubular structure consisting of nodes and inter-nodes. In the internodes the cells are axially oriented while the nodes provide the transverse inter connections. This disposition of the nodes and the wall thickness are significant in imparting mechanical strength to bamboo. In a circular cross-section, bamboo is generally hollow and for structural purposes this form is quite effective and advantageous.

Efforts have been made to update the information as given in the 'National Building Code – 2005', SP 7 : 2005 (Part 6, Section 3B) for structural designing with bamboo. Now it is considered appropriate to formulate a separate standard on the design and construction using bamboo. The information contained in this standard is systematized largely based on the R&D carried out at Forest Research Institute, Dehradun, Indian Plywood Industries Research and Training Institute, Bangalore the technical literature by the International Network for Bamboo and Rattan (INBAR) and national and other international standards. For specific technical details, reference may be made to them. Reference was also made from ISO 22156:2004 'Bamboo-structural design'.

For the purpose of deciding whether a particular requirement of this standard 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 2:1960 `Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

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1 SCOPE

1.1 This standard covers the general principles involved in the design of structural bamboo in buildings with regard to mechanical resistance and durability of structures. It covers minimum strength data, dimensional stability, grading requirements and traditional bamboo joints for quality assurance. Work on site, fabrication of components off-site and their erection on site is 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 The following aspects are not covered in this standard:

a) Bamboo foundations
b) Limit state design and performance of structures
c) Scientific designing of bamboo joints and their fastenings
d) Bamboo reinforced cement concrete/mud structures

2 REFERENCES

The Indian standards listed in Annex A contain provision which through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated therein.

3 TERMINOLOGY

3.1 For the purpose of this standard the following definitions shall apply.

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

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

3.1.3 *Cross Wall* – A wall at the node closing the whole inside circumference and completely separating the hollow cavity below from that above (Syn. Diaphragm, i.e. horizontal partition in a standing culm). (See also **3.1.18** & **3.1.28**)

3.1.4 *Sliver* – Thin strips of bamboo processed from bamboo culm.

3.1.5 *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.

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

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

3.1.8 *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.

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

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

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

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

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

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

3.1.15 *Curvature* – The deviation from the straightness of the culm.

3.1.16 *Delamination* – Separation of mats through failure of glue.

3.1.17 *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.

3.1.18 *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.

3.1.19 *Full Culm* – The naturally available circular section/shape.

3.1.20 *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.

3.1.21 *Inner Diameter* – Diameter of internal cavity of a hollow piece of bamboo.

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

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

3.1.24 *Joist* – A beam directly supporting floor, ceiling or roof of a structure.

3.1.25 *Length of Internode* – Distance between adjacent nodes.

3.1.26 *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.

3.1.27 *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.

3.1.28 *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.

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

3.1.30 *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.

3.1.31 *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.

3.1.32 *Principal Rafter* – A roof member which supports purlins.

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

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

3.1.35 *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.

3.1.36 *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).

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

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

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

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

3.1.41 *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.

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

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

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

3.1.45 *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.

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

4 SYMBOLS

4.1 For the purpose of this code, 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), mm^2 $= \frac{\pi}{4}(D^2 - d^2)$
D	=	Outer diameter, mm
d	=	Inner diameter, mm
E	=	Modulus of Elasticity 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), mm^4 $= \frac{\pi}{64}(D^4 - d^4)$
ℓ	=	Unsupported length of column
m	=	Moisture content, percent
r	=	Radius of gyration $= \sqrt{(I/A)}$
R	=	Modulus of Rupture, N/mm^2
w	=	Wall thickness, mm
Z	=	Section modulus, mm^3
δ	=	Deflection or deformation, mm.

5 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.

5.1 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. 16 species of bamboo are recommended for structural usages in round form. Some physical and mechanical properties of the same are given in **Table 1** both for air-dry conditions and green conditions.

5.1.1 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.

5.1.2 Bamboo shall be properly treated in accordance with IS 9096.

5.1.3 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.

5.1.4 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.

5.2 Grouping

5.2.1 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 fiber 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 corresponding to the spread of properties in structural timber as given below:

	Modulus of Rupture (R) N/mm^2	**Modulus of Elasticity (*E*) in Bending** 10^3 N/mm^2	**Maximum Compressive Strength ($f_{c,\,max}$)** N/mm^2
Group A	$R > 70$	$E > 9$	$MCS > 35$
Group B	$70 \geq R > 50$	$9 \geq E > 6$	$35 > MCS > 30$
Group C	$50 \geq R > 30$	$6 \geq E > 3$	$30 > MCS > 25$

5.2.2 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.

5.2.3 Species of bamboo other than those listed in the **Table 1** may be used, provided their strength characteristics are determined and found in accordance with **5.2**.

Table 1 Physical and Mechanical Properties of Indian Bamboos (in Round Form)
(*Clause* 5.1 & 5.2.3)

Sl No.	Species	Properties							
		In Green Condition				In Air Dry Conditions			
		Density Kg/m^3	Modulus of Rupture N/mm^2	Modulus of Elasticity $x\ 10^3\ N/mm^2$	Maximum Compressive Strength N/mm^2	Density Kg/m^3	Modulus of Rupture N/mm^2	Modulus of Elasticity $10^3\ N/mm^2$	Maximum Compressive Strength N/mm^2
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1.	*Bambusa auriculata*	594	65.1	15.01	36.7	670	89.1	21.41	54.3
2.	*B.balcooa*	783	65.4	7.31	46.7	-	-	-	-
3.	*B.bambos (Syn.B.arundinacea)*	559	58.3	5.95	35.3	663	80.1	8.96	53.4
4.	*B.burmanica*	570	59.7	11.01	39.9	672	105.0	17.81	65.2
5.	*B.glancescens (Syn.B.nana)*	691	82.8	14.77	53.9	-	-	-	-
6.	*B.nutans*	603	52.9	6.62	45.6	673	52.4	10.72	47.9
7.	*B.pallida*	731	55.2	12.90	54.0	-	-	-	-
8.	*B.tulda*	658	51.1	7.98	40.7	722	66.7	10.07	68.0
9.	*B.ventricosa*	626	34.1	3.38	36.1	-	-	-	-
10.	*B.vulgaris*	626	41.5	2.87	38.6	-	-	-	-
11.	*Cephalostachyum pergracile*	601	52.6	11.16	36.7	640	71.3	19.22	49.4
12.	*D.longispathus*	711	33.1	5.51	42.1	684	47.8	6.06	61.1
13.	*D.strictus*	631	73.4	11.98	35.9	728	119.1	15.00	69.1
14.	*Melocanna baccifera*	817	53.2	11.39	53.8	751	57.6	12.93	69.9
15.	*Oxytenanthera abyssinicia*	688	83.6	14.96	46.6	-	-	-	-
16.	*Thyrsostachys oliveri*	733	61.9	9.72	46.9	758	90.0	12.15	58.0

NOTES
1 As the strength of split bamboo is more than that of round bamboo, the results of tests on round bamboo can be safely used for designing with spit bamboo.
2 The values of stress in N/mm^2 have been obtained by converting the values in kgf/cm^2 by dividing the same by 10.

Table 2 Safe Permissible Stresses of Bamboos for Structural Designing[1)]
(*Clauses* 6.2 and 6.3)

Sl No.	Species	Extreme fibre stress in bending N/mm^2	Modulus of elasticity 10^3 N/mm^2	Allowable compressive stress N/mm^2
(1)		(3)	(4)	(5)
	GROUP A			
1.	*Bambusa glancescens (syn.B.nana)*	20.7	3.28	15.4
2.	*Dendrocalamus strictus*	18.4	2.66	10.3
3.	*Oxytenanthera abyssinicia*	20.9	3.31	13.3
	GROUP B			
4.	*Bambusa balcooa*	16.4	1.62	13.3
5.	*B.pallida*	13.8	2.87	15.4
6.	*B.nutans*	13.2	1.47	13.0
7.	*B.tulda*	12.8	1.77	11.6
8.	*B.auriculata*	16.3	3.34	10.5
9.	*B.burmanica*	14.9	2.45	11.4
10.	*Cephalostachyum pergracile*	13.2	2.48	10.5
11.	*Melocanna baccifera (Syn.M.bambusoides)*	13.3	2.53	15.4
12.	*Thyrsotachys oliveri*	15.5	2.16	13.4
	GROUP C			
13.	*Bambusa arundinacea (Syn.B.bambos)*	14.6	1.32	10.1
14.	*B.ventricosa*	8.5	0.75	10.3
15.	*B.vulgaris*	10.4	0 .64	11.0
16.	*Dendrocalamus longispathus*	8.3	1.22	12.0

NOTE - The values of stress in N/mm^2 have been obtained by converting the values in kgf/cm^2 by dividing the same by 10.

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

5.3 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 (*M*) 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. The moisture content of bamboo shall be determined in accordance with IS 6874. Matured culms shall be seasoned to about 20 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 dying in the open can control degrades.

5.4 Grading of Structural Bamboo

5.4.1 Bamboo shall be graded to ensure that the properties of bamboo are satisfactory for use particularly the strength and stiffness properties.

5.4.1.1 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
g) Durability and seasoning.

One of the above characteristics or sometimes combination of 2 or 3 characteristics form the basis of grading. The culms shall be segregated species-wise.

5.4.2 *Diameter and Length*

5.4.2.1 *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 :

Special Grade	70 mm < Diameter $\leq$ 100 mm
Grade I	50 mm < Diameter $\leq$ 70 mm
Grade II	30 mm < Diameter $\leq$ 50 mm
Grade III	Diameter $\leq$ 30 mm

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

Grade I	80 mm < Diameter $\leq$ 100 mm
Grade II	60 mm < Diameter $\leq$ 80 mm
Grade III	Diameter $\leq$ 60 mm

5.4.2.2 The minimum length of culms shall be preferably 6 m for facilitating close fittings at joints, etc.

5.4.3 *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.

5.4.4 *Curvature*

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

5.4.5 *Wall Thickness*

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

5.5 Durability and Treatability

5.5.1 *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. For making bamboo durable, suitable treatment for preserving bamboo shall be given. However, special attention shall be given to environmental impact and to the health aspects of labour and the users.

5.5.2 To ensure an adequately durable structure, bamboo shall be treated in accordance with IS 9096 and the following inter-related factors shall be considered:

a) The expected service life of the bamboo
b) The use of the structure and expected environmental conditions
c) The required performance criteria
d) The quality of workmanship

5.5.3 For provisions on safety of bamboo structures against fire, fire resistance shall be determined in accordance with the applicable national standards.

6 PERMISSIBLE STRESSES

6.1 Ultimate stress values of different species and groups of bamboo shall be determined according to IS 6874. 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.

6.1.1 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
Max. compressive stress parallel to grain/fibres	-	3.5

6.2 The available data for the safe working stresses for 16 species of bamboos are given in **Table 2**.

6.3 For change in duration of load other than continuous (long-term), the permissible stresses given in **Table 2** 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

7 DESIGN CONSIDERATIONS

7.1 Basic Requirements

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

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

- 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.

- the structure will be adequately maintained.

- the structure will be used in accordance with design limit briefs.

- 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.

- 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.

- Accepted principles of mechanics for analysis and specified design procedures shall be applied (or) the design requirements may be satisfied by prototype testing.

- Loads shall be in accordance with IS 875 (Parts1 – 5).

- The worst combination and location of loads shall be considered for design. Also, wind and seismic forces shall not be considered to act simultaneously.

7.2 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* and the same may be adopted to bamboo with the limitations that traditional experience rather than precise calculations generally govern the detailing.

7.3 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, hurricanes etc as criteria for recommendations by the evaluation by competent engineer/builder with adequate experience in the field.

7.3 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.

7.5 Structural Components

7.5.1 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.

7.5.2 *Peculiarity of Bamboo as a Design Material*

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

a) The 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;
c) Nodes do not occur at constant intervals.
d) The 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 be 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.
f) Joints shall be considered to generally act as a hinge or as pinned, unless substantiating data justify a fixed joint.

* 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.

7.6 Flexural Members

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

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

a) The 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. (For each cross-section, the diameter shall be taken twice, in direction perpendicular to each other and the wall thickness shall be taken four times, in the same points where the diameter has been measured).
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.

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

7.6.4 The deflection shall be within the prescribed limits. Permanent load may be doubled for calculation of deflection under sustained load (including creep) effect in case of green bamboo having moisture content exceeding 15 percent. The initial curvature shall also be considered in the calculation of the deflection.

7.6.5 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.

NOTE – The shear stress values (N/mm^2) for at least three species of bamboo for structural use in split form in green condition have been determined as under :

Bambusa pallida	9.77
B. Vulgaris	9.44
Oxytenanthera abyssinicia	11.2

7.6.6 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.

7.7 Columns (predominantly loaded in axial direction)

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

7.7.2 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) The moment of inertia shall be determined as per **7.6.3**.
2) For bamboo columns the best available straight bamboo culms shall be selected.
3) The bending stresses due to initial curvature, eccentricities and induced deflection shall be taken into account, in addition to those due to any lateral load.

7.7.3 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.

7.7.4 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.

7.8 Assemblies, Roof Trusses

7.8.1 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.

7.8.2 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.

7.8.3 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.

7.8.4 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.

7.8.5 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.

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

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

7.8.8 The common roof covering shall include bamboo mat board, bamboo mat corrugated sheet, bamboo tiles, plastered bamboo reeds, thatch, corrugated galvanized iron sheeting, asphaltic sheets, plain clay tiles, etc.

8 DESIGN AND TECHNIQUES OF JOINTS

8.1 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.

8.2 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 IS 2366 and IS 4924 for nailed jointed structures.

8.2.1 *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.

8.2.1.1 *Lengthening joints (end jointing*)

8.2.1.1.1 *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.

8.2.1.1.2 *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.

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

8.2.1.1.4 *Scarf joints*

A scarf joint is formed by cutting a sloping plane 1 in 4 to 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.

8.2.1.2 *Bearing joints*

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.

8.2.1.2.1 *Butt 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.

8.2.1.2.2 *Angled joints*

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

8.2.2 *Improved Practices in bamboo jointing*

a) 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 bolts. Hollow cavities of bamboo need to be stuffed with wooden plugs or otherwise by suitable means.
b) 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.

8.2.3 *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 diameter galvanized iron wire may be used for tight lashing.

8.2.3.1 *Wire bound joints with or without pins*

Usually 2.00 mm 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 10-12 mm dia bamboo pins are driven and fastened to culms.

8.2.3.2 *Fish plates/gusset plated joints*

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.

8.2.4 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.

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

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

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

The designer shall ensure to detail that bamboo in building shell remain air-dry to avoid deterioration due to moisture.

The permeability of walls, floors and roof made from bamboo affect the wind load factor.

9 PANELS FOR WALL/ROOF CLADDING

9.1 Until Indian Standards for bamboo panels are available, the following is applicable.

9.1.1 *Ply bamboo*

Ply bamboo sheets are composed of woven bamboo mats glued together, or of layers of split bamboo strips, laid across each other and glued together.

9.1.2 Particle board and fibre board/reed board

9.1.3 These shall be produced so that they maintain their integrity and strength in the assigned service class though out the expected life of the structure.

9.1.4 Testing for the determination of structural properties of panels shall be carried out in accordance with IS 6874.

ANNEX A

IS NO.	TITLE
IS 875 Parts 1: 1987 Parts 2: 1987 Parts 3: 1987 Parts 4: 1987 Parts 5: 1987	Design loads for building and structures Unit weights of building material and stored materials (Second Revision) Imposed loads (Second revision) Wind loads (Second Revision) Snow loads (Second Revision) Special loads and load combinations (second revision)
IS 883:1994	Design of structural timber in building – Code of practice (*fourth revision*)
IS 1902:2006	Preservation of bamboo and cane for non-structural purposes (*second revision*)
IS 6874:2008	Method of test for round bamboo (*first revision*)
IS 8242:1976	Method of test for split bamboo
IS 9096:2006	Code of practice for preservation of bamboo for structural purposes (*first revision*)
IS 13958:1994	Bamboo mat board for general purposes – Specification