Chapter 4

BAMBOO

4.1 SCOPE

This Section relates to the use of bamboo in construction as structural elements, nonstructural elements and also for temporary works in structures or elements of the structure, ensuring quality and effectiveness of design and construction using bamboo. It covers minimum strength data, dimensional and grading requirements, seasoning, preservative treatment, design and jointing techniques with bamboo which would facilitate scientific application and long-term performance of structures. It also covers guidelines so as to ensure proper procurement, storage, precautions and design limitations on bamboo.

4.2 TERMINOLOGY

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

4.2.1 Anatomical Purpose Definitions

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

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

Bamboo Clump — A cluster of bamboo culms emanating from two or more rhizomer in the same place.

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

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).

Cross Wall — A wall at the node closing the whole inside circumference and completely separating the hollow cavity below from that above.

Hemi Cellulose — The polysaccharides consisting of only 150 to 200 sugar molecules, also much less than the 10000 of cellulose.

Lignin — A polymer of phenyl propane units, in its simple form (C6H5CH3CH2CH3).

Sliver — Thin strips of bamboo processed from bamboo culm.

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.

4.2.2 Structural Purpose Definitions

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

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

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.

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

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

Characteristic Load— The value of loads which has a 95 percent probability of not exceeding during the life of the structure.

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

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

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

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

Curvature — The deviation from the straightness of the culm.

Delamination — Separation of mats through failure of glue.

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.

Flatten 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.

Full Culm — The naturally available circular section/shape.

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.

Inner Diameter — Diameter of internal cavity of a hollow piece of bamboo.

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

Joint — A connection between two or more bamboo structural elements.

Joist — A beam directly supporting floor, ceiling or roof of a structure.

Length of Internode — Distance between adjacent nodes.

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

Matchet — A light cutting and slashing tool in the form of a large knife.

Mat — A woven sheet made using thin slivers.

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

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.

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.

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

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,

Permissible Stress — Stress obtained after applying factor of safety to the ultimate or basic stress.

Principal Rafter — A roof member which supports purlins.

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

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

Roof Skeleton — The skelton 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.

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

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

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

Unloaded End Distance — The end distance opposite to the loaded end

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

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.

4.2.3 Definitions Relating to Defects

Bamboo Bore/GHOON Hole — The defect caused by bamboo GHOON beetle (Dinoderus spp. Bostychdae), which attacks felled culms.

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

Discoloration — A change from the normal colour of the bamboo which does not impair the strength of bamboo or bamboo composite products.

4.2.4 Definitions Relating to Drying Degrades

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.

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.

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

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.

4.3 SYMBOLS

For the purpose of this Section, 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

$$A = \frac{\pi}{4}\left(D^2 - d^2\right)$$

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, mm^4 = $\frac{\pi}{64}\left(D^2 - d^2\right)$

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.

4.4 MATERIALS

4.4.1 Species of Bamboo

In Bangladesh, four species are widely used, hence studied for the mechanical properties as tabulated in Table 6.4.1-6.4.4 for top, bottom and middle positions. Table 6.4.5 further summarize the average mechanical properties of 21 bamboo species.

Table 6.4.1: Moisture content and specific gravity values of four bamboos species at different height positions (average of five bamboo specimens)

Species	Moisture content (%)			Specific Gravity (based on ovendry weight and at different volumes)					
				Green volumes			Ovendry volumes		
	bottom	middle	top	bottom	middle	top	bottom	middle	top
Kali (Oxytenanthera nigrociliata)	129	118	104	0.48	0.49	0.51	0.66	0.69	0.74
Mitinga (Bambusa tulda)	108	92	86	0.54	0.58	0.61	0.75	0.79	0.83
Bethua (Bambusa polymorpha)	104	93	79	0.55	0.57	0.61	0.79	0.81	0.54
Borak (Bambusa balcooa)	100	84	66	0.57	0.64	0.74	0.79	0.84	0.85

Table 6.4.2: Shrinkages of wall thickness and in diameter of four bamboo species at different height positions

Species	Shrinkage in wall thickness (%)						Shrinkage in diameter (%)		
	From green to 12% mc			From green to ovendry condition			From green to 12% mc		
	bottom	middle	top	bottom	middle	top	bottom	middle	top
Kali (Oxytenanthera nigrociliata)	9.6	8.1	5.9	13.2	10.7	8.7	4.8	3.0	2.4
Mitinga (Bambusa tulda)	11.9	7.3	4.9	14.9	9.6	7.6	3.9	3.5	2.6
Bethua (Bambusa polymorpha)	10.7	6.5	5.1	12.1	10.1	8.2	7.3	5.5	4.1
Borak (Bambusa balcooa)	11.1	7.6	4.8	13.7	11.1	8.4	4.2	3.4	2.5

Table 6.4.3: Compressive strength of four bamboo species at different height positions

Species	Compression parallel to the grain (kg/cm^2)					
	green			airdry		
	bottom	middle	top	bottom	middle	top
Kali (Oxytenanthera nigrociliata)	257	287	301	346	387	417
Mitinga (Bambusa tulda)	403	466	513	529	596	620
Bethua (Bambusa polymorpha)	320	361	419	452	512	534

Borak (Bambusa balcooa)	394	459	506	510	536	573

Table 6.4.4: Modulus of elasticity and modulus of rupture values of four bamboo species at different height positions

Species	Modulus of elasticity (1000 kg/cm²)						Modulus of rapture (kg/cm²)					
	green			airdry			green			airdry		
	bottom	middle	top	bottom	middle	top	bottom	middle	top	bottom	middle	top
Kali (Oxytenanthera nigrociliata)	119	131	169	131	150	224	541	459	415	721	580	530
Mitinga (Bambusa tulda)	105	138	147	114	140	168	710	595	542	883	745	671
Bethua (Bambusa polymorpha)	61	65	82	60	70	96	469	426	373	566	468	414
Borak (Bambusa balcooa)	72	92	103	93	108	127	850	712	624	926	787	696

4.4.2 Grouping

Sixteen species of bamboo are suitable for structural applications and classified into three groups, namely, Group A, Group B and Group C as given in Table 6.4.6.

Table 6.4.6: Safe Working Stresses of Bamboos for Structural Designing(1)

Sl No.	Species	Extreme Fibre Stress in Bending N/mm²	Modulus of Elasticity 10³N/mm²	Allowable Compressive Stress N/mm²
(1)	(2)	(3)	(4)	(5)
	GROUP A			
i)	Barnbusa glancescens (syn. B. nana)	20.7	3.28	15.4
ii)	Dendrocalamus strictus	18.4	2.66	10.3
iii)	Oxytenanthera abyss inicia	20.9	3.31	13.3
	GROUP B			
iv)	Bambusa balcooa	16.05	1.62	13.3
v)	B. pallida	13.8	2.87	15.4
vi)	B. nutans	13.2	1.47	13.0
vii)	B. tulda	13.3	1.77	11.6
viii)	B. auriculata	16.3	3.34	10.5
ix)	B. burmanica	14.9	2.45	11.4
x)	Cephalostachyum pergraci[e	13.2	2.48	10.5
xi)	Melocanna baccifera (Syn. M. bambusoides)	13.3	2.53	15.4
xii)	Thyrsotachys oliveri	15.5	2.16	13.4
	GROUP C			
xiii)	Bambusa arundinacea (Syn. B. bambos)	14.6	1.32	10.1
xiv)	B. polymorpha	9.15	1.71	8.97

xv)	B. ventricosa	8.5	0.75	10.3
xvi)	B. vulgaris	10.4	0.64	11.0
xvii)	Dendrocalamus longispathus	8.3	1.22	12.0
xviii)	Oxytenanthera nigrociliata	10.18	2.6	7.2

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.

The characteristics of these groups are as given in Table 6.4.6.

Species of bamboo other than those listed in the Table 6.4.6 may be used, provided the basic strength characteristics are determined and found more than the limits mentioned therein. However, in the absence of testing facilities and compulsion for use of other species, and for expedient designing, allowable stresses may be arrived at by multiplying density with factors as given in Table 6.4.5.

4.4.3 Moisture Content in Bamboo

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. Matured culms shall be seasoned to about 20 percent moisture content before use.

Table 6.4.7 Limiting Strength Values (in Green Condition)

	Modulus of Rupture (R') N/mm^2	**Modulus of Elasticity (E) in Bending 10^3 N/mm^2**
(1)	(2)	(3)
Group A	*R'>70*	*E>9*
Group B	*70≥ R'>50*	*9≥E>6*
Group C	*50≥ R'>30*	*6≥E>3*

Table 6.4.8 Allowable Long-Term Stress (N/mm2) per Unit Density (kg/m3)

Condition	**Axial Compression (no buckling)**	**Bending**	**Shear**
Green	0.011	0.015	—
Air dry (12%)	0.013	0.020	0.003

NOTE — In the laboratory regime, the density of bamboo is conveniently determined. Having known the density of any species of bamboo, permissible stresses can be worked out using factors indicated above. For example, if green bamboo has a density of 600 kg/m3, the allowable stress in bending would be 0.015 x 600 = 9 N/mm2'.

References: IS 6874: 1973, "Method of Test for Round Bamboo", Bureau of Indian Standards, India, 1974.

Table 6.4.5 Physical and Mechanical Properties of Bamboos (in Round Form)

Sl No.	Species	Properties						
		In Green Condition				In Air Dry Conditions		
		Density kg/m3	Modulus of Rupture N/mm2	Modulus of Elasticity 103 N/mm2	Maximum Compressive strength N/mm2	Density kg/m3	Modulus of Rupture N/mm2	Modulus of Elasticity 103 N/mm2
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
i)	*Bambusa auriculata*	594	65.1	15.01	36.7	670	89.1	21.41
ii)	*B. balcooa*	740	64.2	7.06	38.6	850	68.3	9.12
iii)	*B. bambos (Syn.B.atwndinacea)*	559	58.3	5.95	35.3	663	80.1	8.96
iv)	*B. burmanica*	570	59.7	11.01	39.9	672	105.0	17.81
v)	*B. glancescens (Syn.B.nana)*	691	82.8	14.77	53.9	—	—	—
vi)	*B. nutans*	603	52.9	6.62	45.6	673	52.4	10.72
vii)	*B. pallida*	731	55.2	12.90	54.0	—	—	—
viii)	*B. polymorpha*	610	36.6	6.0	31.4	840	40.6	5.89
ix)	*B. tulda*	610	53.2	10.3	39.5	830	65.8	11.18
x)	*B. ventricosa*	626	34.1	3.38	36.1	—	—	—
xi)	*B. vulgaris*	626	41.5	2.87	38.6	—	—	—
xii)	*Cephalostachyum pergracile*	601	52.6	11.16	36.7	640	71.3	19.22
xiii)	*Dendrocalamus giganteous*	597	17.2	0.61	35.2	—	—	—
xiv)	*D. hamiltonii*	515	40.0	2.49	43.4	—	—	—
xv)	*D. longispathus*	711	33.1	5.51	42.1	684	47.8	6.06
xvi)	*D. membranacaus*	551	26.3	2.44	40.5	664	37.8	3.77
xvii)	*D. strictus*	631	73.4	11.98	35.9	728	119.1	15.00
xviii)	*Melocanna baccifera*	817	53.2	11.39	53.8	751	57.6	12.93
xix)	*Oxytenanthera abyssinicia*	688	83.6	14.96	46.6	—	—	—
xx)	*Oxytenanthera nigrociliata*	510	40.70	11.7	25.2	830	51.98	12.85
xxi)	*Thyrsostachys oliveri*	733	61.9	9.72	46.9	758	90.0	12.15
NOTES								

1 As the strength of split bamboo is more than that of round bamboo, the results of tests on romd barnbo CaIlbe 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.

4.4.3.1 Air seasoning of split or half-round bamboo does not pose much problem but care has to be taken to prevent fungal discoloration and decay. However, rapid drying in open sun can control decay due to fungal and insect attack. Seasoning in round form presents considerable problem as regards mechanical degrade due to drying defects.

NOTE — A general observation has been that immature bamboo gets invariably deformed in cross-section during seasoning and thick walled immature bamboo generally collapses. Thick mature bamboo tends to crack on the surface, with the cracks originating at the nodes and at the decayed points. Moderately thick immature and thin and moderately thick mature bamboos season with much less degrade. Bamboo having poor initial condition on account of decay, borer holes, etc generally suffers more drying degrades.

4.4.3.2 Accelerated air seasoning method gives good results. In this method, the nodal diaphragms (septa) are punctured to enable thorough passage of hot air from one end of the resulting bamboo tube to the other end.

References: 1. IS 6874: 1973, “Method of Test for Round Bamboo”, Bureau of Indian Standards, India, 1974.

2. Salehuddin, A. B. M., Unnoto Poddhotite Bash Shongrokkhon o Babohar”, Bangladesh Agriculture Research Institute, 2004.

4.4.4 Grading of Structural Bamboo

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,

(e) Wall thickness,

(f) Density and strength, and

(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.

4.4.4.1 Diameter and Length

4.4.4.1.1 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 70mm<Diameter <100mm

Grade I 50mm< Diameter <70mm

Grade II 30mme Diameter <50mm

Grade III Diameter <30mm

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

Grade I 80 mm < Diameter <100 mm

Grade II 60 mm< Diameter< 80 mm

Grade III Diameter <60 mm

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

4.4.5 Taper

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

4.4.5.1 **Curvature**

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

4.4.5.2 **Wall Thickness**

Preferably minimum wall thickness of 8 mm shall be used for load bearing members.

4.4.5.3 **Defects and Permissible Characteristics**

4.4.5.3.1 Dead and immature bamboos, bore/GHOON holes, decay, collapse, checks more than 3 mm in depth, shall be avoided.

4.4.5.3.2 Protruded portion of the nodes shall be flushed smooth. Bamboo shall be used after at least six weeks of felling.

References: 1. IS 9096: 1979, "Code of Practice for Preservation of Bamboo for Structural Purposes", Bureau of Indian Standards, India, 1974.

4.4.5.3.3 Broken, damaged and discolored bamboo shall be rejected.

4.4.5.3.4 Matured bamboo of at least 4 years of age shall be used.

4.4.6 Durability and Treatability

4.4.6.1 **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 biodeterioration 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 shall be given.

Treatability

Due to difference in the anatomical structure of bamboo as compared to timber, bamboo behaves entirely differently from wood during treatment with preservative. Bamboos are difficult to treat by normal preservation methods in dry condition and therefore treatment is best carried out in green condition.

Boucherie Process

In this process of preservative treatment, water borne preservative is applied to end surface of green bamboo through a suitable chamber and forced through the bamboo by hydrostatic or other pressure.

References: 1. Salehuddin, A. B. M., Unnoto Poddhotite Bash Shongrokkhon o Babohar", Bangladesh Agriculture Research Institute, 2004.

4.4.6.1.1 Performance of treated bamboo

Trials with treated bamboos have indicated varied durability depending upon the actual location of use. The performance in partially exposed and under covered conditions is better.

4.4.6.1.2 For provisions on safety of bamboo structures against fire, see Part 7 'Constructional Practices and Safety'.

4.5 PERMISSIBLE STRESSES

4.5.1 Factor of Safety

The safety factor for deriving 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

4.5.2 Coefficient of Variation

The coefficient of variation (in percent) shall be as under:

Property	Mean	Range	Maximum Expected Value
(1)	(2)	(3)	(4)
Modulus of rupture	15.9	5.7-28.3	23.4
Modulus of elasticity	21.1	12.7-31.7	27.4
Maximum compressive stress	14.9	7.6-22.8	20.0

The maximum expected values of coefficient of variation which are the upper confidence limits under normality assumption such that with 97.5 percent confidence the actual strength of the bamboo culms will be at least 53 percent of the average reported value of modulus of rupture in Table 6.4..

4.5.3

Solid bamboos or bamboos whose wall thickness (*w*) is comparatively more and bamboos which are generally known as male bamboos having nodes very closer and growing on ridges are often considered good for structural purposes.

4.5.4

The safe working stresses for 16 species of bamboos are given in Table 6.4..

4.5.5

For change in duration of load other than continuous (long-term), the permissible stresses given in Table 6.4. shall be multiplied by the modification factors given below:

For imposed or medium term loading	1.25
For short-term loading	1.50

4.6 DESIGN CONSIDERATIONS

4.6.1

All structural members, assemblies or framework in a building shall be capable of sustaining, without exceeding the limits of 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 (see Part 6 'Structural Design', Chapter 11 Timber Structures').

4.6.2

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

4.6.3 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.

4.6.4 Loads

The loads shall be in accordance with Part 6 'Structural Design', Chapter 2 'Loads'.

4.6.5 Structural Forms

4.6.5.1 Main structural components in bamboo may include roof and floor diaphragms, shear walls, wall panellings, beams, piles, columns, etc. Both from the point of view of capacity and deformation, trusses and framed skeltons are much better applications of bamboo.

4.6.5.2 **Schematization of Bamboo as a Structural Material**

This shall be based on the principles of engineering mechanics involving the following assumptions and practices:

(a) The elastic behaviour of bamboo, till failure; (plastic behaviour being considered insignificant);

(b) Bamboo culms are analysed on mean wall thickness basis as hollow tube structure (not perfectly straight) member on mean diameter basis:

(c) 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; and

(d) Bamboo structures be designed like any other conventional structural elements taking care of details with regards to supports and joints; they shall be considered to generally act as a hinge, unless substantiating data justify a fixed joint.

4.6.6 Flexural Memders

4.6.6.1 All flexural members maybe designed using the principles of beam theory.

4.6.6.2 The tendency of bamboo beams to acquire a large deflection under long continuous loadings due to possible plastic flow, if any shall be taken care of. Permanent load may be doubled for calculation of deflection under sustained load (including creep) in case of green bamboo having moisture content exceeding 15 percent.

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

(a) The outside diameter and the wall thickness should 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 so the wall thickness shall be taken as four times, in the same places as the diameter has been taken twice.)

(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.

4.6.6.4 The maximum bending stress shall be calculated and compared with the allowable stress.

4.6.6.5 For shear checks, conventional design procedure in accordance with Part 6 'Structural Design', Chapter 11 'Timber Structures' shall be followed.

NOTE— The basic shear stress values (N/mm2) for five species of bamboo in split form in green condition can be assumed as under:

Bambusa pallida	9.77
B. Vulgaris	9.44
Dedroculumus giganteous	8.86

D.humiltonii	7.77
Oxytenanthera abyssinicia	11.2

4.6.6.6 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.

4.6.7 Bamboo Column (Predominantly Loaded in Axial Direction)

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

4.6.7.2 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:

i) The moment of inertia shall be as per 6.6.3.

ii) For bamboo columns the best available straight bamboo culms shall be selected. Structural bamboo components in compression should be kept under a slenderness ratio of 50.

iii) 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.

4.6.7.3 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, provided the reduced diameter is not less than 0.6 percent.

4.6.7.4 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.

4.6.8 Assemblies, Roof Trusses

4.6.8.1 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 are either tensile or compressive and designed as pin-ended joints (see Fig. 6.4.1.(a)). Bamboo trusses may also be formed using bamboo mat board or bamboo mat-veneer composite or plywood gusset (see Fig. 6.4.1.(b)).

4.6.8.2 Truss shall be analysed from principles of structural mechanics for the determination of axial forces in members. For the influence of eccentricities, due allowance shall be made in design.

4.6.8.3 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.

4.6.8.4 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.

4.6.8.5 For strength verification of members in compression and connections, the calculated axial forces should be increased by 10 percent.

4.6.8.6 The spacing of trusses shall be consistent with use of bamboo purlins (2 m to 3 m).

4.6.8.7 The ends in open beams, joists, rafters, purlins shall be suitably plugged. Bamboo roof coverings shall be considered as non-structural in function. The common roof covering shall include bamboo mat board, bamboo mat corrugated sheet, bamboo tiles/ strings, plastered bamboo reeds, thatch, corrugated galvanized iron sheeting, plain clay tiles or pan tiles, etc.

4.7 DESIGN AND TECHNIQUES OF JOINTS

4.7.1 Bamboo Joints

Round, tubular form of bamboo requires an approach different to that used for sawn timber. 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.

4.7.1.1 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.

4.7.1.1.1 Lengthening Joints (End Joints)

Lap Joint

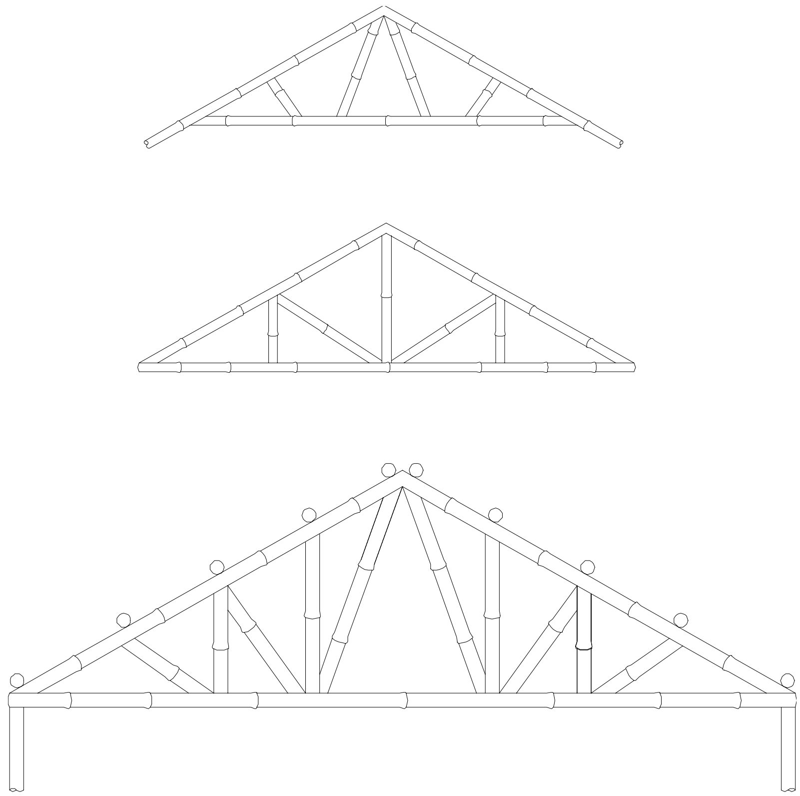
In this case, end of one piece of bamboo is made to lap over that of the other in line and the whole is suitably fastened. It maybe full lapping or half lapping. Full section culms are overlapped by at least one internode and tied together in two or three places. Efficiency could be improved by using bamboo or hardwood dowels. In half lapping, culms shall preferably be of similar diameter and cut longitudinally to half depth over at least one internode length and fastened as per full lap joint (see Fig. 6.4.2).

Butt Joint

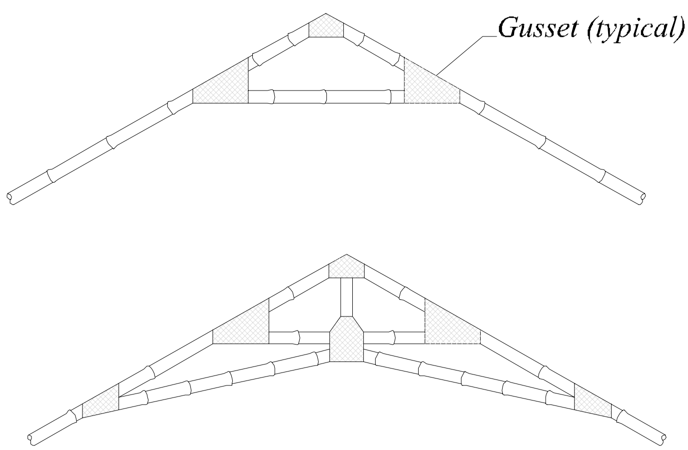
Culms of similar diameter are butted end to end, interconnected by means of side plates made of quarterround culm of slightly large diameter bamboo, for two or more internode lengths. Assembly shall be fixed and tied preferably with dowel pins. This joint transfers both compressive and tensile forces equally well (see Fig. 6.4.3).

Sleeves and Inserts

Short length of bamboo of appropriate diameter may be used either externally or internally to join two culms together (see Fig. 6.4.4).



6.4.1(a)- Pin ended joint trusses



6.4.1(b)- Gusset joint trusses

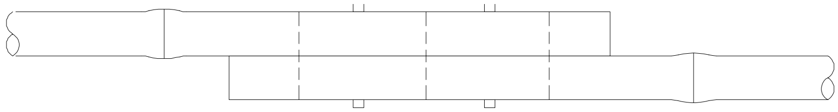
Fig. 6.4.1 Some typical configurations for small and large trusses in Bamboo

Scarf Joint

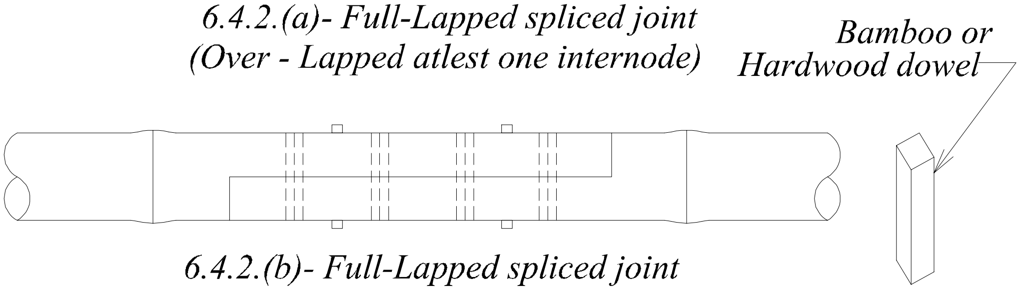
A scarf joint is formed by cutting a sloping plane 1 in 4 to 6 on opposite sides from the ends of two similar diameter bamboo culms to be joined. They shall be lapped to form a continuous piece and the assembly suitably fastened by means of lashings. Using hooked splays adds to the strength and proper location of joints (see Fig. 6.4.5).

4.7.1.1.2 Bearing Joints

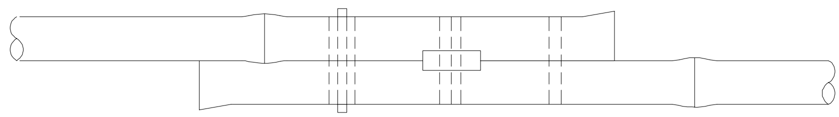
For members which either bear against the other or cross each other and transfer the loads at an angle other than parallel to the axis, bearing joints are formed.



6.4.2.(a)- Full-Lapped spliced joint
(Over - Lapped atlest one internode)



6.4.2.(b)- Full-Lapped spliced joint
(Similar diameter; One interno de length)



6.4.2(c) Lapped spliced joint with pegs and battens

Fig. 6.4.2 Lap joint in Bamboo

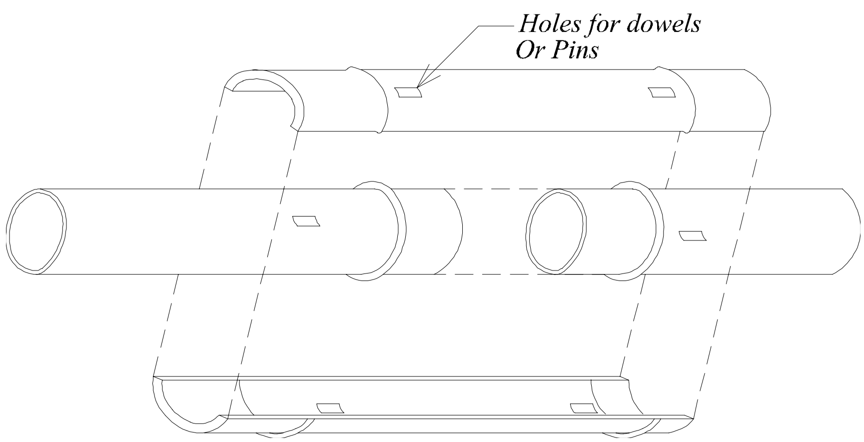


Fig: 6.4.3 Butt joint with side plates in Bamboo

Butt Joint

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 (see Fig. 6.4.6).

Tenon Joint

It is formed by cutting a projection (tenon) in walls of one piece of bamboo and filling it into corresponding holes (mortise) in another and keyed. It is a neat and versatile joint for maximum strength and resistance to separation (see Fig. 6.4.7).

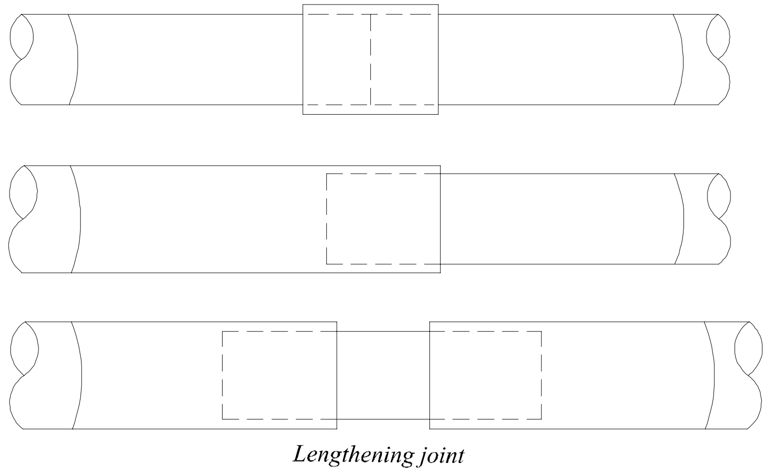


Fig:6.4.4 Sleeves and inserts for Bamboo joint

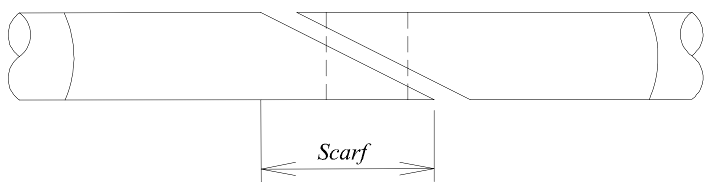


Fig: 6.4.5 Scarf joint

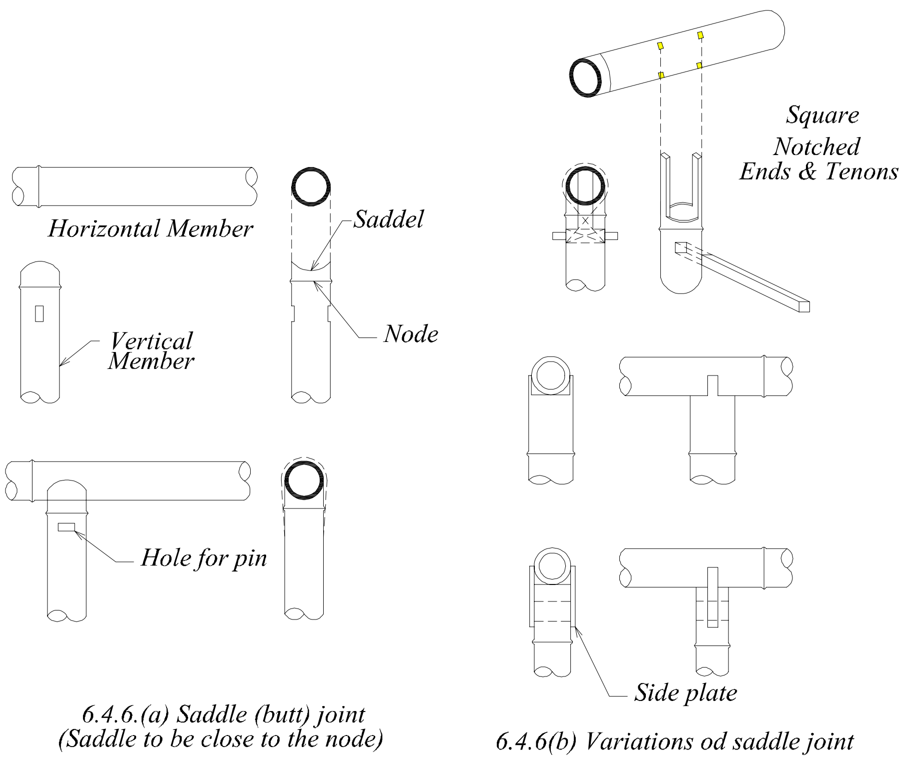
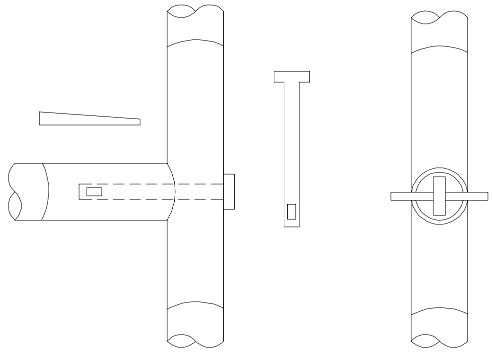
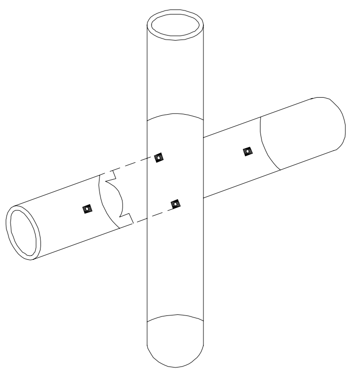


Fig: 6.4.6 Butt joints in Bamboo



Tenon and key joint



Integral tenon (horned) joint

Fig: 6.4.7 Tenon joint

Cross-Over Joint

It is formed when two or more members cross at right angles and its function is to locate the members and to provide lateral stability. In case of the joint connecting floor beam to post, it maybe load bearing (see Fig. 6.4.8). Such joints are also used to transmit angle thrust.

Angled Joint

When two or more members meet or cross other than at right angles, angled joints are formed. For butt joints, the ends of the members may be shaped to fit in as saddle joints. Tenons would help in strengthening such joints (see Fig. 6.4.9).

4.7.1.2 Modern Practices

Following are some of the modern practices for bamboo jointing (see Fig. 6.4.10):

(a) Plywood or solid timber gusset plates maybe 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.

(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.

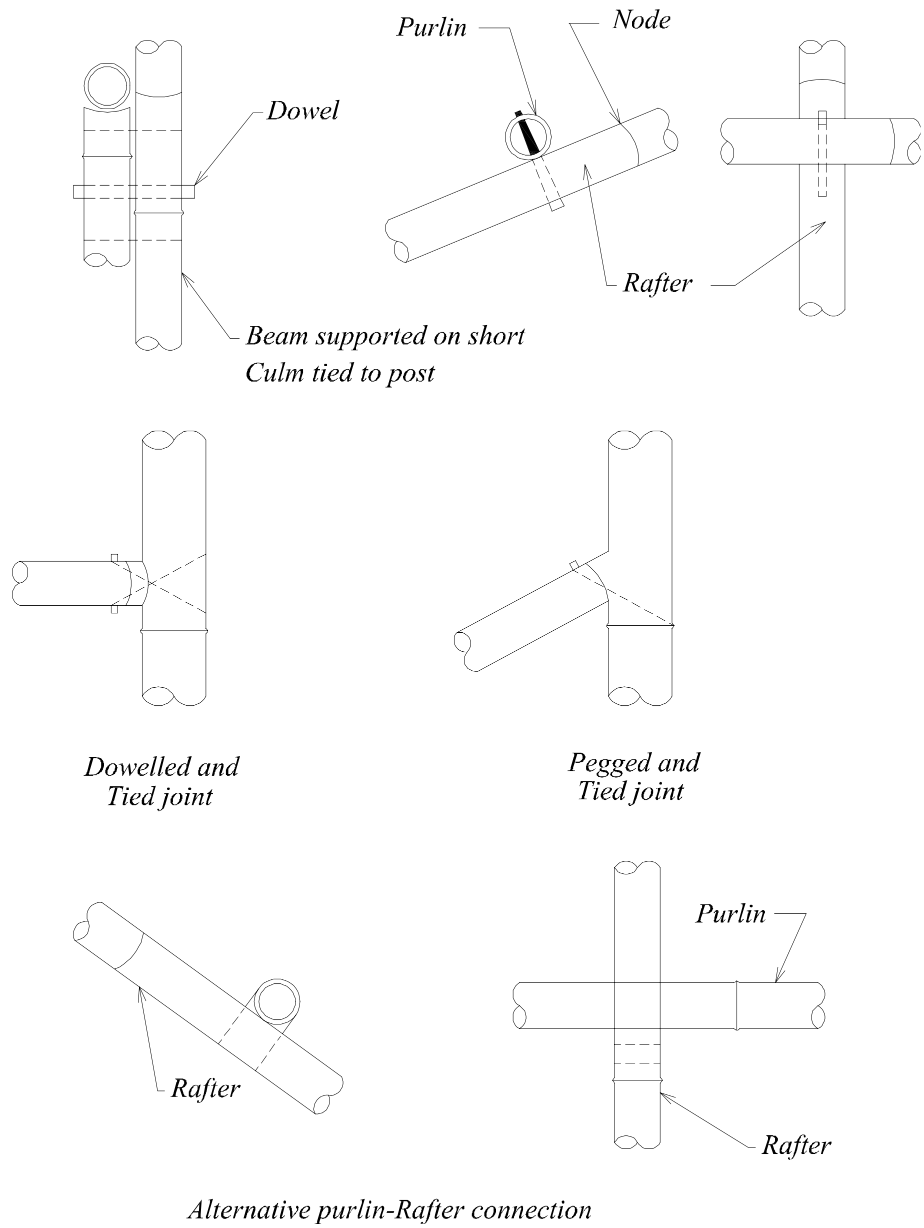


Fig: 6.4.8 Cross over joints (Bearing joints)

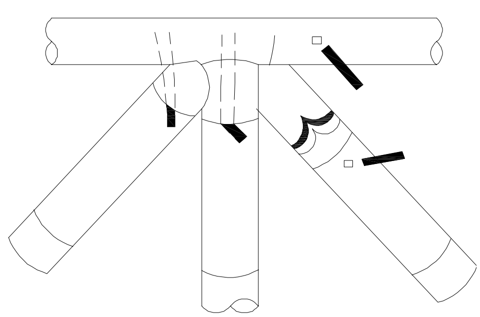


Fig: 6.4.9 Angled joints with integral tenons

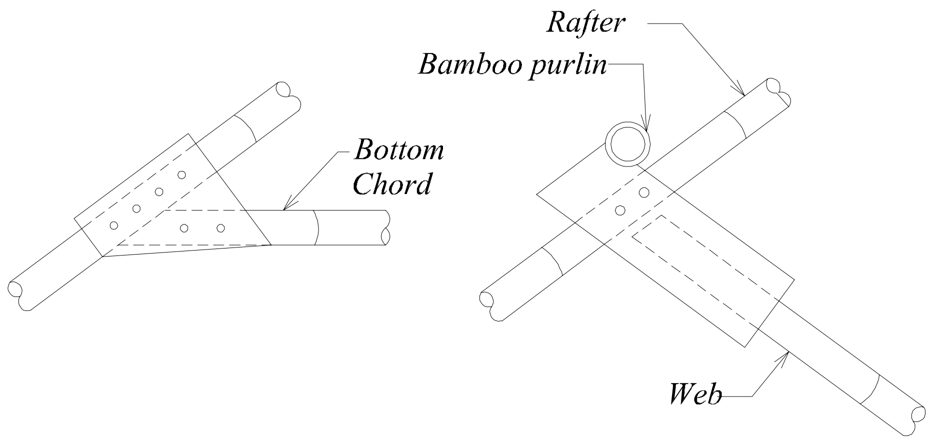


Fig: 6.4.10 Gusset plated joint

4.7.1.3 **Fixing Methods and Fastening Devices**

In case of butt joints the tie maybe passed through a pre-drilled hole or around hardwood or bamboo pegs or dowels inserted into prefomed 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.

4.7.1.3.1 Normally 1.60 mm diameter galvanized iron wire may be used for tight lashing.

4.7.1.3.2 Wire Bound Joints

Usually galvanized iron 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.

4.7.1.3.3 Pin And Wire Bound Joints

Generally 12 mm dia bamboo pins are fastened to culms and bound by 2.00 mm diameter galvanized iron wire.

4.7.1.3.4 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.

4.7.1.3.5 Horned Joints

Two tongues made atone end of culm may be fastened with across member with its mortise grooves to receive horns, the assembly being wire bound.

4.7.1.4 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.

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

4.7.1.6 In disaster 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.

4.8 STORAGE OF BAMBOO

Procurement and storage of bamboo stocks are essential for any project work and shall be done in accordance with Part 7 ‘Constructional Practices and Safety’.