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Project on

Bamboo as a construction material

Under guidance of

Mr. R. G. Tambat

Batch

2018-2019

K.J.Somaiya Polytechnic
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CERTIFICATE

This is to certify that project book submitted by the students of final year Diploma in Civil Engineering (2018-2019) on "BAMBOO AS A CONSTRUCTION MATERIAL" have satisfactory completed the requirements of seminar report and I have instructed and guided them for the said work from time to time and I have found them satisfactory progressive.

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And that I have assessed the said work and I am satisfied that the same is up to the standard envisaged for the level of course.

PRINCIPAL **H.C.E.D** **PROJECT GUIDE**

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SUBMISSION

We, the students of third year Diploma in Civil engineering humbly submit the project book that we have completed from time to time. I have completed the seminar report work by my own skills as per guidance of our guide.

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And the guide has approved that the following students were associated for this.

DATE:- 26th April 2019

Acknowledgement

On completion of our Seminar, we feel that we are inducted to a handful of people without whom our difficulties and doubts would be unsolved thus enduring the progress of our project.

We take this opportunity to express our heartiest thankful and our deepest gratitude to our project guide **Mr. R.G.Tambat** under whose able guidance this work has been successfully carried out. It was his morale support that encouraged us considerably in our project.

We are also thankful to **Mr.Anand Patki (Bamboo Consultant and owner of bamboo nursery, Mangaon)** for permitting us for such visit and providing detail information about the bamboo construction.

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Our project would not have been completed without support of above mentioned.

ABSTRACT

Bamboo is a strong, fast growing and very sustainable material, having been used structurally for thousands of years in many parts of the world. In modern times, it has the potential to be an aesthetically pleasing and low-cost alternative to more conventional materials, such as timber, as demonstrated by some visually impressive recent structures.

This six-part report will bring together current knowledge and best practice on the structural use of bamboo. This report provides an introduction to bamboo, origin and its uses. Basic properties, along with a selection of suitable structural species and harvesting and grading are presented. It also tells about joints and treatment of bamboo.

Bamboos are of notable economic and cultural significance in all over the world being used for building materials, as a food source, and as a versatile raw product. Bamboo has a higher specific compressive strength than wood, brick or concrete, and a specific tensile strength than steel.

While bamboo grows everywhere in the world except those places with extremely cold climates, it is thought to have originated in China, where the first use of bamboo to make every day items was recorded.

Bamboo used for construction purposes must be harvested when the culms reach their greatest strength and when sugar levels in the sap are at their lowest, as high sugar content increases the ease and rate of pest infestation. As compared to forest trees, bamboo species grow fast. Bamboo plantations can be readily harvested for a shorter period than tree plantations.

The present report also tells us about the treatment of bamboo by different chemicals like Boric acid, Copper sulphate and sodium or potassium dichromate and borax. They are treated to remove the soluble sugar which attracts fungi and incest.

This is first part of our study in coming months we will do literature survey along with site visit to bamboo construction buildings. We will also do different types of tests on bamboo and will study more about construction of bamboo.

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CHAPTER 1

INTRODUCTION

1.1General

Bamboo is woody and fast growing grass, which occurs naturally on every major continent except. Europe. There are almost 1200 species of bamboo in the World, distributed across 110 genera.

Bamboo is one of the oldest traditional building materials used by mankind. They are the largest members of the grass family and are the fastest-growing in the world. In fact, within a 24 hour period, bamboo can grow four feet. Bamboos are of notable economic and cultural significance in South Asia, Southeast Asia and East Asia, being used for building materials, as a food source, and as a versatile raw product. Bamboo has a higher compressive strength than wood, brick or concrete and a tensile strength that rivals steel.

This is a substitute building material, which is renewable, environment friendly and widely available, as the wood resources are diminishing and restrictions are imposed on felling the natural forests. Due to its rapid growth, its adaptability to most climatic conditions and due its properties, bamboo emerges as a very suitable alternative.

Timber demand is increasing worldwide at a rapid rate but the timber supply is depleting. Due to its properties bamboo can suitably replace timber and other materials in construction and other works. Industrially treated bamboo has shown great potential for production of composite materials and components which are cost-effective and can be successfully utilized for structural and non-structural applications in construction. Bamboo has several unique advantages like ability to grow fast with a high yield and also it matures quickly. Additionally, bamboo can be grown abundantly and that too at a lower cost which makes it more economical.

1.2About Bamboo

An emerging culm is called a shoot. It is protected by sheaths that stay with the culm till it develops fully. The growing rhizome is similarly protected by a sheath, which is however not normally visible since it is below the ground. Roots extend from the nodes of the rhizome and from that part of the culm which is closer to the soil surface. Most bamboos are monocarp plants; they flower (and fruit) once in their lifetime and then die. Bamboo is widely adopted by different culture for its versatility across the world. Uses of bamboo evolve with the different culture and community and its still evolving.

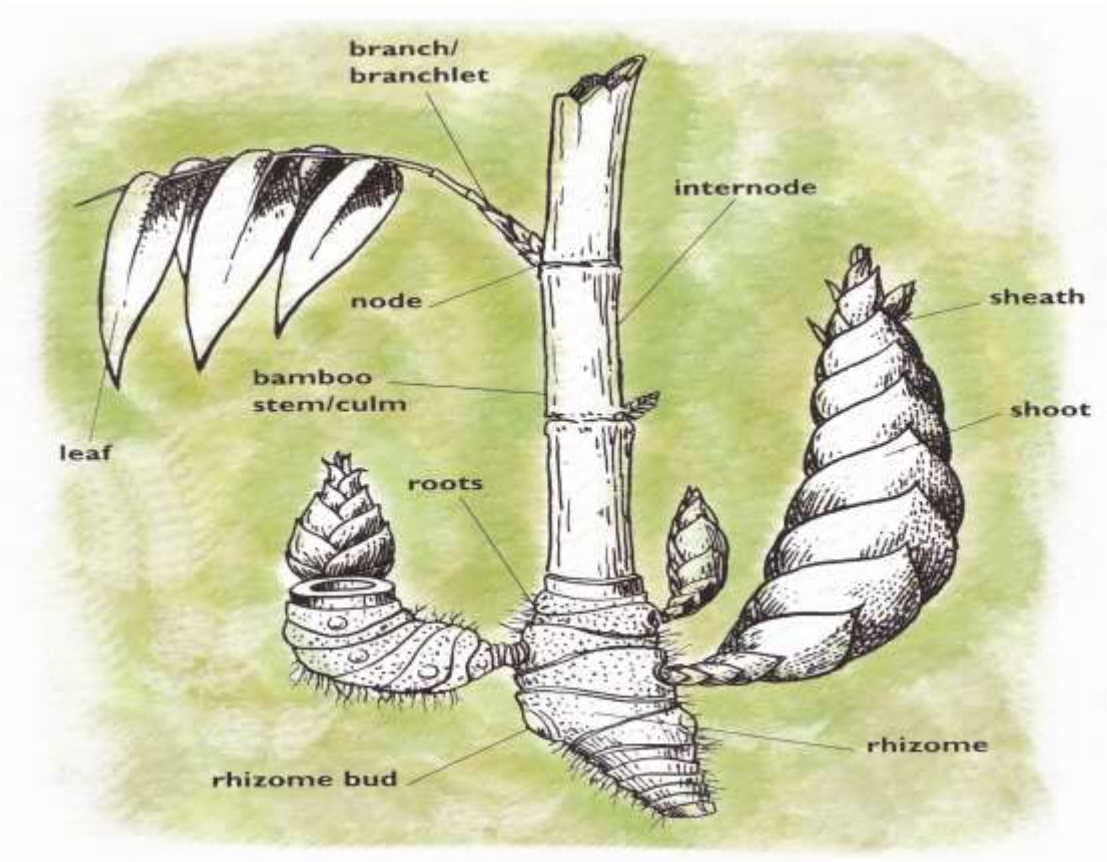


Fig. 1.1 Parts of Bamboo

1.3Necessity of Bamboo

Housing is a basic need for human being, and is now becoming a burden for low and medium income group. Thus, we need cost effective housing and bamboo is the best building material, result for that as:

1. It is fastest-growing renewable natural building material.

2. The material is easily available & Eco friendly.

3. Bamboo is a viable (if not better!) alternative for steel, concrete and masonry as an independent building material.

4. It is cost effective and easy to work.

5. It can be easily bend, give desired shape and can provide joints to suit the construction.

6. Its enormous elasticity makes it a very useful building material in areas with very high risks of earthquakes.

7. Local available materials to some areas, which tries to carry the local tradition & vernacular Architecture of that place.

CHAPTER 2

ORIGIN AND CONSUMPTION

2.1Origin of bamboo

The plant known as bamboo to the entire world has been around and used for centuries. Records dating back more than seven thousand years talk about products made of bamboo such as arrows, paper, building materials, and books. Because of its origins, the current way it is used, and the economic sustainability of the plant, bamboo is an excellent resource.

While bamboo grows everywhere in the world except those places with extremely cold climates, it is thought to have originated in China, where the first use of bamboo to make every day items was recorded. This tall, hearty grass (yep, bamboo is technically grass) was used for as many products as they could manage, as it was a quickly renewable resource.

The species of bamboo that we know today evolved from prehistoric grasses between thirty and forty million years ago, long after the extinction of the dinosaurs. It then became the major food source for herbivorous animals, eventually becoming a food source for the modern human being as well.

Major bamboo research didn't begin until 1920, when the history of the plant was studied. It has shown that there are native species of bamboo almost everywhere, including the United States. It is now used widely in landscaping, but bamboo grows in two styles, clumping and running, which make it a widespread plant that can easily take over a garden if not cared for properly.

While bamboo was used frequently in the eastern hemisphere for housing for centuries, it is now only becoming popular in the western part of the world. More and more architects are seeing the beauty and intelligence in using bamboo for structures and other building material, and are becoming famous from the use of it in buildings.

2.2Various Consumption of Bamboo

Bamboo is adopted for various use and many products developed over the centuries by different cultures and communities. Unidirectional fibre fast growing and simultaneously high strength both in tensile and compression makes this material versatile to be adapted in simple to complex forms and designs. This quality of bamboo, given varied role in human cultural evolution than any other plant.

Use	**Percent Consumption**
Paper Pulp	**35.0**
Housing	**20.0**

Non-Residential	**5.0**
Rural uses	**20.0**
Fuel	**8.5**
Packing, including baskets	**5.0**
Transport	**1.5**
Furniture	**1.0**
Other wood industries	**1.0**
Others, including ladders etc.	**3.0**

CHAPTER 3

FORMS AND SPECIES OF BAMBOO

3.1Forms of Bamboo

- <u>TREE FORMS</u>

These are bamboos up to 35 metres in height, and with large or medium-sized, usually thick-walled, culms. Examples: Bambusa balcooa, Dendrocalamus hamiltonii, Dendrocalamus strictus.

- <u>STRAGGLER FORMS</u>

These are medium-sized bamboos up to 15 metres tall, with the tip of the culm arching or drooping down or climbing on adjacent trees. Example: Melocalamus compactiflorus (climbing bamboo).

- <u>REED FORMS</u>

These are medium-sized bamboos, which commonly grow as reed brakes; they have thin-walled culms up to 9 metres in height with long internodes. Example: Ochlandra travancorica.

- <u>SHRUB FORMS</u>

These are erect short forms of bamboo found in temperate species. They mainly occur at high altitudes, and have very thin culms that rise to a height of up to 5 metres. Examples: Arundinaria racemosa, Sinarundinaria falcata. Shrub forms are widespread in India's Himalayan Regions, near the snow line in Arunachal Pradesh, Uttaranchal, Himachal Pradesh and Sikkim. They also occur in the Ghats areas of Kerala and Karnataka.

3.2 Species of Bamboo used in construction

Bamboo Species	**Description**	**Culm height**	**Diameter**	**Internodes**	**Wall thickness**
Bambusa Balcoa	A tall bamboo, greyish green; nodes thickened with a whitish ring above, hairy below; branches from the lower nodes leafless and hard, mostly spreading, sometimes thorn-like; young shoots blackish- green, green with yellow , brown or orange tinged culm-sheath, clothed sparsely with dark brown hairs.	12-20 m	8-15 cm	20-40 cm	Thick- walled the diameter of the cavity about one-third of that of the culm

Bambusa Tulda	This species is an evergreen or deciduous, tufted, gregarious bamboo. Glabrous, green on maturity, sometimes streaked with yellow, almost un-branched below; inter- nodes white ring below the nodes slightly thickened, lower ones have fibrous roots.	7-23 m	5-10cm	4070cm	Thin walled
Bambusa Nutans	A medium sized graceful bamboo, loosely clumped, much-branched above, usually un-branched below, straight, green, smooth, not shining,	6 - 15m	5 - 10cm	25 - 45cm	Thick Walled

3.3Application based on Ages

- Less than 30 days it is good for eating.
- 6-9 months for baskets.
- 2-3 years bamboo boards or lamination.
- 3-6 years for construction.
- More than 6 years bamboo gradually loses strength up to 12 years old

CHAPTER4

BAMBOO AS A MATERIAL

4.1 Properties of bamboo

- <u>TENSILE STRENGTH</u>

  Bamboo is able to resist more tension than compression. The fibers of bamboo run axially are of highly elastic vascular bundle that has a high tensile strength. The tensile strength of these fibers is higher than that of steel, but it's not possible to construct connections that can transfer this tensile strength. Slimmer tubes are superior in this aspect too. Inside the silicate outer skin, axial parallel elastically fibers with a tensile strength up to 400 N/mm2 can be found. As a comparison, extremely strong wood fibers can resist a tension up to 50 N /mm2 .

- <u>COMPRESSIVE STRENGTH</u>

  Compared to the bigger tubes, slimmer ones have got, in relation to their cross-section, a higher compressive strength value. The slimmer tubes possess better material properties due to the fact that bigger tubes have got a minor part of the outer skin, which is very resistant in tension. The portion of lignin inside the culms affects compressive strength, whereas the high portion of cellulose influences the buckling and the tensile strength as it represents the building substance of the bamboo fibers.

- <u>ELASTIC MODULUS</u>

  The accumulation of highly strong fibers in the outer parts of the tube wall also work positive in connection with the elastic modulus like it does for the tension, shear and bending strength. The higher the elastic modulus, the higher is the quality of the bamboo. Enormous elasticity makes it a very useful building material in areas with very high risks of earthquakes.

- <u>ANISOTROPIC PROPERTIES</u>

  Bamboo is an anisotropic material. Properties in the longitudinal direction are completely different from those in the transversal direction. There are cellulose fibers in the longitudinal direction, which is strong and stiff and in the transverse direction there is lignin, which is soft and brittle.

- <u>SHRINKAGE</u>

  Bamboo shrinks more than wood when it loses water. The canes can tear apart at the nodes. Bamboo shrinks in a cross section of 10-16 % and a wall thickness of 15-17 %. Therefore it is necessary to take necessary measures to prevent water loss when used as a building material.

- <u>FIRE RESISTANCE</u>

  The fire resistance is very good because of the high content of silicate acid. Filled up with water, it can stand a temperature of 400° C while the water cooks inside. Fig 3: Fire resistance of bamboo cane when filled with water.

PROPERTIES	BAMBOO
Specific Gravity	0.575 to 0.655
Average Weight	0.625kg/m
Modulus of rupture	610 to 1600kg/cm2
Modulus of elasticity	1.5 to 2.0 x105kg/cm2
Ultimate compressive strength	794 to 864kg/cm2
Safe working stress in compression	105kg/cm2
Safe working stress in tension	160 to 350kg/cm2
Safe working stress in shear	115 to 180kg/cm2
Bond stress	5.6kg/cm2

4.2 Advantages of Bamboo

1. Bamboo is easy to cut, handle, repair, reposition and maintain, without the need for sophisticated tools or equipment.
2. Bamboo is non-polluting and does not have crusts or parts that can be considered waste. Instead of adding to the problems of polluting land-fills like conventional building waste, any part of the bamboo that is not used is recycled back into the earth as fertilizer or can be processed as bamboo charcoal.
3. Its circular form and hollow sections make bamboo a light building material, which is easy to handle, transport and store. Therefore, building with bamboo saves time.
4. Bamboo can be utilized for permanent and for temporary constructions.
5. In each of its nodes, bamboo has a dividing or transverse wall that maintains strength and allows bending thus preventing rupturing when bent. Because of this fantastic characteristic a bamboo construction offers superior earthquake-resistance.
6. The composition of the fibres in the walls of the bamboo allows it to be cut length-wise or cross cut in pieces of any length, using simple manual tools like the machete.
7. The natural surface of the bamboo is smooth, clean, with an attractive colour which does not require painting, scraping or polishing.
8. Besides being used as a structural element, bamboo can also serve other functions, such as: flooring, wall panelling, water pipes, drainage, and furniture.
9. Another advantage of building with bamboo is, that it can be used in combination with other types of construction materials, like reinforcing materials for foundations.
10. Advantages of bamboo as a building material
11. The flexible nature of bamboo allows it to be grown in any specific shape.
12. It has great shock absorbing capacity
13. Bamboo houses can withstand high speed winds of speeds of 170 mph.
14. It is light weight and hence easy to transport.
15. It is economical and readily available building material. Bamboo grows very fast and very tall too.

4.3 Disadvantages of Bamboo

• It requires preservation.

• Shaped by nature

• Durability- bamboo is subjected insects; for this reason, untreated viewed as temporary with an than 5 years.

• Jointing- although many jointing structural efficiency is low.

• Lack of design guidance and codes.

• Prone to catch fire very fast culms during wind, and is seen to cause forest fire.

4.4Application

4.4.1 Constructional applications

Bamboo is a versatile material because of its high strength-toweight ratio, easy workability and availability. Bamboo needs to be chemically treated due to their low natural durability. It can be used in different ways for roof structure as purlins, rafters and reapers, for flooring, doors and windows, walling, ceiling, man-hole covers etc.

- **Bamboo Trusses**: The bamboo has strength comparable to that of Teak and Sal. A frame is made using bamboo rafters, purlins etc for fixing the roof.

Fig 4.1: Example of Bamboo truss

Fig4.2 : Example of Bamboo house

- **Bamboo Roofs Skeleton**: It consists of bamboo truss or rafters over which solid bamboo purlins are laid and lashed to the rafter by means of G.I.wire. A mesh of halved bamboo is made and is lashed to the purlins to cover the roof.

Fig 4.3: Bamboo roofing

Fig 4.4: Bamboo shingles

- **Bamboo walling/ceiling**: As the bamboo material is light in weight it is beneficial for earthquake prone areas as its chances of falling are very less due to flexibility and even if it falls it can be re-erected easily with less human and property loss with least efforts and minimum cost. Bamboo walls can be constructed in different ways like

➢ Whole stem halved or strips of bamboo can nailed to one or both the sides of the bamboo frame.

➢ Split bamboo mats can be fastened to the bamboo posts or mats can be woven, mud can also be applied to both sides of such mats.

➢ Bamboo strips nailed to bamboo frame or posts for interior walling.

- Cement or lime plastering can be done on the mud covering for better appearance and hygiene.
  It has been found that the bamboo in the vertical position is more durable than in horizontal direction. For partition walls only single layer of bamboo strips are used.

Fig 4.5: Bamboo walling/ceiling

Fig 4.6: Bamboo mat wall

- **Bamboo Doors and Windows**: Bamboo replace timber frames appropriate to function. mat shutters fixed to bamboo frame bamboo board fixed to the frame which wall can be used as door. Small framed to the top in the wall can serve as windows.

- **Bamboo Flooring**: Bamboo can be used material due to its better wear and tear resistance resilience properties. Whole culms act and the floor covering is done using bamboo boards, mats etc by means of wire to the frame.

- **Reed Boards**: Reed boards are made by reed at high temperatures. These reed boards elements like flooring, walls, ceiling and can also be used for partitions, doors, windows

Fig 4.7: Bamboo board

- **Scaffolding**: Bamboo poles used as scaffolding in high strength and resilience. The replaced with bamboo culms the vertical culms.

Fig 4.8: Bamboo scaffolding

4.4.2 Non-Constructional applications

1. Bamboo is used for medicinal purposes.

In China, ingredients from the black bamboo shoot help treat kidney diseases. Roots and leaves have also been used to treat venereal diseases and cancer. According to reports in a small village in Indonesia, water from the culm (the side branches) is used to treat diseases of the bone effectively.

2. Bamboo is used to make clothes.

Bamboo– it's the new hemp. T-shirts, socks, robes, boxers.

3. Bamboo is used to make accessories.

Bamboo is also used to make necklaces, bracelets, earrings, and other types of jewellery.

4. Bamboo is used to feed people and animals.

Bamboo shoots are used mainly in Asian food preparations. In Japan, the antioxidant properties of the bamboo skin prevent bacterial growth, and are used as natural food preservatives. Bamboo leaves and shoots are also the staple diet of pandas and elephants.

5. Bamboo is used to make furniture.

Beautiful and intricately crafted beds, chairs and tables are made from bamboo.

6. Bamboo is used to make durable utensils.

Cups and saucers, spoons and ladles can all be made from bamboo.

7. Bamboo is used to make musical instruments.

Flutes, drums, didgeridoos, even saxophones– bamboo is versatile when it comes to making instruments.

CHAPTER 5

HARVESTING AND GRADING

5.1Harvesting of Bamboo

It is important to follow good harvesting practices to ensure sustainable yields:

- Do not cut culms younger than three years.
- Do not harvest in the rainy season. In India it is advisable to harvest in the winter season when the soluble sugars are the lowest (Joseph 1958).
- Do not harvest from a flowering grove.
- Do not cut lower than the second node, or higher than 300mm above the ground.
- Remove branches, culm tips, and all harvest debris. Waste material obstructs growth, encourages disease and makes later harvests more difficult.
- Retain leaves for mulch. Their 6% silica helps harden later culms.
- Leave a minimum of six mature culms uncut in each clump to sustain grove vitality and ensure a steady yield. As new culms grow around the edge a solution is to use the horseshoe method by cutting a narrow path into the grove and harvest the mature culms from within.
- The best natural protection will result by harvesting mature culms during the winter months, leaving them upright for a few days after harvesting and then soaking them in water for 4-12 weeks.

5.2 Grading of Bamboo

The shape size and quality of bamboo can vary greatly even within a given species. The following grading rules will help in selecting the best material for construction.

- Straightness: - The bamboo culm should be as straight as possible. A line stretched between the tip and butt ends should not fall outside of the culm.

- Taper- or change in diameter over length should be kept to a minimum. A maximum taper of 10mm per meter is acceptable for lengths up to 3 meters.

- Nodes- nodes are the strong points in the culm and should be used to advantage especially at critical joints.

- Splitting- it is a good practice to cut bamboo lengths longer than required to al- low cutting away of split ends that can have a serious effect on the strength of the bamboo.

- Insect/fungal attack- bamboo culms that show signs of insect or fungi attack should be avoided.

5.3 Selection and Size of Bamboo

- Only bamboos with at least three-year maturity shall be used in construction.
- For the main structural elements of the house particularly posts and beams, Bambusa Balcoa or similar in the region can be used.
- For roofing elements like rafters and purlins Bambusa Tulda or Bambusa Balcoa or similar in the can be used.
- Bambusa Nutans or other bamboos shall be used for the lattice work in wattle and daub walls.
- Columns and roof members should be a minimum of 70-100 mm in diameter at thin end of bamboo and wall thickness of bamboo not less than 10-12 mm. The distance between nodes (internodes length) should not exceed 300-600 mm.

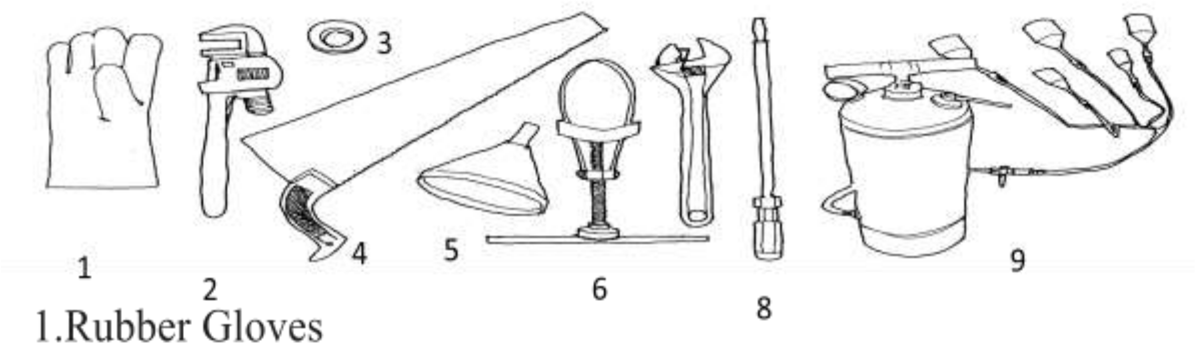
CHAPTER 6

BAMBOO TREATMENT

6.1 Need of treatment

Bamboo has very little natural toxicity and therefore, is easily prone to fungi and insect attack. The objective of treatment is to remove the starch and other carbohydrates (soluble sugars) that attract fungi and insects and replace it with chemicals in the cells of the bamboo thereby increasing the life of the bamboo. Well treated bamboo has a life expectancy of 50 years without losing its structural properties. The efficiency of the chemical treatment is influenced by anatomical structure of the bamboo culm. There are no radial pathways in the culm tissue, like the ray cells in wood, and lateral cell-to-cell movement of preservative depends on a slow diffusion process. Freshly cut culms are easier to treat due to the water-filled cells providing a continuous transportation channel. Both ends of the culms should be cut up to the next node in order to remove the blockage of vessels. Whereas there are several indigenous treatment systems like lime wash and smoking of bamboo, chemical treatments are known to have longer effect against fungi and insects. The use of water as a solvent to carry the preservatives into the cells of the bamboo. Water-soluble salts are dissolved in water; on treatment the water evaporates leaving the salts inside the bamboo. The recommended salts are boric acid, borax and copper sulphate. Boron salts are effective against borers, termites and fungi (except soft rot fungi). High concentrations of salts have fire retardant properties as well. They are not toxic.

6.2 Tools required in treatment



1.Rubber Gloves
2.Adjustable Wrench
3.Tape
4.Hardwood back saw
5.Funnel
6.Clamp
7.Adjustable Spanner
8.Screwdriver
9.Hand Operated Pump

6.3 Protection of bamboo

As with all timbers, the service life of bamboo is governed by its exposure position and durability, which together dictate the rate of attack by biological agents. In general it has been found that untreated bamboo has an average life of l-3 years where it is directly exposed to soil and atmosphere. When used under cover, the life expectancy of bamboo increases to 4-7 years. Under very favourable circumstances, the service life of bamboo can be as high as 10-I 5 years, for example when used for rafters and internal framing.

The chemical constituents of bamboo are known to vary greatly depending on species, position within the culm and the age of the culm. In very general terms bamboo consists of 50-70% hemicellulose, 30% pentosans, and 20-25% lignin 90% of the hemicellulose is xylan with a structure intermediate between hardwood and softwood xylans. The structure of the lignin present in bamboo is unique, and undergoes changes during the elongation and ageing of the culm. Bamboo is known to be rich in silica (0.5-4%), but almost the entire silica content is located in the epidermis layers, with hardly any silica in the rest of the wall. Bamboo also has minor amounts of resins, waxes and tannins. However, none of these have sufficient toxicity to impart much natural durability to the culms. Laboratory tests have indicated that bamboo is more prone to both soft rot and white rot attack than to brown rot.

In bamboo, soluble sugars form the principal nutrients for degrading organisms. Therefore, if these can be by non-chemical removed from the culms, the risk of decay is significantly reduced. A number of methods for lowering the sugar content have been adopted:

- Felling during low sugar content season
- Felling of mature bamboo
- Post-harvesting transpiration
- Water soaking

These methods are outlined below.

<u>Felling of bamboo during low sugar content season.</u>

Sugar content in almost all plants varies according to season. In India, for example, it is higher in spring than in winter. It is therefore advisable to harvest bamboo during the winter months.

<u>Felling of mature bamboo when sugar content is low</u>

Sugar content in bamboo varies with age and is lowest during the first year. However, the usefulness of very young bamboos is limited due to their low strength and yield.

<u>Post-harvesting transpiration of bamboo culm</u>

Sugar content in bamboo can also be reduced by keeping culms upright or leaning them against trees for a few days, with the branches and leaves intact. Parenchyma cells in plants continue to live for some time, even after felling. During this period, the stored food materials are utilised and thus the sugar content of the bamboo is lowered.

Water soaking of bamboo

The soaking method is commonly used in many Asian and African countries and consists of submerging freshly cut culms for 4-12 weeks in stagnant or running water, or mud. Generally, stones are placed on top of the bamboo to keep it submerged during the soaking period.
During the process of soaking, the starch content of the parenchyma cells of the culm is reduced by dilution. As a result it is claimed that the bamboo is more resistant to wood borers. It is important to realise that treatment using this method does not confer added protection to the bamboo. It merely reduces the inherent susceptibility of the material.

Fig 6.1 Water soaking of bamboo

6.4 Preservation of bamboo

Bamboo is subject to attack by micro-organisms and insects in almost any construction application. Unfortunately, like most lignocellulosic materials, bamboo has very low resistance to biological degrading agents. The service life is therefore mainly determined by the rate of attack.
A variety of methods to improve the durability of bamboo have, however, been developed. Several of these techniques are described here with the aim of providing helpful guidelines to users.

Non-chemical of preservation

Non-chemical methods of preservation, otherwise (traditional) methods known as traditional methods are widely used by villagers and can be undertaken without the use of any special or sophisticated plant and equipment or significant increase in costs. Typical traditional methods include:

- Smoking
- Whitewashing
- Elevated construction

Smoking method

Traditionally, bamboo culms are placed above fireplaces inside the house so that the smoke and heat rises up and both dries and blackens the culms. It is possible that the process produces some toxic agents that provide a degree of protection. Alternatively, the heat generated by the fire could possibly destroy or reduce the starch content of the parenchyma cells by pyrolysis.

Whitewashing method

Bamboo culms and bamboo mats for housing construction are often painted with slaked lime. This is carried out mainly to enhance the appearance, but there is also an expectation that the process will prolong the life of the bamboo structure by preventing moisture entering the culms. It is possible that water or moisture absorption is delayed or in some cases 9 prevented which will provide a higher resistance to fungal attack. However, there remains a question as to whether the bamboo can be weakened over time by such an alkaline treatment.
In Indonesia, bamboo mats are tarred and later sprinkled with a layer of sand. When this is dry, up to four coats of whitewash are applied. Plastering is also a common practice, using cow dung mixed with either lime or mortar.

Elevated construction method

The elevated construction method is designed to prevent the bamboo coming into direct contact with the ground by placing the bamboo posts on stones or preconstructed cement walls (see Foundations in Chapter 5). In this way the bamboo can be kept dry, thereby reducing deterioration due to fungal attack. Good air circulation throughout the structure is also necessary. Furthermore, treatment of the bamboo with water repellent formulations reduces the hygroscopic properties with the effect that moulds are discouraged.

Chemical treatment methods

Bamboo culms have a number of important chemical and anatomical differences from hardwoods and softwoods. These differences have a significant influence on the efficacy of treatments applied to bamboo. Three major anatomical differences that influence the penetration of preservative solution between bamboo culms and hardwoods and softwoods can be identified:

- The ray cells in hardwoods and softwoods are linked to form a radial transport system. These structures are absent from bamboo where there are no cells to facilitate an easy movement of liquids in the radial direction.

- The vessels, which run axially between the internodes, are isolated from each other by parenchyma cells. The vessels branch extensively within the node region of the culms.There is a gradation in vessel size - small at the periphery of the culm and larger in the centre.

- The outside wall of the culm is lined with epidermal cells. The inner layer of cells is heavily lignified and appears thicker. The outermost cells of the culm have a waxy coating and the inside of the culm is composed of numerous sclerenchyma cells.

This anatomy and structure mean that there is very little opportunity for radial movement of liquids. Therefore, preservative penetration pathways exist only at the cut culm ends and, to a lesser extent, at the scars around the nodes.

The penetration of liquids into the culm takes place through the vessels in the axial direction, from end to end. To ensure a satisfactory treatment process for the bamboo it is necessary for the treatment solution to diffuse from the vessels into the surrounding fibres and parenchyma cells. The vessels only account for about 5-10% of the barn boo cross section. Thus even when the vessels are filled to saturation point, the bamboo can still be vulnerable to fungal or insect attack if the preservative does not diffuse sufficiently into the main tissue of the culm.

When compared to traditional methods, the use of chemicals for the preservative treatment of bamboo is more effective in providing protection against biological deterioration. However, chemical preservatives are invariably toxic and due care and attention should be exercised whenever they are used.

The following chemical treatment techniques are described below:
- Butt treatment
- Open tank method for cold soaking
- Boucherie method
- Modified Boucherie method
- Pressure treatment
- l-lot and cold bath process
- Glue line treatment

- <u>Butt treatment</u>

The butt ends of freshly cut culms, with the branches and leaves intact, are placed in a drum containing the preservative. The continued transpiration of the leaves draws the chemical solution into the vessels of the culm. The method is used for the treatment of shorter culms with a high moisture content (green or freshly cut). The treatment process is very slow and often the vessels do not take up enough of the liquid to preserve, by diffusion, the surrounding fibres and parenchyma cells. The preservative in the barrel must be replenished regularly in order to maintain the desired level. When the treatment has been completed, care should be taken in the disposal of the contaminated foliage. Butt treatment is usually applied to bamboo posts. Such posts are often used for fruit supporting sticks in banana plantations.

- <u>Open tank method for cold soaking</u>

The open tank treatment method is economical, simple and provides good effective protection for bamboo. Culms, which have been prepared to size, are submerged in a solution of a water-soluble preservative for a period of several days. The solution enters the culm through the ends and sides by means of diffusion.
Immature bamboo culms can be penetrated by preservative solution more easily than mature culms. This is probably largely due to the increased lignifications present in mature culms.
Also, penetration is easier with dried culms than with freshly cut (green) culms. Green culms are difficult to treat because they are likely to have a moisture content in excess of 100%. As a result there will be little or no room for additional liquid within the culm. Preservative

concentration should therefore be higher when green culms are being treated. Following soaking, the culms should be wrapped to enable further diffusion of the preservative.
Since the inner skin of the culm is slightly more permeable than the outer skin, split culms can be 13 treated more effectively than round culms. Some success in the treatment of bamboo has been obtained by punching the internodes region of the culms. Admittedly, this operation is probably not practicable on a commercial basis. Mechanical scratching of the outer skin of the culm can help to speed up the penetration, especially where slow diffusing preservatives are used.
The time of treatment can be reduced considerably by using the hot dipping or the hot and cold method (see Hot and cold bath process). A double treatment can also be applied although this technique is fraught with commercial and technical difficulties that effectively prevent its use in practice.

- Boucherie method

The Boucherie method requires the culms to be in a green condition. The water-transporting part of the culm can be penetrated completely and the treatment itself is applied by an inexpensive installation.
Preservative is fed by gravity from a container placed at a higher level than the culm through pipes into its base end (figure 3). The culms are fastened to the tubes by rubber sheaths and clamps. It is also possible to hang the culm vertically and to scratch the inner wall of the top internodes in order to use it as a reservoir for treatment. The treatment is terminated when the solution at the dripping end shows a sufficiently high concentration of chemicals.
The duration and success of the treatment process depends on the type of preservative, its adhesion and precipitation, and the swelling influences on the cell wall. Preservatives with high adhesion can stop flowing through the culm in a relatively short period of time, blocking the vessels and pits. Also, if the moisture content of the culm is too low, water is withdrawn from the preservative solution causing precipitation and blocking the vessels. The best results are therefore obtained during or shortly after the rainy season, using younger culms with a higher moisture content.
Following the treatment process, the run-through preservative solution can be filtered and re-used. Burial in the ground is also common, but this practice is clearly undesirable and effort should be directed at 14 providing alternative solutions to the problem of disposal. Allowing the bamboo to dry slowly in the shade for a period of at least two weeks after treatment ensures that the solution diffuses into all of the tissue surrounding the vessels.

- Modified Boucherie method

The basic Boucherie method has been improved by the introduction of pneumatic pressure over the preservative fluid in a reservoir, for example by using an air pump or electric pump. The preservative is forced axially through the culm by the air pressure in the reservoir. In this way the time of treatment can be reduced from several days to 3-8 hours. In other respects the process is similar to that for the basic Boucherie method.

- Pressure treatment method

Pressure treatment, using either creosote or water borne preservatives, offers the best method of preservation for bamboo culms. The applied pressure ranges from around 0.5-l .5N/mm2 (5-15 bar) and as such requires special plant and equipment. Accordingly, costs are high, but

a service life of up to 15 years can be expected from adequately treated bamboo when used in the open and in contact with the ground.
In order to achieve sufficient chemical penetration and absorption, the culms must be air dried prior to treatment. Also, since the inner skin of the culm is slightly more permeable than the outer skin, split culms can be treated more effectively than in the round.

- Hot and cold bath process

When pressure treatment facilities are not available the hot and cold bath process offers an acceptable alternative. The bamboo is submerged in a tank of preservative which is then heated, either directly over a fire or indirectly by means of steel coils in the tank. The bath temperature is raised to about 90°C held at that temperature for about 30 minutes and then allowed to cool.
When using preservatives which can precipitate when heated, it is best to pre-heat the bamboo in a suitable liquid, such as water, and then transfer the hot bamboo into a separate tank containing cold preservative. In order to assist the effectiveness of the treatment, the impermeable diaphragm of the nodes should be cleanly bored through, thus providing uninterrupted access throughout the culm for the preservative.
When the treatment process has been completed, the bamboo should be allowed to dry slowly to allow further diffusion of the preservative to take place.

- Glue line treatment

Glue line treatment is specific to the manufacture of bamboo mat board and involves adding preservatives to the glue during manufacture. This process is also more economical than using adhesives of a higher solid content. Additives which have been shown to provide effective preservative treatment without impairing the bond strength of the mat board include 1% Chlordane or 1% sodium octaborate tetrahydrate with a 1:2 diluted PF solution containing 17% solid content .

- Fire retardant treatment

Fire presents a potential hazard in any form of construction, but the risk is especially high in bamboo buildings. The combination of bamboo and matting, and the tendency of the internodes to burst causes rapid fire spread. The danger is increased when the joint lashings are destroyed, which can cause catastrophic collapse of the building.
It is, however, possible to treat bamboo with a combination of preservative and fire retardant chemicals. The process is normally carried out by pressure treatment. A commonly used chemical composition is shown below:
Combined preservative and fire retardant treatment
Water to 100 parts
Ammonium phosphate 3 parts
Boric acid 3 parts
Copper sulphate 1 part
Zinc chloride 5 parts
Sodium dichromate 3 parts
The cost of fire retardant treatment is generally high and is therefore often considered inappropriate. The importance of finding a suitable and cost effective treatment, which will provide combined protection against bio-degrade and fire, is a necessary area for further

research. Boron based retardants offer a possible solution, with the added advantage of being relatively safe to use.

- Drying of bamboo

Green bamboo can have a moisture content of 100-150%, depending on the species, area of growth and felling season. The chemical composition of bamboo results in a comparatively higher hygroscopicity than wood. Additional problems in the drying of bamboo occur because the material lacks an efficient radial transport system and possesses a waxy coating. Therefore, the major pathway for the loss of moisture is from the ends of the culms .

The liability to biological degradation and to deformation owing to excessive shrinkage (which occurs even above the fibre saturation point) necessitates quick drying of bamboo.

- Kiln drying

At the present level of drying technology, kiln drying of round bamboo is not feasible. Even mild drying conditions can increase the incidence of cracking and collapse. Split bamboo can, however, be kiln dried.

- Air drying

Air drying takes 6-12 weeks, depending on the initial moisture content and wall thickness. Collapse can be a major problem in some species, owing to excessive and non-uniform shrinkage of the culm. However, problems are mostly seen in drying of immature culms.

Air drying of split bamboo does not pose any problems, even in direct sunlight. Split bamboo standing upright dries faster than when stacked horizontally. Round bamboo can also be dried standing upright or in stacks, using bamboo crossers of appropriate diameter.

CHAPTER 7

JOINTING TECHNIQUES

7.1Traditional joints

Traditional jointing methods rely principally on lashing or tying, with or without pegs or dowels. The basic joint types are:

- Spliced joints
- Orthogonal joints
- Angled joints
- Through joints

- Spliced joints

Two (or more) culms are joined in line to form longer members. Splicing is usually carried out in one of four ways: Full-lapping: Full section culms are overlapped by at least one internodes and tied together in two or three places. For greater strength, bamboo or hardwood dowels can also be used. One disadvantage of this joint is that it quite bulky.

Catnapping: Culms to be joined should be of similar diameter and cut longitudinally to half depth over at least one internodes length. The components are fixed as for the full lap joint.

Butt joint with side plates: Culms of similar diameter are laid end to end. Side plates, made from quarter-round culms of slightly larger diameter and two or more internodes long, are fixed over the joint by tying and, usually, dowelling

Sleeves and inserts: Short lengths of bamboo of appropriate diameter are used either externally or internally to join two culms together Variations on the basic splice joints

- Orthogonal joints

These are the commonest types of joint, where two or more members meet or cross at right angles. The basic configurations are:

❖ Butt joint
❖ Crossover joint

❖ *Butt joint:*

The simplest form of butt joint comprises a horizontal member supported directly on top of a 66 vertical member. Typical examples would be roof eaves beams on posts or floor beams on intermediate posts. The top of the post can be cut to form a saddle to ensure secure seating of the beam and good load transfer. The saddle should be close to a node to reduce the risk of splitting. A variation on the saddle involves the cutting of a long, integral tongue which is bent right over the transverse member and tied back. Other details include square notched ends, side plates and tenons.The saddle detail can also be applied to horizontal framing. Variations include the double joint and the double bent joint. For the single butt joint, improved stiffness can be achieved by the use of a hardwood tenon and key. The ends of the horizontal members can be cut to form horns or integral tenons to be located in corresponding mortises in the post. However, for both these methods, splitting is a risk. Bamboo inserts also offer a solution, but this requires the cutting of an even larger hole in the vertical member.

❖ *Crossover joint*

These are formed when two or more members cross at right angles. In the horizontal plane, the function of the joint is mainly to locate the members and to provide a degree of lateral stability. Examples would include joist to beam connections which can be effected simply by tying. Where the crossover is in the vertical plane, the joint could be load bearing, as in the connection of floor beams to posts. Simple tying is an option, although improved stability can be achieved by supporting the beam either on the stump of a branch at a node or on a short length of culm tied independently to the post. The tendency to slip can be reduced by insetting the supporting piece into the post, or by dowelling . Most crossover joints are also suitable for connecting inclined members, for example purlin to rafter connections. Variations on these types of joint are shown in figure

- Angled joints

Angled joints are formed where two or more members meet or cross other than at right angles. For butt joints, the ends of the member can be shaped to fit in much the same way as an orthogonal saddle joint. Horns (integral tenons) might also be used but fabrication is time consuming. Examples would include web members in trusses Angled crossovers can be dealt with in much the same way as orthogonal crossovers, for example the diagonal bracing in the plane of a roof.

- Through joints

Members of differing diameters can be joined by passing the smaller through a hole drilled in the larger. The joint is secured by a dowel passing through both members Applications for this type of joint might include partitions, doors and window framing
.

7.2 Improved traditional joints

The mechanical performance of traditional bamboo joints can be improved by the adoption of the following procedures: Form joints at or near nodes: nodes are more resistant to splitting than internodes. It is therefore good practice to make joints as close to nodes as possible. For example, in the simple saddle joint, the saddle should be formed directly above a node. Minimise on holes: it is generally accepted that holes, cuts and notches will reduce the ultimate strength of a bamboo culm. If a hole is made in a culm (for a peg, dowel, mortise, inset support or insert) this should be as close as possible to the node, paying particular attention to the direction of the applied force. Furthermore, whenever possible holes should be round or radiuses rather than square cut as these are less likely to propagate splits. Use seasoned culms: seasoned rather than green bamboo should be used for two reasons. Firstly, bamboo shrinks on drying and this will generally cause joints to loosen. Secondly, drying splits can form which could further weaken the assembly. Reinforce against splitting and crushing: tight binding, especially with wire, can in itself offer good resistance to splitting. In trusses, the use of quarter-round bamboo bearing plates reduces the risk of crushing of the chords by the compression webs. Improve durability, preservative treatment of the bamboo and protection from wetting by good detailing will increase the life of the joint. The use of wire is in many cases preferable to bamboo lashings or rope as it is not subject to insect attack.

7.3 Recent developments

By building on traditional methods and exploiting the strengths and advantages of bamboo, a number of jointing techniques have been developed which offer more structurally efficient solutions to jointing problems. However, their adoption and suitability will depend to a large extent on the cost and availability of materials, equipment and skilled labour.

Gusset plates:

Plywood or solid timber side plates, applied to joint assemblies in trusses for example, and fixed with either bolts or bamboo pegs, show improved stiffness and strength when compared with traditional jointing methods.

lTCR joint:

This is a simple joint developed by the lnstitutoTecnologico in Costa Rica and a variation on the gusset principle. It comprises a plywood insert glued into slots sawn into the ends of the bamboo elements to be joined (figure 70). During curing, the assembly can be readily clamped together using Jubilee clips. A disadvantage of this jointing method is that the ends of the culms remain open. It is also difficult to achieve good and consistent quality glued joints in the field.

Arce joint:

This technique, relies on the use of wooden inserts to reinforce the end of the bamboo and to form the joint. Rectangular blocks, possibly cut from plantation thinning, are turned down at one end to fit inside the culm, which can be reamed to a uniform diameter. Slots are sawn into the culm in order to accommodate slight variations in size. The blocks, when glued in place, can be connected using conventional wood fixings (e.g. nails and screws), perhaps in combination with steel plates

Filled joint:

This is a modification of the Arce joint, developed by Morisco and Mardjono (1995). The inner surfaces of the culms to be joined are cleaned with a wire brush. A gap filling resin is used to bond a wooden plug inside the culms. Holes can then be drilled and the assembly bolted together. Cement mortar can be used in place of a timber plug, in which case the bolts are placed before the mortar is poured. Either system can be used in conjunction with steel or plywood gusset plates

Das clamp:

Steel bands with integral bolt eyes are fitted around bamboo sections. The action of bolting two or more elements together tightens the clamps around the culms Additional steel straps can be used if required. This method, designed by the Bhagalpur College of Engineering in India, would be best suited to connections in one plane, e.g. trusses. Herbert shear pin connector: In this method, developed at the UK Building Research Establishment, bamboo elements are bolted together at sections reinforced with thin gauge steel sleeves. The sleeves are fixed using a series of small diameter pins (pop rivets were found to be more effective than screws and nails) which act to transfer the load to the bamboo .Although strong, the joint is bulky and laterally unstable as in-plane connections are not possible. Other methods of fixing suggested include binding, rather than pinning, and the use of sleeves with integral teeth. Gutierrez joint: this technique is interesting because it exploits the compressive and bending strength of bamboo but does not require it to transmit shear or tensile forces. This is achieved by passing a steel bar through the centre of the element and welding. The protruding-ends of shear pin connector the steel bars can then be welded together to make a joint.

Steel or plastic insert connectors:
Angled joints can be formed by tightening bamboo elements with slotted ends around prefabricated tubular steel connectors using Jubilee clips. Expanding plastic inserts have been used for straight connections
The following jointing methods would not truly constitute new developments but should nevertheless be noted

Nails and screws:
the fixing of small elements to larger elements (e.g. floor decking to joists) or the assembly of joint components using splice plates can be effected by the use of nails and screws but, with few exceptions, this requires pre-drilling due to the tendency of the bamboo to split. Nailed joints also have a tendency to loosen, making for inefficient load transfer and high deformations.

Steel straps:
To help resist wind uplift forces, steel straps can be used in conjunction with nails to anchor major components, for example trusses to posts. The straps, if tightly applied, will help to counteract the effects of splitting.

CHAPTER 8

CONSTRUCTION METHODS

The majority of bamboo construction relates to rural community needs in developing countries. As such, domestic housing predominates and, in accordance with their rural origins, these buildings are often simple in design and construction relying on a living tradition of local skills and methods. Other common types of construction include farm and school buildings and bridges.
Further applications of bamboo relevant to construction include its use as scaffolding, water piping, and as shuttering and reinforcement for concrete. In addition, the potential number of construction applications has been increased by the recent development of a variety of bamboo based panels.

Domestic housing and small building
There is a long-standing tradition of bamboo, dating back many hundreds of years. Different cultures have found in this material an economical system of building, offering sound yet light and easily replaceable forms of shelter. The methods, activities and tools are often simple, straightforward and accessible to even the young and unskilled. Bamboo can be used to make all the components of small buildings, both structural and non-structural, with the exception of fireplaces and chimneys. It is, however, often used in conjunction with other materials, cost and availability permitting.
A typical building comprises the following elements:

- Foundations
- Floors
- Walls
- Roof
- Doors and windows
- Water pipes

Bamboo building construction is characterised by a structural frame approach similar to that applied in traditional timber frame design and construction. In this case, the floor, wall and roof elements are interconnected and often one dependent on the other for overall stability. The need to control lateral deformations inherent in some traditional forms of building. The adequacy and suitability of the building for occupancy will also depend to a large extent on good detailing, for example to help prevent water and moisture ingress, fungal attack and vermin infestation. All of the above features are dealt with in the following sections.

8.1 FOUNDATION

The types of bamboo foundation identified are:

- Bamboo in direct ground contact
- Bamboo on rock or preformed concrete footings
- Bamboo incorporated into concrete footings
- Composite bamboo/concrete columns
- Bamboo reinforced concrete
- Bamboo piles

Bamboo in direct ground contact

Bamboo, either on the surface or buried, can decay within six months to two years. Preservative treatment is therefore recommended. For strength and stability, large diameter thick walled sections of bamboo with closely spaced nodes should be used. Where these are not available, smaller sections can be tied together.

Bamboo on rock or preformed concrete footings

Ideally, where bamboo is being used for bearings it should be placed out of ground contact of footings either rock or preformed concrete. As above, the largest and stiffest sections of bamboo should be used.

Bamboo incorporated into concrete footings

The third approach is to incorporate the bamboo directly into the concrete footing. This can take the form of single posts or strip footings.

Composite bamboo/concrete columns

An innovative development involves the casting of a extension to a bamboo post using a plastic columns tube of the same diameter. The result is a bamboo post with an integral, durable foundation.

Bamboo piles

Bamboo piles have been used successfully to stabilise soft soils and reduce building settlement. Treated split bamboo piles 8m long and 80 to 90mm in diameter are filled with coconut coir strands wrapped with jute. The sections are then tied with wire. After installation of the piles at 2m centres by drop hammer, the area is covered with a 2.5m surcharge of sandy material.

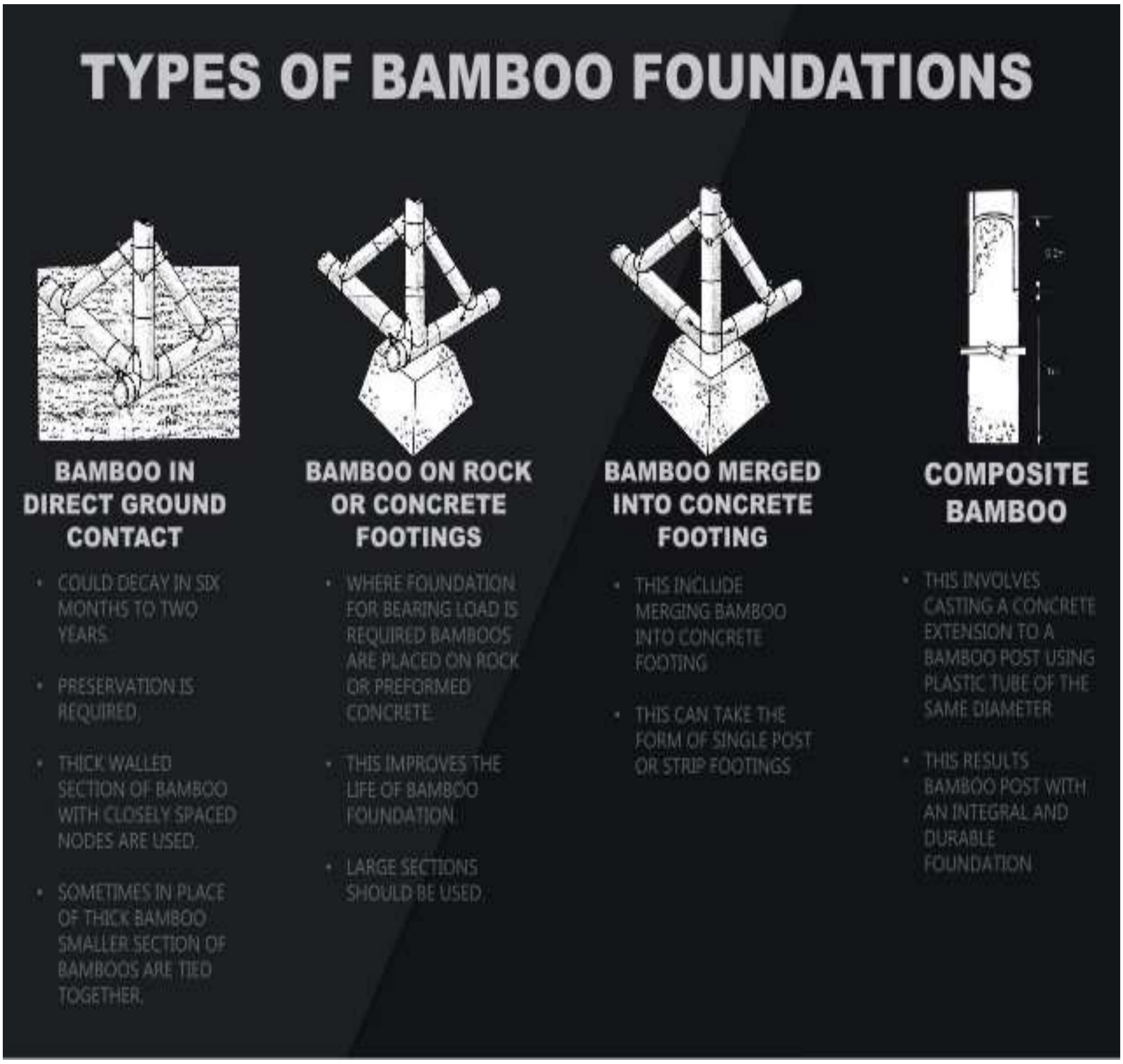


Fig 8.1 Types of Foundation

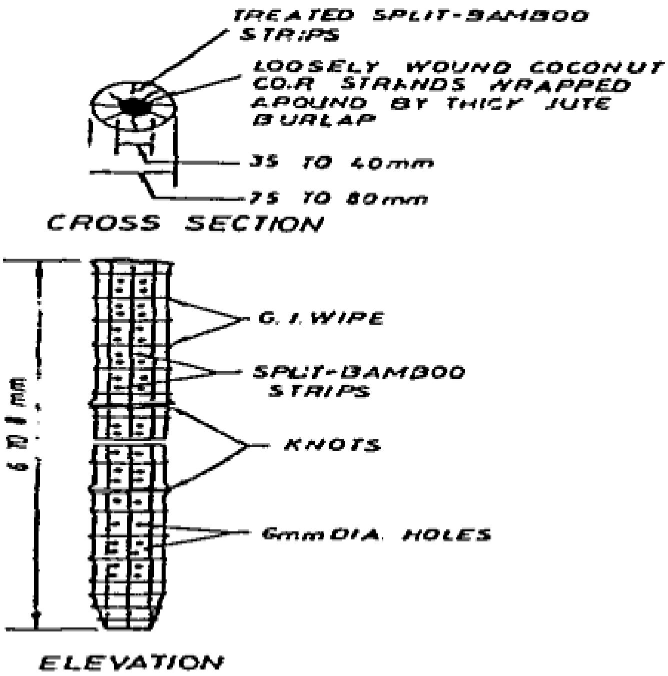


Fig. 1 Split-bamboo piles

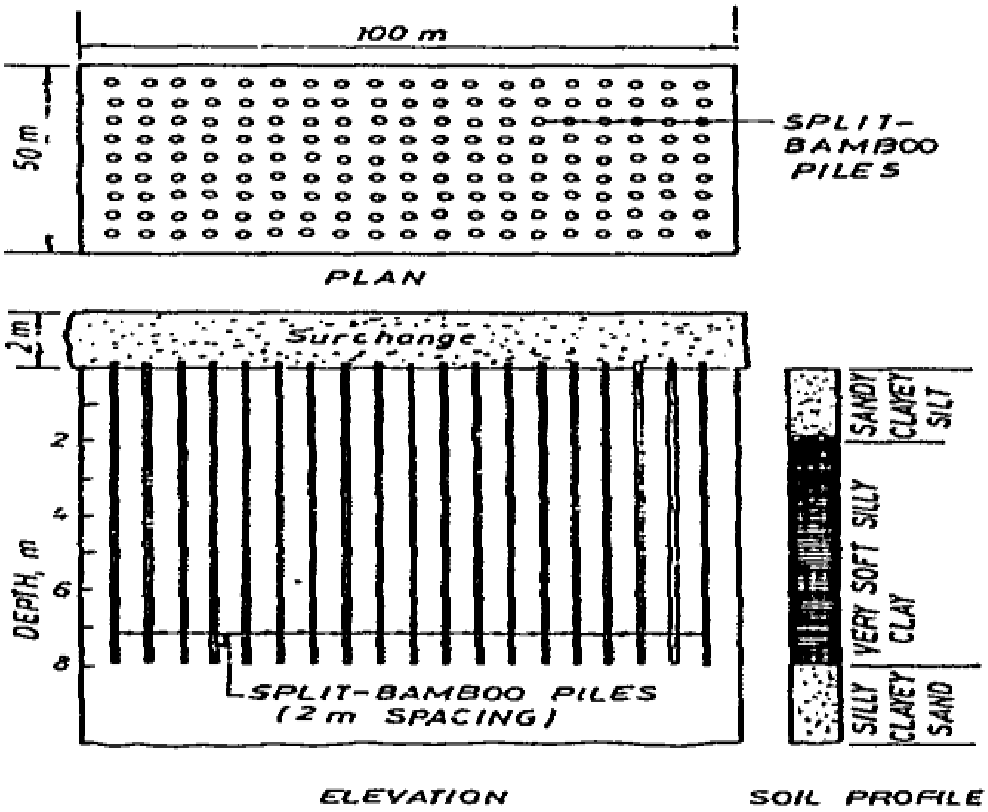


Fig 8.2 Bamboo piles

8.2 FLOORS

The floor of a bamboo building may be at ground level, and therefore consist only of compacted earth, with or without a covering of bamboo matting. However, the preferred solution is to raise the floor above the ground creating a stilt type of construction. This improves comfort and hygiene and can provide a covered storage area below the floor. A minimum ground to floor distance of 500mm is recommended to allow for inspection. When the floor is elevated, it becomes an integral part of the structural framework of the building. The floor will comprise:

Floor structure

Floors normally consist of bamboo beams fixed to strip footings or to foundation posts. The beams therefore run around the perimeter of the building. Where the beams are fixed to posts, careful attention to jointing is required. Beams and columns are generally around 100mm in diameter. Bamboo joists then span in the shortest direction across the perimeter beams. The joists are often laid on the beams without fixing, but some form of mechanical connection is recommended. Depending on the form of floor decking, secondary joists, often taking the form of split culms, may be required. Joist diameters are in the order of 70mm. Joist centres are typically 300 to 400mm, or up to 500mm if secondary joists are used.

Floor decking

Bamboo floor decking can take one of the following forms:

- Small bamboo culms
- Split bamboo
- Flattened bamboo (bamboo boards)

Small bamboo culms

Small diameter culms are tied or nailed directly to the joists.

Split bamboo

Bamboo culms are split along their length into strips several centimetres wide. They can be fixed directly to the joists in the case of tying or nailing, or a timber batten can be fixed to the joist beforehand to facilitate nailing.

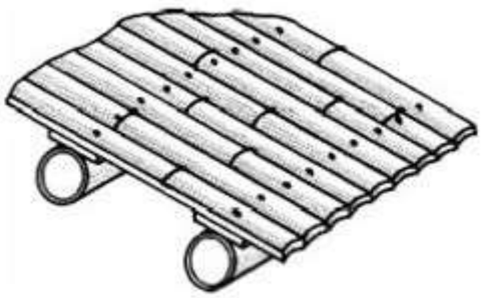


Fig 8.3 Split bamboo floor decking

Flattened bamboo (bamboo boards)

These are formed by splitting green bamboo culms, removing the diaphragms then unrolling and flattening them. The resulting board is laid across the joists and fixed by nailing or tying The surface finish of these three types of floor deck is, understandably, uneven and difficult to clean. They can be Screeded with cement mortar for reasons of hygiene and comfort.

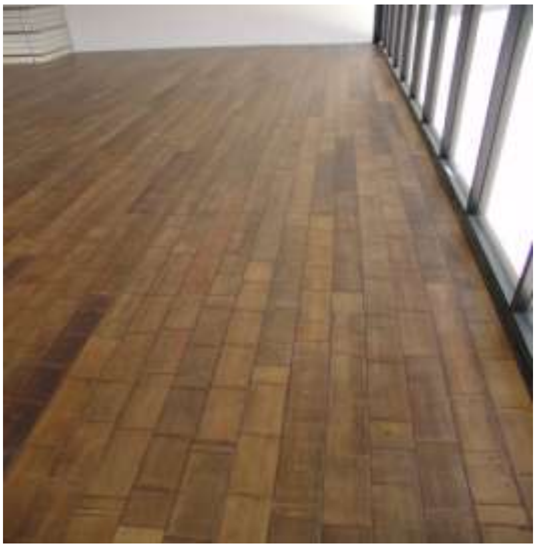


Fig 8.4 Flattened bamboo floor decking

8.3 WALLS

The most extensive use of bamboo in construction is for walls and partitions. The major elements of a bamboo wall (posts and beams) generally constitute part of the structural framework. As such they are required to carry the self-weight of the building and also loadings imposed by the occupants, the weather and, occasionally, earthquakes. To this end, efficient and adequate jointing is of primary importance (see Chapter 8, Jointing techniques). An infill between framing members is required to complete the wall. The purpose of the infill is to protect against rain, wind and animals, to offer privacy and to provide in-plane bracing to ensure the overall stability of the structure when subjected to horizontal forces. The infill should also be designed to allow for light and ventilation. Not least is its architectural and aesthetic function.

This infill can take many forms:

- Whole or halved vertical or horizontal bamboo culms, with or without bamboo mats
- Split or flattened bamboo, with mats and/or plaster
- Bajareque
- Wattle (wattle and daub, lath and plaster)
- Woven bamboo, with or without plaster
- Bamboo panels

Whole or halved vertical or horizontal bamboo culms, with or without bamboo mats

The preferred orientation is vertical as this increases the shear resistance of the wall and is also better for drying after rain. Vertical members can be driven directly into the ground or fixed back to beams by tying with or without facing battens. Halved culms can be fixed in the same way, either as a single or double ply construction, or anchored between horizontal halved culms. Woven bamboo mats can be attached to one or both faces using tied or nailed bamboo battens.

Split or flattened bamboo, with mats and/or plaster

Split or flattened bamboo (see also Floors) can be fixed vertically to intermediate bamboo members tied to or mortised into the posts, or fixed horizontally directly to the posts. Boards can be stretched or covered by wire mesh to provide a suitable surface for plastering. Closely woven matting can also be applied to the board surface, with or without plaster.

Bajareque

This is a type of construction commonly employed in Latin America. It consists of horizontal bamboo strips tied or nailed to both sides of the posts. The cavity is then filled with mud or mud and stones, producing a relatively massive form of construction.

Wattle (wattle and daub, lath and plaster, quincha)

Common in parts of India, Peru and Chile, this comprises coarsely woven panels of bamboo strips (vertical and horizontal warp), plastered on both sides.

Woven bamboo, with or without plaster

Coarsely woven panels similar to those for wattle but with closer wefts can be used with or without plaster (figure 21). The plaster can be made from any combination of mud, clay, and sand, stabilised with lime, cow dung, cement and organic fibres. The surface can be finished with a lime wash to give a typical stucco appearance.

Bamboo panels

Panels have been developed specifically for use in walls and partitions and have the advantage of imparting greater structural rigidity to the construction. Bamboo has also been used as a reinforcement for stabilised or rammed mud walls. However, difficulties exist in achieving an adequate bond between the mud and bamboo to ensure composite action.

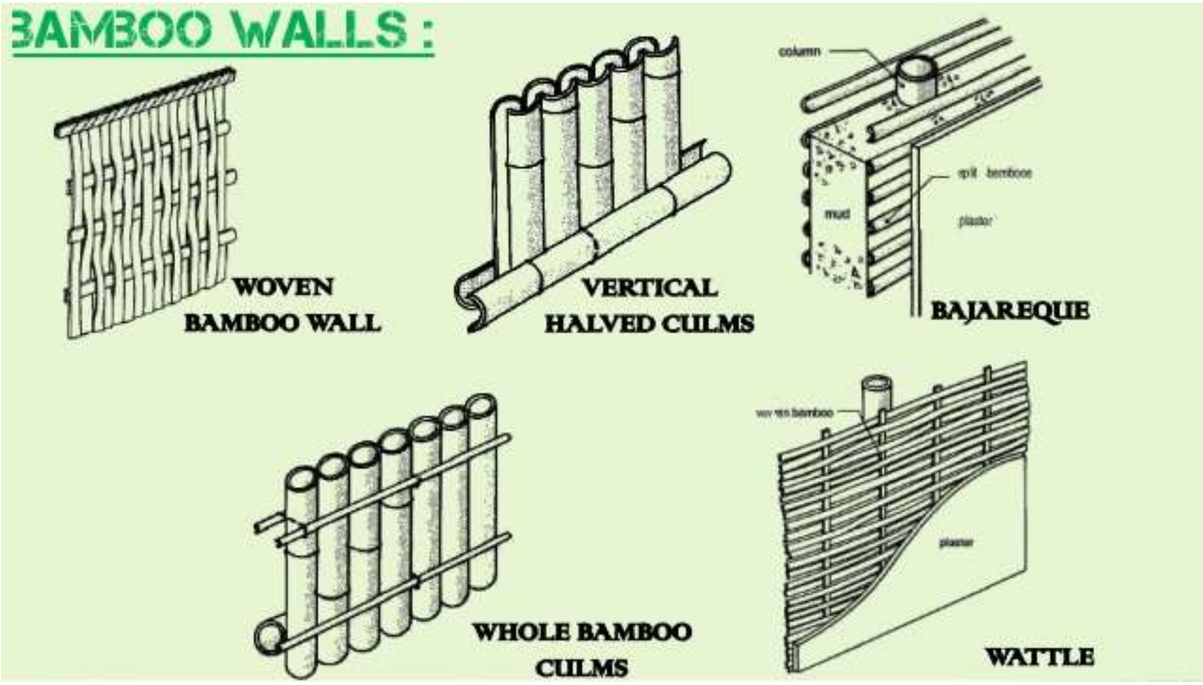


Fig 8.5 Types of bamboo walls

8.4 ROOFS

The roof of a building is arguably its most important component - this is what defines a construction as a shelter. As such, it is required to offer protection against extremes of weather including rain, sun and wind, and to provide clear, usable space beneath its canopy. Above all, it must be strong enough to resist the considerable forces generated by wind and roof coverings. In this respect bamboo is ideal as a roofing material - it is strong, resilient and light-weight. The bamboo structure of a roof can comprise “cut’ components - purlins, rafters and laths or battens, or triangulated (trussed) assemblies. Bamboo, in a variety of forms, is also used as a roof covering and for ceilings.

<u>Roof structure Traditional roof construction:</u>

The simplest form of roof comprises a bamboo ridge purlin and eaves beams, supported on the perimeter posts. Halved culms are then laid convex side down, edge to edge, spanning from the ridge to the eaves. A second layer, convex side up, is then laid to cover the joints. The maximum overall span using this method is about 3 metres. A variation on this is the use of whole culms, suitably spaced to accept battens for tiles or thatch. To extend the span, a central post can be used. Beyond this, the options are almost infinite. Efficient jointing of components is a key consideration.
Trusses: Trusses offer a number of advantages over traditional forms of construction, including more economic and efficient use of materials, the ability to span larger distances, the use of shorter components and the use of prefabrication. Much research and development has been carried out in this area. This work has highlighted the relative weakness of the joints and also of the bamboo in compression perpendicular to its length. In addition, much of the deflection of a loaded truss has been found to be due to deformation at the joints
As with cut roofs, truss configurations are many and various. The King-post and Fink are the simplest, readily spanning 4m using traditional jointing. Culm diameters typically range from 40-l 00mm.
The pitch of the truss should be at least 30° in areas of high rainfall. Truss spacing are consistent with the use of bamboo purlins (2-3m). Needless to say, for both cut and trussed types of roof, the applied loads must be considered and, for trusses in particular, the design justified by test. In-plane stability is another primary consideration; this is usually provided by diagonal bracing members.

<u>Roof covering</u>

Bamboo roof coverings can form an integral part of the structure, as in the case of overlapping halved culms. More often, they are non-structural in function. Examples include:

- Bamboo tiles
- Bamboo shingles
- Bamboo mats
- Corrugated bamboo roofing sheets

<u>Bamboo tiles:</u>
These can take the form of halved, internodal culm sections, fixed to battens and overlapped in a similar manner to the full length halved culms. Roofs covered in this manner are susceptible to leakage. Bamboo shingles: shingles, measuring 30-40mm wide x internodal length (400-600mm) are cut from green culms, 70mm or more in diameter and then air dried.

Fig 8.6 Bamboo tiles for roof

Bamboo shingles

The shingles are hooked onto bamboo battens (maximum spacing 150mm by means of a tongue cut into the underside. Three laps are required to make a roof watertight, requiring some 200 shingles per square metre. Nailing may need to be considered if high winds are likely.

Fig 8.7 Bamboo shingles

Bamboo mats:

a layer of bitumen is sandwiched between two mats forming a semi-rigid panel. The mats can be fixed to rafters at 200-250mm centres. A bituminous or rubberised weatherproof coating is then applied to the finished roof.

Fig 8.8 Bamboo mats.

Corrugated bamboo roofing sheets:

PF resin is applied to a bamboo mats to form a five layer set which is then hot pressed between corrugated platens. UF resin bonded sheets overlaid with PF resin impregnated paper have also been produced. These products are strong and lightweight with good insulation properties.

Fig 8.9 Bamboo roofing sheet

8.5 CEILING

The provision of a ceiling can help to reduce heat radiation into the occupied space and also induce a cooling airstream through the roof space. However, these advantages are often offset by the need to disperse smoke from cooking fires, the reduction in headroom and reduced air circulation within the occupied space. Whether or not a ceiling is installed is therefore dependent upon local needs and customs. Ceilings can be made from small, closely spaced culms, split or flattened bamboo, bamboo boards or bamboo mats in a manner similar to that for floors (see Floors). Woven mat ceilings are sometimes applied as sharking to the topside of the rafters or purlins, separated from the roof covering by battens.

8.6 DOORS AND WINDOWS

In traditional types of bamboo building, doors and windows are usually very simple in form and operation. Bamboo doors can be side hinged or sliding, comprising a bamboo frame with an infill of woven bamboo or small diameter culms. In higher grade buildings, wooden doors are common. Doors and shutters comprising bamboo mat board as panelling, or as flush skins for hollow core doors offer another solution.

Bamboo windows are generally left unglazed and can have bamboo bars, or a sash with woven bamboo infill. The sash can be side hinged or sliding or, more commonly, top hinged to keep out direct sunlight and rain. At night, windows are closed to protect against insects and animals. Hinges are formed from simple bindings, or connecting bamboo elements. As with doors, in higher grade buildings windows are more commonly made of wood and are often glazed.

Fig 8.10 Bamboo doors

Fig 8.11 Bamboo windows

8.7 WATER PIPES AND GUTTERS

Whole bamboo culms, with the diaphragms removed, gutters can be used as water pipes either below or above ground. Below ground: the system is usually gravity fed. To ensure watertight connections, the ends of the culms can be reamed and fitted into short sections of metal, pvc or bamboo pipe and suitably caulked. To control insect attack, the trench can be treated with insecticide before the pipes are laid

The development of water piping in presents possibilities for the wider use of bamboo as piping for the supply of drinking water. In this particular process, the bamboo pipes are coated internally and externally with an approved bituminous paint. The exterior of the pipes can also be treated with a hot bituminous coating which gives sound protection against exterior attack. The pipes are then buried in trenches treated with insecticides which fix in the ground. It has been shown that the life of bamboo pipes can be simply extended by ensuring that the bore is full and that the water carried is clean. It is reported that the bamboo pipes treated in the above manner have given good service for ten years.

Above ground: again, the system is usually gravity fed with pipes supported on bamboo trestles. Joints can simply be formed by tapering or scarfing the ends of the culms to enable the sections to be fitted together end to end. Watertight connections can be achieved as for pipes below ground.

Fig 8.12 Bamboo Pipes

8.8 TOOLS

A major advantage of bamboo is its ability to be worked by hand using very simple tools. If, however, the commercial potential of bamboo as an engineering material is to be realised, then there will be a need to develop efficient handling, machining and production methods.

Hand tools

It is possible to build in bamboo with nothing more than a machete, but a few basic tools will greatly increase the scope and effectiveness of the construction process. The tools listed below will enable the preparation and assembly of most bamboo elements used in building.

TOOL	USE	RECOMMENDED SPECIFICATION
Machete	Miscellaneous: felling, trimming and cutting culms to length; removing fragments of diaphragms from boards etc.	Preference of the user decides type of blade but long, fairly heavy blade recommended
Hacksaw	Felling culms, removing branches, cutting culms to length	Large size; 18 and 24 teeth per inch alloy steel blades
Tripods or trestles	Elevating culms and holding them firm for sawing to length or cracking nodes	May be made locally following preferred pattern
Axe	Cracking the nodes of large culms for making boards	tight-weight with a thick wedge-shaped but narrow blade
Hatchet or small Axe	Cracking the nodes of smaller culms for making boards	Similar but smaller to the axe with a short handle
Whetstone	Sharpening edged tools	Carborundum; coarse grained on one side, fine on the other
Spud	Removing diaphragm fragments and excess soft wood at basal end of bamboo boards	Long handle with broad blade set at an angle to operate parallel to board surface
Adze	Similar use to spud; less convenient but more generally available	Standard design, best quality steel
Gouge	Removing diaphragms to make troughs and drain pipes from split or opened culms	Bent gouge, 25 and 38mm
Chisel	Making holes in culms to accommodate lashings for end ties	Best steel (alloy steel if available), 20mm
Drill	Making holes to accommodate pins or dowels	Hand- or power-drill with best steel twist drills (for metal cutting)
Wood rasps	Levelling prominent culm nodes	Large, half round; coarse, medium and fine
Splitting jig	Facilitating the splitting of whole culms or sections into several strips at once	see figure 78
Splitting knives	For splitting small culms	Short handle, broad blade
Steel rod	Breaking out the diaphragms of unsplit culms	3m x 20mm and 3m x 13mm as a minimum. Hardwood or bamboo may also be used
Piers	For handling wire used for lashings	Long-nose with wire cutting facility

Production machinery

Machines for specific applications are already available, for example the production of high quality bamboo floor boarding. Some of the more basic machining operations could, however, be equally applicable to many other end uses. Typical machines which are now readily available include:

• Cross-cut saw cutting to length
• Regularise removal of external nodal projections
• Splitter splitting into strips
• Strip cutter sawing into strips
• 2-side planer removal of diaphragm and external skin
• 4-side planer accurate dimensioning of elements

CHAPTER 9

LIMITATIONS AND ISSUES

9.1 Material Limitations:

Bamboo is a natural material and hence has certain limitations. Research energies, the world-over have been focusing on countering these limitations.

a. Steps need to elevate bamboo technically to a level for it to qualify as a sufficiently durable and structurally safe material for construction for the building sector and for bamboo buildings to become bankable assets.

b. Fire Rating: Susceptibility to fire is another limiting factor in the use of whole bamboo culms in buildings. Engineered bamboo is a solution to this problem, but it is unaffordable to the majority of clients. Hence fire rating of round bamboo and fire retarding treatment material and methodologies need to be developed for bamboo to be used in large-scale projects.

c. Jointing Systems: Owing to the round shape, jointing is very difficult and cumbersome in bamboo. The reduction of diameter along the length is another limiting factor. Various types of engineered and tested jointing systems with appropriate materials need to be developed for effective structural load distribution and transfer. Not many studies have been done relating suitability of joints and their mechanical behaviour. Researchers need to include connection types with complete structural systems.

d. Conical form of bamboo: Bamboo reduces in diameter and weight along its length. With an approximately hollow circular transverse section with varying density in both directions, bamboo is a unique and difficult material to design with. Digital Image Analysis (DIA) is a reliable tool to derive appropriate equations to map fiber distribution in sections of bamboo. This can help an architect or engineer to calculate the modulus of elasticity of bamboo with fair degree of accuracy. Use of engineered bamboo, bamboo composites and prefabrication-Though whole bamboo has been and can be used in construction for many types of buildings, for bamboo to be established in the building sector as a mainstream material, we need to use it as composite construction with other materials and an large scale usage of engineered and prefabricated bamboo based components. Many of the traditional construction techniques will have to be either improved or substituted for mass usage of engineered bamboo especially for multi-storied buildings. Extensive study is therefore required in the field of processed bamboo construction materials and methods.

e. Splitting Behaviour of bamboo: Most common failure is splitting in longitudinal direction. These failures are usually due to tension, compression and flexure loads in bolted connections and also from drying. It is a technical and practical necessity and needs to be fully addressed. We need to formulate simple mathematical equations involving fundamental properties of bamboo which can be used for designing complex structures with bamboo with the same confidence as for other materials. 10th World Bamboo Congress, Korea 2015 Theme: Architecture, Engineering and Social Housing

f. Hygroscopic nature of bamboo: The main deterrent for bamboo to be used as reinforcement in place of steel is its water absorbing capacity. The swelling and then shrinking of bamboo in concrete results in micro and macro cracks. To avoid this, effective water-repellent treatments for bamboo splits with suitable modification of concrete is necessary.

g. Small spans of bamboo buildings: For a medium size building, a span of 3-4 meters is generally considered suitable and economical even for steel reinforcement. Bamboo can be conveniently used as reinforcement in modest size buildings economically. Large spans difficult with bamboo as it is difficult to get splits of uniform cross-section for reinforcement for very long lengths owing to its tapering structure.

h. Building industry in India is still an unorganized sector and hence even conventional buildings are very poorly implemented. Bamboo buildings are even more poorly implemented for lack of severe human resource deficit.

Once these problems are countered, bamboo will become a highly appropriate building material for India. For seismic regions it is reputed to cause the least damage to life and property. Due to its light-weight, foundation costs also can be saved. BRC, Bamboo Reinforced Concrete can also be designed in a manner similar to that of steel reinforced concrete with a few extra precautions. All these technological advancements will help bamboo to get its rightful place in the building sector and result in tremendous economic and environmental advantage.

9.2 ISSUES

9.2.1 SOCIAL ISSUES

a. Affordability vs. Priorities- Affordability is perhaps the prime reason for people to opt for a more permanent solution. At the same time a substandard house can be very demanding in terms of time, energy and money for its maintenance. Ever increasing expensive lifestyles, new emergent priorities, and erratic non-budgeted expenditure patterns, could lead to a skewed result, making affordability a highly sensitive variable rather than a constant indicator. Bamboo being one of the cheaper materials can play an important role in providing an economic alternative in combination with other materials for a durable and safe house. This is especially true for urban areas close to bamboo growing regions.

b. Substituting Bricks, Cement, Steel and Timber Alone can Account for a Cost Reduction of up to 40%: By substituting bricks, cement, steel and timber with bamboo even partially for constructing walls, floors, roofs etc., buildings can be designed for a longer life, improved quality, and low maintenance. Bamboo in combination with other alternative materials for these components alone can give a cost reduction of up to 40% (Figure 31).

c. Social acceptability: Experts from the industry indicate that whole bamboo has failed to live up to the social urban image. This can be dealt with by modern bamboo construction and aesthetical architectural design using global innovations and best practices. Cost reduction by using prefabricated components, increasing the speed of construction, availability of finance and insurance facilities will go a long way in social acceptance of bamboo buildings.

d. Need to evolve Standards: -Some of the important housing terminologies needs to be redefined, so that the benefits of all the research reaches the general public. Translating them into a series of standard thumb rules will make it easy for bamboo to be used for construction in rural and tribal areas without the involvement of professionals further reducing the cost. This will tap a vast market segment of buildings in the rural and tribal sector thereby generating livelihood options as well and solving the housing and infrastructure problems.

9.2.2 EXECUTION ISSUES

a. Material availability: Availability of good quality and quantity bamboo of suitable species for building sector is a major issue hindering the usage of this material . If treated and standardized Figure 31 10th World Bamboo Congress, Korea 2015 Theme: Architecture, Engineering and Social Housing graded bamboo is made available readily, use of bamboo in building sector will increase manifold within no time. Bamboo depots need to be set up by government and private agencies in across the country to make the material available to clients, architects, designers and engineers.

b. Skill development: Capacity building measures at every level of design, supervision and execution, and on war footing basis on large scale must precede the actual construction boom in order to cater to the demands of bamboo building sector. The training institutes can provide vocational education and training programs with emphasis on hands-on experience. NGOs, grassroots level workers, elected representatives, along with self help etc all have to work in coordination to create a skilled workforce for the bamboo building sector. The skill development program could be implemented through smaller action plans, either location specific or activity specific through it is, Polytechnics etc. Training schedules and content could be designed accordingly.

c. Pre fabrication- Building components, partially replaced with bamboo and bamboo composites etc if made available to create permutations and combinations, for creating a variety of architectural designs, will provide choices for selection for design and budget, and also enhance the speed of construction on site thereby making it economical. Engineered bamboo can provide more options for increasing speed of construction.

d. Treatment of bamboo- Elaborate procedures of treatment also is a major issue in usage for bamboo by contactors. Quality treated bamboo is a mandatory requirement for structurally safe, economical and long lasting bamboo buildings. Governments need to set up treatment plants near forests and other areas for value addition to bamboo from the forest areas and ensure continued and sufficient supply of bamboo in bamboo depots. SHGs and JFMs could be financed by the govt to set up these units creating large livelihood opportunities to otherwise economically poor and marginalized bamboo communities.

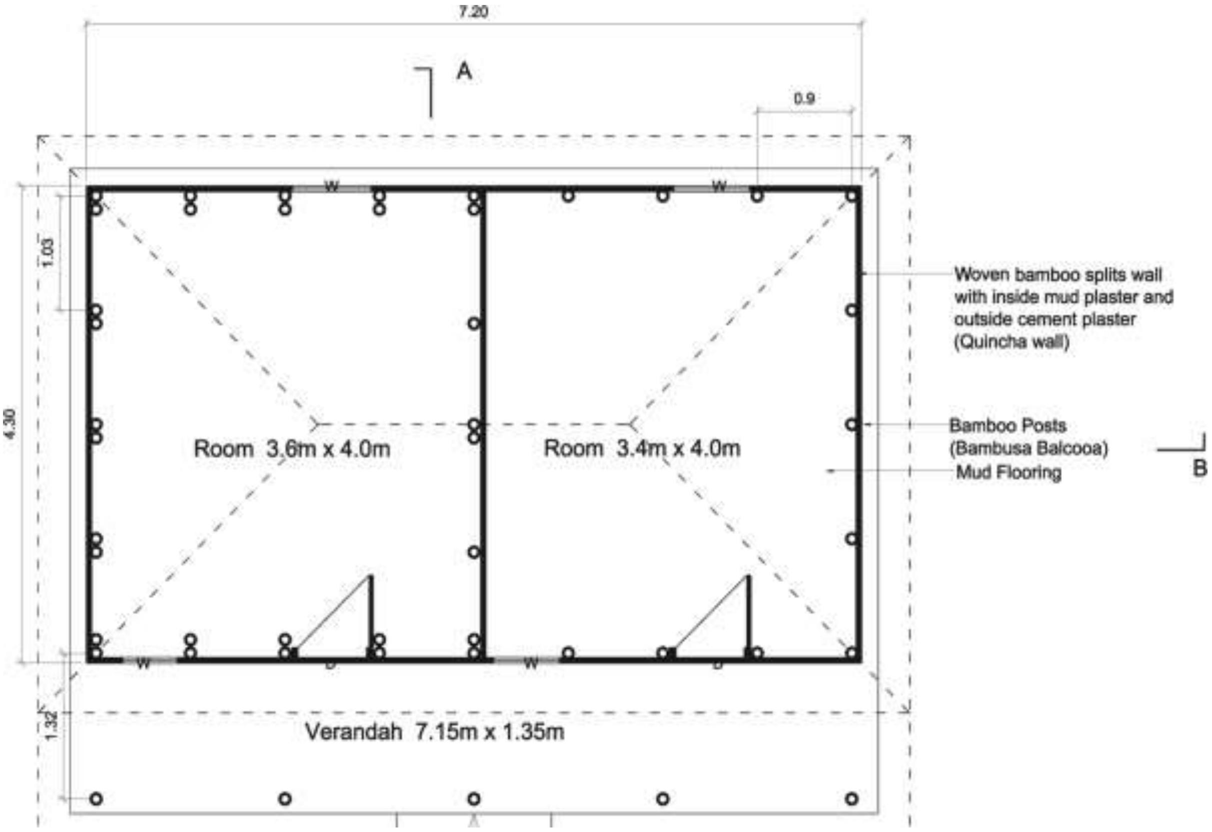
e. Raising the standards of implementation: In India, bamboo had been a well-established building material. But this has drastically changed recently because of bamboo buildings being generally very poorly implemented most of the time. Concrete and steel buildings are typically difficult to construct, requiring skilled workers and quality materials for a successful result. Bamboo offers an easier alternative. However, the implementation of bamboo structures seem to be generally quite poor, with poor planning and design, and specifications being abandoned in favour of other building techniques. We need to form superior guidelines and frameworks for building bamboo structure. A multipurpose kit for constructing bamboo structures that includes pre-fabricated connections, tools and instructions etc can be made available. In this way, we will empower the execution team with basic building skills to become more confident and execute high quality bamboo building.

f. Elaborate, expensive and inaccurate testing methods- The testing procedures for bamboo building components are complex, expensive and inaccurate and unavailable most of the time. This makes it very uneconomical and difficult for the contractor to adhere to standards and timelines. Standard field tests for non-conventional materials will also provide rural communities greater equity in terms of safe, adequate, and reliable housing and sustainable development using local resources resulting in an improved standard of living and will serve both technical and social purposes.

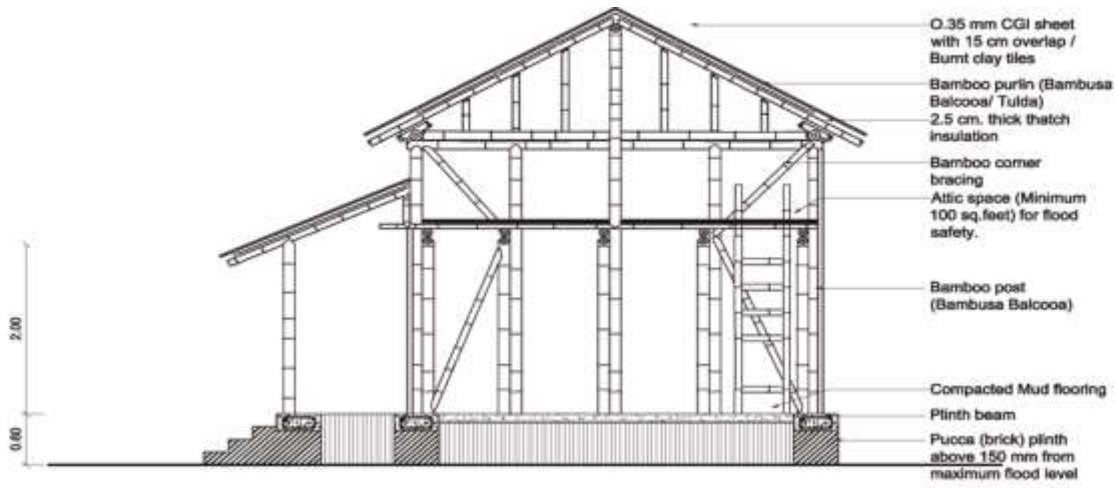
g. Backward linkages unavailable – In order to be able to substitute the energy intensive materials on a large scale ,parallel activities involving plantation, drying, seasoning and chemical treatment have to be promoted and up scaled as parallel industries , as backward linkages within an extension of a “focused agro-based employment scheme” for small and marginal farmers. The product would thus be “especially and exclusively treated and graded bamboo for the purpose of building and mass housing for the urban and rural areas, following the customized design

CHAPTER 10

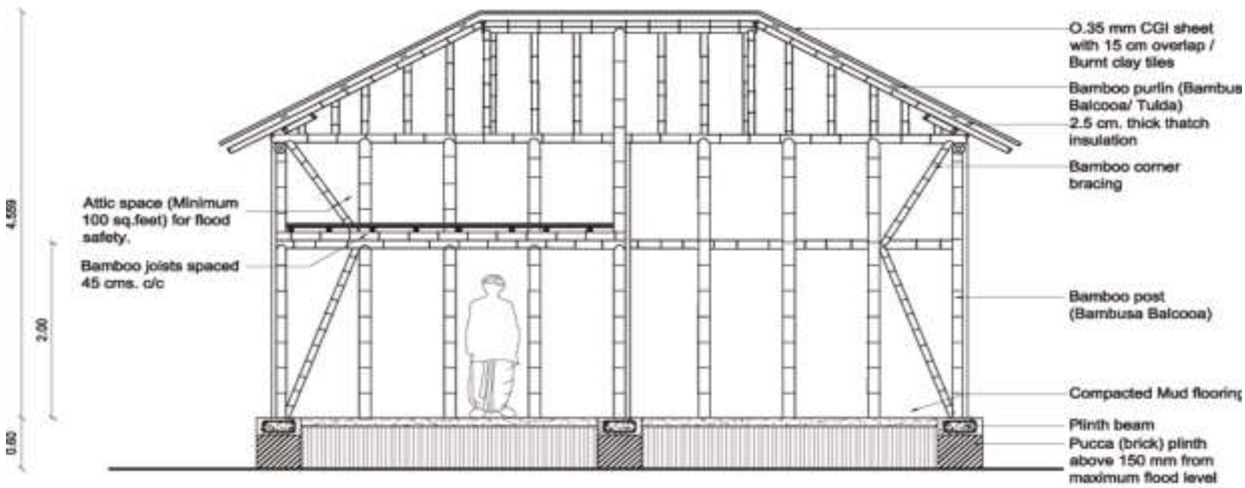
SAMPLE DESIGN OF BAMBOO HOUSE



GROUNG FLOOR PLAN



Section AA



Section BB

PHOTO GALLERY

<u>BAMBOO FOR SUSTAINABLE DEVELOPMENT SEMINAR AT PUNE</u>

<u>BAMBOO FOR SUSTAINABLE DEVELOPMENT SEMINAR, PUNE</u>

DIFFERENT TYPES OF FURNITURE MADE OF BAMBOO, PUNE

BAMBOO NURSERY, MANGAON

BAMBOO NURSERY, MANGAON

BAMBOO NURSEY, MANGAON

MAKING OF BAMBOO ROOF MODEL, MANGAON

MAKING OF BAMBOO ROOF MODEL, MANGAON

BAMBOO ROOF MODEL, MANGAON

CONCLUSION

India having the largest reserves of bamboo in the world is dealing with the shortage of bamboo as a raw material in its industries. Presently it is underutilized and found in abundance. If bamboo sector has to be grown beyond the certain level the regulatory restrictions on trade and transits need to be taken care off. India can have 4-5 times better productivity then now and is expected to have an increase in the market size by 2015 if proper management, cultivation and plantation practices are followed with proper market linkages. Thus, bamboo can play an important role in meeting the future human needs of timber used as input for housing and construction. In the light of increasing demand of raw materials for housing and construction, including timber and decreasing forest area, bamboo based materials can serve as an alternative in bridging the gap of demand and supply.

Bamboo is a material which gives an aesthetic view and pleasing architectural effect. It is been since many decades. Bamboo has been used through history not only because of the strength of the material, but also through the renewable prospects. Through history, wood has become more and more scarce, simply because to produce a full grown tree can take up to sixty years, and then another sixty years time for a replacement. Species of bamboo equal to the height and width of a tree take as little as sixty days to mature completely.

Bamboo is also easy to grow, because of the root systems. Running bamboo species are especially easy to grow, as they produce several shoots at a time, and will take over as much room as they possibly can. Bamboo is also difficult to get rid of, unless it is completely ploughed under.

The unknown building material and resource of the future, bamboo has had a long and rich history. It will be used for years to come in everything from housing to bed sheets, and even more as more information is learned about this amazing plant.

Advancement in technology and innovation can encourage more number of manufacturers or manufacturing units to come up. Further, there is a need for market establishment with product testing for quality being a necessity which will ultimately lead to market acceptability. There is a need to set up technology institute in order to train people about new and advanced bamboo technology.

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