# Contents

# Acknowledgements

The authors have referred to many important texts while compiling this book and original sources are acknowledged individually.

The authors are particularly grateful to the International Network for Bamboo and Rattan (INBAR) for the technical assistance provided during preparation and editing. Appendices 1 to 5 have been reproduced from the publication "INBAR Technical Report No. 3" by Satish Kumar, K. S. Shukla, Indra Dev and P. B. Dobriyal, with the kind permission of the Indian Council of Forestry Research and Education (ICFRE), INBAR and the International Development Research Centre (IDRC).

Special thanks are extended to Mr M. W. Parkes, the former DFID Senior Architectural and Planning Adviser, and Mr M. Mutter, the present Adviser, without whose support and guidance this book could not have been published.

# Preface

Bamboo is one of the oldest and most versatile building materials with many applications in the field of construction, particularly in developing countries, It is strong and lightweight and can often be used without processing or finishing. In spite of these clear advantages, the use of bamboo has been largely restricted to temporary structures and lower grade buildings due to limited natural durability, difficulties in jointing, a lack of structural design data and exclusion from building codes.

The diminishing wood resource and restrictions imposed on felling in natural forests, particularly in the tropics, have focused world attention on the need to identify a substitute material which should be renewable, environmentally friendly and widely available. In view of its rapid growth (exceeding most fast growing woods), a ready adaptability to most climatic and edaphic conditions and properties superior to most juvenile fast growing wood, bamboo emerges as a very suitable alternative. However, in order to fully exploit the potential of bamboo, development effort should be directed at the key areas of preservation, jointing, structural design and codification. In addition, socio-economic, appropriateness and technical studies will be essential to identify factors which govern current bamboo usage, and those which will influence its use in the future. Once these issues have been addressed, bamboo will be ideally placed to become a principal engineering and construction material for the twenty first century and beyond.

# 1. Introduction

Bamboo has a long and well established tradition as a building material throughout the world's tropical and sub-tropical regions. It is widely used for many forms of construction, in particular for housing in rural areas. Bamboo is a renewable and versatile resource, characterised by high strength and low weight, and is easily worked using simple tools. As such, bamboo constructions are easy to build, resilient to wind and even earthquake forces (given the correct detailing) and readily repairable in the event of damage. Associated products (bamboo based panels and bamboo reinforced concrete, for example) also find applications in the construction process.

There are however a number of important considerations which currently limit the use of bamboo as a universally applicable construction material:

- **Durability:** bamboo is subject to attack by fungi and insects. For this reason, untreated bamboo structures are viewed as temporary with an expected life of no more than five years

- **Jointing:** although many traditional joint types exist, their structural efficiency is low (Herbert et al. 1979). Considerable research has been directed at the development of more effective jointing methods.

- **Flammability:** bamboo structures do not behave well in fires, and the cost of treatment, where available, is relatively high.

- **Lack of design guidance and codification:** the engineering design of bamboo structures has not yet been fully addressed.

The aim of this publication is to offer a general introduction to bamboo as a construction material, with the key areas of preservation and jointing addressed in more detail.

A range of chemical and non-chemical treatment methods is discussed and appropriate preservative formulations and treatment schedules are presented. Consideration is given to environmental and health and safety issues, and areas requiring further research are highlighted.

The section on jointing attempts to summarise and illustrate the many different joint types and connection methods that have been devised, from traditional techniques to recent developments. It is hoped that this accumulated knowledge will inspire further work in this area.

# 2. *Protection of bamboo*

**Natural durability** 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-l 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 (Tamolang et al. 1980, Chen et al. 1985). 90% of the hemicellulose is xylan with a structure intermediate between hardwood and softwood xylans (Higuchi, 1980). The structure of the lignin present in bamboo is unique, and undergoes changes during the elongation and ageing of the culm (Itoh et al. 1981). 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 (Liese, 1959).

The natural durability of bamboo varies according to species. For example, Dendrocalamus strictus is known to be less resistant to termites than *Dendrocalamus longispathus.* Although the culms of a few bamboos, notably Guadua *angustifolia,* appear to have a relatively high resistance to wood eating insects and decay fungi, they are all susceptible to biodegradation. Variation in durability has also been observed along the length of the culm and through the thickness of the wall. The lower portion of the culm is considered more durable, while the inner part of the wall deteriorates faster than the outer harder portion. This is probably related to the anatomical and chemical nature of the woody cells.

Because of the lack of any toxic constituents, bamboo forms a ready food source for a variety of organisms. The presence of considerable quantities of starch in green or dry bamboo makes it more attractive to such organisms, especially stain fungi and borer beetles (Beeson, 1941, Gardener, 1945, Mathew et al. 1990, Gnanaharan et *al.* 1993). The most serious borers of felled bamboo are Lyctus and three species of *Dinoderus (celluris, minutes, brevis),* which attack bamboo rich with starch (Casin et *al.* 1970, Sandhu, 1975). They cause immense damage during drying, storage, and subsequent use. Carpenter bees and termites also attack bamboo (Beeson, 1938, Sensarma et *al.* 1957). Bamboo is susceptible to attack by marine organisms and, when used in sea water, can be destroyed in less than a year (Anon, 1945),

**Protectionof plantations**

Only a limited amount of research has been carried out into insect pests of standing bamboo. However, some defoliators (Mathur, 1943), bamboo stem beetles (Roonwal, 1977), weevil borers (Chatterjee et *al. 1964)* and sap suckers (Singh, 1988) have occasionally been observed.

Defoliators can be controlled by spraying with 0.2% fenitrothion or 0.1% carbaryl in water with a sticker. Silvicultural controls work better with weevils, while sap suckers can be controlled by spraying kerosene oil in soap emulsion or folian spray with 0.04% dimacron/ rogor or 0.2% fenitrothion.

Dangers from fungal attack are low in plantations, but vigilance is necessary during normal silvicultural practices in the event that some protection or control is needed (hilohanan et *al.* 1990).

**Protectionpre-and post-harvesting** by non-chemical methods

In bamboo, soluble sugars form the principal nutrients for degrading organisms. Therefore, if these can be 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.

*Felling* of bamboo during low sugar content season

Sugar content in almost all plants varies according to season. In India, for example, it is higher in spring than in winter (Joseph, 1958). It is therefore advisable to harvest bamboo during the winter months.

*Felling of mature* bamboo when sugar content *is* low

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.

*Post-havesting transpiration* of bamboo culm

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 (Sulthoni, 1987). 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.

Comments

The best likely protection will result from a combination of the above methods, for example 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.

Efforts have also been made to correlate the natural durability of bamboo with phases of the moon (Kirkpatrick et al. 1958), but any connection appears to be more myth than scientific fact.

**Protection pre- and post-harvesting by chemical methods**

Pilot-scale trials for short term protection of bamboo were carried out at three different mills under different climatic conditions in India by the Forest Research Institute, Dehra Dun. Stacks of bamboo were prepared following the pattern adopted by individual mills in a crisscross arrangement, and were treated by the same chemicals found effective in laboratory trials with minor variation in chemical ratio. The material was assessed after different storage periods, both with and without prophylactic treatment, for incidence of fungal and borer attack (Table 1, Kumar et *al. 1985).*

*Table 1: incidence of borer/fungal attack on prophylactically treated bamboo with different compositions*

| *Treatment* | *NO attack* | *Fungal attacked only* | *Fungal and borer attacked* | *Number of borer holes per bamboo* | *Remarks* |
|---|---|---|---|---|---|
| Control | 40 | 35 | 25 | 110 | Severe stain and fungal attack |
| *Na PCP 2% | 90 | - | 10 | 100 | No stain fungi |
| Boric acid : Borax (1:1) 2% | 86 | - | 14 | 50 | Stain fungi present |
| *Na PCP:boric acid : borax (1:1:1) 3% | 83 | - | 17 | 70 | No stain fungi |

The use of PCPs is under constant review from a health, safety and environmental standpoint. Note that the efficacy of boric acid/borax (relatively safe chemicals) is comparable with that of PCP formulations.

Laboratory and field trials have shown that losses from fungi and insects can be significantly reduced if proper treatment is carried out at the time of stacking, even under open storage. It should be noted that pest attack of stored bamboo can be sporadic. For instance, with beetle attack of reed bamboo, harvesting season and mode of transportation (by water or road) are not important, but maturity of the culms is the key element.

For long term storage of bamboo in the open, it is recommended that the stacks are raised on specially prepared ground to prevent termite attack. The stacks should be profusely treated during different stages of stack forming (i.e. at 3, 4, 5 and 6 metres height) and can be covered with treated bamboo mats or grass thatch. However, coverings produced from non-biological materials can offer improved protection as they are less likely to harbour a reservoir of infection.

For protection of structural bamboo (if stored outside), repetition of the treatment after four to six months is recommended. Such bamboo can be treated with any of the compositions listed in Appendix 2.

In all cases, treatment must be carried out in a safe and responsible manner. For example, the use of fine spray nozzles can result in more than 50% preservative loss and heavy pollution of the environment.

# 3. *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 (traditional) methods ofpreservation

Non-chemical methods of preservation, otherwise 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 fire-places 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 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 (see *Walls* in Chapter 5).

*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 pre-constructed 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.

In addition, careful attention to construction detailing will help to enhance the service life of the building (see *Detailing for durability* in Chapter 5).

Comments

Undoubtedly traditionally treated bamboo culms show increased resistance to insect and fungal attack when compared to freshly cut bamboo culms. However, because of the low natural resistance of bamboo to biological deterioration, the methods do not provide durability of product or structure in the long term and therefore offer no real cost saving benefits.

## 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 5-1 0% 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 (see Chapter 4, *Health, safety and environmental aspects of preservative treatment*).

The following chemical treatment techniques are described below:

- Butt treatment
- Open tank method for cold soaking
- Boucherie method
- Modified Boucherie method
- Pressure treatment
- I-lot and cold bath process
- Glue line treatment

The types of preservative suited to these methods of application are listed in Appendices 2-4. The application of fire retardant treatments is also addressed.

**Butt treafmenf**

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.

**Open tank method for cold soaking**

The open tank treatment method (figures 1 and 2) 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 lignification present in mature culms.

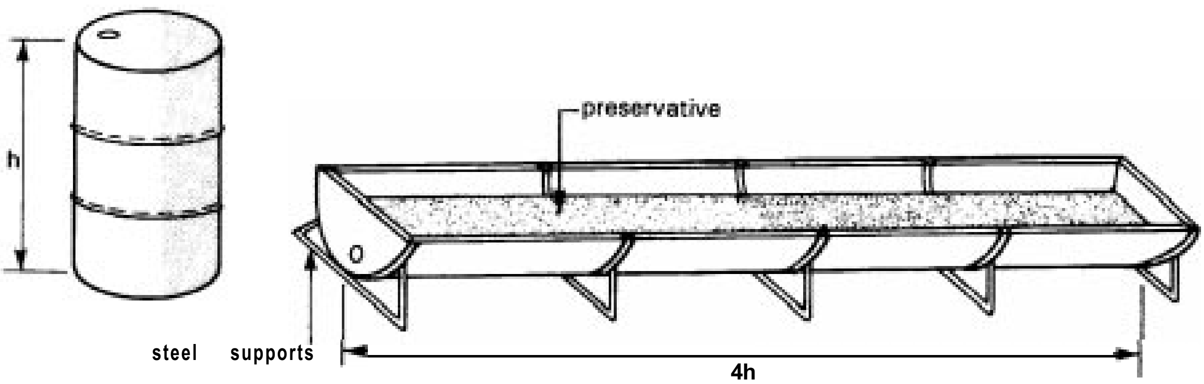
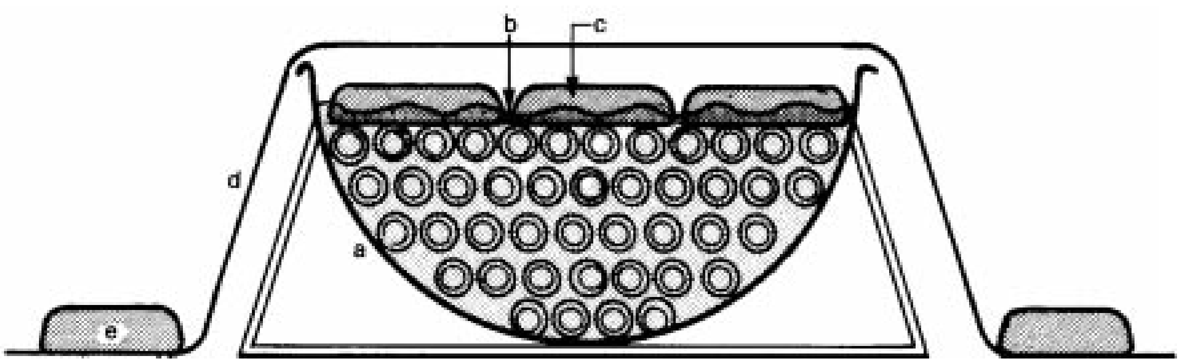



*Figure 1: Open tank method for coid soaking (afterNienhuys, 1976)*




*Key*

| | |
|---|---|
| a | Trough containing submerged bamboo. |
| b | Level of preservative. |
| c | Large stones to keep bamboo submerged. |
| d | Plastic cover to protect against rain. |
| e | Stones to keep plastic cover in place. |

*Figure 2: Cross section of open tank (after Janssen, 1995)*

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 treated more effectively than round culms. Some success in the treatment of bamboo has been obtained by punching the internode 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 internode 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 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

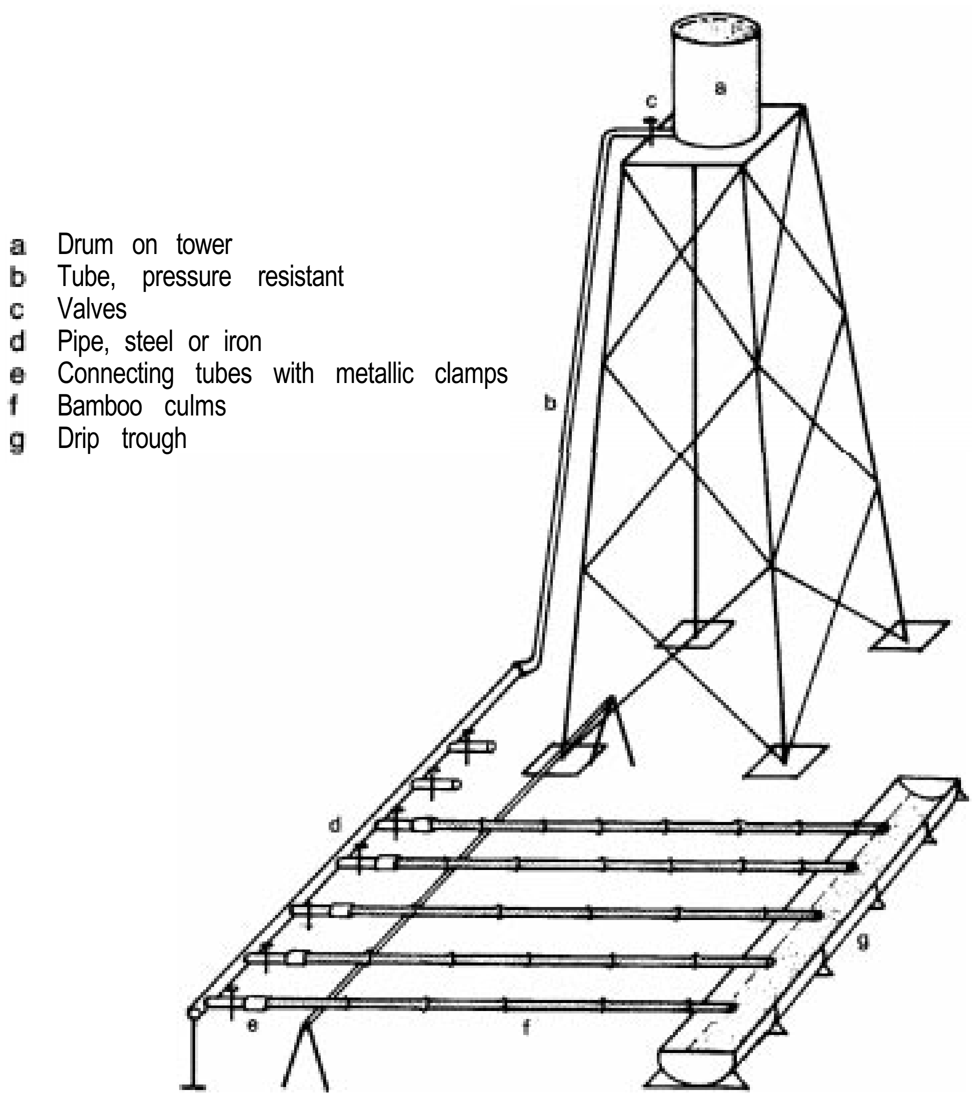



*Figure 3: The Boucherie method (after Janssen, 1995)*

**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 (A. Purushotham et *al.* 1953) 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.

The modified Boucherie apparatus is illustrated in figure 4. A detailed manual on the operation of the modified Boucherie apparatus has been prepared by the Environmental Bamboo Foundation in Bali, Indonesia.

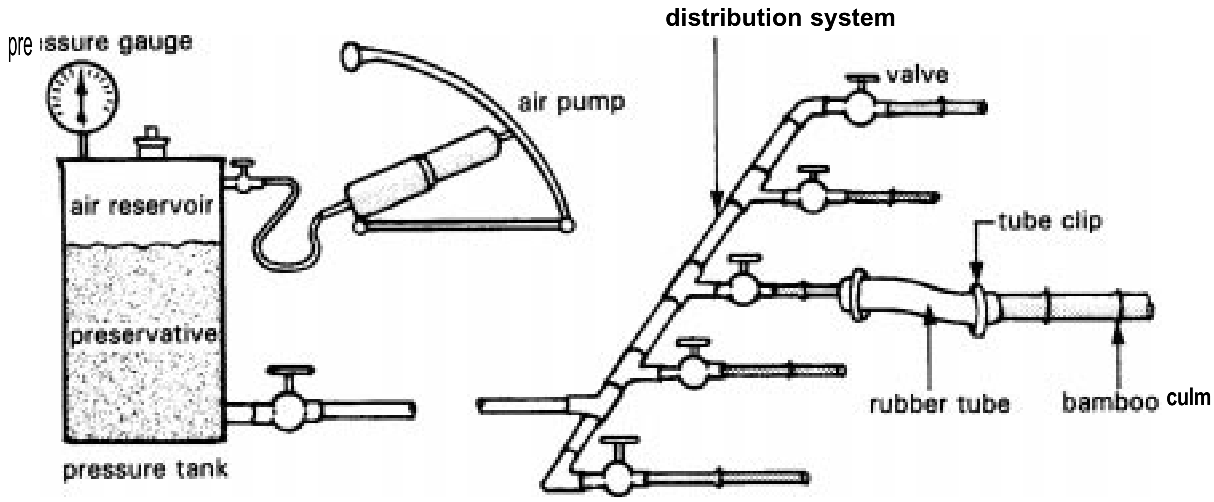



*Figure 4: The modified Boucherie apparatus (after Nienhuys, 7976)*

*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/mm$^2$ (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 (Padmanabhan *et al.* 1994).

*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 add: |
| 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 (Sekhar et *al. 1964,* Laxmana, 1985).

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 (Rehman et *al.* 1947). 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.

**Developmental needs** While chemical treatment has proved to prolong the serviceable life of bamboo by making the material more resistant to decay caused by fungal and insect attack, it is nevertheless the subject of continued research and investigation in order to find the best and safest forms of application, and at the same time to improve cost effectiveness. Future benefits for bamboo could emerge from the results of bio-genetic research. In the meantime the current lack of management expertise and commercial energy required to achieve the maximum benefits from the existing technology is depriving many regions and indigenous communities of significant improvements to their standards of living.

In addition to the design and support of new research programmes, the governments concerned, together with appropriate institutions, must take the lead role in establishing the necessary technical, commercial and economic framework for the wider use of treated bamboo through:

- The advancement of developments through international co-operation
- The introduction of building legislation
- The formulation of health and safety regulations
- The use of technically and commercially trained management teams to assess the best treatment process for the locality or region
- The provision and/or establishment of suitable and safe treatment facilities
- The promotion of education, training and appropriate marketing techniques

# 4. Health, safety and environmental aspects of preservative treatment

The methods of preservative treatment described under non-chemical (traditional) techniques in Chapter 3 are considered very safe and pose little threat to health or risk of environmental pollution. However, these benefits are offset by the limited scope of such methods for extending the service life of bamboo.

Chemical preservation methods employ substances toxic to fungi and insects which are also invariably toxic to mammals Nevertheless, the preservatives listed in Appendix 2 (under constant review by various pollution control agencies) have good safety records when used correctly. Formulations containing arsenic and chromium have been rigorously tested for leaching in laboratory and under service conditions, and meet current safety standards. Such formulations make complexes with wood substances and are rendered safe, and are therefore unlikely to present any toxicity threat. Rather, the danger with such chemicals arises from the formulation and impregnation process itself. Slight carelessness in handling of either the chemicals or freshly treated materials can pose serious risks to humans and animals alike. Proper safety garments such as gloves, aprons and eye protection glasses should be worn, and any spillage of chemicals should be immediately attended to. Freshly treated material should be stored under cover during drying to avoid rain leaching of chemicals. A useful reference book covering these issues has been issued by UNEP (Anon, 1994).

Boric-acid, borax and Cu/Zn naphthenates/abietates are among the safest preservatives and are in use world-wide. Many new chemicals considered to be environmentally safe such as Tebuconazole, IPBC (3-iodo 2-propanyl butyl carbamate), chloro-thalonil, isothiozolones and synthetic pyrethroides are under various stages of adoption as preservatives. In addition to their high cost, the efficacy of such chemicals in bamboo treatment has yet to be established.

Pollution hazards exist at formulation as well as impregnation sites. It is suggested that premixed and ready-to-use formulations should be used to minimise the risks and that necessary safety precautions as specified by the manufacturers should be rigorously followed. Treatment effluents, if generated on a large scale, should be adequately treated before disposal.

Disposal of preservative treated bamboo after prolonged service can present a problem. In some countries, it is not considered a hazardous waste, but in others it has to be brought to special dumping sites.

# 5. 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.

## Domestichousing and small buildings

There is a long-standing tradition of bamboo construction, 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 (Arce, 1995).

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. A recent study by Arce (1995) has highlighted 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.

## Foundations

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 on footings of either rock or preformed concrete (see figure 5). As above, the largest and stiffest sections of bamboo should be used.

### Bamboo incorporated info 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 (figures 6 and 7).

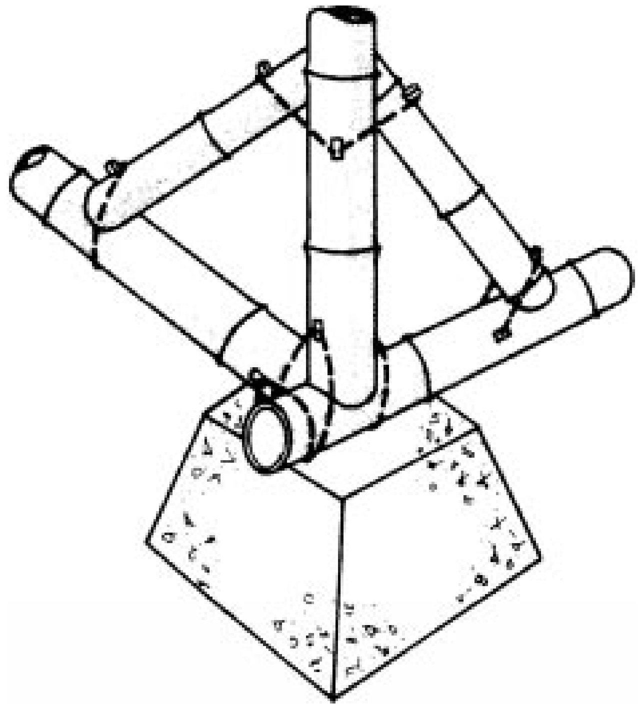


*Figure 5: Preformed concrete footings (after Bandara, 1990)*

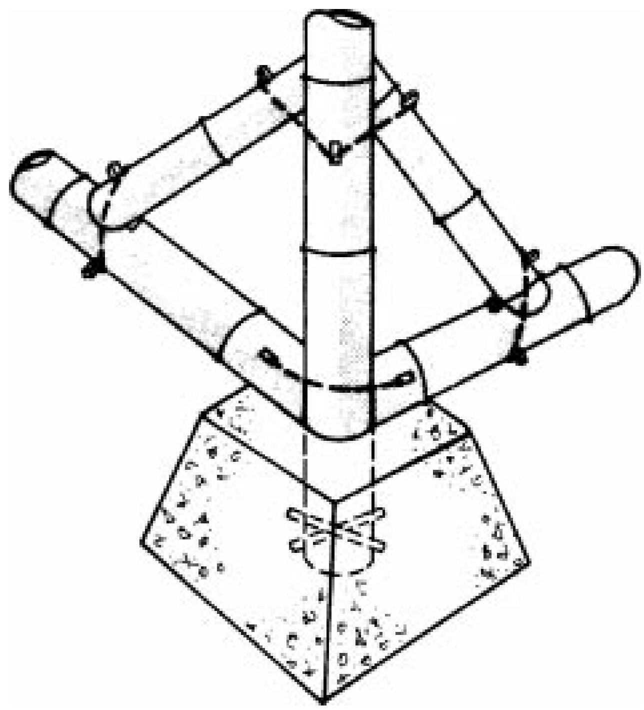


*Figure 6: Single post footing (after Banclara, 1990)*

***Composite bamboo/concrete columns*** An innovative development involves the casting of a concrete extension to a bamboo post using a plastic tube of the same diameter (Janssen, 1995). The result is a bamboo post with an integral, durable foundation (figure 8).

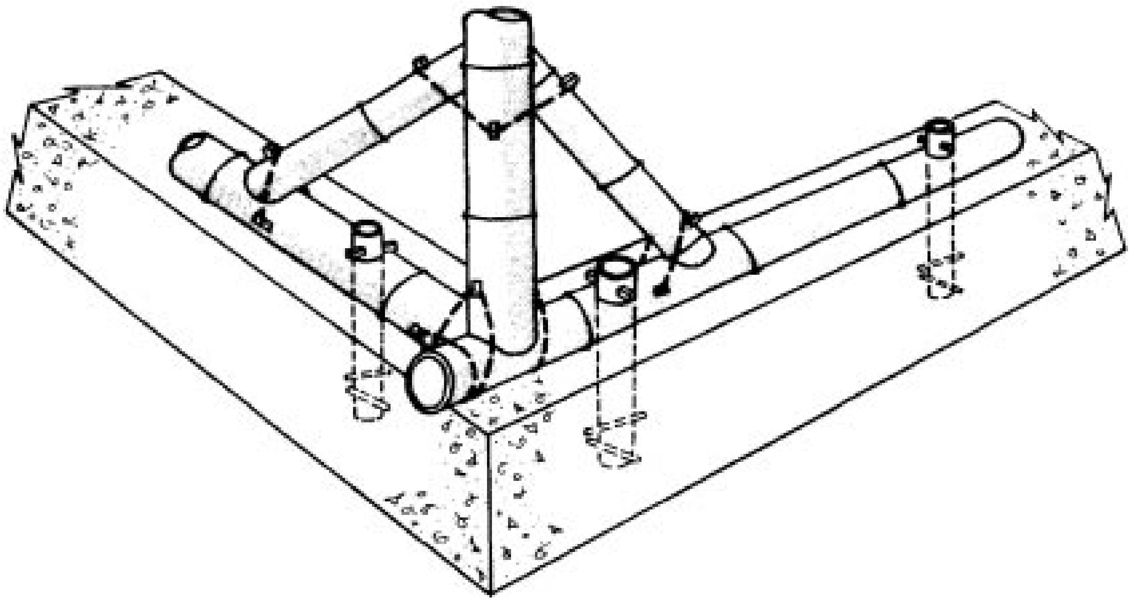


Figure 7: Strip footing

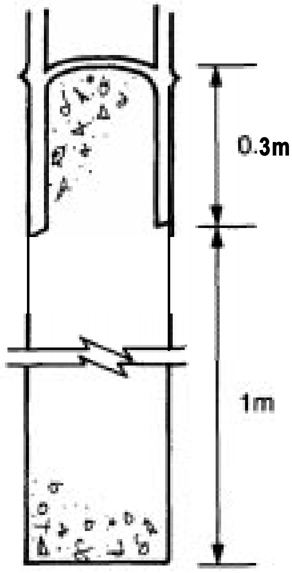



Figure 8: Composite bamboo/concrete column
(after Janssen, 1995)

*Bamboo reinforced concrete*

Bamboo reinforced concrete slabs offer another solution, although this type of construction has its own specific problems. These are dealt with in more detail in Chapter 7.

*Bamboo piles*

Bamboo piles have been used successfully to stabilise soft soils and reduce building settlement. In the example cited (Stulz, 1983), treated split bamboo piles 8m long and 80 to 90mm in diameter were filled with coconut coir strands wrapped with jute. The sections were then tied with wire. After installation of the piles at

2m centres by drop hammer, the area was covered with a 2.5m surcharge of sandy material (see figure 9).

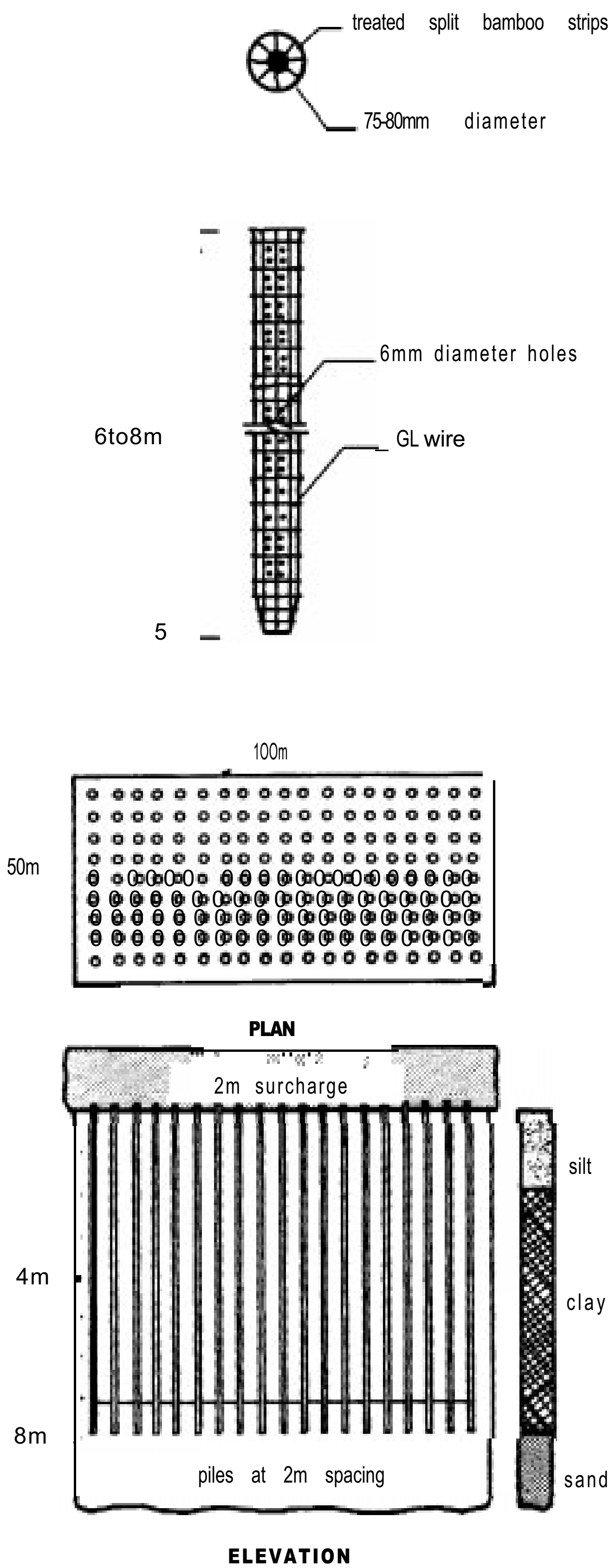



*Figure 9: Bamboo piles (after Stulz/IGE, 1983)*

**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 (Janssen, 1995). When the floor is elevated, it becomes an integral part of the structural framework of the building. The floor will comprise:

- structural bamboo elements
- bamboo decking

**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 (see Chapter 8, Jointing techniques). Beams and columns are generally around 1 00mm 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 (figures 10 and 11).

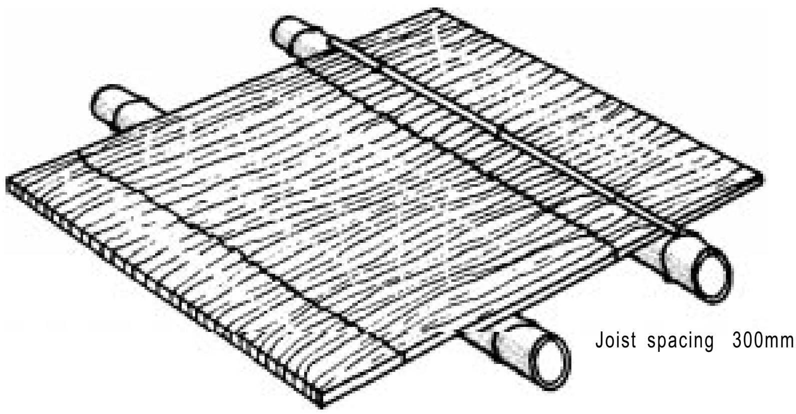



*Figure 10: Joist arrangement - primaries on/y*
*(after Siopongco* et al. 1987)

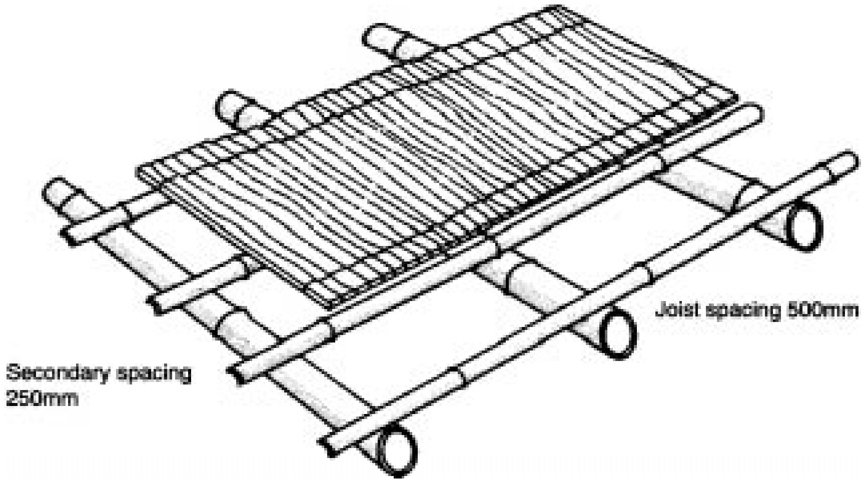



*Figure I I: Joist arrangement - primaries and secondaries (after Siopongco* et al. 1987)

*Floor decking* Bamboo floor decking can take one of the following forms:

- Small bamboo culms
- Split bamboo
- Flattened bamboo (bamboo boards)
- Bamboo mats
- Bamboo panels
- Bamboo parquettes

*Small bamboo* culms: small diameter culms are tied or nailed directly to the joists (figure 12).

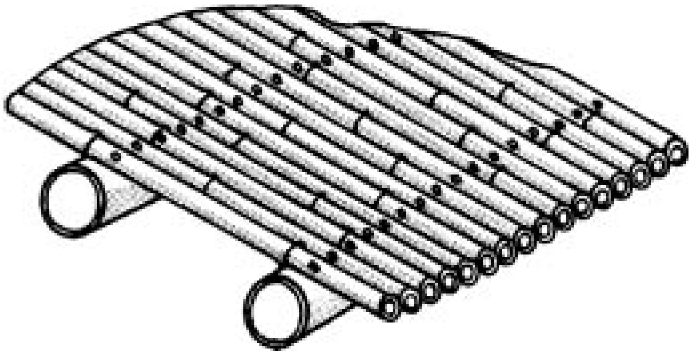


*Figure 12: Bamboo cane floor decking (after Janssen, 1995)*

*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 (figure 13).

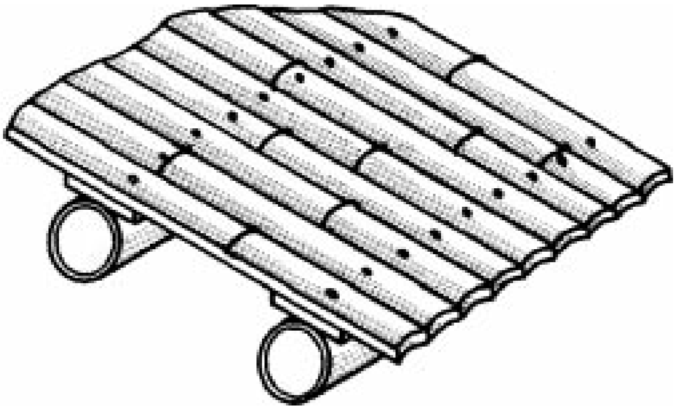


*Figure 73: Split bamboo floor decking (after Janssen, 1995)*

*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 (figure *14).*

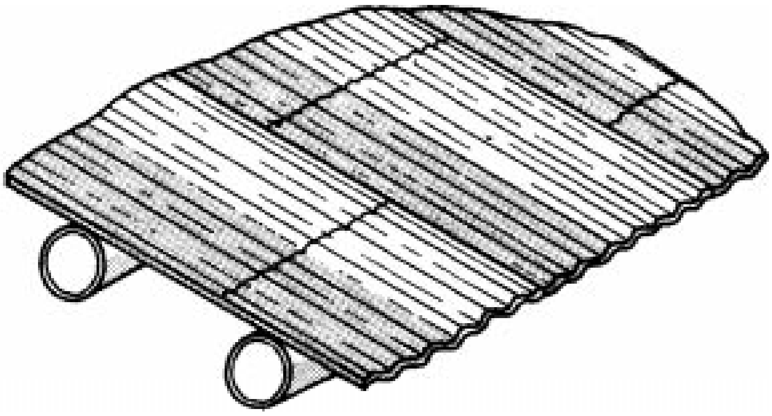


*Figure 14: Flattened bamboo floor decking (after Janssen, 1995)*

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.

*Bamboo mats:* these are formed by weaving thin strips of bamboo. Strips vary in size from 20 x 2mm to 2 x i mm, depending on the intricacy of the pattern. Some examples are shown in figure 15.

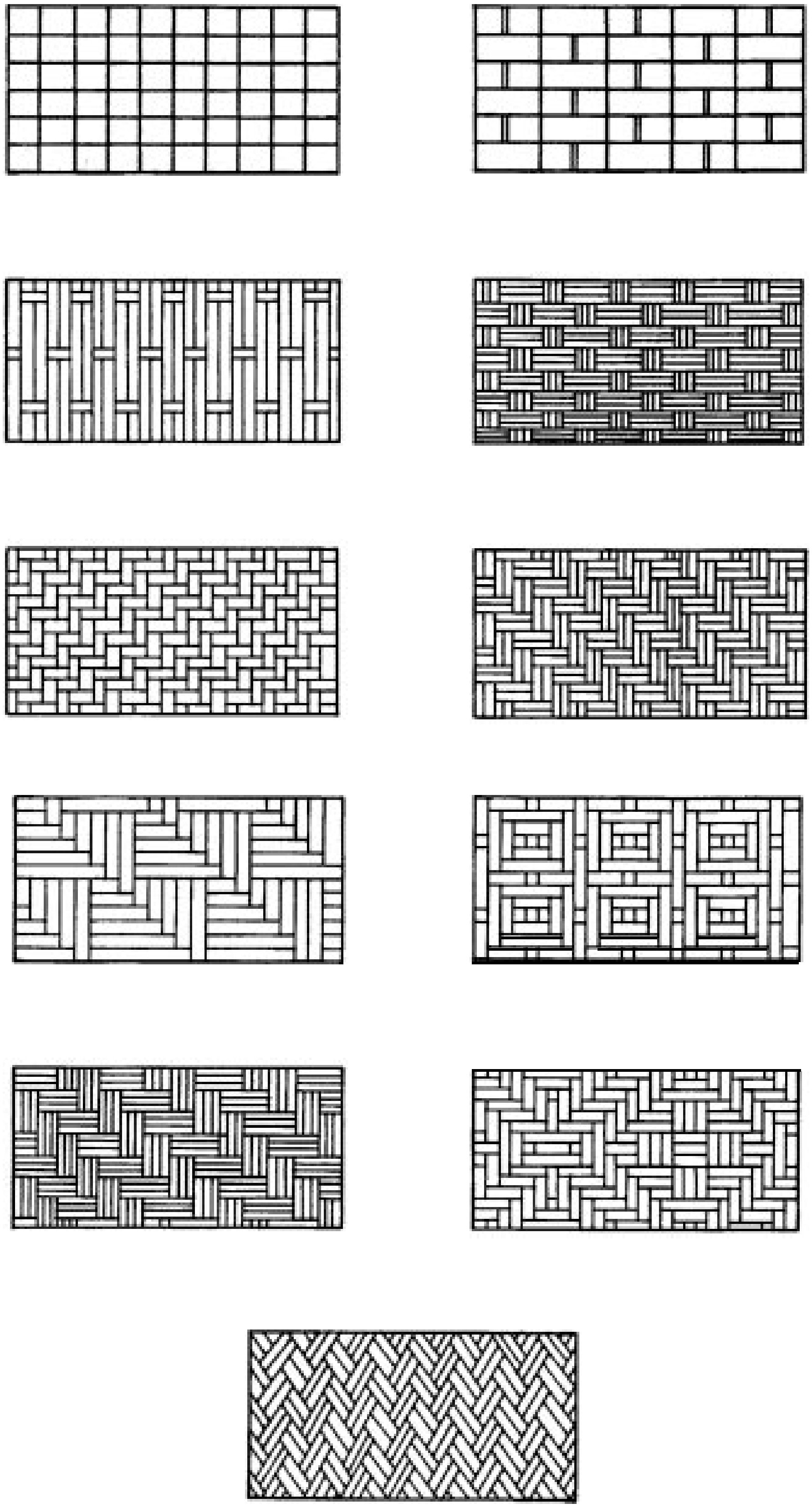


*Figure 15: Examples of woven bamboo mats*
*(after Janssen, 1995, Narayanamurty* et al. 7972
*and Siopongco* et al. 1987)

Mats should not be fixed by direct nailing, but are held in place by bamboo strips or timber battens tied or nailed over the top (figure 16). This is one of the easiest types of traditional floor to keep clean.

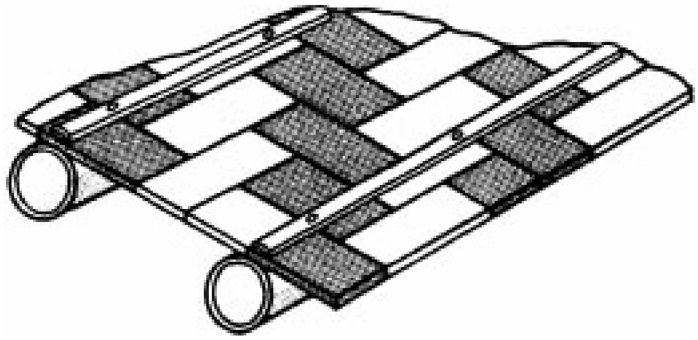


*Figure 16: Woven bamboo mat floor decking (after Janssen, 1995)*

*Bamboo panels:* layers of woven mats or strips, laid at right angles, are bonded together into boards (see *Bamboo based panels* in Chapter 7), which are then nailed to the joists.

*Bamboo parquette:* thin slivers or mats of bamboo are formed into multi-layered tiles and laid on treated bamboo or wooden strips fixed to compacted earth or a concrete sub-floor.

**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, quincha)
- Woven bamboo, with or without plaster
- Bamboo panels

*Whole or halved bamboo culms*

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 (figure 17). Halved culms can be fixed in the same way, either as a single or double ply construction, or anchored between horizontal halved culms (figure 18). Woven bamboo mats can be attached to one or both faces using tied or nailed bamboo battens.

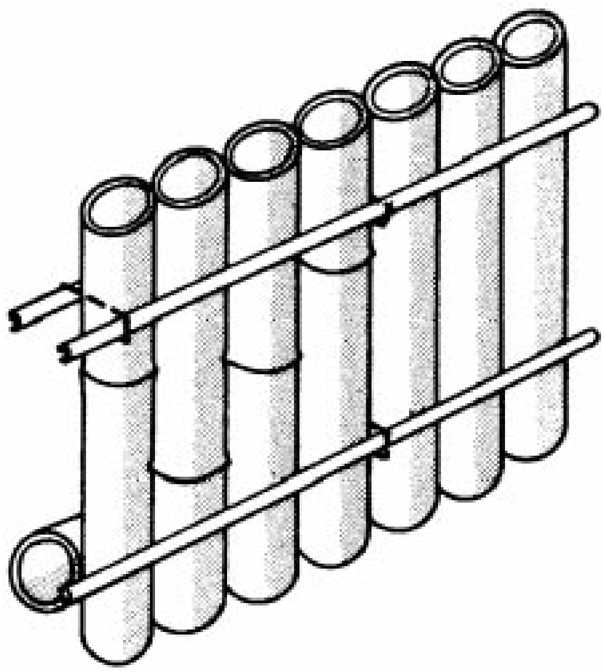


*Figure 17: Wall of whole bamboo culms (after Janssen, 1995)*

*Split or flattened bamboo*

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.

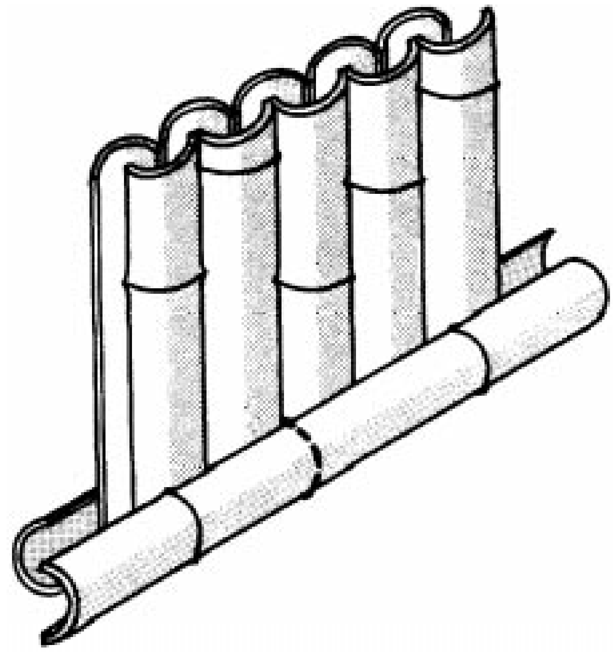


*Figure 18: Wall of vertical halved culms*
*(after Bandara, 7990)*

*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 (figure 19).

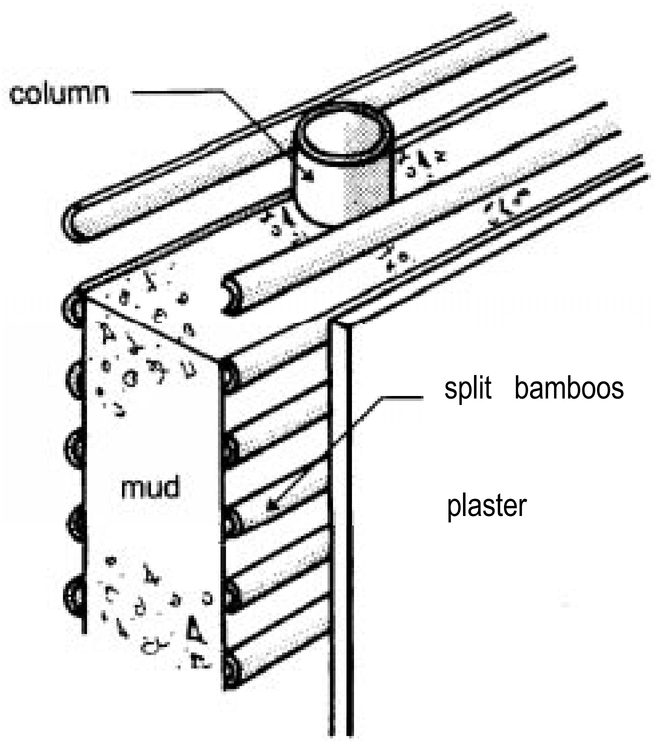



*Figure 19: Bajareque wall construction*
*(aftef Janssen, 1995)*

*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 weft and horizontal warp), plastered on both sides (figure 20).

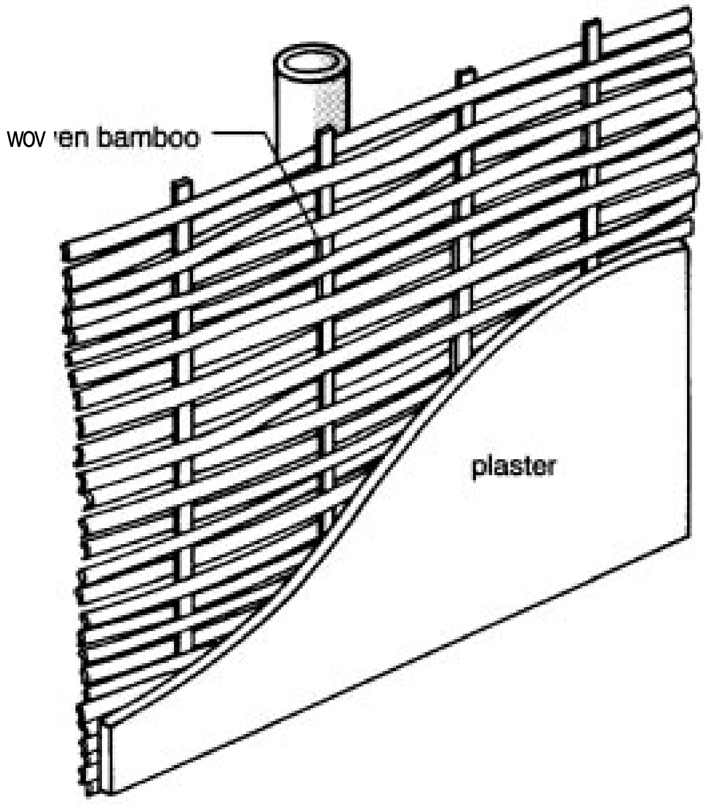



*Figure 20: Quincha wall construction (after Siopongco et al. 1987)*

*Woven bamboo* 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, cowdung, cement and organic fibres. The surface can be finished with a lime wash to give a typical stucco appearance (Jagadeesh and Ganapathy, 1995).

Preservatives may be added (Satish Kumar *et al.* 1994), but due attention should be paid to health, safety and environmental matters.

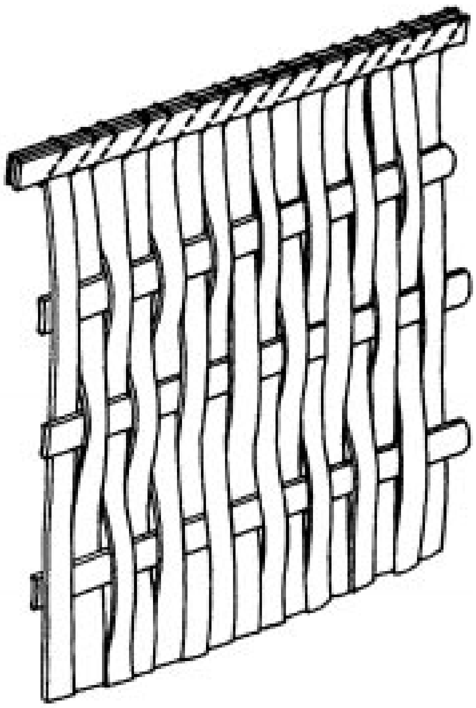


*Figure 21: Woven bamboo wall construction (after Siopongco et al. 1987)*

**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 (see Bamboo *based panels* in Chapter 7).

Bamboo has also been used as a reinforcement for stabilised or rammed mud walls (Mishra, 1988). However, difficulties exist in achieving an adequate bond between the mud and bamboo to ensure composite action.

**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.

Roof structure

Traditional roof construcfion: 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 (figure 22). The maximum overall span using this method is about 3 metres.

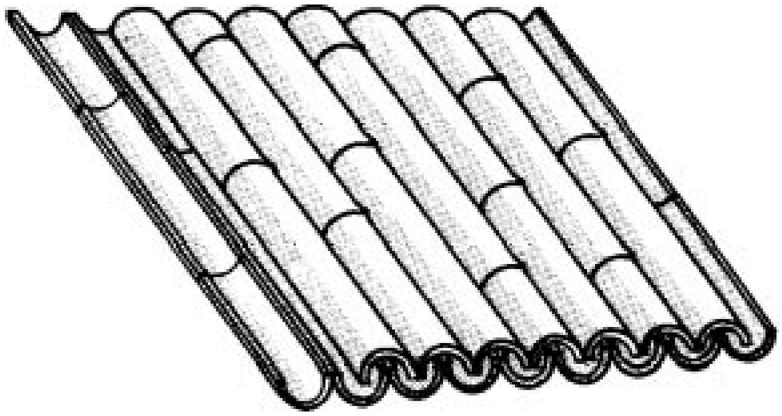


*Figure 22: Roof of halved bamboo culms (after Siopongco et al. 1987)*

A variation on this is the use of whole culms, suitably spaced to accept battens for tiles or thatch (see *Roof covering).* To extend the span, a central post can be used. Beyond this, the options are almost infinite. A selection of cross sections is shown in figure 23. Efficient jointing of components is a key consideration (see Chapter 8, *Jointing techniques).*

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 (counteracting effects of bow, crook and taper) 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 (Janssen, 1995, Punhani et *al.* 1989, Tular et *al. 1984) (see* Chapter *8, Jointing techniques).*

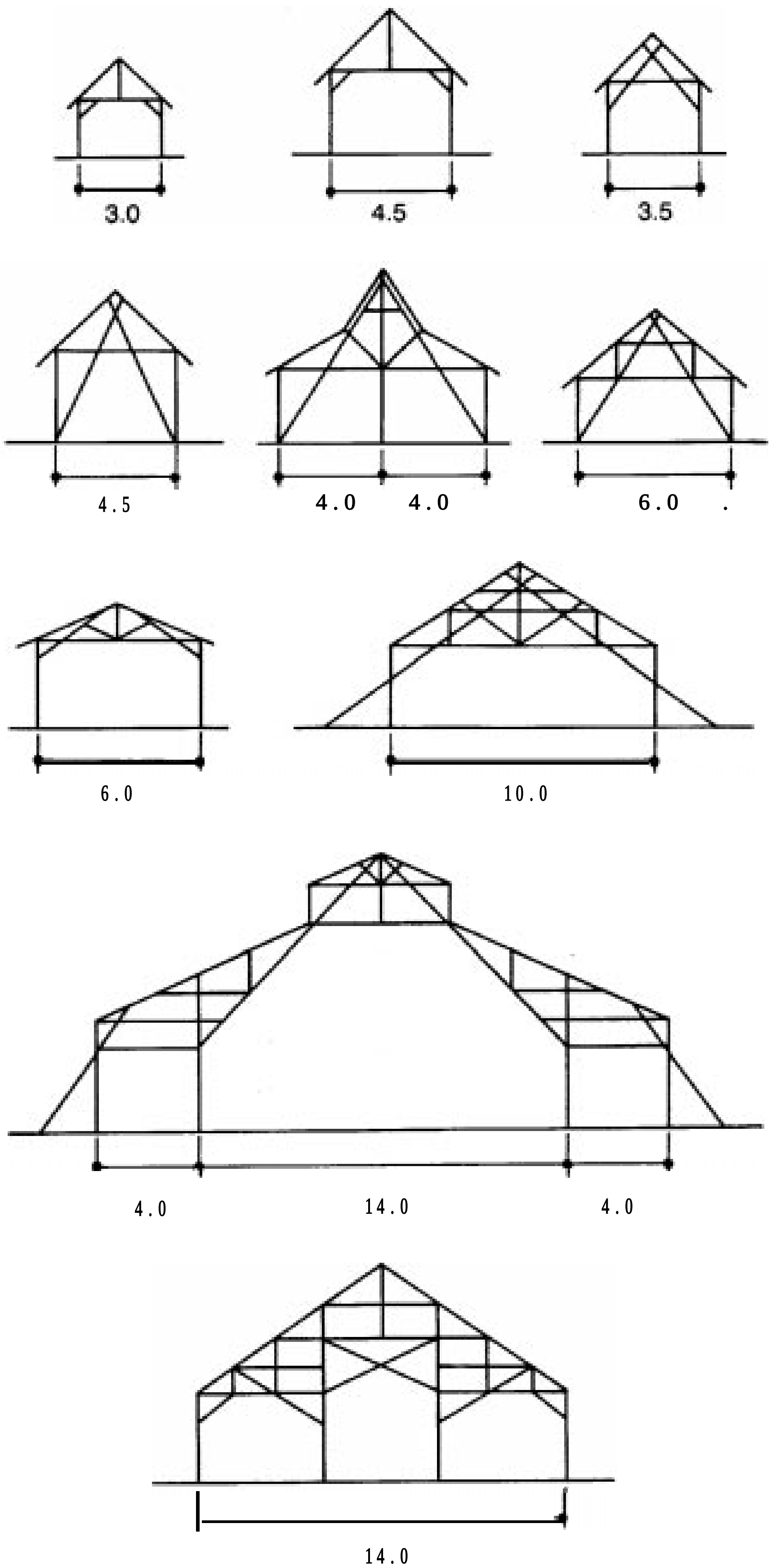



*Figure 23: Possible roof framing configurations using traditional forms of construction - dimensions in metres (after tular et al. 1984 and Janssen, 1995)*

As with cut roofs, truss configurations are many and various. The King-post and Fink are the simplest, readily spanning 4m using traditional jointing (figures 24 and 25). Culm diameters typically range from 40-I 00mm. Janssen (1995) has achieved an 8m span using improved jointing (figure 26).

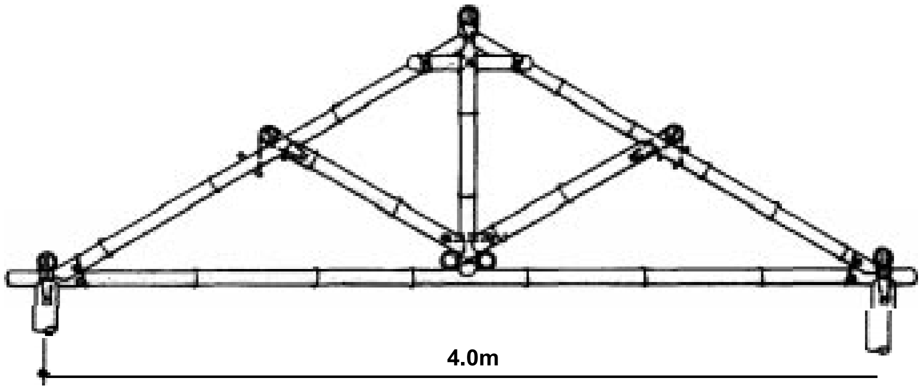



*Figure 24: King-post truss (after Siopongco et al. 7987)*

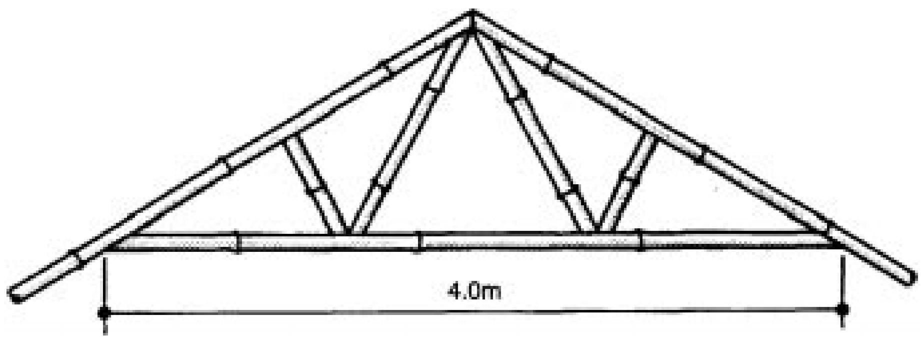



*Figure 25: Fink truss (after Punhani et al. 7989)*

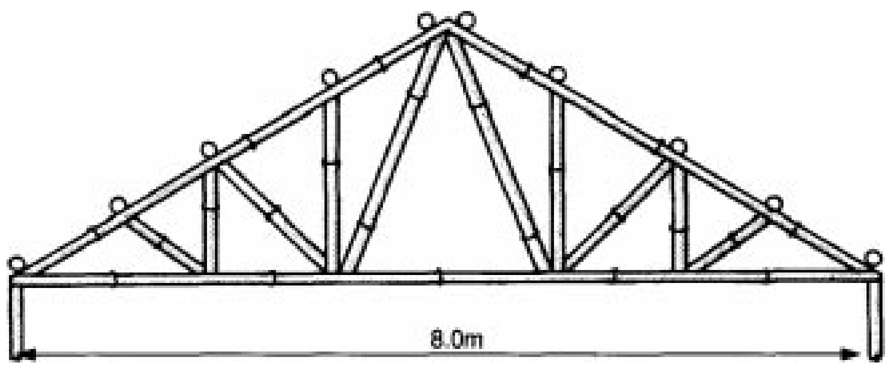



*Figure 26: Janssen (1995) truss configuration (joints omitted for clarity)*

The pitch of the truss should be at least 30° in areas of high rainfall (Narayanamurty et ***al.*** 1972). Truss spacings 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.

Roof covering

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
- Plastered bamboo

***Bamboo*** files: 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 (figure 27). Roofs covered in this manner are susceptible to leakage (Mathur et ***al.*** 1964).

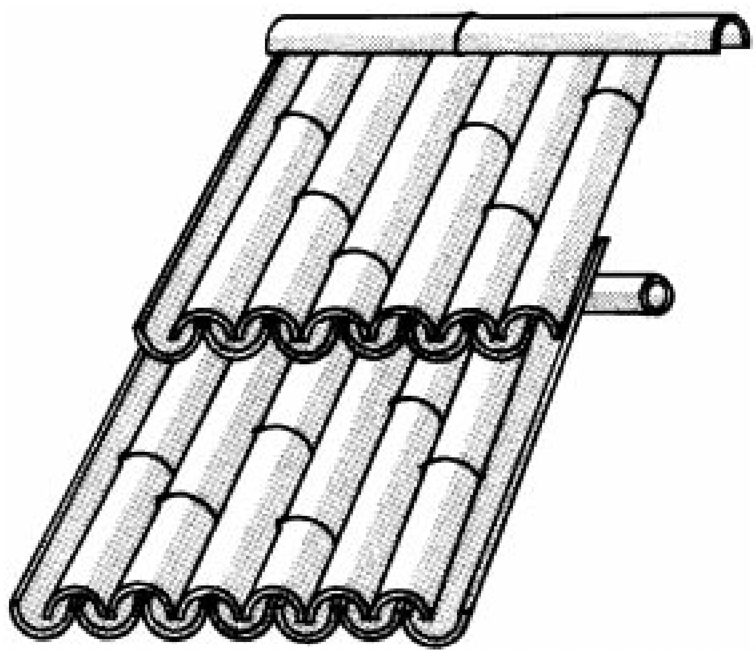


*Figure 27: Bamboo tiles (after Mathur et al. 1964)*

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. The shingles are hooked onto bamboo battens (maximum spacing 150mm - Narayanamurty et al. 1972) by means of a tongue cut into the underside (figure 28). 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 li kely.

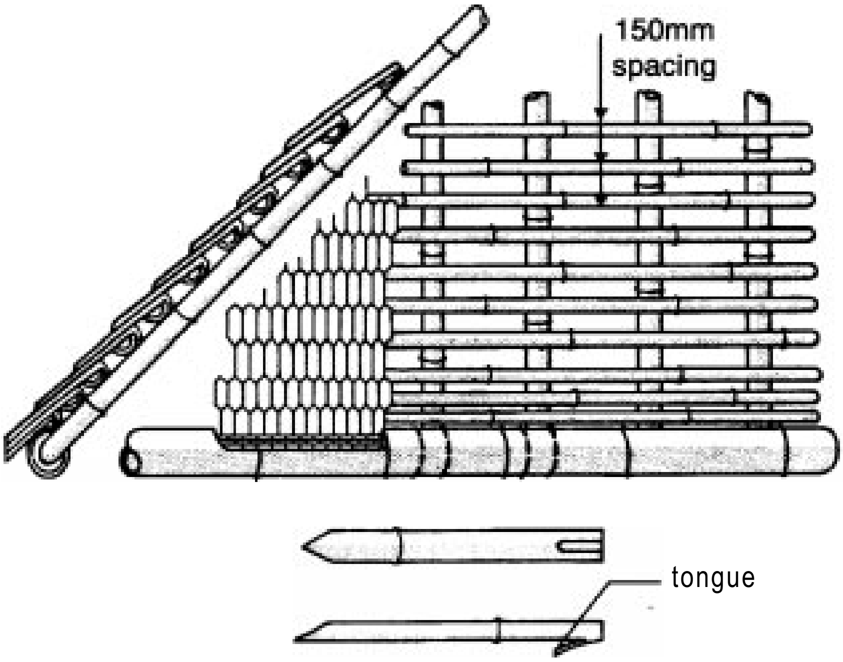



*Figure 28: Bamboo shingles*
*(after Nrayanamurty* et al. 1972)

*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 (figure 29). A bituminous or rubberised weatherproof coating is then applied to the finished roof (Damodaran *et al.* 1991).

*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.

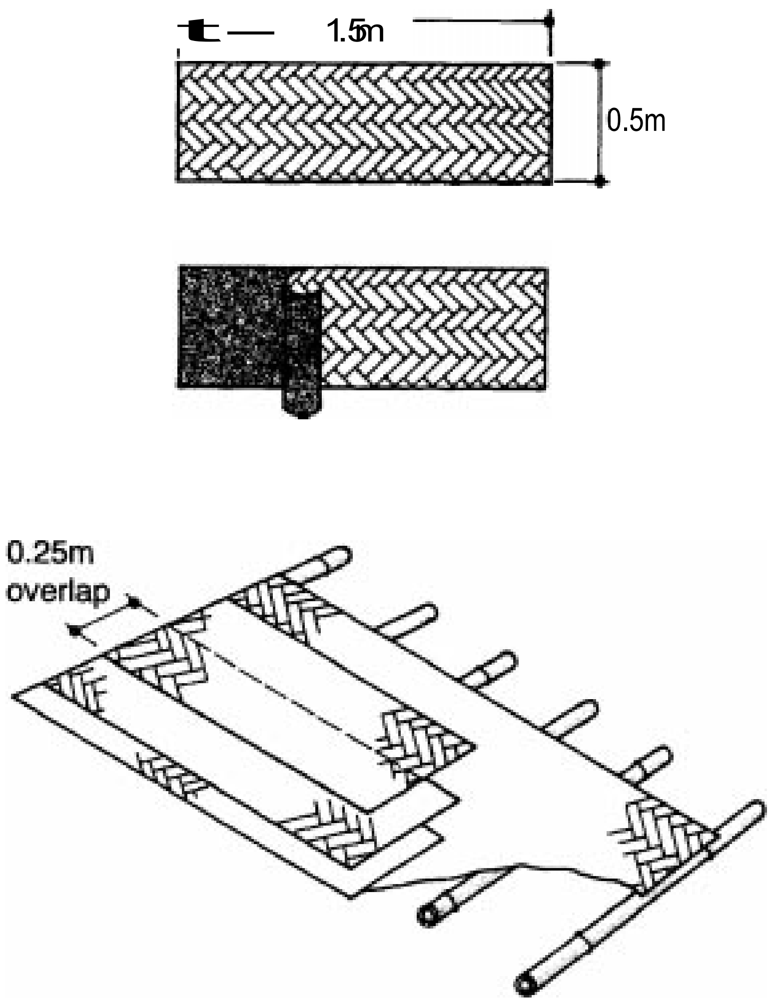



*Figure 29: Bituminised bamboo mats*
*(after Damodaran* et al. 1991)

*Plastered bamboo:* a cement plaster, with or without the addition of organic fibres, is traditionally applied to bamboo roofs in South America.

Other typical roof coverings include:

- Reed thatch
- Corrugated iron sheeting
- Plain clay tiles
- Clay or concrete pan tiles

The weights of roof coverings vary considerably (20kg/m$^2$ for bamboo tiles and shingles, 42kg/m$^2$ for reed thatch, t 3kg/m$^2$ for corrugated iron and 71 kg/m$^2$ for clay tiles - Herbert *et al.* 1979) and this must be reflected in the strength of the roof structure.

**Ceilings** The provision of a ceiling can help to reduce heat radiation into the occupied space and also induce a cooling airstream through the roofspace. 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 sarking to the topside of the rafters or purlins, separated from the roof covering by battens.

**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 (figures 30 and 31).

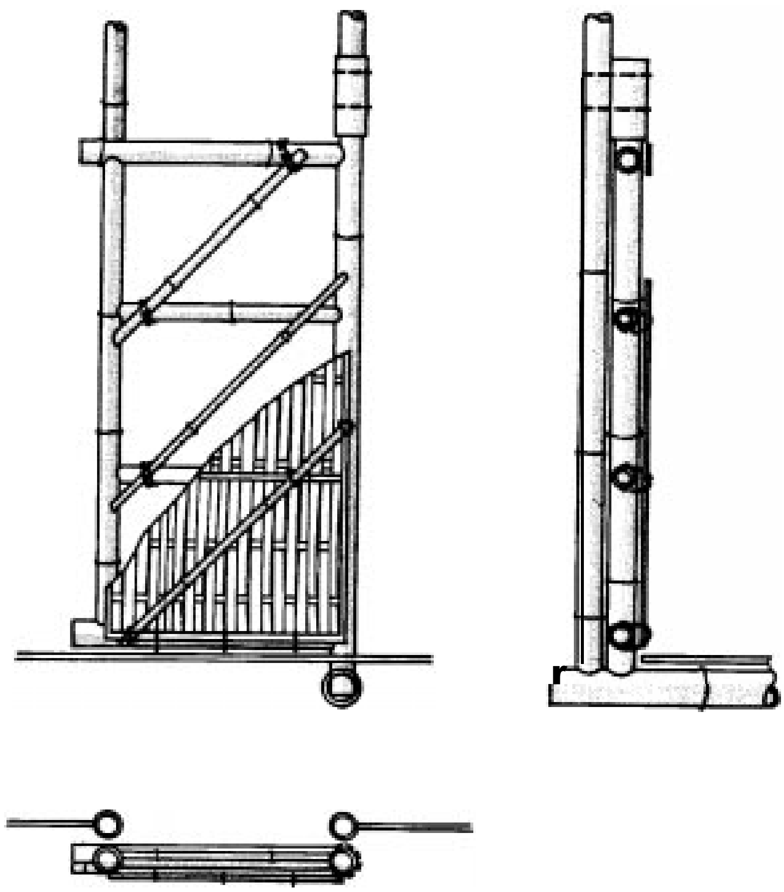


*Figure 30: Arrangement of hinged door (after Siopongco* et al. *1987)*

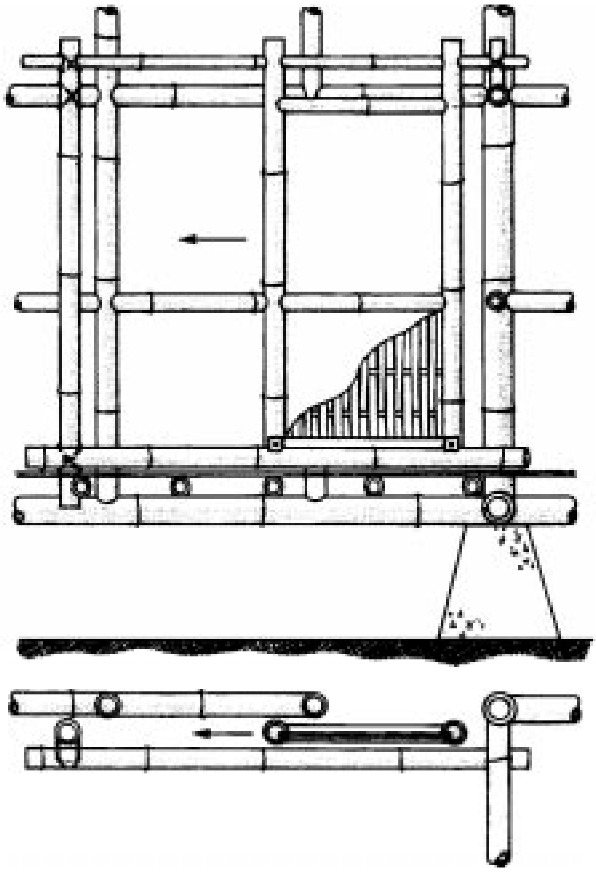


*Figure 31: Arrangement of sliding door (after Siopongco* et al. 1987)

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 (figure 32) offer another solution (Ganapathy and Zoolagud, 1993).

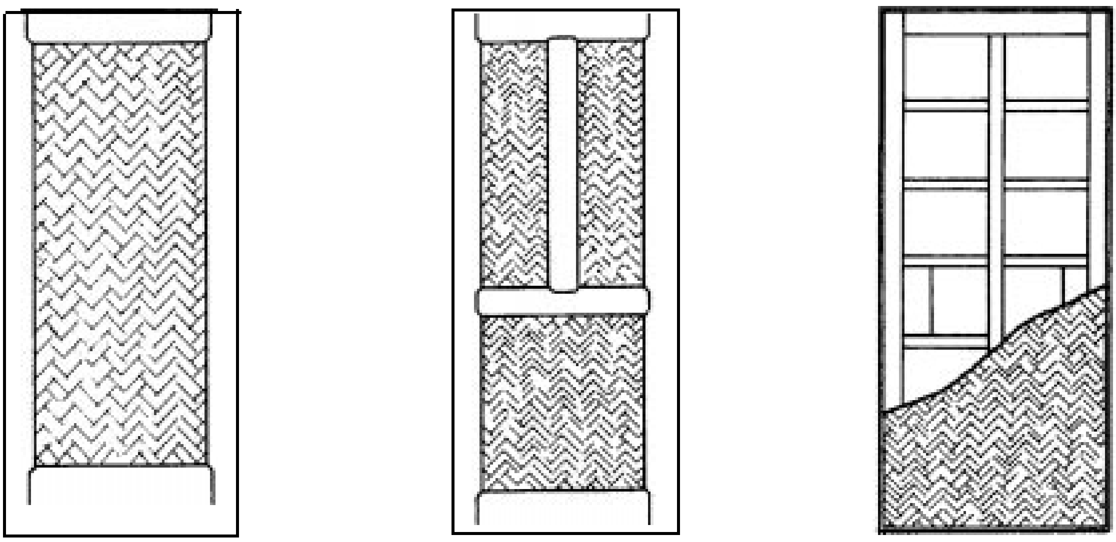


*Figure 32: Bamboo mat board panelled and hollow core doors (after Ganapathy* et al. 1993)

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 (figure 33), 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.

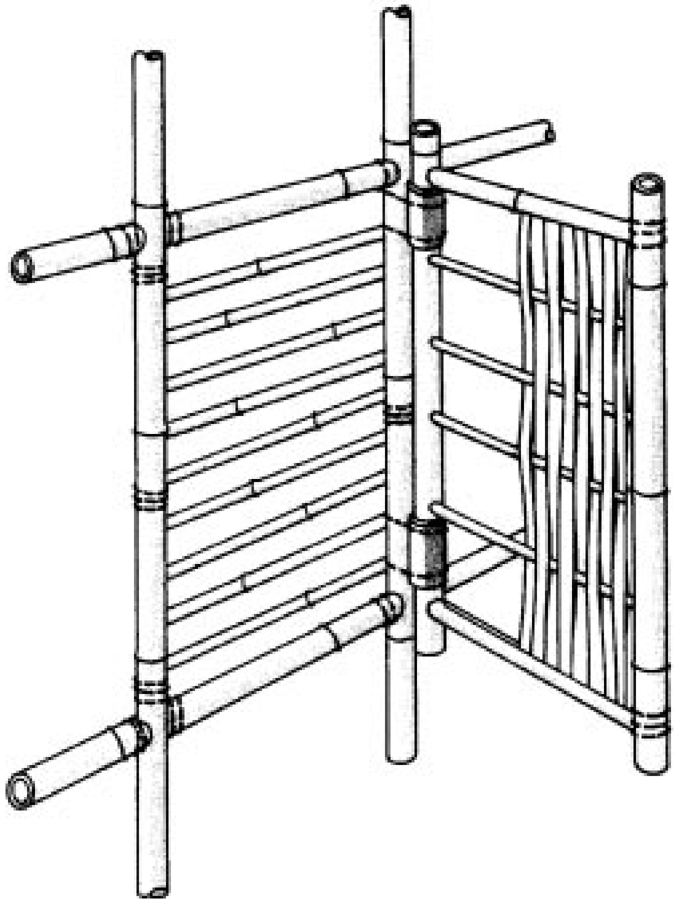


***Figure 33: Hinged sash window (after Siopongco** et al. **1987)***

**Water pipes and gutters** Whole bamboo culms, with the diaphragms removed, 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 (figure 34). To control insect attack, the trench can be treated with insecticide before the pipes are laid.

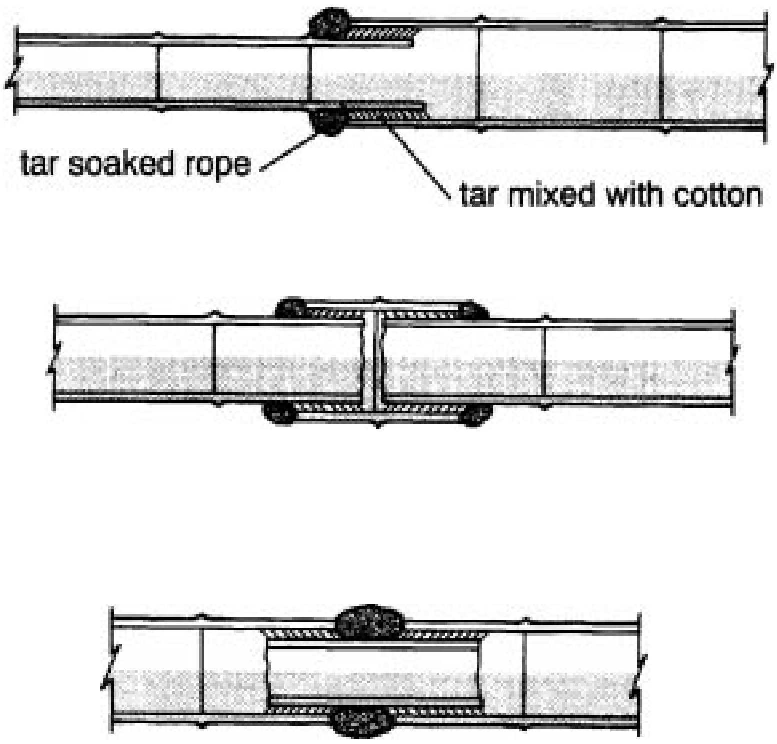



*Figure 34: Jointing of bamboo pipes below ground (after Bandara, 1990)*

The development of water piping in Tanzania (Lipangile, 1985) 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 (figure 35). Watertight connections can be achieved as for pipes below ground.

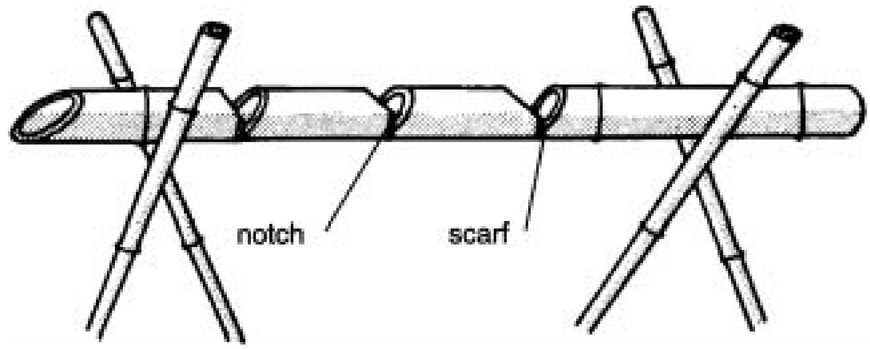



*Figure 35: Bamboo piping above ground (after Janssen, 1982)*

Halved culms, with the diaphragms removed, can be used as eaves gutters and drainage troughs (see *Detailing for durability*) .

**Detailingfor durability**

In addition to structural and functional considerations, the suitability and durability of any construction will depend to a large extent on good detailing. Protection against wetting and vermin infestation are two such factors with particular relevance to bamboo buildings.

*Wetting*

Inhibiting wetting is the first defence against decay. Wetting is caused by direct rain, flooding and, to a lesser extent, washing and cooking water.

To prevent wetting of the interior, water can be ducted away using bamboo pipes and troughs (see *Water pipes and* gutters). To protect the foundation posts against flooding, local effects caused by roof run-off can be minimised by ensuring good eaves and gable overhangs, and perhaps guttering to discharge the water some distance from the building. The provision of good overhangs will also help to protect the walls from direct rain. The effects of more generalised flooding can be countered by building above the ground on a graded site and using stone or concrete footings.

The life of foundation posts can be further shortened by splashing rainwater. Janssen (1995) proposes interchangeable post ends as a possible solution to this problem (figure 36).

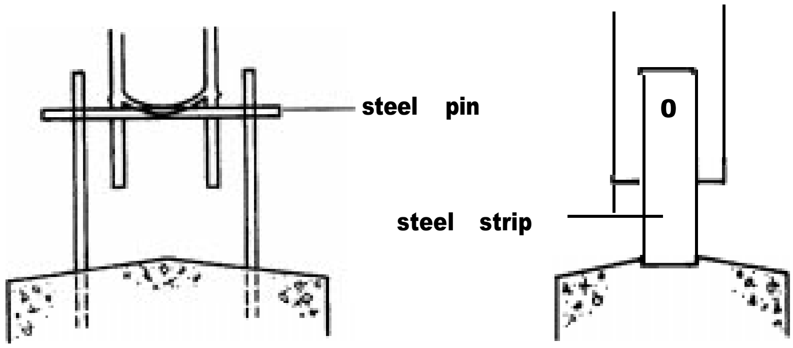



*Figure 36: Arrangement for interchangeable post ends (aftef Janssen, 1995)*

*Vermin infestation* Bamboo constructions by their nature feature hollow members and overlapping joints, forming cavities which can provide ideal nesting areas for rodents. This problem can be largely overcome by careful detailing. In general, open beam, joist, rafter and purlin ends should be plugged. More specifically, relating to different constructional details, the following points should be observed:

*Floors:* wall cladding should not extend past the end of the joists - this creates a concealed area between the beams and floor deck (figure 37).

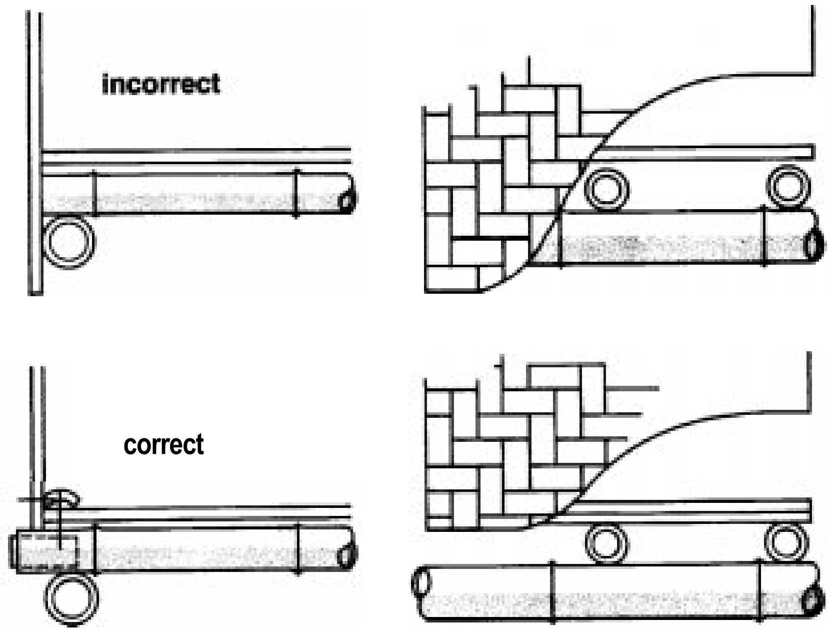



*Figure 37: Preferred beam/joist end detail*

Walls: walls should preferably not be of cavity construction. If two layers of bamboo are used (halved culms, boards or mats, or any combination of these), they should be fiied closely together.

Roofs: cavities will inevitably result where rafters cross ridge purlins and eaves beams. Here, the solution is to ensure good visibility and regular inspection.

Ceilings: access to the roof space via a closeable hatch should be provided for inspection purposes. Where the ceiling takes the form of sarking, it should extend past the wall (figure 38).

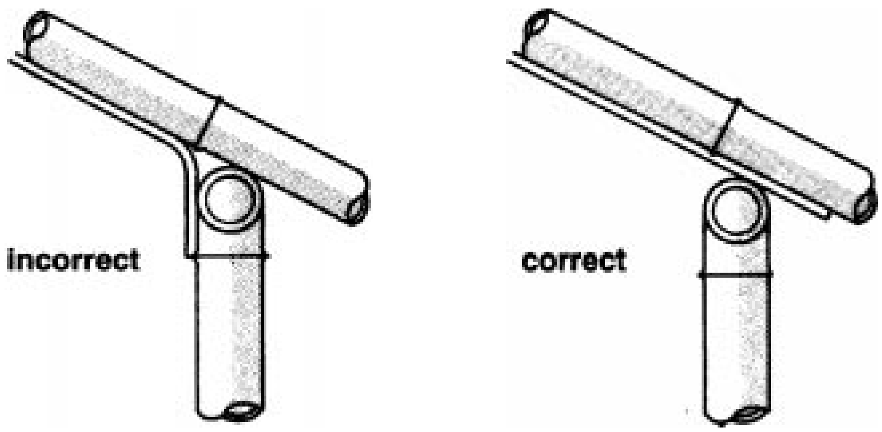



*Figure 38: Preferred ceiling (sarking) detail*

# 6. Other types of construction

While domestic housing and small buildings account for the majority of bamboo construction, applications extend to other areas often less constrained by scale and convention. Bridges and scaffolding fall into this category.

**Bridges** A bridge can be defined as an elevated structure supported at intervals for carrying traffic across obstacles (valleys and rivers, for example). In general terms, therefore, the range of types, spans and capacities is almost infinite. Bamboo bridges, however, are generally of trestle construction and of limited span for carrying only light (usually pedestrian) traffic. Simple trussed constructions have also been built and have been shown capable of supporting substantial loads.

Some examples of bamboo bridges are described below:

Footbridge (figure 39): this bridge consists of simple cross-braced frames with the walkway formed at the crutch. Culms of 50-75mm diameter are bound with bamboo lashings. The bridge is suited to rivers with muddy or sandy bottoms where the height above the bed does not exceed 5m (Royal Engineers Training Memorandum, 1945). A typical crossing might be 20m.

Handcart bridge (figure 40): this is a more elaborate construction with abutments and pilings. The abutments are formed from pairs of culms staked to the ground. The piles, culms of 80-120mm diameter, are cut to a point at the thinner end and driven in with a sledgehammer. A pair of horizontal culms form the pile cap and diagonal braces stabilise the assembly. The projecting pile ends act as handrails. To form the roadway, three longitudinal bamboo beams of 100mm diameter are lashed to the caps and tied together at the centre of each bay with a cross-member.

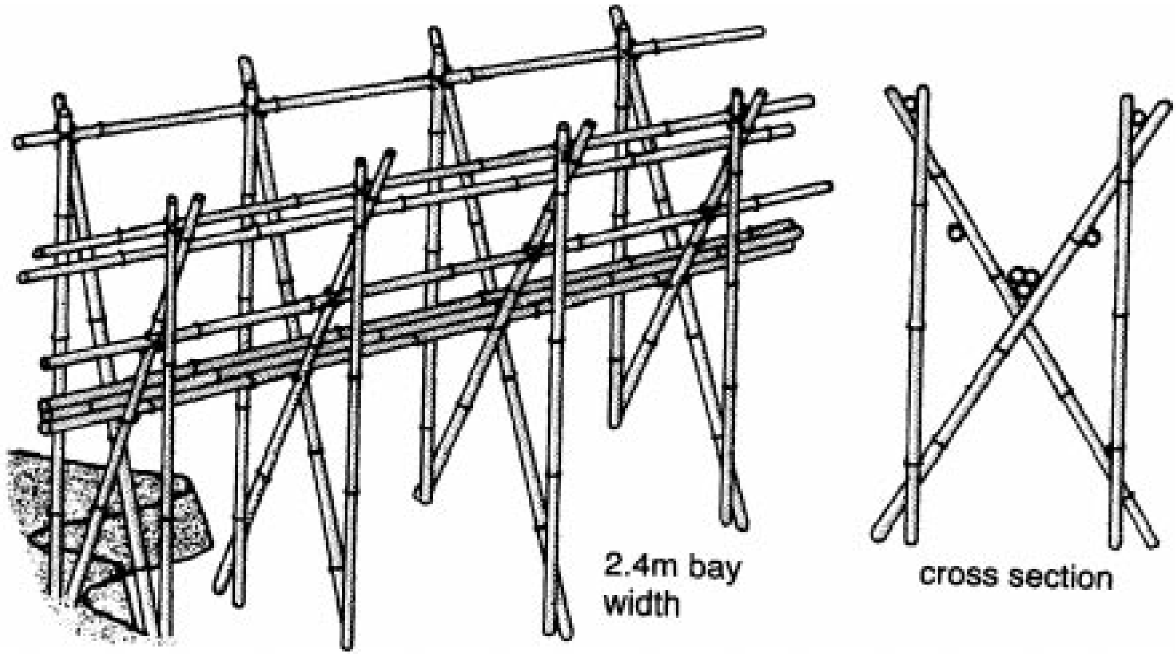



*Figure 39: Footbridge (after Janssen, 1982)*

Closely spaced culms laid transversely and covered with split bamboo form the deck. A kerb is laid along each edge of the deck and secured to the outer beams by torsion lashing (twisting the lashings with a cane or stick). This ties the deck assembly together.

A bridge of this type can support 200kg per metre length, for example people carrying loads on their backs or propelling small handcarts (Trojani, 1930).

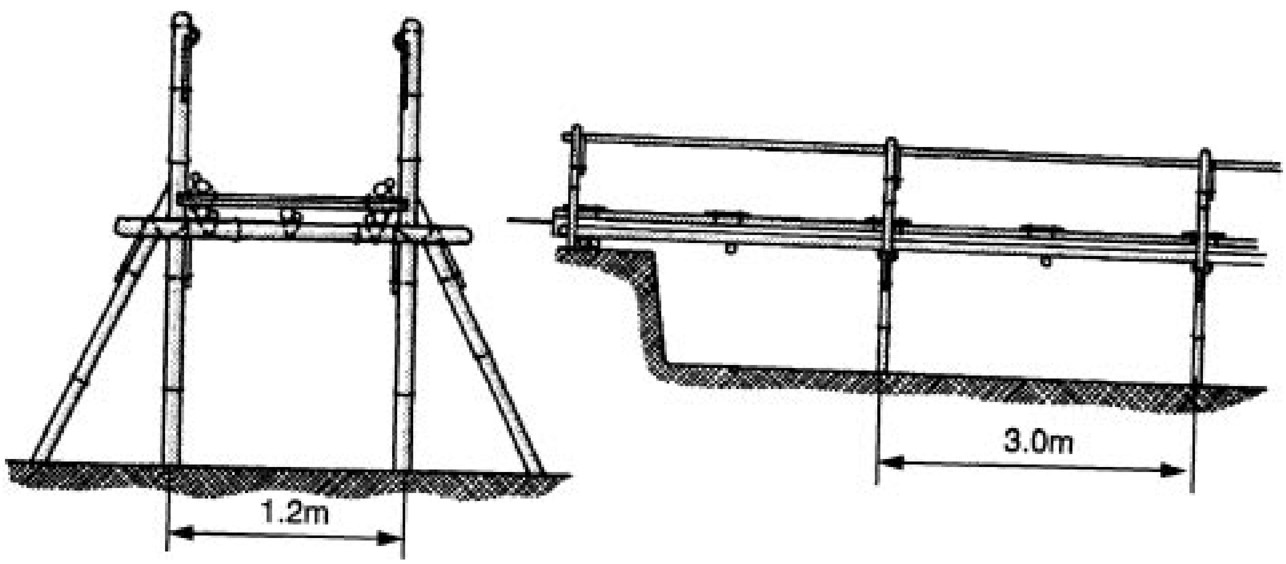



*Figure 40: Handcart bridge (after Janssen/Trojani, 1982)*

**light traffic bridge** (figure 41): this is a heavier duty version of the handcart bridge. It features four piles per bay and double abutments. The bay size remains the same (about 3m) but the piles are at closer centres (nominally 750mm). Bracing is also increased with the addition of two diagonal tie members. The roadway comprises paired beams, rather than singles, decked in a similar manner to the handcart bridge. This bridge can support 500kg per metre length, for example herds of cattle or animal-drawn wagons with four people plus loads (Trojani, 1930).

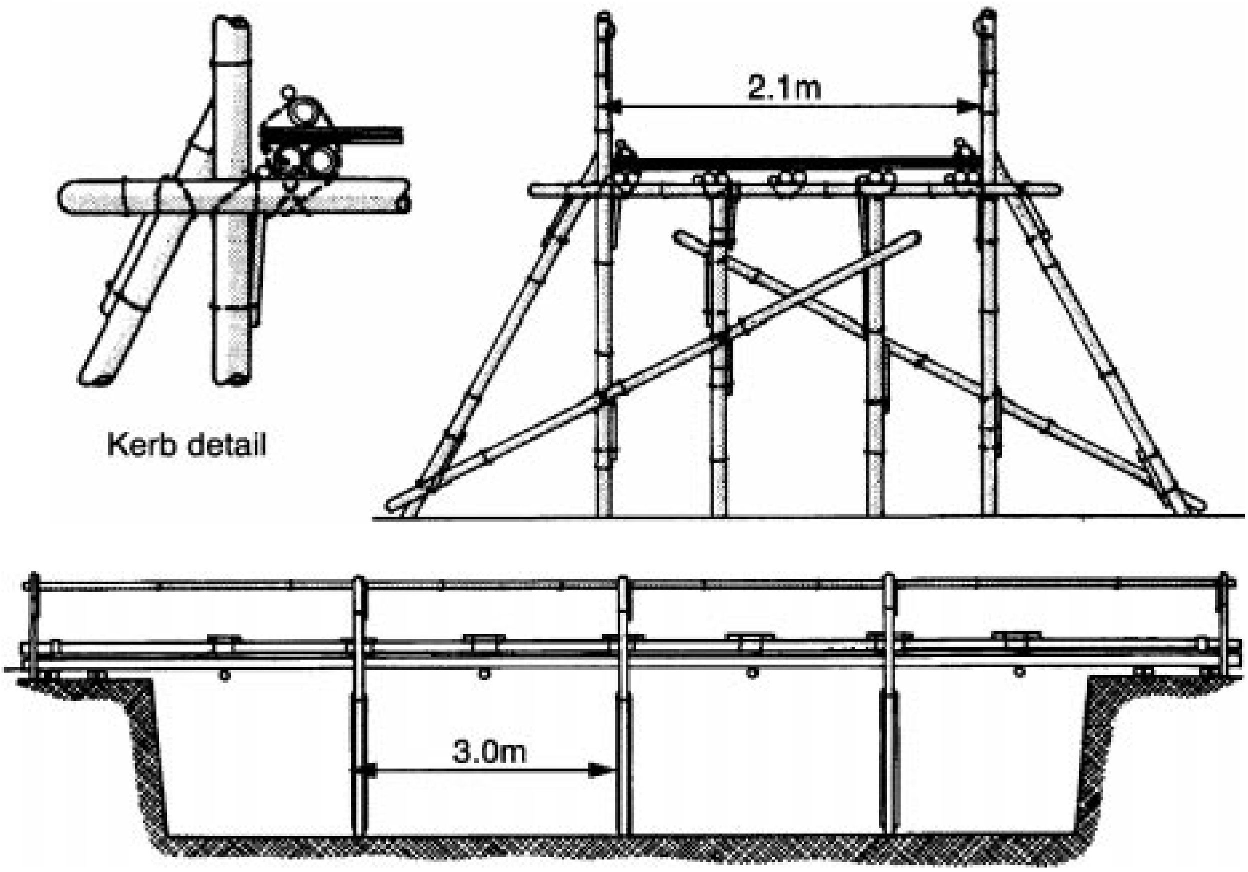



*Figure 4 l: Light traffic bridge (after Janssen/Trojani, 1982)*

*Simple* **truss** *(flying buttressed) bridge* (figure 42): this bridge is designed to cross deep, narrow rivers. It will clear-span about 4m and relies on triangulation to carry the loads back to the abutments, The scissors frame is made from culms of 100-l 20mm diameter, stabilised with diagonal members. The roadway and deck are made in a similar manner to that for the handcart bridge, and the bridge will carry similar loads (Janssen, 1985).

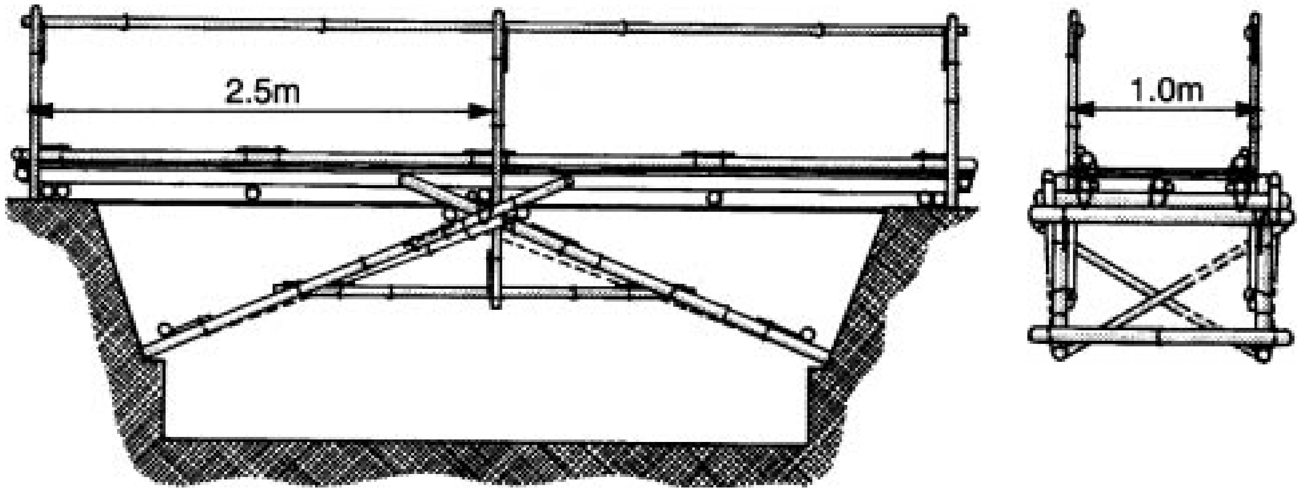



*Figure 42: Simple truss (flying buttressed) bridge (after Janssen/Trojani, 7982)*

*Pylon bridge* (figure 43): Prefabricated bamboo pylons, or towers, are set at intervals across the bed of a shallow river using an aerial ropeway. The pylons can then be decked *in situ* or by using prefabricated sections of walkway (Janssen, 1982).

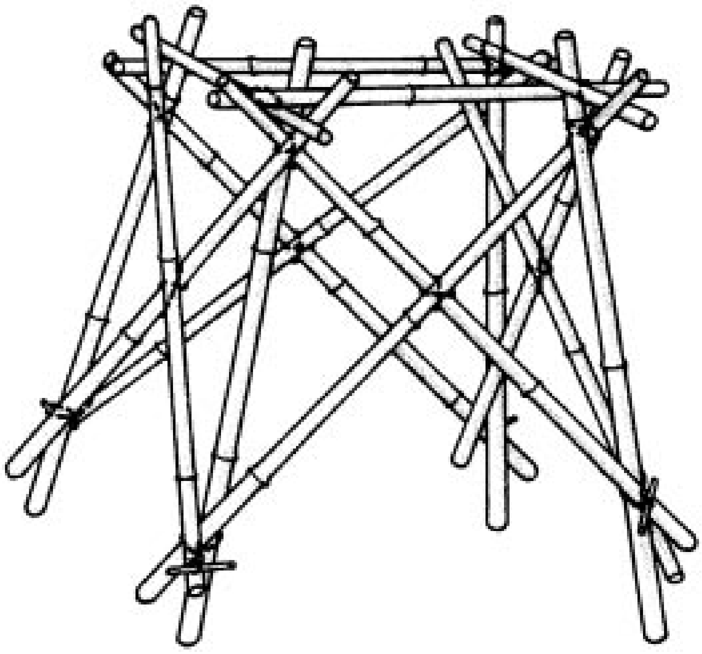
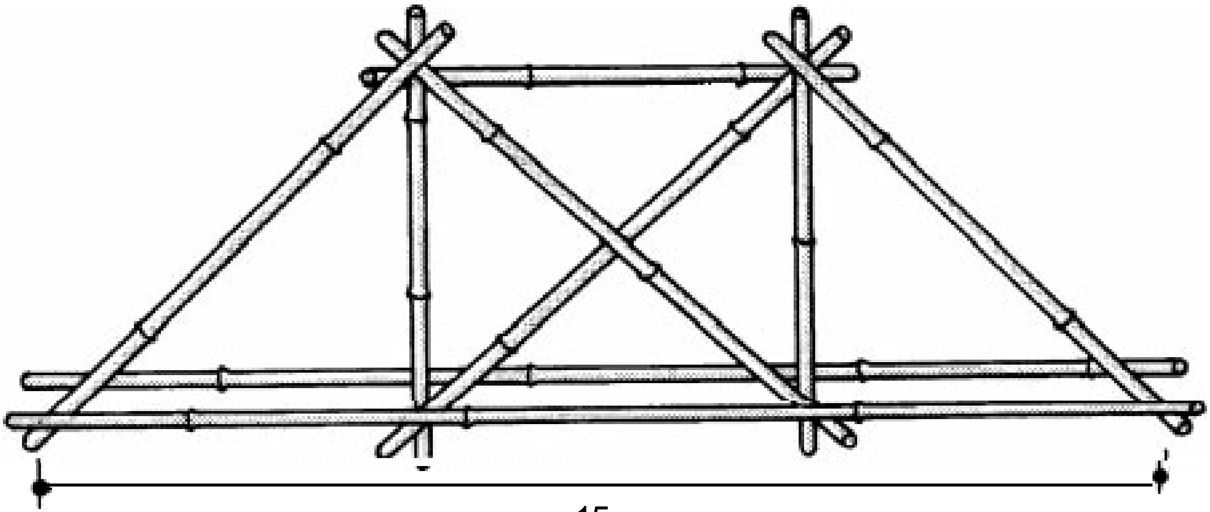


*Figure 43: Pylon bridge (after Janssen/Sweet, 1982)*

*Queen post truss bridge* (figure 44): using compound members (four culms per chord) and a combination of wire lashing and steel pins, a 15m span prototype bridge was constructed comprising two modified queen post trusses. The bridge supported a load of 1.6 tonnes with only slight damage to the deck and some of the pinned joints (Kumpe, 1937).



15m

*schematic - compound members omitted for clarity*

*connection details*

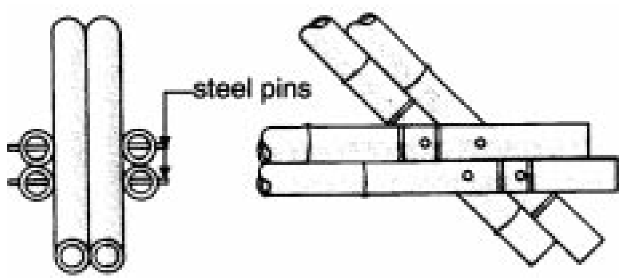



*Figure 44: Queen post truss bridge (after Janssen/Kumpe, 1982)*

**Scaffolding** Bamboo scaffolding is widely used throughout South and South East Asia and also South America as a temporary structure for supporting working platforms in building construction and maintenance. There appears to be no height limit - 40 storeys is not uncommon - but for taller constructions wooden posts are often used as the main supports (Fu, 1979).

Usually, two layers of scaffolding are used. The outer layer provides the main strength and stability and is fixed to the building at intervals. The inner layer provides the means of supporting walkways (timber boards or bamboo culms) and accessing the face of the building. The distance between components is dictated by practical considerations such as the effective reach of the s&folder. The strength and stability of the scaffold is judged to be adequate if individual components and joints can support the weight of the scaffolder. Joints are typically made with bamboo strips.

The main advantages of bamboo scaffolding when compared with steel are its lightness and low cost. It is also readily tailored to suit the shape of a building. A typical arrangement is shown in figure 45.

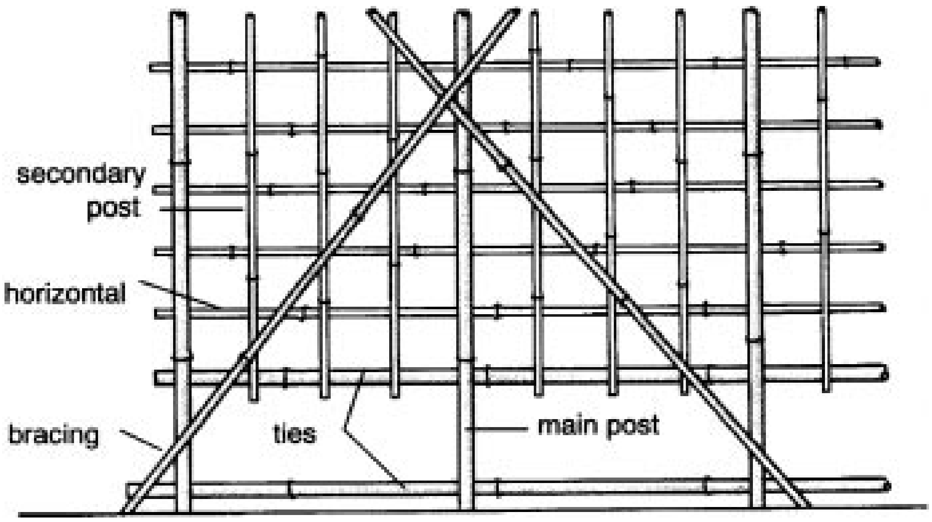



*Figure 45: Typical scaffoldjng arrangement (after Fu, 1979)*

# 7. Other applications relevant to construction

**Bamboo reinforced concrete** The use of bamboo as concrete reinforcement is one of the more broadly covered topics relating to bamboo in construction and considerable research effort continues to be directed at this subject.

There are several good reasons why bamboo might be considered as reinforcement for concrete:

- It is of low cost compared with steel
- It is readily available
- Its strength to weight ratio compares favourably with steel

However, bamboo exhibits certain characteristics which limit its effectiveness as concrete reinforcement. The more important considerations are summarised below:

Bond If seasoned (dry) bamboo is used as reinforcement, when the concrete is poured it will absorb water and swell. Later, as the concrete dries, the bamboo will shrink and the bond will be broken. If unseasoned (green) bamboo is used, it will lose water and shrink as the concrete dries and again the bond will be broken.

The bond can be improved in a number of ways:

- Mature culms (at least 3 years old) should be used.
- Bamboo strips rather than whole culms should be used as the inner surface develops a better bond than the outer surface. Also, culms with prominent and numerous nodes offer improved bonding (figure 46).
- Moisture related movement can be inhibited by the use of a brushed bitumen coating which acts as a moisture barrier. If the coating is too thick, it can create a shear zone which will in itself reduce the bond.

- Sand, nails and thin rope can be used in conjunction with the bitumen coating to improve the bond.
- Thin strips of bamboo with the inner layer removed, plaited into a cable, exhibit improved characteristics (figure *47).*

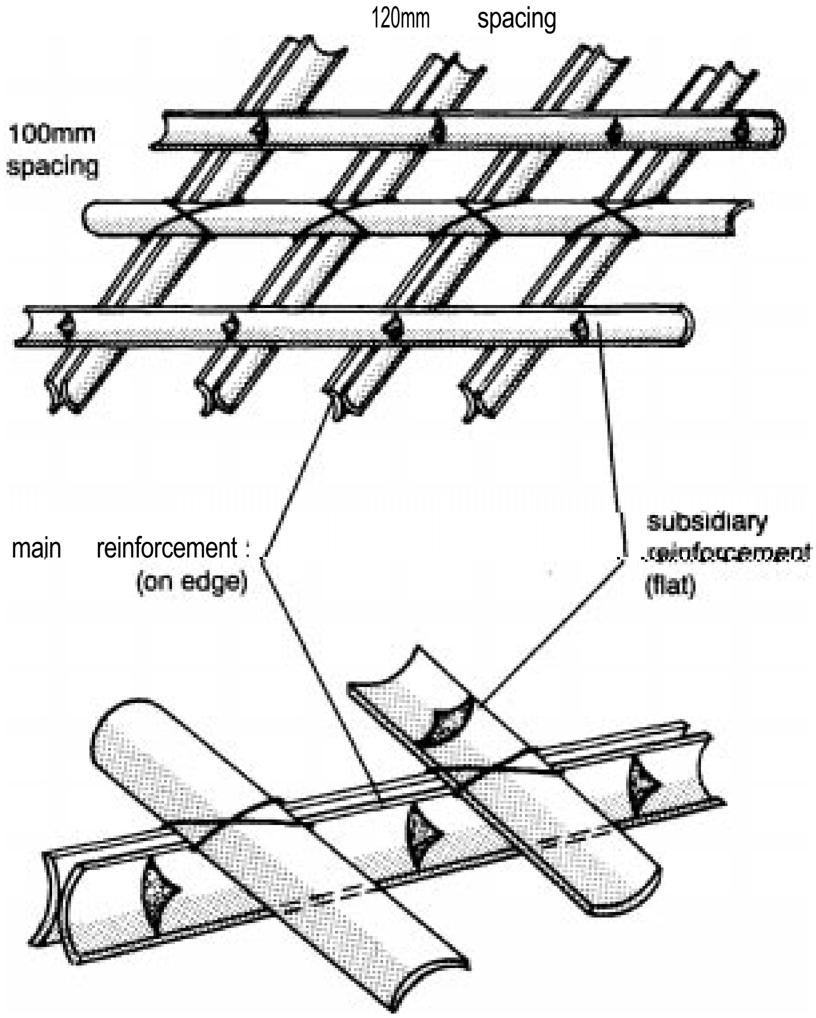



*Figure 46: Bamboo strip reinforcement (FRI, India)*

Low *modulus* of *elasticity* The relatively low modulus of elasticity can cause problems in respect of the following:

*Cracking and deflection:* a bamboo reinforced element will crack and deflect perhaps 50% more than a steel reinforced element of equivalent section.

*Quantity of reinforcement:* ten times more bamboo is required than in an equivalent steel reinforced section, i.e. 5% of the cross sectional area compared with 0.5% for steel.

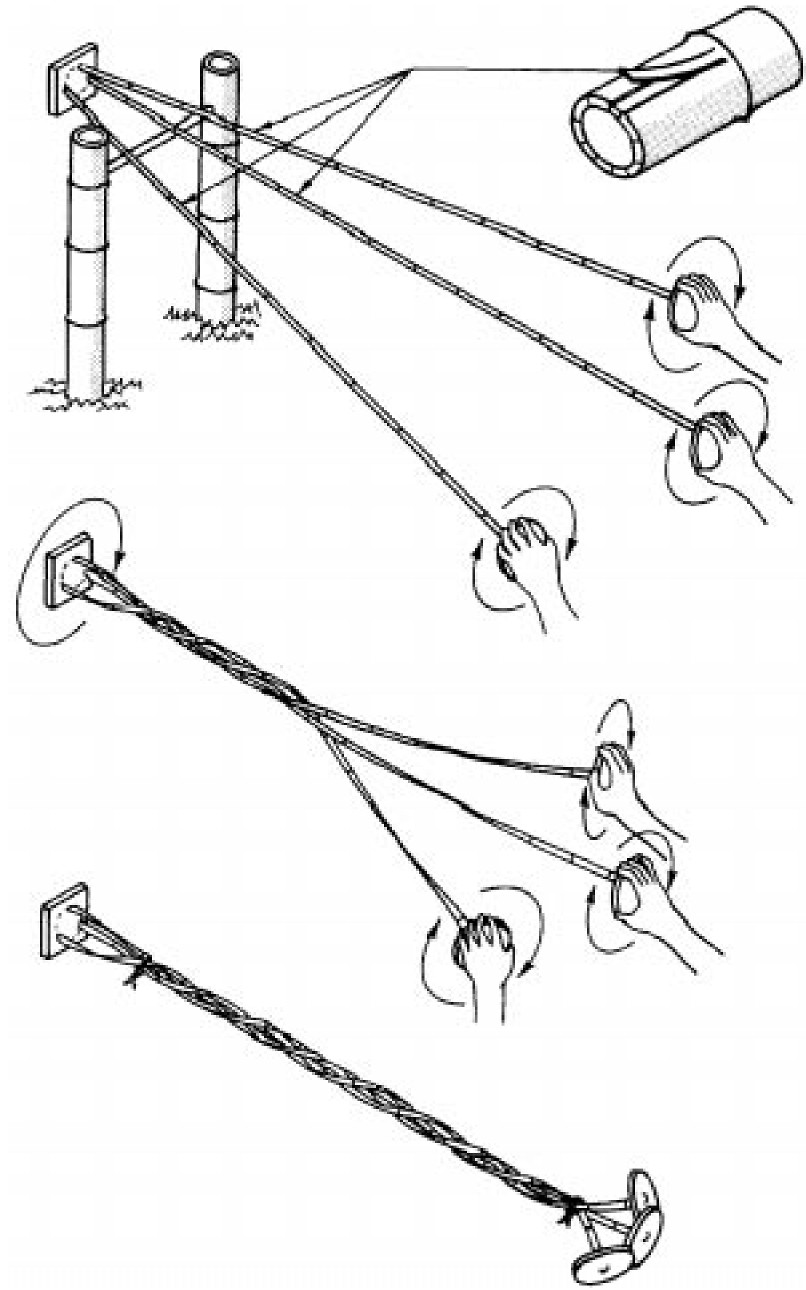


*Figure 47: Bamboo cable reinforcement*
*(after Hidalgo,* 1992)

*Durability* Concrete is very alkaline and will attack the bamboo reinforcement. tile is known about its likely long term performance. In addition, cracking can allow water ingress which will cause further deterioration.

In general, while bamboo can be used to reinforce beams and suspended slabs, it is perhaps more suited to use in floor slabs, roads and lightly loaded elements such as partition walls where cracking, or even failure, would not be so critical.

**Bamboo based panels**

The earliest bamboo panel was made in China during the First World War. To date, some 28 different panel types have been developed, mostly in Asia, but investigations into construction applications have only recently been carried out (Ganapathy et al. 1995). Bamboo based panels have proved suitable for structural as well as non-structural applications, in both low and high grade building work. Specific end uses include floors, walls, partitions, doors, ceilings and roofs, and by virtue of their inherent rigidity and enhanced durability (through preservative treatment), such panels can offer significant advantages over the use of bamboo in its natural state. The various types of panel product can be broadly classified as follows:

- Processed strips, laths or slivers
- Processed, peeled veneers
- Strands, particles or fibres reconstituted into panels
- Combinations of one or more of the above
- Combinations of one or more of the above with wood, other lignoceliulosic materials and inorganic substances

The two most common panel types, for which product standards have been formulated in countries where they are commercially produced, are:

- Bamboo mat board (bamboo mat plywood)
- Bamboo strip board (bamboo strip plywood)

*Bamboo mat board (bamboo mat plywood):* as the name suggests, these boards are formed from bonded layers of mats (see figure 15), woven from mechanically or manually cut slivers of uniform size (8-16mm wide x 0.8-l .2mm thick). After drying to a moisture content of 8-16%, adhesive is applied to the mats by spreader or by dipping. Several layers are then either cold pressed (urea-formaldehydes) or hot pressed (phenol-formaidehydes) to produce the board. The boards are finished by sanding and then trimmed to size.

To increase durability, preservative chemicals are generally incorporated in the adhesive, but better results can be achieved by treating the mats themselves (Padmanabhan et *al.* 1994). To improve the appearance of the board, slivers can be sanded, bleached and dyed prior to weaving.

The number of layers and board thickness will vary according to end use. 2 to 7 layers are common, varying in thickness from 1 to 10mm, with the thinner boards used for panelling and the thicker boards for concrete formwork. Products of this type have also been used for roof cladding, barrel vaulting, grain silos and as webs in I- or box-beams spanning up to 9m (Damodaran et al. 1991) .

Using a similar process, researchers in China have developed a bamboo curtain plywood laminated with resin impregnated paper, or BCPLRIP, panel with properties equivalent to those for plywood and also suitable for use as concrete formwork (Zhao et al. *1992).*

*Bamboo strip board (bamboo strip plywood):* in its simplest form, common to South America where bamboos do not split so easily, this is made by gluing together cross-banded flattened bamboo or bamboo strips (Janssen, 1995).

The process, however, lends itself well to improved methods of processing and production. With the outer surface and nodal projections removed, culms are split then softened by soaking and heating at 130-l 45°C. The pieces are flattened, the inner surface is scraped and they are then dried by heat and pressure to 8% moisture content. The subsequent manufacturing process is much the same as for conventional ply-woods (Guisheng, 1987). The strips are planed and edged, spread with PF adhesive, assembled into cross-banded panels and then hot pressed. The resulting boards are finished by sanding and trimming. Typical applications include floor decking and walling. The product has good strength and stiffness properties and a high degree of resistance to abrasion and weathering. (Ganapathy *et* al. 1995)

It is now possible to obtain automated processing and production machinery for the manufacture of high quality laminated bamboo flooring following the principles outlined above. The material compares favourably with other panel products in terms of mechanical performance and is also highly decorative (Chin Yung Machine Works, 1995).

Bamboo mat board, coated with a PF film or overlaid with suitable materials, offers a stable and durable alternative to plywood for concrete shuttering and formwork.

# 8. *Jointing techniques*

Effective jointing is fundamental to the structural integrity of a framed construction. Furthermore, the suitability of a material for use in framing is largely dependent upon the ease with which joints can be formed.

Because of its round, tubular form, jointing of two or more bamboo members requires a different approach to that adopted for, say, solid timber. Despite its relatively high strength, bamboo is susceptible to crushing, particularly of open ends. It is also characterised by a tendency to split; the use of nails, pegs, notches or mortises can therefore result in considerable reductions in strength. Connections must also cope with variations in diameter, wall thickness and straightness.

Clearly, these limitations have not presented an obstacle to the use of bamboo in traditional forms of construction. However, the building of structurally efficient, more durable and possibly larger and more economical bamboo structures will depend to a large extent on improvements and developments in jointing technology.

## Traditional 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 joins

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 internode 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 (figure *48).*

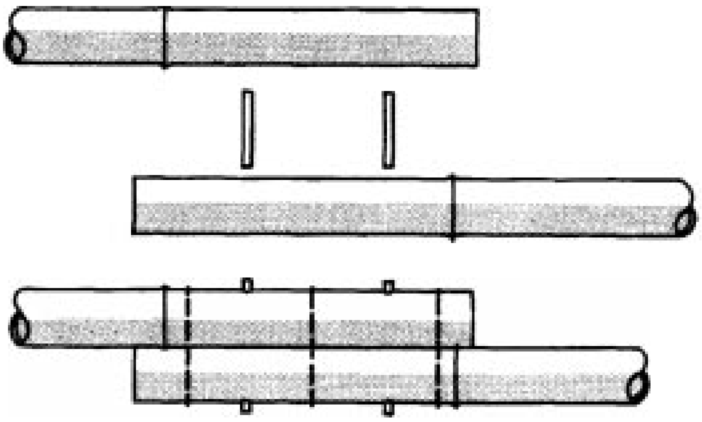


*Figure 48: Full lapped splice joint*

*catnapping:* Culms to be joined should be of similar diameter and cut longitudinally to half depth over at least one internode length. The components are fixed as for the full lap joint (figure 49).

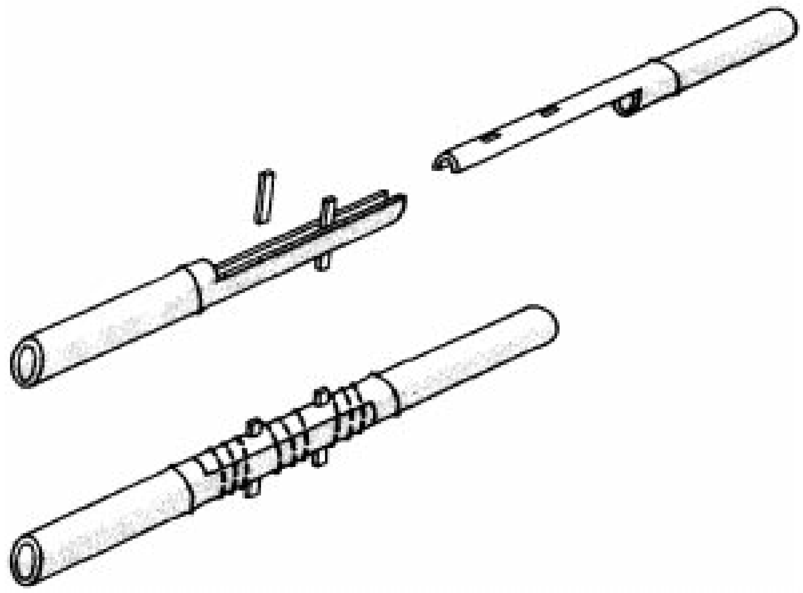


*Figure* 49: *Half-lapped splice joint*
*(after Siupongco* et al. 1987)

*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 (figure 50).

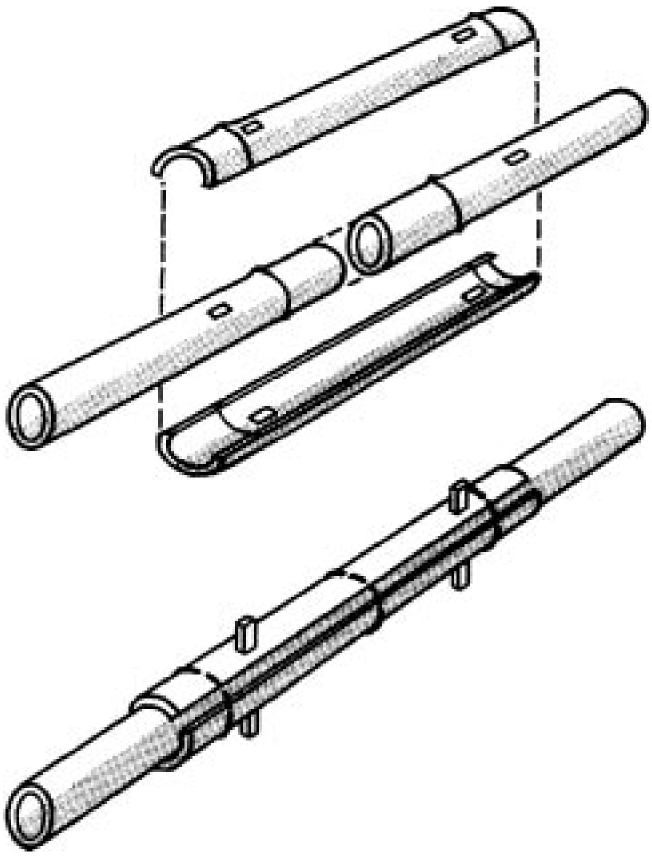


*Figure 50: Butt joint with side plates*

*Sleeves and inserts:* short lengths of bamboo of appropriate diameter are used either externally or internally to join two culms together (figure 51).

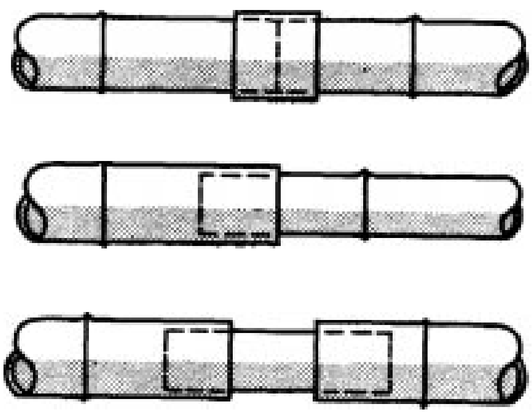


*Figure 51: Sleeves and inserts*
*(after Stulz/Hidalgo, 198 1)*

Variations on the basic splice joints described above are shown in figure 52.

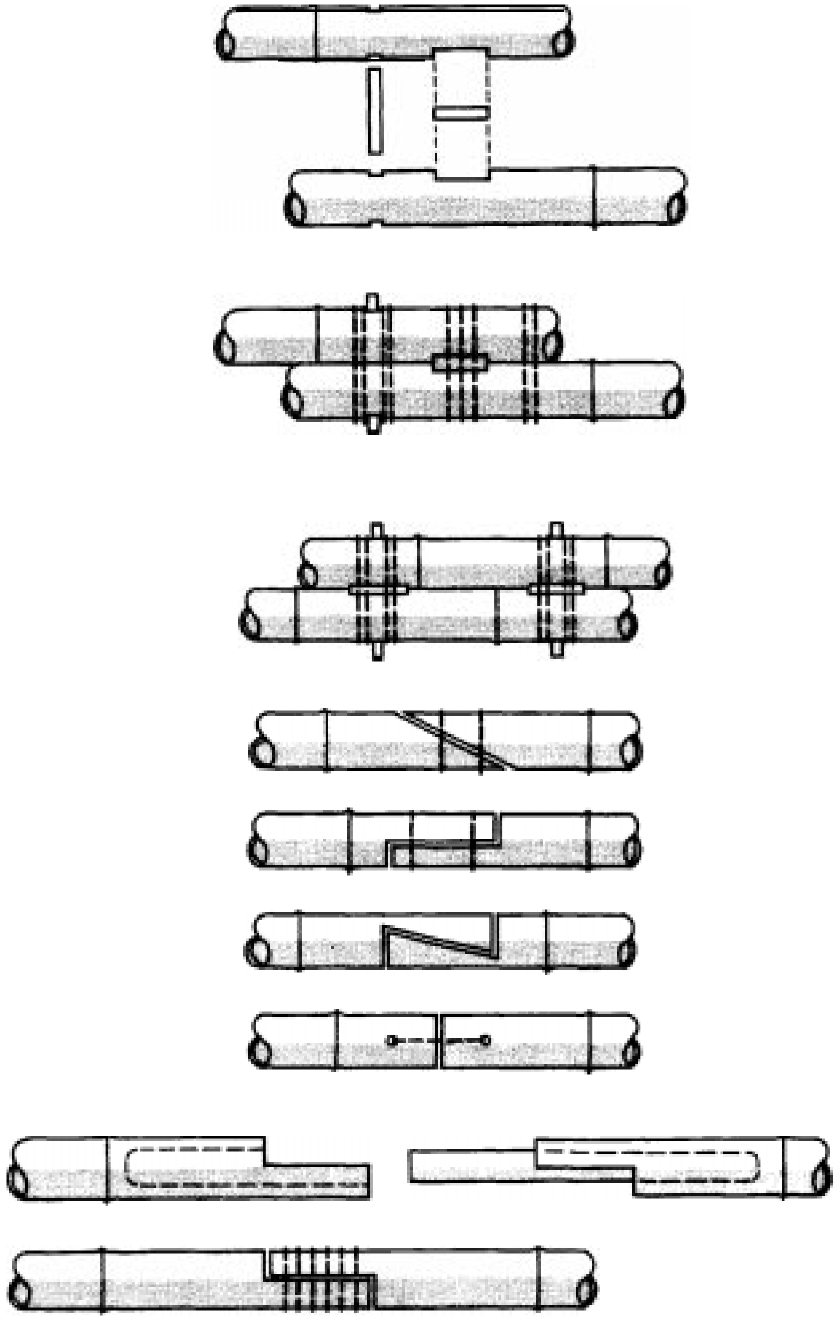


*Figure 52: Variations on splice joints*
*(after Nienhuys, 1976, Stulz/Hida/go, 198 I and Narayanamurty* et al. 1972)

*Orfhogonal 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 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 (figure 53). 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 (figure 54). Other details include square notched ends, side plates and tenons (figure 55).

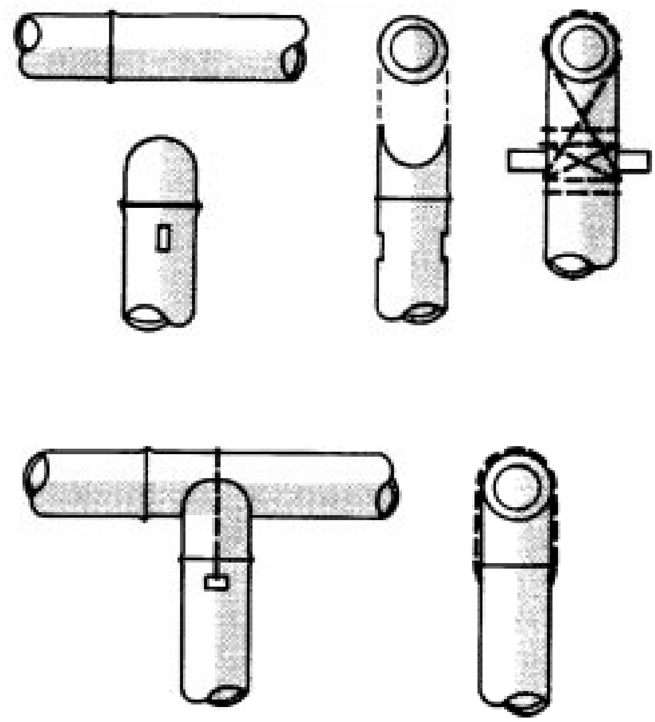


*Figure 53: Saddle (butt) joint (after Nienhuys, 1976 and Narayananwty* et al. *1972)*

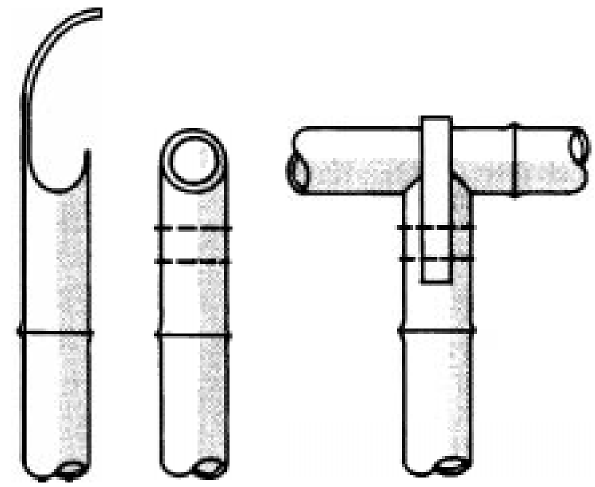


*Figure 54: Saddle joint with tongue (after Stulz/Hidalgo, 198 1)*

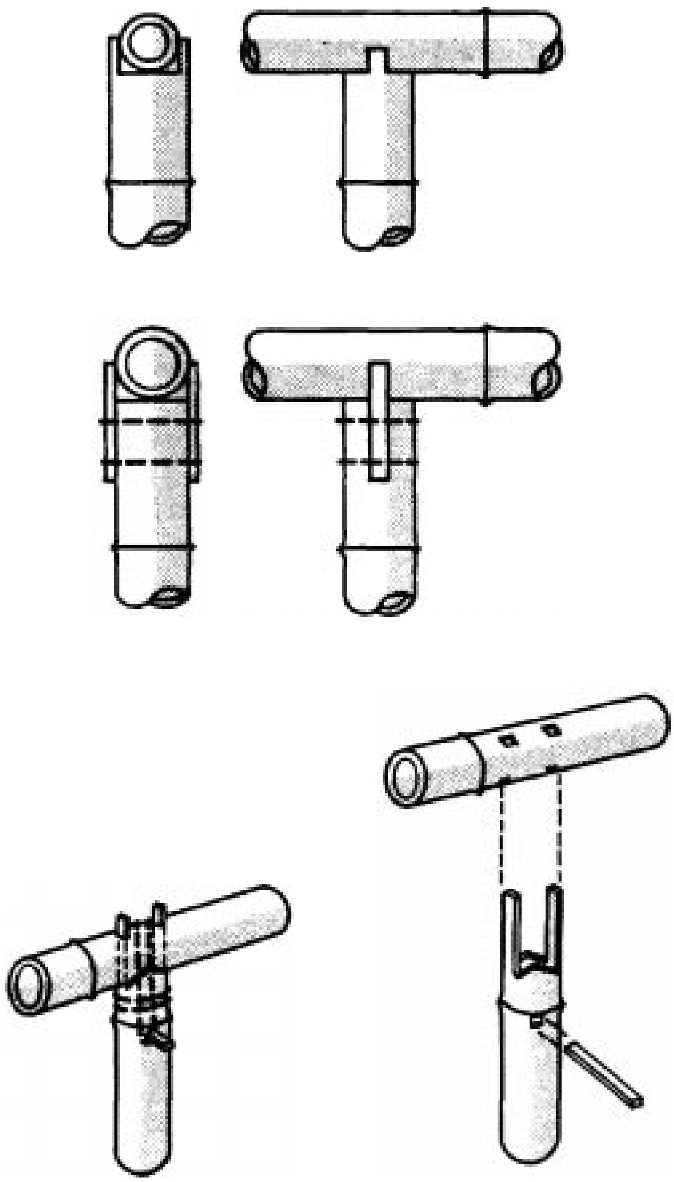


*Figure 55: Variations on the saddle joint (after Siopongco* et al. *1987 and Stulz/Hidalgo, 1981)*

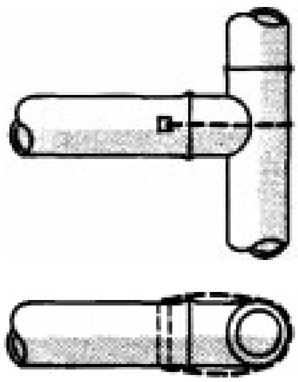


*Figure 56: Saddle detail applied to horizontal framing (after McClure, 1953)*

The saddle detail can also be applied to horizontal framing (figure 56)). Variations include the double joint (figure 57) and the double bent joint (figure 58).

For the single butt joint, improved stiffness can be achieved by the use of a hardwood tenon and key (figure 59). The ends of the horizontal members can be cut to form horns or integral tenons to be located in corresponding mortises in the post (figure 60). 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 (figure 61).

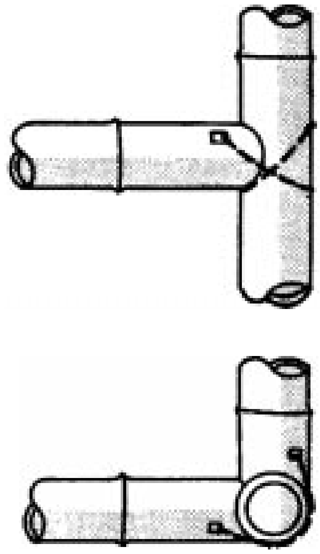


*Figure 57: Double butt joint (after McClure, 1953)*

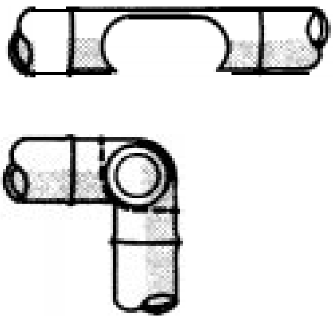


*Figure 58: Double bent joint (after Stulz/Hidalgo, I98 I)*

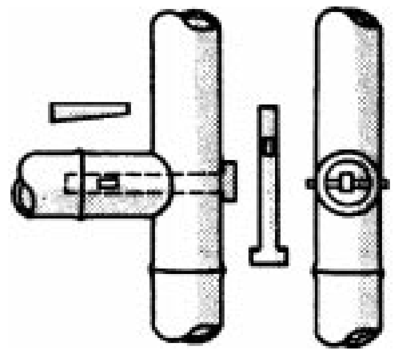


*Figure 59: Tenon and key joint (after Stulz/Hidalgo, 798 1)*

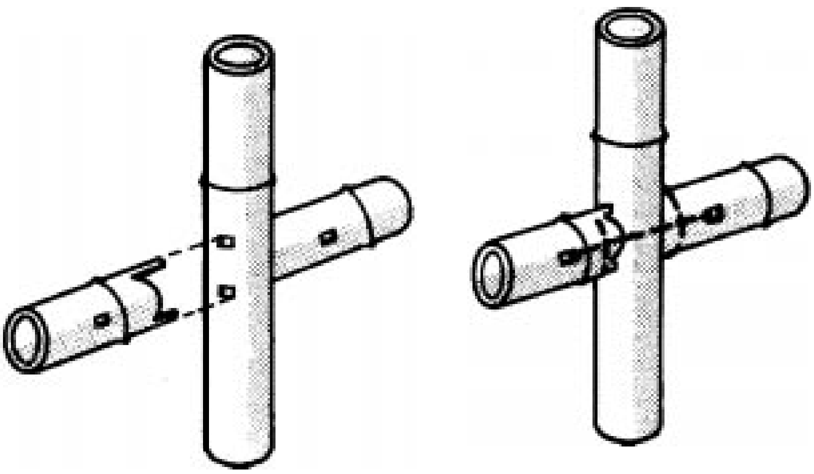


*Figure 60: Integral tenon (homed) joint (after Siopongco* et al. 1987)

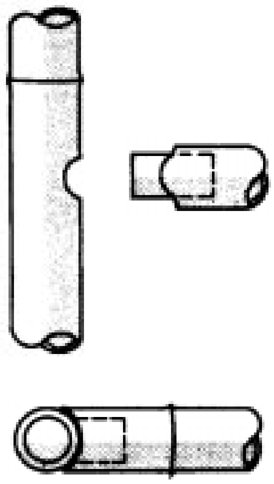


*Figure 6 I : Insert joint (after Stulz/Hidalgo, 198 1)*

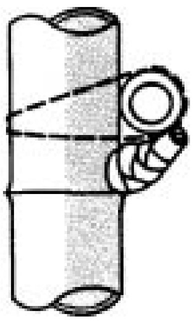
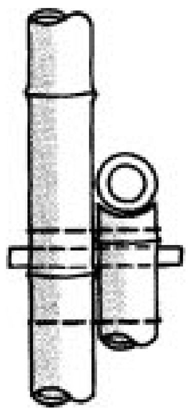


*Figure 62: Beam supported on stump of branch*

*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 loadbearing, 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 (figure 62) 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 (figure 63).

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 64.

***Figure 6'3: Beam supported on independent bracket (after Janssen, 1995)***

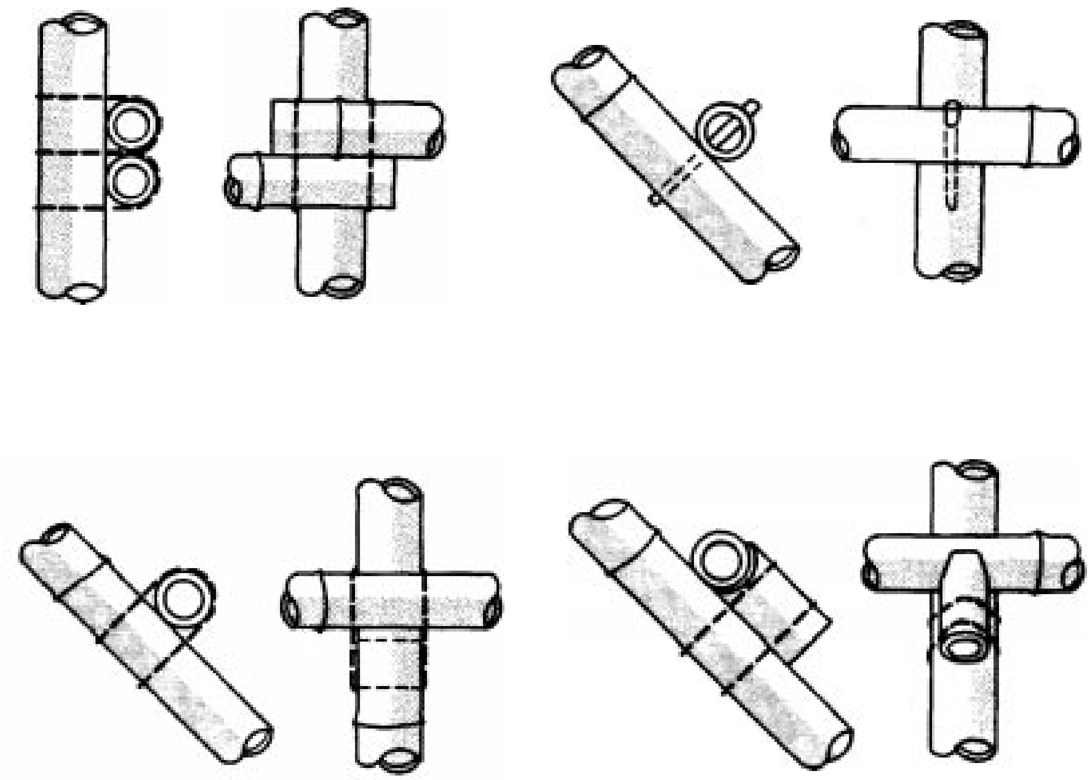


***Figure 64: Variations on crossover joints (after Stulz/Hidaigo, 1981)***

***Fixing methods:*** Most types of joint rely mainly on tying or lashing, with or without the use of pegs or dowels. Ties can be made from split bamboo, coir rope, palm fibre rope, iron wire (preferably galvanised) or tape. In the case of butt joints, the ties can be passed through a predrilled hole (figure 56) or around hardwood or bamboo pegs or dowels inserted into preformed holes. Pegs are driven from one side, usually at an angle to increase strength (figure 65); dowels pass right through the member, usually at right angles (figure 66). Crossover joints can similarly be dowelled and tied.

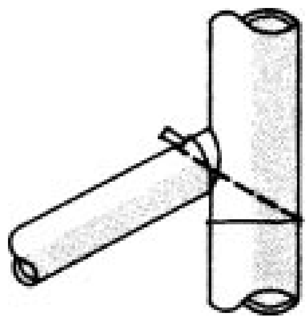


Figure 65: Example of pegged and tied joint

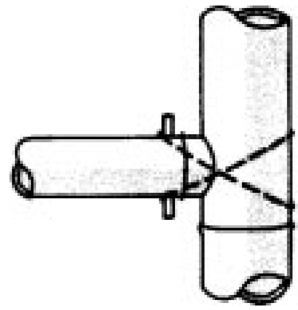


Figure 66: Example of doweled and tied joint

*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 (figure 67). 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 (figure 68). Applications for this type of joint might include partitions, doors and window framing.

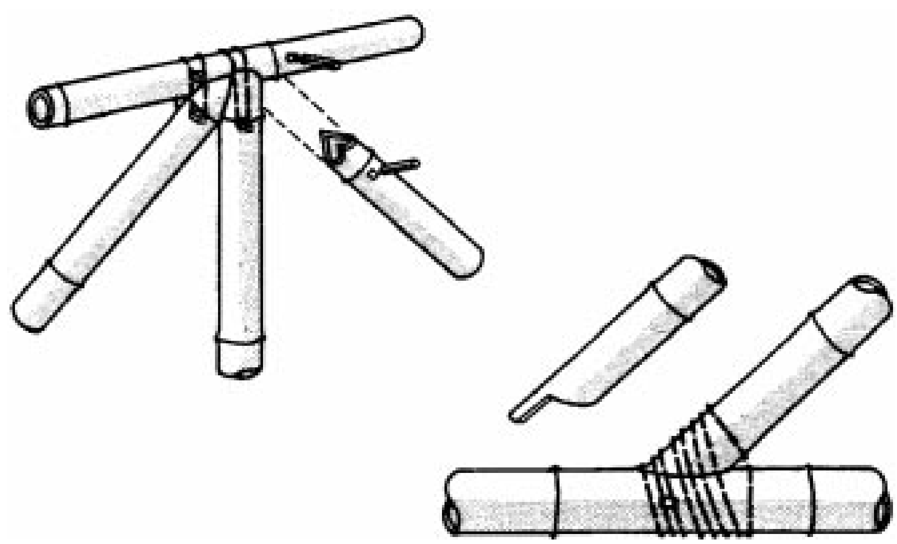


*Figure 67: Angled joints with integral tenons (after Siopongco* et al. *1987 and Nienhuys, 1976)*

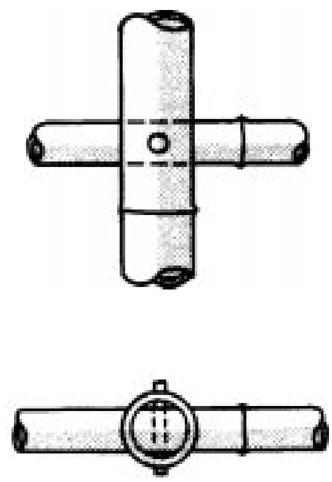


*Figure 68: Through joint (after Stulz/Hidalgo, 198 I)*

**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 radiused 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 (Narayanamurty et al. 1972).

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 (Janssen, 1995).

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.

**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 (Janssen, 1995, Punhani et al. 1989) (figure 69).

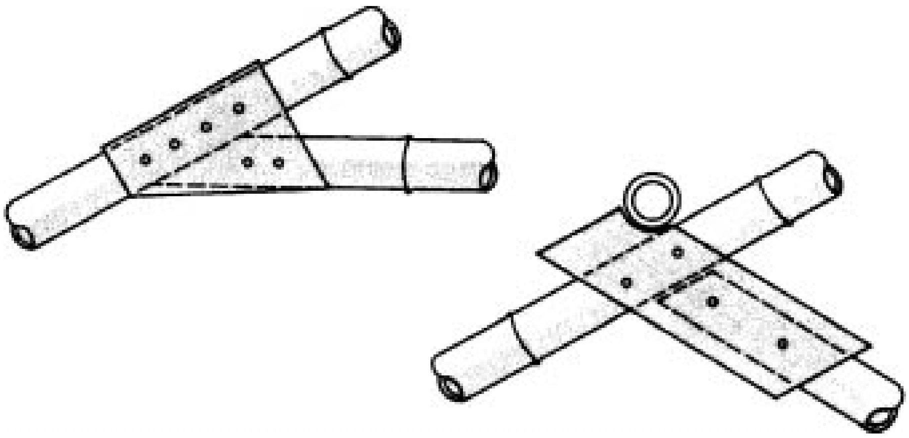


*Figure 69: Gusset plated joints*
*(alter Mishra* et al. 1991 *and Janssen, 1995)*

*ITCR joint:* this is a simple joint developed by the Instituto Tecnologico 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.

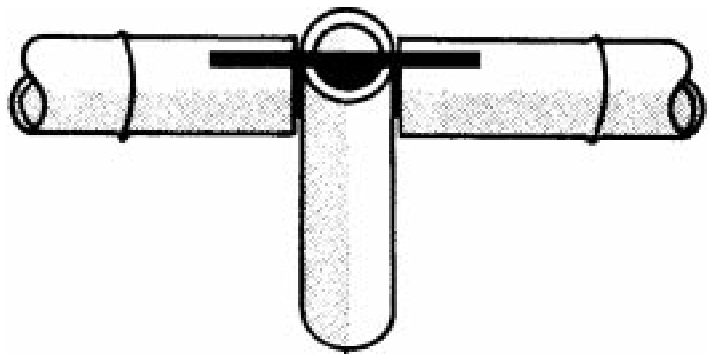


*Figure 70: ITCR joint*

*Arce joint:* this technique, developed by Dr Arce of ITCR, 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 thinnings, 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 (figure 71).

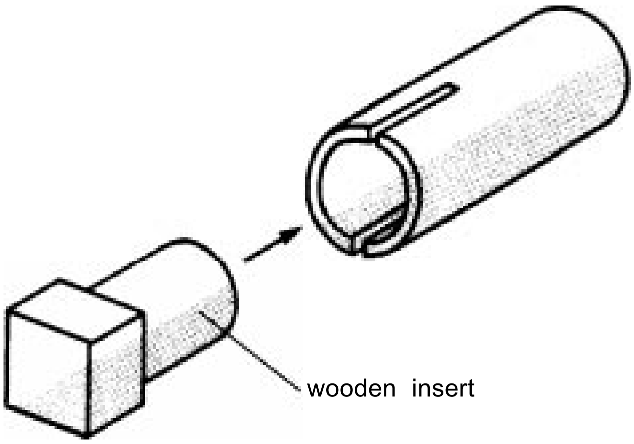



Figure 71: *Arce joint*

Filled *joint:* this is a modification of the Arce joint, developed by Morisco and Mardjono (1 995). 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 (figure 72).

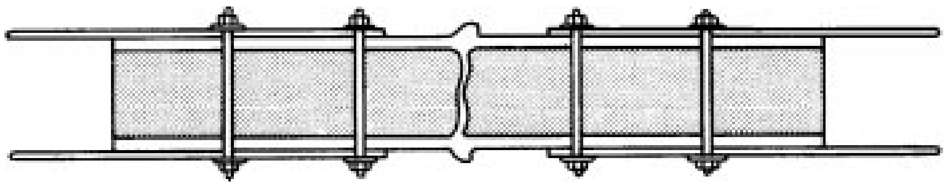


*Figure 72: Filled joint*
*(after Mofisco* et al. 1995)

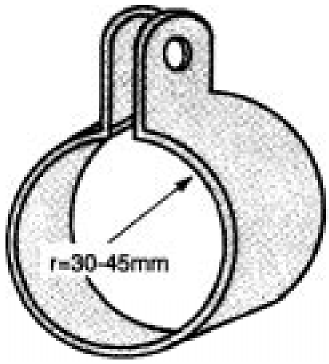
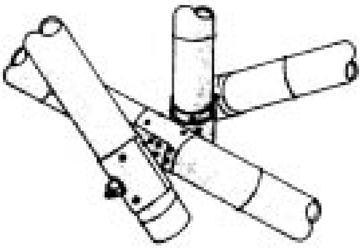



*Figure 73: Das clamp*



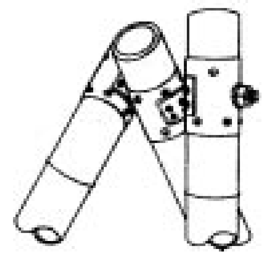


*Figure 74: Herbert shear pin connector joint*

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 (figure 73). 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 (figure 74). 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 a steel plate at both ends (figure 75). The protruding-ends of the steel bars can then be welded together to make a joint.

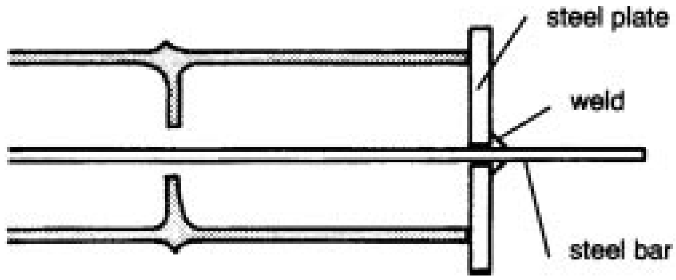



*Figure 75: Gutierrez joint*

*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 (figure 76). Expanding plastic inserts have been used for straight connections (figure 77).

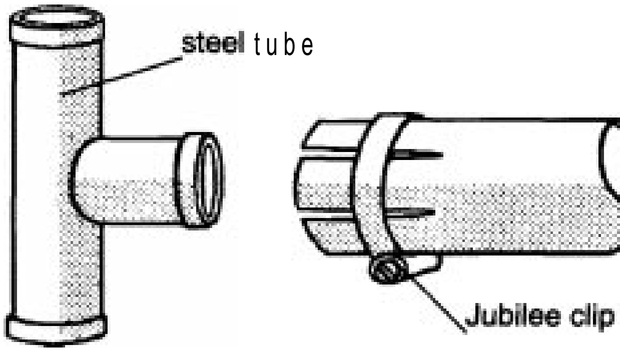



*Figure 76: Jubilee clip joint (after Nienhuys, 1976)*

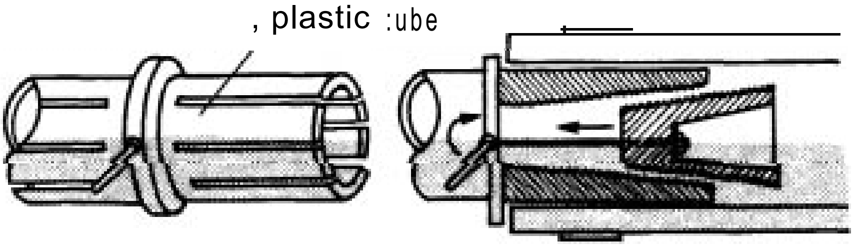



*Figure 77: Expanding insert joint (after Nienhuys, 7976)*

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 (some *Guadua* and *Chusquea* species - McClure, 1953), 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 (Arce, 1 991).

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.

# 9. Design considerations

The use of bamboo as an engineering material is limited from the point of view of design by two major considerations:

- The formulation of structural design guidance is governed to a large extent by practical, engineering experience. In the case of bamboo, information from this source is somewhat limited.

- Basic mechanical properties have been dealt with by many authors, but, unlike timber, bamboo properties do not relate well to species because of the dependency on other factors, such as geographical location and age (Arce, 1993).

Considerable effort continues to be directed at the derivation of mechanical properties, but perhaps with insufficient regard to applications in the field. Janssen (1995), however, has conducted his research with the field practitioner in mind and, as such, his design approach is very simple. Accordingly, it is possibly best suited to simple constructions.

Janssen has shown that a relationship exists between density and permissible stress which forms the basis of the following table:

| | *Allowable long-term stress (N/mm²) per unif volume (kg/m³)* | | |
|---|---|---|---|
| | *Axial compression (no buckling* | *Bending* | *Sheaf* |
| Air dry | *0.013* | *0.020* | *0.003* |
| Green | 0.01 1 | 0.015 | - |

For example, if green bamboo has a density of 600kg/m³, the allowable stress in bending would be $0.015 \times 600 = 9\text{N/mm}^2$. As these are long-term stresses, Janssen suggests they may be increased by 25% for live, or medium-term loading, and by 50% for short-term loading.

Other studies relate to specific species, or groups of species. Rajput et al. (1994) considered sixteen species and derived minimum long-term safe working stresses for the green condition as summarised in the tables below:

| | |
|---|---|
| Group A | *Bambusa giaucescenes* (syn. *B. nana), Dendrocaiamus strictus, Oxytenanthera abyssinica* |
| Group B | *Bambusa balcooa, B. pallida, B. nutans, B. tuids, B auriculata, B. burmanica, Cephaiostachyum pefgfaciie, Melocanna baccifera, Thyrosostachys oliveri* |
| Group C | *Bambusa ventricosa, B. vuigaris, B. bambos* (syn. *B. arundinaceae), Dendrocaiamus longispathus* |

| | *Safe long-tern) stress (N/mm²)* | | |
|---|---|---|---|
| | *Bending* | *Stiffness* | *Compression* |
| Group A | 17.2 | 1,960 | 9.8 |
| Group B | 12.3 | 1,370 | 8.3 |
| Group C | 7.4 | 680 | 6.9 |

Although densities are not detailed, assuming 600kg/m$^3$, the values for group C compare quite well with those from Janssen (9 and 6.6 N/mm$^2$ for bending and compression respectively).

Another study conducted by Chandrakeetthy (1995) in relation to temporary bamboo structures deals exclusively with *Bambusa vuigaris.* The recommended design values of 16.7N/mm$^2$ in bending and 1 5.2N/mm$^2$ in compression (in the green condition) are considerably higher than those for either Rajput (Group C, within which *B. vulgaris* falls) or Janssen.

Codification, along similar lines to timber, can be seen as the next important step towards the promotion and wider acceptance of bamboo as a valid building material. This will provide an objective and coherent approach to bamboo design, taking into account not only its more favourable qualities but also its limitations.

# 10. 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. While this subject has been addressed recently in an INBAR initiative (Gnanaharan, 1995), the list draws almost exclusively on McClure (1953, a reference which has lost little of its relevance or value over the last 40 years.

| *Tool* | *Use* | *Recommended specifications* |
|---|---|---|
| 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 (figure 79) |
| | For making bamboo lashings | Long handle, blade bevelled on one side only (figure 80) |
| 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 |
| Pl iers | For handling wire used for lashings | Long-nose with wire cutting facility |

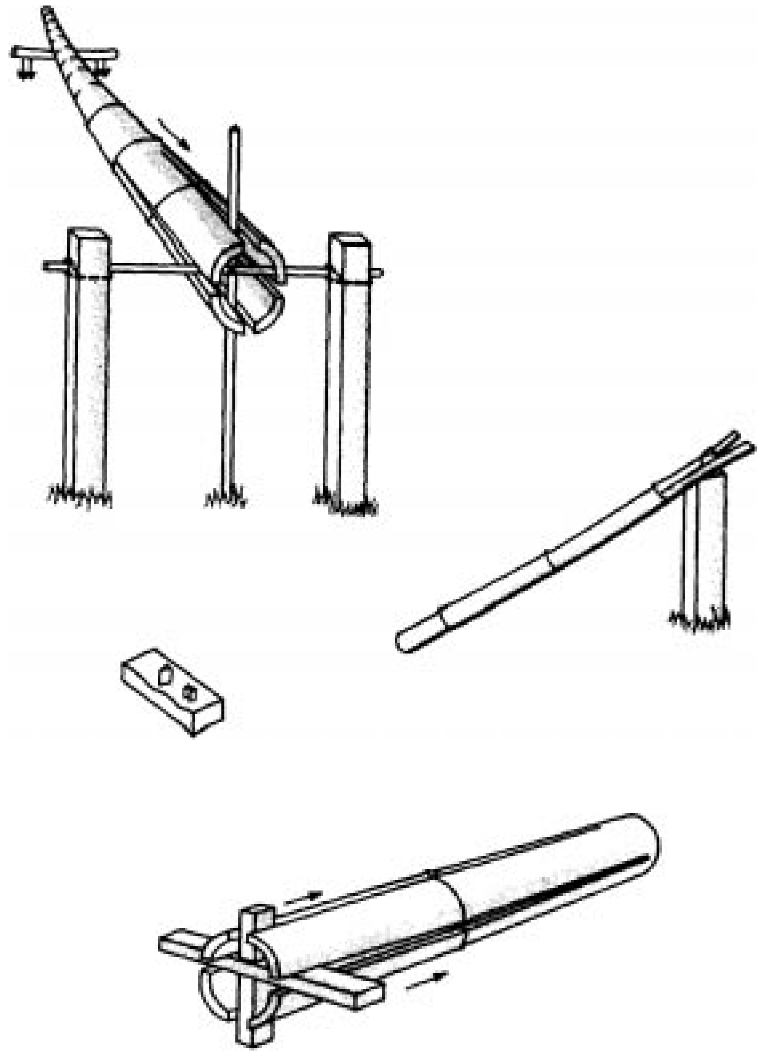


Figure 78: Splitting jigs (after McClure, 1953)

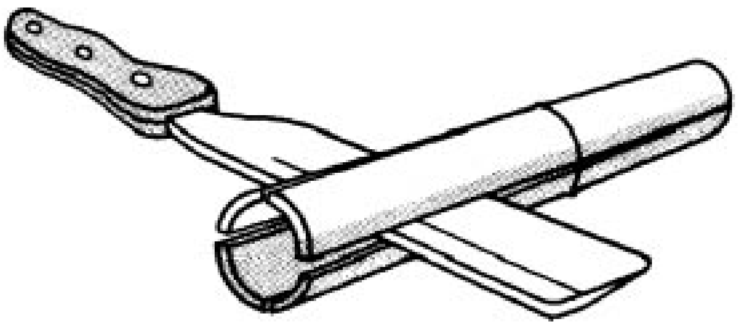


***Figure 79: Splitting knife for small culms (after McClure, 1953)***

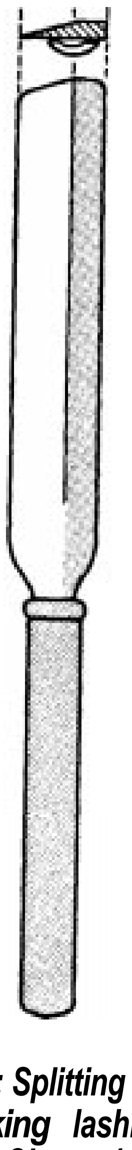



***Figure 80: Splitting knife for making lashings (after McClure, 1953)***

**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* |
| Regulariser | *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* |

# 11. Bamboo species suitable forconstruction

Approximately 1250 species of bamboo have been identified to date (FAO, 1978). While many species find applications in construction, their use will be dictated by availability in sufficient quantity, suitability for different end uses and local custom.

The following table, based on data compiled by McClure (1953), gives an indication of species suited to certain applications. It should be emphasised, however, that other species can be used, subject to an understanding of their relevant properties. Further information is given in Appendix 6.

| *Application* | | *Scientific name* |
|---|---|---|
| Framing | | *Bambusa balcooa , B. nutans, B. polyfnorpha , Gigantochloa apus, Guadua angustifolia* |
| Walls | Wattling | *Bambusa balcooa, B. nutans, B. polymorpha, Gigantochloa apus, Guadua angustifolia* |
| | Whole or half culms | *Bambusa balwoa, B. nutans, B. polymorpha, Gigantochloa apus, Guadua angustifolia* |
| Roof | Tiles | *Batnbusa balwoa, B. polymorpha, Guadua angustifolia* |
| | Shingles | *Schizostachyurn lima, S. lumatnpao* |
| Floor | Boards | *Bambusa polymorpha, Guadua angustifolia* |
| | Strips | *Bambusa nutans, B. polymorpha, Gigantochloa apus, Guadua angustifolia* |
| Sheathing | Whole culms | *Bambusa nutans, B. polymorpha* |
| | Strips | *Bambusa balwoa, 8. nutans, B. polymorpha, Gigantochloa apus, Guadua angustifolia* |
| Matting | | *Bambusa polymorpha, Gigantochloa apus* |

| | | |
|---|---|---|
| Lashings | | *Gigantochloa apus* |
| Concrete formwork | Boards | *Bambusa polymorpha, Guadua angustifolia* |
| | Shoring | *Bambusa balcooa, B. nutans, B. polymorpha, Guadua angustifolia* |
| Scaffolding | | *Bambusa bakooa , B. nutans, B. polymorpha , Gigantochloa apus, Guadua angustifolia* |
| Pipes and troughs | | *Bambusa balcooa, B. nutans, B. polymorpha, Gigantochloa apus, Guadua angustifolia* |

# 12. Useful contact addresses

The following alphabetical list, which represents people and organisations with extensive knowledge and experience of bamboo, may be helpful if further information is required.

Agence Cooperation et Amenagement (ACA)
6 Rue Clisson
75013 Paris
France

Dr. Oscar Arce
Construction Engineering Dept.
Instituto Technologico de Costa Rica
P.O. Box 159 - Cartago
Costa Rica

Bouwcentrum International Education (BIE)
700 Weena
P.O. Box 299
3000 AG Rotterdam
The Netherlands

Ms. Linda Garland
P.O. Box 196
Ubud
Bali 80571
Indonesia

Prof. K. G havami
Centre for Science and Technology
Pontificia Universidade Catolica do Rio de Janeiro
PUC - Rio de Janeiro
Brazil

Dr. Jorge A. Gutierrez
Proyecto National de Bambu
Aptdo Aereo 45 40
San Jose
Costa Rica

INADES - Documentation
African Inst. for Economic and Social Development
15, Avenue Jean-Mermoz, Cocody
P.O. Box 8
Abidjan
Ivory Coast

International Network for Bamboo and Rattan
(INBAR)
17 Jor Bagh
New Delhi - 1 10 003
India

Dr. Jules J. A. Janssen
Technische Universiteit (Eindhoven)
Den Dolech 2, Postbus 513
5600 MB Eindhoven
The Netherlands

Eur. Ing. Lionel Jayanetti
TRADA Technology Ltd
Hughenden Valley
High Wycombe
Buckinghamshire HP1 4 4ND
UK

Harutsugu Kashiwagi
Fuji Bamboo Garden
Nagaizumi-Cho, Sunto Gun
Shizuoka-Ken, 411
Japan

Dr. Kodira Kushalapa
Indian Plywood Industries Research and Training
Institute
P.B. No. 2273, Tumkur Road
Bangalore 560 022
India

Dr. Prof. Walter Liese
University of Hamburg
Leuschnerstr. 91
D-21 031 Hamburg
Germany

Arq. Oscar Hidalgo Lopez
Centro de Inv. del Bambu
Univ. Nac. de Colombia
Aptdo Aereo 54118
Bogota
Colombia

Fu Maoyi
Xiao Jiang Hua
Subtropical Forestry Research Institute
The Chinese Academy of Forestry
Fuyang, Zhejiang
China

Dr. Abdul Latif Mohmod
Forest Research Institute Malaysia
Kepong, Selangor, 52109
Kuala Lumpur
Malaysia

Mrs. Maria C. T. A. Rigter
Bamboo Development Corporation
Lindengracht 197L
1015 KG Amsterdam
The Netherlands

Dr. R. M. Singhal
Forest Research Institute
Indian Council of Forestry Research and Education
P.O. New Forest
Dehra Dun 248006
India

Stichtings Technische Ontwikkeling
Ontwikkelings Landen (TOOL)
Entrepot Dok 68A/69A
1010 AD Amsterdam
The Netherlands

University of Leuven
Post Graduate Centre of Human Settlements
Kastcel Aren berg
3030 Leuven - Heverlec
Belgium

Dr. Feiizardo Virtucio
Philippine Bamboo Research & Development Project
ERDB
College, Los Banos, Laguna 4031
Philippines

Dr. Masatoshi Watanabe
Kamigamo Exp. Forest
Kamigamo, Kita-ku, Kyoto
Japan

Dr. Elisabeth Widjala
Herbarium Bogoriense
National Biological Institute
Bogor
Indonesia

K. M. Wong
Forestry Department
Bandar Seri, Begawan 2067
Brunei

Ms. Zhang Xinping
Bamboo Information Centre
The Chinese Academy of Forestry
Wan Shou Shan
Beijing 100091
China

# References


Abang Abdullah, A.A. and Abang Abdulrahim. 1987. Bamboo as *a low cost material of construction.* First CIB-W18B Conference on Tropical and Hardwood Timber Structures, Singapore.

Anon. 1945. *War against Bostrichidae.* Pest control pamphlet of Ordnance Factory, Kanpur, India, No.1.

Arce, O.A. 1991. *Connection of bamboo elements.* Bamboo in Asia and the Pacific. 2.12. Proceedings of the Fourth International Workshop, Chiangmai, Thailand. Technical Document GCP/RAS/134/ASB, FORSPA Publication 6. International Development Research Centre, UNFAO, United Nations Development Program 1994.

Arce, O.A. 1993. *Fundamentals of the design of bamboo structures.* Doctoral thesis, Eindhoven University of Technology, Netherlands.

Arce, O.A. 1995. *Bamboo housing in seismic prone areas.* Paper presented at the Fifth International Bamboo Workshop, Bali (unpublished).

Bains, B.S. and Satish Kumar. 1978. *Diffusion of ions through bamboos II, Anisotropic behaviour of bamboos.* J. Timb. Dev. Assoc. (India) 24(4):25-32.

Bakshi, B.K., Guha, S.R.D and Gupta, *S.* 1960. *Effect of fungal damage to bamboo in the yield and quality of pulp.* Pulp Res & Ind, 5(2):38-39.

Bandara, D.H.M.S. 1990. *Possible uses of bamboo in low cost housing.* National Building Research Organisation, Sri Lanka.

Beeson, C.F.C. 1938. *Carpenter bees.* Ind. For. 64(12):735-737

Beeson, C.F.C. 1941. *Ecology and control of forest insects of India and neighbouring countries.* Vasant Press, Dehra Dun, India.

Bureau of Indian Standards. 1961. *Specification for creosote and anthracene oil for use as* wood *preservative* IS:218. BIS, Manak Bhawan, New Delhi, India.

Bureau of Indian Standards. 1973. *Methods of tests for round bamboos IS:6874.* BIS, Manak Bhawan, New Delhi, India.

Bureau of Indian Standards. 1981. *Specification for water soluble type wood preservatives IS: 10013 Part I. Acid-copper-chrome (ACC) wood preservative.* BIS, Manak Bhawan, New Delhi, India.

Bureau of Indian Standards. 1981. *Specification for water soluble type wood preservatives IS:10013 Part II. Copper-chrome-arsenic (CCA) wood preservative.* BIS, Manak Bhawan, New Delhi, India.

Bureau of Indian Standards. 1981. *Specifiation for water soluble type wood preservatives IS:10013 Part III. Copper-chrome-boron (CCB) wood preservative.* BIS, Manak Bhawan, New Delhi, India.

Bureau of Indian Standards. 1982. *Code of practice for preservation of timber IS:401.* BIS, Manak Bhawan, New Delhi, India.

Casin, R.F. and Mosteiro, A.D. 1970. *Utilization and preservation of bamboo.* Wood Preservation Report (Philippines) 5:86-92.

Chandrakeerthy, S.R. de *S.* 1995. *Design recommendations for bamboo elements in exposed temporary structures.* Journal of the Institution of Engineers, Volume XXIII Number 2. Colombo 7, Sri Lanka.

Chatterjee, P.N. and Sebastian, V.O. 1964. *Notes on the outbreak of the sap-sucker, Oregma bambusae in New Forest and measures taken to control them.* Ind. For. 90(1):30-31.

Chen Guisheng. 1987. *Bamboo plywood - a new product of structural material with high strength properties.* Forest Products Laboratory, Nanjing Forestry University.

Chen, Y., Quin, W., Li, X., Gong, J. and Ni, M. 1985. *Study on chemical composition ten species of bamboo.* Chem. Ind. For. Prod. 5:39-46.

Damodaran, K. and Jagadeesh, H.N. 1991. *Application of bamboo mat composites in construction and packaging.* Bamboo in Asia and the Pacific. 2.12. Proceedings of the Fourth international Workshop, Chiangmai, Thailand. Technical Document GCP/RAS/134/ASB, FORSPA Publication 6. International Development Research Centre, UNFAO, United Nations Development Program 1994.

Damodaran, K. and Jagadeesh, H.N. 1994. *End use applications of bamboo mat board.* Wood News, Ganesh Publications Pvt Ltd 57, P.O. Bangalore 560 086, India.

Dev, I., Pant, S.C., Prem Chand and Satish Kumar. 1991. *Ammoniacal-copper-arsenite - A diffusible wood preservative for refractory timber species like eucalyptus.* J. Timb. Dev. Assoc. (India) 37(3):12-I 5.

Dunham, D.C. 1991. *Upgraded bamboo as a housing material: step by step from housing to shelter.* Bamboo in Asia and the Pacific. 2.12. Proc. Fourth International Workshop, Chiangmai, Thailand. Technical Document GCP/RAS/134/ASB, FORSPA Publication 6. International Development Research Centre, UNFAO, United Nations Development Program 1994.

Espiloy, Z.B. 1985. *Physico-mechanical properties and anatomical relationships of Philippine bamboo.* In “Recent Research on Bamboos” A.N. Rao, G. Dhanarajan and C.B.Sastry (Eds) Proc. Third International Bamboo Workshop. CAF/IDRC, pp6-14.

Espiloy, Z.B. *1994. Effect of age on the physico-mechanical properties of some Philippine bamboos.* In “Bamboos in Asia and the Pacific” Proc. Fourth International Bamboo Workshop. IDRC/FAO/UNDP, FAO Bangkok, pp 180-I 82.

FAO. 1978. Bamboo-forest news for Asia and Pacific, Vol.3 No.4 Bangkok

Fu, W.Y. 1979. *Bamboo scaffolding in Hong Kong.* Housing Department, Hong Kong Government.

Ganapathy, P.M., Turcke, D., Espiloy, Z.B., Zhu Huan-Ming and Zoolagud, S.S. 1995. *Bamboo based panels - a review* (unpublished). International Development Research Centre, New Delhi, India.

Ganapathy, P.M. and Zoolagud, S.S. 1993. *Bamboo mat board.* (unpublished). Final technical report to IDRC of Canada.

Gardener, J.C.M. 1945. *A note of the insect borers of bamboo and their control.* Ind. For. Bull. Ent. (NS) Ent 125.

Ghavami, K. and Moreira, L.E. 1992. *Bamboo space structures.* International symposium on industrial use of bamboo, Beijing, International Tropical Timber Organisation, Chinese Academy of Forestry, Beijing, China.

Ghosh, S.S. and Negi, B.S. 1959. *Anatomical features of bamboo used for paper manufacture.* Symposium on Cellulose Research. CSIR, New Delhi.

Gnanaharan, R. *1995. Indigenous tools, equipment and technology for processing bamboo and rattan* (unpublished). International Network for Bamboo and Rattan, New Delhi, India.

Gnanaharan, R., Mohanan, C. and Chand Basha, S. *1993. Post-harvest technology of reed bamboo.* BIC India Bull. 3(1):1-6.

Gnanaharan, R., Nair, K.S.S. and Sudheendrakumar, V.V. 1982. *Protection of fibrous raw material. in storage against deterioration by biological organisms.* Res. Rep. 12, Kerala Forest Research Institute, Peechi, India.

Grosser, D. and *Liese,* W. 1971. *On the anatomy of Asian bamboos with special reference to their vascular bundles.* Wood Sci. Technol. 5:290-312.

Guha, S.R.D, Bakshi, B.K. and Thapar, H.S. 1958. *The effect of fungus attack on bamboo on the preparation and properties of pulp.* J. Sci. Ind. Res. *17(4):72-74.*

Guha, S.R.D. and Chandra, A. 1979. *Studies on the decay of bamboo (Dendrocalamus strictus) during outside storage. 1 - Effect of preservatives, II - Effect on pulping qualities.* Ind. For. 105(4):293-300.

Herbert, M.R.M. and Evans, P. 1979. *The development of structural connections for bamboo.* N 143/79. Building Research Establishment, Watford UK.

Hidalgo, A.O. 1992. *Technologies developed in Columbia in the bamboo housing* **and** *construction field.* International symposium on industrial use of bamboo, Beijing, International Tropical Timber Organisation, Chinese Academy of Forestry, Beijing, China.

Hidalgo, A.O. *1995. Suggested solutions to the existing problems in the study of mechanical properties of bamboo and for its use as reinforcement in concrete* (unpublished). Paper presented at the V International Bamboo Workshop, Bali.

Jagadeesh, H.N. and Ganapathy, P.M. 1995. *Traditional bamboo based wall/flooring systems in buildings and research needs.* Paper pesented at the Fifth International Bamboo Workshop, Bali (unpublished).

Janssen, J.J.A. 1982. *A series of articles on the use of bamboo in building construction.* ITDG, London WC1 E 8HN.

Janssen, J.J.A. 1991. *The future of bamboo.* Bamboo in Asia and the Pacific. 2.12. Proceedings of the Fourth International Workshop, Chiangmai, **Thailand.** Technical Document GCP/RAS/134/ASB, FORSPA Publication 6. IDRC, **UNFAO,** United Nations Development Program 1994.

Janssen, J.J.A. 1995. *Building with bamboo, a handbook.* Second edition. Intermediate Technology Publications, 103/1 05 Southampton Row, London, UK.

Janssen, J.J.A. *Bamboo trusses.* CICA publication 8202. University of Eindhoven, The Netherlands.

Kirkpatrick, T.W. and Simmonds, N.W. 1958. *Bamboo borers and the moon.* Tropical Agriculture, Trinidad 35(4).

Kumar, S. and Bidhi Singh. *1978. Diffusion of ions through bamboo. I- diffusion paths and generalprinciples.* J. Timb. Dev. Assoc. (India) 24(2):9-21.

Kumar, S. and Dobriyal, P.B. 1992. *TreatabiMy and flow path studies in bamboo Pad I. Dendrocalamus strictus* News. Wood and Fiber Sci. 24(2):113-I 17.

Kumar, S.K.K., Kalra and Dobriyal, P.D. 1985. *Protection of pulp bamboo in outside storage.* J. Timb. Dev. Assoc. (India), 31(4):5-12.

Kumar, S. and Bains, B.S. 1979. *Diffusion through bamboo III. Ionic selectivity and temperature* effects. J.Timb. Dev. Assoc. (India), 25(4):34-44.

Kumar, S., Singh, M.M. and Guha, S.R.D. *1980. Protection of pulp wood in outside storage.* J. Timb. Dev. Assoc. (India), 26(2):30-42

Kumar, S., Dobriyal, P.B., Tandon, R.C. and Tipre, D.S. *1990. Long-tern, protection of flowered bamboos during storage.* Third For. Prod. Conf, F.R.I. Dehra Dun, June *26-28.*

Kumar, S. and Dobriyal, P.B. 1990. *Management of biodegradation of timber logs and bamboos during storage : A review for Indian conditions.* J. Timb. Dev. Assoc. (India) 36(4):5-I 4.

Latif Abd. Mohmod. 1992 *Culm characteristics of Bambusa blumeana and Gigantochloa scotechinii and its effect on physical and mechanical properties.* In “Bamboo and its use” International Symposium on Industrial Uses of Bamboo. CAF/ITTO.

Laxmana, M.G. 1985. *Drying of some commercial Philippine bamboos.* FPRDI Journal, 14:8-1 9.

Liese, W. *1959. Bamboo preservation and soft-rot.* FAO report to Govt. of India, No. 1106.

Liese, W. 1980. *Preservation of bamboos.* In "Bamboo Research in Asia" G. Lessard and A. Chouinard (Eds), IDRC, pp 165-172.

Liese, W. 1985. *Bamboos - biology, silvics, properties, utilisation.* GTZ, Eschborn, Germany.

Liese, W. 1986. *Characterisation and utilisation of bamboo.* Proc. IUFRO World Congress on Bamboo Production and Utilisation, Ljubljana, Yugoslavia.

Liese, W. *1987. Research on bamboo.* Wood Sci & Technol. 21 :I 89-209.

Liese, W. *1988. Bamboo as an alternative material in the context of diminishing resources.* Proceedings of the International Bamboo Workshop.

Liese, W. and Grover, P.N. 1961. *Untersuchungen ueber den wassergehalt von Indischen Bambushalmen.* Ber. Deutsche Bot. Ges. 74:105-1 17.

Limaye, V. D. *1952. Strength of bamboo (Dendrocalamus strictus).* Ind. For. 78:558-575.

Lipangile, T.N.C. 1985. *The use of bamboo as waterpipes.* Wood/bamboo project, P.O. Box 570, Iringa, Tanzania.

Mather, G.C, Ratra, R.S. and Bindlish, D.D. 1964. *Bamboo for house construction.* Directorate of Advertising & Visual Publicity, Ministry of I & B for the National Buildings Organisation, Ministry of Works and Housing, Government of India.

Mathew, G. and Nair, K.S.S. 1990. *Storage pests of bamboos in Kerala.* In "Bamboos: Current Research". I.V.R. Rao, R. Gnanaharan, and C.B. Sastry (Eds) Proc. International Bamboo Workshop, KFRI/IDRC, pp 212-214.

Mathur, R.N. 1943. *Bamboo defoliators.* Ind. J. Ent. 5(1):117-128.

McClure, F.A. *1953* (1983). *Bamboo as a building material.* Peace Corps, Division of Volunteer Support, Washington D.C. 20525.

Mishra, H.N. and Sanyal, S.N. 1991. *Mature bamboo in mass housing.* Bamboo in Asia and the Pacific. 2.12. Proceedings of the Fourth International Workshop, Chiangmai, Thailand. Technical Document GCP/RAS/134/ASB, FORSPA Publication 6. International Development Research Centre, UNFAO, United Nations Development Program 1994.

Mohanan, C. and Liese, W. 1990. *Diseases of bamboos.* Int. J. Trop. Plant Diseases, 8(1):1-20.

Morisco and Mardjono, F. *1995. filled bamboo joint strength.* Paper pesented at the Fifth International Bamboo Workshop, Bali (unpublished).

Mukerji, K. and Mathur, *G.C.* 1987. *Curved bamboo roof structures.* A contribution of ESCAP to the International Year of Shelter for the Homeless. Building Technology Series No 11. UN Economic and Social Commission For Asia and the Pacific, Bangkok 10200 Thailand.

Nair, K.S.S, Mathew, G., Varma, R.V. and Gnanaharan, P. *1983. Preliminary investigations on the biology and control of beetles damaging stored reed.* Kerala Forest research Institute Res. Rep. 19.

Narayanamurti, D. and Bist, B.S. 1947. *Preliminary studies on building boards from bamboo.* Ind. For. Leaflet No. 103.

Narayanamurti, D., Purushotham, A. and Pande, J.N. 1947. *Preservative treatment of bamboos Part I. Treatment of green bamboos with inorganic preservatives.* Ind. For. Bull. No. 137.

Narayanamurty, D. and Dinesh Mohan. 1972 *The use of bamboo and reeds in building construction.* United Nations Secretariat.

Nienhuys, *S.* 1978. *Bambu cana guadua. Recomendaciones para el uso en la construccion.* Instituto Ecuatoriano de Normalization INEN.

Ota, M. 1955. *Studies on the properties of bamboo stem Part II. On the fibre saturation point obtained from the effect of moisture content on the swelling and shrinkage of bamboo.* Bull. of Kyushu Univ. For. 24:61-72.

Padmanabhan, S., Kamal, S.Z.M. and Ananathanarayanan. 1994. Glue line preservative *treatment of bamboo mat* board. Wood news, Volume 4 Number 1, Ganesh Publications Pvt Ltd, Bangalore 560 086, India.

Parmeswaran, N. and W. Liese. 1976. *On the fine structure of bamboo fibres.* Wood Sci. Technol. 10: 231-246

Pathak, P.S. 1989. *Bamboo* resources *in* the *word.* Paper presented at seminar on Silviculture and Management of Bamboos, Jabulpur, India.

Prawirohatmodjo, *S.* 1990. *Comparative strength of green and air dry bamboo.* In "Bamboos: Current Research". I.V.R. Rao, R. Gnanaharan and C.B. Sastry (Eds). Proc. International Bamboo Workshop, KFRI/IDRC, pp 218-222.

Punhani, R.K. and Mishra, H.N. 1989. *Laboratory and field investigations on bamboo-trusses and their feasibility for rural housing.* Division of Forest Products, Forest Research Institute, Dehra Dun, India.

Punhani, R.K. and Pruthi, K.S.C. 1992. *Substitution of wood in buildings - alternative forest based materials and their technology.* Forest Research Institute, Dehra Dun, India.

Purushotham, A. *1963. Instructions for treatment of timber, bamboos, etc. when facilities for pressure treatment are not available.* J. Timb. Dryers Pres. Assoc. (India) 9:17-1 8.

Purushotham, A., Sudan, S.K. and Vidya Sagar. 1954. *Preservative treatment of green bamboos under low pneumatic pressures.* Ind. For. Bull. No. 178.

Rajput, S.S., Inder Dev and Jain, V.K. 1994. *Classification, grading and processing of bamboos for structural and other applications.* Wood news, Volume 4 Number 1, Ganesh Publications Pvt Ltd 57, P.O. Bangalore 560 086, India.

Rehman, M.A. and Ishaq, SM. 1947. *Seasoning and shrinkage of bamboo.* Ind. For. Rec. (New Series) Utilisation 4(2): I-22.

Roonwal, M.L. 1977. *Field ecology and biology of bamboo beetle,* Estigmena chinensis Hope (Coleoptera:Chrysomelidal) *in western Sub-Himalayas.* J. Ent. Res. 1(2):168-175.

Sandhu, *G.S.* 1975. *Studies on insects infesting wooden and bamboo household articles and their control.* J. Res. Punjab Agric. Univ. 12(2):152-I 55.

Sattar, M.A., Kabir, M.F. and Bhattacharji, D.K. 1990. *Effect of age and height position of muli* (Melocanna baccifera) *and borak* (Bambusa balcooa) *bamboos on their physical and mechanical properties.* Bangladesh J. For. Sci. 19(1&2):29-37.

Sekhar, AC. and Gulati, A.S. 1973. *A note on the physical and mechanical properties of* Dendrocalamus strictus *from different localities.* Van Vigyan 11(314):17-22.

Sekhar, AC. and Rawat, B.S. 1956. *Strength tests of bamboos.* Ind. For. Leaflet No. 147.

Sekhar, A.C. and Rawat, M.S. 1964. *Some studies on the shrinkage of* Bambusa nutans. Ind. For. 90(3):182-I 88.

Sekhar, A.C. and Bhartari, R.K. 1960. *Studies of strength of bamboo. A note on its mechanical behaviour.* Ind. For. 86(5):296-301.

Sekhar, A.C., Rawat, B.S. and Bhartari, R.K. 1962. *Strength of bamboos:* Bambusa nutans. Ind. For. 88(1):67-73.

Sekhar. 1987. *Effect of prefreezing on circumferential shrinkage of* Bambusa gigantica. J.Timb. Dev. Assoc. (India), 33(1).

Sensarma, P.K. and Mathur, R.N. 1957. *Further record of occurrence of* Cryptotermes dudleyi *(Banks) in India* (Insecta Isoptera: Kalotermitidae). Curr. Sci., 12:339.

Sharma, *S.N. 1988. Seasoning behaviour and related properties of some Indian species of bamboo.* Ind. For. 114(10):613-621.

Sharma, S.N. and Mehra, M.L. 1970. *Variation of specific gravity and tangential shrinkage in the wall thickness of bamboo and its possible influence on trend of the shrinkage moisture content characteristic.* Ind. For.Bull.259.

Shukla, K.S., Jain, V.K. and Kambo, A.S. 1979. *An improved technique for the treatment of poles by Boucherie process.* Int'l. J. Wood Preservation. 1(2):83-86.

Shukla, N.K., Singh, R.S. and Sanyal, S.N. 1988. Strength *properties of eleven bamboo species and study of some factors affecting strength.* J. Ind. Acad. Wood Sci. 19(2):63-80.

Siegel, J. 1982. *Traditional bridges of Papua New Guinea.* Appropriate Technology Development Institute, University of Technology, Lae, Papua New Guinea.

Sing, P. 1990. *Current status of pests of bamboos in India.* In "Bamboos Current Research" I.V.R. Rao, R. Gnanaharan and C.B. Sastry (Eds) Proc. International Bamboo Workshop, pp. 190-194.

Singh, B. 1976. *Studies on the diffusion of water soluble wood preserving chemicals in bamboos.* Doctoral thesis, Punjabi University, Patiala.

Singh, B. and Tewari, M.C. 1980. *Studies on the treatment of green bamboos by steeping and sap displacement methods.* J. Acad. Wood Sci. 11(1):21-27.

Singh, B. and Tewari, M.C. 1981a *Studies on the treatment of green bamboos by different diffusion processes Part I. Dip diffusion and osmose process.* J. Timb. Dev. Assoc. (India) 27(1):38-44.

Singh, B. and Tewari M.C. 1981 b. *Studies on the treatment of green bamboos by different diffusion processes Part II. Steaming and quenching and double diffusion.* J. Timb. Dev. Assoc. (India) 27(2):38-46.

Singh, M.M. 1977. *Summary of FRI investigation on effects of storage on paper making raw materials.* IPPTA Zonal seminar on afforestation, exploitation and preservation of forest raw materials, Dehra Dun, India.

Siopongco, Dr J.O. and Munander, M. 1987. *Technology manual on bamboo as a building material.* Prepared in cooperation with FPRDI Philippines and IHS Indonesia for UNIDO/UNDP (DP/RAS/82/012).

Sonti, V.R. 1990. *A workable solution for presenving round bamboo with Ascu (CCA type salts).* In "Bamboos: Current Research". I.V.R. Rao, R. Gnanaharan and C.B. Sastry (Eds) Proc. International Bamboo Workshop, KFRI/IDRC, pp 207-208.

Spence, R.J.S. and Cook, D.J. *1983. Building materials in developing countries.* John Wiley and Sons Ltd. UK

Stulz, R. 1983. *Appropriate building materials.* SKAT and Intermediate Technology Publications Ltd, CH-9000, St Gallen, Switzerland.

Suhirman, K.T. and Tatick Khunsniati 1987. *Laboratory study on the effect of mud-submersion treatment on the durability of two bamboo and one wood species against fungi* Mater. Org. (Berl.)22(4):289-296.

Sulastiningsih, I.M. and Sutigno, P. 1992. *Some properties of bamboo plywood (plybamboo) glued with urea formaldehyde.* International symposium on industrial use of bamboo, Beijing, International Tropical Timber Organisation, Chinese Academy of Forestry, Beijing, China.

Suri, S.K. and Chauhan, R.S. 1984. *Indian timbers, Bamboo information Series* 28, FRI, Dehra Dun, India.

Suthoni, A. 1987. *Traditional preservation of bamboo in Java.* In "Recent Research on Bamboos" A.N. Rao, G. Dhanarajan and C.B. Sastry (Eds). Proc. 3rd International Bamboo Workshop. CAF/IDRC, pp 349-57.

Suthoni, A. 1990. *A simple and cheap method of bamboo preservation.* In "Bamboos: Current Research". I.V.R. Rao, R Gnanaharan and C.B. Sastry (Eds). Proc. International Bamboo Workshop, KFRI/IDRC, pp 209-211.

Tamolang, F.N., Lopez, F.R., Semana, J.A., Casin, R.F. and Espiloy, Z.B. 1980. *Properties and utilisation of Philippine bamboos.* In "Bamboo Research in Asia" G. Lessard and A. Chouinard (Eds), IDRC, pp 189-200.

Tewari, D.N. 1993. *A monograph* on *bamboo.* International Book Distributors, Dehra Dun, India.

Tular, R.B. and Sutidjan. *1984. Bamboo as a building material and its processing methods.* Directorate of Building Research, Bandung Indonesia. Presented at TCDC programme training course, Indonesia.

UNEP IE/PAC. 1994. *Environmental aspects of industrial wood preservation. A technical guide.* UNEP IE/PAC Technical Report Series Np. 20. United Nations Environment Programme, Industry and Environent/Programme Activity Centre, France.

Willeitner, H. and Liese, W. *1992. Wood protection in tropical countries. A manual on the know-how.* GTZ Eschborn, Germany.

Williams, J.T. and Ramanatha Rao, V. (Eds) 1994. *Priority species of bamboo and rattan.* INBAR/IBPGR. INBAR Technical Report No. 1.

Zhao, R.J. and *Yu, Y.S.* 1992. *Bamboo curtain plywood laminated with resin impregnated paper.* International symposium on industrial use of bamboo, Beijing, International Tropical Timber Organisation, Chinese Academy of Forestry, Beijing, China.

Zoolagud, S.S. and Rangaraju, T.S. 1991. *An improved and economical process for the manufacture of bamboo mat board.* Wood news, Volume 4 Number 1, Ganesh Publications Pvt Ltd, Bangalore, India.

# Appendix 1

## PRACTICAL GUIDELINES FOR THE PRESERVATIVE TREATMENT OF BAMBOO

### A. Steps in the treatment of bamboo strips

*Preparation of material*

a) Cut mature culms at least three years old.

b) Make strips using appropriate tools (see Chapter 10, Tools, figures 78 and 79).

*Treatment of strips*

a) When strips have a high moisture content and there is insufficient time for seasoning, treat the strips by steeping or diffusion process.

b) When strips are dry, treat strips by either cold soaking, open-tank or pressure process.

### B. Steps in the treatment of freshly felled whole round bamboo

*Preparation of material*

a) Cut mature culms at least three years old. These should be cut at least 30cm above the ground. Keep the branches and leaves on.

b) Cut the top of the culm at a position above which it is unsuitable for the purpose for which it is being treated.

*Treatment with preservatives*

a) Treat the culm by the modified Boucherie process using water-borne preservative solutions.

b) Branches should be cut immediately after the treatment is completed. If this is not done, a part of the preservative is likely to be drawn into the branches due to the evaporation of moisture through the leaves.

c) Treated bamboo should then be stored under shade to facilitate further diffusion and fixation of the preservative.

d) Cutting and boring carried out on treated bamboo is likely to expose untreated surfaces. Therefore, such surfaces should be brushed, sprayed or flooded with the same preservative solution.

## C. Steps in the treatment of round bamboo of short lengths

*Preparation of bamboo posts*

a) Cut culms that are at least 2-3 years old.

b) Cut culms to the required length. It is best if the top node is at least 8-10cm below the top of the post. Cut posts from the lower two-thirds of the culms, since the upper part of the culm usually splits during seasoning.

c) Knock out all nodes except for the top one with an iron bar, then bore 6mm diameter holes for fastening wire to the post at the appropriate height. It may not be possible to knock out all nodes (due to irregular shape, or smaller internal diameter due to greater wall thickness, or the nature of the bamboo species in which case, bore 6mm holes as given in figures Al and A2 (a&b) in such a way that the holes remain on the upper side of the post when grouted in the ground. Culms intended for use as tent poles or scaffolding should also be bored in the above manner, keeping the bore position just above the node when grouted.

*Treatment with preservatives*

When bamboo is of sufficiently high moisture content, preferably almost green:

i) Treat the bamboo with water soluble preservatives by the diffusion process.

ii) Drain out the preservative from the tank after achieving the requirements of treatment.

iii) Take out the treated bamboo from the preservative tank and leave them upright over a fixed support to allow the preservative to drip out from the bamboo culms. Collect the left-over preservatives for safe disposal.

iv) Stack the bamboo under shade and allow to air dry.

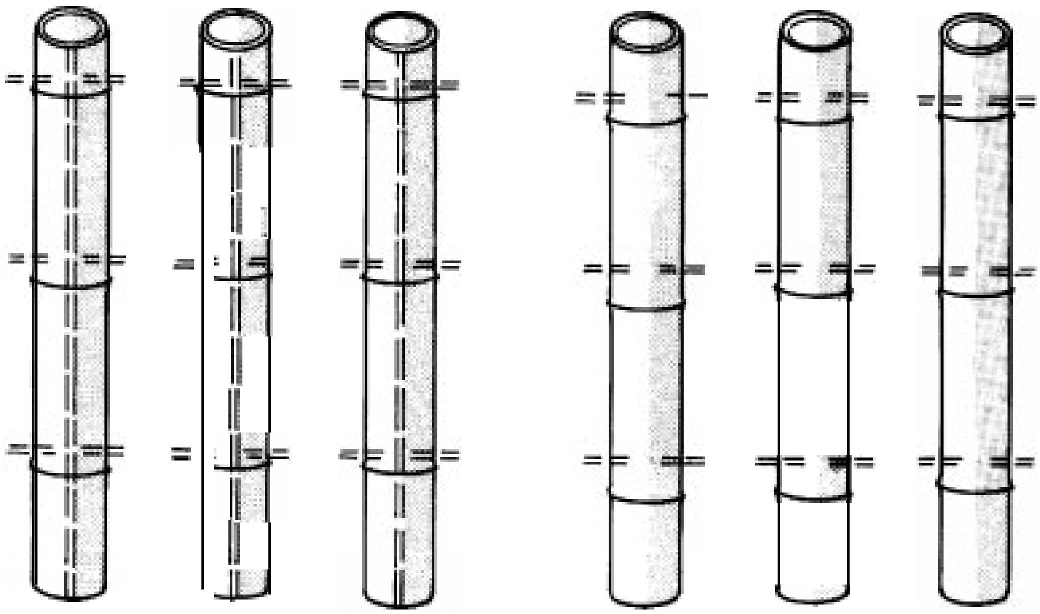
When bamboo is partially dry and there is sufficient time for drying:

i) Stack the material for air drying, as green bamboo or bamboo with high moisture content will not absorb preservative solution. First, place two or more bamboos across each block and then place the material cross-wise. Season the material for 4-5 weeks in dry weather and 8-10 weeks in wet weather, or until the material reaches a moisture content of 1520%.

ii) Give prophylactic treatment, either by dipping or spraying, to prevent stain/fungus/powder-post beetle attack during drying.

iii) The material can be treated when dry. This can be done by either cold soaking, hot and cold bath treatment or pressure processes.

iv) After draining the cylinder, take out the treated material and keep it upright, resting on some fixed support, so as to allow the preservative to drain out. Collect and safely dispose of left-over preservative.



*a* *b*

*Figure A I: Boring pattern with nodes bored or knocked out*

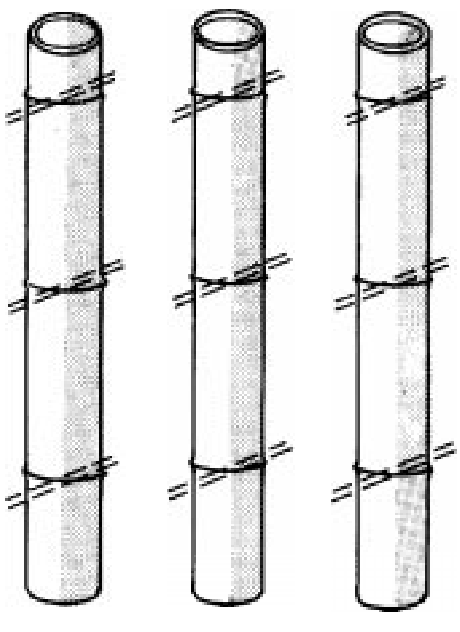


*Figure A2a: Boring pattern to puncture node*

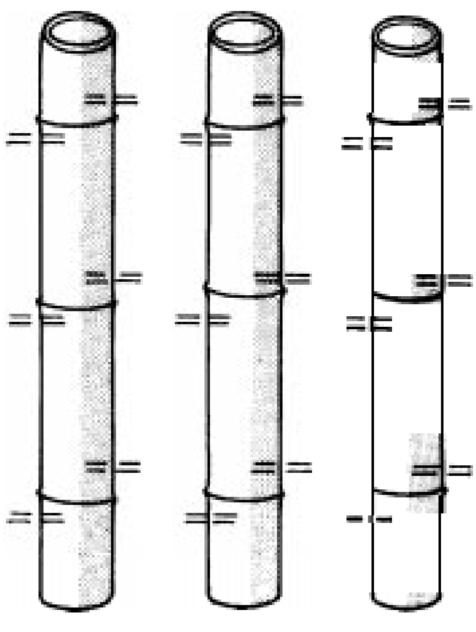


*Figure A2b: Alternative boring pattern with holes near nodes*

# Appendix 2

**LIST OF POSSIBLE PRESERVATIVES FOR TREATMENT OF BAMBOO**

*Note: The use of certain chemicals is restricted or banned in some countries.*

a) Coal tar creosote and fuel oil (5050) by weight. In high termite-infested areas, it is possible to add 1% dieldrin. Coal tar creosote should meet the relevant standard specification for preservation purposes (Bureau of Indian Standards, 1961).

b) Copper-chrome-arsenic composition containing copper sulphate ($CuSO_4H_2O$), sodium or potassium dichromate ($Na_2Cr_2O7,2H_2$ or $K_2Cr_2O_7$, and arsenic pentoxide ($As_2O_52H_20$) in the proportion of 3:4:1 (Bureau of Indian Standards, 1981 b). In some countries, CCA of different formulations are also used.

c) Borated-copper-chrome-arsenic (SBOR) composition conforming to Forest Research Institute, Dehra Dun composition (Patent pending).

d) Acid-copper-chrome composition containing copper sulphate ($CuS0_4$ $2H_20$) 50 parts, sodium dichromate ($Na_2Cr_2O_72H_2O$) 47.5 parts, chromic acid ($CrO_3$) 1.68 parts (equivalent to 2.5 parts of sodium dichromate) (Bureau of Indian Standards, 1981 a).

e) Copper-chrome-boron composition containing boric acid ($H_3BO_3$), copper sulphate ($CuSO_45H_2O$) and sodium or potassium dichromate ($Na_2Cr_2O_72H_2O$) or ($K_2Cr_2O_7$) in the proportions of 1.5:3:4 (Bureau of Indian Standards, 1981c).

f) Ammoniacal-copper-arsenite composition containing copper-sulphate, arsenic trioxide dissolved in ammonia (Dev *et al.* 1990).

g) Boric acid:borax (1: 1.54).

h) Copper naphthenate/abietate and zinc naphthenate/abietate containing 0.5% copper or 1% zinc.

# Appendix 3

**PRESERVATIVES, RETENTION, SUGGESTED CONCENTRATIONS OF TREATMENT SOLUTIONS AND METHODS OF TREATMENT OF BAMBOO FOR STRUCTURAL PURPOSES***

| *Structural uses of treated bamboo* | *Suggested preserva tives*+ | *Preservative concentration* | *Preservative absorption kg/m*$^3$ | *Method of treatment* |
|---|---|---|---|---|
| *Posts, pole fencing, etc. exposed to weather and in contact with ground:* | | | | |
| a) Dry bamboo | a | | 80 to 128 | Open tank or pressure |
| | b,c,f | 6to8% | 8to12 | Pressure |
| | d,e | 8to10% | 10to16 | Pressure |
| b) Green bamboo | b,c,f | 8to10% | 8to12 | Diffusion |
| | d,e | 10to12% | 10to16 | |
| *Bridges, scaffolding, ladders etc. exposed to weather but not in contact with ground:* | | | | |
| a) Dry bamboo | a | | 48 to 80 | Hot dipping or open tank or pressure |
| | b,c,f | 6% | 5 to 8 | |
| | d,e | 8% | 6to10 | |
| b) Green bamboo | b,c,f | 6to8% | 5 to 8 | Modified Boucherie or diffusion or sap displacement |
| | d,e | 8% | 6to10 | |
| *House building, walls, trusses, purlins, rafters, tent poles, etc. under cover:* | | | | |
| a) Dry bamboo | a | | 4 to 8 | Hot dipping or open tank or pressure/ steeping |
| | b,c,f | 4% | 4 | Pressure |
| | d,e,g | 6% | 6 | Pressure/ steeping |

| | | | | |
|---|---|---|---|---|
| | | 2% cu<br>3% Zn (in mineral oil) | 0.4 as Cu<br>0.6 as Zn | Soaking |
| b) Green bamboo | b,c,f<br>d,e,g | 6%<br>8% | 4<br>6 | Modified Boucherie or diffusion |
| *Ceiling, door and door panelling:* | | | | |
| a) Dry bamboo | b,c,f<br>d,e,h<br>h | 3%<br>5%<br>2% cu<br>3% Zn (in mineral oil) | 3.5<br>4<br>0.4 as Cu<br>0.6 as Zn | Steeping/ pressure<br>Soaking |
| b) Green bamboo | b,c,f<br>d,e,g | 4%<br>5% | 3.5<br>4 | Modified Boucherie or diffusion |

* A code of practice for preservation of bamboo for structural purposes (IS:9096) was formulated by FRI, Dehra Dun and Bureau of Indian Standards, New Delhi. This Appendix incorporates some new additions.

+ Letters refer to list of preservatives given in Appendix 2.

# Appendix 4

## PRESERVATIVES, RETENTION, SUGGESTED CONCENTRATIONS OF TREATMENT SOLUTIONS AND METHODS OF TREATMENT FOR BAMBOO FOR NON-STRUCTURAL PURPOSE*

| *Non-structural uses of treated bamboo* | *Suggested preserva tives*+ | *Preservative concentration* | *Preservative absorption kg/m*$^3$ | *Method of treatment* |
|---|---|---|---|---|
| *Window blinds and mats exposed to the weather:* | | | | |
| a) Green split bamboo | b,c,f<br>d,e | 4to6%<br>5to8% | 5<br>8 | Diffusion |
| b) Dry split bamboo | b,c,f<br>d,e | 4to6%<br>5to8% | 5<br>8 | Steeping |
| | h | 1%Cu<br>2% Zn (in mineral oil) | 0.5 as Cu<br>0.8 as Zn | Dipping |
| *Furniture exposed to the weather:* | | | | |
| a) Whole green bamboo | b,c,f<br>d,e | 4to6%<br>5to8% | 5<br>8 | Modified Boucherie/ diffusion for legs and arms |
| b) Split bamboo for parts other than those in a) above | b,f<br>d,e<br>h | 4to6%<br>5to8%<br>1%Cu<br>2% Zn (in mineral oil) | 5<br>8<br>0.4 as Cu<br>0.6 as Zn | If green, diffusion process, if dry painting/soaking |
| c) Indoor furniture | 9 | 2to4% | 5 | If green, diffusion process, if dry painting/soaking |
| *Basketware:* | | | | |
| a) Agricultural use other than in (c) below | a<br>b,c,d,e,f | <br>4to6% | 4-8<br>5 | Hot and cold Diffusion/ soak/steeping |

| | | | | |
|---|---|---|---|---|
| b) Household use including window blinds, mats and furniture under cover | d,e,h<br>h | 4 to 5%<br>1%Cu<br>2% Zn (in mineral oil) | 4<br>0.4 as Cu<br>0.6 as Zn | Diffusion<br>Soaking/ steeping |
| c) Packing of edible material including fresh fruits and vegetables | g<br>h | 2to4%<br>1% Cu in mineral oil<br>2% Zn in mineral oil | 4 | Diffusion<br>Brushing/ spraying |

* A code of practice for preservation of bamboo for non-structural purposes (IS 1902) was formulated in 1961 by FRI, Dehra Dun and Bureau of Indian Standards, New Delhi. This appendix incorporates some new additions.

+Letters refer to list of preservatives given in Appendix 2.

# Appendix 5

## STANDARD METHODS FOR DETERMINING PENETRATION OF PRESERVATIVES

*Note: The following methods are suited to specialist institutes and organisations with the capacity to conduct the tests.*

### Method for determining penetration of arsenic-containing preservatives

*Reagents*

*Solution* 1: Dissolve 3.5g ammonium molybdate in 90ml distilled water; then add 9ml concentrated nitric acid.

*Solution* 2: Dissolve 0.07g benzidine dihydrochloride in 10ml concentrated acetic acid and add the solution to 90ml distilled water.

*Solution* 3: Dissolve 30g stannous chloride in 100ml of 1:1 hydrochloric acid (one part concentrated hydrochloric acid added to one part distilled water).

Best results are obtained with freshly prepared solutions. Agitate the solution until all chemicals are dissolved. Solution 1 is clear and colourless; solution 2 (benzidine is difficult to dissolve) is clear and light violet in colour; solution 3 is colourless or slightly turbid. Solution 1 must be prepared for each day's testing; solutions 2 and 3 will keep in clean, glass-stoppered, brown-glass bottles for one week.

*Method of application*

*Solution* 1 is first applied by dipping the boring or cross section in a flat glass dish containing the solution or pouring the solution over the cross-section or boring. The entire wood surface must be saturated. After waiting two minutes, shake off the excess solution and allow to dry for about one minute.

*Solution* 2 is next applied in the same manner as solution 1. After waiting minutes, shake off excess solution and allow to dry for about one minute.

*Solution* 3 is applied last by pouring the solution on the cross-section or boring, beginning at the untreated part. The entire wood surface will immediately turn bluish; hence, it is necessary to wait several minutes for the reaction to bring about the maximum colour contrast. Untreated portions will fade to a bright red or reddish orange, while treated portions will be light bluish-green to dark bluish-green. Usually the colour differences are more distinct when the specimens are observed at arm's length. After about one hour, the stain fades; the colours can then be renewed by another application of solution 3.

### Methodfordeterminingpenetrationofboron-containingpreservatives

*Reagents*

*Solution* 1: Extract 10g turmeric with 90gm ethyl alcohol. Decant or filter to obtain clear solution.

*Solution* 2: Dilute 20ml of concentrated hydrochloric acid diluted to 100ml with ethyl alcohol and then saturate with salicylic acid (about 13g per 1 00ml).

*Procedure*

A smooth surface showsthe results of the spot test better than a rough surface. The surface must be dry; otherwise, the test will not be satisfactory.

*Solution I* is applied, preferably by spraying, or with a dropper, to the surface to be treated. The surface being treated is then allowed a few minutes to dry.

*Solution* 2 is then applied in a similar manner to the areas that have been coloured yellow by the application of solution 1. The colour changes should be observed carefully and will show up a few minutes after application of the second solution. In the presence of boron, the yellow colour of the turmeric solution is turned red.

After reagent application, placing bamboo in a warm oven accelerates and intensifies the colour reaction to better differentiate between treated and untreated bamboo.

### Methodfordeterminingpenetrationofcopper-containingpreservatives

*Reagent*

Dissolve 0.5g Chrome Azurol **S** concentrate and 5g sodium acetate in 80ml water and dilute to 100ml.

*Procedure*

Spray the solution over split borings or freshly cut surfaces of treated bamboo. A deep blue colour reveals the presence of copper.

## Method for determining penetration of chromium

*Reagent*

Dissolve 0.5g diphenyl carbazide in 50ml of isopropyl alcohol and 50ml distilled water.

*Procedure*

The boring or cross-section of bamboo to be tested shall be reasonably dry, dipped into or sprayed with the solution of diphenyl carbazide. The treated wood quickly turns purple, while the untreated wood retains nearly its original colour.

## Method for determining penetration of zinc-containing preservatives

*Reagents*

1. 1 g of potassium ferricyanide in 1 00ml of water.

2. 1 g of potassium iodide in 1 00ml of water.

3. Starch indicator solution. Make a paste of 1 gm of soluble starch in about 5ml of distilled water, add 100ml of distilled water and boil for one minute with constant stirring. Cool. This solution is subject to decomposition, and should therefore not be used for longer than three days before a new batch is prepared.

*Method of application*

The boring or cross-section of bamboo to be tested should be reasonably dry. Mix 10ml each of the three stock solutions and pour into a good atomiser. Spray the boring or cross-section of wood evenly. The reaction between the zinc chloride and the spraying solution will cause the treated wood to turn a deep blue instantly, while the untreated part will retain its original colour. This method is a positive test. Should the colour fade, repeat the process.

# Appendix 6

## TABULAR DATABASE OF SOME BAMBOOS USED IN CONSTRUCTION

The following tabular database contains information relating to some of the more useful species of bamboo suited to construction. The layout is designed to enable ready access to relevant data including vernacular as well as scientific names, regional distribution and applications. The identification numbers allocated to each species in Table 6.1 are referred to for convenience in the subsequent tables. The database is by no means fully comprehensive, but should rather be treated as a template or model to which additional information may be added as appropriate.

### TABLE 6.1: COMMON BAMBOO SPECIES LISTED BY SCIENTIFIC AND VERNACULAR NAMES

| ID | Scientific name | Vernacular name(s) |
|---|---|---|
| 1 | *Arundinaria alpina* | Alpine bamboo, Bambu Alpina |
| 2 | *Arundinaria callosa* | Uskong, Uspar, Spa (Khasia) |
| 3 | *Arundinaria elegans* | Jilli (Naga) |
| 4 | *Arundinaria falcata* | Himalayan Bamboo, Ringal, Nirgal, Nagre, Narri, Garri, Gorwa, Spikso, Ningalo, Kewi, Tham, Utham, Kutino |
| 5 | *Arundinaria griffithiana* | Khnap (Khasia), U-spar |
| 6 | *Arundinaria intermedia* | Nigala (Nepal), Parmick (Lepcha), Titi Nagala, Prong Nok |
| 7 | *Arundinaria khasiana* | Namlong, U-kadac Namlong |
| 8 | *Arundinaria mannii* | Beneng (Khasia) |
| 9 | *Arundinaria prainii* | Kewa, Keva, Sampit (Naga) |
| 10 | *Arundinaria racemosa* | Maling (Nepal), Phyeum Miknu, Mheem, Pheong, Pithiu |
| 11 | *Arundinaria spathiflora* | Ringal, Garu, Deo Ningal |
| 12 | *Arundinaria wightiana* | Chevari |
| 13 | *Bambusa arundinacea* | Thorny Bamboo, Berua, Kata, Koto (Assam), Ily, Mulu (Malay), Bans, Behor Bans (Bengali), Mulkas, Vedru (Telugu), Mundgay (Bombay) |
| 14 | *Bambusa balcooa* | Balku Bans (Bengali), Baluka (Assam), Borobans, Sil Barua. Teli Barua. Wamnah, Beru, Betwa |
| 15 | *Bambusa blumeana* | Buloh Duri (Malay), Kida (Semang), Bambu Duri, Bambu Gesing, Pring Ori, P.Gesing (Java), Haur Chuchuk (Sudan) |
| 16 | *Bambusa dolichoclada* | Chang Chih Chu (Chinese) |
| 17 | *Bambusa khasiana* | Serim, Tyrah (Khasia) |
| 18 | *Bambusa multiplex* | Hedge Bamboo, Silver Leaf Bamboo, Ngau Kan Chuk (Chinese) |

| ID | Scientific name | Vernacular name(s) |
|---|---|---|
| 19 | *Bambusa nutans* | Pichle, Bidhuli, Nal Bans, Mukial, Makal, Mahlu, Mahl, Paoshi-ding-ying, Jotia, Deo-bans, Wa-malang, Sering-jai |
| 20 | *Bambusa pallida* | Phai Sonakham. Mai-Phiu |
| 21 | *Bambusa polymorpha* | Kyathaungwa (Myanmar), Betua (Assam), Jama Betua (Bengali) |
| 22 | *Bambusa stenostachva* | Tzu Chu (Chinese) |
| 23 | *Bambusa textilis* | Wong Chuk, Mit Chuk (Chinese) |
| 24 | *Bambusa tulda* | Tulda, Jowa, Dyowa Bans, Mak, Makor, Kiranti, Matela, Peka Mittenga, Wati, Wamuna, Wagi, Nalbans, Deobans, Bijuli, Jati, Jao, Ghora, Theiwa, Thai kwa |
| 25 | *Bambusa tuldoides* | Punting-pole Bamboo, Chaang-ko Chuk, Yau Chuk (Chinese) |
| 26 | *Bambusa vulgar-is* | Common Bamboo, Bambu, Buloh Minyak Haur, B. Tutul, B. Gading, Aur Gading, Pau, Po-o, Pook (Malay), Jajang Ampel, J. Gading, Pring Ampel, P. Legi, P. Tutul (Java), Awi Ampel, A. Gading, A. Haur, A. Koneng, A.Tutul (Sudan), Auwe Gadieng, A. Kunieng, Bambu Kunieng, B. Kuring-Kuring (Sumatra), Pai Mai (Thailand) |
| 27 | *Cephalostachyum pergracile* | Tinwa (Myanmar), Latang (Naga), Madang (Singpho) |
| -28 | *Chusauea spp.* | Chusaue, Surro, Carrizo |
| 29 | *Dendrocalamus asper* | Bulah Betong, B. Panching (Malay), Kuur (Sakai), Deling Petung, Jajang Betung, Pring Petung (Java), Awi Betung, Bitung (Sudan), Bambu Batueng, Pering Betung (Sumatra), Bontong |
| 30 | *Dendrocalamus brandisii* | Kyellowa, Waya, Wapyu (Myanmar), Wakay (Warren), Waklu |
| 31 | *Dendrocalamus giganteus* | Wabo (Myanmar), Worra (Assam) |
| 32 | *Dendrocalamus hamiltonii* | Wabo-myetsangye (Myanmar), Chye (Dehra Dun), Tama (Nepal), Pao (Lepcha), Kokwa (Assam), Pecha (Bengali), Tonay (Mikis), Wanoke (Garo) |
| 33 | *Dendrocalamus hookerii* | Seiat, Ussey, Sejasai, Sijong, Denga, Ukotang, Patu, Tili. Kawa Ule |
| 34 | *Dendrocalamus latiflorus* | Ma Chu (Chinese), Phai Zangkum (Thailand) |
| 35 | *Dendrocalamus longispathus* | Khang, Ora, Wa -ya, Talagu, |
| 36 | *Dendrocalamus mem-branaceus* | Wa-ya, Wa-yai, Wa-mu, Wapyu (Malay) |
| 37 | *Dendrocalamus merrillianus* | Bayog (Ilocos), Kawayan-bayog (Pangasinan) |
| 38 | *Dendrocalamus sikkimensis* | Pugriang (Lepcha), Wadah (Garo Hills), Tiria, Vola (Nepal) |
| 39 | *Dendrocalamus strictus* | Male Bamboo, Bans, Bans Kaban, Bans Khurd, Karail, Mathan, Mat, Buru Mat, Salis Bans, Halpa, Vadur, Bhiru, Kark, Kal Mungil, Kibi Bidaru, Radhanapavedru, Kauka, Myinwa |
| 40 | *Gigantochloa apus* | Bamboo Apus, B. Tali (Malay), Delingi Apoos, D. Tangsool, D. Pring, Pring Apes, P. Apoos, P. Tali (Java), Awi Tali (Sunda), Pereng Tali (Madura) |
| 41 | *Gigantochloa levis* | Kawayan-bo-o, K. Sina, K. Puti, Boho (Tagalog), Boko, Bolo, Botong (Bisaya), Butong |
| 42 | *Gigantochloa macrostachya* | Tekserah, Madi, Madaywa, Wanet, Wabray |

| ID | Scientific name | Vernacular name(s) |
|---|---|---|
| 43 | *Gigantochloa verticillata* | Whorled Bamboo, Bamboo Andong (Malay), Pring Soorat (Java), Andong Kekes, Awi Andong, A. Gambong, A. Liah, A. Soorat (Sunda) |
| 44 | *Guadua aculeata* | Tarro (Central America) |
| 45 | *Guadua amplexifolia* | Cauro (Nicaragua, Mosquito) |
| 46 | *Guadua anoustifolia* | Guadua |
| 47 | *Guadua superba* | Marona |
| 48 | *Melocanna baccifera* | Terai Bamboo, Muli, Metunga (Bengali), Tarai (Assam), Wati (Cachari), Artem (Mikir), Turiah (Naga), Watrai (Garo), Kayoungwa (Magh), Kayinwa (Myanmar), Paia. Taria. Paautulla |
| 49 | *Ochlandra rheedii* | |
| 50 | *Ochlandra stridula* | Batali Battaaass |
| 51 | *Oxvtenanthera abvssinica* | Arkai, Chommel |
| 52 | *Oxytenanthera albociliata* | Phai Rai, Phai Kai (Thailand) |
| 53 | *Oxytenanthera nigrociliata* | Poday (Andaman), Washut (Garo), Bolantgi Bans (Orissa), Lengha (Java) |
| 54 | *Phyllostachysaurea* | Buddha Bamboo, Hotei-chiku (Japanese), Fat-to Chuk (Chinese) |
| 55 | *Phyllostachys bambusoides* | Giant Timber Bamboo, Madake (Japanese), Kam Chuk (Chinese) |
| 56 | *Phyllostachys edulis* | Meng Tsung Chu (Chinese) |
| 57 | *Pseudostachyum polymorphum* | Filing (Nepal), Purphiok, Paphok (Lepcha), Wachall (Garo), Bajal, Tolli, Ral (Assam), Bawa (Myanmar) |
| 58 | *Schizostachyum brachycladum* | Buloh Nipis, B. Lemag, B. Padi, B. Urat, B. Pelang, Busa |
| 59 | *Schizostachyum hainanense* | Tang Chuk (Chinese) |
| 60 | *Schizostachyum lima* | Bolo, Bagacay |
| 61 | *Schizostachyum lumampao* | Lakap (Bosayan), Tamblang (Bila-an) |
| 62 | *Schizostachyum zollingeri* | Buloh Tulo, B. Telor, B. Palang, B. Nipis, B. Dinding, B. Pauh, B. Kasap, B. Lemang, Phai Po (Thailand) |
| 63 | *Teinostachyum dullooa* | Dulooa (Assam), Paksalu, Pogslo, Wadroo, Gyawa |
| 64 | *Thyrsostachys oliverii* | Thanawa (Myanmar), Maitong (Kachin) |
| 65 | *Thvrsostachvs siamensis* | Kvauna-wa |

## TABLE 6.2: REGIONAL DISTRIBUTION

| Continent | Country | Location | Height above sea level(m) | ID | Notes |
|---|---|---|---|---|---|
| All | Pantropic | | | 26 | |
| | Pan-temperate | | | 54 | Probably most common next to 26 |
| Africa | Angola | | | 51 | |
| | Benin | | | 51 | |
| | C A R | | | 51 | |
| | Cameroon | | | 51 | |
| | Congo | | | 51 | |
| | Ethiopia | | | 51 | |
| | Gabon | | | 51 | |
| | Ghana | | | 51 | |
| | Kenya | | | 51 | |
| | | | 2400-3000 | 1 | |
| | Nigeria | | | 51 | |
| | Sudan | | | 51 | |
| | | | 2400-3000 | 1 | |
| | Tanzania | | | 51 | |
| | Togo | | | 51 | |
| | Uganda | | | 51 | |
| | | | 2400-3000 | 1 | |
| | Zaire | | | 51 | |
| | | | 2400-3000 | 1 | |
| America | Argentina | | | 46 | |
| | | Andean hiahlands | | 28 | |
| | Brazil | | | 25,46 | |
| | | Acr e | | 47 | |
| | | Rio Purus | | 47 | |
| | Chile | Andean hiahlands | | 28 | |
| | Colombia | | | 45.46 | |
| | | Andeam highlands | | 28 | |
| | Costa Rica | | | 28.44.45 | |
| | Ecuador | | | 46 | |
| | | Andean highlands | | 28 | |
| | El Salvador | | | 25, 28, 44,45 | |
| | Guatemala | | | 28, 44, 45 | |
| | Guyana | | | 46 | |
| | Honduras | | | 28, 44, 45 | |
| | Mexico | | | 28, 44, 45 | |
| | Nicaragua | | | 28, 44, 45 | |
| | Panama | | | 28, 44, 45 | |
| | Paraguay | | | 46 | |

| Continent | Country | Location | Height above sea level (m) | ID | Notes |
|---|---|---|---|---|---|
| America continued | Peru | | | 46 | |
| | | Andean highlands | | 28 | |
| | Surinam | | | 46 | |
| | Venezuela | | | 45,46 | |
| Asia | Bangladesh | | | 24, 35, 42, 48. 63 | |
| | | | 0-1050 | 21 | |
| | Bhutan | | 1200-1800 | 38 | |
| | Borneo | | | 15 | Cultivated |
| | China | | | 25 | |
| | | | | 54 | Probably most common next to 26 |
| | | | | 55 | Widely cultivated in other countries |
| | | Hainan Island | | 59 | |
| | | S.E. provinces | | 23 | |
| | | Wangtung | 0-300 | 18 | Virtually pantropic in cultivation |
| | India | Pantropic | | 13 | |
| | | | | 15 | Cultivated |
| | | | | 20,24,48 | |
| | | | | 39 | Commonest bamboo |
| | | | 0-600 | 64 | |
| | | | 0-1050 | 21 | |
| | | | 0-1500 | 33 | |
| | | Andaman Islands | | 53 | |
| | | Assam | | 14, 27, 42, 57, 63 | |
| | | | 0-1500 | 19 | |
| | | Assam, Jaintia Hills | 0-900 | 8 | |
| | | | 0-1200 | 17 | |
| | | | 0-1350 | 5 | |
| | | | O-2850 | 9 | |
| | | Assam, Khasia Hills | | 32 | Widely cultivated |
| | | | 0-1200 | 17 | |
| | | | 0-1350 | 5 | |
| | | | 0-2000 | 2 | |
| | | | 0-2850 | 9 | |
| | | | 1500-1800 | 7 | Often cultivated |
| | | Bengal, Lower | | 14 | |
| | | Bengal, N. | | 32 | Widely cultivated |
| | | Bihar | | 14 | |
| | | Himalaya, Central & E. | | 32 | Widely cultivated |

| Continent | Country | Location | Height abovesea level (m) | ID | Notes |
|---|---|---|---|---|---|
| Asia continued | India continued | Himalaya, E. | | 57 | |
| | | | 0-1350 | 5 | |
| | | | 0-2000 | 2 | |
| | | | 0-2100 | 6 | |
| | | | 1200-1800 | 38 | |
| | | Himalaya, N.W. | 2100-2700 | 11 | |
| | | Himalaya, W. | | 4 | |
| | | Jumna | 0-1500 | 19 | |
| | | Kerala | | 49 | |
| | | Manipur | 0-1200 | 17 | |
| | | Moist forests | 0- | 36 | |
| | | N.E. | | 31 | |
| | | N.E.hills | 0-1200 | 30 | |
| | | Naga Hillls | 0-2850 | | |
| | | | 1500-2250 | 3 | |
| | | Nilairi Hills | | 12 | |
| | | Sikkim | | 57 | |
| | | | 0-1500 | 19 | |
| | | | 1200-I 800 | 38 | |
| | | | 1800-3600 | 10 | |
| | | South | | 12 | |
| | | West | | 12 | |
| | Indonesia | | | 29 | Widelv planted |
| | | | | 62 | |
| | Japan | | | 54 | Probably most common next to 26 |
| | | | | 55 | Widely cultivated in other countries |
| | Java | | | 15 | Cultivated |
| | | | | 40 | Widely cultivated |
| | | | | 43,53 | |
| | Malaysia | | | 15 | Cultivated |
| | | | | 25 | |
| | | | | 29 | Widely cultivated |
| | | | | 41 | Wild and cultivated |
| | | | | 58,62 | |
| | Myanmar | | | 24, 27, 31,35, 39, 42, 48, 53, 65 | |
| | | | | 32 | Widely cultivated |
| | | | 0- | 36 | |
| | | Upper | | 57 | |
| | | Upper | O-600 | 64 | |
| | | Upper | 0-1500 | 33 | |
| | Nepal | | 1800-3600 | 10 | |
| | | Himalava. E. | 0-2100 | 6 | |

| Continent | Country | Location | Height above sea level (m) | ID | Notes |
|---|---|---|---|---|---|
| Asia continued | Philippines | | | 15, 29, 34 | Cultivated |
| | | | | 37,58 | |
| | | | | 41 | Wild and cultivated |
| | | Luzon | | 60,61 | |
| | | Mindanao | | 60 | |
| | | Mindoro | | 60 | |
| | | Palawan | | 60 | |
| | | Penay | | 61 | |
| | Sri Lanka | | | 31 | |
| | | S. | | 50 | |
| | Sumatra | | | 15 | Cultivated |
| | | | | 53 | |
| | Surinam | | | 40 | Widely cultivated |
| | Taiwan | | | 16, 22, 34 | Cultivated |
| | | | | 56 | |
| | Thailand | | | 20, 24, 27,31, 35, 39, 52, 53, 62,65 | |
| | | | | 29, 32, 34,40 | Cultivated |
| | | | 0- | 36 | |
| | | | 0-600 | 64 | |
| | | | 0-1050 | 21 | |

## TABLE 6.3: PHYSICAL CHARACTERISTICS

| ID | Height m | Diameter mm | Wall thickness mm | Internode length mm | Notes |
|---|---|---|---|---|---|
| 1 | 13.5-18 | 60-100 | Thin | | |
| 2 | 3.6-6 | 12-25 | | | |
| 3 | 3.6-6 | 8-20 | | | |
| 4 | 4.5-6 | 12-20 | | | |
| 5 | 3.6-6 | 12-25 | | | |
| 6 | 2.4-3.6 | 10-12 | | | |
| 7 | 3-3.6 | -12 | | | |
| 8 | -9 | -12 | | | |
| 9 | | | | | Slender |
| 10 | 1.5-4.5 | 18-25 | | | |
| 11 | 7.5-9 | -38 | | | |
| 12 | 3-4.5 | -25 | | | |
| 13 | 25-30 | 150-200 | Thick | | Commonly crooked |
| 14 | 15-21 | 75-l 50 | | | |
| 15 | 9-18 | 75-100 | Thick | 400-600 | |
| 16 | 6-20 | 40-100 | | | |
| 17 | 9-12 | 25-35 | | | |
| 18 | -9 | -25 | Thin | Long | Resistant to Dinoderus |
| 19 | 10-15 | 40-80 | Thick | 350-450 | Strong, straight, hard |
| 20 | 12-18 | 50-80 | Thick | | |
| 21 | 15-24 | 75- 150 | | | |
| 22 | 5-24 | 50- 150 | | | |
| 23 | -12 | -50 | Thin | Long | |
| 24 | 6-21 | 50-100 | | | |
| 25 | -16.5 | -50 | | | |
| 26 | 6-21 | 50-100 | Thickish | 200-450 | Susceptible to *Dinoderus* |
| 27 | 9-12 | 50-75 | Thin | | |
| 28 | Long | slender | | | Weak, pithy |
| 29 | -30 | 150-200 | Thick | | |
| 30 | 18-36 | 125-200 | | | |
| 31 | 24-30 | 200-250 | | | |
| 32 | 12-18 | 100-225 | Thin | 300-500 | soft |
| 33 | 15-18 | 100-150 | 25 | 450-500 | |
| 34 | -25 | -200 | 5-35 | 200-700 | |
| 35 | -18 | 75-l 00 | 12 | | |
| 36 | -21 | -100 | 6-9 | 225-375 | |
| 37 | 15-18 | 60-100 | 25-30 | 150-210 | |
| 38 | 15-21 | 125- 175 | | | |
| 39 | 5-15 | 25-80 | Often solid | | Very strong |
| 40 | -19.5 | 100-150 | 6-12 | -650 | Versatile and useful |
| 41 | -20 | 150-230 | 15-30 | 290-360 | Very straight, easily worked |
| 42 | 9-15 | 65- 100 | | | |
| 43 | -20 | -150 | 20 | | Straight, easily worked |
| 44 | -22.5 | -125 | Moderate | Short | |
| 45 | -18 | -100 | Semi-solid | Short | |
| 46 | -27 | -150 | -20 | Short | Versatile and resistant |

| ID | Height m | Diameter mm | Wall thickness mm | Internode length mm | Notes |
|---|---|---|---|---|---|
| 47 | -22.5 | -125 | | | |
| 48 | 15-21 | 38-75 | Thin | 300-500 | Straight, strong, durable |
| 49 | 4.5-6 | 25-50 | Thin | | |
| 50 | 1.8-5.4 | 12-20 | | | |
| 51 | 7.5-15 | 38-75 | | | |
| 52 | 7-10 | 15-30 | 5-10 | 150-400 | |
| 53 | 9-12 | 12-50 | | | |
| 54 | 7.5 | 25 | | | |
| 55 | -22.5 | -150 | Moderate | | Excellent quality |
| 56 | 4-20 | 50-180 | | | |
| 57 | -15 | -25 | Thin | Long | |
| 58 | | -80 | Thin | | Very straight, easily split |
| 59 | -30 | -25 | Thin | Long | |
| 60 | 6-10 | 25-48 | 3-5 | 800-1000 | |
| 61 | 12-15 | -75 | 4-6 | 300-500 | Straight |
| 62 | -15m | 20-100 | Thin | -400 | Easily split and flattened |
| 63 | 6-9 | 25-75 | Thin | -1000 | |
| 84 | -25 | 50-80 | Thin | 300-600 | |
| 65 | 7.5-12 | 38-75 | Thick | 150-300 | Very strong and straight |

## TABLE 6.4: APPLICATIONS

| Application | | ID |
|---|---|---|
| General | | 1, 13, 14, 15, 16, 17, 19, 20, 21, 22,24, 26, 27, 29, 30, 31,32, 33, 34,35, 36, 37, 38, 39, 40, 41, 42, 43, 44,45, 46, 47, 48, 51, 52, 53, 55, 56, 64, 65 |
| Framing | | 1, 13, 14, 15, 16, 17, 19, 20, 21,24, 26, 29, 30, 31, 33, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46,47, 48,51,53, 55, 64, 65 |
| Walls | Wattling | 1, 4, 9, 13, 14, 17, 19, 21, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 35, 36, 37, 38, 40, 41, 42, 43, 44, 45, 46, 47, 48, 51, 53, 54, 55, 57, 59, 60, 61, 63, 64, 65 |
| | Whole or half culms | 3, 7, 14, 15, 17, 18, 19, 21, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 46, 47, 48, 51, 53, 54, 55, 59, 60, 61, 64,65 |
| Roof | Tiles | 13, 14, 15, 21, 26, 29, 30, 31, 32, 33, 35, 36, 41, 42, 43, 44,45, 46, 47, 50, 55 |
| | Shingles | 59,60,61,63 |
| Floor | Boards | 1, 17, 21, 30, 31, 35, 36, 43, 44, 45, 46, 47, 55, 58,62 |
| | Strips | 1, 13, 17, 19, 21, 24, 25, 26, 30, 31, 32, 33, 35, 36, 37, 38, 40, 41, 42, 43, 44, 46, 47, 48, 51, 53, 55 |
| Sheathing | Whole culms | 1, 4, 10, 18, 19, 21, 23, 24, 25, 27,28, 45, 48, 51, 53, 54, 55, 57, 59, 64, 65 |
| | Strips | 1, 14, 15, 17, 19, 21, 24, 25, 26, 29, 30, 31,32, 33,35, 36, 37, 38, 40, 41, 42, 43, 44, 45, 46, 47, 48, 51, 53, 55, 57, 58, 59, 60, 61, 62, 63, 64, 65 |
| Matting | | 2, 5, 6, 10, 12, 17, 21, 23, 27, 40, 43, 48, 49, 55, 57, 59, 60, 61, 63 |
| Lashings | | 1,2,5,8,23, 40, 43, 55, 57 |
| Concrete formwork | Boards | 1, 17,21,30,31,33,35,43,44,46,47,55 |
| | Shoring | 1, 14, 15, 17, 19, 21, 24, 30, 31, 33, 35, 37, 38, 39,41,42, 43, 44,45,46,47, 51, 53, 55,64, 65 |
| Scaffolding | | 1, 13, 14, 15, 17, 19, 21, 24, 25, 26, 29, 30, 31, 33,35, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 51, 53, 55, 56, 64, 65 |
| Troughs | | 13, 14, 15, 21, 26, 30, 31, 32, 33, 35, 38, 41, **42,** 43, 44,45, 46, 47, 48, 55 |
| Pipes | | 14, 15, 21, 26, 30, 31, 33,35, 38, 41, 42, 43, 44, 45,46, 47,48, 55 |

**Bold** numbers indicate the most useful species. The less desirable species are in italics.