For my friend Ranjanan with best regards.

New delhi, february 28/004

BAMBOO

THE GIFT OF THE GODS

by

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PART-1

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BAMBOO THE MARVELOUS PLANT

Bamboo is the most marvelous plant in nature.

Some giant culms of genus *Phyllostachys pubescens*, grow up to 1.22 meters in 24 hours.

In less than five months, the culms of giant species like *Guadua angustifolia* complete their whole growth of 20 meters which, in many trees of the same diameter takes many years

Bamboo is stronger than wood or timber in tension and compression. The tensile strength of the fibers of a vascular bundle could be up to 12.000 kilograms per square centimeter, almost twice that of the steel.

In spite of the strength and hardness of the giant bamboo culm wall, the culm can be cut very easily in few minutes, even with a stone ax, if we know the exact place of the internode where it should be cut. To cut the trunk of a high density tree with the same diameter using a stone ax would take several days and many stone axes

With bamboo wee can replace wood or timber in all their applications, but we cannot use wood or timber to make all of the things and structures that can only be made with bamboo.

Only a supernatural beign or a superplant can support the radiation of an atomic bomb. In Hiroshima, Japan, the only plant which survived the radiation of the atomic bomb in 1945 was a bamboo plant. The incinerating heat developed by the radiation destroyed all the trees and wooden houses and the whole city was razed except this bamboo plant.

I have been fortunate to have worked and studied bamboo for many years. Now I also agree with the Garrows and other ancient cultures of Asia, that in the world of plants bamboo is the representation of the divinity because it is A GIFT OF THE GODS

Oscar Hidalgo-López

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Introduction

One afternoon in 1963 at the end of the lecture which I gave to the last semester students at the College of Agricultural Sciences of the National University of Colombia in Palmira, about the traditional uses of "guadua" (the vernacular name of our main giant bamboo species, *Guadua angustifolia* Kunth) in rural construction, one of the students asked me: *What is guadua?, What is its origin?* When he noted the surprise his question caused me, because I am an architect and he was almost an agronomist, he told me, *I have to write a thesis about guadua and so far I have not been able to find any botanical or technical information about this plant in the library.*

I could not believe what he said. I could not believe that there were no scientific or technical studies about the most useful of all our plants, which for centuries has contributed to the social and economic development of Colombia, where about 60% of the total population of the cities and rural areas use this material not only in the construction of their houses, but also in buildings, factories and in the construction of stables, bridges, aqueducts and many other uses.

Based on my belief, I promised my student that I would get some information for his thesis. During several days, I visited the libraries of various universities including that of Natural Sciences in Bogota where I found hundreds of books written by our botanists, even about plants which have no economic value, but I could not find any botanical or technical information about our "guadua". My student was right and I became frustrated because I could not help him with any information. Unfortunately, this student died in an accident two months later, not knowing that his questions were the seeds which created in me a great interest for the study of our marvelous "guadua" in which I have spent many years of my life.

What was the reason for the lack of interest of our botanists, agronomists and forestry universities in the study of this plant? I talked with several forestry engineers who told me that at that time (1963), there were so many large natural plantations of bamboo in our country that this plant was considered to be a weed and the Cinderella of our natural resources since it was only used by poor people in the construction of their houses. Consequently, nobody was interested in the study of this plant since it was considered a waste of time. For this reason, there was no technical or scientific information about this plant. Therefore, students had not received any information about it from their professors at the university, not even about the way it could be cultivated. I became frustrated, because if there was no information about this plant, how could I start studying it?

Several weeks later I received from my friend Dr. Guillermo Ramos Nuñez a small publication, "Bamboo as Construction Material" written in 1953 by Dr. Alonzo McClure at the U.S Department of Agriculture, Washington D.C In this publication, I learned that "guadua" was not a tree (as it was believed to be in Colombia) but a giant grass, which was considered to be one of the best bamboos in the world for durability and strength. For me, this information opened the doors of that marvelous world of bamboo in which I have been wandering for many years and which has taken me to visit several countries of Asia such as Japan, China, the Phillipines, Taiwan and Indonesia, where I started my studies on bamboo.

There has been little interest in this plant in Latin America as a result of the lack of technical and scientific information written in Spanish about our native bamboo species, so most Latin American countries have destroyed their native giant species up to the point that in most of them bamboo is on the brink of extinction like in Venezuela, México and Guatemala.

It is very important to point out that Colombia is the only country in Latin America which has still preserved most of its native species, thanks to the Colombian Institute of Natural Resources (INDERENA). In 1960, when our giant native bamboo species were on the brink of extinction due to the intensive destruction of the natural bamboo plantations which began in the nineteen fifties, this institute forbade the cutting of bamboo without its permission and fortunately this norm is still in force.

This book is the result of many years of research that I have carried out at the National University of Colombia at the School of Architecture, where I founded the CIBAM (Bamboo Research Center); as a United Nations consultant in Ecuador and Costa Rica; as a consultant for the Acuerdo de Cartagena PADT -REFORT in Peru and Bolivia, and in the libraries of several universities including Washington University in Canada, the University of Columbia in NewYork, and the University of California in Berkeley, where I received great collaboration.

This book includes some traditional applications of giant bamboos and some of the most important and advanced studies on this plant carried out in recent years by outstanding researchers from-China, India, Japan, Germany and United States in different fields.

The first part of the book include: Anatomy and Physiology of bamboo in which I received the collaboration and guidance of my friend and teacher Professor Dr. Walter Liese of Germany. I think that this is the most important part of the book because the anatomy and physiology of bamboo are the basis for understanding not only the structural behavior of bamboo, but also the thousands of different applications of this marvelous plant that has been considered to be a gift of Gods since ancient times.

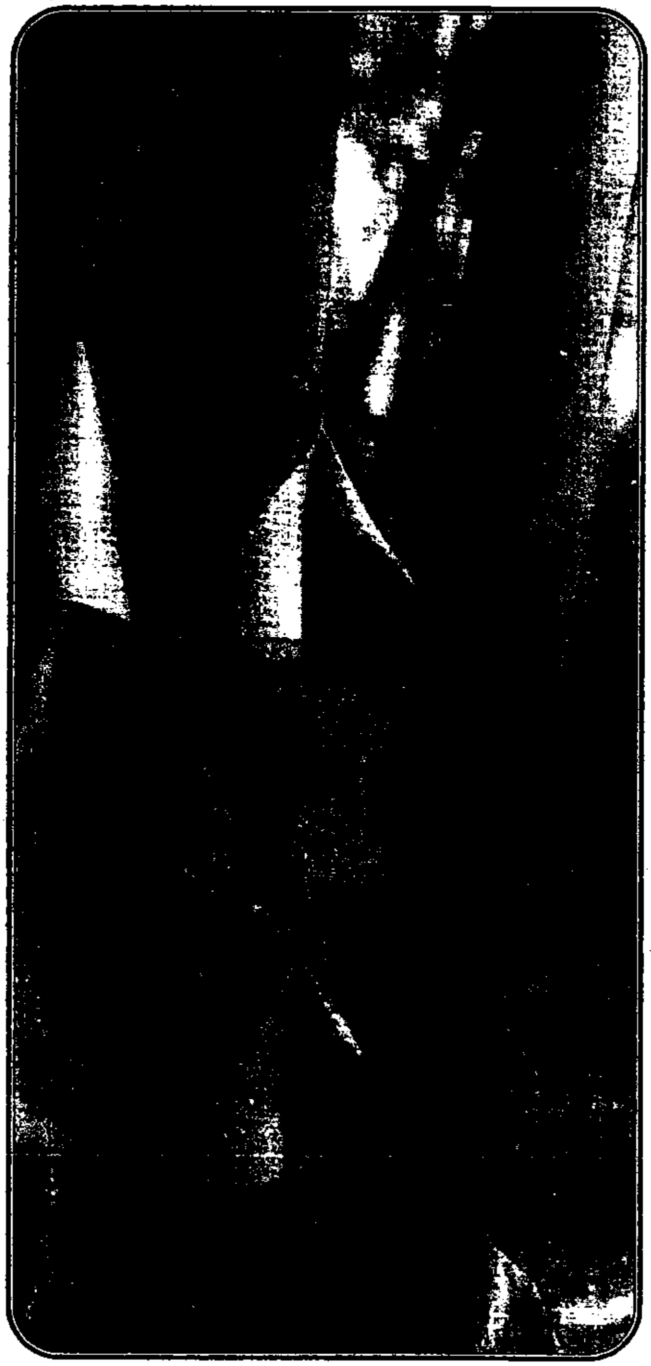
The other chapters deal with the use of bamboo in different fields of ancient and modern architecture, in different branches of engineering, and in theconstruction of modern structures. It also considers its use inthe manufacture of new types of composite materials, which will generate new applications of bamboo in the future, and finally its use in the field of medicine and as a biomedical material.

I hope that this book will contribute to the technical and scientific study of our native giant bamboo species, to the development of many industries related to the manufacture of composite materials, and the development of new types of structures, in Colombia and the other countries of the Americas where this marvelous plant can grow.

Finally, I want to dedicate this book with my deepest gratitude to my student, who changed the direction of my life with his questions, to Dr. Walter Liese, to Mrs Ingrid Radkey of the University of California and many other people of other institutions, who taught and helped me in my reseach.

PART ONE

The Bamboo Plant



1 THE BAMBOO PLANT

WHAT IS [illegible]

Bamboo is not a tree as it is considered by the majority of people, but a giant arborescent grass, or in other words, a woody giant herbage. As such, it belongs to the family *Gramineae (Poaceae)*, subfamily *Bambusoideae*, whose members possess a similar distinctive in the leaf blade anatomy, i.e., fusoid cells and arm cells, which sets the bamboo apart from grasses. All grasses that possess this ty-pe of leaf anatomy are known as *"bambusoid grasses"*. They range from a few centimeters in height, such as those of genera *Raddiella* which grow on wet rocks near rapids in the Guianas, South America, to giant species up to 40 meters high, as *Dendrocalamus giganteus*, from India.

PALEOBOTANY

In relation to the origin of the plant, Velenovsky claims that the bamboo plant flourished in the Cretaceous period, when grasses and cereal appeared, just before the beginning of the Terciary period, when the first humans also appeared. (Porterfield 1925).

Fossils of *Chusquea rolloti* of the Tertiary were found in the area of La Virginia near Girardot, Colombia (about 140 kilometers from Bogota). (Berry 1929). According to Taylor & Smoot (1984), the earliest recorded paleobotanical contribution was the description of fossil "bamboo shoots" by the Chinese scholar Shen Kua (1029-1093), published in 1086 in his work entitled *"Dream Pool Essays"*.

Although the beginning of paleo-botany may be traced to this work, it was not until the seventeenth century that paleobotanical investigation began in Europe. Shen Kua reported in his work that in the year 1080 there was a landslide in China on the bank of a large river in Yang-Ning Kuang near Yenchow;"*...The bank collapsed, opening a space of many meters, and under the ground a forest of bamboo was thus revealed. It contained several hundreds bamboos with their roots* (rhizomes) *and trunks* (culms) *complete, and all turned to stone. Now bamboos do not grow in Yenchow. Perhaps in very ancient times the climate was different so that the place was low, damp, gloomy, and suitable for bamboos...*" (Deng. 1976; Li. 1981).

ETYMOLOGY

The origin of the word "bamboo" is a puzzle to etymologists. Some believe that this word is Malayan in origin and it is the onomatopoeic for *bam-boom*, the cracking sound made by the culms when they are burned. With the heat, the air in the sealed hollow bamboo internodes expands until they blow apart. Other authors consider that the term "bamboo" had its origin in"*mambu*", the ancient Indian term for bamboo.

Herbaceous and woody bamboos

The subfamily *Bambusoideae* is divided into two broad groups: The *herbaceous bambusoid grasses*, or herbaceous bamboos, that usually have soft culms, and the *woody bambusoid grasses* or woody bamboos, or simply "bamboos". This latter group forms the tribe *Bambuseae* (See Table 3-3) which have woody culms, usually hollow and are divided by septums or diaphragms. They branch at the nodes and usually reproduce from rhizomes that give rise to new long-lived culms. They flower only after many years, at which time most of them produce seeds and then die, in the majority of cases, while grasses only flower annually and most commonly reproduce by seed

Classification of the woody plants

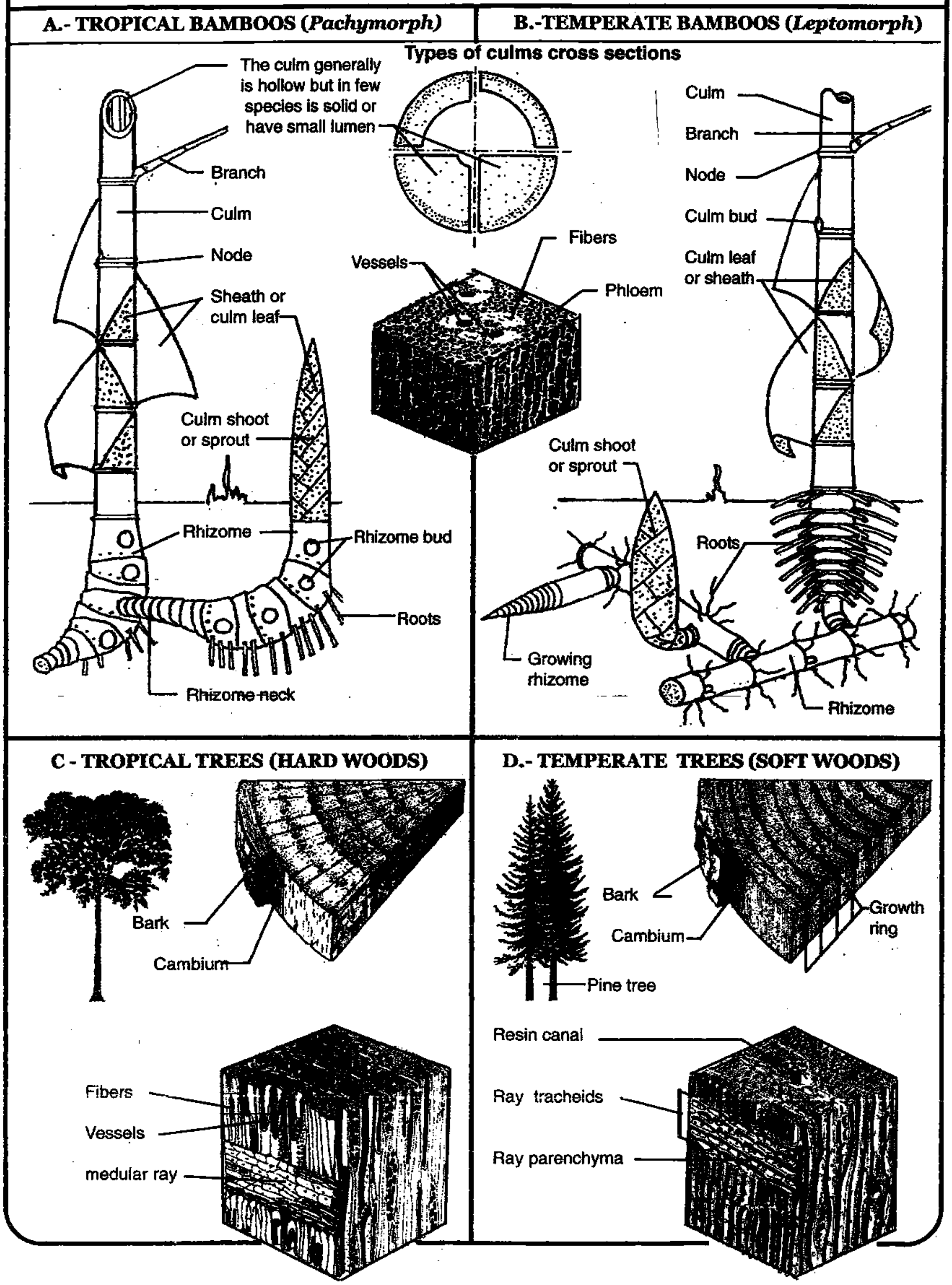
The basic anatomical element of the plant is the cell.. The joining of cells forms the tissue, and the joining of tissues forms the woody body or mass. As a woody grass, bamboo is a member of the woody plants, which also include trees (softwoods and hardwoods) and palms. All of them have differences in their morphology, and also in their anatomical structure and tissue organization.

The woody plants are classified into two groups: *Gymnosperms* and *angiosperms*. The *Gymnosperms* include the coniferous species or *"softwoods"*, which have needle like leaves, such as pines or scale- like leaves which, except for a couple of species, remain on the tree throughout the year.

The *Angiosperms*, are subdivided into two groups: *dicotyledons* and *monocotyledons*. *Dicotyledons* include the *"hardwoods"* which have broad leaves. They are often deciduous and shed their leaves in the fall or during the winter, except in warmer regions, depending on the species. Bamboos and palms are the most important members of the *Monocotyledons*. The palms include rattan, which has solid but flexible stems and belongs to the climbing, spiny palms. Once the spines are removed, it is used in the manufacture of furniture. Rattan has certain similarity with some bamboo species, but they are different, bamboos are generally hollow and rattan is solid.

Besides the differences which exist in the anatomical characteristics of the woody plants, they have also differences in their growing process. The growing process of the woody plants is based on the formation of new cells by specialized tissues known as *meristems*. For instance, in trees (softwoods and hardwoods), the initial growth of the plant is due to the primary or apical meristem which is later replaced by a lateral meristem known as *cambium* located between the bark and the wood. In bamboos there are not *cambium* because bamboo does not grow in diameter, as will be explained in this chapter.

Fig. 1.1 BAMBOOS AND TREES FROM TROPICAL AND TEMPERATE ZONES



BAMBOO MORPHOLOGY AND PHYSIOLOGY

PARTS OF THE PLANT

1.- THE RHIZOME

Bamboos are perennial plants consisting of a ramifying system of segmented vegetative axes which form a regular alternation of nodes and internodes. These segmented axes, according to their shape and position on the plant, have the following names:the *culm or stem* with the branches, which forms the aerial part of the plant and the *rizome system* with its *roots* which forms the subterranean part of the plant; and its structural foundation. The rhizome performs important functions in the life of the plant; it is the vital organ with which bamboo plants reproduce vegetatively or asexually through the branching of rhizomes. As an organ, it has the function of storage and transportation of nutrients. The culms depend on rhizomes for their growth, vigor and spacing on the ground.

Types of bamboos

As mentioned above, the tree species are commonly divided into two large groups according to their geographical position. They are:"softwoods" which naturally grow in the temperate zones, and "hardwoods" which grow in the tropical zones. These two groups have differences particularly in the anatomy of their trunks and their leaves.

Like trees, bamboos are also classified in two main types on the formation pattern of the subterranean part of the culm which also depends on the geographical position where they grows naturally. These main groups or types are: the *leptomorph or monopodial type* which grows in temperate zones; and the *pachymorph* or *sympodial type* which grows in the tropical zones. There is a subgroup or intermediate known as *metamorph* which is a combination of the two main groups, but has no relation with the geographical position.

The only thing that these two groups have in common is the morphology and anatomy of their culms and their growing process.The aerial part of these two groups is so similar that if the species are not known, it is difficult to recognize visually to which group they belong, unless the rhyzomes can be seen, because there is a great difference in the morphology and in the form of branching of the rhizomes between the two main groups and in the formation of the culm shoot, as can beseen in the Fig 1.1.

On the other hand, the two main groups of bamboos have differences in the number of chromosomes, which in the leptomorph type is 2n=48, and in the pachymorph type is 2n=72. The basic number of chromosomes is assumed to be 2n=18. Bamboos with low multiple chromosomes are considered to be of the advanced type and those with high ones are of primitive type. The basic number for most bamboo species is X=12, except for certain bamboo species (especially paquimorph bamboos). The difference in chromosome number and nucleous type can help to explain the systematic development, and classification of bamboos.

In 1879, the Rivieres were the first to publish a clear distinction between the two basic forms of the bamboo rhizomes. They used the terms "*caespitose*", or "clumping " for pachymorph, and 'traçant" or "running" for leptomorph. In 1925 McClure introduced the terms "monopodial" and "sympodial" when he was living in China, and later, at the Smithsonian Institution, in Washington, he developed the concept of "leptomorph" and "pachymorph" respectively. Today the terms "leptomorph" and "paquimorph" are used in the Americas by the botanists and taxonomists, and the terms "monopodial" and "sympodial" in Asia.

a).-LEPTOMORPH RHIZOME

The leptomorph rhyzome is also known by the names of monopodial, traçant, indeterminate, and running bamboos. Bamboos with leptomorph rhizomes are usually distributed in temperate regions, such as Japan, Korea and China, where winters are severe. They are characterized by relatively strong frost-resistance, and consequently they can be cultivated at high elevations in the tropics.

Bamboos with this type of rhizome are represented in Asia by the genera *Arundinaria*, and *Phyllostachys*. The most cold-resistant are: *Phyllostachys praecox*, *Ph. propinqua*, *Ph. dulcis*, *Ph. iridenscens*, *Ph. nuda*, *Ph. angusta*, *Ph. aureosulcata*, and *Indocalamus*. In the Americas there are only three native species of leptomorph type which belong to the asiatic genus *Arundinaria*, and grow in the temperate zones of the southeastern of the United States up to 46° north latitud.

The subterranean part of the plant consists of two major parts, the *culm-base* with its root system and the *rhizome* system (See Fig. 1.1). The *culm-base* corresponds to the subterranean prolongation of the aerial culm and is conected to the rhizome by the *culm neck*. The internodes at the lower part of the culm-base are the shortest and there are usually 13-16.

The leptomorph rhizome has the creeping habit. It is long and slender, with a cylindrical or subcylindrical form, and a diameter usually less than that of the culm originating from it. The internodes are longer than broad, and they are generally shorter than those of the culm. They are typically solid with narrow lumen. Every node bears a solitary lateral bud and an encircling belt of roots at each node. Beyond the bud there is a longitudinal groove.

Most of the lateral buds are temporarily or permanently dormant. The majority of those that germinate generate single culms, directly, or rhizomes. But it is very difficult to determine whether a lateral bud of the rhizome is going to form a rhizome or a culm shoot when it is still dormant. The meristem generated in the lateral bud forms a culm neck which turns its apex upward forming the *culm base* and the culm shoot, and finally the culm proper. The buds on the *culm-base* can only grow into rhizomes and cannot grow into new culms.

The culms and the rhizomes grow in alternation all through the year. According to Ueda (1960), in temperate zones the rhizome grows during summer and autum when the temperature is relatively high, and the culms grow through winter to spring when the temperature is relatively low. The rhizome begins to develop after the new culm shoots have attained their full growth and the new branches and leaves have developed. This usually starts in March after the soil temperature rises up to about + 5° C. The rhyzome grows fastest in August and September, and ceases to grow gradually from November onwards.

The rhizome shoot is slender and runs its apical meristem forward, parallel to the ground surface. The elongation of a leptomorph rhizome shoot depends on the activity of two meristems: the *apical meristem* at the terminal end of the rhizome, and the *intercalary or intermediate meristems* located between the internodes of the rhizome. The apical meristem consists of tunica-corpus and its derived meristem. The cells of a derived meristem differenciate into sheaths, buds, primordial roots and vascular bundles. The original slanted bundles and enlarged parenchyma cells form a new node at the young sheath position, and divide the derived meristem into several intercalary meristems.

The growth of a rhizome is mainly determined by the stretching action of a terminal portion of the rhizome which consists of 14-16 actively elongating internodes. The internodes of the streching portion elongate according to the rhythm of "slow-fast-slow" from back to front. The latter sections of the stretching portion mature and stop stretching. As the growing season proceeds, the apical meristem produces new nodes and internodes continnuously. The new internodes formed by the meristem at the terminal end, act in succession replacing the former part of the stretching portion. The rhizome tip continues to grow.

The apical meristem of the rhizome shoot is tightly embraced layer by layer by hard thick sheaths and is sharply pointed like a borer which can penetrate through the hard-textured soils or the gravel gaps with driven force generated from the internodal elongation. The rhizome shoot does not necessarily maintain a horizontal position nor does it fallows in a fixed direction but it may twist, bed, shrink, elongate or wind with the topogragraphical and soil conditions. It grows in all directions, and forms a complex interwined network. It may run to considerables distances and send out many single culms that appear on the ground scattered at certain distances every year.

Ueda (1960) made extensive excavations of the leptomorph rhizomes of several species of Japanese bamboos,

Fig. 1.2 RHIZOME SYSTEM OF THE LEPTOMORPH TYPE

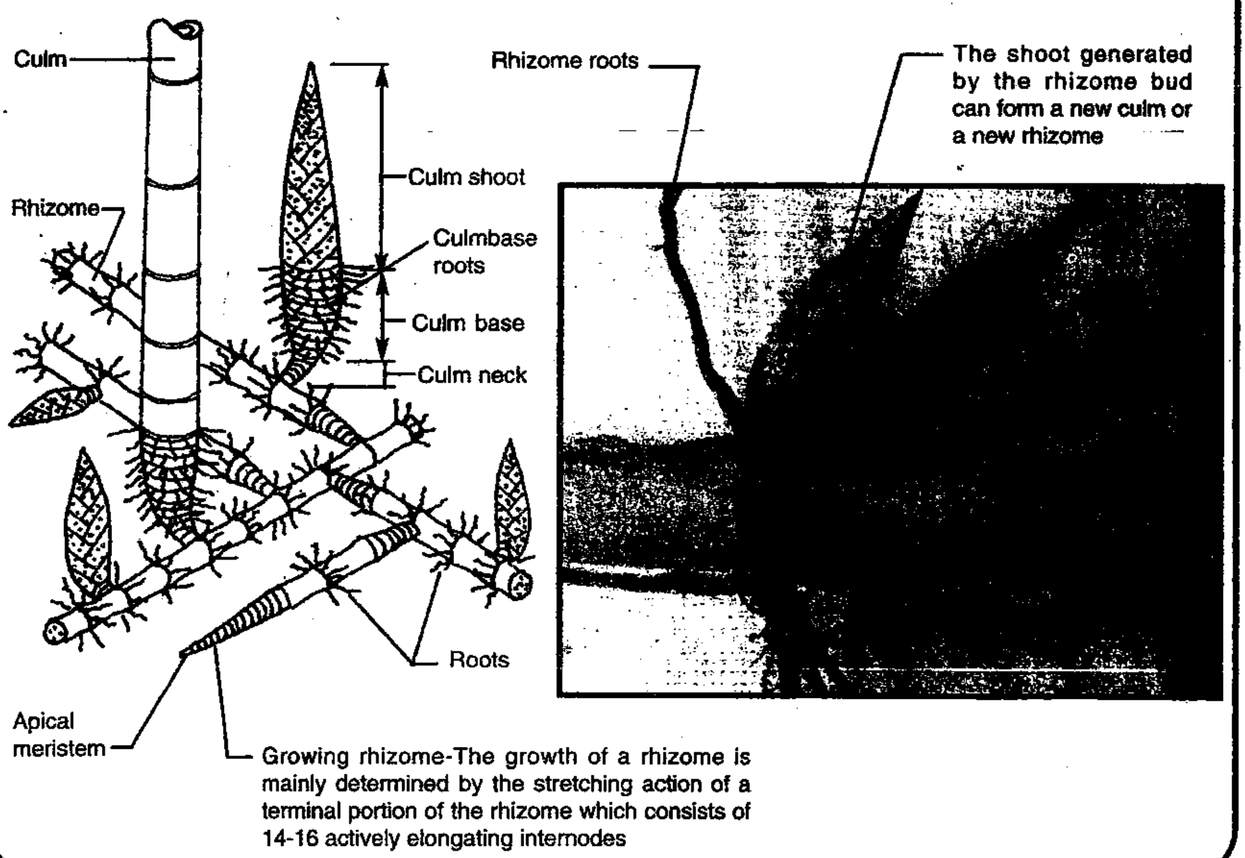


Fig.1.3 *The soil has been removed by Ueda in order to show the intrincate system of rhizomes which form a net-work just below the surface and conect most of the standing culms. This means that the whole grove is one plant.*

plotting the pattern and rate of their extension. He found that the total length of living rhizomes per 0.1 ha. in bamboo groves of *Phyllostachis reticulata* was from 6.300 to 18.740 meters; in groves of *Pleioblastus pubescens* from 47,000 to 57,920 meters.

The rhizome neth under the ground prevents landslide and collapse of river bank and hill sides where there are an erosion problems. Bamboo cultivation for the protection of river banks was recommended in Japan in the sixteen century. This is also the reason why a bamboo plantation is considered a safe refuge when an earthquake takes place.

The depth that the rhizome travels on the ground also varies with the type of bamboo. The horizontal growth mostly take place in the upper soil layer between 10 -30 cm in depth, where water, heat, and air are easily available. Very few rhizomes grow deeper than 50 cm.

The annual extention of the rhizomes ranges from 0.30 to 0.70 meters in small bamboos and about 4- 6meters in large culm bamboos such as *Phyllostachys bambusoides* (Madake). Their length varies according to species and habitat. The growth period is shorter in areas of high latitud and high elevations than in low latitudes and low elevations. The same is the case on shaded slopes compared to sunny slopes.

According to Takenouchi (1932), in special conditions, the rhizome top goes out of the earth or soil and some continue to grow upwards to become bamboo shoots. Some, however, enter the earth again after stretching a bit on earth, forming the socalled *"jumping rhizome"* like a bow. Jumping rhizomes tend to appear where the upper layer of forest soil is hardened and impervious. The same author points out that when the rhizome is injured or cut off, the nearest bud behind the injured part develops into a new rhizome, which continues to grow in the same direction of the parent rhizome.

The longevity of the rhizome also varies with the specie of bamboo. According to Takenouchi (1932), the rhizome of *Pleioblastus simoni* (Madake) and *Phyllostachys nigra henonis* (Hachicu) continue to function actively to the third year, after which they gradually decline in vigor and from about the fifth year they slowly go into decay and die in the seventh or eighth year. In *P. edulis* (Mosochicu) the period of highest activity of the rhizome is from the third to the sixth year. In the eighth or ninth year decay sets in, and kills it in the twelfth or thirteenth year (Takenouchi 1939, Wen et all. 1981. ;Xiao 1991).

Direction which the leptomorph rhizome takes when it starts its growth

The following information was found in the Chinese book "Treatise on Husbandry" *(Chi min yaoshu)*, written by Chia Suniu in the 5th century: *"Owing to the nature of the bamboo it has a tendency to spread its rhizome growth in a southwesterly direction. Therefore they are usually planted in the northeastern part of the garden or grove. After several years they will spread in their growth until the culms fill the whole garden. There is a tradidition that if the bamboos are planted on the western side of the house their roots will spread, covering the ground until they reach a neighbor's house on* the west."

Taking into account that China is located in the northern hemisphere, I think that it is very important to experiment this interesting theory south of the Ecuador, (in the southern hemisphere), in order to see if there is any change in the direction the rhizome takes when it starts its growing process.

b).-PACHYMORPH RHIZOME

This type of rhizome is also known as *clump type*, sympodial, caespitose and determinate. It is typical of tropical zones of the Americas, Asia, Africa and Oceania. It can not withstand freezing temperatures. Bamboos with this type of rhizome are represented in the Americas by genus *Guadua*, and in tropical Asia by the genera *Dendrocalamus* and *Bambusa*.

The morfology and growing process of pachymorph rhizomes is different from that of the leptomorph rhizomes and has the following characteristics: The culm-base does not exist in the subterranean part of the culm and the aerial culm is generated directly by the rhizome, which, in this case could be considered as the culm-base.

The rhizome is solid, with roots on the lower side, the shape is usually more or less curved, and the internodes are broader than long. The maximum thickness of this rhizome is somewhat greater than that of the culm that generates. The lateral buds of the rhizome are dome-shaped and generate only rhizomes. The rhizome is narrow at the neck where it is attached to the mother rhizome, and thick and broad at the other end whose apex protudes out of the ground and grows into a new culm shoot which generates the culm. In the following year a new rhizome grows, which is is generated by the meristematic zone of one of the lateral buds of the mother bamboo.

The bud protrudes forming first the new rhizome neck, and then the shoot of the rhizome itself, which is covered with sheaths. In the rhizome, the sheaths have the function of protecting the tender apical meristem by forming a sharp-pointed resistant shield around it to protect it when the rhizome is pushed through the soil by the elongation of the rhizome internodes during its growing process. Once developed, (in two or three months, depending on the species),the new rhizome turns its distal end or apical meristem turns upward and forms the culm shoot.

In the tropics new culm shoots or sprouts begin to appear after the beginning of the rainy season. They protrude from the ground as scaly cones covered with sheaths. In warm regions with precipitation at frequent intervals throughout the year, the growth is often more or less continuous.Once the culm-shoot is formed, the apical meristem stops its function and the intercalary meristems located between the nodes start the growing process of each one of the internodes starting from the lowest one.

In pachymorph species, the distance between the culms depends on the length of the rhizome neck and on the position of the rhizome. When the rhizome neck is short, and the position of the rhizome is almost vertical, densely caespitose clumps of bamboo are formed, as in the genera *Bambusa (Bambusa vulgaris)*, *Dendrocalamus* and some species of genus *Guadua* such as "Guadua brasilera", which is cultivated in Costa Rica .Fig 1.6 B. When the neck of the rhizome is long and the rhizome has an almost horizontal position, as in genera *Melocana, Fargesia*, and *Guadua angustifolia*, the culms grow separatelly and open clumps are formed. According to Arbelaez (1996) the minimum and maximum separation beetwen the mother bamboo and the new culm shoot in a clump of *Guadua angustifolia* was 0.85 to 1.70 meters. In Asia there are species of *Melocanna*

Fig. 1.5 *Rhizomes of Guadua angustifolia in which the length of the neck, the separation of the culms, and the short necks developed by the rhizomes for providing a colective foot to support the heavy culms can be seen.*

(pachymorph) in which the culms are separated by more than 3 meters.In some species the neck and the rhizome grows almost vertically and looks like part of the culm (Fig. 1.6).

In general, the pachymorph rhizome system is superficial and does not penetrate more than 0.60 meters below ground level. The longevity of the pachymorph rhizome varies with the specie of bamboo.

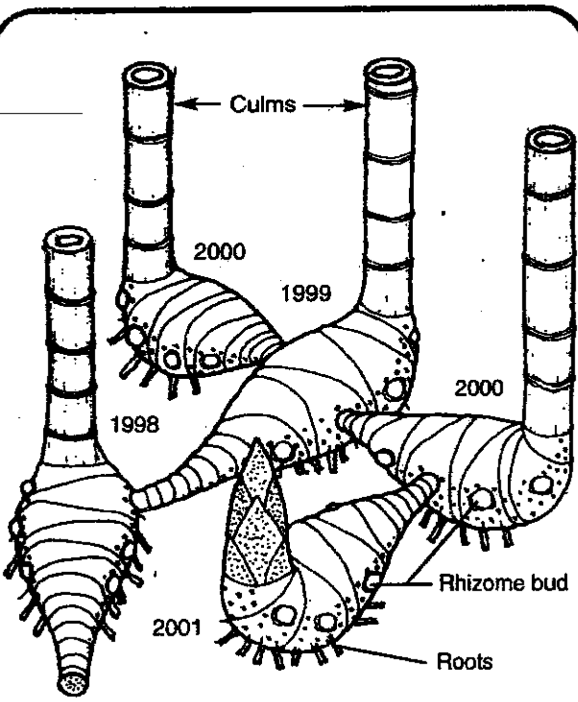


Fig.1.4 *Rhizome system of pachymorph type of tropical areas. In this case, the rhizome bud only generates new rhizomes with their respective culms.*

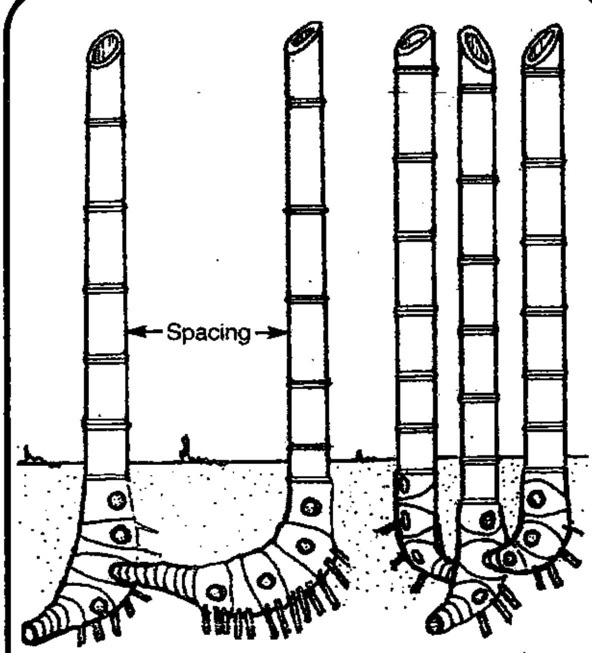


Fig.1.6 *The spacing between culms depends on the length of the rhizome necks and the vertical orientation of the rhizome, as in the case of G.brasilera.*

According to Deogun (1936), the rizhome of *Dendrocalamus strictus* show signs of deterioration in their fifth year, so one would not expect new culms from rhizomes of culms five years or more in age.

According to Bahadur (1979), the rhizome of *Dendrocalamus hamiltonii* with slight trimming and dressing is an exact replica of a rhinoceros horn which fetches a fabulous price as an aphrodisiac. Perhaps only an expert can identified the imitation rhino horn from the real one. The nefarious use, however, needs to be discoraged. Be careful!

C.-METAMORPH RHIZOME

Known also as amphipodial, the metamorph rhizome includes those species which have the capacity to produce both typical pachymorph and typical leptomorph rhizomes in the same plant. In America this is a characteristic of *Chusquea fendleri (Fig. 1.7)* and others species of this American genus. In Asia, according to Tian (1989), *Bashania fargesii*, from China, produces shoots in spring, summer and autumn, but 98.9% of its total shoot output is produced in spring.

The peak period of shooting comes when the soil temperature at the depth of 10 cm underground reaches 10° to 12°C. The formation and emergence of shoots are closely related to the altitud. With every rise of 200 m in elevation, shooting begings by 13 - 15 days later.

Both the rhizome bud and culmbase lateral bud of this bamboo come up into shoots due to its amphipodial rhizome system. This results in the mixed distribution of shoot in the stands. The shoots developed from culmbase side buds are more and better than those from rhizome buds. The rhizome system keeps its shooting power for more than 15 years, while the side buds only 5- 6 years. The buds of 4 - 5 years old rhizome is most productive. The shoots attained their full height in 90 days.

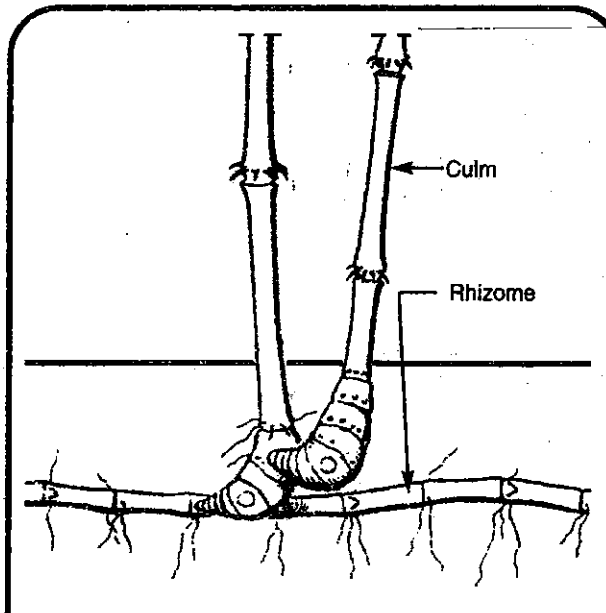


Fig. 1.7 *Metamorph rhizome of Chusquea fendleri. This kind of rhizome can produce leptomorph and paquimorph rhizomes in the same plant.*

2.-THE CULM

As mentioned above, in species with leptomorph rhizome, the culm consist of two parts: the aerial part or culm proper and the subterranean part of the culm known as *culm base* with its root system, which is conected to the rhizome by the *culm neck*.

In species with pachymorph rhizome, the culm base with roots does not exist and the aerial part of the culm is conected directly to the rhizome, which in this case could be considered as a culm base.

Formation and growing of the culm base and culm shoot in species with leptomorph rhizomes

In species with leptomorph rhizomes the culm is generated from one of the apical meristems located in one of the buds of the rhizome, which protrudes and forms the culm neck and then it swells until it becomes a long shoot or sprout, thicker than the rhizome and covered with sheaths, which looks like two cones joined by their bases (See Figure 1.9). Compressed in the short lower inverted cone,this shoot includes 13 to 16 nodes, which once developed form the culm base. The upper cone, which is longer, than the lower one, corresponds to the culm shoot, which once elongated becomes the culm(See Figure 1.8).

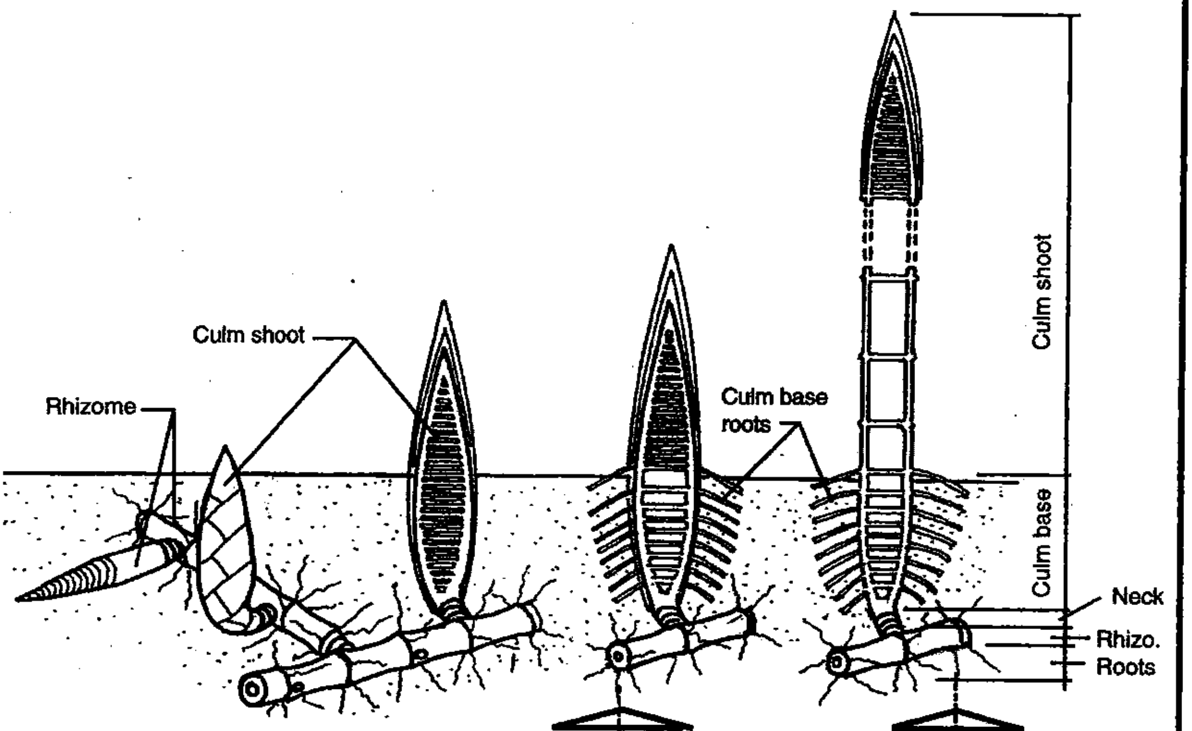
An interesting feature of this long shoot, is that all the nodes of the culm base, and the nodes of the culm shoot that once elongated will become the whole culm, (the aerial culm and the culm base) are compressed into it. In other words, most of the nodes of the culm lie flat one on the top of the other like a pile of plates, with the pith betwen them larger and thicker on the bottom, and tapering off to the smaller and thinner at the top near the growing point or apical meristem.

Once the apical meristem have finished the formation of the whole culm shoot, it stops its function and the intercalary meristems located between the nodes of the culmbase, start the construction or elongation of their internodes The elongation of the internodes of the culm base is very short because its function is to rise the maximum diameter or base of the culm shoot (which separate the culm proper from the culmbase) up to the ground level. Once the growing proccess of the culm base has been completed, and the base of the *culm shoot* is already located at the ground level, starts its growing process.

Growing process of the culm shoot in species with leptomorph and pachymorph rhyzomes.

The growing process of the culm shoot or aerial culm, is the same for species with leptomorph and pachymorph rhizomes, but is different of that of tree trunks. Unlike trees the bamboo culm does not grow in diameter and the growing process of the culm is carried out by two kinds of meristems known as *apical meristem* and *intercalar meristems*. The *apical meristem* is in charge of the formation of the rhizome shoot, culm base and culm shoot, and branch shoots. The *intercalar meristems* located between the nodes, are in charge of the growing of each of these parts which have been formed by the apical meristems, including the growing

Fig.1.8 FORMATION AND GROWING PROCESS OF THE CULM BASE AND CULM SHOOT IN LEPTOMORPH BAMBOOS



of the walls of each one of the internodes of the culm shoot starting from the lowest.

Once the formation process of the culm shoot is completed by the apical meristem, it stops its function and the growing process or growing of the internodes of the culm shoot continues. Thus each internode has its growing zone or *intercalary meristem*, between the nodes and consequently each internode grows separately, starting from the basal internode The culm elongates joint by joint until it reaches its maximum height. The culm shoot ceases growing only when the last internodal growth is completed. It can be confirmed that the growth of each internode is completed when the culm sheaths peel off slightly from their base or sheath scar.

Sprout emergence of tropical bamboos is commonly at the onset of the rainy season and in temperate bamboos it is in spring. Nevertheless, it can vary according to the species, the vigour of the mother bamboo, and the environmental condition of the site Even in one bamboo grove, however there are variations of 50 to 60 days between early and late sprouting.

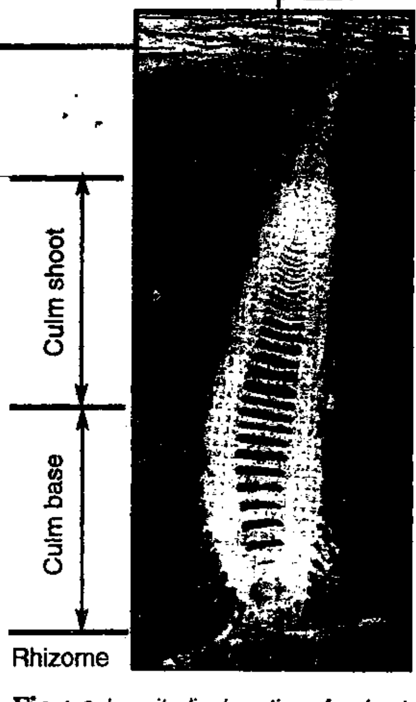


Fig.1.9 *Longitudinal section of a shoot or sprout of Phyllostachys pubescens (Ph. edulis) showing most of the internodes of the culmbase and culm shoot compressed, and the rhizome in the lowerpart. (Young 1961).*

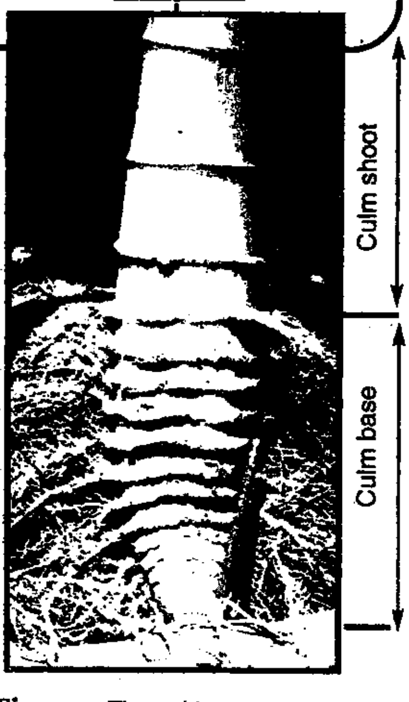
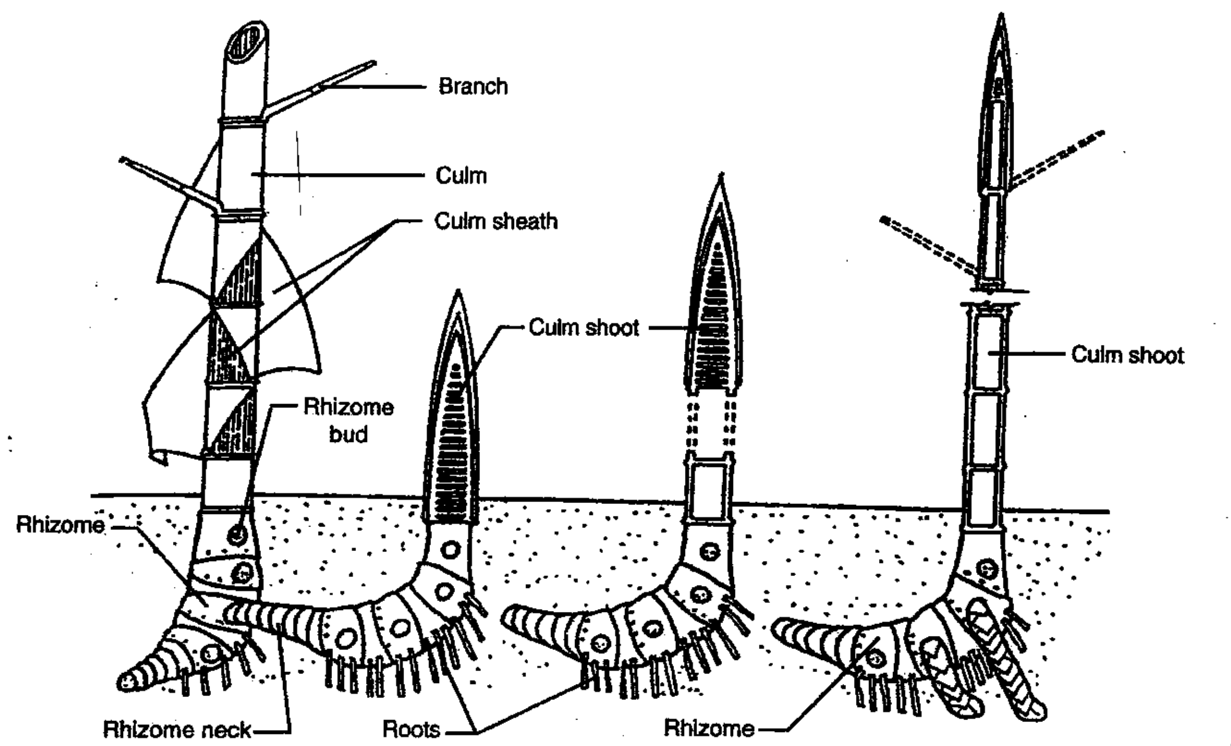


Fig.1.10 *The subterranean part of the plant which includes the rhizome, the neck, the culm base, and part of the culm or aerial part. The front roots of the culm base have been removed in order to show the internodes of the culm base. (See bamboo carving).*

Fig. 1.11 GROWING PROCESS OF THE CULM SHOOT IN PACHY MORPH BAMBOOS



The growing period is longer for early sprouts and shorter for the late sprouts. Early sprouts tend to develope into larger culms with superior quality, while late sprouts develop into smaller culms with inferior quality. When the precipitation is low the number of sprouts decreases. (Ueda 1960, Lu et al 1989).

In Northern India *Bambusa arundinacea* and *Dendrocalaus strictus* send up their new culm shoots in June or July when the south west monsoon rains begins, but in South India the new culms shoots appear in September or October with the northeast monsoon rains.

According to Kurz (1875) in some provinces of India there is the belief that a thunderstorm is necesary before the bamboo can shoot. Perhaps this is due to the coincidence of the rainy season and storms. This is confirmed by Wang (1993) who says that the Chinese specie *Phyllostachys praecox* ,sprouts when thunder occurs in early spring so it is called *Ph. praecox*, which means"thunder shoot".

When the culm shoot of giant bamboos appears on the ground covered with sheaths and it has a height of about 30 to 40 cms, the culm base has reached its maximum diameter, and thereafter this will never increase. The culm shoot starts growing by elongation of the internodes, starting at the lowest internode. At first they grow slowly, then very fast and finally very slowly again until they complete their full growth. In species of pachymorph type the whole growth takes about 80 days, and in giant species such as *Guadua angustifolia*.up to 180 days. In species of the leptomorph type, it takes 30 days for the small species and up to 130 days (4-5 months) for the giant species Then it develops the branches and leaves and becomes a mother bamboo before completing the first year.

If the apex of the growing culm shoot is cut off, the elongation of the remaining portion does not stop. This shows that when the intercalar meristems are activated, the apical meristem is deactivated. Once the full growth of the last internode is completed the height ~~of the culm do not~~ encrease any more. At this point, the growing process of the lateral branches of the culm which are generated from the meristematic zone located in the culm buds (axillary meristems) starts.

The branch shoot emerge from the buds located on alternate sides of the culm just above the sheath scar at successive nodes, and they elongate in the same way as the culm. Once the full growth of the last internode is completed, development of the leaves starts.

Daily growth of the culm-shoot

According to several studies, the daily growth correlates positively with temperature and negatively with humidity. In most of species of leptomorph type such as those of genus *Phyllostachys* which sprouts in the spring in Japan, the elongation of the culm sprout occurs more during the day than during the night. However, the pachymorph bamboos in tropical regions are the opposite. For example, *Dendrocalamus strictus* grows twice as much during the night as during the day, and there are species such as *Bambusa oldhami* which grows three times more during the night than during the day.

Jin (1989) reported that in the southern region of jiang, China, the total growth of *Bambusa oldhami* lasted 171 days

(65 days for underground growth and 106 days for above-ground growth). The total growth in this time (or accumulative growth) was 712 cm and the mean daily growth was 6.71 cm.

According to the updated records mentioned by Ueda (1960, 1981) the greatest growth rates of a bamboo culm shoot per day (24 hours) are the following:

a) **91.3** cms by *Bambusa arundinacea* observed at Kew Garden in England in 1855.

b) **88** cm by *Phyllostachys edulis (Ph. pubescens)* which K. Shibata observed at Koishikawa Botanical Garden in Tokio in 1898.

c) **119** cm by Moso-chiku, *Phyllostachys edulis* (diameter of 16 cm), observed on May 24, 1956 by Koichiro Ueda in Nagaoka, Kyoto Prefecture, Japan.

d) **121** cm by Madake, *Phyllostachys reticulata* (12 cm in diameter) which is the maximum record of daily elongation (24 hours). It was measured by Koichiro Ueda on the outskirts of Kioto on June 23, 1955.

In Colombia, the maximum elongation observed in *Guadua angustifolia* has been 30 cm in 24 hours. I have observed only elongations of 11 to 15 cm. (Hidalgo 1978).

CHARACTERISTICS OF THE CULM

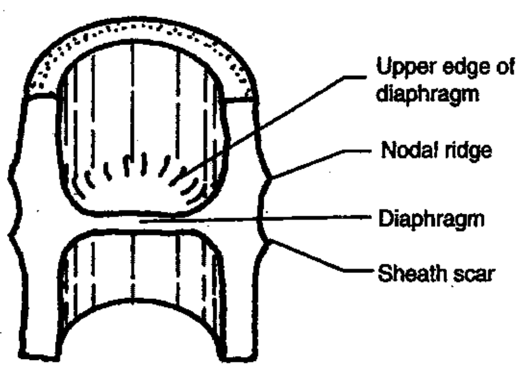
Once the culm shoot has finished the elongation of the last internode it becomes a culm. The culm or stem of bamboos consists of a regular alternation of nodes and internodes, generally hollow, which together with the hard, thick and cylindrical wall gives the culm great mechanical strength.

The nodes are important centers of morphogenetic activity and intercalary growth. Roots and branches emerge only at the nodes and in many species they may be swollen. The culm node consists of sheath scar, the supra-nodal ridge, the diaphragm and the intranode. In most species culm buds emerge from the midle part upwards on alternate sides of the culm just above the sheath scar at successive nodes, but in *Guadua angustifolia* culm buds emerge from the lower to the top part of the culm

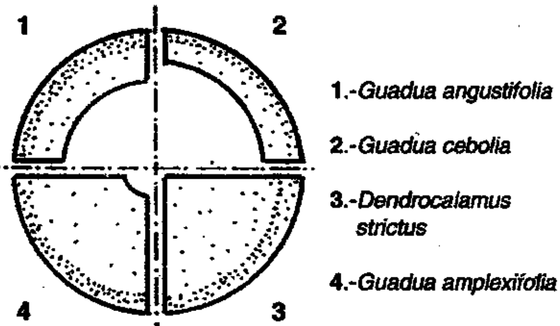
According to Yulong & Liese (1996) The intranode (between the nodal ridge and the sheath scar) can vary in length between 3-10 mm. The nodadl region of bamboos revealed that the anatomical structures are basically similar between pachymorph and leptomorph species. Most of the bamboos have distinct nodes, which differ in shape among the species. Some pachymorph species develop dense air roots around the nodal ridge at the bottom part of the culm. The form of the diaphragm can vary along one culm. It may be plane or its central part formed upwards or downwards or it may even be folded. Furthermore, the nodal structure is important for the liquid movement during drying and preservation as well as for the physical and mechanical properties of the culm.

The internodes are delimited by a sheath scar, which marks in the exterior surface the insertion of the culm sheath or culm leaf to the culm. The internodes are shorter on the bottom and top of the culm and are generally longer at the middle part of the culm. For example in *Guadua angustifolia* the average lengths are : 12-24 cm. (bottom), 40 cm. (middle) and 30 cm (top). There are species such as *Pleioblastus longinternodios* in which the length of the internodes varies between 70 -94 cms. (Yang 1989). In some species the internodes of the base are very long as in *Dendrochloa distans* (tamyinwa) of southern Burma, which may reach a length of 1.80 meters.

Fig. 1.12 - Nodal and internodal morphology



A. Nodal Morphology (Liese, 1998)



B. Morphology of internodal bamboo sections

Culms of the same clump and with the same high do not have the same number of internodes In Colombia, I have found in two culms of *Guadua angustifolia* with lengths of 17,13 m and 17,36 m., 80 and 76 internodes respectively, and in two culms of 18.40 and 19 meters, 82 and 78 internodes respectively. This means that there is no relationship between the height of the culm and the number of internodes. Some of the internode characteristics are the surface texture, the combination and pattern of colors, and the type of pubescense. The internodes are usually glabrous and smooth or rough and hairy, becoming glabrous at maturity. When young they are covered with a waxy coating on top. A characteristic of many bamboos is the appearance of a white exudate on the surface of the culm internodes.

Color of the culms.

Not all the bamboo culms are green, some are green with yellow stripes such as *Guadua angustifolia* var. bicolor, which is the most beautiful specie of the Americas. Other culms are yellow or yellow with green stripes such as *Phyllostachys viridis sulphurea* and *Bambusa vulgaris* var. *vittata*. It is important to point out that the yellow and green colors of this specie were chosen for the Brazilian flag. There are species that are black like *Phyllostachys* *nigra*, or black with yellow stripes like "guadua rayada amarilla" (still not identified) of Colombia. Also, there are small white and red species.

According to Tai Kai-chi (265-306 A.D.), in China there were red and white giant species such as the *Kuei chu* (cassia bamboo), whose culms were red and the largest one had a circunference of "two chi" (0.66 mts). The white specie known as Huang chu (Bushy bamboo), "has a skin as white as hoar frost". The white specie which was known as Pai lu chu, (white deer bamboo) has the characteristic that "in the hot summer season, the white skin and flesh both become red". This variety is found in Wuling (Changte).

Natural culm forms

Most of the bamboo species have round culms in section but there is also a specie which has natural square culms, and in ancient China there were also species with triangular culms. It is important to point out that the culm can be deformed artificially, transversally and longitudinally as we will see in other chapter. The following are some of the unusual bamboo forms:

1.-The natural square bamboo from China

According to Porterfield (1925), the first information about the square bamboo *Tetragonocalamus angulatus (Phyl-lostachys quadrangularis)*, appeared in a Japanese book "Mo Ku Kin Yo Siu "(Trees and shrubs with ornamental foliage) published in Kioto in 1829. It is said that this bamboo was introduced from China.

The earliest references to square bamboo (Fang chu) in Chinese literature, says that in the year 128 B.C. in Szechuan, walking-stiks or staves made from square bamboo of Chiung which never breaks were used. The Chinese atribute the squarness of this peculiar bamboo to supernatural powers.

The Ningpo Gazetteer say that a Ko Hsien (fairy) prepared some elixir of life which he drank and ascended the mountain called Ling feng in Ting hai, where he planted some chopsticks which grew and developed into bamboo with square form. (Kuang-chi, 1640).

This bamboo grows from 3 to 10 meters high. The squareness is not so evident in smaller and less mature culms as it is in the older and specially the larger culms. This specie is valued chiefly as an ornamental garden plant. It was first discovered in the form of staves being used by Buddhist monks and village elders. The smaller and less squarish culms were used for opium pipes, and the still smaller ones for tobacco pipes. (See How to make square bamboo).

2-Internodes with the shape of bottles

These are found in the species: *Dendrocalamus latiflorus Munro* var. *lagenarius* Lin. and *Bambusa ventricosa* McClure. This is one of the most beautiful bamboos.

3.-Triangular. In the book *Kuan Chun Fang Pu*, published in China in 1707, there is a description of an ancient Chinese bamboo known as *San leng chu* (Triangular bamboo). *The culms of this variety had three angles.*

4.-Flat culms. In the same book the *Pien chu* (Flat bamboo) is also mentioned. According to Sun pu this variety was grown in large numbers in the Kuang lu shan, a mountain between Hsing-tzu and Chiu-chiang distiricts in Kiangsi). The culm and the nodes are flat and very long. It is said that this variety has been flattened into this form by the Buddist God. Probably this specie is the same square bamboo or a similar variety.

Freak culms

There are several bamboo species that suffer a typical deformation during their growing proccess. These deformations are known as freeks and make them valuable pieces used for decorative purposes. The most important variations are the following:

1).-Turtle shell bamboo.-In Chinese this deformation is referred to as Loo Hann because of its strangeness and rarity and it is regarded as a vehicle of divinity. In Japan it is known as Kikko-Chiku. It is considered by botanist as *Phyllostachys pubescens* var. *heterocycla* form subconvexa.

2).-Budda's face Bamboo. This is known in Japan as Butsumen-Chicu . It is an unusual form of *Phyllostachys pubescens. (Ph. edulis)* For many people the form of turtle shell and budda's face bamboos are not clearly distinguished.

In both cases, the internodes of the lower part of the culms of this two forms are greatly reduced in length and are arranged obliquely in a zigzag fashion. In Budda's face the oblique arrangement of the nodes is such that each node almost form right angles with the nodes immediatelly above and below it.

3).-Spiral bamboo or "aobadake". *Pleioblastus gramineus* f. *monstrispiralis* (Rasetsu chiku) . This specie has rhizome metamorph (anphypodial), culms 2-4 meters height and a diameters of 1-4 centimeters. The culms that shoot out with leptomorph branching are normal types, and many of the ones with pachymorph branching are abnormal. The long spiral culms are used for decoration. (Okamurka 1986).

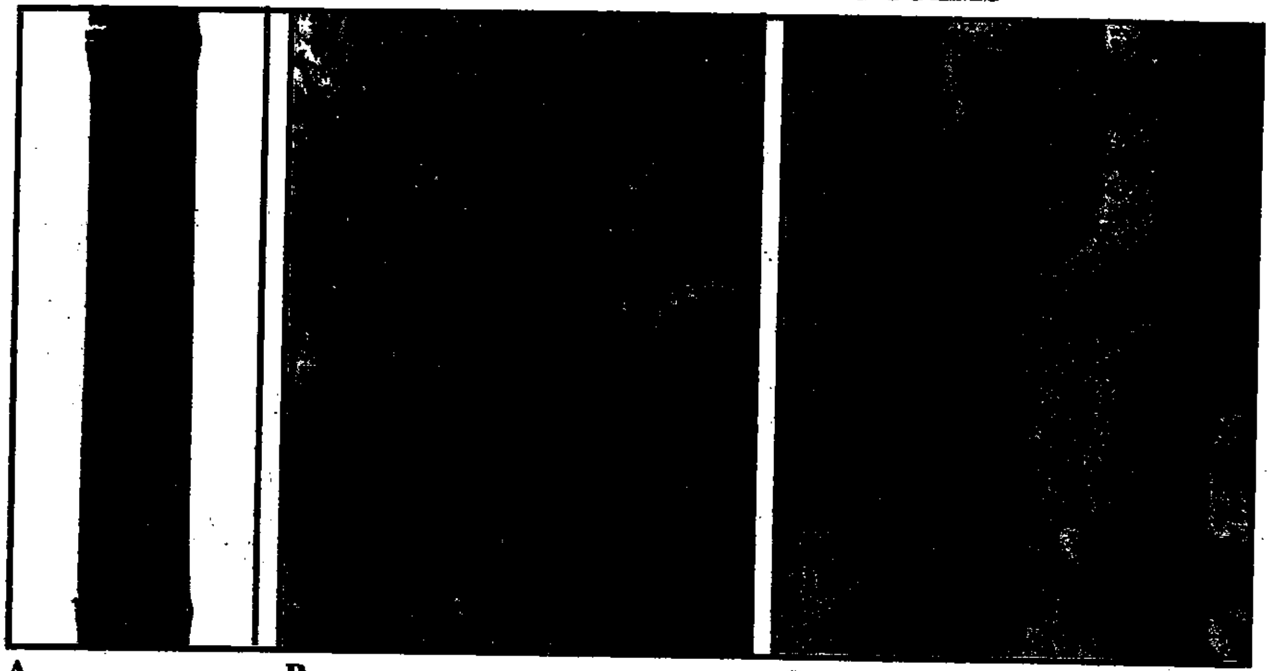
Abnormality of the internodes

According to Zang and Ma (1991), plant species reproduced via asexual means are genetically stable, yet due to their heterozygote nature, some variations and mutations might occur during the process of asexual reproduction, under certain specific conditions. Mean while , due to the extensive existence of changeable genes, some individual become the chimaera of mutated and unmutated genes.

It is ~~not~~ unusual for vegetative plants and their progeny to produce diversifications, variations and mutations. *Ph. edulis var. heterocycla* which has a very high ornamental value is a specie resulting from a virus infection of normal *Ph. edulis* which causes abnormality of the culm's internode.

Due to the fact that this mutation occurs only under certain specific conditions, reverse mutation might occur when the specific conditions disappear. Other examples include *Bambusa vulgaris cv. wamin, Bambusa ventricosa cv. nana*, and *Phyllostachys aurea* which have swollen and inclined internode at the base of the culm.

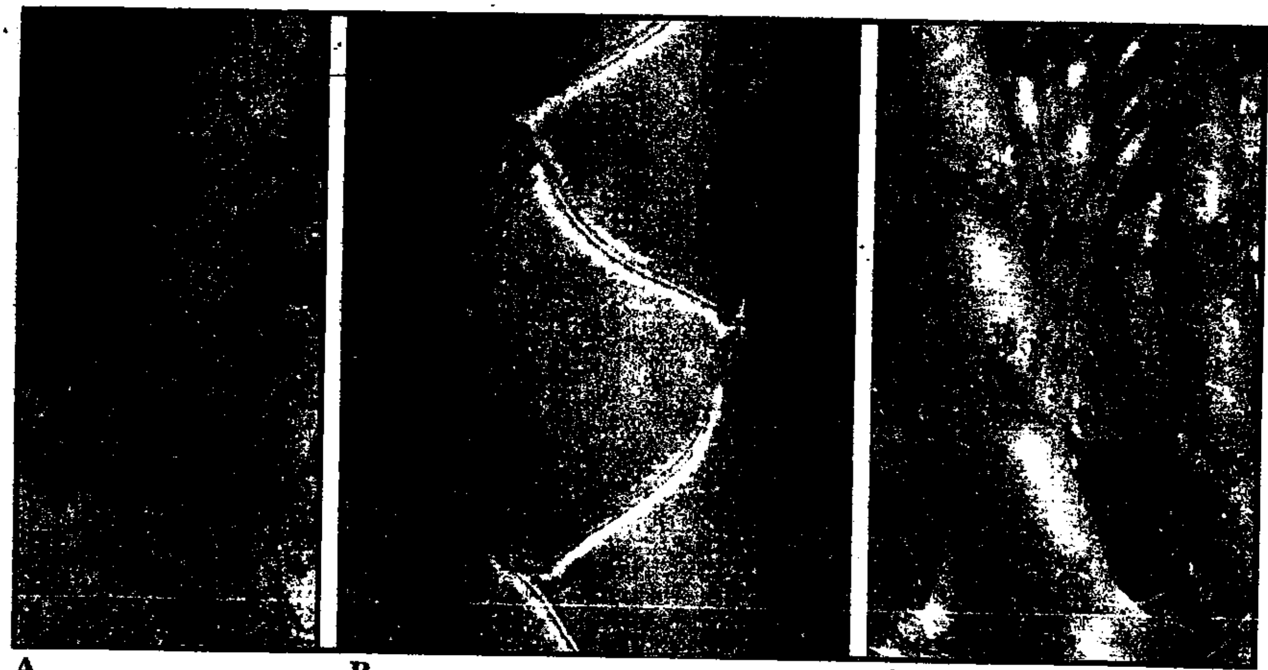
Fig.1.13 NATURAL SHAPES OF BAMBOO CULMS



A B C

A. -*Natural square bamboo* (*Tetragonocalamus angulatus*)
B.- *Dendrocalamus latiflorus Munro var. lagenarius* Lin.
C.- *Bambusa ventricosa*

Fig. 1.14 FREAK CULMS

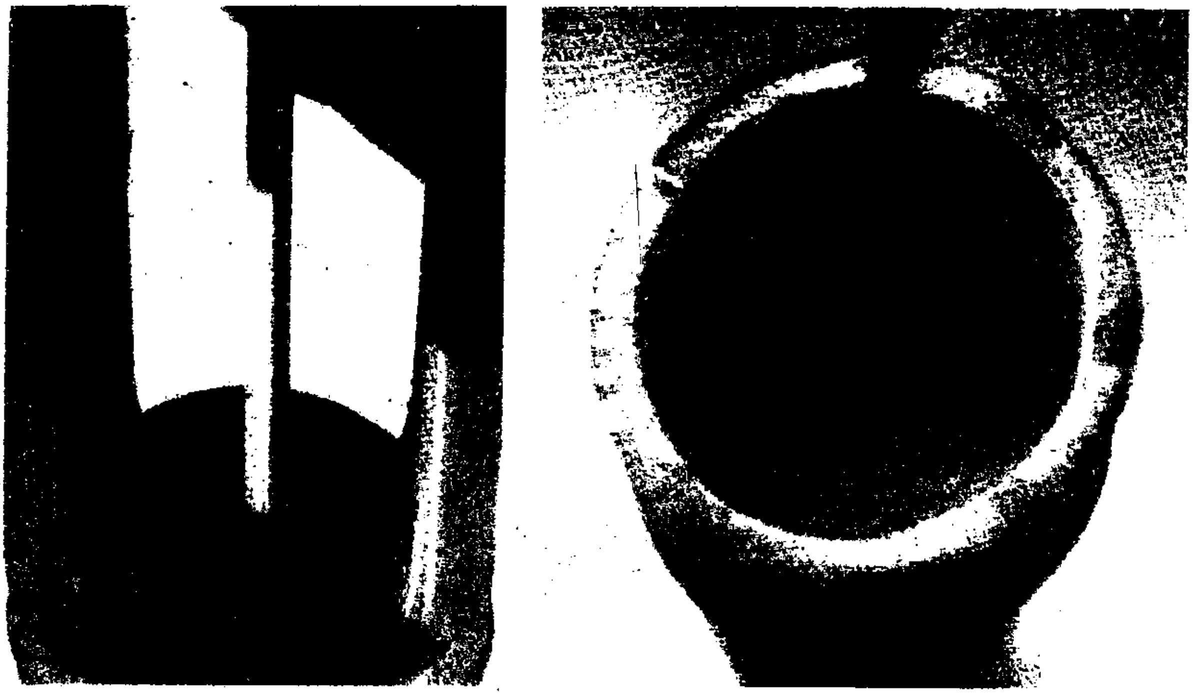


A B C

A The turtle shell (*Phyllostachys pubescens var. heterocycla form subconvexa)*.
B -Budda's face bamboo *(Phyllostachys pubescens)*.

C*-Spiral bamboo (Pleioblastus gramineus f. monstrispiralis) (Rasetsu).*

Fig 1.15 **ABNORMALITY IN CULMS OF *Guadua angustifolia***



On the Cotove farm belonging to the Nacional University in the State of Antioquia, near the city of Santa Fe de Antioquia, there is a small plantation (0.33 hectares) of Guadua angustifolia According to Anacilia Arbelaez, in the central part of the internodes, most of the culms have like a wooden rod with an average diameter of about 5 mm which connects several diaphragms along the culm's length, but in some internodes the rod disappear.

However, these characteristics are some time stable and some time unstable in their progenies. The segregation of the progenies often makes producers very uncertain. This is caused by the instability of the genetic factors, or the environmental conditions which play a leading role in the occurence of such diversifications which need convincing test data to be proven.

Therefore, no one is able to take the iniciative in production. In addition there are changeable genes in the vegetative plants which produce chimeras. This can be seen in the chimeras of various colors on the culms, branches and leaves of many bamboo species such as *Phyllostachys bambusoides f. tanakae* Makino, *Ph. glauca f. youzhu* Lu which have spots or strips of various colors on the culms, or on the culms, branches and leaves. Human beings often make use of these variations to breed new bamboo species of various ornamental values.

Many species of the genera *Phyllostachys, Bambusa*, etc. have many varieties or mutans which possess strips of various colors . For example the normal color of the culms, branches and leaves of *Ph. edulis* are green. *Ph. edulis f. luteosulcata* is a specie of gene mutation which has regular yellow strips on the concave site of the internodes. *Ph. edulis f. nabeshimana* has yellow and green strips on culms, branches and leaves. *Ph. aureosulcata, Ph. bambusoides, Ph. praecox, Ph. vivax, Bambusa glaucescens, B. vulgaris*,all have similar variations.

MATHEMATICAL RELATIONSHIPS OF THE CULM

Bamboo is the only plant which have a mathematical relationship between the circumference and the internode and the circumference and the length of the culm, which permits not only the identification of the species but also the determination of the culm height.

1.-Identification of bamboo species by mathematical relationship.

Dickason (1941) developed an interesting theory related to the identification of the species using as diagnosis the mathematical relationship which exists between the circunference or culm girth "C" taken at a height of 1.35 meters (4.5 feet) above the ground, and the length of the internode "L" located at this elevation (1.35 meters).

He gives the following relations C/L taken in some species: *Bambusa waming* Br. 1.4; *Dendrocalaus giganteus* Mun. 1.2; *Thyrsostachys siamensis* Gam. 0.94; *Bambusa vulgaris* Schrad. 0.92; *Bambusa vulgaris* var. *striata* Riv. 0.90; *Dendrocalamus membranaceus* Mun. 0.70. *Meloccanna bambusoides* Trin. 0.44; *Cephalostachyum pergracile* Mun.. 0.35 ; *Melocanna humilis Kurz* 0.17.

He sugested this height (1.35 mts)above the ground as a matter of convenience: it is easy to reach, it is usually not covered by persistent overlapping sheathes, does not require the cutting of the culm.

2.-Approximate mathematical determination of the culm's height

There is a mathematical relation between the culm height and the girth or circumference of the culm taken at the eye level, as is traditional in Japan; but it can be taken at the breast level (the difference between the girth at breast level and that at eye level is very small).

Most buyers of bamboo culms in Japan, multiply the culm girth at eye level by a constant = 60 to obtain the culm length, or they multiply the diameter by "pi" (3.1416) and then by 60. This procedure is applicable to the culms over 7 cm. in diameter. In Japan thi method has used as means to judging the quality of the culms. If the culm is longer or the same length as that determinated mathematically, the culm is of very hihgt quality. If it is smaller then it is very low quality and consequently has a lower cost.

The constant varies according to the species. In Colombia I cut about 60 culms of *Guadua angustifolia* for my experiments. With Prof. Jorge Escobar we took all the measurements of each culm in order to find the "constant" that we had to use in order to calculate approximately the height of a culm in this specie, and the result was 58.2.

For example, if the girth at breast level is 0.40 mts. the aproximately height of the culm will be 0.40 x 58.2 = 23.28 m. Using the diameter instead of the girth, the height will be: diameter x 3.1416 x 58.2.

Approximate dimensions of some giant bamboos of genus *Guadua* at the time of Columbus' arrival in the Americas in 1502.

Using on the above mathematical relation which allows us to determine approximately the height of the culms of giant species of *Genus ~~Guadua~~* using the ~~girth~~ or circumference of the culm, it is possible to calculate approximately the height of the giant culms of genus *Guadua*, which there were in the Americas at the arrival of Colubus, five hundred years ago. For this purpose we can take in account the information which exist about the dimensions of their circumferences at that time.

For example: in 1526, Oviedo, a Spanish historian, wrote in ancient Spanish, about the circunferences of bamboo species in Ecuador: *"But among all types of bamboo, there are some that are extremely large and the internodes are as big as a heavy man's thigh, and they are three palms or more in circumference"* (Patiño 1975). - The "palm" is an old Spanish measurement = 23 cm=9 inches. If the largest bamboo in Ecuador (*Guadua angustifolia*) had a circumference of 3 palms "or more." this means that the minimun circumference was of 3 palms = 0.69 m, which corresponds to a diameter of 0.22 m.Then the minimum high of this bamboo was 0.69 x 58.2 (constant) =40 meters. If we compare these dimensions with those that this specie has today: 0.10- 0.12 m in diameter by 18 to 21 m hight; this means that the dimensions of *Guadua angustifolia* have been reduced by 50% in almost 500 years.

In discussing to the dimensions of the internodes, Simon (1637) points out that *"The largest internodes have the capacity of one arroba of water"* The arroba is a Spanish liquid measure which is equal to 25 pounds= 11,500 gr.= 11,500 cm^3 of water capacity.

If the exterior diameter was 22 cms. the interior was about 18 cms.This means that the length of the internode was about 48-50 cms. Probably was taken of the center of the culm where are found the largest internodes.

Marco Polo said than on his trip to India in 1290, he saw very large bamboos with a diameter of 45 centimeters which were used as boats by the natives for going from one side to the other of the largest rivers.

Without doubt he was refering to the specie *Dendrocalamus giganteus*, the largest bamboo native to India. According to Prosea (1995), this bamboo today is 18-25 cms in diameter and 26- 30 meters height. This means that this specie also has reduced its dimensions by 50% in 710 years.

According to the above, the diameter and height of the bamboo culms in Asia and the Americas have been reduced little by little, probably due to continuous climatic changes in the world and to the destruction of the bamboo forests in the last 200 years.

The huge dimensions of giant bamboos in ancient China

Up until now I have been very sceptical about the information I had found in several ancient books from China about the extraordinary and incredible dimensions which some bamboos in that country had 3000 years ago. But keeping in mind the reduction of the dimensions of the culms of most of the giant species in the world, I think that this informations could be valid.

For example, according tothe book *Sheng iching* (*Records related to the marvelous things*) written by Tung Fang, who lived in the 2nd century B.C; in the southern wildernesses in China there was a bamboo known as *Ti chu* (Weeping bamboo) which grew to a height of several hundreds of chan (one chan= 10 feet=3,33 m; one Chinese foot or chi = 0.333 m). The circumferece of this bamboo was 3 chan and 6 chi; and the culm thickness was eight or nine "tsun". (tsun =one inch). Its shoots are delicious and if they are eaten they will cure ulcers

If the dimensions have not changed since ancient times and if there is no mistake in the dimensions given by Hagerty (1919) in his translation of this book, this bamboo had a circunference of three "chan" antd six "chi"=36 Chinese feets =12 m, which corresponds to a diameter of 3,80 m., and the thickness of the wall would be about 20-22 cm.

The book *Chu Pu* written by Tai Kai Chi (265-306) says that *"in Yuang-chiu a bamboo known as Tin Chun Chu grows. This bamboo is so large that a boat can be made from each one of their internodes "*, this is confirmed also by Kuo Po of Erh ya.

The Treatrise on Agriculture (*Nung Cheng Chuan Shu*) compiled by Hsu Kuang-chi and originally published in 1640 says that the *P'ei chu* (Giant bamboo) is found in the southwestern part of the Han-shan district in Anhui pro-ince. According to the *Tz'u yuang*, this variety measures one-hundred "chan" (= 333 m in height), has a circumference of three "chan" and five or six chi (about 35 chi = 11.65 m = 3,70 m in diameter. The thickness of the culm wall is eight or nine 'tsun'. Its lumber can be used for building boats. Its seeds have a good flavor and, if they are eaten they will cure ulcers or sores.

The same Treatrise on Agriculture (1640), says that the *Lung kung chu* (Dragon duke bamboo) is a large variety that has a diameter of seven "chi" (1 chi= 0.333 m x 7 = 2.33 m in diameter) and between each joint (internode) there is a space of one "chan" (ten Chinese feet) and two "chi" (12 chi =0.333 x 12 = 4 m). The leaves of this variety are like those of the Chiao (banana) which grows in the Lo fou shan (range of mountains in the Kuangtung province).

In the book *Tu Shu Chi Cheng* there is information about two varieties from the Fan yu hsien district which have the same characteristics as the above species, but with different names, the " Dragon duke bamboo" is known as "King of Yueh bamboo" (Yueh wang chu) which has a culm so thick that it requires about four or five people with joined hands to encircle it. This variety of bamboo produces shoots in the fourth and fifth months, the volume of which are the size of a "tou" (tou=100 liters).

The opposite in dimensions is the " *Lung sun chu* (Dragon's grandson bamboo) which grows in Chen-chou (locality in Hunan) usualy in the valleys and ravines. They are as fine and slender as a needle with a height that does not exceed 30 cm.

The influence of the culm age

The influence of the culm's age on its economic value is perhaps greater in bamboos than in any other timber. The age of the culm when cut has an important bearing on its use in the manufacture of industrial products and as material for construction.

Age is a very important factor for the development of certain strength properties. It is the general assumption that bamboo culms mature in about three years and have then reached their maximum strength.

According to Liese (1985), investigations with *Dendrocalamus strictus* have shown that in the green condition, older bamboo culms have higher strength properties than younger ones. According to my experiences with *Guadua angustifolia* the age of the culm increases only certain strength properties, such as compression strength and shearing stress, but in the case of tensil strength there is little difference between young bamboos one or two years with older ones.

In the experiments I did with bamboo strips taken from the external part of the culm wall, the maximum tensil strength was 3,217 kg/cm2 for culms 3.5 years old, and 3.206 kg/cm2 for culms one year and a half old. Probably this is the reason why the Chinese used bamboo strips one year old or less for the manufacture of bamboo cables which they use for the construction of suspension bridges with more than one hundred meters of span.

The durability of an individual culm varies according to the specie and the maximum is about 12 years at the end of which the culm dies and becomes dry and white.

According to my observations the strength of *Guadua angustifolia* starts decreasing in the grove when it is about 7 to 8 yeas old, consequently it is recommended that culms up to 6 years old be used in all the fields of construction.

Determination of the culm's age

Unlike trees, the diameter and height of a bamboo culm do not determine its age, but certain changes are generally recognizable as the culm becomes older. The only method for determining the age of bamboo culms accurately, is marking each culm shoot using an aluminum plate with a collar (nylon) located around the shoot with the year and date of its emergence.

In the second method, "visual factors" that are not very exact are used. In this method the one year old culms of many giant species of genus *Guadua* are easily recognizable by the emeral green color of the culm, and because they still have the lower sheaths partially fixed to the culm in its lower part.

The three years old culms can be recognized because the green color is not so dark and small white dots about 1-2 mm appear on the surface With the years these increase in diameter and become large lichens when the culms are 5 to 6 years old. One of the best methods consists in counting the leaf scars in the branches as is shown in the Fig. 1.16

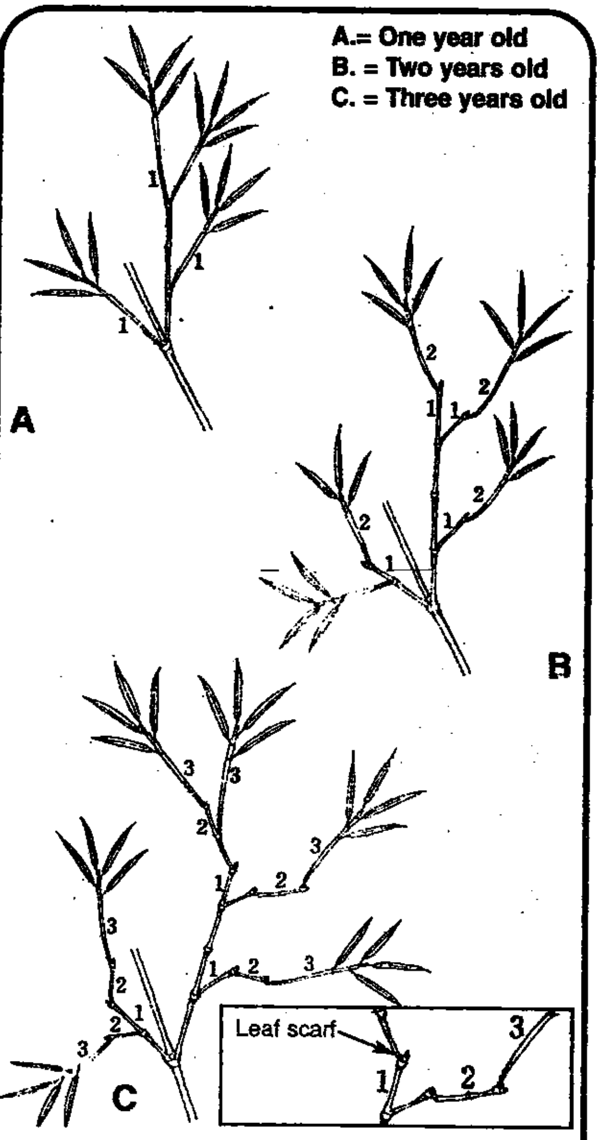


Fig. 1.16 *Determination of the culm age by number of leaves scarfs in the branches. The top branch (A)belongs to a bamboo one year old. The branches (B and C) belong to plants two and three years old respectively.*

CULM BRANCHES

Branchesare generated from the branch bud, or axillary meristem, which are arranged on alternate sides of the culm. Each internode bears a branch bud (primordium) located just above the culm leaf scar, and may be found from the lowermost node upwards as in *Guadua angustifolia*, or from the midculm node upwards. In some species branches develop while the culm is still growing, in others they develop only after the culm reaches its full height.

In some bamboos the branch bud is solitary. The branch system is often very characteristic of bamboo genus. If the apex of the culm is damaged, the dormant primary branch axis of each node will grow and elongate to replace the main culm. The array of branches may develop at a single culm node and is called a branch complement. In bamboos whose culms are branched, it is at the mid-culm nodes than the typical form of the branch complement appears.

The number of branches on each node of the mid-culms is important taxonomically and it differs with the genus. The branch complement appears most typically at the mid-culm nodes. The lowermost and uppermost branch complement are generally less well developed than those at the mid-culm nodes. In bamboo plants there is only one bud at each node in all genera.

About the branch primordium and its growth . In many bamboos the branch primordium ramifies precociously in the prophyll at the early stage. In *Sasa, Sasamorpha* and most *Sasaella*, the primordial branch axis possesses no basal buds and does not ramify, so the branch remains solitary. *Phyllostachys* typically ramifyes one time and is binary; the primary and secondary branches being unequal, some times a third much smaller one develops between the other two. The primary branch emerges, and remains strongly dominant. Subsequent orders of axes that develop from its basal buds gradually become smaller in size and shorter in length.

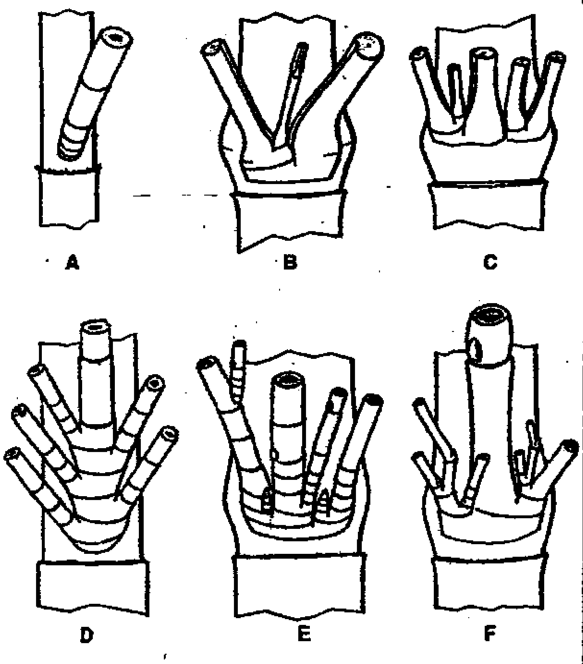


Fig.1.17 *Examples of diverse basal proliferation in the mid-culm branch complement in several genera: (A) Guadua angustifolia, (B) Phyllostachys dulcis, (C) Shi-bataea kuma-sasa, (D) Arundinaria tecta, (E) Arundinaria simonii, (F) Semiarundinaria fastuosa. McClure (1966).*

THE LEAVES

Probably the specie which have the largest leaves is *Neurolepis elata* from the Andes which may reach a length of 5 meters and a width of 0.50 m. While the smallest are those of *Arthrostylidium capillifolium* which are no wither than 3 mm.

According to Ueda (1987) , bamboo leaves fall off at one year after they appear and are renewd. Old leaves change into new leaves at the same time. Even the season and the way of renewal are different according to the species. The season for the species of large size bamboos is spring in general. This special ability for quick renewal is efficient for staying greeen and heightening the efficiency of photosynthesis.

That is because a bamboo ought to be strong in air polution. In general the small species also stay green by gradually changing old leaves for new ones as a unit of individual living bamboos.

In japan leaf change of new bamboos with pachymorph rhizome is finished in July. This is the period for vigorous growth of new leaves and is also the period for new rhizome growth. There is a close relationship between the leaf change and shoot sprouting. The number of sprouts is less in leaf changing year, but increases the next year.

Nonaka &Sasaki (1992), observed that in the damage of bamboo groves in Fukuoka, Japan, by a typhoon in 1991 leaves lost color and withered in a few days just after the typhoon but about ten days later new leaves appeared.

Uses.-Bamboo leaves are used for thatching houses and provide valuable fodder for cattle and for elephants in India. According to Kawase & Ujie (1987), in Japan, the leaves of miyakozasa, or tini *Sasa*, have been used as the feed for pastured horses since old times. Dried mature bamboo leaves are used for deodorising fish oils. At the same time, there has been the folklore belief that the extracts from the leaves are effective for the treatment of some cancers, and an infusion prepared from them has been drunk.

Since the cancer became a leading cause of mortallity in Japan, the medicinal effect of the extract from Sasa leaf (called Bamfolin) has been brought to the atention of the medical and farmaceutical fields. A lot of useful results are reported by the tests of animals receiving transplanted cancer cells. In relatively few clinical tests, Oshima treated 69 patients of seriously cancerous diseases with Bamfolin for over six months and reported that some curing effects were recognized by 10% of all patients, besides a promotion of appetite and an alleviation of pain. (See Pharmaceutical uses of leaves).

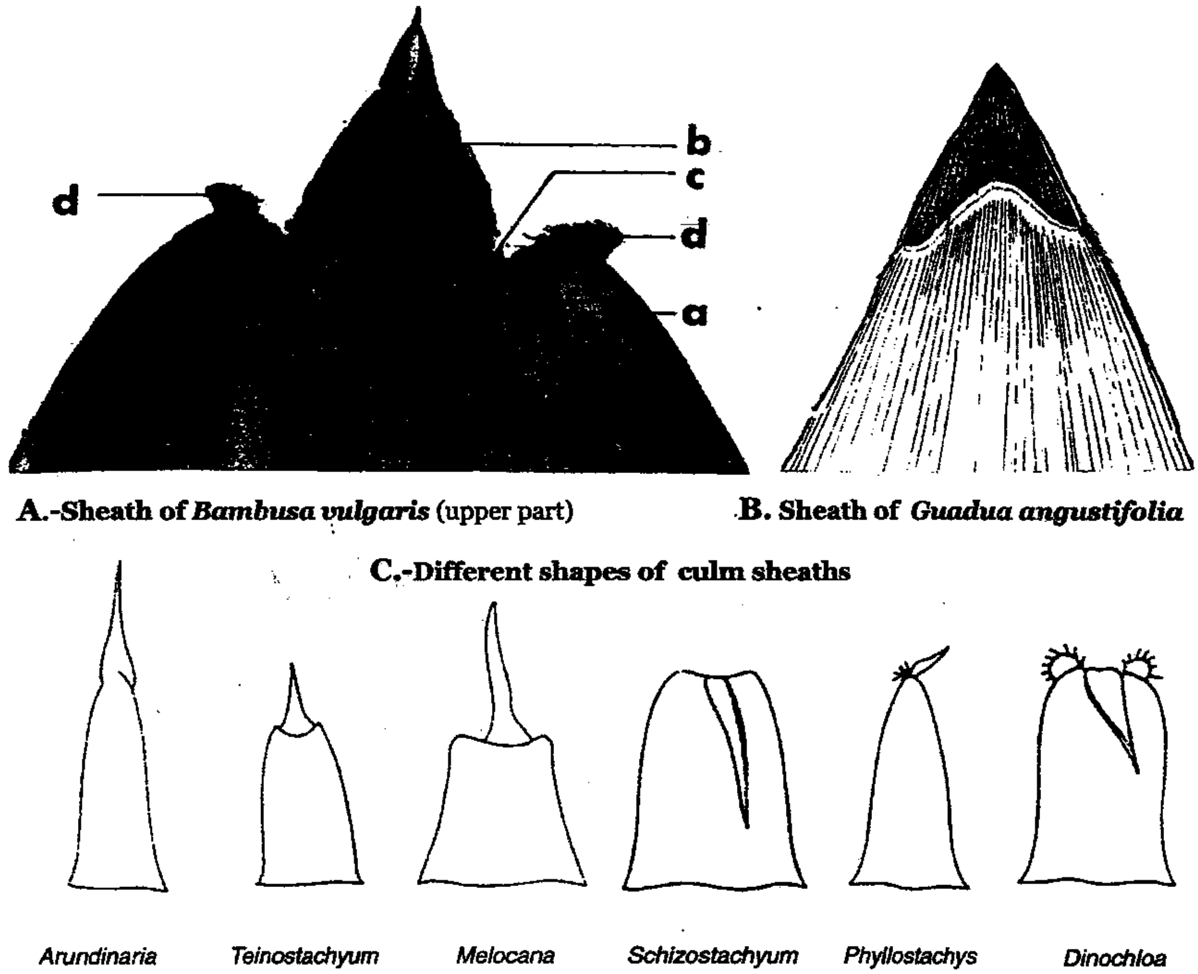


Fig. 1.18 Types of culm sheaths or culm leaves. *1.- Upper part of the sheath of Bambusa vulgaris showing one part of the structures that are important in classification and in identification of the different bamboo species: (a) Sheath proper, (b) Sheath blade, (c) Ligule, (d) Pair of auricles. 2.-Upper part of the sheath of Guadua angustifolia in which it can be seen that the triangular border is continuous around the sheath. 3.- Some different types of sheaths.*

Culm sheath (Culm leaf)

As was explained before, the growing of the bamboo culm takes place in the internodes. The upper part of each node consists of meristematic tissue, surrounded by the culm sheath, which has the function of protecting, supporting and stiffening the tender meristematic zone of the internodes of the culm and branches during their growing process. In the culm sheath there are many vascular bundles running longitudinally in almost parallel lines.

According to McClure (1966), when Chinese gardeners wish to dwarf a bamboo, they remove each culm sheath prematurely, beginning with the lowest, before the elongation taking place above its node is completed. Upon the removal of a sheath, the elongation above its node ceases.

The culm-sheath is an important structure for bamboo classification. The shape, size, thickness and hairiness of both the sheath proper and sheath blade and the existence of auricle or oral setae are invaluable for recognizing the genus or species. The inside face is smooth and shiny; when young the outside or the back is usually covered with irritant hairs which may be white, pale brown, golden brown or black. The sheath also varies in color and may be green, bluish or purplish-green, or yellow tinged with orange.

Culm sheaths generally shed the culm upon attaining maturity, but may also be persistent (*Sasa, Pleioblastus*), late desiduous (*Indocalamus Semiarundinaria, Fargesia* etc.) or early deciduous (*Bambusa, Phyllostachys, Dendrocalamus* etc.). In the external form, the sheaths of *Guadua* and *Chimonobambusa* are triangular, while those of *Dendrocalamus* and *Phyllostachys* are bell-shaped, and for *Schizostachyum* and *Lignania*,they are lanceolate. Sheath leaves of *Chimonobambusa* are short and small, and awl-shaped. (Keng and Wen, 1991).

Uses: Bamboo sheaths provide substitute material for lining hats and sandals, and used also for packing food.

ANATOMY OF THE BAMBOO CULM

The anatomical structure of the bamboo culm is the basis for understanding the physical and mechanical properties of the culm and its structural behavior.

As mentioned earlier, the bamboo culm is a tapered cylinder, generally hollow divided into segments or internodes separated by diaphragms (nodes) which, together with the hard, thick and cylindrical wall gives the culm great mechanical strength. While the culmss of most bamboos are hollow and erect, in others they are solid and either erect, scandent, or climbing and vinelike. Solid culms, known as "male bamboos" are found in the Americas in genera *Chusquea* , *Atractantha*.and *Otatea* from Mexico. In India are found in the specie *Dendrocalamus strictus.* According to Deogun (1936),this specie is solid when it grows on arid slopes, ridges and rocky soils, and hollow when it grows in the moisture valleys, and Sometimes some of the lowest internodes of a culm are solid but the rest of the culm is hollow.

Along the culm axis, the average internode length increases from the base to about the middle part, and then decreases to the top of the culm. In the internodes the cells are axially oriented whereas in the nodal diaphragm an intensive branching of the vessels provides transverse and radial conduction through the nodal diaphragm so that all parts of the culm are interwoven. Liese (1992).

The transversal section of an internode wall of a mature culm, shows the following typical anatomical structure:

1)- The epidermis, or outer most layer of the cortex. is formed by two epidermal cells layers with a high silica content which strenghtens the epidermal layer. The epidermal cells of the cortex are covered by a cutinized layer or glossy surface known as *cuticle* composed of cellulose and pectin with a wax coating on top. Beneath the epidermis lies the hipodermis, consisting of several layers of thick -walled sclerenchymatous cells (Liese, 1985).

2)-The inner layer of the culm wall in the interior or central cavity called *lacuna*, is composed of layers of parenchyma cells which are often thick and highly lignified and some times shows a suberized membrane which makes the chamber formed by the internodes impervious and airtigth. This thin membrane may be closely attached to the inner wall or loosely attached even in a one year old culms. This occurs in the first year in some species (*Phyllostachys viridiglaucescens, P. aurea*) and after three years in *P. heterocycla.*

According to Takenouchi (1939), In Japan, people used to call this membrane "bamboo paper". It is, of course, a dead and dry pith tissue, not a paper. This membrane was used in playing the Japanese flute by covering a finger hole with it to produce a characteristic sound.

The same author points out that the inner surface of the culm wall varies with the kind of bamboo. In some species like *Pseudosasa japonica* (Yadake) there are small scattered floccose particles resembling cotton which vary in form. They could be fairly large, arranged in cros-stripes or stepladder, while in others the surface is clean and smooth.

3)-The fibro-vascular area is located between the cortex and the inner layer of the culm. It consists of parenchyma cells as a ground tissue and vascular bundles composed of a conducting tissue (metaxylem vesells, sieve tubes with companion cells.) and fibres.According to Liese (1998), on an average, a culm consist of about 52% of parenchyma, 40% fibers and 8% of conducting tissue. These values vary with the species as can be see in Table 1-19

PARENCHYMA

The ground tissue of the fibrovascular area of the culm wall, consists of parenchyma cells which surrounds the vascular bundles. There are two types of parenchyma cells: vertically elongated cells (100 x 20 mm) and short cube-like ones interspersed between them. The vertically elongated parenchyma cells are characterized by thicker walls with a polylamellate structure. They already become lignified in the early stages of internodial development or shoot growth, but can still be alive in culms more than ten years old. The walls of the short parenchyma cells remain mostly non-lignified even in mature culms; these cells have denser cytoplasm and thinner walls and retain their cytoplasmatic activity for a long time. The function of these two different types of parenchyma cells is still unknown. (Parameswaran & Liese 1981.; Liese, 1995).

VASCULAR BUNDLES

When we cut the transverse section of a bamboo culm many brown dots can be observed in the wall. These dots at the out side and inside of the cross-section have different shapes. Each one of these dots is a vascular bundle. Enlarged photographs of the culm wall showing the vascular bundles can be seen in Fig. 1.19 and 1.20.

The gross anatomical structure of a transverse section of any culm internode is determined by the shape, size, arrangement and number of vascular bundles which are composed of both the mechanical tissue made up by *fibers,* and the *conducting tissue* which consists of two *metaxylem vessels, phloem,* a few *sieve tubes* with their *companion cells,* and *protoxylema,* which are the main arteries for the longitudinal movement of sap. The vessels transport water from the roots of the underground rhizome all the way to the upper leaves. The sieve tubes transport nutrient solution or assimilates from the leaves to the parenchyma cells in the rhizome and culm, and the protoxylem located between the two large metaxylem vessels, has the function of transporting water to the shoot in its early stages of growth. Because of the length of the bamboo culm the conducting tissue is reinforced by an outside mechanical tissue which embrace the conducting tissue and protect it when the culm is bent by the wind. The vascular bundles are surrounded by the parenchyma ground tissue.

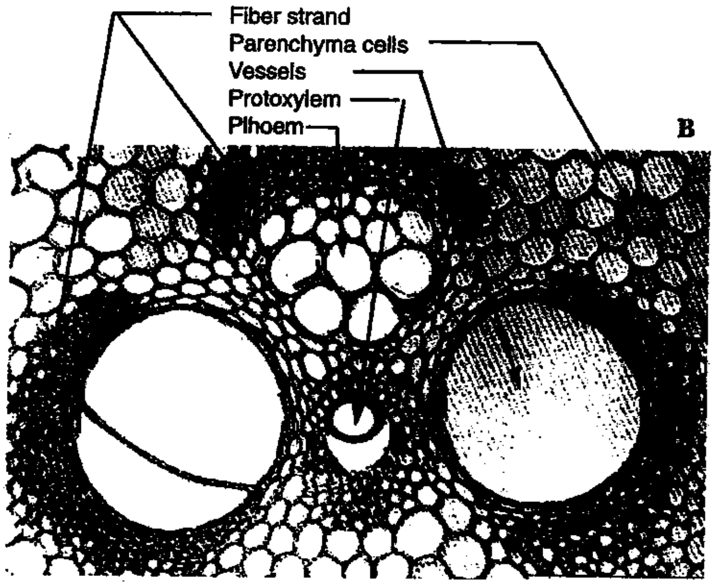
According to Taihui and Wenwei (1985) the parenchyma in the vascular bundles serves as a buffer zone contributing to the elasticity of the culms, without which the culms would be inflexible and brittle.

The thickness of culmwall decreases from base to the top due to the reducction of its inner portion containing more parenchyma and fewer vascular bundles.

Fig. 1.19 THE VASCULAR BUNDLES

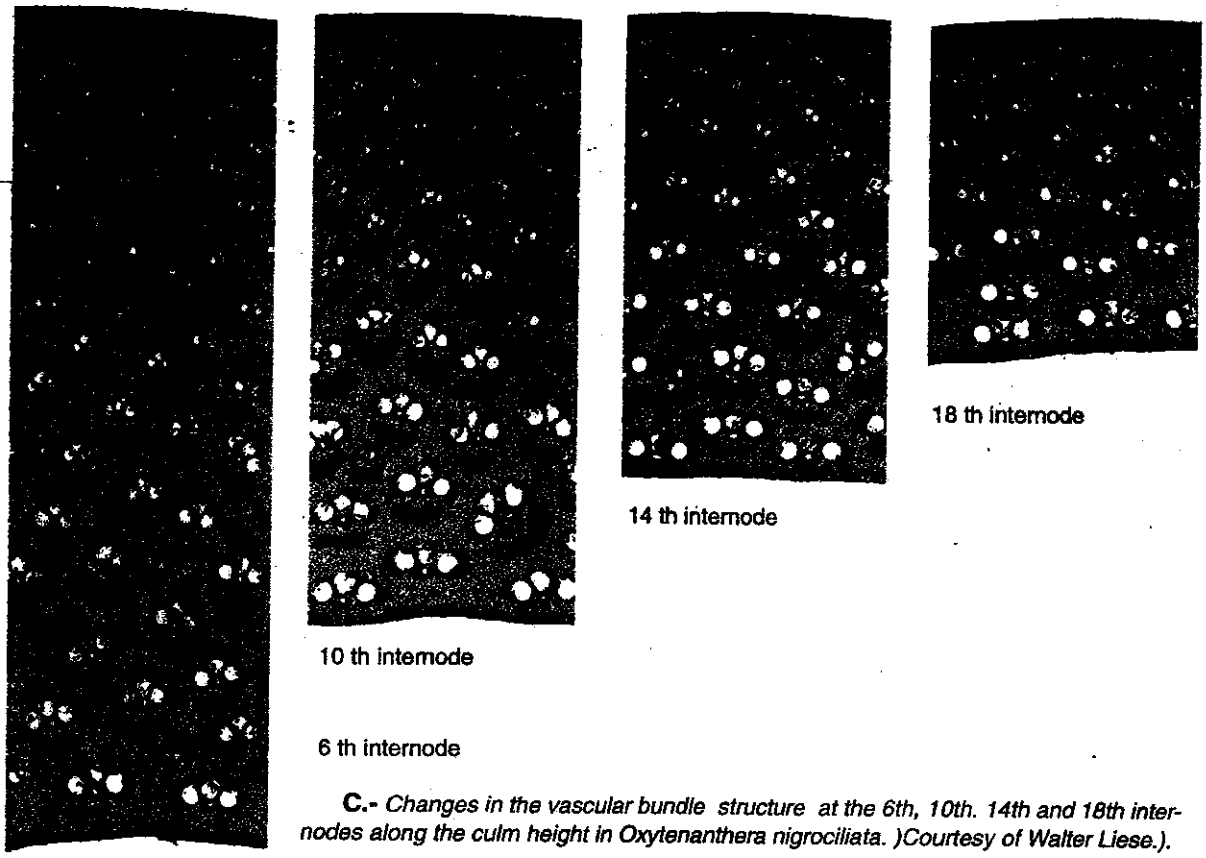
A

B



A- Three- dimensional view of a transversal section of a culm wall, showing part of the fibro-vascular area with several vascular bundles surrounded by parenchyma (courtesly of W. Liese). .

B *Vascular bundle with two large metaxylemvessels (4))and phloem (3) surrounded by fibers (1). (Courtesy of W. Liese).*



C.- *Changes in the vascular bundle structure at the 6th, 10th. 14th and 18th internodes along the culm height in Oxytenanthera nigrociliata.)Courtesy of Walter Liese.).*

The upper part of the culm with more vascular bundles and less parenchyma, has a higher specific gravity and therefore bending and compression strengths increase with height. Only the fibre length exhibits a slight decrease in the top part. Liese (1995). Liese Weiner (1996).

The total number of vascular bundles in the culm wall decreases from outer to inner parts and from the bottom to top. At the peripheral zone of the culm, the vascular bundles are smaller and numerous, at the inner part of the culm they are larger and fewer, and reach its maximum dimension at the innermost part of the culm wall.

The vascular bundles immediately below the cortex are circular in transverse section. Towards the midle of the culm wall, the vascular bundles become larger and more widely spaced. In most species, they exhibit their maximum size and characteristic form in the central part. In the inner culm part, the vascular bundles again became smaller. (Liese 1998). To characterize the two-dimesional variation of vascular bundles in different internodes within a culm, Grosser (1971) developed vascular bundles patterns or diagrams for several species in which bundle shape and frequency are given in horizontal rows for succesive internodes. Fig. 1.20.

The density of vascular bundles or number of vascular bundles ocurring in one square millimiter varies from the epidermal layer toward the pith peripheral layer and according to the species. In the study conducted in Taiwan by Wu & Wang (1976) on the density of vascular bundles, at the middle part of the culm wall, they found one vascular bundle by square millimeter in *Dendrocalamus latiflorus* and about 3-4 for *Phyllostachys pubescens* var. *pubescens*.

Wu & Hsieh (1991) found in *Dendrocalamus latiflorus* and *Phyllostachys pubescens* var. *pubescens* at the first millimeter inside the epidermal layer, there are significantly high densities of vascular bundles with 8-10 for the former and 7-8 for the the latter. The density decreases at the second milimeter, 2.5-3.5 for the former and 3.5-4.5 for the latter. Espiloy (1985) reported that the density of vascular bundle at the top of the culm is larger than that at the base. Along the axis of the culm of *Bambusa blumeana*, she found 3.80 for the top and 1.74 by square millimeter at the base.

The vessels. The diameter of vessels increases from the epidermal layer to the inner pith cavity of the culm wall. Wu & Hsien reported that in *Dendrocalamus latiflorus* the average diameter in the 6th, 14 th and 22th internodes are 18.8 µm, 15.0 µm and 15.2 µm respectively at the outer part of the culm wall. The average diameter increases to 164.6 µm , 151.4 µm and 132.0 µm at the middle part of the culm wall and increases further to 205.0 µm , 202.4 µm, and 176.4 µm at the inner part of the culm wall.

In *Phyllostachys pubescens* var. *pubescens* the variation of vessel diameter increases from the base to the top of the culm. Espiloy (1985) found that the average diameter of vessels of *Bambusa blumeana* is 186.3 µm at the base internode, decreases to 136.6 µm toward the middle part and increases to 173.6 µm at the top.

According to Liese (1998) The vessel area at the inner half of the culm generally amounts to double that at the outer half. The area and size of metaxilem vessels in transverse sectionare very important for determining the conductivity of water in the living plant, and also for the preservative treatment of fresh culms by the sap displacement method, since the vessel area is a decisive factor for calculate the treatment parameters.

A detailed analisis of the bundle types and their variations was undertaken by Grosser (1971) and Grosser and Liese (1971,1 973) for 52 species in 14 genera. They analyzed the variability of vascular bundles in form and size, and grouped them into four basic types. There are a considerably variability in the appearance in the vascular bundles within one culm, both across the culm wall and longitudinally along the culm for simpodial bamboos. Further investigations on other species have contributed additional information. (Liese 1998).

Fig. 1.20 Anatomical characterization of the vascular bundles of *Phyllostachys edulis* Riv. in six internodes *(Groser 1971; Lieese 1998)*

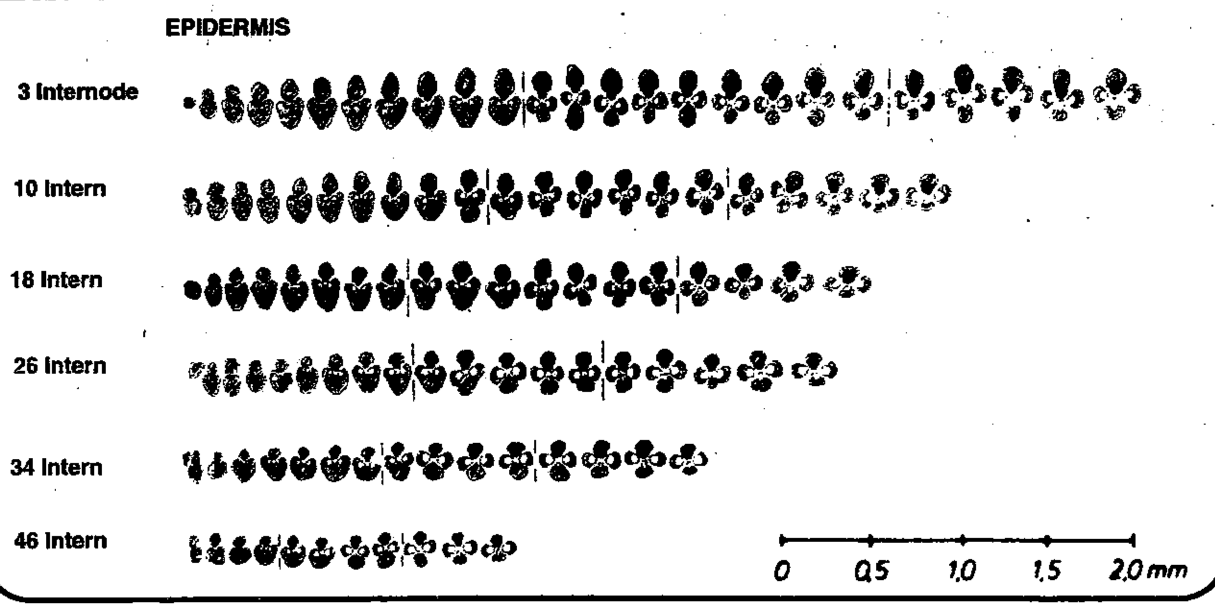
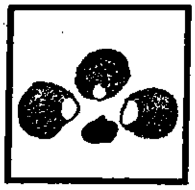
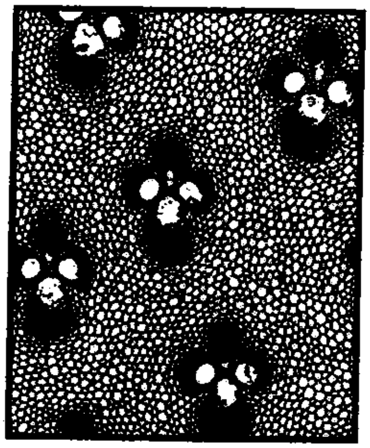


Fig. 1.21 TYPES OF VASCULAR BUNDLES



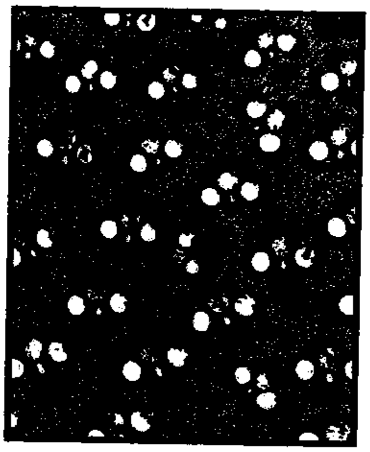
Type I



Vascular bundle Type I -(Open type)

This type onsists of one central vascular strand with supporting tissue only as sclerenchyma sheaths. The vascular bundles sheaths are of the same size and symmetrically located. Most of the bamboo species which possess this type of vascular bundle sheath are of monopodial and amphipodial types. Examples are the genera *Arundinaria, Phyllostachys, Pleioblastus, Shibataea, Bashania, Brachystachyum, Cephalostachyum, Chimonobambusa, Chimonocalamus, Neomicrocalamus, Pseudosasa, Indosasa, Qiongzhueea, Acidosasa, Oligostachyum*, and *Sinobambusa*.

Type III

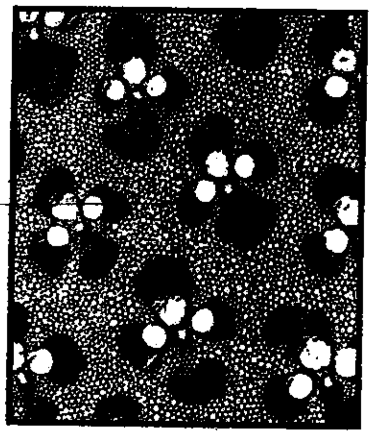


Vascular bundle type III (Broken waist)

This type consists of two parts, the central vascular strand with sclerenchyma sheaths and one isolated fiber bundle. The sheath of the inner vascular bundle between the cells (protoxylem) is usually smaller than the other vascular bundle sheaths. Bamboo species of this type all belong to pachymorph type (sympodial).

Examples are genera *Bambusa, Ampelocalamus, Dendrocalamopsis, Dendrocalamus, Melocalamus, Pseudostachyum, Gigantochloa*, as well as some species of *Schizostachyum*.

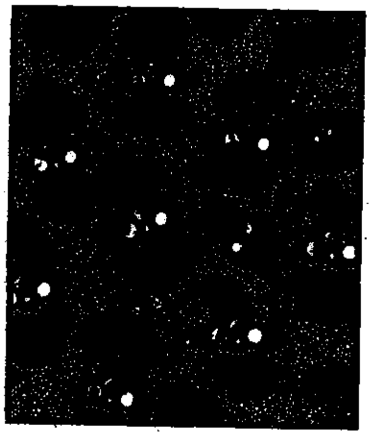
Type II



Vascular bundle Type II (Tight-waist)

This type consists of one central vascular strand with supporting tissue only as sclerenchyma sheaths. The sheath at the intercellular space (protoxylem) is strikingly larger than the other three and extends in a fan-like shape. Bamboo species which possess this type of vascular bundle are pachymorph type (sympodial). Examples are the genera *Schizostachyum, Melocana* as well as some individual species of *Cephallostachyum*.

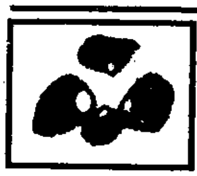
Type IV



Vascular bundle Type IV (Double-broken)

This type consists of three parts, the central vascular strand with small sclerenchyma sheaths and two isolated fibres bundles outside and inside the central strand. Bamboo species of this type are all pachymorph type (sympodial) and grow into dense clump.Examples are the genera *Thyrsostachys, Gigantochloa, Dinochloa, Dendrocalamopsis, Dendrocalamus* as well as some species of *Bambusa and Neosinocalamus*.

After Grosser and Liese (1971,1 973)



Type V.

-In 1992 Ya & Xu added the type V that they called Vascular bundle type V (semi-open) There is no fiber sheath, but the lateral and inner vascular bundle sheaths are linked together. Bamboo species of this type are the genera *Sasa, Sasamorpha, Yushania, Fargesia*, as well as some individual species of *Qiongzhuea and Indosasa*.

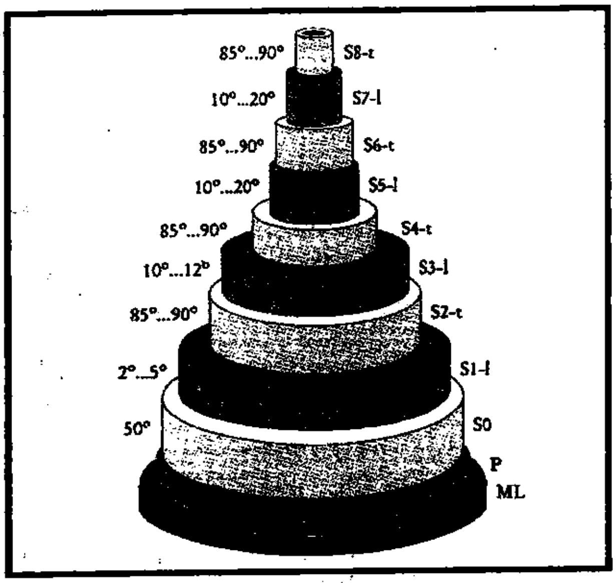


Fig. 1.22 *Model of polylamellate structure of thick-walled bamboo fiber Figures on the left indicate the fibril angle. (Courtesy of W. Liese. 1998).*

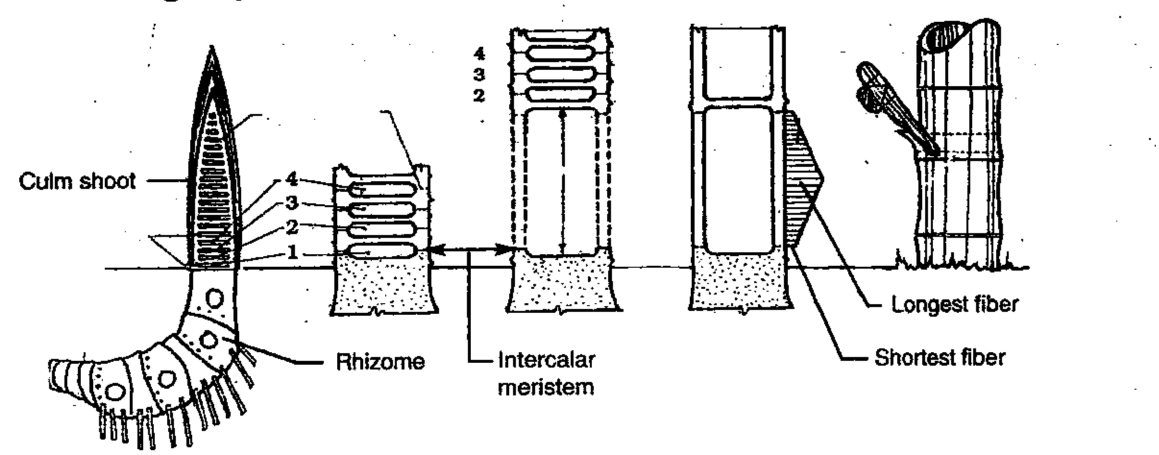
Fig.1.23 *Polylamellate structure of a parenchyma cell wall, Phyllostachys pubescens (Syn. Ph. edulis) 19/000 X. (Courtesiy of W.Liese. 1998).*

FIBERS

Fibers are the mechanical tissue and their function is essentially to impart strength to the culm. They constitute 40-50% of the total tissue. They occur in the internodes at the vascular bundles as fiber caps (sclerenquima sheaths) surrounding the conducting elements and in some species additionally found as isolated strands. At the periphery of the culm near the epidermis, there are generally one or two layers of fibre strands closely arranged giving mechanical strength.

The ultrastructure of most of the fibers is characterized by thick, polylamellate secondary walls. This lamellation consists of alternating broad and narrow layers with differing fibrillar orientation. In the broad lamellae the fibrils are oriented at a small angle to the fibre axis, whereas the narrow ones mostly show a transverse orientation.(See Fig. 1.22) The narrow lamellae exhibit a higher lignin content than the broader ones. This polylamellate wall structure is present especially in fibres at the periphery of the culm and their significance for bending properties appears obvious. (Parameswaran & Liese 1981); Liese 1976, 1995, 1998).

Fig. 1.24 Relationship between the fiber lengths in the internode



The shortest fibers are always located near the nodes and the longest are to be found in the middle part of the internodes. This means that the strongest and weakest part of the internode are located respectively in the center and the nodes. This made possible that the the first civilizations could cut the bamboo with stone axes (See Homo erectus), cutting the culm It two cm above the node, where the intercalary meristem starts and the grow of the internode finishes.

Table 1-1 The average fiber dimensions of some bamboo species.

Specie	Length mm	Width µm
Arundinaria alpina	2.30	23.0
Bambusa arundinacea	1.73	22.0
B.longispiculata	2.31	13.5
B. multiplex	2.20	14.0
B. tulda	1.45	24.0
B. vulgaris	2.64	10.0
Dendrocalamus strictus	2.23	22.0
Guadua angustifolia	1.60	11.0
Oxytenanthera abyssinica	1.51	12.0
Phyllostachys bambusoides	2.15	15.0
P.edulis	1.56	13.0
P. nigra	1.04	10.0
P. reticulata	1.56	13.0
Pseudosasa japonica	1.34	18.0
Sinocalamus latiflorus	2.88	14.0
Thyrsostachys siamensis	1.81	10.0

Source: Liese and Grosser (1972) Liese (1998)

Fibers contribute 60-70% of the weight of the total culm tissue. They are long and tapered at their ends. The ratio of length to width varies between 150:1 and 250:1. The fiber length shows considerable variation both between species and withing individual species. Across the culm wall the fiber length often increases from the periphery towards the middle of the wall and decreases towards the inner part. In the inner zone fibres are 20-40 % shorter. A greater variation in fiber length exists longitudinally within one internode. The shortest fibres are allways near the nodes, the longest fibres are in the midle part of the internode. This variation could be within one internode of up to 100% or more.

According to Wu and Hsieh (1991),the fiber length at the lower node of the second internode above the ground of *Dendrocalamus latiflorus* is 1.52 mm and 1.40 mm for *Phyllostachys pubescens* var. *pubescens*. The upper node of the same internode are 1.385 mm and 1.25 mm.

In the middle part of the internode the maximum fibre length reaches 2.49 mm and 1.98 mm respectively. The variation showed that the shorter fibers occurred about 2-3 centimeters near the node.Vertically, the fiber length increased from the basal part to the middle and decreased at the top (3.17-3.27-2.78 mm).These means that the fibers in the middle part of culm are the longest, next are those in the lower part, and those on the top are the shortest.

Generally, the bamboo fibers are much longer than those from hardwoods, but shorter than those of softwoods. Their length increases from the periferal layer inwards to a maximum in the outer third of the culm wall and decreasing again towards the inner wall. Different values have been reported within the same species. This is mainly due to the considerable variation of fibre length within one culm.

According to Liese (1990)the fiber length-to-width ratio varies across the culm from 70:1 to 150:1 (which is considered as suitable for pulping). As fiber length is an important pulping property, any measurement has to consider the pattern of variation within the culm by taking representative samples. The fiber length positively and strongly correlated with fiber diameter, cell wall thickness and internode diameter.

The fiber diameter varies from 10 to 40 µm, the lumen diameter from 2 to 20 µm and the cell wall thickness from 4-10 µm.The Runkel ratio (2Xwall thickness: lumen diameter) ranges from 1 to 4.. These values are influenced by fibre maturation, which leads to an increase in wall thickness. Immature culms are some times investigated for their pulping quality. But their small fibers wall thickness gives a lower Runkel ratio that makes them unsuitable for pulping. Bamboo fibres have hight tearing resistance, but low tensil strength based on their slenderless ratio and flexibility coefficient (Widjaja and Risyand 1987; Latif 1995).

Ma (1993) reported that the fiber lengths in culms of 26 different species are: 1.33-2.22 mm, averaging 1.89 mm; the width of fibers are 10.8- 18.7 mm, averaging 15.1 mm. ~~The ratio of length and~~ width is 87-153, averaging 121. The ratio of fiber length and width of different parts is the same.

Certain species generally have shorter fibers, such as *Phyllostachys edulis* (1.5 mm), *Ph . pubescens* (1.3 mm.), other longer ones like *Dendrocalamus giganteous* (3.2 mm), *Oxytenanthera nigrocilliata* (3.6 mm.) *Dendrocala mus membranaceous* (4.3 mm) have longer ones.

Table 1-2 Percentage of cell types in bamboo species

Species	Parenchyma	Fibers	Conducting Tissue
Bambusa polymorpha	48	44	8
Bambusa tulda	47	45	8
Cephalostachyum pergracile	52	40	8
Dendrocalamus hamiltonii	51	41	8
Dendrocalamus strictus	50	43	7
Melocanna bambusoides	43	50	7
Oxitenanthera nigrociliata	51	43	6
Phyllostachys edulis	54	38	8
Phyllostachys machinoi	55	37	8
Schizostachyum brachycladum	54	38	8
Teinostachyum dullooa	52	40	8

Source: Liese (1998).

The fiber length influences density and strength properties and it is closely related to elastic bending stress. So far fiber length is hardly considered when selecting a bamboo species for a given purpose, except pulping, but from practical experience such relationships may already be utilized (Liese 1992).

The Tables 1-1 and 1-2 are very important for manufacturers of paper, composite materials and for builders because the length of the fiber influences the pulping properties and the strength of the culm. On the other hand the most strongest bamboos have height percentage of fibers and the lowest percentage of parenchyma.

BAMBOO FLOWERING

2

TYPES OF FLOWERINGS

The physiology of bamboo flowering is unique among flowering plants, since most species of bamboo flower periodically and some once during their life time and die soon afterwards. The factors which determine the life cycle of bamboos, the occurrence of gregarious or general flowering and subsequent death are still considered by scientist as a botanical enigma surrounded by some mysterius facts, such as the factors that switch a bamboo plant from a vegetative to a flowering state. There are two types of flowering among bamboos: The *sporadic* or *irregular flowering*, and the *gregarious* or *periodical flowering*.

1) Sporadic or irregular flowering

Most of the bamboo species flower sporadically or irregularly every year at any time, for several reasons, such as a fire in the area, or insect attack. In this case, one or several culms of any age of the same clump flower and die soon afterwards, but the entire clump does not die. Some sporadic flowering in one or several culms takes place every year in practically all bamboo areas.

If a new culm and its rizome spring from the rhizome of a flowering culm, this new culm generally produces flowers in the first year of its growth and then dies. With the death of a culm after flowering, the rhizome from which it arises also dies in most of the cases.

2).Gregarious flowering

This type of floweringtakes place at long intervals which are known as *life cycles* or *physiological life cicle*. This cycle is more or less constant for each specie of bamboo and it varies from 4 to 120 years, depending on the species. The longest cycle known in bamboos is that of 120 years in *Phyllostachys bambusoides* and *Phillostachys nigra henonis*, which are native to China and Japon. Of course no culm in a clump lives to be 120 years old. At most, a culm reaches an average of 12 years of age in the clump and then becomes dry and dies. The reason for this is that bamboo is a perennial plant, which means that the clump is a continuous plant that produces new culms (in giant species) every year. The life cycle starts when the bamboo seed germinates, and ends when the clumps formed by this seed flower gregariously many years later at the end of their life cycle. This means that the period between successive gregarious flowering of any bamboo species in the same area represents its life cycle or physiological life cycle.This cycle varies with different species and is more or less constan for a given specie and site. In the Table 2-1 are listed the lyfe cycles of some of the most important species from Asia and the Americas.

There are species such as *Bambusa vulgaris* the yellow Asiatic specie with green strips which are very common in our parks, and have never been observed to flower gregariously. There is information on its sporadic flowering in Central America and Brazil in a few culms that die after flowering. The flowers so produced are reported not to have seeds.

In contrast, there are some species that have a persistent tendency to flower, such as *Bambusa atra (B. lineata)* from Malaya. Also, there are species that flower annualy without dying, such as *Indocalamus wightianus* (Syn. *Arundinaria wightiana*) and *Ochlandra rheedii*, or the specie *Phylostachys heteroclada f. solida* that flowers twice a year in China.

When gregarios flowering occurs in any specie, all the culms of a clump, and all the clumps that belong to the same stock or have been raised from the same seed source, flower simultaneously all over the world, wherever this species grows naturally or has been cultivated or reproduced by tissue culture, and regardless of the geographic location, climatic conditions, soil differences or age of the clump.

According to Soderstrom (1979). it appears as if the plant had an internal physiological calendar that controls the length of the vegetative period. It seems like there is an alarm clock in each cell of the plant that rings once its vegetative period or physiological life cicle is over. At this moment and before its death, all its energy goes toward flower and seed production, and its vegetative growth ceases, as the bamboo sacrifices everything for the production of its off-spring.

When flowering take place, all the leaves of the culm are replaced by flowers and the flowering is completed within 2-3 months The flowering is so profuse that the whole culm, from top to bottom is transformed into a gigantic inflorescense. In some bamboo plants the flowers first appear on part of the branches or on one branch.

However, the flowers appear at upper and lower position on bamboo culm at the same time or they can appear on only one side of the culm while the other side is left bare. The sequence of flowering generally continues from upper to lower part of the bamboo, but in some species (*Dendrocalamus latiflorus*) the formation of the inflorescences begins at the lowest node and proceeds toward the tip. In most species, the plant then produces large quantities of seed and dies.

If all the culms of a clump flower, the entire clump dies. Nevertheless, there are species such as *Guadua angustifolia* which do not die after flowering gregariously, proba-bly because only part of the leaves of the culm are replaced by flowers as I could observe in the gregarious flowreing which took place in Colombia in 1976. Only the culms in which all the leaves were replaced by flowers died.

The ripe seed which have fallen to the ground germinates immediately or when the first rains come, thus starting a new life cycle. Soon after the fall of the ripe seed, and some times before, all the culms of the clumps that have flowered start dying from the top downwards and become weakened and easily bended and broken in his base by the wind, as can be seen in the Fig. 2.6.

Generally the young and old culms which have flowered die about one year after the seed has fallen and generally also the rhizome from which they arises. **Cutting down a clump in flower will not stop it from dying.**

In gregarious flowering, all the clumps do not flower in the same year; there is a main mast flowering year in which most of the clumps flower, while some clumps flower a year earlier, and some a year later. This is the reason why gregarious flowering may take three or more years. to complete. Gregarious flowering often progresses in a definite direction in succesive months involving one grove after another. This is the reason why there is little difference in time between the flowering of the mother clump and those generated from the mother clump that has been cultivated in different places of the world. For example, when the flowering of *Guadua angistifolia* took place in Colombia in 1976, it progressed from north to south, starting in the Antioquia State and then continue in the states of Caldas, Valle del Cauca, and Cauca respectively and aproximately one month later this specie was flowering in Ecuador.

In India where the largest extensions of natural bamoo plantations are found, after a gregarious flowering thousands of culms are found dry and they have to be removed before a fire starts. Because these culms have lost their strength, it is recommended that they dont be used as construction material. Nevertheless they could be used in the manufacture of pulp and paper and rayon. According to Sharma (1980), between 1960 and 1965, *Bambusa arundinacea* and *Dendrocalamus strictus* flowered gregariously. The dead bamboo clumps were all clear-felled and supplied to paper and rayon industries.

The flower

Bamboos, as member of the grass family, have a compound inflorescense consisting of many flowers or florets that are usally very small (2-15 mm long) .The flower structure consist of a lemma, a palea, 3-6 stamens, a pistil, three lodicules and an ovary with 1-3 stigmas. The whole structure is called a "spikelet" When flowering, the lemma and palea open, with extended stamens and stigma splits in three directions. After opening, the flowers last for about 2-3 hours, and then close. When the weather is dry, the flowers closes more quickly.

Bamboos generally flower between 5-9 o'clock in the morning and the flowers close at noon. Good flowers occur when the temperature is between 20° C and 25° C. High temperature would affect the quality of bamboo flowers. Pollen distribution usually begins one hour after flowering. Bamboo pollen loses its germination capacity very easily due to the influence of light, rain and air humidity. (Zhang G.C. & Chen 1991).

The fruit

The bamboo fruit varies greatly in size, shape, and other characteristics. and can be of the pear type, berry type, or caryopsis type which is the most common one. Most of them resemble grains of wheat, rye or other similar cereals and consist of a pericarp enclosing the seed. The seed itself consists of the endosperm and an embryo comprising a radicle, a plumule and a scutellum. In several genera of Asia and the Americas, the pericarp of the fruit is thick and fleshy.

The seeds may cover the ground as much as 12-15 cms depth. A 33 square meters clump of Indian *Dendrocalamus strictus* can produce 320 pounds. There are 800-1000 seeds of this specie to the ounce. By hand gathering and threshin, and adult can collect 4-6 pouns of *D. strictus* seed per day (Janzen 1976).

Problems caused by the gregarious flowering

In some parts of India , Burma and other countries of Asia, farmers believe that the flowering of the bamboo heralds times of famine. But on the other hand, in other areas of these countries the flowering of the bamboo is considered as a *God's blessing* since bamboo have flowered in times of drought and famine and their seeds had been used by poor people as a food which is prepared in the same way than rice.

In the first case, according to Parry (1931), in India in the Lushai Hills District, natives know that bamboos flower at regular intervals, seed and die. After the seeding millions of rats suddenly appear, invade the flowering area and devour the seed that the plants produce, and the grain in the graneries. Then they go on to ravage rice fields and consume everything edible. Having devoured all they can find, the rats die, presumably of starvation, and the native people have not food for several months.

The same author points out that in 1911-12, after the flowering of *Meloccana bambusoides* (which flowers every 50 years in the Lushai Hills), the Districtt was absolutely desvastated by millions of rats ~~which swept right through~~ it, devouring everything that lay in their path. The Government had to give out large sums in loans as the people were absolutely destitute.

Lackhers only recognize one famine, the *Maotam*, as they call it the Mawta. They say that the period between two Mawtas is about fifty years and that during the interval a bamboo called *rongal* in Lushai and *rangia* in Lackher (*Cephalostachyum capitatum*) flowers. The seed of this bamboo does not seem to induce a plague of rats and the period of its seeding is generally a period of very good crops

According to Janzen (1976), in Madagascar bamboo mast crops contributed to an ivasion of an estimated 40-60 million rats to nearby 10,000 ha of crops, which were destroyed before the rats starved to death.

On the other hand, in times of famine in some parts of India and other countries, bamboo flowering was considered as a God's blessing.

According to Munro (1868), in 1864, during a general flowering of the bamboo in the Soopa jungles in India, a very large number of people, estimated at 50,000, came from Dharwar and Belgaum districts to collect the seed. Each party remained about ten to fourteen days, taking away enough for their own consumption during the monsoon months, as well as some for sale.

The importance of the life cycles

As it was explained before the life cycle of a bamboo specie correspons to period between successive gregarious flowering of any bamboo species in the same area.

Trought informations found in ancient publications of China , India and Japan about gregarious flowering of several bamboo species which took place in these countries many year ago, was posible to find out the different dates of their gregarious flowering and consequently to establish their life cycles. Some of them are shown in the Table 2-1, For example: Janzen (1976) points out that in the year 919, the main- land Chinese bamboo *Phyllostachys bambusoides* seeded in mass. According to the records of Kauamura (1927) this specie flowered again in Japan sometime between 1716 and 1735 of the Kioho era, and again in 1844 and 1847 in the Kokwa era. The last gregarious flowering occured in 1960 in Japan and also in England, United States and Russia ,where stocks were transplanted from Japan.

Kawamura (1927) found the following records of gregarioous flowering of *Phyllostachys nigra var. henonis* (Hachiku) in Japan. They occured in the years: 813 - 931 - 1247 - 1666 - 1786 - 1848 - 1908. He concluded that the flowering of "Hachiku" has occurred at intervals of about 120 years (occasionally 60) years.

Numata et al (1927) reported the following historical records of the universal flowering and withering of the bamboo specie "hachiku" (*Phyllostachys nigra henonis*) in Japan, including the year and the bibliographical source.

Year 813 - Nihon-Kiryaku".
931 - FussoRyakki"
1247 - "Matsunoya-Hikki" (vol. 40)
1666 - "Honzo Bengi" (vol.4, 1681)
1786 - "Gokoku Muzinzo" (1787)
1848 -
1908 -

Taking into account the lack of complete chronological records such as the above, we may be justified in concluding that the flowering of "Hachiku", has ocurred at intervals of about 120 years (occasionally 60 years). The same author recognised that "Madake", *Phyllostachys reticullata*, also flowers every 120 years.

It is very important to know the life cycles of our most important and useful bamboo species, particularly when we are planning tho establish large bamboo plantations for the manufacture of pulp, paper and rayon, for the manufacture of bamboo composite materials or for the construction of houses and other purposes.

If we plant a bamboo specie on a large scale using asexual propagules or tissue culture taken from the same clump and we ignore the life cycle of this specie. It is posible that this specie is on the brink of flowereing, for example, it may be in flower two years later. When this occurs, all the small plants will flower and die and consequently we are going to lose a lot of money. In order to avoid this problem we have to take into account the following recommendations:

1). Choose the specie with the longest life cycle which is appropriate to the final purpose. For example, for the manufacture of pulp, paper, and rayon the most recommended is the specie *Bambusa vulgaris* due to the following reasons: a) The average length of their fibers is one of the longest (2.64 mm) among bamboo species. b) The most important is that this specie has not flowered gregariously up to the present time as was explained before. c) This specie is very easy for cultivate. d) It grows very fast, and e) Because the rhizomes of this specie are almost vertical the clums are very dense and consequently has more culms by square meter.

If for any reason is not posible to get this specie, two or three different species with the longest life cicles (30-50 years) should be culyivated, taking into account that the year of the flowering does not coincide.

2.-For the manufacture of composite bamboo materials, such as plybamboo and laminated beams etc. it is necessary to use straight culms with the largest diameters (larger than 10 cm) of the central part of the culm. For this purpose, *B. vulgaris* is not recommended because in most cases the culms are not straight. Instead, the use of *Guadua angustifolia*, guadua de castilla o guadua brasilera is recommended. The life cycle of the latter, is still unknown.

Is it possible to predict the gregarious flowering?

According to some authors the gregarious flowering of a bamboo specie could be predicted one year in advance by certain signs, such as the following:

a) According to Hosain (1962), normally only younger bamboos contain free water within their internodes. During the year of flowering of *Mellocana bambusoides* in East Pakista, however, all the culms, irrespective of age, were observed to contain free water within their hollow internodes. Furthermore, the amount of water contained in each culm was much greater than which is normally contained in a young culm. This appears to be nature's provision for the growth of the flowers and fruits, as before flowering the rhizome becomes incapable of maintaining the flow of water to the culm.

b) A decline in growth rate. c) A decrease in amount of bamboo sprouts. d) The early formation of bamboo shoots.

e) The bamboo clump does not produce any additional culms for a year prior to the gregarious flowering.

f) Frequently emerging short, slender culms were seen as undergrowth in the tall bamboo stands, at a time which does not always coincide with the ordinary season.

g) The formation of leaves which are smaller than usual or the appearance of amoeboid leaves and. h) Breakable bamboo wood.

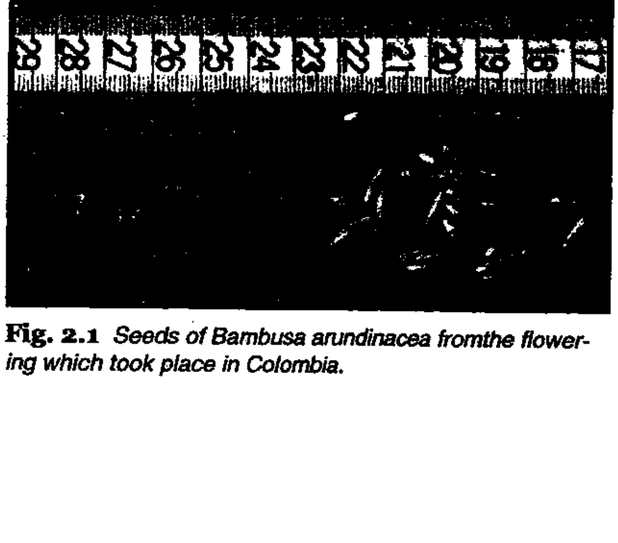


Fig. 2.1 *Seeds of Bambusa arundinacea fromthe flowering which took place in Colombia.*

Table 2-1 DATES OF GREGARIOUS FLOWERINGS AND LIFE CYCLES OF SOME SPECIES FROM ASIA AND THE AMERICAS

Species	Countries and years of flowering	Life Cycle (years)	Source
Arundinaria falcata	India (Simla and Jaunsar) - 1858 - 1886 - 1916	28-30	Blatter 1929
*Bambusa arundinacea**	1)- India (Dehra Dun) 1836 - 1881 -1926 -1970	45	Seifritz 1950- Blatt./29
(3 life cycles 1, 2, 3,)	2)- Brazil - 1804 - 1836 -1868 - 1899	30	Janzen 1976-Blatt. /29
	3) -India (Orisa)- 1881 - 1913 - 1976	30	Blatter 1929
	Puerto Rico 1945 - 1975 -Colombia Panama 1975	30- 32	Hidalgo/ 1981
*Bambusa bambos**	(India,China,Thailand and Indo-China) intervals16-32-45	16 (?)	PROSEA 1995
*Bambusa polimorpha **	Bangladesh, Thailandia	60	Blatter 1929, PROEA
*Bambusa tulda**	Burma, 1852 - 1913	25	Blatter 1929
Dendrocalam. glanteus	Burma, 1865 - 1892 - 1914 and India,	30-40	PROSEA 1995
Dendrocalamus strictus	Buma , India	20	Gupta 1952
(6 life cycles)	1)- Burma	25	Banik 1980
	2) - South India, Mysore State	40	Brandis (Blatter 1929)
	3) - North India, Uttar Pradesh.	65	Troup (Blatter 1929)
	4) - East India, Horshiarpur, Punjab	47	Watanabe & Hamada
	5) - Taiwan	44	Watanabe & Hamada
	6) - Cuba	25	Kennard(1955)
Guadua amplexifolia	Puerto Rico - Colombia - Venezuela - 1953 - 1978	32-35	Hidalgo 1981
Guadua angustifolia	Colombia 1854, Colombia Puerto Rico 1945 -1976	32	Parodi (1955)
Guadua trinii	Brazil 1902 - 1934 . Argentina 1922 - 1953	30-45	Varmah&Bahadur1980
Melocanna baccifera	Bangladesh, Burma, India	30	Varmah & Bahadur
Oxytenantera abyssinica	Tropical Africa, Rhodesia	15	Bean 1907,Ginkul1936
	China, Japan, All the world.- Italia (Florencia) 1876 -		Gamble 1920
Phyllostachys aurea	Belgica, England, Rusia 1904.-Japon Europa,	15	Kawamura 1927
	Argentina 1919-1934-36. -Taiwan, England 1966.		Janzen 1976,Lin 1974
	China - 999 - 1114 -Japon 1716-35 - 1844-47 - 1900-04		Kawamura 1927
Ph. bambusoides	Japan , Taiwan. United States, England 1960-70	120	
	Japan -813 - 931 - 1247 - 1666 - 1786 - 1848 - 1908		Kawamura 1927
Ph. nigra henonis	Japan	120	Watanabe 1981
Ph. pubescens	Burma, Thailand, India	67	Watanabe 1981
Thyrsostachys olivery		48	

The life cycle varies with different species and is more or less constant for a given species and site. Nevertheless some species such as Bambusa arundinacea, and Dendrocalamus strictus have five different life cycles, one for India and other for Brazil. Some authors consider that this is due to the long distance between these countries. However, from the experience I had with the gregarious flowering of Bambusa arundinacea, which occurs at the same time in Puerto Rico, Panama and Colombia and also at the same time in India; I think that the great difference which exists between the life cycle in Brazil and in India is because the seeds brought from India to Brazil originated from a sporadic flowering that occurred in India or even in Brasil.

GREGARIOUS FLOWERINGS IN THE AMERICAS

1.-Gregarious flowering of *Bambusa arundinacea* in India, Puerto Rico, Panama and Colombia

At the beginning of the last century several bamboo species, including *Bambusa arundinacea*, were brought from India to the Federal Experiment Station of Mayaguez in Puerto Rico. In 1920, this specie and some others were taken from Puerto Rico to the Summit Garden of Panama and to other botanical gardens in tropical America. In 1940, plantlets of *Bambusa arundinacea* and *Bambusa vulgaris* were brought from the Summit Garden of Panama to the Granja Experimental located in Palmira, Colombia, where they were planted in the central oval. In October of 1974, I was visiting this place where there were three dense clumps of *Bam.busa arundinacea*, each one with a diameter of about 8 cm. and about 12 meters high, and at that time they were starting to flower.

In April 4th, 1975 I wrote a letter to Thomas Soderstrom, Curator of the Department of Botany at the Smithsonian Institution in Washington D.C. reporting to him about the flowering of *Bambusa arundinacea* in Colombia. He answered my letter on April 10 th, and he gave me the news that this specie was also flowering in Puerto Rico and Panama. By July 1976, all culms were dry and dead. However, the most spectacular thing was to know that almost simultaneously with the flowering of this specie in Panama, Puerto Rico, and Colombia the mother plant was also flowering in India in the south of Orissa. I got this information from The Indian Forester No.7 (July 1976, page 473), where a letter was published from Mr. T. Das, in which he reported the occurrenee of the flowering of *Bambusa arundinacea* ~~that he observed~~ in ~~February~~ 1976 in the Ganjam District (South Orissa) on both sides of the National Highway (No.5) between Berhampur and Rambha. All the existing culms were in full bloom.This means that the flowering which took place in Orisa also started in 1974 almost at the same time as in the Americas.

From Mr Das' information, we can come to the following conclusions : a) The specie of *Bambusa arundinacea* cultivated in the Americas belongs to the same clone of the mother clump located in the Gamjam District in the South of Orissa, India. b) That the mother plant' flowering also started in 1974.

In order to complete this story, at the end of february of 1977 I received a letter from the Forest Research Institute, Dehra Dun, India, signed by Mr. F.R.I in which he offered me seeds of *Bambusa arundinacea* at a cost of 600 rupiasl/kilogram.

In Colombia, in July 1976 the clumps had produced a lot of seeds, and the culms had started to dry from top to bottom and some of them had died. We planted part of the seeds near the northern limit of the grounds of the College of Agronomy of the National University in Palmira, beside a chanel of combined sewage.

Bearing in mind that in Orisa this specie has a life cycle of 30-32 years, this specie will flower again gregariously in India, Puerto Rico, Panama and Colombia between the years 2004 and 2007.

Fig. 2.2 *The flower of Bambusa arundinacia in the gregarious flowering which took place at the same time in India, Puerto Rico Pana and Colombia in 1974.*

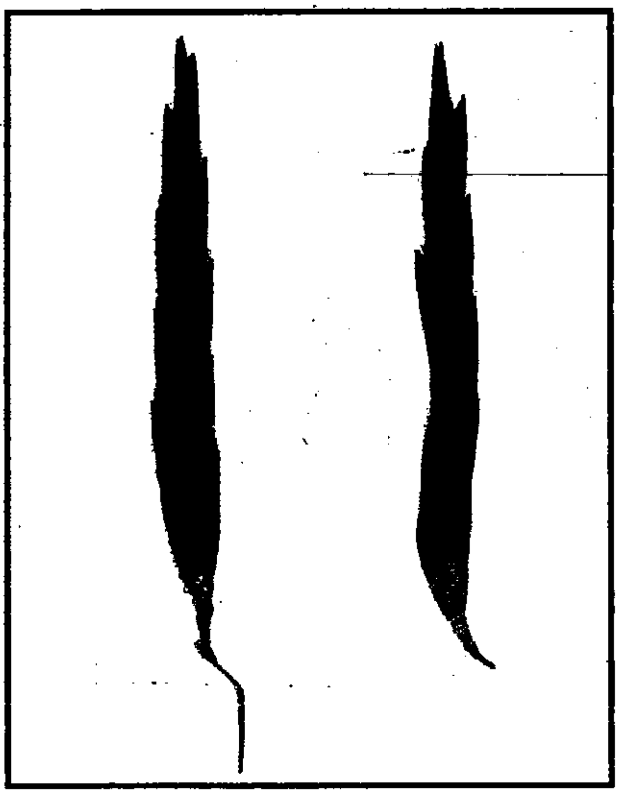


Fig. 2.3 *Spikelet of Bambusa arundinacea. The seeds are used as human food in India and are prepared in the same way as rice.*

Fig. 2.4 The gregarious flowering of *Bambusa arundinacea* in Colombia

A-*On the left side this figure shows a clump of Bambusa vulgaris var. vittata. On the right side, a clump of Bambusa arundinacea starting its gregarious flowering is shown. The color of their leaves has changed and they will be replaced by flowers and seed as shown in Fig.C .*

B. *After the flowering, the culms become dry from top to bottom and die.*

C. *All the leaves were replaced by flowers and later by seeds and finally, the whole clump died.*

D. *When we cut the clump near the base, we found some small green culms which flowered and died in one week.*

E. *Many seeds of this flowering were planted in the North ern boundary of the School of Agriculture in Palmira, Colombia.*

Gregarious flowering of *Guadua angustifolia* in South America in 1977-78

In many cases, a bamboo specie can have a sporadic flowering once or twice before the gregarious flowering. This was the case of the specie *Guadua angustifolia* which had two sporadic flowerings before the gregarious flowering.

In Colombia, between October 1976 and December 1977 there were two sporadic flowerings and one gregarious flowering of *Guadua angustifolia*. The first one took place in the whole country between October 1976 and February 1977. The second one took place from the end of March to May of the same year; while the Gregarious flowering started in October, 1977 in the states of Antioquia, Caldas, Risaralda, and Quindio. In December of the same year all the guadua forests of the Cauca Valley, and Cauca States started their flowering. This means that the direction of the flowering was from north to south. In January 1978 the guadua forests of Ecuador started flowering (Personal information Edgar Caldas, 1978). Most probably it the flowering continued inSouth America to northern of Argentina.

It is important to point out that when the flowering began in the northern Colombia, there was a drought throughout the country. On the other hand the production of seeds was very poor. The most important conclusion of this flowering is that most of the culms did not lose all their leaves and did not die. Only the few culms that had lost all their leaves died. Generally, these culms were broken at the base by the wind. See Fig.2.6 in relation with the life cycle of *Guadua angustifolia*, according to old dates of flowering, the life cycle of Guadua angustifolia could be about 32-35 years. This means that this specie will probably flower again between the years 2007-2010.

Fig. 2.6 *Gregarious flowering of Guadua angustifolia in Colombia and Ecuador in 1976. Only the flowering culms which lost all their leaves died and were felled by the wind.*

3. Gregarious flowering of *Guadua amplexifolia* -1979

The specie *Guadua amplexifolia* is native to northern Venezuela and Colombia, Central America and southern Mexico. Its culm is almost solid at the base and it is 6-10 cm in diameter and 10-12 meters height. It is not useful for construction and the only industrial application that it has in Venezuela is in the manufactue of pulp and paper.

The following information is related to its flowering in Venezuela and Colombia because there is not information of its flowering in Central America and Mexico, probably because it was not observed.

On March 5, 1979 I received in Bogota a telephone call from Mr. Carlos Seijas, the Manager of MAMPA Co. in Venezuela inviting me to go to Caracas to study a problem that they had in the factory of Papeles Maracay with the bambu "guafa" (*Guadua amplexifolia*) that they used for the manufacture of paper and that was becoming dry in the clumps. As I supposed, the problem was a gregarious flowering, and this was confirmed when I visited several small clumps with Dr. Alfredo Gonzalez D. in our trip from Maracay to Acarigua and then to Barquisimeto.

I found that the life cycle of this specie is about 25 years based in the quotation made by McClure on t page 86 of his book "*The bamboos a fresh perspective*" which according to Kennard this specie flowered in the Federal Experimental Station in Mayaguez, Puerto Rico in 1954. This information was confirmmed by a farmer in Venezuela who told me that he saw the "same problem" with this specie 25 years ago. This means that this specie will flower again between 2003 and 2005.

Fig. 2.5 *Spikelet of Guadua angustifolia.*

3 TAXONOMY - DISTRIBUTION OF BAMBOO IN THE WORLD

The purpose of the taxonomy is to distinguish, identify and classify plants. The identification of plants is mainly based on their flowers and fruits. However, the identification and classification of bamboos present more problems to taxonomists than any other group of flowering plants, because, as was explained before, most bamboos flower at long intervals, some only once or twice in a century and most of them die soon afterwards.

On the other hand, there are also species like *Bambusa vulgaris*, the most common species, which remains mostly sterile, and this makes the collection and study of their flowers and fruits difficult. Because of this problem botanists have been forced to make their identification on the basis of specimens either with flowers or with vegetative organs, but separately.

For this reason, there are many cases where the same specie has been classified by different botanists in different genera, or the same species may be described under different names. This has created a lot of confusion for bamboo taxonomy in the world. For example, Chao (1989) revised 42 species originally described under *Arundinaria* by Munro, Gamble, A. Camus and others. He found that only two species are considered to be true *Arundinaria*, the rest (40) have been transferred into seven other genera: *Sinarundinaria, Tamnocalamus, Chimono-bambusa, Recemobambos, Acidosasa*, and others. Consequently bamboo classification is far from complete and most genera are still not very clear.

DISTRIBUTION OF BAMBOOS IN THE WORLD

Worldwide there are about 1,600 bamboo species distributed in about 121 genera (25 herbaceous and 96 woody). Geographically, these species are found in the tropical, subtropical and temperate areas of all the continents, except Europe where there are no indigenous species.

The approximate continental distribution of bamboos is as follows: 67% in Asia and Oceania; 3% in Africa, and 30% in the Americas.

1)- In the Americas. According to Thomas Soderstrom *et al* (1988), about 440 species native to the Americas have been identified, of which approximately 320 are woody and 120 herbaceous, distributed in 41 genera (20 woody, and 21 herbaceous). There are still a great number of woody species to be identified.

Horizontally these species are distributed in the Americas between 46° north latitude, in the temperate zone of the United States, and 47° south latitude, in lake Buenos Aires between Argentina and Chile, where is found the specie *Chusquea culeau*. Vertically they are distributed from sea level up to almost 5,000 meters in the eastern chain of the Andes in South America, where the specie *Neurolepis aristata* can be found.

The giant woody species are distributed horizontally between the south of Mexico (22° north latitud) down to about 34° south latitud in in the Parana river.

The herbaceous bamboos are distributed between 29° north latitude in Mexico and 34° south latitude, and they are confined to warm humid environments, within forests usually under dense shade. Vertically they are rarely found higher than 1,200 meters above sea level. (Soderstrom& Calderon 1979).

2)- In Asia and Oceania. Asia is the richest continent in bamboos, with more than 1,000 species and about 72 to 82 genera. They are found in large area, covering southeast Asia between a latitude as far north as 51° on Sakhalin Island where the specie *Sasa kurilensis* is found, and a southern limit at about 20° south latitud.

This area include the southern half of China, Japan, Korea, Vietnam, Thailand, Malaysia, Burma, Bangladesh, India, Sri Lanka, Taiwan, Philippines, Indonesia, New Guinea, the Northern Territory of Australia, and the Pacific Islands where, according to Watanabe (1987), many bamboos grow spontaneously on the Molucca islands, and a few bamboos are also distributed over the islands of Fiji, Samoa, Vanuatu, New Caledonia, and New Ireland. There are some in the Caroline Islands, but is not clear whether all of these bamboos are native.

The vertical distribution of bamboo in Asia is from sea level to a maximum of 4,000 meters in the subalpine zone of Himalayas in Sikkin and Buttan, where the specie *Arundinaria racemosa* is found. The greatest number of bamboo species and the greatest proportion of bamboo forests are found in India and China.

3)- In Africa. This continent has the smallest number of species (less than 12). But according to Watanabe (1987) the island of Madagascar has about 40 species and 11 genera. On the continent the species are distributed horizontally from a northern limit that goes from Southern Senegal (16° north latitude) over to the high mountains in Kenya and Uganda, and then going through the highlands of East Africa down to southern Mozambique, while on the Atlantic side, the distribution areas are spread across tropical areas in the Central Africa, and then to Cape in South Africa.

The vertical distribution in Africa reaches 2,000-3,300 m. above sea level on Mt. Kenya and high mountains where large communities of *Arundinaria alpina* are found Other species such as *Oreobambos bunchwaldii* K. Sch. and *Oxytenanthera abyssinica* Munro grow indigenously from 200 - 2,000 m. in Rwanda and around Lake Tanganyka.

Fig .3.1 ORIGINAL DISTRIBUTION OF BAMBOOS IN THE WORLD (up to 1960)

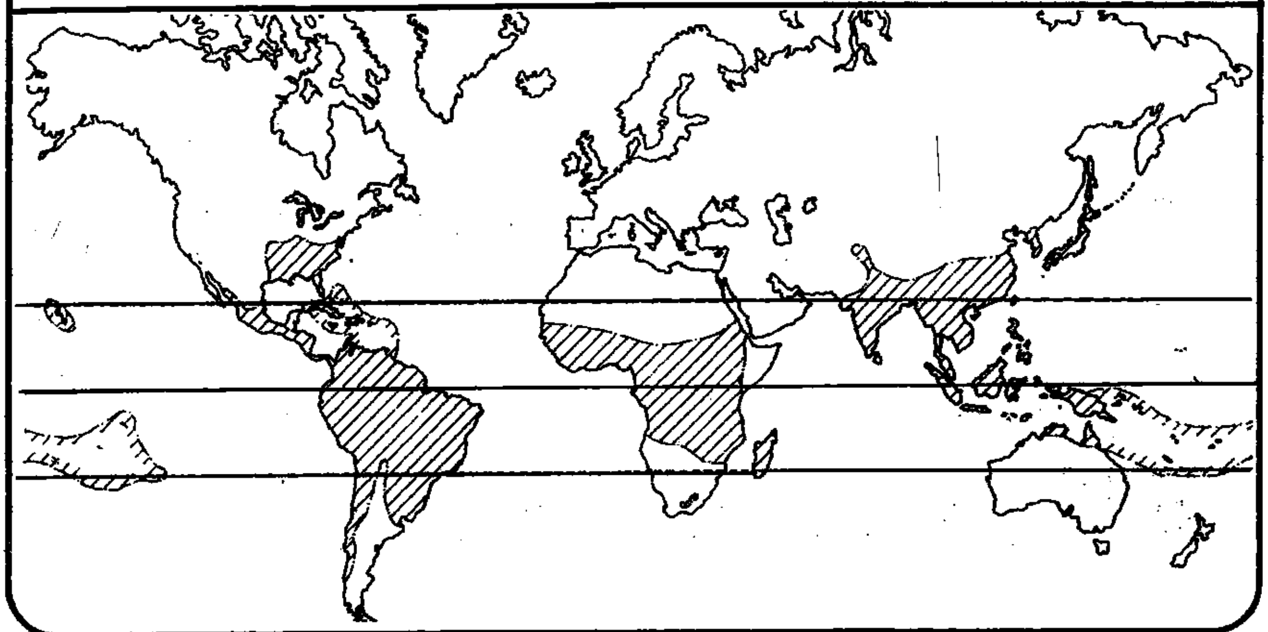


Table 3-1 GENERA OF BAMBOOS NATIVE TO THE AMERICAS

Woody bamboo genera		Herbaceous bamboo genera	
1.-*Actinocladum* Soderstrom	(1)-Brazil	1.-*Anomochloa* Brongniart	(1)-Brazil
2.-*Alvimia* Soders. & Londo.	(3) Brazil	2.-*Arberella* Soders. & Cald.	(7)-Costa Rica and Pana.
3.-*Apoclada* McClure	(4)- Brazil	3.-*Cryptochloa* Swallen	(10-15)-Brazil, Ecuador, San Blas, Panam to Mex.
4.-*Arthrostylidium* Ruprech	(20)- Brazil	4.-*Diandrolira* Stapf	(5)-Brazil
5.-*Arthroostachys* Bentham	(1)-Brazil	5.-*Ekmanochloa* Hitchcock	(2)- Cuba
6.-*Atractantha McClure*	(9-10)-Brazil	6.-*Eremitis* Doell	(5)-Brazil
7.-*Aulonemia Goudot*	(25-30)-From Mexico to Bolivia, Guiana and Brazil	7.-*Froesiochloa* G.A.Black	(1)-French Guiana, Brazil.
8.-*Chusquea Kunth*	(120)- Mexico to Argentina Chile, Juan Fernandez Islands, Uruguay, Brazil, Caribbean Islands	8.-*Lithachne* Palisot de Beao vois.	(4)-Central America, West Indies, Paraguay- Parana basin, Brazil.
9.-*Colanthelia* McClure	(7)-Brazil	9.-*Maclurolyra* Cald. & Sod.	(1)-Panama
10,-*Criciuma* Sod..& Londoño	(1)-Brazil	10.-*Mniochloa* Chase	(2)-Cuba
11.-*Elytrostachys* McClure	(2)From Venezuela and Colombia to Honduras	11.-*Olyra* Linnaeus	(23)-Mexico and northen Central America, Brazil
12.*Eremocaulon* Sod. & Lond.	(1)-Brazil	12.-*Pariana* Fusee-Aublet	(30)-From Costa Rica to Bolivia, Brazil.,Trinidad
13.-*Glaziophyton Franchet*	(1)-Brazil	13.-*Pharus* P. Brown	(7)-Mexico to Ecuador.
14.-*Guadua Kunth*	(35)-From Mexico to north Argentina and Brazil	14.-*Piresia* Swallen	(6)-Brazil, Guianas, Trinid.
15.-*Merostachys* Sprengel	(40)-From Guatemala to Argentina and Brazil	15.-*Raddia* A. Bertoloni	(5-7)-Venezuela, Guianas, Brazil.
16.-*Myriocladus* Swallen	(20)-Venezuela and Brazil	16.-*Raddiella* Swallen	(8)-Guianas, Colomb.Bra.
17.-*Neurolepis* Meisner	(10)- Venezuela and Col. to Peru, Brazil, Bolivia.	17-*Rehia* Fijten	(1)-Surinam, Brazil
18.-*Olmeca* Soderstrom	(2)-Mexico	18.-*Reitzia* Swallen	(1)-Brazil
19.-*Otatea* Calderon & Sod.	(1)-Mexico and Central America	19.-*Streptochaeta* Nees fon Esenbeck	(3)- From Mexico to Argentina
20.-*Rhipidocladum* McClure	(15)-Mexico to Argentina, Trinidad	20.-*Streptogyna* Palisot de Beauvois.	(2)-Africa,India, Sri Lanca, South America.
		21.-*Sucrea* Soderstrom	(1)-Brazil

Source: Soderstrom et al (1988)-D. Ohmberger & J.Goerrings (1983).

Table 3-2 GENERA OF BAMBOOS NATIVE TO ASIA, OCEANIA AND AFRICA

Woody bamboo genera		Woody bamboo genera	
1.-*Acidosasa*	(4)-Asia	43.-*Neomicrocalamus* Keng	(2)-Asia
2.-*Ampelocalamus*	(2)-Asia	4.-*Neosinocalamus* Keng	20)-Asia, China
3.-*Arundinaria* Michaux	(81)-Asia,Africa, U.S.A	45.-*Ochlandra* Thwaites	(11)-Asia,Madagascar
4.-*Bambusa* Schreber	(91)-Tropic. Asia, Austr.	46.-*Oligostachyum* W. Y.	(1)-Asia
5.-*Bashania* Keng & Yi	(2)-Asia	47.- *Omeiocalamus* Keng	(1)-Africa
6.-*Bonia* Balansa	(1)-Asia	48.-*Oreobambos* Shumann	(1)-Africa
7.-*Brachystachyum* Keng	(1)-Asia	49.-*Oreocalamus* Keng	(2)
8.-*Burmabambus* Keng	(1)-Asia	50.-*Oxytenanthera* Munro	(16)-Africa, New Guinea
9.-*Butania* Keng	(1)-Asia	51.-*Perrierbambus* Camus	(2)-Asia
10.-*Cephalostachyum* Munro	(17)-India , Malaysia	52.-*Phyllostachys* Sieb.& Zu.	(41)-Asia
11.-*Chimonobambusa* Makino	(9)-Asia	53.-*Pleioblastus* Nakai	(26)-Africa
12.-*Chimonocalamus* Hsueh	(11)-Asia	54.-*Pseudocoix*	(1)-Asia
13.-*Decaryochloa*	(1) Africa	55.-*Pseudosasa* Nakai	(13)-Asia
14.-*Dendrocalamopsis* Keng	(8)-Asia	56.-*Pseudostachyum* Munro	(1-2)-Burma ,India
15.-*Dendrocalamus* Nees	(29)-India-Philippines	57.-*Quiongzhuea* Hsueh & Yi	(6)-China
16.-*Dendrochloa* Parkinson	(1)-Burma	58.-*Racemobambos Holttum*	(16)-Malesia
17.-*Dinochloa* Buse	(20)-Philippines, Indone.	59.-*Sasa* Makino & Shibata	(38)-Japon
18.-*Drepanostachyum* Keng	(4)-Asia	60.-*Sasaella* Makino	(13)-Asia
19.-*Fargesia* Franchet	(76)-China (Yi Tongpei)	61.-*Sasamorpha* Nakai	(6)-Asia
20.-*Ferrocalamus* Hsüeh,Keng	(1)-Asia	62.-*Schizostachyum* Nees	(45)-South East Asia, Africa
21.-*Gelidocalamus* Wen	(5)-Asia		
22.-*Gigantochloa* Kurz	(16)-India, Philippines	63.-*Semiarundinaria* Makino	(11)-Asia
23.-*Glaziophyton* Franchet	(1)- Australia	64.-*Shibataea* Makino	(4)-Asia
24.-*Greslania* Balansa	(4)-Asia	65.-*Sinarundinaria* Nakai	(13)-Asia
25.-*Hibanobambusa* Marruya	(1)-Asia	66.-*Sinobambusa* Makino	(17)-Asia
26.-*Hickelia* Camus	(2)-Africa	67.-*Sinocalamus*	(5)-Asia
27.-*Himalayacalamus* Keng	(1)-Asia	68.-*Soejatmia*	(1)-Malaysia
28.-*Hitchcockella* Camus	(1)-Asia	69.-*Sphaerobambos*	(3)-Malesia
29.-*Holttumochloa*	(3)-Peninsular Malaysia	70.-*Swallenochloa* McClure	9)- Asia
30.-*Indocalamus* Nakai	(25)-Asia	71.-*Teinostachyum* Munro	(3)-Asia
31.-*Indosasa* McClure	(18)-Asia	72.-*Tetragonocalamus* Nakai	(1)-Asia
32.-*Kinabaluchloa*	(2)-Malaysia	73.-*Thamnocalamus* Munro	(4-6)-Asia, Africa, Australia
33.-*Klemachloa* Parker	(1)-Asia		
~~34.-*Leptocanna* Chia~~	(1)-Asia	74.-*Thyrsostachys* Gamble	(2)-Thailand a Vietnam
35.-*Lignania* McClure	(12)-Asia	75.-*Vietnamosasa*	(3)- Thailand to Vietnam
36.-*Maclurochloa*	(1)-Malaysia	76.-*Yushania* Keng)-Asia	(12)-Taiwan, Malasia
37.-*Melocalamus* Bentam	(2)-India , Burma, Thailand.		
38.-*Melocanna* Trinius.	(3)-India	**Herbaceous bamboo genera**	
39.-*Menstruocalamus* Yi	(1)-China		
40.-*Morospatha*	(1) -China	.-*Buergersiochloa* Pilger	***(1)-Asia***
41.-*Nastus* Jussieu	(23)-Indonesia, New Guinea	2.-*Guaduella* Franchet	***(6) Africa Central***
		3.-*Leptaspis* Brown	***(10)-Asia, Africa,***
42.-*Neohouzeaua* Camus	(5)-Bangladesh to Thail.	4.-*Puelia Franchet*	***(6)- Africa Central***

Source: Lin (1970), Tewari (1992), Chen & Ju (1994), Su 1991, Yi (1992), Ohrnberger and Goerrings (1985).

NOTE: *Here is a refresher course for those who are not familiar with botany and do not know or do not remember the meaninig of the terms* **specie, genus,** *and* **family:**

My name is Oscar 'Hidalgo or HIDALGO oscar = ***GUADUA angustifolia*** Kunth

HIDALGO michel = ***GUADUA aculeata*** Ruprecht

With these example it is easy to understand that the last name ***"HIDALGO"*** *is equivalent to* ***genus " GUADUA",*** *and the names:* ***oscar*** *and* ***miguel*** *are equivalent to the "species"* ***angustifolia*** *and* ***aculeata.*** *In this example, be careful not to confuse HIDALGO and GUADUA with FAMILY. At the presen time about 1,600 species distributed in about 121 genera (96 woody and 25 herbaceous). have been identified.All of those 121 genera form the FAMILY Poacea or Gramineae- The third name located after the specie,* ***(Kunth)*** *is the last name of the person who identified the species with the scientific name of Guadua angustifolia.*

Table 3-3 THE CLASSIFICATION OF WOODY BAMBOO GENERA

FAMILY ***Poacea (Gramineae)***

SUBFAMILY ***Bambusoideae A.& G.***

TRIBE ***Bambuseae* Nees**

1.-SUBTRIBE *Arthrostylidiinae*
13 genera confined to the Americas

Actinocladum	*Colanthelia*
Alvimia	*Elytrostachys*
Apoclada	*Glaziophyton*
Arthroostachys	*Merostachys*
Arthrostylidium	*Myriocladus*
Atractantha	*Rhipidocladum*
Aulonemia	

2.-SUBTRIBE *Arundinariinae*
14 genera confined to temperate regions and high mountains in the tropics of Asia and United States in North America (*).

Acidosasa	*Himalayacalamus*
Ampelocalamus	*Indocalamus*
Arundinaria (*)	*Indosasa*
Borinda	*Pseudosasa*
Chimonocalamus	*Sasa*
Drepanostachyum	*Thamnocalamus*
Fargesia	*Yushania*

3.- SUBTRIBE *Bambusinae*
13 genera, mostly tropical Asia

Bambusa	*Melocalamus*
Dendrocalamus	*Oreobambos*
Dinochloa	*Oxytenanthera*
Gigantochloa	*Soejatmia*
Holttumochloa	*Sphaerobambos*
Kinabaluchloa	*Thyrsostachys*
Maclurochloa	

4.-SUBTRIBE *Chusqueinae*
2 genera, Americas
Chusquea
Neurolepis

5.- SUBTRIBE *Guaduinae*
5 genera confined to Americas tropics
Criciuma
Eremocaulon
Guadua
Olmeca
Otatea

6.- SUBTRIBE *Melocanninae= Schizostachydinae*
8 genera mostly tropical Asia.

Cephalostachyum	*Ochlandra*
Davidsea	*Pseudostachyum*
Melocanna	*Schizostachyum*
Neohouzeaua	*Teinostachyum*

7.- SUBTRIBE *Nastinae*
6 genera, mostly in the southern hemisphere of the Old World tropics.

Decaryochloa	*Hitchcockella*
Greslania	*Nastus*
Hickelia	*Perrierbambus*
Hickelia	

8.-SUBTRIBE *Racemobambosinae*
3 genera, Himalaya and tropical Asia
Neomicrocalamus
Racemobambos
Vietnamosasa

9.-SUBTRIBE *Shibateinae*
5 genera, temperate Asia
Chimonobambusa
Phyllostachys
Semiarundinaria
Shibataea
Sinobambusa

Source: Soderstrom & Ellis, (1987). - Prosea (1995).

THE MOST IMPORTANT SPECIES OF ASIA AND THE AMERICAS

The most important species of Asia

In South East Asia, where there are more than 1.000 species, only about 250 species (200 from China and 50 from other countries) have some economic value in different fields such as human food, housing construction, handicrafts and industrial purposes.

The most outstanding species from Asia, from the economical point of view are the following: *Bambusa bambos* Voss; *B. blumeana* J.A & J.H Schultes; *B. polymorpha* Munro; *B. textilis* McClure; *B. tulda* Roxb.; *B. vulgaris* Schrad.ex Wendl.; *Cephalostachyum pergracile* Munro; *Dendrocalamus asper* (Schultes f.) Backer ex Heyne; *D. giganteus* Munro; *D. latiflorus* Munro; *D. strictus* (Roxb.) Nees;: *Gigantochloa apus* J.A y J.H. Schultes; G. levis (Blanco) Merrill; *G.pseudoarundinacea* (Steud.) Widjaja; *Melocanna baccifera* (Roxb.) Kurz: *Ochlandra Thw.*(Spp); *Phyllostachys aurea Carr. ex A & C Riviere; Ph.. bambusoides* Sieb.; *Ph. pubescens* Mazel ex H. de Leh.; *and Thyrsos tachys siamensis* (Kurz) Gamble.

The most important species of genus *Guadua* in the Americas

Of the about 440 native species which there are in the Americas (320 woody and 120 herbaceous). Non of the herbaceous and about the 95% of the woody species have had any aplication so far. Only about 15 species (5%) of the woody species which belong to the genus *Guadua*, are considered to be the best species of the Americas. This is because of their large size, their use in construction and, specially their industrial potential. However, up to the present time, this has not been taken into consideration, due to our ignorance regarding these species, which in our countries are regarded as weeds, used only by Indians and poor people in the costruction of their houses

For this reason, non of our countries have been interested in the study, cultivation and preservation of their species. On the contrary, bamboos have been destroyed to the point that most of the 15 giant species which grew from the southern Mexico down to Argentina and Uruguay have disappeared from many of our countries or are on the brink of extintion, except in Colombia which is the only country in the Americas which has preserved most of their native giant species.

Due to this destruction, of the 15 giant native species which there were in the fifties, today there are only 8 of which 4 are the most widely used in Colombia in construction, and 4 are found in Brazil and northeastern part of South America.

In the Americas, most of the giant native species of the genus *Guadua*, have been described by European botanists. Some of them visited several of our countries in the the nineteenth century. Others made the identification using the specimens that were transported to different herbariums in Europe.

Alexander von Humboldt and Aimé Bonpland, who visited several of our countries including Colombia, Ecuador, Peru, Venezuela and Mexico. In 1806, in Colombia they described two of our giant species of bamboo and gave them the scientific names of *Bambusa guadua* and *Bambusa latifolia*. They included these species in the Asiatic genus *Bambusa*, due to the similarities which they found between the South American and the Asiatic species which belong to this genus, as it is indicated in the book *Plantae Equinoctialis* published by them in Paris in 1908.

In 1822, the German Carl S. Kunth, decided to place the two New World species in a new genus that he called *Guadua*. Later, Alonzo.McClure (1973), uncertain of its generic separation, reduced it again to a subgenus of *Bambusa*, and in 1987 Soderstrom and Londoño restored *Guadua* to generic status based on a number of distinctive features, i.e., a triangular sheath leave in which the margins of the sheath and blade are continuous or almost so, presence of thorns on the culms and branches, a distinctive band of short white hairs both above and below the scar or nodal line, and a palea of firm texture with prominent wings emanating from the keals.

At present, the genus Guadua includes about 36 identified species and some still unidentified giant species, with diameters which varies between one and 22 cm, and heights which varies between and 30 meters and more. Around 20 species of this genus are native from Brazil, andt 8 are native from Colombia.

The other countries of Latin America (with the exception of Chile where these giant species do not grow), originally had from one to 3 native species. Unfortunately due to the lack of interest which exists in all the countries towards our giant species, most of these countries, such as Mexico, Venezuela and the Central American contries have destroyed all of their native species. Colombia is the only country that has preserved most of its species.

The most outstanding giant species of Colombia are the following: members of the genus Guadua:

a). "guadua macana" (*Guadua angustifolia* Kunth).Its diameter varies from 10 to 14 cm and its height from 18 to 23 m. It s is considered to be one of the best specie of the world due to its durability and high strength; it is the most widely used bamboo in Colombia and Ecuador in construction. This specie grew from Colombia to the north of Argentina, and Venezuela, but it has dissapeared from the latter country.

b) "guadua de castilla", native to Colombia, it still has not been identified. It is the largest species in Colombia with a maximum diamter of 20 cm andabout 30 meters height. It is the best material for the manufacture of bamboo boards used in the construction of walls, floor, ceilings and it is the most appropiate for the manufacture of plybamboo and other composite materials. This species is in the brink of extintion.

c) "Guadua cebolla" (Onion guadua). This species is native to Colombia, and has diameters of 10 cms and is 17 meters height. It is an excelent material for construction and for the manufacture of woven boards.

d) "Guadua rayada verde" (*Guadua angustifolia* var. *bicolor*, This is the most beautiful species in the Americas, but it is now on the brink of extinction. It is used in construction. Its diameter physical and mechanical characteristics are similar to *"guadua macana"*.

THE THREE MOST IMPORTANT NATIVE SPECIES OF THE GENUS *GUADUA* IN COLOMBIA

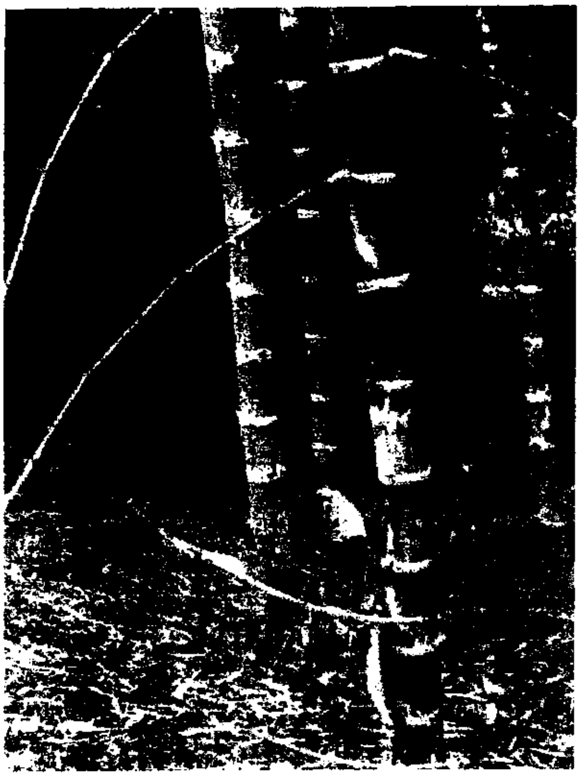


Fig. 3.2 *Guadua angustifolia Kunth (macana)*
The strongest bamboo of the Americas and the most durable of the world. It has branches with thorns on the lower part of the culm.

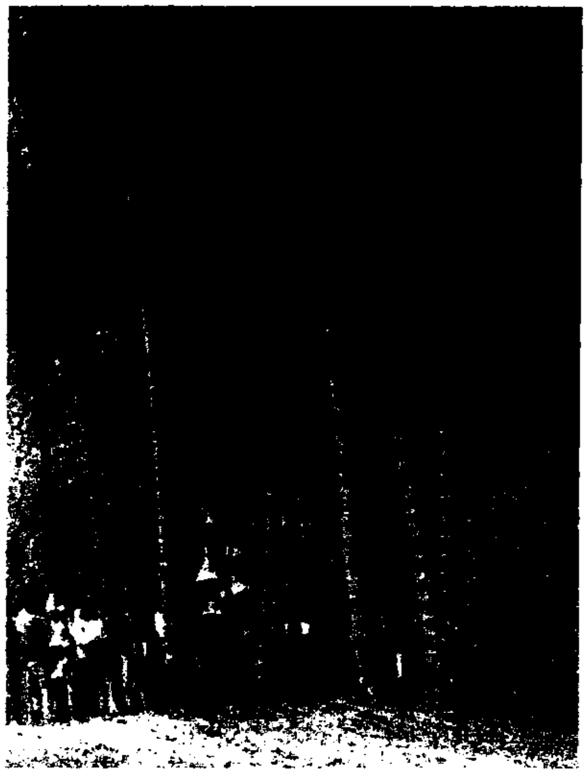


Fig.3.3 *"Guadua cebolla " (onion guadua) Still has not been identified. It is one of the best for construction and weaving. It has no branches on the lower part of the culm.*

Fig. 3.4 *"Guadua de castilla" .is still not identified. It has a maximum diameter of 20 centimeters and its height varies between 30 and 36 meters. This species has an excellent industrial use in the manufacture of composite materials such as plybamboo and laminated structures.*

The following list includes most species of genus *Guadua* which existed in the nineteen fifties and the place where they grow; most of it was made at that time by Dr. Alonzo McClure at the Smithsonian Institution. Unfortunately the list is not complete and in many cases only the scientific name of the species was indicated. In most cases I have included some additional information that I got from E.G. Camus(1913) It is very important to point out that many of these species have disappeared from the places indicated by Dr. McClure. and Camus.

1.-Guadua angustifolia Kunth, 1822 b: 253.

As was mentioned above, this is one of the the most important species in the world, due to its great strength and durability and consequently it is the best material for building structures, and it has a great potential for the manufacture of composite materials.

Its diameter varies from 10 to 14 cm and the height of the culms varies from 17 to 23 metros. One of the characteristics of this species is the long branches with long thorns which grow in the lower part of the culm.

This species is native to South America where it grew originally from Panama and northern Colombia to about 28º south latitud along the Parana River on the north border between Argentina and Paraguay. This species was originally found in the banks and in the basins of the largest rivers of Colombia, Ecuador, Venezuela, the Guayanas, Brazil and Paraguay. It grew in the banks of the Paraná River from Minas Geraes and Goias down to Posadas and Corrientes in Argentina on the border with Paraguay. Unfortunately it has been destroyed in Venezuela and in most of the countries of Central and South America , except in Colombia .

This specie is known by different common names in each country: In Panama is known as "Cañaza"; in Colombia "guadua" or "macana"; in Ecuador as"caña guadúa or caña brava"; in Venezuela as "guafa"; in Brazil as"tacuaruçu"; in Argentina, as"tacuara"; en Paraguay as"tacurú-pucú; and in Perú as "caña de Guayaquil".

2.-Guadua angustifolia var. ***bicolor***, McClure Londoño (1989). I have seen this specie only in Colombia where it is known with the vernacular name of "guadua rayada ". Culms 15 to 18 meters high and 10 to 11 cms in diameter. The color of the culm is green with yellow stripes.

***3.-Guadua aculeata* Ruprecht ex Fournie** 1881 -130. Originally this species grew from the southern Mexico and Central America to Panama.. Its diameter is 9-13 cms. and its height is 15-18 meters. This species is closely related to *Guadua angustifolia* and it can be differenciated only by means of vegetative features and also by the culm habit; in this species the culms are broadly arched above,while in *Gudua angustifolia* the culms are erect. In Mexico and Guatemala this species was known with the vernacular names of "tarro" and also as "cañabrava" due to the long thorns on their branches. This species is on the brink of extinction in all the countries from Mexico to Panama. and in some of them it has dissapeared.

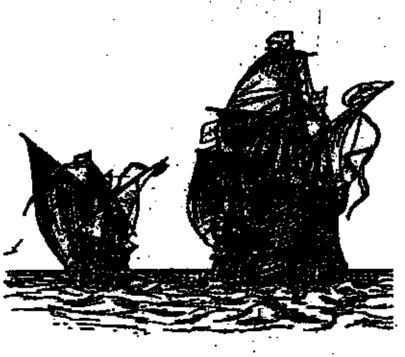
4.-Guadua amplexifolia Presl, 1830: 256.This species was distributed on the Atlantic coast of Venezuela, Colombia, and also from Central America to theYucatan in Mexico. In Venezuela it is known by the vernacular name of "guafa", in Colombia as "guaduilla" and in Mexico where it grows in swampy areas of Yucatan, it is known as "jimba". The culm of this species is almost solid at the base with a small lumen. Diameter is 6-10 cms, and the height is 10-12 meters.

According to McClure (1973), this species is very thorny in Venezuela and Colombia up to El Salvador in Central America and progressively less thorny forms appear from El Salvador northward, and a completely unarmed form is found in the state of Sinaloa in Mexico. This species flowers gregariously every 25 years and dies after flowering. Of all the giant species of genus *Guadua* this species is the less useful and it is not recommended for construction because it is easily attacked by insects.

5.-Guadua barbata Trinius, 1835:627. This species grows grows in Brazil in the state of Minas Gerais.

6.-Guadua capitata (Trinius) Munro, 1868:81. It grows in Brazil in the state of Matogroso do Sul on the Pardo River, which a tributary of the Paraná River.

THE ENCOUNTER OF COLUMBUS WITH THE GIANT SPECIES OF THE AMERICAS



In September of the year 1502 on his fourth and final trip to the Americas, Cristopher Columbus, arrived at the cape that he called "Gracias a Dios", in Central America between Honduras and Nicaragua Several weeks later, he visited the mouth of the San Juan River which today is the border between Nicaragua and Costa Rica There he saw for the first time the beautiful giant bamboo species of the Americas that he describes as "canes so thick as the legs of a strong man". He was referring to *Guadua aculeata* and *Guadua inermis*, native to Mexico and Central America.

The encounter of Columbus with these giant bamboo species contributed to the clarification of the mystery of the origin of the gian canes which, according to Fray Pedro Simon, Spanish Clergyman, were periodically seen on the beaches of several European countries, where they were dragged by the sea, but nobody new their origin. These circumstances also contributed to the discovery of the Mexico Gulf Stream.

The reason for this mystery was that in the rainy season, many bamboo culms from the forests of Mexico were carried by the flooding of the rivers to the Gulf of Mexico, and from there they were carried to the European coasts by the gulf streams.

The discovery of the Gulf Streams in which bamboo had a great part, made it posible for European ships to travel faster from Mexico and Central America to Europe.

Fig. 3.5
Guadua angustifolia, native to South America. In Colombia is known as "macana " and in Ecuador as "cañabra-va". It is very similar to Guadua aculeata which is native to Mexico. Its culm is erect with a little curve at the top.

Fig. 3.6 *Guadua aculeata, is known as "caña brava" in Mexico and Central America. Its culm is curved at the base.*

7.-Guadua Chacoensis (Rojas) Londoño. The Culms are 10-20 meters height; with a diameter 8-15 cms. It grows in the northern part of Argenina, southern Paraguay and southeastern Bolivia. at elevations between 75 to 450 meters above sea level.

8.-Guadua distorta Nees,1834:470. This species grows in Brasil in the state of Santa Catarina and in Sao Paulo in the Serra of Catareira.

9.-Guadua glaziovii (Hackel) Camus, 1903:194. This species is found in the state of Rio de Janeiro.

10.-Guadua glomerata Munro, 1868:79. It grows in the state of Amazonas, Brazil; Barra, Gapo on the Negro river; state of Para; Santarem and Guayanas.

11.-Guadua inermis Ruprech ex Fournie. This species grew in Mexico and Central America. According to the information I got in Mexico in 1980, it disappeared from Mexico and Central America in the nineteen fifties because it has not thorns and therefore was the most commonly used for construction. Due to. its lack of thorns, this specie was known by the vernacular name of caña mansa".

12.-Guadua Lindmani Camus 1913. It grows in Brazil, State of Rio Grande do Sul. Colonia Martius.

13.-Guadua latifolia (Humboldt et Bonpland 1808: 67), Kunth,1822:254. This species. grows in Brazil, State of Amazonas, Negro river, from Barcellos to San Gabriel.

14.-Guadua longifimbriata E.-G. Camus, 1913, I: 113. Brazil, in the State of Rio de Janeiro;in Petropolis; San Cristavao (where the Don Pedro Palace which is now the National Museum is located)-; This is probably the same species being cultivated in Costa Rica that I call by the vernacular name of "guadua brasilera" (See "guadua brasilera" at the end of this list).

15.-Guadua macrostachya Ruprech, 1839:39. Thisspecies is found in Brazil, in the state of Para. from Santarem to Obidos. Cayena (French Guyana).

16.-Guadua maculosa (Hackel) E.G. Camus, 1913, I:106. This species is found in Brazil, in Goias.

17.-Guadua paniculata Munro, 1868:85.This species grows from sea level to 1.300 meters, from the north of Paraguay to Venezuela, Panamá, Nicaragua, El Salvador, Mexico and Brazil in the state of Goias, Porto imperial, and Tocantins river. Culms from 9 to 12 meters height; diameters 5 to 7 cms. It has thick but weak walls(Swallen, 1955).

18.-Guadua paraguayana Doell, in Martius 1880 179. This species has solid culms 3-5 mts high and diameteres 2 -4 cms in the base. It could be found in the Paraguay river from the north of the country to Reconquista, state of Santa Fe in Argentina. (Parodi, 1936).

19.-Guadua refracta Munro, 1868:84 Brazil, in the state of Goiaz.From the capital of Goiaz to Calvacante.

20.-Guadua riograndensis (Dutra) Herter, 1941: 49.It is found in Brazil, in the state of Rio Grande do sul,

21.-Guadua spinosa (Swallen) McClure, 1954:82. (*Arthrostylidium spinosum Swallen*). Known also with the vernacular name of "Jimba" in México, Guatemala and Belice. The .culms 5 m high, and 5 cms in diameter, thorny, oftem clambering bamboo, found at low elevations (up to 60 meters) along rivers and in poorly drained areas.

22.-Guadua spinosissima (Hackell) E.G. Camus 1913; I:112. This species grows in Brazil, in the state of Santa Catarina near Blumenau.

23.-Guadua superba Huber, 1904:479 . This species has culms up to 20 meters high with a diameter of 10 to 15 cms at the base. It is found in Peru and Brazil, in the state of Acre, along the Purus River, and in the state of Amazonas, at Redondo lake near Bom Logar.

24.-Guadua tagoara (Nees) Kunth, 1834:611. This species is found in Brazil, in the state of Sao Paulo at Taubati and Lorenau and in the state of Parana at Ca-pao Bonito and Santa Catarina. The culms are 20 to 25 meters high and the diameter is 8 to 15 cms.

25.-Guadua tessmannii Pilger, 1924:124 (?)

26.-Guadua tomentosa Hackell & Lidman, in Lidman, 1900:20. Is found in Brazil at Rio Branco do sul and Colonia Ijuhy.

27.-Guadua Trinii (Nees) Nees ex Ruprech, 1839: 40. Culms from 6 -10 meters high with a diameter of 3 to 5

Fig.3.7 *Guadua brasilera, native from de Brasil. The largest bamboo from the Americas.*

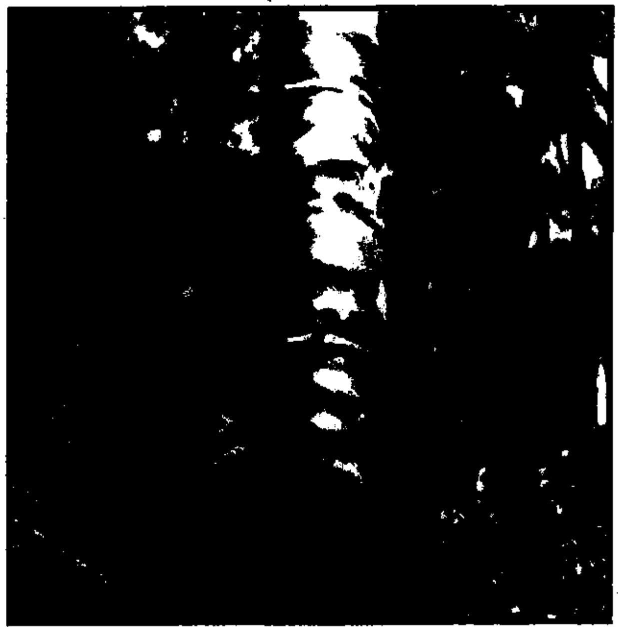


Fig. 3.8 *"Guadua cotuda" from Colombia.*

cms. It grows from the south of Brazil (Rio Grande do Sul) up to 340 40' south latitud in Argentina. It grows in the Parana delta and tributaries of Uruguay river. This specie has a flowering cicle of 30 years. (Parodi, 1936,1955).

28.-Guadua venezuelae Munro 1868:86. This species is found in Venezuela, along the Orinoco River up to Maranhao.

29.-Guadua virgata (Trinius) Ruprech, 1839: 40. This species is found in Brazil in the state of Minas Gerais at Mount Geraldo.

30.-Guadua weberbauery Pilger, 1905:152. This species has the longest internodes of this genus; they have an average of 90 cms. The culms are 8-10 meters high and have a diameter of 5-6 cms. The thickness of the wall is about 4 to 6 mm. It is found in Brazil in the states of Acre and Amazonas, and in Peru in the Amazon area.

Species of the genus *Guadua* that still have not been identified

The following giant bamboo species from Colombia, and Brasil, still do not have scientific names. They include three of the most outstanding species in the world, and are considered among the best for construction. They are known by the following vernacular names:

31 x.-"Guadua de castilla". This species is native to Colombia. It is the largest species in this country with a culm height of 30-34 meters and diameters from 17 to 20 centimeters. This bamboo is the most used in the manufacture of bamboo boards. It has an excellent potential in the manufacture of composite materials. This species is on the brink of extinction.

32 x.-"Guadua cebolla" (onion guadua). This species is native to Colombia and Ecuador, where it is known as "caña mansa" because it has no spines. It is on the brink of extinction. In Venezuela (guafa) has been eliminated. In Colombia ,it is commonly used for construction and for many other purposes.

33 x- "Guadua cotuda" (goiter guadua). This specie presents a protruding zone which surrounds the top and the lower part of each internode. I saw this characteristic in about ten culms located in the central area of a *Guadua angustifolia* plantation in Caicedonia, near Armenia in Colombia. For this reason, I think that these culms are abnormalities of *Guadua angustifolia.* (See Abnormalities of the internodes). The height of the culm is about 20 meters and the diameter is 10-14cms.

34 x.-"Guadua rayada negra". This species was only found on one farm located in the Quindio state in Colombia. It is black with yellow stripes and its characteristics are similar to those of *Guadua angustifolia.* (See Abnormalities of the internodes).

35 x.-"Guadua brasilera". This is the largest species of the Americas. The culms are 30-36 meters in height and the diameters are up to 22 centimeters. This species is native to Brazil, but it disappeared from that country many years ago. Fortunately, this species was introduced to Costa Rica and cultivated on the Bremen Ranch, in Canton Siquirres, by the owner, Mr. Manuel Rojas Quiroz. During a conversation I had with Mr. Rojas at his home in San Jose, Costa Rica, on January 25, 1989, he told me that in 1946 he brought the rhizomes of this species from the Quitandinha Hotel located in Petropolis near Rio de Janeiro in Brazil, where he and his wife spent their honeymoon. At that time the hotel and the gardens were surrounded by these huge and beautiful bamboos. The rhizomes which he brought were planted first on the Eva farm (Canton Sarchi) and then on Atirro farm in Turrialba and finally on the Bremen farm where I saw this specie for the first time..This species is one of the best in the world.

In 1995 , I had to travel to Brazil to give a seminar on bamboo at the Pontifica Universidad Catolica of Rio de Janeiro. After the seminar, I traveled with Professor Khosrow Ghavami to Petropolis, where we visited the famous old Quitandinha Hotel. We found out that in the sixties the hotel was transformed into an apartment building but preserving its beautiful original German architecture. Most of the gardens have disappeared and all the bamboos had been destroyed, and replaced by new streets, avenues and several apartment buildings and houses.

The same day we traveled throughout the region looking for this specie but we could not find it, and nobody gave us information about this plant. I think that it can be found in other place of of Brazil.

I gave to this specie the vernacular name of "guadua brasilera" in order to avoid confusion, because it was erroneously identified as *Guadua angustifolia*, later as *Guadua aculeata*, an finaly as *Guadua chacoensis*. Probably the scientific name of this specie is *Guadua longifrimbiata*.

The rizomes of guadua brasilera have the characteristic that they are samall and grow almost vertically and consequently their culms are very near each other, which is a problem for harvesting them. According to Eng. Francisco Castaño from Colombia, who made in Costa Rica a study of the number of culms per hectarea of guadua Brasilera in 1996, there were an average of about 60.000 culms per hectare, while in a hectare of *Guadua angustifolia* there are only between 7.000 and 10.000 culms due to the length of the rhizome neck, the rhizome length and the fact that the position of the rhizome is horizontal.

This bamboo species is considered to be the most outstanding species of the Americas from the economic point of view. I consider guadua brasilera to be the best material for the manufacture of bamboo boards which are used in the construction of walls, ceilings, floor and roofs and in the manufacture of plybamboo and bamboo laminated beams and other composite materials.

Original distribution of the giant species of the genus *Guadua* in the Americas

As it was explained before, these 18 giant species, of genus Guadua (which probably they were many more in precolumbian times), were originally distributed between Mexiico and northern of Argentina, in five large areas or regions, located along the basins of the largest rivers of the Americas, forming inmense natural pure and mixed bamboo forests, which are gradually disappearing.. Today most of the largest original forests have disappeared and only very small patches can be seen in a few of our countries but they too will soon disappear. The original distribution of this giant speciees is as follows:

The first region coversd the North and Central America, from Mexico to Panama. The largest pure bamboo forests consists of *Guadua aculeata* (caña brava) and *Guadua inermis* (tarro). In Panama alone. there were 3 species including *Guadua angustifolia* which in this country is known with the vernacular name of "cañaza".

It is said that the extraordinary qualities of *Guadua angustifolia* were discovered by the Mayas and Aztecs of Guatemala and Mexico who in precolumbian times used to come to the Darien mountains, between Panama and Colombia in order to get medicinal plants. On their return trips they took with them seedlings of this specie of bamboo which they planted along the main road in order to facilitate its future transportation to their countries. This is probably why this species can be found in several Central American countries.

Today, in Mexico and Central America the specie *G. inermis* has disappeared, and *G. aculeata* is in the brink of extinction. In Panama most of the species have been destroyed and there are only very small patches of *G. angustifolia* in the state of Chiriqui near the border with Costa Rica.The only countries in Central America which have planted giant bamboo species are Costa Rica and El Salvador.

The second region is located between the northern Colombia and the Gulf of Guayaquil in Ecuador. This region consist of two areas: the area of Colombia and the area of Ecuador. The area of Colombia originally had the largest forests and the largest number of species, which at that time were distributed along the basins of the Cauca and Magdalena rivers.

Today, in this area there are only about 7 giant species, of which only three have a scientific name while the other 4 are known by their common names. They are: *Guadua angustifolia* (guadua macana), *Guadua angustifolia* var. *bicolor* (guadua rayada). *Guadua amplexifolia* (guaduilla), and the other 4 are: " guadua de castilla, guadua cebolla, guadua cotuda, guadua rayada negra". All of these giant species are known in Colombia by the vernacular name of "guaduas".

In the area of Ecuador, there are only two species: Guadua angustifolia, which also is known as "caña brava" because of the thorns, and the other is known as "caña mansa",which is the same species known in Colombia as "guadua cebolla". Both species are known in Ecuador by the vernacular name of "cañas guadúas". these species are found mainly in the basins of the Napo, Santiago, Cayapas, Daule and Babahoyo Rivers.and will disappear from Ecuador in three or four years if their destruction is not stopped or controlled. The biggest problem in Ecuador is the aversion which exists towards the giant species of bamboo which are generally used by the poor people for the construction of houses of very low quality and an unpleasant aspect.

The third region is located in South America and covers Venezuela, Guyana, Surinam, and French Guyana. The bamboo forests are located along the basin of the Orinoco river. In this region there are several species: the first is *Guadua angustifolia*; the second is the same species known in Colombia as"guadua cebolla"; the third one is *Guadua amplexifolia*; and the fourth is *G. venezuelae*. All of these giant species are known in Venezuela by the vernacular name of "guafas" and all of them are in the period of extinction, due to the aversion which exists towards this plant because it is considered to be a weed.

The fourth region of natural pure bamboo forests was formed by the basin of the Parana River, covering Brazil, Paraguay, Uruguay and Northern Argentina. In this area several species, which include *Guadua angustifolia, G. Chacoensis, G. trinii, and G. Paraguayana*, were found. Today,in many places these species have disappeared because people are not interested in preserving them and only very small patches that will probably disappear soon can be seen.

In my trip to Paraguay in August of 1996 I saw several small forests of *G. Paraguayana* that probably will desappear if they are not used in any purpose. I think that is. very important for this country to make a study about its potential in the paper industry, or in the manufacture of comf composit materials like fiberboards (See the chapter of composite materials).

The fifth region was located in the Amazon jungle, in Acre, in the border of Brasil, Bolivia and Peru, and in the basin of the Purus River, an affluent of the Amazon River.. It was the largest mixed forest of the Americas.

According to the Colombian newspaper "*El Pais*" (1976), in that year the RADAM organization (Radar de Amazonas), using aerial photographs as part of its survey of Brazilian vegetation, discovered an area of 85.000 sq. kilometers which include around four giant species around this location.

Destruction of the giant bamboo species of the genus *Guadua* in Latin America

1) Destruction of the giant native species in the Amazon area of Brasil. In 1993, 17 years after the RADAM Organization (Radar de Amazonas) found this huge area of giant bamboos on the Purus river, the publication: "*Diagnostico Geoambiental e Socio-Economico PMACI (Projeto de Proteçao do Meio Ambiente e das Comunidades Indigenas)*- IBGE - IPEA) stated that there were only 32.000 sq. kilometers on the Purus river. This means that in 17 years 53.000 sq. kilometers were destroyed (3.100 square. km.per year).

In order to study the possibility of saving these species by cultivating them in other areas of Brazil, in August 1996, I visited part of the area of the Purus River, in Acre, Brasil, near the town of Sena Madureira. I was very lucky to find kindly families that invited me to spend several days at their homes onthe Purus River, like the family of Manuel Marquez de Oliveira and his wife Lourdes, and Adolar Rosella, for whom I feel the deepest gratitude.

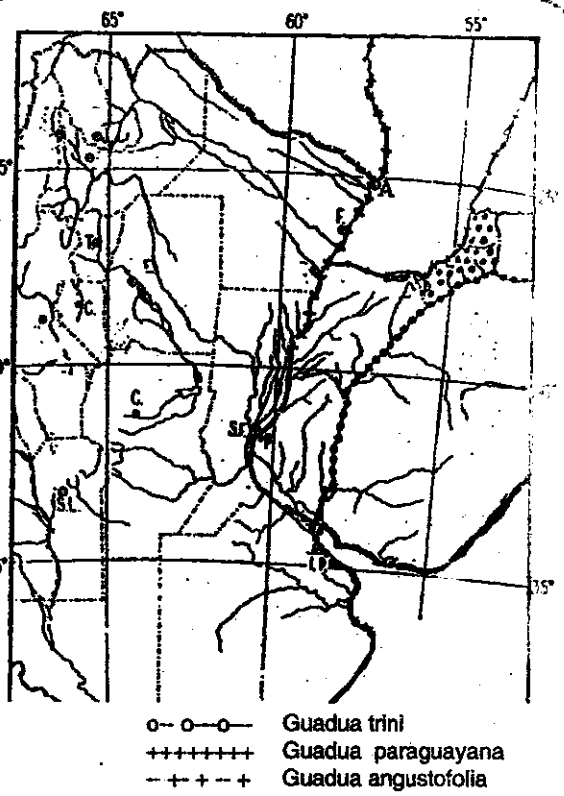
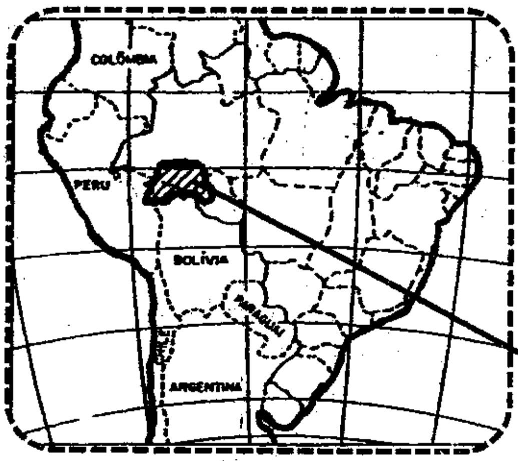


Fig 3.9 *The map shows part of the four regions where the species Guadua trinii, G. paraguayana and G. angustifolia were found in 1936 in the northeastern part of Argentina, in the basin of Parana River. Most of the bamboo of this region has disappeared .(Parodi 1936).*



Fig, 3.10 A *Map of South America showing the location of the largest bamboo reserve of the Americas which in 1976 had an area of 85.000 sq. kilometers, in 1993 only 32.000 since the rest had been destroyed by the colonists.*

B.- Enlarged area shown in the map

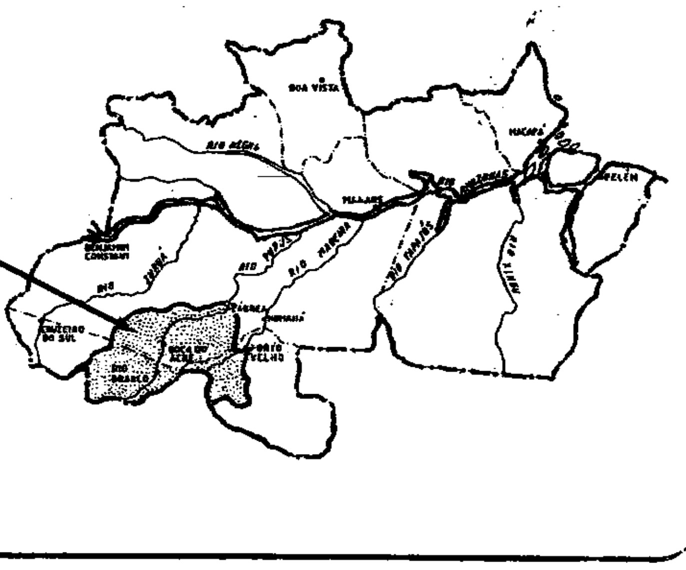


Fig.3.11 *Even this type of bamboo, which does not belong to the Genus Guadua, could be used for the manufacture of particle boards.*

Fig.3.12. *The destruction of the jungle. All of the large trees are cut and sold. The rest, including bamboos, are destroyed by fire.*

I will remember with terror for the rest of my life,the four hours that we got lost in the jungle with Manuel Marquez, looking for a bamboo species.

During my visit to the Purus river I could observe how the bamboos were set on fired. Figs. 3.11 and 3.12. The problem is so serious that according to the colonists that I met in Sena Madureira and Rio Branco on my return, at the present rate of destruction, the remaining species in this area, which in the nineteen seventies was the largest bamboo reserve of the Americas, will disappear in the first decade of the 21 st century.

Unfortunately, all the efforts that I have made up to now to get financial support for saving these especies, have been in vains because in Brazil and in general in the Americas nobody is interested in the preservation of our native giant species of bamboo, and the American foundations which I have asked for money have answered that they do not have money or that they are not interested on bamboos.

The only collaboration that I received in Brazil, which I have appreciated very much, is the offer of lands for planting this species that I received from FUNTAC (Fudaçao de Technologiaa do Estado do Acre) in Rio Branco.They offered me 40,000 hectares, when I needed only 20 hectares. Also the University Stadual Paulista UNESP, and the Botanical Garden of Bauru, Sao Paulo, both offered me small areas for cultivating and preserving these species.

I alsowant to thank also to Paulo Roberto Zandomingues, Director of researches in FUNTAC and Prof. Marco Antonio Pereira of the UNESP for their interest in helping me.

During the ten days I spent in the Amazon jungle I was only able to visit two places on the Purus River thanks to Manuel and Adolar. My purpose was to visit other places on the Purus River, but to rent a canoe with a driver, two helpers and fuel was very expensive and I could not afford it ($ 2,000 U.S dollars for three days) and the money that was obtained from a Hawaiian foundation for this purpose disappeared.

Fig. 3.13 *After everything is consumed by the fire, grass is planted for the cattle. In other contries, instead of grass different crops are planted.*

Fig. 3.14 *The Purus river in the dray season. In the basin of this river, the largest bamboo reserve of the Americas which may disappear in few years is located.*

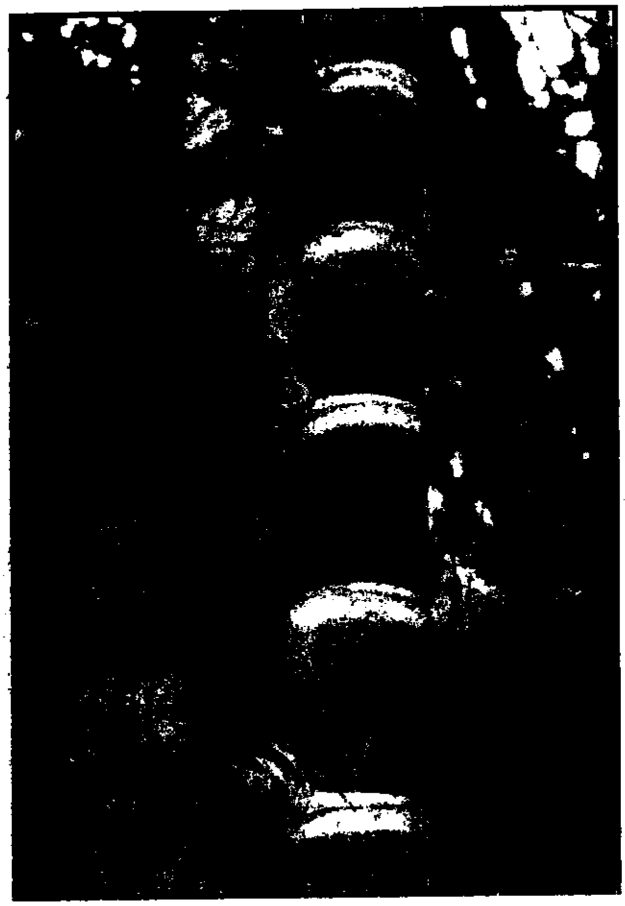


Fig. 3.15 *This species is Guadua angustifolia because it has the same characteristics: one main branch in each node and the lower branches are long with thorns.*

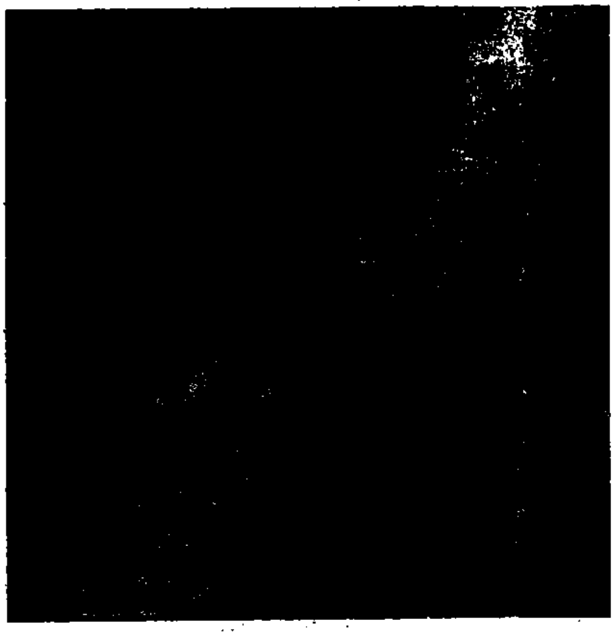


Fig. 3.16 *In this species that we found in the Amazon jungle the main branch has two lateral branches which are not seen in the Fig. 3.15. This species is probablyGuadua superba Huber. This species has the same diameter and height as that shown in Fig 3.15.*

For this reason I could not visit other places that were located far away. But in these two places I found the two types of culms of genus *Guadua*. shown in Fig 3.15 and 3.16. They are different varieties because the base of the branches are different

The diameter of both culms are 14 centimeters, the thicknes of the walls at the base is 2.5 cm and the height is about 20 meters. The quality of the culms is very good and they could be used in the manufacture of composite materials and structures.

On my return from Sena Madureira to the city of Rio Branco, I met Mr. Nielson Paulo Piovesan who had traveled to this city in order to buy an area of about 3.330 hectares in the Amazon jungle which he was to transform in pasture in about 8 to10 years. Two of his friends bought the rest of the land in order to complete one million hectares. Mr Piovesan told me that between 1975 and 1994, a jungle area of 600 kilometers long by 200 kilometers wide located between Porto-Velho and Cuiba was transformed into large cities and towns. In this area millions of bamboos were destroyed.

If the government of Brazil would have established the norm that the colonists had to leave temporarily small patches with different species of bamboo, they had not di sappeared.

2) The destruction of the giant native species from Mexico to Ecuador.

The destruction of the giant bamboo species of the Americas which originally grew in all the countries from southern Mexico to northern Argentina, began during the conquest of the Americas with the arrival of the Spanish conquerors to Mexico, Central America and northern South America, where they started a sanguinary persecution against the Indians in order to steal their treasures or with the purpose of dominating them.

This period ended in the sixteenth century with the genocide of 90% of the indigenous population of the Americas, many of which perished incinerated by the Spanish conquerors in the bamboo forests where they sought protection or where they used to have their towns. With them, their traditions disappeared as did the precolumbian bamboo culture that existed in most countries from Mexico to Peru. Consequently, many large cities, such as Gumarcaah in Guatemala, disappeared.

According to Resinos (1952), Gumarcaah, the largest and most important city in Central America, was the capital of the Quiche culture, whose people were the descendants of the Mayas. The Aztecs of Mexico called this city Utatlan, which means the city of "cañaverales" or canefields, because it was surrounded by bamboo forests. This city was set on fire by the Spanish conquerors after killing the king, and most of the inhabitants were incinerated.

In order to have an idea of the largest bamboo forests which existed in Colombia in the sixteenth century, inside of which the Indians used to build their towns, I would like to quote Fray Geronimo Escobar, a Spanish clergyman who made the following reference to the city of Cartago, which at first was located at the present site of the city of Pereira in the state of Risaralda, Colombia, "*This town is surrounded by a dense bamboo forest with large canes more than ten leagues wide*" (Patiño 1975). (One league=5,752 meters).

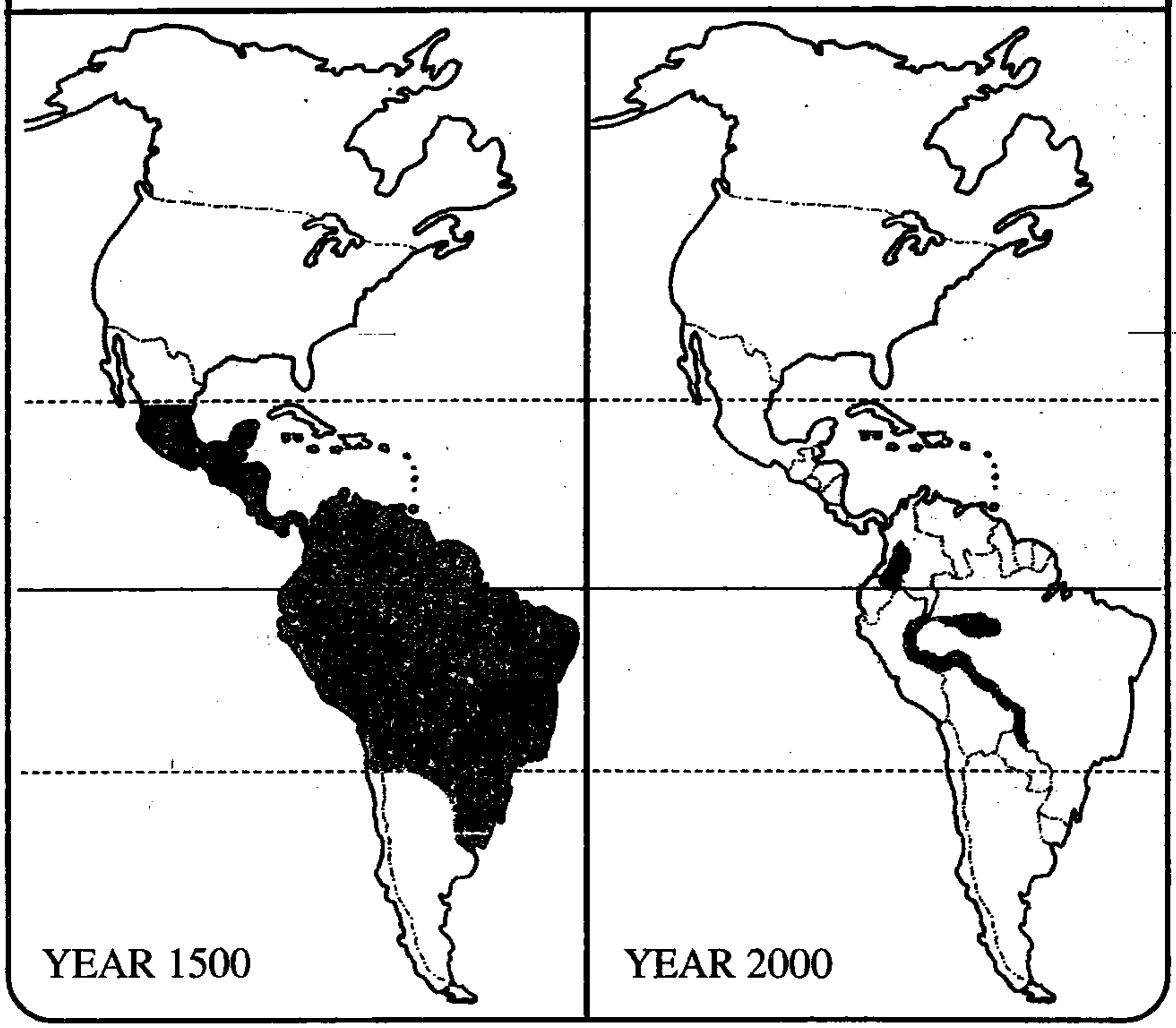
This means that the bamboo ring which surrounded the city was more than 57 kilometers wide. Today it is necessary to travel almost the same distance fromPereira in order to find a small bamboo grove Needless to say, thousands of square kilometers of bamboo were destroyed by fire by the Spanish conquerors, not only during the conquest of the Americas, but also during the colonial period when the largest cattle farms were established by Spanish families.

At the beginning of the nineteenth century, the second largest destruction of bamboo in Central America, Colombia and Ecuador occurred. It began in 1899, when the United Fruit Co. of the United States, was established in Colombia and Ecuador, and based on the belief that the species Guadua angustifolia, *G.aculeata* and *G. amplexifolia* were plants indicative of good soil for planting bananas, this company transformed great extensions of pure bamboo forests into banana plantations in these countries. In Colombia alone, this company destroyed more than 60,000 hectares of bamboo forests which were transformed into 41 banana plantations, which were reduced to 4.000 hectares in 1986 (*El Tiempo*, November 9, 1991).

But the largest scale destruction of the bamboo forests in Latin America started after the Second World War, in the nineteen fifties, when President Eisenhower of the United States promoted agricultural and cattle development in most Latin American countries. Since that time, millions of hectares of bamboo forests have been razed to be replaced by coffee, rice, sugar cane, corn, or bananas and cattle development.

The worst part, though, is the fact that from that time up to the present, it has been impossible to restrain this

Fig. 3.17 - 500 YEARS OF DESTRUCTION OF THE GIANT SPECIES OF THE GENUS GUADUA



destruction, because none of the goverments of our countries were opposed to it. Colombia was the only country which, in the nineteen sixties, could stop the destruction of our native species when they were on the brink of extincion, thanks to the Colombian Institute of Natural Resources (INDERENA), which at that time established a regulation that is still in effect. According to this regulation, it is forbidden to cut bamboo, and it is necessary to get permission from the INDERENA (or its representatives) in order to cut it. Thanks to this entity, we have preserved most of our native species. Otherwise these specieswould have disappeared from Colombia many years ago, as has happened in the rest of Latin American countries, including Mexico, Venezuela and some Central American countries where their native giant species were razed while in other countries they are on the brink of extinction, as in Ecuador.

On the other hand, in Colombia bamboo is the most important material for farmers who live in areas where this plant grows because this material is used in rural areas in the construction of houses, warehouses, milk pails, henhouses, bridges, telephone and electrical posts, fences etc. For this reason, on most farms, there are one or several bamboo patches depending on the size of the farm. This is why farmers believe that a farm which has one or several patches of "guadua" is more valuable, whereas on the coast of Ecuador, farmers believe the opposite: that a farm with bamboo patches has a lower value and it is necessary to cut them in order to increase its value. This is due tothe aversion which exists in Ecuador towards the giant native species of bamboo because of the low quality houses that they build with this material.

Consequences of the aversion and ignorance which exist in our countries towards the giant native species.

The aversion towards the native giant bamboo species is found in Colombia and other Latin American countries, but to a lesser degree than in Ecuador. It is possible that we have inherited it from the Spaniards who came to the Americas in the sixteenth century and who had as a maxim that "Spaniards who have any self respect do not live in bamboo houses but in adobe houses". This was not interpreted as a safety measure (although the Indians used to set fire to the Spaniard's houses when they first lived in bamboo houses), but was considered as an aversion towards the giant bamboos, which, due to their abundance, were looked upon weeds that were only used by the Indians and poor people in the construction of their houses. Consequently these plants were considered as the Cinderella of our natural resources.

This aversion has been the cause of the lack of interest in studying the giant bamboo species in the scientific and technical fields or for preserving these species, that exists in our universities and forestal research centers. This iswhy many species have disappeared from the Americas, as was explained before. If we revise the great diversity of treatises which Latin American botanists have written about the flora of their countries, we find very thorough studies, even on plants with practically no economic value.

However, the most ironic part of this is that in these treatises one cannot find any botanical information about any of the native bamboo species, not even in Colombia where this plant has made the greatest contribution to the economic and social development of the country.

On the other hand, in most countries in Southeast Asia and particularly in China, Japan and India, bamboo is the plant which for many centuries has exerted a great influence on their life, culture and economy and today they are the leaders in the research on their most important native bamboo species. Many studies and publications have been made by their universities and research centers, not only in the scientific fields, which include taxonomy, morphology, physiology, anatomy, ecology and genetics, but also in the technological field in which the industrial uses of their most important species have bee studied.

Due to the lack of technical and scientific information which exists in our countries about our bamboo species, there are no professors in our schools and universities, and particularly in the forestry engineering and agricultural colleges, who transmit to their students the most elemental knowledge about this plant. As a consequence, the great majority of professionals who complete their studies in these colleges not only ignore the fact that our giant species are not trees, but also how to cultivate them. They believe that if they have not received any information about the bamboos in their colleges, it is because this plant really is a weed which is not important for the country. Due to this, when they get high positions in the management of forestry programs, they do not include our bamboo species because they have no interest in this plant.

As a consequence of the above, there is a complete ignorance in all social, economic and academic levels in our countries about our giant bamboo species and particularly about the botany of this plant, which has generated the following problems:

1.-Most people associate the term bamboo only with the plant which generally has yellow culms with green stripes and adorns the parks of our towns and cities (*Bambusa vulgaris var. vittata*), which is believed to be native to India or Burma. There is the belief that the giant green bamboo species are not bamboos but trees because many times they are found mixed with trees in the forests of our countries. For this reason, it is very common to see articles in the newspapers and magazines in Colombia in which reference is made to "guadua and bamboo" and really "guadua" is a bamboo.

2.-As was mentioned before, the giant bamboo species of the genus *Guadua* were originally distributed from Mexico to Argentina and in each country (except Chile where this species do not grow) there were generally a minimum of 2-3 different giant species. In Colombia, there were about 7-8 giant species and in Brazil about 12. Some of these species grew in several countries, as is the case of *Guadua angustifolia* which grew in most of the countries in South America.

3-Due to the similarty which exists among all the giant bamboo species in relation to the shape of their shoot and the shape and color of the culms of all the species once they are developed, the majority of people in different Latin American countries believe that all their native species are the same with different dimensions. This is why in each country, all of their native giant species are known by one vernacular name which varies from one country to another.

For example, in Colombia all of the 7 giant species are known by the vernacular name of "guadua"; in Ecuador as "caña guadua"; in Peru as "caña de Guayaquil"; in Bolivia as "tacuarembo; in Argentina as "tacuara"; in Paraguay as "tacurupucu"; in Brasil as "tacuaruçu"; in Venezuela as "guafa"; in Panama as "cañaza"; and in Mexico and other Central America countries they are known by the vernacular names of "tarro" and "cañabrava".The term "cañabrava" is also used for other species of canes.

4.-The erroneous belief that in Colombia there is only one giant bamboo species which is known by the vernacular name of "guadua" and by the scientific name of *Guadua angustifolia*, has caused a lot of confusion in the thesis written by engineering students about studies of the physical and mechanical properties of this material. Generally the titles of these thesis are "Study of the Physical and Mechanical Properties of Guadua" or "Physical and Mechanical Properties of *Guadua Angustifolia*". These studies have no value, because in the first case they do not indicate which of the 7 species of "guadua" was used in the experiments.

The second case, it is very difficult to know if the students really used "macana" (*Guadua angustifolia*) or if they used "guadua cebolla" or "guadua de castilla" or some other species which, for them, has the same scientific name. Consequently these studies are not trustworthy.

The same problem exists in Argentina in relation to the study about the physical and mechanical properties of "tacuara" (the vernacular name of the giant bamboo species in this country) which was carried out in one of the schools of engineering with the title "Physical and Mechanical Studies of 'Tacuara'". The thesis did not indicate which of the 3 species of tacuara that they have in Argentina was used in this study. On the other hand, the students who know that there are only 2 species believe that both have the same mechanical and physical properties, and this is not true, as we will see in the chapter on mechanical properties.

5.-Some of the people who are in charge of bamboo nurseries confirm the belief that there is only one species in Colombia, based on the fact that there are no clear differences between the seedlings of different species of "guadua" (when they are small). They erroneously believe that any of the seedlings of "guadua" that they are selling will generate one of the 3 best known species used in construction, depending on the place or habitat where it is cultivated. In other words, any guadua seedling can generate "guadua de castilla", "guadua cebolla", or *Guadua angustifolia*, depending on where it is cultivated. This is as absurd as believing that if a lemon seed is planted at 200 meters above the sea level, this seed will produce oranges and at 700 meters, it will produce grapefruit. As a consequence, if anyone goes to a bamboos nursery and wants to buy *Guadua angustifolia*, they could sell him a different species, for example "guadua cebolla". I want to clarify that the people at the nurseries do not do this in bad faith but rather out of ignorance.

6.- The most common problem is that most people, including many of those who work in the bamboo nurseries, do not know how to distinguish one species from another in the forest, for example, *Guadua angustifolia* from "guadua cebolla", with the exception of "guadua rayada amarilla" or "guadua rayada negra". As a consequence, the same problem mentioned in item 5 will occur, that is, if someone goes to a bamboos nursery and wants to buy *Guadua angustifolia*, they could sell him a different species. I believe that this problem has caused the one described in item 5.

7.-Another problem that causes a lot of confusion occurs when the common or vernacular name that is given to a specific species of bamboo in one country or region, is the same as that given to a different species of bamboo or to a cane that is not a bamboo in another country or region. For instance, in Ecuador the term "caña brava" is used as the vernacular name of the species *Guadua angustifolia*, on account of the thorns on its branches. In Mexico and Guatemala the species *Guadua aculeata* is known by the same vernacular name for the same reason.This has originated such confusion that there is an article in a magazine in which the author said that "the same bamboo species, known as caña brava in Ecuador grows in Mexico". But the term "caña brava" is also the common or vernacular name that, in many countries, is given to a native cane that is not a bamboo. This cane has the scientific name of *Gynerium sagittatum* and is also used in the construction of walls and ceilings in several countries.

8.-The lack of scientific names for some of the giant species that are the most used in construction in Colombia, such as "guadua de castilla" and "guadua cebolla", has been a barrier for the use and the identification of these species in technical and scientific works.

In September of 1980 I asked two of the most important botanists in the United States, who were dedicated to the study and identification of herbaceous bamboos of the Americas, why there was more interest in the study of herbaceous bamboos, that are not so important from the economic standpoint instead of first studying the giant bamboos that are used the most and do not yet have a scientific name.

The answer was, *"First, because the herbaceous species are disappearing from the Americas, and second, because the woody giant species of the genus Guadua are the most difficult to identify. For these reasons, most taxonomists are more dedicated to the identification of herbaceous bamboos than they are to the identification of the giant woody species."*

I still don't understand how it was possible that Humbolt & Bonpland, Kunth and other European botanists who came to the Americas at the beginning of the nineteenth century could have identified most of the giant species using a small low quality magnifying glass without any information about bamboos because at that time there were not any scientific publications about this plant. How is it that today, when the best electronic microscopes exist, and the most complete information about bamboos has been developed in Japan, China and India, it is still difficult to identify the giant bamboo species of the genus Guadua?

DNA (Deoxyribonucleic acid) and the identification of species

Colombia is the only country in the Americas where still exists a bamboo culture but related to the use of its largest native species in construction. In this field this country has developed the best construction technologies which exist in the world. Nevertheless, as I explained above there is in this country the most complete ignorance about our giant species and particularly of the four giant species which are the most used in construction.

As I explained before, most of the people believe that all these giant native species are the same specie which is known with the common name of "guadua" and with the scientific name of *Guadua angustifolia*. This is due to the similarity which exists among the culms and particularly among the seedlings of these species when they are small. Due to this reason some people which works in bamboo nurseries believe that if one of these seedlings is cultivated in different locations they can generate "guadua macana", *Guadua angustifolia* or "guadua de castilla", or " guadua cebolla" depending of the habitat where the seedling is cultivated.

In order to solve these problems and the identification of our giant species which still has not scientific name it is very important to study the DNA of each one of our most important species. By the other hand this information will solve the doubts which exists about the identification of some of our native species in Colombia and other countries of the Americas.

What is DNA?

Information governing the characteristics of all organisms is stored in long thin molecules of deoxyribonucleic acid (DNA).. DNA molecules contain regions (genes) that specify the structure of other molecules called proteins. Protein-molecules in turn control cellular chemistry and contribute to cell structure.

The basic unit of life is the cell, an organized set of chemical reactions bounded by a membrane and capable of self-perpetuation. Our bodies are collections of trillions of cells working together, with each cell having its own identity and function. With few exceptions, every cell contains all the information required for an independent existence; indeed, under the right conditions, human cells can be removed from the body and grown in laboratory dishes.

According to Drlica (1992), the information necessary to control the chemistry of the cell (i.e. the chemistry of life) is stored in the long thin fibers called DNA. Each DNA fiber is a molecule, a group of atoms joined together to form a distinct unit. DNA fibers are found in every cell except mature red bood cells, and they dictate how a particular cells behaves. Thus DNA controls our body chemistry by controlling the chemistry of each of our cells.

Isolated DNA looks like a tangled mass of string. Our cells, which are generally less than a millimeter long, contain about two meters of DNA specially packaged to fit inside. DNA can be bent, wrapped, looped , twisted, and even tied into knots. Many DNA molecules are circles, which are sometimes found interlinked like a magician's rings. In terms of three-dimensional structure, DNA is very flexible, but in terms of information content, DNA is quite rigid, for the same information must pass from generation to generation. Distinct regions of DNA contain distinct bits of information. The specific regions of information are called genes. In some ways DNA is similar to motion picture film. Like film, DNA is subdivided into "frames" that make sense when seen in the correct order. In DNA the "frames"correspond to the letters in the genetic code. When a number of frames or genetic letters are organized into a specific combination, they create a scene in the case of film and a gene in the case of DNA..

Information in genes is used primarily for the manufacture of proteins. Proteins are chainlike molecules that fold in a precise way to form specific structures. Some proteins contribute to the architecture of the cell while others directly control cell chemistry.

Occasionally we can easily see the effects of particular genes and proteins; for example, a small group of genes is responsible for determining eye color. It is the specific information in the DNA, in the genes, that makes human beings different from honey bees or fir trees. Information in your DNA makes you different from anyone else on earth, unless you have an identical twin (Drlica 1992).

1.- Chromosome number in bamboo

If bamboo is going to be fully domesticated and used in breeding programs, an understanding of its basic genetics is a prerequisite; unfortunately genetics of bamboo remain to be unravelled and the study of bamboo genetics has been restricted mainly to chromosome counts. In many bamboos, the somatic numbers may differ between tissues, and the number referred to is the most common number. Common numbers are $2n = 48$ for temperate bamboos, and $2n = 72$ for tropical bamboos. In subtropical China, a number of species are found with chromosome numbers $2n = 64$. The highest chromosome number is in *Bambusa variostriatus* where $2n = 96$ (Guangzhu 1987).

2.- Fingerprints of bamboo

According to Gielis, 2001 (personal communication) In the second half of the twentieth century very rapid progress has been made in unravelling the secrets of life, in DNA and proteins. Several biotechnological techniques and tools make it possible today to study the DNA of bamboo. One of the most promising techniques is fingerprinting of bamboos. With tools such as Amplified Fragment Length Polymorfism fingerprints can be generated that allow to distinguish every individual bamboo, or every single seed in a seed lot. While today taxonomists, ecologists and foresters have great difficulty in distinguishing different bamboos within a single species, DNA-based technology circumvents all problems.

Building a database of such fingerprints will be an important aid for bamboo study. It would allow to distinguish several clones of *Guadua* that are nowadays considered as the same species.Besides fingerprinting DNA based technology will also allow in the future to precisely determine specific gene sequences in bamboo, and this in turn will allow to modify certain characteristics of bamboo. The amin problem for genetic improvement through breeding however is the complete lack of controllable bamboo flowering, which still remains one of the greatest mysteries in botany.

3.- Estimation of DNA content of some bamboos

To estimate if the complexity of the DNA of bamboo was comparable to rice DNA, Gielis, et al (1997), carried out an estimation of the DNA content of 16 temperate and 10 tropical bamboo genotypes using flow cytometry (FCM). When a fluorochrome is applied to the cells and binds to the DNA, this DNA gives a flurorescent color when illuminated by.a laser beam and the color intensity is measured by the Flow Cytometer. The range of application is very large; among other uses, FCM can measure cell size and DNA content.

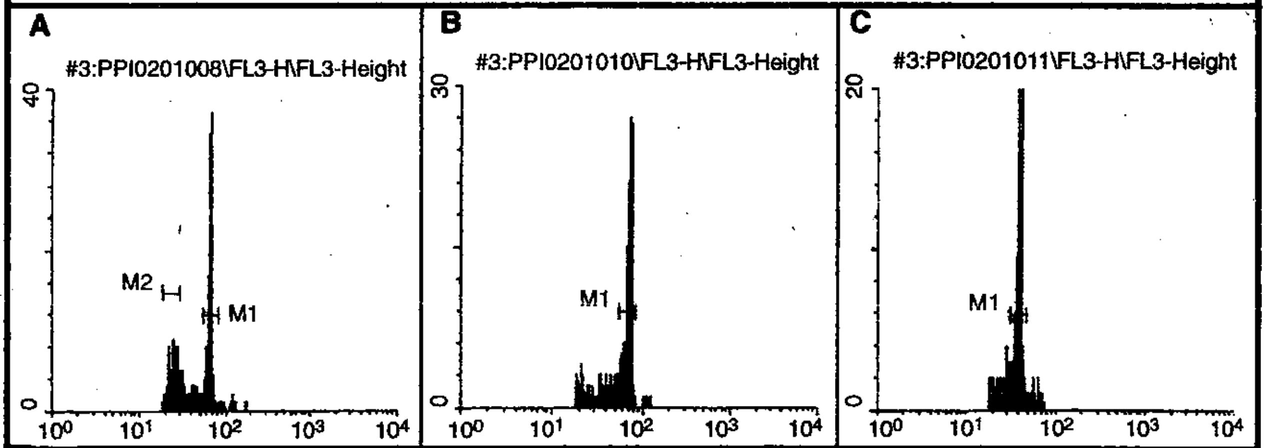
An important result has been that two distinct groups of bamboo exist, namely tropical bamboos and temperate bamboos.The latter group has fewer chromosomes (2n = 48), but it has a higher DNA content than tropical bamboos which have 72 chromosomes. The chromosomes of tropical bamboos are more numerous, but they are also much smaller. The DNA content in bamboo is comparable to the amount present in rice if calculated per chromosome (rice has only 24 chromosomes in the vegetative state). This confirms the very close evolutionary relationship between bamboo and rice (Gielis 2001).

Table 3-4 Estimation of DNA content in 16 temperate and 10 tropical bamboo species using flow cytomery (FC) and confocal laser scanning microscopy (CLSM)

Bamboos	DNA (pg) 2C M	
	FC	CLSM
Bashania fargesii	4.45	
Chimonobambusa quadrangularis	5.17	
Chimonobambusa marmorea	4.4	
Fargesia murielae	5.11	5.32
Indocalamus tesselatus	5.18	
Phyllostachys aurea	4.18	4.8
Ph. bambusoides	4.18	
Ph. edulis	4.19	
Ph. nigra	4.17	
Ph. vivax	4.25	
Pleioblastus viridistriatus	4.67	
Pl. pygmaeus var. pigmaeus	4.66	
Sasaella glabra f. albostriata	5.35	
Sasa palmata	4.95	
Shibataea kumasasa	5.11	5.3
Yushania anceps	4.5	
Bambusa multiplex	3.03	
Bambusa multiplex cv. *Fern leaf*	3.23	
Bambusa vulgaris		
Old leaves	2.45	2.56
Young leaves	2.85	2.98
TC leaves	3.02	
Bambusa striata		
Young leaves	2.7	2.68
Old leaves		2.39
Dendrocalamus asper	3.04	
Dendrocalamus strictus	2.9	
Guadua angustifolia	3.03	
Oxythenanthera abissinica	2.94	3.11
Thyrsostachys siamensis	2.353.6	
Lithachne humilis		3.56

Source: J.Gielis, P. Valente, C,Bridts & J.P. V. 1997.

Fig. 3.18 *Flow cytometry peaks of bamboos:* **A.** *Fargesia murielae.* **B** *Shibataea kumasasa.* **C** *Bambusa vulgaris striata*



Source: J.Gielis, P. Valente, C,Bridts & J.P. V. 1997.

4 BAMBOO ECOLOGY AND SILVICULTURE

ENVIRONMENTAL CONDITIONS FOR BAMBOO GROWTH

Bamboo silviculture is the science that deals with the technology and methods for bamboo afforestation or reforestation. According to Ma (1994), different species have different growth and development patterns, and different requirements for environmental conditions. In the same way, bamboo forest growth and development are dependent on the genetic characteristics of the species and on the environmental conditions. Forestry is different from agriculture. Its production period is longer than that of agriculture; generally nine or ten years are needed.

In order to achieve expectations, i.e. fast growth, high quality, high yield and strength, it is necessary to select the species with the best adaptability and the highest economic profit according to particular environmental conditions, or to select the best climate, soil and topography for a certain bamboo species. That is to say, selecting a suitable species for a certain site. In order to reach the target mentioned above, first of all, it is necessary to know the requirements for each species as regards climate, topography, soil, etc. For example, different species need different climatic conditions such as temperature, precipitation, relative humidity and so on.

The environmental conditions for the growth of bamboos vary widely among the numerous bamboo species and are concerned with many associated factors like latitude and altitude, temperature, rainfall, soil, and topograhy. The growth of bamboo in North China is obviously consistent with the climatic cycle during the year. Seasonal changes influence the growth and phenological phases of bamboo. Similar temperatures are required for the sprouting and growth of bamboo shoots, in spring and in autumn alike. The four seasons of the year are very distinct in North China, and the growth of bamboo in this area is such that in spring the bamboo sprouts, in summer, the rhizomes grow, in autumn new shoots are developed, and in winter the plant becomes dormant, following the climatic cycle.

1.-Latitude and altitude

In the world, all of the bamboo species are distributed at different latitudes and altitudes according to the species. Geographically, bamboos are distributed horizontally in the tropical, subtropical, and temperate areas of all continents (except Europe), between a latitude as far north in Asia as 510 and 470 south latitude in Argentina and Chile. According to Porterfield (1926), in China bamboo does not grow wild north of 350.

The vertical distribution is from sea level to a maximum of 4,000 m in the Himalayas in Asia, and almost 5,000 m. in the eastern chain of the Andes in South America.

In the Americas, the native species grow between 46° north latitude in the southeastern part of the United States and 47° south latitude. In the case of the species of genus *Guadua*, they grow approximately between the Tropic of Cancer in Mexico and as far south as about 34° south latitude along the Parana and Uruguay Rivers. Most of the giant bamboos of the genera *Guadua* grow at altitudes which vary between almost sea level and 1,900 meters.The best quality of these species is found between 1,000 and 1,600 mts above sea level. Above 1,900 m. the diameter and height, start their reduction.

There are species that predominate at low and medium altitudes of the tropical areas and others at high elevations or altitudes in tropical areas or in temperate climates in high latitudes. Altitude and temperature are closely related and it is difficult to separate one from the other. For example, some species of Phyllostachys which grow in temperate zones at low elevations can also grow at high elevations in the tropics.

2.-Temperature

Temperature is a very important factor for the growth of bamboo. Higher temperatures generally promote their growth, and lower temperature inhibit it. Most bamboos grow at temperatures which vary between 9° C. and 36° C. (48° F. and 97°F). *Guadua angustifolia* and other giant species of this genus grow well at temperatures between 20° C and 26° C. with a relative humidity of 80%.

Most pachymorph bamboos have lower resistance to cold, so only a very few, such as *Bambusa glaucescens*, can grow in the natural conditions in central subtropical areas. Most of the leptomorph bamboos have higher cold resistance to the cold, so they can be planted at high elevations in tropical areas.

The temperature is determined more by altitude than by latitude. Generally a rise in the altitude of 270 meters accounts for a fall of 1° C. in mean temperature.

According to Young (1946), the U.S. Department of Agriculture began cultivation of the specie *Guadua angustifolia* in Florida, and found that the plants suffer from frost injury at temperatures below -3° C and are cut to the ground at temperatures 2 or 3 degrees lower while at -8° C (17° F) they may be killed outright.

3.-Rainfall

There is not a single environmental factor that limits the growth of bamboos more than rainfall. As a component of the climate, it affects the distribution of bamboos. During the dry season, the plant reduces transpiration by shedding leaves.With the first rains, new buds or culm shoots emerge and the culms will then be crowned with leaves. This shows that the vegetative growth in bamboos is more affected by soil moisture as a result of rainfall than by temperature.

However, bamboos retain their green leaves all year round when they grow along rivers or streams. Bamboos that grow in moist soils generally have larger leaves than do those species growing in drier sites.

On the average, an annual rainfall of 1,000 / 2,000 mm is needed. Probably the minimum and maximum average annual rainfall required for a bamboo species is that indicated by Deogun (1936) for *Dendrocalamus strictus* in India: a minimum of about 762 mm (30 inches) and a maximum of 5,000 mm (200 inches). The best giant species of the genus *Guadua* are located in places where the annual reinfall is above 2,000 mm.

4.-Soils

Most bamboos are unsuited to soil with excessive moisture. They grow best on well-drained, fertile, friable soil, such as sandy loam, loam with a granular structure derived from river alluvium or from the underlying rocks. Soils that are suitable for bamboo growing vary from yellow, to clear reddish yellow, to brownish yellow.

Species which grow in fertile soil, are usually taller and have a greater diameter than the same species cultivated in dry or poor soils. But there are also bamboos like *Dendrocalamus strictus* from India, which, according to Deogun (1936), prefer coarse grained dry soils such as those derived from sandstone, granite and granitic gneisses. It is completely absent from the pure quarzite soils particularly favored by salt. In some places of India it has been successfully planted on sand dunes.

Land with a high water table or low land to which water easily flows is very unsuitable for growing bamboo. A river bank is an apparent exception to this rule, but it is sumerged only temporarily and the flood waters carry fertile soil and deposit it along the bank. For this reason, we see many bamboos forming picturesque stands along river banks. Rarely can one find bamboos in continuosly swampy places, with the exception of *Guadua aplexifolia* which grows in swampy areas in Yucatan, Mexico.

In the book Kuang Chun Fang Pu (Thesaurus of Botany 1708) it is said that in ancient China in the southern part of Omei Mountain in Sichuan Province, where the face of the mountain is as vertical as a wall, there was a bamboo known as Chien sui chu (Thousand year bamboo) that could only grow on gravel and stone soils. In order to propagate this variety, one should set the young bamboo in a basket filled with gravel and stones. This bamboo was used as an ornament to suspend from the front eaves of the house. If earth is piled up around its culm, it will wither and die.

Tropical bamboos have weak saline resistance and saline soils are not good for their growth and development. A pH of about 5-6.5 is most suitable for bamboos. According to Uchimura (1987), even with a pH 3.5 it is possible to grow bamboo. (pH values from 0 to 7 indicate acidity, and from 7 to 14 indicate alkalinity).

5.-Topography

In growing bamboo, it is best to select land with good natural drainage. In this respect a hillside or the foot of a mountain is the proper place to develop a grove. According to Takenouchi (1932), a hillside with a slope of 7 to 8 degrees is most desirable. In Japan, it is preferable to select a slope facing southeast or south. A south or southeast slope receives intense sunlight, and on a northern slope the bamboo is likely to be injured by snow in the winter season. However, since *Phyllostachys nigra henonis*, as compared with other bamboos, has a stronger resistance to wind and snow, it is better to develop a hillside grove of this species on a slope where strong winds blow.

On the other hand, topography has a very important influence on the bamboos' strength. Experiments conducted in Indonesia (Soeprayitno, et al 1988) came to the conclusion that the specific gravity, static bending and tensile strength of the culms growing on hill slopes are higher than they are in those growing in the valley. For this reason, it is recommended that hill slopes areas be used for planting giant bamboos for construction and other uses instead of wasting these areas. Bamboo is also the most appropriate plant to be grown in areas where there are problems of erosion or inorder to prevent it.

6-The influence of tree species in the development of bamboo in mixed forests (biotic factor)

Besides the environmental conditions mentioned above, the distribution of areas where bamboo can be grown is somewhat governed by the surrounding flora. In the study conducted by Huang (1988) in Fujian, China, he found that some tree species seriously affect the growth of *Phyllostachys pubescens*. When this species is mixed with trees such as *Myrica rubra*, *Photinia glabra*, and *Liquidamlar formosana*, the per unit area yield of phyllostachys is higher than that of purebamboo stands. However, while mixed with *Taxodiaceae*, *Pinus* and *Fagaceae*, its per unit area yield is lower than that of pure bamboo stands.

The average breast-height diameter, whole height and clear-bole height of *Ph. pubescens* in mixed forests are all higher than those in pure stands-whose density is less than 2250 culms/ha. The observations showed that trees like *Photinia glabra*, *Liquidamlar formosana*, and *Myrica rubra* are good accompanying species, which should be retained in mixed forests. *Quercus acutissima* and *Pinus massoniana* are harmful to the growth of bamboo, and, therefore, they should be cut. *Cunninghamia lanceolata* is more valuable, though it is not good for bamboo, so it should be retained moderately.

The same author considered that if the vast area bamboo mixed forest were changed into pure bamboo stands, the ecological balance would be destroyed and diseases and insect pests would increase.

Porterfield (1926) points out that bamboo in China does not grow in the presence of oak or chestnut. Persimmon trees do not check the production of shoots. This is probably due in part to the effect of root excretion. Some may have observed the frequent association of bamboo with conifers in many places of Chekiang, in the Fang district of Hupeh. On the other hand, according to Barrett (1992), in Japan the bamboo splints used for the manufacture of the common type of mold or flexible screen known as *su*, on which the finest paper is still made by hand, are taken from bamboo growing among cedar trees. In such an environment, the bamboo has a tendency to grow straighter and with a greater distance between nodes, as a result of its effort to reach the light above the cedars.

BIOMASS OF BAMBOO STANDS

Biomass of bamboo stands is the amount of living matter in a particular area, such as culms, branches, leaves and rhizomes, in relation to the diameter at breast height (or 1.3 m height above ground) expressed as weight per unit area of habitat or as volume or weight per unit volume of habitat. Such investigation is necessary to understand the ecological characteristics of bamboo species in comparison with tree species.

One of the few investigations in this field in Japan was carried out by Suzuki (1987), using the following method:

The plot size for the investigation is ordinarily from 10 x 10m to 20 x 20m depending on average height of standing bamboos. After setting up the plot in the stand, diameter at 1.3m high above the ground (DBH) of all bamboos is calipered, and then about ten sample bamboos are selected and felled. After the height of each sample bamboo is measured, the bamboo is divided into one or two meter deep strata, excepting the base and the top.

The fresh weight of each part of each stratum, such as the culm, branches leaves and other living organs, is measured separately. For conversion of fresh weight to dry weight, small samples of each part are brought back to the laboratory and dried at 85° C to obtain a constant weight. To calculate the leaf area of the study stand, the leaf area of the leaf samples is measured by an automatic area meter before drying.

Allometric correlation has been the main method used for the estimation of forest biomass in Japan. This method is based on the relationship between D2H and the amount of parts in the sample bamboo. The relationship is represented asfollows: Log W = A log. D2H + B where W is dry weight, D is DBH, H is height ,and A and B are constant. A and B are calculated by the least square method.

Results. Table 4-1 shows the above ground biomass in five bamboo stands of three species which are popular in Japan, estimated using the regression formula mentioned above.

The above ground biomass of the five bamboo stands shown in Table 4-1 ranges from 48.2 - 105.6 ton/ha. On the other hand, in cases of tree stands, 254.4 ton/ha was found in a *Chamaecyparis obtusa* forest in Japan, 260.5 ton/ha in a *Swietenia macrophylla* stand, 261.8 ton/ha in a dipterocarp forest, 75.6 ton/ha in a *Albizia falcata* stand, and 127.0 ton/ha in a *Gmelina arborea* forest in the Philippines, as well as 4-8 ton/ha in a *Miscanthus sinensis* community on grassland are known.

Thus, the above ground biomass of bamboo stands is considered to be smaller than that of the ordinary tree species mentioned above, and much larger than that of the grass community, but it is roughly similar to that of some fast growing tree species, such as *A. falcata* and *G. arborea.*

The total above ground biomass divided by the average height gives the apparent density of dry organic matter per unit of space occupied by the forest. As shown in table 4-1, the dry organic matter density of bamboo stands of three species was in the range of 0.44-0.80 kg/m3. On the other hand, that of fully closed forests in Japan tends to be 1.0-1.5 kg/m³. The dry organic matter density of the fast growing species *A. Falcata* and *G. arborea* was estimated at 0.6 and 0.8 kg/m³, which is similar to that of the bamboo stands.

The leaf biomass of bamboo stands was in the range of 4.2-6.0 ton/ha. These values were much greater than the .6-1.7 ton/ha in *A. falcata* stands and the 1.4 ton/ha in *G. arborea* stands, and they were also greater than the 3.1 ton/ha in Japanese deciduous broadleaved forests. However, they were a little smaller than the 9.3 ton/ha in *S. macrophyla* stands and the 8.6 ton/ha in Japanese evergreen broad leaved forests.The leaf area index was in the range of 8.1-11.6 ton/ha forthe stands of two bamboo species. These values nearly correspond to the10.4 ton/ha in *S. macrophyla* stands, the 8.9ton/ha in dipterocarp forests, and are much greater than the 2.2 ton/ha in *A. falcata* stands and the 1.6 ton/ha in *G.arborea* stands.

The leaves of bamboo species usually fail annually or every other year, but they are immediately renewed. Bamboos of the phyllostachys species change their foliage in May or June, when most bamboo sprouts have appeared on the ground.

Ueda, et al (1961) analyzed the seasonal changes in the chemical properties of *Phyllostachys reticulata* foliage in detail and reported that the water content and some chemical nutrients varied periodically, especially in the season of leaf renewal. Therefore, the leaf biomass and leaf area index may vary with the seasons. (Takeyoshi Suzuki 1987).

Table 4-1 Above ground Biomass of each bamboo stand (Source: Suzuki , 1987)

	Phyllostachys edulis	*Ph. edulis*	*Phyllostachys bambusoides*	*Ph. Bambusoides*	*Phyllostachys Pubescens*
Number: 1000 pcs/ha	8.8	5.1	8.9	4.8	15.2
Average diameter (cm)	9.2	9.3	7.2	8.7	4.4
Average height (m)	13.3	13.2	14.1	16.7	9.2
Dry weight of culms (ton/ha)	87.6	49.2	61.2	55.2	36.6
Dry weight of branches (ton/ha)	12.5	9.2	13.7	12.4	7.2
Dry weight of leaves (ton/ha)	5.5	4.2	6.0	5.4	4.4
Totall dry weight (ton/ha)	105.6	62.6	80.9	73.0	48.2
Organic matter density (kg/m³)	0.80	0.47	0.57	0.44	0.52
Leaf area index (ha/ha)	11.6	8.8			8.1

BAMBOO PROPAGATION METHODS

Nursery land selection and preparation

The quality of the nursery site directly affects production costs, output and quality of the nursery stock. Great loss has been causesd by poor site selection (Tan Hongchao 1996) According to Ma (1994), in China bamboo nursery land should be selected on the lee side in areas where there are typhoons in summer or strong winds. In general the site selected should be sunny with little slope (12-15%) and good drainage, near a water source and easy to irrigate. The nursery soil should be loose and fertile sandy loam, or loam with a granular structure. The ground water level can not be high; usually it should be lower than one meter. Land where the soil is rocky, sandy and very sticky and strongly saline-alkali should not be selected as nursery land.

Before raising seedlings, nursery land requires overall soil preparation, i. e. loosening soil for increasing and preserving soil fertility and humidity, weeding, and sterilizing to eliminate soil pests. Overall soil preparation can create favorable conditions for bamboo seedling growth and development. Nursery soil should be deep plowed and carefully prepared.

In temperate areas, the time for soil preparation is usually before freezing or after thawing in spring. The best time for plowing is the beginning of winter. Digging out roots and rocks, raking the soil and scattering the soil are essential to soilpreparation. After deep plowing, nursery soil should be made into seed-beds. These are usually 1 meter wide and 15-20 cm high, with alength determined according to the terrain. The space between beds is 50 cm, Low seedbeds can be made in high terrain and in well drained places where the seedbed level can be 15-20 cm. lower than its dike. If possible, enough manure or plant ashes should be applied as basic fertilizer for improving the bamboo seedlings growth and root development (Ma, 1994).

Afforestation land preparation

The Treatise on Husbandry (Chi min yao shu) by Chia Su-niu in the 5th century, says that the land suitable for growing bamboo is found in high level places; sites near hills which are somewhat elevated, are very suitable. In low level fields, the culms obtain too much water and die.

According to Takenouchi (1932), after selecting planting land and before the bamboos are planted, the soil should be thoroughly tilled in order to bring it to a friable state. Well hoed soil will allow the rhizomes to spread freely, hasten growth and produce a good quality culm.

If the land selected is on the edge of a cleared forest, the roots and stumpsshould be dug out and burned In the case of an open field; the weeds should be dug out and not burned but spread over the surface. In tilling it does not matter from what direction the soil is hoed if the land is flat, but on sloping land it is re-commended that the tilling be started from the lower side.

In order to improve the soil, organic fertilizers, such as fallen leaves, hay, straw or compost, are sometimes hoed in at the time of tilling. If soil of a clay or gravelly nature is to be improved, a sandy loam should be added. Soil preparation must be done in autumn or at the start of winter.

PROPAGATION METHODS

There are two methods for raising seedlings and propagating bamboo: the reproduction by seeds, known as sexual reproduction, and vegetative propagation, known as asexual reproduction, which is carried out using culm or branch cuttings, layering, stumps with rhizomes, or rhizomes alone, and tissue culture. Some of these vegetative methods are more aproppriate for the propagation of leptomorph and some for the propagation of pachymorph types of bamboos.

Propagation by seeds (sexual propagation)

This method has the advantage that the seeds can be transported easily and it gives a broad genetic base, but it depends on seed availability. Some bamboos only flower at long intervals and generally they produce fewer viable seeds. As soon as the seeds (fleshy-type and grass type) are mature, they will germinate readily in a moist medium in a nursery, if sown immediately after gathering. The seeds are generally dibbled in beds or in trenches with 5-8 seeds per hole, and covered with a layer of 3-5 cm of soil. Then they are covered with straw and watered. After germination, when the seedlings are about 10 cm high, they should be transplanted into individual containers, or they can be planted out in the field when they are 0.75 to 1 meter high, or when they are 1 or 2 years old.

The viability of the seeds lasts only up to about two months, but it can decrease if they are not kept under suitable conditions. Seeds may retain their viability for periods up to 2 years when stored in a place with low humidity (6-10%) at low temperatures (between -5° C and 4° C).

Asexual propagation of leptomorph (monopodial) bamboos in areas with very cold winters

For monopodial bamboo, rhizome buds can grow into both rhizomes and shoots, which can be used to raise plants. Li (1985) recommends the following environmental conditions for the cultivation of leptomorph species in areas where there are very cold winters and wind, as in northern China: a) Choose plots sheltered against the wind. Inter-mountain basins or the foot of a hillslope are preferable if a water supply is available, and b) During the shooting period, the soil moisture should be kept at a level of 20%.

Monopodial bamboos prefer a site with a warm moist climate and annual precipitation of over 1.200 mm. They grow fast and have strong underground rhizome-root systems which grow in soil 20-30 cms deep, and do not exceed 50 cms.

METHODS FOR PROPAGATION OF LEPTOMORPH BAMBOO

Generally there are three methods for the asexual propagation of leptomorph bamboos, by rhizome cuttings, by the culm base with the rhizome and roots, and by the culm (with some branches) with roots and rhizome.

1.- By Rhizome cutting (Fig. 4.1)

This method is the best way to propagate bamboo vegetatively. In this method robust rhizomes with a fresh color,plump buds and sound roots are selected; using 2-4 year old rhizomes for large and middle size bamboos, and 1-3 years old rhizomes for small size bamboos. After the rhizome is dug out (keeping enough host soil on the rhizomes), it is cut into lengths of about 30-50 cms (or 10 -15 nodes and their roots), using a pair of pruning scisors or a sharp knife. Trenches 15-20 cms deep should be dug, with 30-50 cms spaces between the seedbeds. Then the prepared rhizomes should be placed horizontally in the trenches and covered with 4-6 cms soil and compacted. Then cover them with another layer of loose soil and finally cover them with straw to keep the seedbed moist. They are planted either directly in the field in spring (February-March) or during the rainy season or they may be planted first in a nursery bed prepared sandy loam. The rhizomes bud, gradually sprout and grow up into plants in April or May (Ma 1994).

When new culms are up, each one should have the top part cut off, as well as the branches from the lower 4 or 5 nodes. This is necessary in order to keep the new culms from falling over in the event of strong winds. According to Takenouchi (1932), in adition to the foregoing method there are others, such as developing the runner rhizomes with roots which become exposed above the ground, or those with roots which become exposed at the edge of a grove. In dealing with these rhizomes, the number planted in an area of one Tan should be from 200 to 250. Shoots are produced after 2 or 3 months.This method is recommended for transporting to distant places. In this case, they are wrapped with sphagnum moss and covered with vinyl sheets after the soil is washed away.

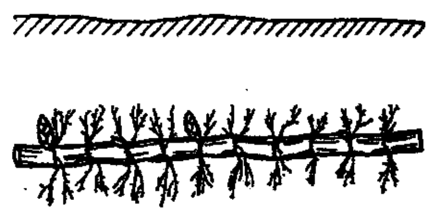


Fig. 4.1 -By Rhizome cutting (rhizome with roots)

Inducing method

According to Takenouchi (1932), this method is used when a bamboo grove is to be increased in size by extension of the rhizomes. The soil along the edge of the bamboo grove is tilled 5 to 6 meters wide in autumn or winter and supplied with compost or stable manure. The rhizomes from the grove will soon invade the prepared soil, and the new culms will appear in a scattered fashion in the following year. In four to five years, the additional area will be completely occupied by the bamboo. By this method, the work is rather slow, since the rhizomes do not grow more than 2 to 3 meters in two years.

2.-Propagation by culm base with rhizome and roots (Fig. 4.2)

In this method developed and recommended by Tsuboi, the culm is cut at 30 cm above the surface level and the rhizome with the culm base attached is transplanted. The rhizome must bear buds, otherwise no shoots can be expected to grow. As a nursery plant and for transplanting a long distance, this type is quite convenient to handle, but it has the defect of being slow to produce good culms as compared to other types of planting stock.

The plant should be a healthy one, of medium size and 1 to 3 years old. It is important to keep a section of the rhizome 30 to 60 cm long attached to the base of the culm and extending in both directions from it, so that the whole plant is in the form of an inverted "T" when dug. Although the required size of the planting holes varies according to the speciesof bamboo, the proper size in general is said to be about 1 m. long, 60 cm wide and 40 to 50 cm. deep.

In planting, the rhizome is placed in a horizontal position in the soil and after the hole is filled in, it is lightly pressed with the foot in order to bring it into close contact with the rhizome. The soil is then irrigated and given an application of fertilizer, such as soybean cane or the like (Takenouchi 1932, Ueda1960).

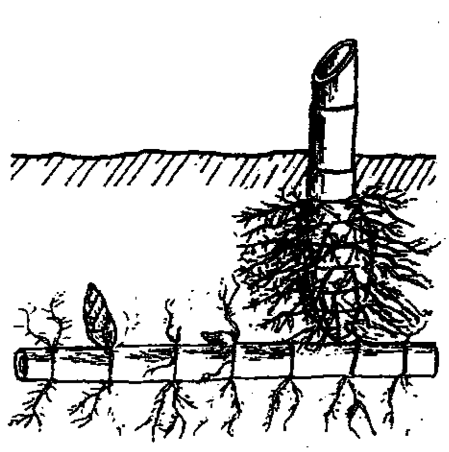


Fig. 4.2 By culm base with rhizome and roots

3.- By the culm (with some branches), rhizome and roots. (Fig. 4.3)

This method is also used for transplanting the culm with branches. The plant should be a healthy one, of medium size and one to three years old, but Ueda (1960) recommends the use of young culms sprouted in the same or the previous year.

After cutting off the upper part of the culm at the 4th or 5th node above the lowermost branch, it is important to keep a section of the rhizome 40 to 60 cm long with about ten nodes and buds attached to the base of the culm and extending in both directions from it, so that the whole plant is in the form of an inverted "T" when dug.

The rhizome of the culm should be yellowish, young, vigorous, and bearing good buds. Old rhizomes should not be used, for they lack the buds that develop into culms. Fibrous roots on both the culm and the rhizome must be left. The rhizome should be cut carefully with a saw. Cutting with a hatchet will cause damage to the buds due to the strong shock.

Although the required size of the planting holes varies according to the species of bamboo, the proper size in general is said to be about one meter long, 60 cm wide and 40 to 50 cm. deep. In planting, the rhizome is placed in a horizontal position in the hole, and after the soil is filled in, it is lightly pressed with the foot in order to bring it into close contact with the rhizome. The soil is then irrigated and given an application of fertilizer, such as soybeans or the like. Finally, supports are placed from 3 or 4 directions in order to protect the culm from falling in case of rain or wind. In a dry site, chaff or straw is spread around the plant and water is given occasionally; the culm is sometimes wrapped with straw or matting in order to protect it from the direct rays of the sun (Takenouchi 1932).

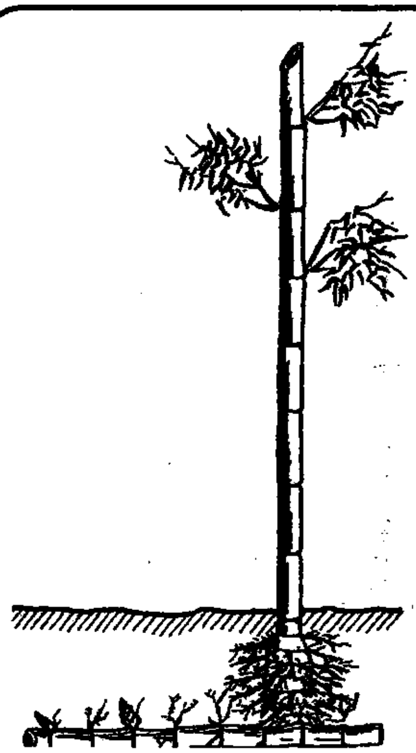


Fig. 4.3 - By the culm (with branches), roots and rhizome.

METHODS FOR PROPAGATION OF PACHYMORPH BAMBOO

The nursery methods for pachymorph or sympodial bamboos are easier than those for monopodial bamboos. The methods are: 1. Propagation by rhizome cuttings (a) the rhizome ~~with part of the culm and lower~~ branches and (b) the rhizome without theculm; 2. Cuttings including one,two and three nodes, with or without branches; 3. Cuttings with a leader branch, lateral branch and secondary branch; 4. Ground and air layering; and 5. Tissue culture with young plants transplanted.

According to Lan (1996), no matter which method is adopted, the highest survival rate and best plant growth can be obtained on sandy soil and loamy soil, but the growth of young plants is weak. As the roots system has less soil with it,the survival rate after transplanting is not high.

1.-Propagation by rhizome cuttings (A) Rhizome with part of the culm and lower branches. (B) Rhizome without culm (Fig 4.4)

This is the best method of vegetative propagation of clump-forming bamboo species (pachymorph) because young clumps are quickly produced. For propagation by rhizome cuttings (in both cases) offsets or 1 and 2 years old culms are used, but in the case of *Guadua angustifolia*, they may be up to 3 years old. The former method includes, besides the whole rhizome, part of the culm with the lower branches and leaves, while the latter method only includes the whole rhizome with the roots and at least 30 cm of the culm above the ground. The culm with the attached rhizome is separated from the mother bamboo and planted either directly in the field during the rainy season or in the nursery first. Shoots are produced after 2-3 months, followed by the formation of roots. After 6 months, young plants in the nursery are ready for transplanting to the field.

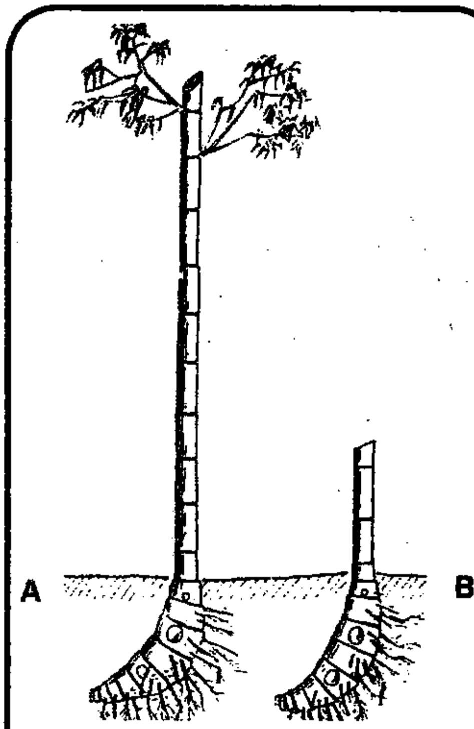


Fig. 4.4 - Propagation by rhizome cuttings (Offsets)

2.-Propagation by culm cuttings (Fig. 4.5)

Either the whole culm or culm segments can be used as vegetative propagules. If the whole culm is used, it is buried. This will stimulate the alternating buds to produce young branch shoot. These gradually transform into stronger culmlets which at the same time form roots. McClure and Kennard (1955) suggested that two year old culms would produce the highest percentage of planting material. It has been found, however, that one year old culms of tropical bamboos give the highest percentage of plantlets (Prosea 1995).

The second method involves culm portions or cuttings, bearing from 1 to 3 nodes taken from the culms at the age of one to 2 years depending on the species. Two or three node sections or cuttings may be planted horizontally, level with the ground. A 2.5 cm hole is made in the center of each internode and it is filled with water to about 3/4 of the internode capacity. This method is successful for *Guadua* species, and *Bambusa vulgaris.*

Lin (1962) conducted several studies at the Taiwan Forestry Research Institute on the propagation by level cuttings of various bamboos.(Fig. 4.5) The purpose of these studies was: (1) To find out the optimum period for cuttings; (2) Todetermine the most suitable ages and nodes for cuttings; and (3) To compare the different parts of the culm from which the cuttings are made, which include : a) Cuttings from the lower part s of the culm; b) Cuttings from the middle part of the culm; and c) Cuttings from the upper part of the culm. The species used in these experiments were: *Dendrocalamus latiflorus, Bambusa stenostachya,* and *Bambusa dolichoclada*. The results obtained may be summarized as follows:

1) Study on proper period for propagation by level cuttings: *Dendrocalamus latiflorus* shows the best percentage of sprouts from nodes of cuttings in February and March; in April the results are the second best, and after May they are the worst.

2) Study on the different ages and the number of nodes of cuttings: a) In *Dendroclamus latiflorus,* the 3 year old cuttings appear to be the best in the percentage of sprouts on the nodes of the cuttings, and in the number and height of the surviving stocks; 2 year old cuttings are the second best; and 1 year old cuttings are the worst. The two node cuttings are the first in the percentage of sprouts from the nodes and number of surviving stocks; the three node cuttings are the second; while the one node cuttings are the last. This means that the 2 and 3 year old, and two node cuttings are the most suitable for propagation.

b) In *Bambusa stenostachya,* the height of surviving stock in one and two year old cuttings appears to be very good, but in 3 year old cuttings, it is fair. The one and two node cuttings are the best in the percentage of sprouts from

Fig. 4.5 Propagation by culm cuttings, Lin (1960)

X: Buds in the nodes of cuttings.

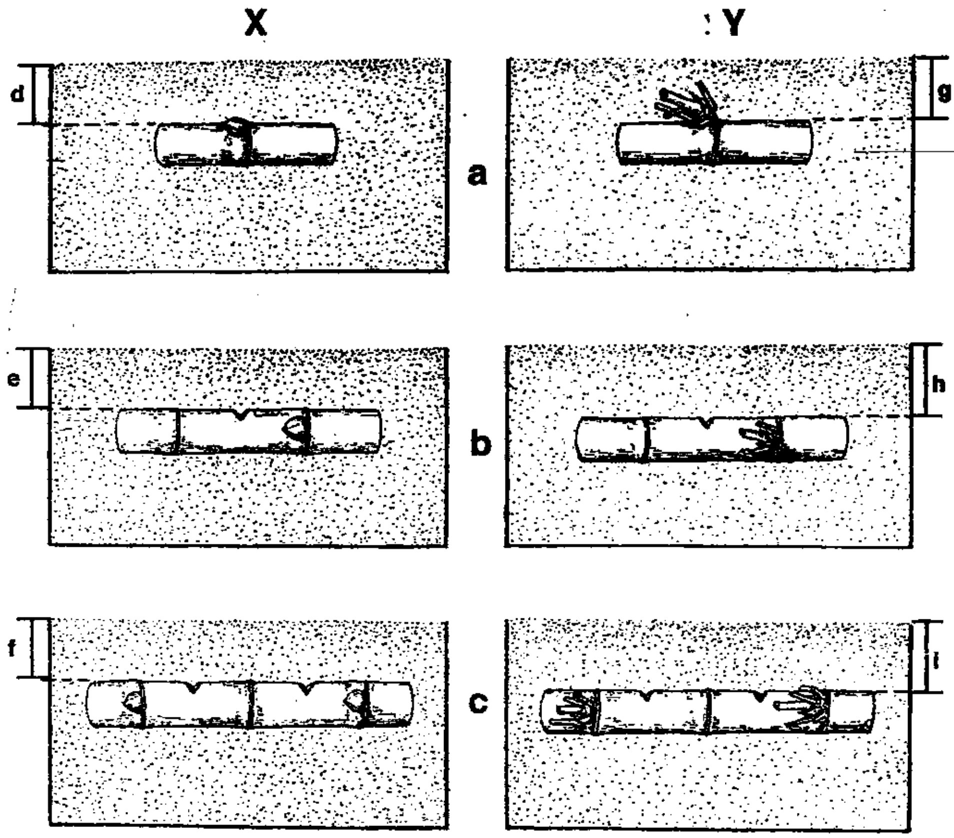
a One node cuttings

c Three node cuttings

Y: Branches on the nodes of cuttings.

b Two node cuttings

d- i Planted horizontally and burried with soil 6 -10 cm in depth



the nodes of the cutting and number of surviving stock; the three node cuttings are second. This means that the one and two node cuttings that are 2 or 3 years old are the most suitable for propagation.

c) In *Bambusa dolichoclada*, the bamboo's age shows no significant difference in the percentage of sprouts from the nodes of the cutting, or the number, height and diameter of surviving stock. In this study, the bamboo node showed a high significant difference in height and diameter of surviving stocks but no significant difference in the percentage of sprouts from nodes and the number of surviving stock. The two and three node cuttings are better than one node cutting for propagation.

3) Study of the cuttings from the different parts of the culm of *Dendrocalamus latiflorus, Bambusa stenostachya,* and *B.dolichoclada*. Cuttings from the lower part of the culms are the best in the percentage and the number of surviving stock of *Dendroclamus latiflorus*, in height and diameter of surviving stock of *Bambusa stenostachya*, and in percentage of sprouts from the nodes of the cuttings and the number of surviving stock of *Bambusa dolichoclada*. The middle part of the culm was the second best; and the upper part of the culm was the worst. This proves that the cuttings collected from the middle part of the culm are acceptable; cuttings collected from the lower part of the culm are most suitable for propagation.

In conclusion, February and March, before sprouting, is the best period for propagation by level cuttings of *Dendrocalamus latiflorus*. It is not suitable to use them after May because the shoots grow up from the bud at the node of the cuttings. The two node cuttings collected from 2 or 3 year old *Dendrocalamus latiflorus*, one or two node cuttings from 3 year old *Bambusa stenostachya*, and two or three nodes cuttings from1 to 3 year old *Bambusa dolichoclada* are suitable for propagation. The cuttings made from the lower part of the culm are better than those from the middle part, and the upper part of the culm is not suitable for propagation.

3.-Propagation by branch cuttings

Branches with 3 nodes are collected from 1 to 2 year old culms; care should be taken not to injure the dormant buds. The presence of root primordia is essential for successful propagation, and induction of root primordia in situ may be possible. The branch cuttings may be treated with 100 ppm indoleacetic acid (IAA) and propagated in sand. Normal branch cuttings develop roots only after 3-6 months, and rhizomes after 12-15 months.

Propagules bearing roots, rhizomes and shoots are considered essential for successful establishment and development of bamboo plantations. Artificial induction of roots and rhizome formation at the branch base is possible by chopping off the culm tops and removing newly emerging culms yielding "pre-rooted and pre-rhizomed" plants (Banik 1987).This method of propagation seems to be promising for future mass propagation of, for instance, *Bambusa vulgaris* and *Dendrocalamus asper* (PROSEA 1995). In the studies carried out in China, Tan (1997) found that the species *Bambusa vulgaris, B.Intermedia, Dendrocalamus brandisii, D. farinosus, D. hamiltonii, D. semiscandens and D. yunnanensis*, have healthy branches, and most of the branch stumps have formed root primordium. When treated with auxin, they put forth new roots which developed into a root system. First, healthy leading branches, and secondary branches, which are fresh and green, 1 -2 years old, with plump buds, and free from disease and insects should be selected. When taking bran-ches, do not hurt the branch stumps and do not let them be exposed to the sun.

After long distance transportation, the viability of branch cuttings can be restored after 3-12 hours of soaking in running water. They should be treated with ABT rooting powder No. 1 (5 ppm) or No.2 (100 pm) for 30 to 40 mm. 3 branches slatingly put into one hole radially.

They should be buried 8-10 cm. deep with one internode left above the soil, and then covered with loose soil and compacted. They are mulched with hay t avoid being exposed to the sun. To ensure survival, branch selection and planting should be done in the same place. Each branch should have one or two internodes, and only two branches are inserted in each hole.

Large and medium clump type bamboos with thick culm walls and branch buds that are easy to root should be selected.After being transported a long distance, mother bamboo and branches should go though treatment before planting so as to have their viability restored.

4.- Propagation by layering

Success was achieved by both ground and air layering in bamboo, mainly in the midculm zone, but it varied from species to species. Several methods of propagation by layers can be applied. Either a whole culm, or only that part of the culm bearing branches, is bent down to the ground into a shallow trench and fastened in place by hooked or crossed stakes; sometimes it is notched below the branch bearing nodes. It is then covered with soil or some other suitable medium.However, this is a rather cumbersome method and is probably useful only for small bamboos.

For the propagation of *Bambusa tulda* and *B. vulgaris*, the layers are made by partly cutting a culm and layering in the soil for rooting. When the shoots appear, the internodes are cut, and the layer is planted separately. The cuttings can be raised in several ways, i.e. in a nursery, in stagnant water, floating in a pond and in the bed of water courses. Stump layers maybe prepared by cutting off one or more culms in a clump, leaving 1 or 2 nodes with a bud or a branch complement. The stumps prepared in this way are then covered with a suitable mulch.

Another method is a form of air layering known also as Marcotting. This involves bending a one year old culm and making an undercut at its base. The branches at the nodes are pruned to about 2.5 cm in such a way that the dormant buds are not injured. A mixture of garden soil and leaf mold is placed around each node and wrapped longitudinally with coconut fiber or surrounded by a suitable propagating medium held in place by a receptable.

When roots and shoots develop at the nodes, the buried or covered parts are separated from the mother plant, the internodes are cut, and the layers are planted separately. Layering of *Bambusa vulgaris* and *Dendrocalamus giganteus* showed only 10% success (Banik 1987), and there are bamboos that do not respond to any layering methods. However, air layering in *Dendrocalamus asper* appeared to be fairly successful (up to 50%) in Indonesia (PROSEA 1995).

PROPAGATION BY TISSUE CULTURE

In a few years, the present shortage of woody material in Latin American countries, due to the continuous destruction of forests, will be a serious problem for the factories which use this material in the manufacture of paper, houses, furniture composite materials for construction, etc.

As I intend to show in this book, with the new bamboo composite materials and technologies which have been developed in the last 25 years,bamboo can replace wood in strength, durability, cost and fast growth in all the fields in which wood has been used up to the present time. Consequently, in a few years it will be necessary to establish large plantations of giant bamboo species in the underdeveloped countries of the Americas, Asia and Africa large plantations of giant bamboo species.

While the traditional methods of propagation are largely applied with good or partial success, they seem to be inadequate to increase the desired levels of production. Tissue culture methods offer an attractive alternative to offsets, cuttings and seeds for the propagation of bamboos and the best solution for rapid large scale propagation of different bamboo species. Tissue culture is a laboratory technique for culturing plants, organs or tissues under aseptic conditions and it has been successfully employed for the propagation of some plant species which are generally difficult to propagate by any conventional vegetative means.

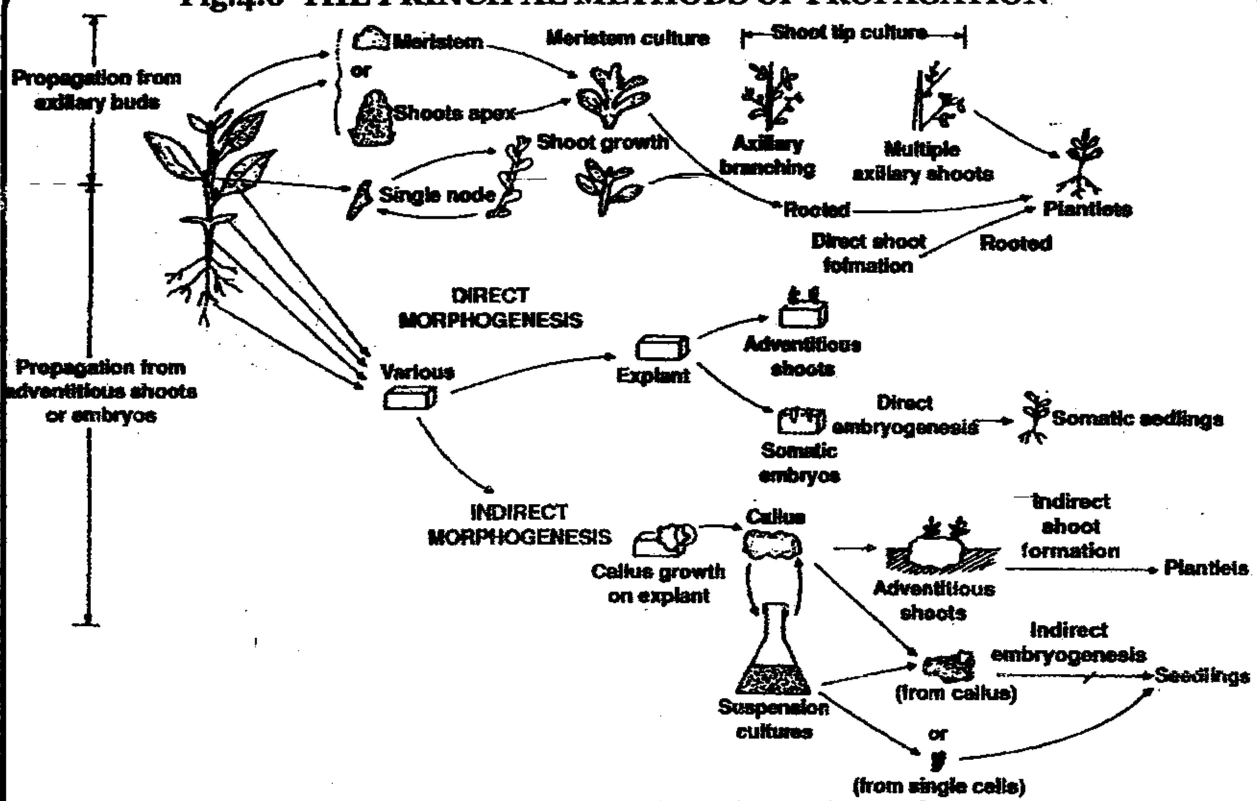
Using tissue culture methods, year round production of plantlets, which ensures a steady supply of planting stock, is possible. Most of these methods are based on micropropagation and somatic embriogenesis from seedling tissue.

Somatic embryogenesis is defined as embryo initiation and development from cells that are not products of gametic fusion. Thus, hundreds of plantlets can be formed from embryoids. For obtaining somatic embriogenesis, different explants, such as inflorescenses, immature and mature embryos, seedling roots, or seedling sheaths are used.

In recent years, methods have also been standardized for tissue culture propagation of bamboos from mature explants.Using mature tissue as the starting material permits the selection of desirable characteristics, but the life cycle of the clump from which the explants are collected must be known.. Using explants from a mature clump in the later stage in its vegetative growth phase, or a clump nearing the flowering stage, presents a disadvantage as the plantlets may also flower, seed and die along with the mother clump.

Using seedling explants has both an advantage and a disadvantage. The advantage is that the selection of only vigorous seedlings as the starting material is possible; the disadvantage is that seeds are available only at long intervals, and under normal conditions, seed viability is lost very quickly.

Fig.4.6 THE PRINCIPAL METHODS OF PROPAGATION



Diagrammatic representation of different source material and methods that can be used for micropropagation. (Source:Lindsey and Jones , 1989).

The bamboo species that have been used for plant tissue culture are the following: *Bambusa arundinacea, B. beecheyana var. beecheyana, B glaucescens, B. multiplex, B. oldhami, B. ventricosa, B. vulgaris, Dendrocalamus brandisii, D.giganteus, D. Hamiltonii, D.latiflorus, D. strictus, Phyllostachys aurea, Ph. viridis, Sasa pigmaea, Sinocalamus latiflora, Schizostachyum brachycladum, and Thyrsostachys siamensis.*

The availability of explants all year round for tissue culture is not a problem. Moreover diverse explants, such as inflorescenses, immature embryos, mature embryos (plantlets through somatic embryogenesis), seedling leaf sheaths, seedling roots, seedling rhizomes, seedling nodes, seedling basal nodes, mature nodes, shoots, and mature rhizomes can be used for tissue culture work.

Techniques of micropropagation

The technique of micropropagation (or in vitro vegetative propagation), can yield millions of replicas of an original parent plant. In bamboos, the minor nodes bear axillary buds or lateral meristems which remain dormant most of the year and generally sprout during the rainy season; these buds have the capacity to transform themselves into complete plantlets (McClure 1966). This has been achieved in tissue culture, although with uneven success in some bamboos.

Meristem culture techniques involve the dissection of the shoot's apical domes and culturing them on a nutrient medium where differentiation and complete plant development take place. However, the required conditions for each plant speciesvary and must be ascertained experimentally. Principles and procedures have been established, and it is technically possible to apply the same methods to certain plants as a specialized method of micropropagation.

A freshly isolated plant part usually bears bacteria or fungi or both. Consequently, the initial requirement in preparing for micropropagation is to eliminate such microorganisms; second, a sterile culture medium containing the required nutrients must be prepared; and third, the sterile plant part must be excised, planted, and grown in such a way that no recontamination can occur.

Nutrients needed in the culture medium vary with the kind of plant and the purposes for which the culture is prepared.Required substances can be conveniently grouped into several categories: 1) Inorganic elements, 2) Sugar, 3) Vitamins, 4) Growth regulators, and 5) Organic complexes, (i.e. coconut water, tomato juice, etc).

Most cultures are grown on a semi-solid medium made by adding powdered agar to the solution. This material dissolves when heated but, when cool, solidifies to a semi-solid gel that can be used as an effective support for tissue and organ cultures. An alternate procedure is to grow the cultures in a liquid medium, but some means of aeration is required.

A tissue culture is an independent mass of callus tissues growing separately from the plant on an artificial medium. It increases in size by continuous division of cells within the mass. This technique is a method of reproducing a clone. It is used considerably in research and has potential value as a specialized propagation procedure. The practical significance of tissue culture propagation depends on a plant's capacity of reproduction from a single cell or from a

Fig.4.7 *Tissue culture of an apical meristem.*

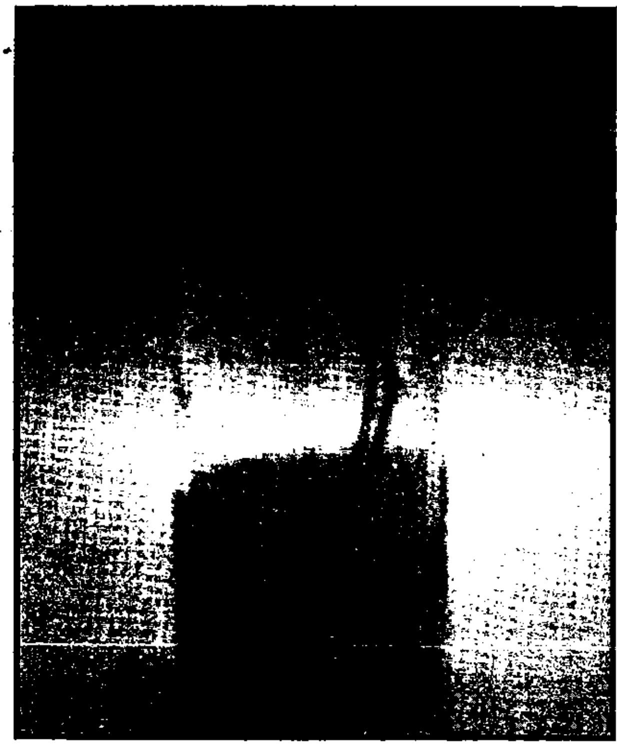


Fig. 4.8 *The first bamboo plant developed by tissue culture in Colombia.*

a small clump of cells or the ability of callus from it to differentiate roots and shoots with subsequent growth into a normal plant. It is possible to apply these techniques on bamboo, but the best medium for it and the kind of material that gives the best results still needs to be investigated.

Tissue culture propagation of *Dendrocalamus strictus*

Dendrocalamus strictus is one of the most widely distributed and cultivated bamboos in India. It has solid culms and isalso one of the best and hardiest bamboos as it can withstand drought. A method for the rapid large-scale multiplication of *D. strictus* been standardized (Mascarenhas, et a. 1990). The procedure is as follows:

1.-Seeds are husked, the surface is sterilized and innoculated on a semi-solid. White's basal medium (White 1963) containing 2% sucrose, and they are incubated in the dark.

2.-After about a week when seeds germinate, seedlings are tranferred to light conditions for healthy growth, and in 15 to20 days they attain a height of 40-50 mm.

3.-Seedling sections are transferred to liquid MS medium (Murashige & Skoog 1962) containing 0.2 mg l^{-1} 6-benzylaminopurine + 5% coconut water (CW) + 2% sucrose, in 250 ml flasks and kept in a rotary shaker at 120 rpm, for shoot multiplication.

4.-Subculturing is done at 20-day intervals.

5.-Shoots are excised and given rooting treatment in half strength liquid MS medium containing 2% sucrose and auxins (IAA, IBA, IPA, NAA, etc. at concentrations ranging from 0.05 to 5.0 mg l^{-1} for varying periods of time in the dark.

6.-The shoots are then moved to the same medium without auxins for root development, and later to light for root and shoot growth to produce plantlets.

7.-Plantlets 50-60 mm high are planted in a sterile 1:1:1 mixture of sand: soil: vermiculite.

8.-Plantlets are acclimatized, initially at a high relative humidity (>90%) and gradually the humidity is reduced.

9.-New shoots emerge in 30-40 days.

10.-After complete hardening, plantlets are field planted. Small scale field trials using micropropagated plantlets of *D. strictus* indicated many advantages, the most important being early clump formation and culm production in plantations raised from tissue culture derivated plantlets as compared to seedling raised plantations.

This information needs further confirmation in large scale field trials. If found consistently, this could cut down the gestation period and offer early returns from bamboo plantations. (Mascarenhas et al 1990; Nagauda, John, Joshy, Parasharami, Mascarenhas 1997; Gielis 1995).

ARTIFICIAL INDUCTION OF FLOWERING

It is very difficult to get two or more species of bamboo to flower concurrently in time and space. The majority of bamboos fall at two physiological extremes: either constant sterility (*Arundinaria variegata, Bambusa vulgaris* and *Sasa tesselata*) or gregarious flowering manifested by the cyclical recurrence of the flowering state at species-specific intervals.

In 1990, Nadgauda, et al, reported artificial induction of flowering in three bamboo species: *Bambusa arundinacea, Dendrocalamus Brandisii* and *D. strictus*. In brief, the procedure for the in-vitro induction of flowering is as follows.

1.-Surface-sterilized seeds are germinated on White's basal medium (White 1963) in the dark.

2.-Excised seedling explants containing coleoptile regions are cultured in liquid. MS medium containing 0.5 ml l^{-1} 6benzylaminopurine, 5% coconut water (CW) and 3% sucrose, with the pH adjusted to 5.8.

3.-After several subcultures, spickelets emerge in the majority of the subcultures.

4.- When inflorescense segments are separated and subcultured in the same medium, they multipy, givng rise to an infloerescence culture.

5.-In 30-50% of the cultures, seed-set is observed. However, seed viavility is very low.

6.-Flowering shoots transplanted to the field after excising the spickelets and rooting, do not produce any spickelets.

So far there are four reports on the induction of flowering in bamboos: Nadgauda et al, 1990; Rao& Rao, 1990; Chambers, et al.,1991; and Rout & Das, 1994. In all, flowering could be induced in six species: *Bambusa arundinacea, B. vulgaris, Dendrocalamus brandisii, D. giganteus, D. hamiltonii* and *D. strictus*. When all four reports are analysed, there are some similarities and some differences. The similarities are the use of seed/seedling tissue as the starting material, and the use of benzyladenine (BA)/6-benzylaminopurine (BAP)/ adenine sulphate (AdS), a cytokinin-like activity, in the medium. The differences are the use of different basal media and the presence/absence of coconut water in the medium (Mascarenas et al 1990; Nagauda, John, Joshy, Parasharami, Mascarenhas,1997).

What is the significance of this phenomon? The obvious answer to this question is that, in bamboos which normally take many years to flower and seed, induction of flowering by in vitro techniques is useful in perennial seed production and in hybridizations. It provides a means to overcome the barrier placed by nature on hybridization between bamboo species, by providing predictable, frequent and synchronous flowering in two or more species. (Nagauda *et al, 1993*).

What are the problems and prospects of using in vitro flowering for perennial seed production and hybridization? So far all reports are based on seed/seedling/somatic embrio-derived plantlet explants. This is one of the serious limitations of using this technique for perennial seed production and hybridization. Induction of flowering in mature clump-derived explants woul be almost useful advance.

BAMBOO HYBRIDIZATION

The hybridization of bamboo is the production of hybrids by crossbreeding different bamboo species and genera in order to get a hybrid which combines the best mechanical, anatomical, and physiological characteristics of the two species or parent bamboos.

1.-Crossbreeding different bamboo species and genera. Natural and artificial hybridizations have played significant roles in the evolution of grassses. In cereals, high yielding hybrids are produced and used for augmenting food production. However, introducing breeding programs in bamboos is very difficult. This is because of the peculiar flowering and seeding behavior of most species, involving long species-specific vegetative growth phases, ranging between 3 and 120 or more years (Jansen 1976). Although there are various difficulties in bamboo plant crossbreeding, according to Zhang & Ma (1994), researchers at the Guandong Institute of Forestry in China have obtained good bamboo crossbreeds, such as "*Bambusa pervariabilis x Dendrocalamus latiflorus No 1*", "*Bambusa textilis x Dendrocalamus latiflorus* No 4" and "*Sinocalamus minor x Dendrocalamus latiflorus* No 5" etc. These good bamboo crossbreeds have the following excellent merits: good shooting ability, good shoot taste , fine mechanical strength, not easy to split or too high of a ratio of fiber length and width, high tissue volume, good paper-making features, etc.

The following effective measures were taken by Zhan & Chen (1985) to raise the percentage of seed setting.

1.-Bamboo were transplanted in a special nursery or in a large pot. Fertilizers with only phosphorous and potassium were applied and light conditions were improved. The flower buds developed normally so as to promote seed setting. While transplanting, the experimental material was cut into dwarf plants in order to polllinate the flowers conveniently.

2.-During the period from February to June, especially in May and June, bamboos flower in great quantities. Generally speaking, the earlier the flowering, the better the seed setting. Therefore it is preferable to do the hybridization work in the early part of the season.

3.-During this season, many flowers are formed but not all of these be pollinated, so it is reasonable to remove some of them in order to reduce nutritient consumption. The flowers in the middle part of the spikelet develop much better than those at the top of the spikelet. Therefore, it is better to select the flowers in the middle part of inflorecense to pollinate in order to get a larger percentage of seed setting in hybridization.

4.-Bamboo flowers generally open between 5 a.m. and 9 a.m. and close at noon. It is necessary to pollinate them in the early morning because it is cooler and atmospheric humidity is higher, which is good for carrying out controlled pollination.

5.-Precautions should be taken against bad weather which affects the germination ability of pollen. During, and soon after, pollination the plant should be left out of sunshine and rainfall. The parent material should be grown in large pots so they can be moved into the sun or the shade, as the case may be, and **6.**-It is necessary to control pests during lowering. T.T.V. solution with a concentration of 0.1% was sprayed 2 or 3 times and this helped to control them.

2.-Crossbreeding between bamboo and rice (Oriza sativa). According to Soderstrom et al (1988), the grass family is currently divided into five subfamilies, one of which is the Bambusideae which includes the true bamboos as well as rice (Oriza) and related genera. According to Gielis (1997), bamboo and rice probably share the same basic chromosome number (x=12). Rice is diploid (2n=24), while tropical bamboos are hexaploid (2n=72) and temperate bamboos are tetraploids (2n=48), If the lowest value of tropical woody bamboos is divided by 3, the result is about 0.8, which approximates the 2CDNA content of rice (0.78-0.91 pg/2C) (Arumuganathan & Earle 1991). This indicates that the complexity of the bamboo genome is higher in absolute value, but is theoretically comparable to rice when calculated per basic chromosome number, x =12. This opens possibilities to unravelling the genetics of bamboos. According to Zhang & Ma (1994), in 1970, researchers at the Agricultural Research Institute of Haifeng County in Guandong Province in China, succeeded in crossbreeding rice (Oriza sativa) and bamboo plants and obtained the crossbred seeds. In this crossbreeding, they used the progenies of the crossbreeding between Keng rice (Oriza sativa) and Hsien rice (Oriza sativa subsp. hsien), which have great variations, as the maternal line and *Bambusa textilis* as the paternal line, and they succeeded in obtaining seeds. The progenies of rice and bamboo showed a special basic leaf morphological structure and a longer growth period which are absent in rice. However, along with the increase in generations, the growth period has shortened. For example, F1 of rice and bamboo eared and seeded in two years, while F2 did so in one year and a half and F3 in less than one year. The progenies of the hybrid between rice and bamboo have shown great variations in plant type, and tiller and disease resistance, but all feature a strong stalk. Through multiple-crossings, some progenies have approached rice morphology, showing promising features, such as small, thick and straight leaves, a strong tillering ability, small hard stalks, strong disease and pest resistance, and optimal characteristics of the ear and grain. If further back crossing and multiple crossing are undertaken, it may be possible to breed plant lines, strains and new varieties which possess the excellent characteristics of both bamboo and rice.

Sexual crossing involves the following techniques:

1.- Crossing season: It is suggested that crossbreeding beundertaken during the season of full blossoming because at this time the development of pollen is better with large quantities of mature pollen and a low rate of pollen abortion.

2.-Pollination: It is suggested that well developed strong flowers from the mid ear be selected for pollination. Pollination should be carried out between 5 and 9 a.m. or in the evening when the air is humid, which is beneficial for the success ofpollination. As the distan crossbreeding between bamboo and rice (Oriza sativa), it is suggested that the rice ears be soaked in warm water so as to solve the issue of synchronizing the flowering period and emasculation. This should be accompanied by repeated pollinations.

MANAGEMENT OF BAMBOO STANDS

Bamboo stands should be managed on a yearly basis, not only for harvesting but also for maintenance. Usually the felling cycles are 3-4 years, as systematic and regular exploitation increases the production of the bamboo stock. Management of bamboos is based on the physiological development of the clumps. In tropical bamboos, the new culms are produced from the rhizome, generally along the periphery of the clump.

New culms shoots appear at the beginning of the rainy season in the form of cones which are covered with overlapping sheaths inserted in the nodes. The culms develop fast, reaching their full height in about 3 to 5 months, depending on the species, i.e. *Guadua angustifolia* and other giant species of genus Guadua take at least 5 months to reach their full height.

Generally branches develop only after the growth in height is completed. Once the growing process of the culm is finished, its mechanical properties are very poor and it can only be used for manufacturing woven panels and baskets, but in no case as construction material. Due to their lack of strength, young culms can be bent by the wind; consequently, during the fellings it is necessary to leave 3 or 4 culms of different ages to support the young culms which are growing.

As explained above, there are several important factors that we have to consider in the management of bamboo forests with clump formation (pachymorph) and individual culms (leptomorph), which are: the material selection, the felling cycle, the intensity of felling, and the time of harvesting.

The general practice in the material selection is to select the mature culms and to harvest them. Young culms, less than 3 years old, are considered to be immature with less strength and consequently not useful for construction. Mature culms are those 3 -4 years old, depending on the species. Guadua angustifolia is considered mature when it is 3 years old. (See determination of the culm's age.)

For management purposes, it is very important to know the average life span of a culm. The life of an individual culm (in the clump) varies depending on the species and the site where it grows, but it rarely lives more than 12 years. In *Guadua angustifolia*, the average life span is about 7- 8 years, but the culms begin to show signs of deterioration and start to dry one year earlier.

The felling cycle, is the time that elapses between successive principal fellings in the same area. It differs from rotation, which is the number of years between the formation or regeneration and the final felling of a forest crop. Rotation does not exceed 5-8 years, while the felling cycle may be annual, biennial and triennial and sometimes quadrennial. It is thus clear that rotation and felling cycles apply to culms and clumps respectively.

The length of the felling cycle is determined by the minimum age at which the culm is exploitable. A felling cycle of 3 - years is therefore generally prescribed, depending on the species; too short a felling cycle brings about the deterioration of the clump, and a long felling cycle may result in overcrowding. If clumps are not regularly managed, they become dense and congested, so cutting will be extremely difficult. Regular exploitation increases the production of newe bamboo stock Continued and excessive cutting results in reduced diameter in new bamboos and finally extermination of the clump. Felling all the culms (both young and mature) of a clump will kill the clump in 2 to 3 years.

The following felling rules are recommended:

1) All culms should be cut above the first node above the ground. No portion of the internode (above the first node) should be left. In India, culms of *Bambusa blumeana* were cut at a height of 2-3 m, just above the dense growth of spiny branches. However, it was found that removal of the spines and the cutting of culms close to the ground increased the number of shoots that appeared each year, reduced shoot mortality and reduced the number of deformed culms.

2) Inmature culms younger than 2 years old should not be cut.

3) The centrifugal direction in which the clump (pachymorph) expands leaves most of the younger culms on the periphery enclosing the older ones. All of the younger ones on the periphery (unless dead) should be retained. In this case, it is suggested that the horse-shoe method of exploitation be used for removing the older culms. Culms left uncut should be evenly distributed throughout the clump.

4) In clumps with an annual felling cycle, not more than 50% of the living mature culms (three years old and over) should be cut. In clumps with a biennial felling cycle, no more than 65% of the living mature culms should be cut; and in clumps with a triennial felling cycle, not more than 75% of the living mature culms should be cut. It is important to point out that the number of culms to be cut depends entirely on the conditions of the clump.

Over-mature and other non-marketabl culms (dry culms or those with cracks) should be cut out to preserve maximum vigor and productivity of the rhizomes and culms. If dry culms are not removed from the clump, the coppice shoots produced in such a clump may also caus congestion. Coppice shoots, which are thinner than the culms, are some times referred to as switches.

5) All of the debris and cut branches of the culm should be completely removed.

6) Bamboos should not be cut in the year of their flowering; all such clumps should be clear-felled after they have shed their seed.

7) The optimum spacing for productivity is very important. The distance recommended for giant species is 5-7m in square (5x5 m),according to the position of their rhizomes. If the rhizomes grow almost vertically, such as in Bambusa vulgaris, the separation in square could be 5x5 m. In the case of Guadua angustifolia, which has long horizontal rhizomes,the separation must be 7 meters in square.

8) Fertilizer application. According to PROSEA (1995), it has been shown that fertilizer application increases the production of culm shoots. In the case of *Thyrsostachys siamensis, Dendro calamus asper* and *D. Strictus*, the applicationof 15-15-15 NPK fertilizer resulted in a significant increase in the yield of culm shoots by applying 100-100 and 200 kg/ha of fertilizer respectively.

CULTIVATION OF BAMBOO SHOOTS

Edible bamboo shoots

The bamboo shoot or sprout. As was explained before, a bamboo generally reproduces asexually after a bud on a rhizome swells up, becomes a culm shoot or sprout and grows into a young culm. This bamboo shoot has been used traditionally in many Asian countries as food source from immemorial times.

The various kinds of dishes and the techniques for their preparation, as described in many Asiatian cookbooks, differ from one country to another and even from one ethnic group to another. Since each country or ethnic group has a specific name for every recipe, it is unavoidable that sometimes similar dishes will have different names.

In the Americas, only Brazil has bamboo plantations for the production of bamboo shoots for the large Japanese colony living there. In the rest of Latin American this tradition does not exist and consequently, it is very important to warn people that bamboo shoots can be consumed only once the hydrocianic acid, which the sap contains, has been removed by cooking. (See therapeutic uses of bamboo shoots).

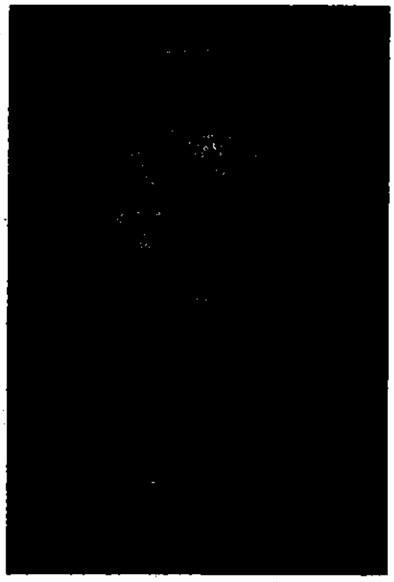


Fig.4.9 *Shoots cans of Bamboo manufactured in China and Japan*

Some of the many species of bamboo in the temperate zones of China and Japan used in the production of bamboo shoots are the following: *Phyllostachys pubescens, Ph. praecox, Ph nigra* var. *henonis, Ph. bambusoides, Chimonobambusa marmorea, Pleioblastus hinsii,* and *Sasa paniculata.*

In tropical zones of Asia, the species most used for the production of bamboo shoots are: *Dendrocalamus latiflorus, D.hamiltonii, D. minor,* and *Bambusa bechegana.* The two most important species for bamboo shoot production are *Phyllostachys pubescens* and *Dendrocalamus latiflorus.*

The site. According to Nonaka (1989), for the sake of marketing bamboo shoots earlier, it is importan to select proper sites, apply fertilizer to the mother bamboo, irrigate the sites and maintain the proper temperature. The most suitable site for bamboo stand is on a gentle southeastward slope, with a water source near by. The desired density of the mother bamboo is 150-200 culms of different ages per 1,000 m2. The composition of the age groups should be 25% one year old bamboos, 35% two years old and 40% three years old. The cutting of the parent bamboos is best done in the winter when they are 5-6 years old.

Fertilizer application. According to an investigation, for the output of 1.000 kg shoots, 4.0-4.6 kg nitrogen can be absorbed. In addition, mother bamboos and rhizomes also need to absorb nutrients, so the amount of fertilizers applied needs to be considered. At the same time, the natural supply of nutrients in the soil is preserved. To produce 1000 -1200 kg of shoots, 30 - 35 kg nitrogen (N), 15 - 20 kg phosphorus(P), and 20 - 25 kg potassium (K) are needed. After shoot sprouting, from mid May to early June, about 130-150 kg N, 80 kg P and 110 kg K/ha are applied.

Irrigation. There is a close relationship between bamboo shoot growth and rainfall. Precipitation directly affects the quality and output of shoots. Rainfall from July to September is closely related to bud sprouting and quality on each node of the rhizome. Rainfall in December is of great importance to improving shoot development. Rainfall from February to April has a great effect on the shape, size and apparent color of bamboo shoots during this period, which is the time of shoot development. Irrigation is necessary if annual rainfall is not enough to maintain 1.5-2.0 PF which is suitable for soil moisture. If this condition is maintained, bamboo shoots can smoothly develop. When soil temperture increases, early harvesting is possible. On different topography, hole digging can be adopted. The method of water retaining can ensure soil moisture.

The best harvesting time for bamboo shoots in temperate areas is in the spring. Bamboo shoots begin to come up around April 15th and finish coming up during the first ten days of May. Bamboo shoots come up early and the amount of bamboos growing is high if the soil moisture is great. Strong bamboo shoots come out of the ground early. The height growth can be divided in three periods: Before May 9th is considered to be the earlier stage and growth is slow. After May 9th is the later stage and growth is faster. During last ten days May, there is stable growth (Fang 1988).

The shoot producing period for the species of tropical areas like *Dendrocalamus hamiltoni* is from mid May to mi November. The vigorous period is from June to September 8-14 shoots and culms can be produced. Cutting should be conducted in the last ten days of September, and cleaning up operations after the cutting should be finished before the end of October. Fertilizer application is generally carried out in January, May and August, although nitrogenous fertilizer should be applied in February and October (Nonaka 1989; Xie 1996).

Harvest season: Bamboo sprouts are harvested when the surface of the soil has cracked at least 5 cm and the tips of the shoots are yellowish. According to Porterfield (1926), at that time the farmers feel along the ground with their bare feet and when their toes come across the point of a shoot, a small mound of earth is piled over the place, not only to mark it, but to keep it under cover as long as possible.

This is the same kind of treatment accorded asparagus to keep it white. If the bamboo shoot is exposed to the sun, it turns green immediately. Very often, instead of piling earth over the young shoot, farmers cover it with a wooden bucket to keep it in the dark.

Nishino (1995) points out that from the time of the shoot sprouting (in April) in temperate areas, the old leaves of mother bamboo begin to fall and new leaves come out in mid April. In the case of new mother bamboos retained for shoot growth, the branches come out with leaf growth from early May to June. During this period the nutrients stored in the rhizomes, culm, branches and leaves are supplied for shoot growth, so the nutrient source is very important as long as possible.

There are two ways to force an earlier emergence of bamboo sprouts. One is to advance the period of sprout emergence by 7 to10 days. There is a practical means of doing this. By covering the soil with a vinyl sheet for about one hundred days before the beginning of the emerging period, the underground temperature can rise 10° C and we can advance the emerging period. On the other hand, we can harvest sprouts about 30-40 days earlier than usual by rising the underground temperature to 13° or 15° C starting in January. However, the cost is great and today this means is not practical.

Standing bamboos over 6-7 years old should be harvested because they are like and age woman bamboo. If they are still remain, development of new bamboo shoots is influenced and productivity goes down.

The executive plan to be thought at the present problem is that the harvested bamboo culms should be used to make charcoal and the charcoal should be applied to shoot cultivation stands. Then these bamboo culms should be put to practical use as substitute sources of energy, raw materials for pulping, and fodder for livestock.

For the cultivation of bamboo shoots, it is really necessary to apply great deal of labors In order to improve stands with low productivity, it is necessary to carry out reasonable selective felling, adopting appropriate stand density and introducing fertilization management in accordance with physiological and ecological theories. For fertilization, not only chemical fertilizers, but also organic fertilizers should be applied.

Types of commercial bamboo shoots

There are three types of commerical bamboo shoots: fresh shoots, dried shoots and canned shoots, of which there are two types. One is canned shoots of the genus *Dendrocalamus* for Chinese dishes and the other is *Phyllostachys pubescens*. One ton of dried shoots is generally produced from 20 tons of fresh shoots, while 40 tons of domestic canned shootswere to be produced from 100 tons of fresh shoots, but 70 tons of imported cannned shoots were made from 100 tons of fresh shoots 20 tons of fresh shoots = 1 ton of dry shoots;. 100 tons of fresh shoots = 40 tons of domestic boiled can shoots ;100 tons of fresh shoots =70 tons of imported boiled can shoots

Storage and preservation of shoots

The requirements for storage and shoot preservation are to keep the normal color, smell and taste, to prevent rot and to increase economic benefits.

In the experiments carried out by Liu (1996) in his study on storage methods for conserving *Phyllostachys pubescens* shoots, healthy living shoots 10-15 cms in height without insect pests were dug out from Dayuan Forest Farm in Zhejian, in April 1986.

The fresh weight of the uninjured shoots without stumps averages 0.5-1 kg. Loaded in baskets, the shoots are transported promptly with ventilation. Basking in the sun should be avoided and the shoots should be kept at low temperature after transportation and stored quickly.

The time elapsed from digging to storage should be less than 48 hours. The fresh shoots are put into two polyvinyl bags separately. The tops of the bags are bound, and they are packed into cardboard boxes with each box weighing 7.5 kg,. Four boxes are filled at a time with 7-10 fresh shoots with sheaths or 15-20 shoots without sheaths in each box. Packing is done under normal conditions with a constant temperature of 1° c after packing. They studied five treatment methods:

1.- Air tight cold storage with shoot sheaths: vacuum packed plastic bags are put into cold storage at 1°C.

2.-Quick frozen cold storage with sheaths: vacuum packed shoots are quick frozen in the bags at a low temperature (-18° C) for 20 minutes and then put into cold storage.

3.-Bags are put directly into boxes and are put in cold storage (contrast).

4.-Cold storage without sheaths: the sheaths are removed, the air is extracted from the bags, and then they are put into cold storage.

5.- Quick frozen cold storage withou sheaths: the sheaths are removed from the shoots and then they receive the same treatment as 2.

The results show that the quick frozen method with sheaths in vacuum packed plastic bags can conserve shoots for the longest time (over 3 months) in edible condition.

The second most efficient method is cold storage in vacuum packed plastic bags with sheaths, while cold storage with air in the bags or without sheaths can only conserve the fresh shoots for a short time in edible condition (Liu 1996).

The bamboo shoot cannery technique

Raw material preparation : The length of bamboo shoots should be less than 35 cm , free from insect and desease and mechanical damage . The time from digging to processing in not more than 24 hours (in winter itis not more than 24 hours). The weight of each shoot dug in early stage should be no more than 1.5 kg. Shoot should be solid with four basal internodes, and have red root points.

The technological process is: grading of raw materials ->preliminary cooking -> cooking -> pealing of sheaths for better looking -> rinsing -> improving shoot shape -> grading -> filling cans -> Adding soup -> sterilizing -> sealing the cans ->. can cooling -> storage .

According to different demand, cans of different size are used. In a 18 litre can , the shoot flesh should not be less than 11 kg. and 9 litre one not less than 5 kg. It is not allowable of negative weight error . No microorganism and rotten shoot should be found in cans. (Shi, Q. 1994)

PESTS AND DISEASES IN LIVING AND FELLED BAMBOOS

5

DECAY FUNGI AND INSECTS WHICH ATTACK LIVING BAMBOOS

All living species of bamboo and felled bamboos are liable to the attack by fungi and insects. Generally, the microorganisms and insects which attack living bamboos are different from those that attack felled culms, unless the living culms were sick. In the Americas very little information exists about this field and most of the following information is from Asia.

1.-DECAY FUNGI IN LIVING BAMBOOS

In Brazil, *Bambusa vulgaris* is affected by a disease caused by *Tomentella bambusina*, whose symtoms are: yellowing of the culms, droping of the bracks and shrivelling of the whole plant. Young shoots suffer most severely, becoming completely dessicated. The rhizomes are also invaded, the cortex rots entirely and only the central cylinder remains more or less intact.

In India, according to Banerjee and Ghosh (1942), of the 31 higher fungi collected on bamboo, seven occurred on living plants: *Polyporus durus, P. friabilis, Canoderma lucidum, Amauroderma rugosum, Tremetes persoonii, Merculius similis, and Stereo percome.* The fungus *Shiraia bambusicola* P. Henn, is parasitic on the young twigs of *Phyllostachys bambusoides, P. nigra henonis,* and other bamboos, and it is the cause of "red-patch" disease. *Aciculosporium Miyako* is parasitic on thebranches of several species and causes the "witches -broom" disease, particularly in old bamboos.

Phyllachora shiraiana Syd. is parasitic on the leaves, and gives rise to "black spot" disease. *Ustilago Shiraiana* P. Henn, is parasitic on the growing tips and tender internodes of some species and is the cause of smut. *Stereoostratum corticioides* Magnus is parasitic on several species and causes the "mat" disease of bamboo, alsoknown as "red coat" or "vermelion desease". *Puccinia kuisanoi* Diet is parasitic on leaves and causes a "rut disease".

Control.-In most cases, it is essential to cut down and burn the affected culms before the spores scatter. In some cases, it is only necessary to spray the affected area with fungicide or to scrape off the affected area before using fungicide. Bamboo groves must be thoroughly fertilized and the aim should be to have ventilation and penetration of sunlight into the grove. Some diseases break out mostly in crowded groves with saturated soil. In this case, it is necessary to obtain good drainage and thin out the grove.

Decorative fungus

Not all the fungus deteriorates bamboo. Some of them create beautiful patterns or spots on the surface of the culms of some species, and these are used for making various kinds of expensive art goods. This is the case of the fungus

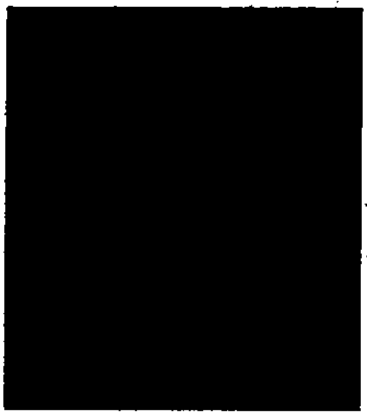


Fig.5.1 *A "princess fungus" Dictyophora, (China).*

Micropaltis bambusicola P. Henn and Shirai which is parasitic on the culms of *Sasa paniculata* and gives rise to the "round spot" disease.

Many attractive objects can be made from culms affected by this fungus. *Miyoshiella fusispora* Kawamura is parasitic on the culms of *Semiarundinaria fastuosa* making the so called "tiger pattern", also known on the market as spotted bamboo of Okayama. *Miyoshiella macrospora* Kawamura is parasitic on *Bambusa shimadai* from Taiwan and creates a characteristic pattern on the culm surface known as the leopard-pattern bamboo of Taiwan. *Leptosphaeria tigrisoides* Nara is parasitic on *Phyl-lostachys bambusoides* and produces a beautiful pattern on the culm known as the tiger pattern. *Asterinella hiugensis causes* the rare and beautiful spots on *Phyllostachys bambusae* bamboos. *Phragmothyrium semiarundinaria (Micropeltis bambusicola)* also produces a handsome spotted effect on *Semiarundinarea narikirae* (Takenouchi 1936; Hino 1934).

2.-INSECTS IN LIVING BAMBOOS

Insects that attack living bamboos are: *Artona funeralis* Butl. (Fam. Zygaenidae). The larvae make a mass attack on the leaves. According to Chin (1937), in Hangchow, China, its larvae sometimes defoliate more than 80% of the plants. *Atrachea vulgaris distincta* (Phalaenidae, syn Noctuidae) Warren. In the same area (Hangchow, China), its larvae attack young stems and shoots, causing them to dieback. The larvae pupate in soil. About 30% of them are parasited by Apanteles spp. The best method of control is cutting off the infected shoots for several years.

According to Ma (1934), *Estigmina chinensis* (Chrysomelidae), attacks the new growing culms, typically the internodes become short and sometimes crooked. Eggs are laid on the tender growing culms and then the larvae work their way inside the internode arresting the growth of the culm. If the attack is on one side, the internode bends to that side. If the attack is on both sides of a shoot, the internodes do not lengthen.

Cyrtotrachelus longipes (Curculionide). According to Deogun (1936), this is a weevil which attacks the growing tops of the new culms and, in the majority of cases, eats out the top bud. Growth is diverted to new leaders which arise from the upper nodes.

Brachytripus portentosus licht (B. achatinus Stal) (Fam. Grillidae). This insect bores holes in the culm near the ground line causing much damage. *Odonaspis inusitatus* Green (*Aspidictus inusitatus* Green) (Fam Coccidae) occurs in Japan and Ceylan. The male insects lodge in the space between culm and the leaf sheath and suck the juice. *Odonaspis secretus* Ckll (*Aspidiotus secretus* Ckll) occurs in Japan and Hawaii.

Chionaspis signata Mask (Chionasp Kuwana) (Coccidae) occurs in Japan. The females are parasitic on the leaf surface *Chionaspis bambusae* Ckll. occurs in Japan and is parasitic on the lower surface of the leaves. *Aclerda tokionis* Ckll. occurs in Japan and North America. The female lives inside of the leaf sheath. The juice secreted by the insects causes the growth of a sooty fungus. *Phenacoccus takae* Kuw. (Coccidae) occurs in Japan.

Eriococcus onuki Kuw occurs in Japan. During their growth, they secrete the honey-dew on which a sooty fungus grows. *Polydesma vulgaris* Butl. (Phalaenidae). The larvae feed on the bamboo shoots of several species, which finally die and decay.

Cosmotriche albomaculata Brem. (Lasiocampidae). The larvae feed on bamboo leaves. *Neope goschkevitchii* Menertries (Satyridae). *Clytanthus annularis* F. (Cerambycidae) larvae bore holes in the culm and rheum and fills them with a powdery substance. *Oligomerus brunneus* Steph. (*Lyctus brunneus* Steph. (Fam. *anobiidae*). This insect bores holes in the culm and fills the hole with a powdery substance. It occurs in Japan and Europe.

Control: The best method of ~~control is cutting off and~~ burning all of the attacked culms in winter (rainy season) when the sap is low and the insects are hibernating. Also it is recommended that a light ground fire be run though the infested areas, as the insects are believed to spend the winter under debris on the ground.

Tan Hongchao (1996), in his study about high yield cultivation techniques for *Dendrocalamus giganteus*, includes the following information about control of the main insect pests:

1. Shoot rot. Damage: The shoot tops and young leaves on the internodes and the buried culm are damaged. Rot can be seen where brown spots appear. This disease occurs in the shoot sprouting period of the first year.

Control: Kitchen garden, pine and fir forest land should not be used for nurseries. A basic composite manure should be used and plantlets should be grown fromhealthy mother bamboos 2-4 years old. Shoots with rotten tips should be cut off at the base. A Bordeaux mixture of 1:1:150 times or 0.1% potassium permanganate should be sprayed at the initial incidense of disease and it should continue to be sprayed every ten days, until the plantlets show vigorous growth.

2. Witches' broom. Damage: This causes a cluster of branchlets grow on part or all of the bamboo. The time of incidence is from March to August when branching and leaf unfolding take place.

Control: Dig the diseased bamboos up in time and burn them. The old ones should be cut as soon as possible and new mother bamboos should be selected from a disease-free forest. Improvements should be made to strengthen the stand, such as loosening the soil, weeding, fertilization, and thinning.

3. Smut. Damage: Dark stains appear on the surface of the branches and leaves. The time of incidence is during the bamboo growing season.

Control: Aphids and scales are the main insects that must be killed in the forest. Timely thinning of the stands is carried out to facilitate air circulation and let in more sunlight. Bamboos are sprayed with a mixture of 0.2-0.3 degree lime sulfur solution.

4. *Oligia vulgaris*. Damage: Shoots are bored by larvae, resulting in lower quality shoots. The time of incidence is from March to May, when the insects feed on weeds and farm crops, and then they bore the shoots in mid June.

Control: Strengthen tending and weeding. Shoots should be covered with earth and the damaged shoots should be dug out early. A 223 emulsion (25%) diluted 200 times is sprayed in the forest or nursery.

5. *Algedonia coclesalis*. Damage: larvae spin and envelop the leaves in a web, then they eat the bamboo leaves. The time of incidence is i from May to September.

Control: Hill leveling and soil loosening can kill the wintering larvae. During the larval period, Dipterex liquid diluted 500 times or Dichlorvos emulsion diluted 1000 times can be sprayed. *Thrichrogramma evanescens* can also be used for biological control at a release rate of 22.5 millions/ha. or 2-3 ml of systemic pesticides such as Acephate or Omethoate may be injected in each new bamboo.

6. *Oregma bambusicola*. Damage: They congregate on leaves and branchlets to suck bamboo sap, causing smut. The time of incidence is from May to September.

Control: A 50% Dimethoate emulsion diluted 2000-3000 times, Dichlorvos diluted 2000 times, or a 50% "1605" emulsion diluted 1000-2000 times is sprayed. Biological control is carried out using lady bugs.

7. Leaf hopper. Damage. These damage the leaves and suck the sap from them. The time of incidence is from June to October.

Control: a Dimethoate emulsion diluted 3000 times or Dichlorvos diluted 2000 times is sprayed.

8. *Ceracris kiangsu*. Damage: Adults and nymphs all eat bamboo leaves.The time of incidence is May to October.

Control: A 6% BHC WP diluted 200 times is sprayed or the fumigant Dichlorvos is used at a dose of 7.5 kg/ha. A mixture of 50 kg. of urine with 2 kg of 6% BHC becomes a solution, in which straw is soaked and used for locust trapping. Masses of people are roused to catch them when an outbreak occurs.

9. *Chionaspis bambusae*. Damage: They live on branches, twigs or culm tops for sap sucking and cause smut.

Control: Strengthen the quarantine for mother bamboos. Dichlorvos diluted 1000 times or malathion diluted 1000 times is sprayed during the nymph period. When Song-Jian Mixture is used, it is diluted 10-24 times in summer and to 8-12 times in winter, or Fluoro acetamide diluted 20 times may be poured 6-10 cm deep into the soil around the bamboo roots.

DECAY FUNGI AND INSECTS WHICH ATTACK FELLED BAMBOO

Most bamboo species, once felled, are highly susceptible to attack by decay, fungi, and insects (beetles, borers and termites), particularly if they are less than three years old and if the moisture content is above the fiber saturation point (18% in bamboo). Decay fungi (brown rot, white rot, soft rot) and staining fungi, attack especially in tropical areas where deterioration can be very severe and reduce the bamboos' natural durability. In sea water, bamboo is destroyed by marine organisms in less than one year.

On the other hand, in Colombia, where bamboo is used in conjunction with hardwoods in the construction of houses, generally the beetles or borers that attack felled culms, do not attack timber and vice versa, except the subterranean termites, that attack both, particularly when they are used in contact with the ground. This can be observed in Colombia in many old bamboo houses that were built using the species *Guadua angustifolia* and "guadua cebolla" (still not identified), together with hardwoods. In some cases, there is old wood which has had to be replaced by new wood because of insect damage, while the bamboo still remains in very good condition; while in others, the opposite occurs.

Decay fungi.

Moisture content has an important effect on susceptibility to decay. In bamboo, most decay fungi require a moisture content above the fiber saturation point to develop.In addition, it is essential that they have a favorable temperature, an adequate air supply and a source of food.

Cut bamboo (round, split or transformed into boards), are commonly attacked by decay fungi when stored in non ventilated areas, in contact with the soil, or continuously wet from rain, or in cases that green bamboo boards are stacked for several days one on top of the other without any separation. But bamboo that is continuously water-soaked (as when sumerged) or continuously dry (with a moisture content below its fiber saturation point) will not decay.

Felled bamboo culms, transformed into splints or boards, when green or mature, are more severely deteriorated by white rot, and especially soft rot fungi, than by brown rot. Under humid conditions, bamboo articles can be discolored by molds.

White and brown-rot fungi produce progressive changes in the chemical properties of bamboo components, such as carbohydrates and lignin. Brown rot in progressive decay reduces the weight of the culms, and decreases the hemicellulose an alphacellulose.

Because of the rich content of starch, polysaccharides, and water soluble in bamboo, a staining type of fungus, known as mold, can quickly infect and propagate on bamboo culms after felling and during usage when they are in the conditions of high temperature and humidity.

This means that mold is an indication of moist conditions, which are conducive to the development of decay. Mold does not materially destroy the strength of bamboo, except its toughness, but it causes a decrease in the value of bamboo culms and products.

Insects

The insects which attack felled culms and produce serious damage in round bamboos, or bamboo culms transformed into splints or boards are termites and beetles or borers. These generally attack the inner part of the culm wall, which is the softest part, and consequently, the most susceptible to beetle attack. It appears that in most species the top part of the culm has a higher resistance to insect attack than the bottom and middle portions due to a lower amount of parenchyma and consequently less starch. Split bamboo and bamboo boards are more rapidly destroyed than round bamboos.

Termites.

Termites are among the few insects capable of utilizing cellulose as a source of food. There are two types of termites, subterranean and nonsubterranean or dry-wood termites, which live in bamboo as well as in drywood in some areas of Southeast Asia. In Colombia, I have never seen bamboo culms attacked by non subterranean termites. Bamboo culms used as posts or columns, are attacked by subterranean termites, that live in the ground and build earthen tubes above theground to reach their food, the cellulose of the bamboo wood.

Control.-The subterranean termites can be controlled by: 1) Destruction of the earthen tubes. 2) Installing a metal shield on the top of the pedestal piles and the bases of columns. 3) Poisoning the soil adjacent to bamboo houses or under them. For treatment against termite attack, Sulthoni (1990) recommends a simple and cheap method of bamboo preservation, soaking air dried bamboo in 7% copper sulphate solution or in diesel oil. He treated small air-dried (5x46 cm) stakes with a cold soaking for a period of seven days. The treated samples were put into the ground in the open for one year. It is clear that both the copper sulphate and the diesel oil effectively prevented termite attack. However, the diesel oil treatment proved to be much cheaper.

Borers.

Starch, soluble carbohydrate and protein are essencial food requirements for a borer attack. These food materials vary with the season. The most active period of borer attack in India is from March onwards.

Starch, soluble carbohydrates and protein are the essential food requirements for a borer attack. These food supplies vary with the season, and the most active period i of borer attacks in India is from March onwards.

In Asia, the most dangerous borers that attack felled bamboos, bamboo articles , bamboo houses and structures are the species of *Dinoderus* (Coleoptera: *bostrichidae*), *Dinoderus minutus* Fabr., *D. ocellaris Steph*, *D. japonicus*, *D. brevis*, and also *Bostrichus paralelus (Bostrichidae)*, and *Stromatium barabatum* (Cerambicidae).

In the Americas, the most serious damage is produced by *Dinoderus minutus* Fabr. known as the powder-post beetle, which also attacks a large number of other vegetable products. The crisscross tunnels produced in the culms reduce their useful life. This insect attacks the bamboo for

Fig.5.2 *In young culms (from 9 months to 2 years old) even the cortex or exterior part of the culm is attacked by the insects.*

Fig. 5.3 *In older culms the insects only attack the interior soft part of the culm wall if it has starch.*

the starch, and the damage it causes is proportional to the starch content of the culms. The starch is detected by the beetles almost immediately after the culms are felled and assembled for drying or storage.

Flies swarming over the cut ends of felled green bamboos are a sign that that particular bamboo culm is going to be attacked. There is a rather definite correlation between susceptibility to insect attack and the starch content of the culm. According to Liese (1985), the starch content in the culm reaches its maximum in the driest months, just before the rainy season and sprouting.

This is the reason why bamboos felled during the dry season are more rapidly destroyed than those felled after or in the rainy season and sprouting. This is also in accordance with the observations made by Channigaraya (1939), who points out that in India in the Bhadravati division, bamboos of the species *Dendrocalamus strictus* and *Bambusa arundinacea* collected during the summer are more susceptible to beetle attack than those felled after the rains, since the beetle population dies down with the advent of the rains. Deogun (1936) comments that the attack may be controlled by cutting the culms in the rainy season when the sap is low and the insects are probably hibernating.

The adult insect enters bamboo through its cut ends, through the cracks or a break in the surface, or through the scars left when the branches are cut. The insects go through a complete metamorphosis, passing through four stages of development: egg, larvae, pupa and adult.

According to Plank (1948), once the insects penetrate the cut ends to the inner culm wall, they extend their cylindrical galleries along the soft inner portion of the wall. For the purpose of oviposition, the adults extend their galleries at right angles to the grain of the wood in the soft tissue. Inside the culm, in the tubular vessels of the fibro-vascular bundles thus cut, they deposit elongated oval eggs that hatch within 3 to 7 days.

The larvae reared in small pieces of bamboo have a feeding period of 41 days, pullpate in cells at the end of their mines, and gave rise to adults about 4 days later. The emerged adult spends about 3 days in its pupation cell before gnawing an exit hole for leaving to the outside. Development from the time of the deposition of the egg to the emergence of the adult averages 51 days. The larvae and pupa are parasitited by the *Braconid doryctes parvus* Mues. and *Pteromalid proamotura aquila* Gir. respectively. Some bamboo species are more susceptible than others to beetle attack.

The starch content of the wood of the culms, varies with the species and with the age of the culm,and decreases from the base to the top of the culm. Plank (1936) worked in Puerto Rico on susceptibility studies of various species. Exploratory tests indicated that *Bambusa vulgaris* was the most susceptible of all bamboo species to infestation by the *Dinoderus minutus*. For this reason, its usc for construction is not recomended. (See Treatments)

Fig. 5.4 PLAGUES

In 1972 I started doing research on the use of bamboo cables as reinforcement in concrete beams at the National University of Colombia in Palmira. I cut about 90 culms of *Guadua angustifolia* and a few of them had a crack about 12 mm wide (See figs 5.3C) by 100mm long. The internodes in this part of the culm were very short. This indicates that the insect attack was made during the elongation process of the internode. We opened these culms longitudinally, but we did not find the insect. However, in other culms that we opened longitudinally, which did not have a crack, we found a white worm living at the end of some of the internodes, separated from the rest of the internode by a thin wall. (Fig. 5.3A).

(2). The worm (Fig.5.3B) was about 8-10 cms long with a diameter of 9 mm in the central part and an inverted "Y" in the front. According to Dr. Adalberto Figueroa, who at that time was an Entomology professor at the Agronomy College of the National University in Palmira, the moth lays its eggs above the node and the small worm perforates the culm wall in order to go inside the internode (Fig.5.3 (1). When the worm is bigger, it opens a hole one centimeter in diameter from the inside to the outside, next to the node (Fig.5.3A (4)), through which it will leave the culm internode once transformed into a moth. The worm builds a wall or partition in order to protect itself from a fly that attacks the worm and this fly goes inside the internode through the hole. Later on, woodpeckers locate the worm by the vibration of the culm, open a large hole in the culm, and with a small branch chase the worm.

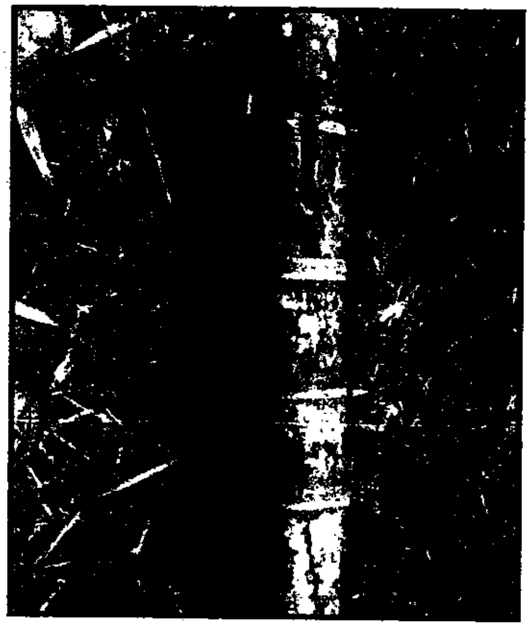
The moth was sent to the Smithsonian Institution in Washington D.C. where its genus was identified as *Mielobia sp.* (I think that it is important to verify this identification.)

It is not recommended that sections of culms with this type of cracks (as shown in fig, 5.3D) be used in construction because the crack continues along the neutral axis of the beam.

A (1) (2) (3) (4)

B

C



D. *Don't use bamboo culms with this defect in construction because they present a crack along the culm as shown in this figure.*

PART 2
Bamboo Properties

Carrier with a Bamboo chair. (Ferdinandus' drawing). Geografia Pintoresca de Colombia in 1869.

6 PHYSICAL - MECHANICAL AND CHEMICAL PROPERTIES

A. PHYSICAL PROPERTIES

For the appropriate use of each specie of bamboo and wood it is very important to study their physical properties (density, moisture content, hardness, etc.) which are related with the characteristics of the material; and also their mechanical properties which are related with the strength of the material (tensile and compresion strength, etc). There is a great relation between the physical and the mechanical characteristics For example the strength properties of bamboo are influenced by the specific gravity and moisture content of bamboo Due to this reasons each bamboo specie can have one or several aplications in one or in severalt fields-(construction, handcrafts etc) depending on their physical and mechanical properties. The main physical properties of the culm are the following:

DENSITY - SPECIFIC GRAVITY

Density is the mass of a material per unit volume.-The specific gravity is the ratio of the density of a material to the density of an equal volume of water. When the metric system is used, the density of the water is 1 gr. per cubic centimeter, and consequently density and specific gravity have the same value.

The specific gravity of culm wood is a measure of its solid wood substance and an index of the mechanical properties of the culm. It depends mainly on the anatomical structure such as the quantity and distribution of fibers around the vascular bundles, as well as fiber diameter, and cell wall thickness. The specific gravity in bamboo varies from about 0.5- 0.9 g/cm^3, depending mainly on the species and type of rhizome. According to Du & Zhang et al (1992), the absolute dry density of the clump type (pachymorph) is also higher than that with leptomorph rhizome. In timbers, the specific gravity is in the order of 0.3 -1.04.

The specific gravity or density of bamboo increases from the innermost layers to the peripheral part of the culm and along the culm from the botton to the top with the increase of the fiber percentage (bottom 0.547 - center 0.607 -top 0.675). In the radial direction the variation could be 20-25% in thick-walled bamboos like *Dendrocalamus strictus*.

In thin-walled bamboos, the differences in density are much less. According to Liese (1998) about 50% of the fibres of the culm wall are located in the outer third of the culm wall and this increase its density. These indicates that the strength of the culm wall gradually increases from the inside to the outer part of the wall, and that the strongest part of the culm is the external 1/3 layer of the culm wall.

The specific gravity of the internodes increases from bottom to top (0.75-0.78- 0.78).The specific gravity of the nodes is generally higher than that of the internodes due to less parenchyma, an more fibre wall, whereas bending strength, compression strength and shear strength are lower. (Sharma & Mehra 1970).

A close correlation exists between specific gravity and maximum crushing strength. It seems that resistance to compression parallel to the grain is more or less uniform, hardly being affected by the height of the culm.

The upper part of the culm, with smaller but more vascular bundles and their fiber sheaths, has an increase fiber percentage and hence a higher specific gravity. In most of the species the upper part of the culm is the strongest part to compresion of the whole culm For bending strength and modulus of elasticity, higher values were obtained from the upper part of the culm.

MOISTURE CONTENT

In adition to the anatomical structure of the culm wall, the strength properties of bamboo are influenced by moisture either as vapor in the air or as a moisture content. Moisture content (MC) is the weight of the water contained in the wall and cell lumen of a culm section expresed as a percentage of its oven-dry weight.

For example: If a section of a culm has an initial weight of 10 kg. and the dry weight, once it gets a constant weight in the oven of 7 kg., then the moisture content per cent can be calculated from the following formula

$$\text{M.C.\%} = \frac{\text{Initial weight - dry weight}}{\text{dry weight}} \times 100$$

$$\text{Example: M.C.} = \frac{10 - 7}{7} \times 100 = 42.9\ \%$$

The amount of moisture in a living bamboo culm varies widely among species, in individual culms within the same species, in different parts of the same culm, and is influenced by its age and the season of felling. Young immature culms contain more moisture than mature ones. In the green condition the moisture content in the culm varies from as little as 40% to about 150%.

Young culms have an almost uniform moisture content over their lengt, Young one year-old culms have a moisture content of about 120-130% both at the bottom and top. In culms older than two years the moisture content decreases from bottom to top. e.g. for *Dendrocalamus strictus* about 100% moisture content and 60% respectively.

Generally the internodes have a higher moisture content than the nodes. Across the culm wall the moisture is higher in the inner part than in the outer part. The variation reportrted is 155% for the innermost layer to 70 percent for the peripheral layers. Throughout its life the living culm remains moist or fresh.

Different species show different moisture value even at the same location. This variation is closely related to the amount of parenchyma cells pressent, the site of water storage. The strength properties of bamboo are influenced by the moisture content of the culm as in timber. Generally, in the dry condition the strength of the culm is higher than in the green condition. The differences between the air-dry and green condition are some times relatively small, especially for bending and cleavage. (Liese, 1985).

The moisture content of the bamboo culms varies widely among species, and among individuals culms. In green bamboos the moisture content decreases from bottom to top, but after air drying, the moisture content does not vary greatly from the bottom to the top of the culm. For example, in the studies conducted by Prawirohatmodjo (1988) in several species of Indonesia the moisture content at the basal, middle and top of green *Bambusa arundinacea* was 48.5-38.5-31.6 %. After air-drying it was 15.7-15.6-15.2 %. (Liese, 1985; Sharma & Mehra, 1970; Kumar & Dobriyal, 1988). The moisture content in timber and bamboo is commonly determined using electrical moisture meters.

Equilibrium moisture content

Bamboo and timber are hygroscopic. It means that any dry piece of bamboo or timber in use, placed in a very humid space will take up moisture from the air, but wet bamboo will give up some of its moisture to a drier atmosphere until the amount of moisture in the culm has cometo a balance with that in the atmosphere. The moisture content of the culm at the point of balance is called equilibrium moisture content (E.M.C) and is expressed as a percentage of the oven-dry weight of the culm section. At constant temperature, the equilibrium moisture content depends entirely on the relative humidity of the atmosphere surrounding the culm and the hygroscopicity of the bamboo wood.

Fiber saturation point

Moisture in green bamboo is partly absorbed in the cell walls and partly present in the cell cavities or cell lumen by capillary forces. As the bamboo wood dries and loses moisture, the cell walls do not give off moisture, until the cell cavities are empty. The condition in which the cell walls are fully saturated and the cell lumen are empty is known as the fiber saturation point (F.S.P.). In timbers, the fiber saturation point varies with the species in the range of 28 to 30%. but is commonly taken to be at a moisture content (MC) of about 30%. The fiber saturation point in bamboo is influenced by the composition of the tissue and varies within one culm and between species in the range of about 13% (for *Phyllostachys pubescens*) to about 20% (for *D. strictus*).

SHRINKAGE

Bamboo, like wood, is anisotropic and has as its principal directions the longitudinal or axial, radial and tangencial as referred to the cylindrical shape of the culm In timber, moisture content variations above the fiber saturation point (30%) have no effect upon the volume or strength of wood. As wood dries below the fiber saturation point and begins to loose moisture from the cell walls, shrinkage begins and strength increases.Shrinkage of timber takes place between fiber saturation point and the oven dry condition. It is greatest in the direction of the annual growth rings (tangentially), somewhat less across the rings (radially), and very little along the grain (longitudinally). Unlike timber, bamboo begins to shrink from the very beginning of seasoning. According to Liese (1985) the shrinkage affects both the wall thickness of the culm and the diameter, and it shows a tendency to decrease from the bottom to top. Seasoning of mature culms from green condition to about 20% moisture content leads to a shrinkage of 4 to 14% in the wall thickness, and 3 to 12% in diameter.

Bamboo tissue mainly shrinks in the radial direction, and the minimum deformation occurs in the axial direction. The tangential shrinkage is higher in the outer parts of the wall than in the inner parts. The shrinkage of the whole wall appears to be governed by the shrinkage of the outermost portion which also possess the highest specific gravity. Mature culms shrink less than immature ones.

Shrinkage starts simultaneously with the decrease of moisture content but does not continue regularly. As water content diminishes from 70 to 40%, shrinkage stops; below this range it can again be initiated. Parenchyma tissue shrinks less in bamboo that in timber, while vascular fibers shrink as much as in timber of the same specific gravity. When the moisture content is low, swelling due to absorption of water is almost equal to shrinkage. Moist heating leads to irreversible swelling in all directions.

Variation in moisture content, density and strength along the wall thickness of bamboo is probably responsible for the adverse behavior of bamboo in use. Green bamboo experiences show irreversible and excessive shrinkage well above the fiber saturation point with only partial recovery at the intermediate stages.This behavior is linked to collapse. Below the fiber saturation point the behavior is similar to wood.

Bamboos dries best under air dry conditions. Rapid drying in kiln may lead to surface cracking and splitting due to excessive shrinkage. Values of shrinkage from the freshly felled to the oven-dry state were determined for *Phyllostachys pubescens* as follows: tangential, 8.2% for the outer part of the wall, and 4.1% for the inner. Radial, 6.8 for the outer part and 7.2% for the inner. Longitudinal, 0.17% for the outer part, and 0.43% for the inner. The percentage of swelling decreases with an increase of basic density. (Liese 1985, Sekhar & Rawat 1964. Sattar et all 1992).

Timber increases in strength as it dries. For example, the strength in endwise compresion of small pieces is about twice as great for a moisture content of 12% as for green timber, and drying to about 5% moisture content will some times triple this property (Wood hand book 1955). Unlike timber, the increase in strength in bamboo as it dries, is much lower than that of timber. For this reason there is not any risk in using green bamboos for construction purposes as far as strength is concerned. (See Seasoning or drying of bamboo).

In the study conducted by Prawirohatmodjo (1988) in 6 species from Indonesia related to comparative strengths of green and air-dry bamboo, he found that the moisture contents of green bamboos decrease from bottom to top of the culm e.g., in *Dendrocalamus asper*. 76.-36%; This is due to the amount of parenchyma of the culm wall which also decrease from bottom to top. (Liese,1980).

The average bending strength for the bottom, middle and top part of *Dendro-calamus asper* (green = 6,873 N/cm2; Air-dry =10,336 N/cm2); *Gigantochloa apus* (green =10,203 N/cm2; Air dry = 8,750 N/cm2) . In compression strength the total maximum crushing for the bottom, middle and top portion were respectively for *Dendrocalamus asper*, green =1,462; 2, 453; 2942 N/cm2. Air-dry=2,155; 3,043; 4,261 N/cm2.;*Gigantochloa apus*, green=2,173; 2,372; 2,650 N/cm2; air-dry 2,729; 3654-4,864 N/cm2. In tension parallel the average in *Dendrocalamus asper*; greeen = 28,426 N/cm2.; air-dry 51,916.*Gigantochloa apus*, green = 29,410 N/cm2; air-dry=29,891 N/cm2

SPLITTING

Unlike trees, bamboos has not radial cells which in trees increase their shear strength parallel to the axis. This is the reason why bamboo culms split easily. This could be a disadventage for nailing bamboo but also it could be a great adventage because it makes easy to split bamboo into fine strips for making baskets of various sorts, framework for umbrellas, window screens, fans and so forth.

The splitting quality depends on the number of fibrovascular bundles. The greater the number, the easier the culm splits. The area occupied by the vascular bundles is the sum of those areas seen in cross section. The species belongin to the genus *Phyllostachys*, specially *Ph. niogra henonis* and *Ph. bambusoides* have good spplitting quality so that they are very easily split.

THERMAL CONDUCTIVITY

Thermal conductivity is a measure of the rate of heat flow through materials subjected to a temperature gradient. Bamboo like wood is a cellular substance and in the dry state the cell cavities are filled with air , which is one of thepoorest conductors known. Because of this fibrous structure and the entrapped air , bamboo has an excelent insulation property .Experiments show that the coefficient of thermal conductivity of bamboo is a little higher than that of wood, but the diffference is too small to be taken into account.

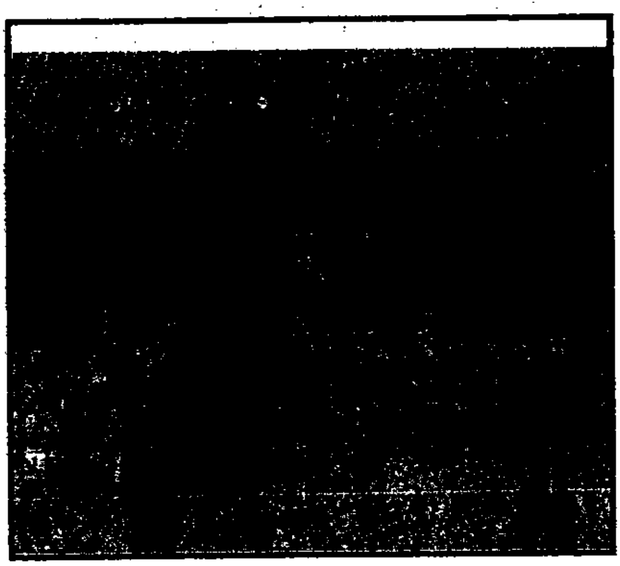
The thermal conductivity of wood is about two to four times that of common insulating materials. For example, structural softwood lumber has a conductivity of about 0.75 British thermal units per inch per hour per square foot per degree Fahrenheit, compared with 1.500 for aluminum, 310 for steell, 6 for concrete, 7 for glass, 5 for plaster, and 0.25 for mineral wool.The thermal conductivity is affected by a number of basic factors such as density, moisture content, temperature. It increases as the density, moisture content, temperature, or extractive content of the wood increases.

HARDNESS

Hardness represents the resistance of bamboo to wear and marring. It is measured in wood by the load required to embed a 0.444 inch ball to one half its diameter in the wood. Values presented are the average of radial and tangential penetrations (Wood Handbook 1987). This method of testing used in bamboo can probably produce the separation of the fibers in the culm and consequently a crack along the internodes, if the ball is located in the center of the internode. For this reason ,it is better to locate the ball near the node where the shortest fibers of the internode are found.

As was explained before, the strongest part of the culm wall is the external third, which includes the largest number of fiber bundles, and the least strong is the internal third of the culm wall where the least number of fiber bundles and the largest amount of parenchyma cells are found.

The cortex or outermost layer of the culm wall consists of two epidermal cells layers with a high silica content which strengthens the epidermal layer. The exterior layer of the cortex is covered by a cutinized layer or glossy surface, which is known as cuticle, and is composed of cellulose and pectin with a wax coating on top. Beneath the epidermis lies the hipodermis, consisting of several layers of thick walled sclerenchymatous cells. These two layers impart an extraordinary hardness to the outer surface of the culm, forming a sort of protective shield against insects, hits, wearing out, and even for improving the acoustical quality of the sound field in a bamboo forest.



Figs 6.1 and 6.2 - *The extraordinary hardness of bamboo cortex is utilized in China in the form of bamboo splints for covering the steps of wooden staircases to protecting them from wearing out, as can be seen in photographs 6.1 and 6.2.taken in the Forbidden City in Beijing, China, which is visited daily by thousands of tourists.*

THE BAMBOO THAT SURVIVED THE RADIATION OF AN ATOMIC BOMB

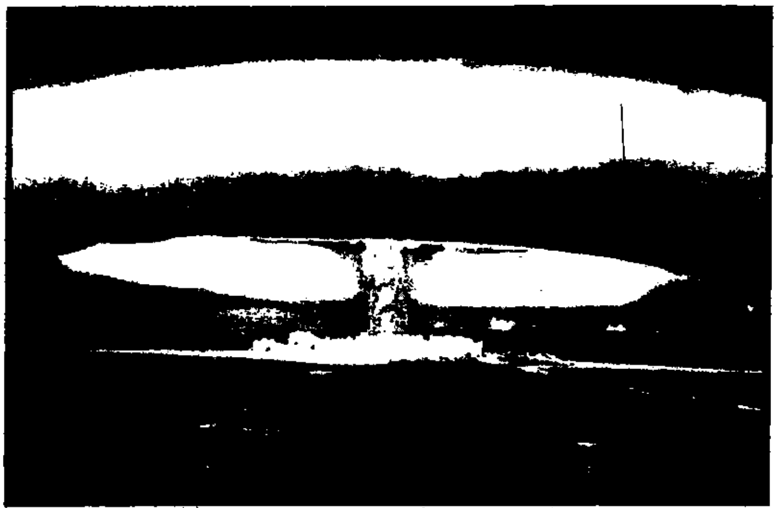


Fig. 6.3 *The first atomic bomb*

Fig.6.4 *In the very epicenter of this horrible destruction of the city of Hiroshima only this bamboo plant survived to the incinerating heat, which was expanded with the wind and the concussive shock wave (After Junko 1972).*

The extraordinary hardness of the cortex or outer part of the culm, served as a protective shield, which only suffered scorching on the side of the culm which directly received the radiation

Only a supernatural being or a superplant with extraordinary physical and mechanical properties can withstand an atomic radiation without being destroyed. Perhaps the Garrows, people that inhabited the western extremity of the Himalayas, were correct in their belief that in the world of plants bamboo is the representation of the divinity. This terrible experience demonstrate the extraordinary characteristics of the bamboo cortex hardness.

On August 6, 1945, at 8:16 a. m., an atomic bomb was exploded about 580 meters above the city of Hiroshima, Japan, producing an incinerating heat, a concussive shock wave, and a towering cloud that cast day into darkness. Within a matter of seconds 200,000 people, one half of the city's total population perished, 70,000 buildings were destroyed,. wood houses ignited. Steel twisted and stone glowed. Raging winds from of the blast spread a conflagration. Trees and grass were charred to bits. According to Junko (1972), in the wake of the relentless destruction, however, one living thing survived. In the very epicenter, a thicket of bamboo stood through the blast, suffering only scorching on one side . The sight was of great encouragement to the war-shattered citizens. But, unfortunately the plants were not allowed to stay there long, they were dug out to build the Memorial Museum for Peace, and a portion of the plants is now housed in the Museum.(*Junko 1972*).

I will never understand why the Japanese did not leave this plant in place in order to study the consequences of the radiation on each part of the plant and on their descendants.

Probably many people will wonder why this bamboo did not catch on fire as all the trees and wooden houses did? The answer is that the extraordinary hardness of the cortex or outer part of the culm served as a protective shield, which only suffered scorching on the side of the culm which directly received the radiation. In this case, the same thing occur as when a bamboo section is going to be bent using a gas torch. The area of the culm where the torch is applied for several seconds becomes scorched, but if the torch is applied in the same place for a long time, the culm can be set on fire.

THE INFLUENCE OF BAMBOO PHYSICAL PROPERTIES ON THE ACOUSTICAL QUALITY OF THE SOUND FIELD IN A BAMBOO FOREST

Sakai, Shibata and Ando (2001), investigated the acoustical quality of the sound field in a bamboo forest of the specie *Phyllostachys pubescens* in Kioto, Japan, in 1997. They concluded in their paper *"Ortogonal acoustical factors of a sound field in a bamboo forest"*, published by the Acoustical Society of America (2001), that the sound field in a bamboo forest have excelent acoustical properties, due to the physical characteristics of their culms such as uniform diameter, hollow tube structure and hardness or rigid surface

Before this investigation, a number of acoustical measurements were carried out in three tree forests in England under different atmospheric conditions of temperature, humidity, and sound speed. The reverberation time and the attenuation of the sound pressure level (SPL) as a function of distance in a tree forest were also investigated. A prediction model that considered excess attenuation by the ground and multiple scattering by trees was used. However, it is quite difficult to estimate sound fields due to the complicated conditions of excess attenuation, multiple scattering effects, temperature, tree leaves, tree distribution, and so on, especially for the higher frequency range.

Recent results related to the acoustical quality of sound fields in a tree forest are briefly introduced by Sakai *et al*, *(1998)*. In this study the temporal and spacial factors were analyzed and the results were compared with those in a concert hall. First, subsequent reverberation time T_{sub} became larger mainly in the middle frequency range such as 500 Hz and 1 kHZ of 1/1 octave band center frequency and at measurement points far (40 m) from the sound source.

Second, the decay level of reverberation in the forest kept its level after an initial decay as a result of multiple scattering from tree trunks althought it normally decreases linearly in an inclosure. Such a decay curve–shape is generally considered to be specific characteristic of a sound field in the tree forest.

Third, IACC, which is defined as a maximum value of interaural cross-correlation functions between signals at the ears withinits time duration t=± 1 ms, decreased at positions farther from the source. Finnally, SPL relative to that at 5 m from the source decreased by about 12 dB for every doubling of distance, although in a free field it decreases in accordance with the low inverse square.

This article o only include part of the investigation carried out by Sakai,Shibata and Ando (2001) about the acoustical characteristics in a bamboo forest obtained by using the same procedure for the previous measurement in the tree forest and in an enclosure. Bamboo is unique for its uniform diameter, hollow tube structure and rigid surface. In the previous forest the wave- length of the frequency band that was efective for T_{sub} and IACC approximatelly matched the diameters of the tree trunks (0.6 m in average). thus a bamboo forest was selected in order to ensure the relationship between the efective frequency band and trunk diameter. In such a sound field, complicated conditions such as multiple scattering from tree trunks, excess attenuation by the ground, trunk distribution, and many atmospherical factors, including temperature, humidity and wind affect the sound field. Considering these factors, the sound field is difficult to simulate and the impulse responses are to complicated to calculate. At the present stage, therefore the only effective approach is to use measure results.

Site description Acoustical measurements were conducted in part of the bamboo forest of the specie *Phyllostachys pubescens* which consists of randomly distrubuted culms of bamboo. The density of bamboo in the area was about 50 culms per 100 m². Althought the tree diameters in the previously studied forest were almost random between 0.3 and 1.0 m, those in the bamboo forest were almost uniform with its diameter about 0.13 m. The height of bamboo around the area was about 8 m. The area had a space about 3 m wide in front of the source without any bamboo. The area in front of the sound source had a gentle slope (10-12°). On the day when the measurements were conducted, there was not wind, and the temperature was between 25-27° C.

Procedure The measuring procedure was exactly the same as for the previous measurements in the tree forest Receiver positions for sites, 5-10-20 and 40 m from the sound source S were selected. An omni directional dodecahedron loud speaker was used as a sound source with its height 1.5 m. As a receiver, a person with a tiny half-inch condenser microphone at each ear was used. The maximum length sequence (MLS) was used as a source signal. The signal was radiated from the dodecahedron loudspeaker with its A-weighted SPL 100 dB at 1 m from the source. In this measurement, sequence length was 2.7 s, the number of average was four and sampling frequency was 48 kHz. Binaural impulse responses (h_l and h_r) at each receiving position were calculated using the Hadamard transformer of signals at both ears, all acoustical factors were calculated from the binaural impulse responses.

The results were compared with previous results for a sound field in a tree forest (Sakai, S.Sato and Y. Ando, 1998). The IACC, which is defined as a maximum value of the normalized interaural cross-correlation function between signals at the ears, was 0.07 (4kHz) and 0.16 (2kHz) at positions 20 and 40 m from the source, respectively. these values are much better than those in the previously investigated forest.

The subsequent reverberation time T_{sub} was up to 1.5 s in the frequency range above 1 kHz at the position 40 m from the source. For certain music sources with higher frequency components, therefore, sound field in the bamboo forest have excellent accoustic properties The results show that the sound field in a bamboo forest is suitable for listening to music. Thus, these measurements provide valuable and useful information for designing outdoor concert spaces using bamboo an other natural forests and concert halls having a number of columns

Like the sound field in the ordinary forest previously investigated. The specific sound field was determined, especially in terms of the factors T_{sub} and IACC. The tendency found was that the effect appears in higher frequency ranges (around 1 kHz). than in the sound field in an ordinary tree forest.

B.- MECHANICAL PROPERTIES OF THE CULM

Wood and bamboo are both ancient organic building materials and their use in this field has been more traditional than technical. Metals are of more recent origin and are produced from a materials technology. To meet the competition from metals, a technology has arisen in the United States and Europe during the past 80 years for the appropriate use of wood in the construction field and for the manufacture of composite materials such as wood laminated beams, plywood boards, etc. For this purpose, in the forties, several universities, research centers and wood associations of the United States, in conjunction with the American Standard forTesting Materials (ASTM), laid down the standard test procedures for the determination of the mechanical properties of timber, which include the dimensions and shapes of the test specimens based on the anatomy and morphology of softwoods and hardwoods.

However, in the case of bamboo, in the Americas and in Asia there are no forest research centers or universities interested in studying the norms or standard test procedures for the evaluation of the mechanical properties of their native bamboo species, because it has been considered unnecessary since in these continents bamboo has been mostly used by the poor people for the construction of their houses, in which they employ traditional construction technologies which do not require architects or engineers.

The first serious study on the mechanical properties of bamboo was carried out in Germany in 1912 by Von R. Bauman. He found that the tensile strength of the outer culm wall was about twice as strong as the interior layer (3068 - 1594 kg/cm2). The strength of the entire thickness of the wall cross section was 2070 Kg/cm2. In a smaller diameter bamboo (Tonkin cane) with an outer diameter of 3.5 cm, the tensile strength of the outer and interior fibers was 3843 and 1353 Kg/cm2 respectively, which is greater than in the 8 cm diameter bamboo.

The most complete research related to the mechanical and chemical properties of several species of bamboo was carried out in Japan by Sioti Uno at the Utsunomiya Agricultural College in 1932. He found that the top part of the culm is stronger in compression than the central and lower part of the culm and that the central part is stronger in tension than the upper and lower parts of the culm; and that there are species such as Bambusa stenostachya in which the exterior layer of the culm wall of the lower part of the culm is 5.5 times stronger than the interior layer, as can be seen in the tables in this chapter.

The most important research about the mechanical properties of bamboo and its application as reinforcement in concrete instead of steel bars, was promoted by the United States Army during the Second World War and carried out by H.E. Glenn in 1944 at Clemson Agricultural College in South Carolina and published in 1950.The purpose of this research was to study the use of both bamboo strips taken from giant bamboos and small diameter culms as reinforcement in concrete. The final results of this research were applied during the Vietnam War in the construction of warehouses and other types of buildings with disappointing results. (See Concrete reinforced with bamboo.)

The reason for this lack of success was that at that time (1944) there was no information about bamboo anatomy, which is different from that of timber, and Glenn, like many other people, erroneously considered that if both bamboo and wood were woody plants, it was possible to evaluate the mechanical properties of bamboo culms using the norms for shapes and dimensions of test specimens recommended by the ASTM for the evaluation of the mechanical properties of wood. This was a big mistake because bamboo anatomy and morphology are quite different from that of wood.

It is very important to point out that the reason the ASTM had for using small specimens for testing the mechanical properties of wood is that the strength properties of any species of wood are truly representative only when obtained from tests on small, clear pieces of wood, because the effect of such things as knots, cross grain, checks and splits, and wood compression is then eliminated (Hoyle Jr. 1973). All of these defects are not present in bamboo wood because it has a different type of anatomy and morphology. On the other hand, the structure of the bamboo culm is composed of a series of internodes separated by nodes which impart great mechanical strength to the culm and permit the culms to be bent by the wind without damage to their structure. Consequently, each internode with the two nodes forms a structural element and this has to be tested instead of using small rings taken from the internode which are 10 cm high or ten times the thickness of the culm wall, as is erroneously recommended by some bamboo researchers.

The problem is that all of the methodology followed by Glenn (1944) in his experiments, and the dimensions of the test specimens used for testing the mechanical properties of bamboo based on the recommendations of the ASTM for testing the mechanical properties of wood have been taken as a guide by most reseachers and students at different engineering colleges in Europe, the United States and South America who have carried out studies or theses related to the mechanical properties of bamboo and its use as reinforcement in concrete since 1950. This means that in all of these studies bamboo has been tested erroneusly, as if it were timber. As a consequence of the inadequate data obtained using different methods of testing, bamboo culms and the use of widely varying dimensions and shapes of test specimens, there are many variations and significant differences in the results obtained in studies of the mechanical properties of bamboos. This is why the studies that have been carried out so far in different parts of the world on the mechanical properties of different bamboo species are not trustworthy.

For the above reasons, and due to the growing interest in planting several bamboo species for the development of new industries for the production of composite materials and for the construction of spatial structures, which require a study of the mechanical properties of the bamboo species; it is very important to develop a new methodology and a new type of specimens for testing the mechanical properties of bamboo culms, based on the anatomical structure, morphology, and physiology of this organic material, in this chapter I am suggesting a new methodology for testing bamboo that I have developed based on the anatomy and structural behavior of bamboo.

DIFFERENCES BETWEEN WOOD AND BAMBOO

The first thing that wee have to establish is that bamboo is not a tree but an arborescent grass that the only thing that it has in common with trees (*hardwoods* and *softwoods*) is that both are woody plants, with very similar chemical components (See Table 6-2),but both have differences in their anatomy, morphology, in the growing process, and even in their mechanical properties which are superior in bamboo. (See Table 6-1) On the machro scale, wood is a solid cylinder composite of bark, sapwood and heartwood, conformed by alternative spring and summer wood which consists of cells of various sizes, shapes and functions, while bamboo is a hollow cylinder with many internodes separated by nodes. These nodes play an important role of the axial crack arrester, in preventing the cylinder from structural buckling, in strengthening bamboo and in increasing bamboo's rigidity.

In its ultrafine structure the cell wall of wood fiber appears as a multilayered composite cylinder and the helical angle s of the microfibrils in each layer are different, greatly affecting the mechanical properties of the wood. The majority of cells are elongated and pointed at the ends and are called *fibers* (in hardwoods), or *tracheids* (in softwoods); they impart strength to the wood.

Bamboo can be taken as unidirectional ligno-cellulosic composite material, reinforced axially by bast fibres sheaths in vascular bundles surrounded by a matrix of thin-walled cells known as *parenchyma*.

The vascular bundles consist of conducting tissue (metataxylem vessels, sieve tubes with companion cells) and fibers. The total number of vascular bundles decrease from outer to inner part and from bottom to top On an average, a culm consists of about 52% of parenchyma, 40% of fibers and 8% of conducting tissue. These values vary with species (Liese 1998). Regardles of the five type of vascular bundles seen in the first part of this book, all bamboos exhibit striking differences in the distribution of cells within one culm, both horizontally and vertically.

On the micro scale, wood tracheid and bamboo bast fiber are both hollow tubes or cylinders composed of several concentric layers and each layer is reinforced with helically wound michro fibrils (Fig, 6.5). In bamboo cells the lamellation consist of alternating broad and narrow layers with different fibrillar orientation. In the broad lamellae the fibrils are oriented at small angle to the fibre axis, whereas the narrow ones show mostly a transversal orientation. Liese,1985. Li, Zeng, Xiao, Fu, Zhou (1995). Amada *et al* (1996).

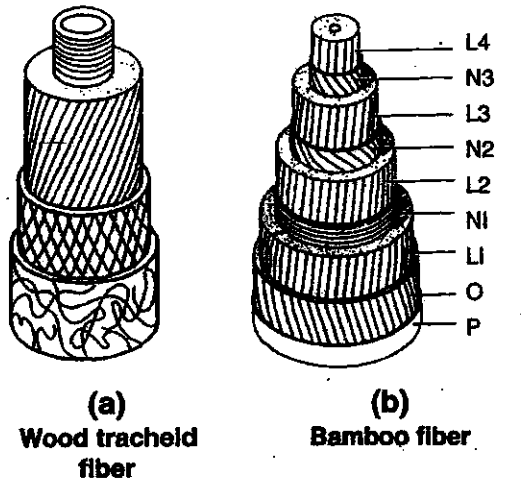


Fig. 6.5 **(a)** *Schematic diagram of wood tracheid. and* **(b)** *polylamellate structure of a thick bamboo fiber.* **(P)** *= Primary wall,* **(O)**= *outermost layer of the second wall -***(L1-L4)** *broad layers.-***(N1-N3)**, *narrow layers (After Wai et al, in Li et al 1995)*

Due to the differences which exist in the anatomy and morphology between wood and bamboo it is necessari to establhish a new methodology or test procedures for the determination of the mechanical properties ot bamboo which include the dimensions and shapes of the test specimens, based in the anatomy and morphology of bamboo, which are going to be discussed in this section.

Table 6-1 Mechanical properties of several woods and bamboo (*Phyllostachys edulis*)

Woods	Strength (MPa)	Mod. Elast (GPa)	Density (g/cm3)
Cedar	29.3-48.5	4.4-9.8	0.29-046
Fir	30.7-33.8	5.9-6.7	0.31-0.34
Pine	34.0-41.6	6.5-8.8	0.36-0.42
Spruce	31.0-40.0	7.3-8.5	0.38
Hickory	62.5-81.0	8.9-11.4	0.56-0.67
Oak	47.7-74.9	7.9-12.4	0.53-0.61
Bamboo (fibre)	610	46	1.16
Bamboo (matrix)	50	2	0.67
Bamboo (composite)	140-230	11-17	0.6-1.1

Source: (Bodig & Jaine, 1993) in Amada *et al* (1996)

Table 6-2 Chemical composition and tensile strength of wood and bamboo (*Ph. edulis*)

Components	Wood	Bamboo
Cellulose (%)	40-50	45.3
Hemi-cellulose (%)	20-35	-
Lignin (%)	15-35	25.5
Polyoses (%)	--	24.3
Extractive (%)	<10	2.6
Tensile strength (MPa)	34-220	150-520

Source: Li, Zeng, Xiao, Fu, Zhou (1995)

THE MAIN FACTORS WHICH WE HAVE TO KEEP IN MIND FOR STUDYING THE MECHANICAL PROPERTIES OF THE CULM

Every bamboo species has its own anatomical, physical and mechanical properties, which varies from one specie to another, even within the species of the same clump.

These variations depend on several factors such as: the environmental conditions under which they grow, which includes the climate, altitud above sea level, soil, the chemical components of the soil, and the topographical conditions.

For the above reasons, one cannot use the strength values, for example, of *Guadua angustifolia*, and apply them to other species of the same genus, even if the other species grows in the same area, for example, *Guadua amplexifolia*."

1.-The Climate

In the study conducted by Gnanaharan (1991) related to the physical and mechanical properties of mature culms of *Dendrocalamus strictus* grown in three different locations in Kerala, India, at different altitudes (1,000 - 200 - 800 meters) respectively, and with different annual rainfall (2,500 to 3,000; 1,000 to 1,500 and 1,000 to 1,500 mm); he found a great variation in the physical and strength properties depending on the location from which the bamboo was collected. *Dendrocalamus strictus* that grew in a moist area had longer internodes, a larger diameter and poorer strengths in modulus of rupture and modulus of elasticity. *D. strictus* that grew in a dry place was much stronger, even though the culm and internode length and diameter were shorter. This means that the best bamboo of this species is that which grows in a dry location.

2.-The Topography

In Indonesia, the Sundanese who live in West Java, use the bamboo species *Gigantochloa pseudo-arundinacea* for house construction. They believe that the best quality bamboo, in strength, of this species should be harvested from the slope inhabiting groves, rather than from those growing in the valley. In order to determine whether the Sundanese pratice had any scientific justification, Soeprayitno et al (1988) undertook a study of the physical-mechanical properties of this species growing on the hill slopes and in the valleys of Cibitung village near Bogor in West Java.

The results show that the preference of the Sundanese for slope-inhabiting bamboo is scientifically justified, because the specific gravity, static bending and tensile strength of the culms growing on hill slopes are higher than those of culms growing in the valley.

The modulus of rupture (MOR) of bamboo culms from the two habitats did not differ significantly. On the other hand, the modulus of elasticity (MOE) and tensile strength of the slope-inhabiting bamboo culms were markedly higher than the other, maybe due to the higher specific gravity. This information is very important for rural people who have sloping areas on their farms where they cannot use their tractors for preparing the soil. In this case, it is recommended that they use these sloping areas to plant giant bamboos for construction and other uses. Bamboo is also the most appropriate plant for planting in areas where there are problems of erosion or to prevent it. The scientific reason for this belief is clearly explained in the studies carried out by Nogata & Takahashi (1995) in item No. 9 in this section.

3.-The soil

Most bamboo species grow in fertile soils and at certain elevations to develop their best physical and mechanical properties. According to Deogun (1936), *Dendrocalamus strictus* is the only bamboo species which grows in very good soils as well as in coarse grained dry soils such as those derived from sandstone, granite and granitic gneisses. It is is completely absent from the pure quarzite soils. In some places of India it has been successfully planted on sand dunes. This bamboo, as mentioned before, develops its best physical and mechanical characte-ristics when it is cultivated in dry areas. Therefore, I consi-der this species to be one of the best in the world.

4.-The altitude above sea level

Guadua angustifolia, only grows in fertile soils from sea level to 1800 m. These specia develops its best physical and mechanical properties when it grows at about 1400 meters above sea level (in Colombia) and particularly in volcanic soils like those of the area around the city of Armenia in Colombia. At this location, this species has an average diameter of 14-16 cm, while at sea level on the coast of Ecuador, it has an average of 9-10 cm at the base.

From the above, we can conclude that if the species *Guadua angustifolia* which grows in the coastal area is going to be used as a structural element, it is not possible to use the strength values obtained from the study of the mechanical properties of *Guadua angustifolia* which grows at 1,400 meter above sea level because they are different from those of the species which grow at sea level. In this case, it is necessary to study the mechanical properties of the species which grows at sea level. This is why it is necessary to study the mechanical properties of each giant species of each genus located at different elevations.

5.- The influence of the culm's age

For trees, aging has considerable influence on the cellular make-up and thus on the technological properties. In bamboo, aging effects are restricted to the primary tissue and this is an important factor for the development of strength properties in bamboos. It is a general assumption that bamboos mature until they are about three years old and have reached their maximum strength.

According to Liese (1985), investigations with *Dendrocalamus strictus* have shown that when they are green, older bamboo culms have higher strength properties than younger ones (the moisture content of the latter is much higher).

When they are dry, however, higher values were obtained at the age of one and two years than from older culms. Tests on splints from the central portion of the culm wall indicated better strength properties for one year old bamboos than for two year old ones, whereas those of older Comprehensive tests by Zhou (1981) revealed a further increase of strength properties with age, as well as for radial and tangential bending strength up to 8 years. Older culms (10 years) decreased in all strength properties.

In most of the research which has been carried out in different universities in the United States and Europe, where giant bamboos do not grow, this material has been imported from China, Japan Indonesia and India.

During the long trip by ship, they have lost their natural color and consequently it is impossible to determine the age of the culms. Furthermore, because of the lack of experience or ignorance, many researchers do not know how to determine the age of the culms, or they believe that this is not necessary in order to determine their mechanical properties. As a consequence, there are many differences in the results because mature culms and very young culms are tested at the same time. Due to this reason, the results of most of the researches which has been carried out in the United States and in several countries of Europe, which imported the bamboo, are not trustworthy.

The best method for selecting bamboos which are going to be studied is that the researcher visits the plantation and choose the bamboos, with the help of an expert, before exporting them, and also to find out the scientific name of the species which are going to be tested.

6.-Parts of the culm which have the lowest and highest strength

a)-In the whole culm. According to studies carried out by Sioti Uno (1930) and other researchers, the mechanical properties vary from the base to the top of the culm. If we divide the useful part of the culm into three sections of equal length (See Fig. 6.6), in most cases the top section is stronger in compression and bending strength than the central and lower sections. The central section, which has the longest internodes is stronger in tension than the top and lower sections; and the lower section has the lowest values for mechanical properties, in most of the cases.

b)-In the internode. According to studies carried out by Liese, in the internode, the fibers are short in the area near the nodes and the longest are found in the center of the internode (See Fig. 6.6(a). Consequently, the strongest part is located in the center of the internode, and the weakest near the nodes.

For this reason, if we test one internode in tension, with the nodes and another internode without the nodes, according to Zen, Li, Zhou (1992) (See Table 6-3), the tension strength of the cylinder which is tested with the nodes will be 19.2 % lower than that of the cylinder tested without nodes. In compression, the cylinders tested with nodes will be 6.4% lower than the cylinder tested without nodes.

c)-In the culm wall. The specific gravity and the tension and compression strength of the culm wall increase from the internal to the external surface ofthe culm. Consequently, the zone with the lowest strength is the internal 1/3 of the culm wall.

7.-The extraordinary tensile strength of vascular bundles

As mentioned before, the vascular bundles of bamboo internodes consist of two metaxylem vessels, phloem, protoxylem which are partially surrounded by fiber bundles which impart strength to the culm. Each one of these vascular bundles which looks as points in the culm section, once enlarged looks like the ones shown in Fig. 1.21. (Page 23).

The shape and size of vascular bundles change tremendously across the bamboo wall and along the culm. The size of vascular bundle is getting smaller toward the exterior surface of the culm wall. On the other hand, the distribution density of vascular bundles is much higher near the exterior surface as compared to that near the interior surface of the culm wall or endodermis.

M.C.Yeh (1995) conducted an interesting study in Taiwan related to the evaluation of the tensile strength of vascular bundles of the specie *Phyllostachys pubescens.*

The size of vascular bundle is getting smaller toward the exterior surface of the culm wall. On the other hand, the distribution density of vascular bundles is much higher near the exterior surface as compared to that near the interior surface of the culm wall.

The bamboos of the specie *Phyllostachys pubescens.* were selected from a plantation which grows in the central Taiwan at 1200 m above sea level. The ages of the bamboo culms were 4-5 years.The portion used for the experimens were located about 1.80 m above the ground from where were taken sections of 1.20 m long.

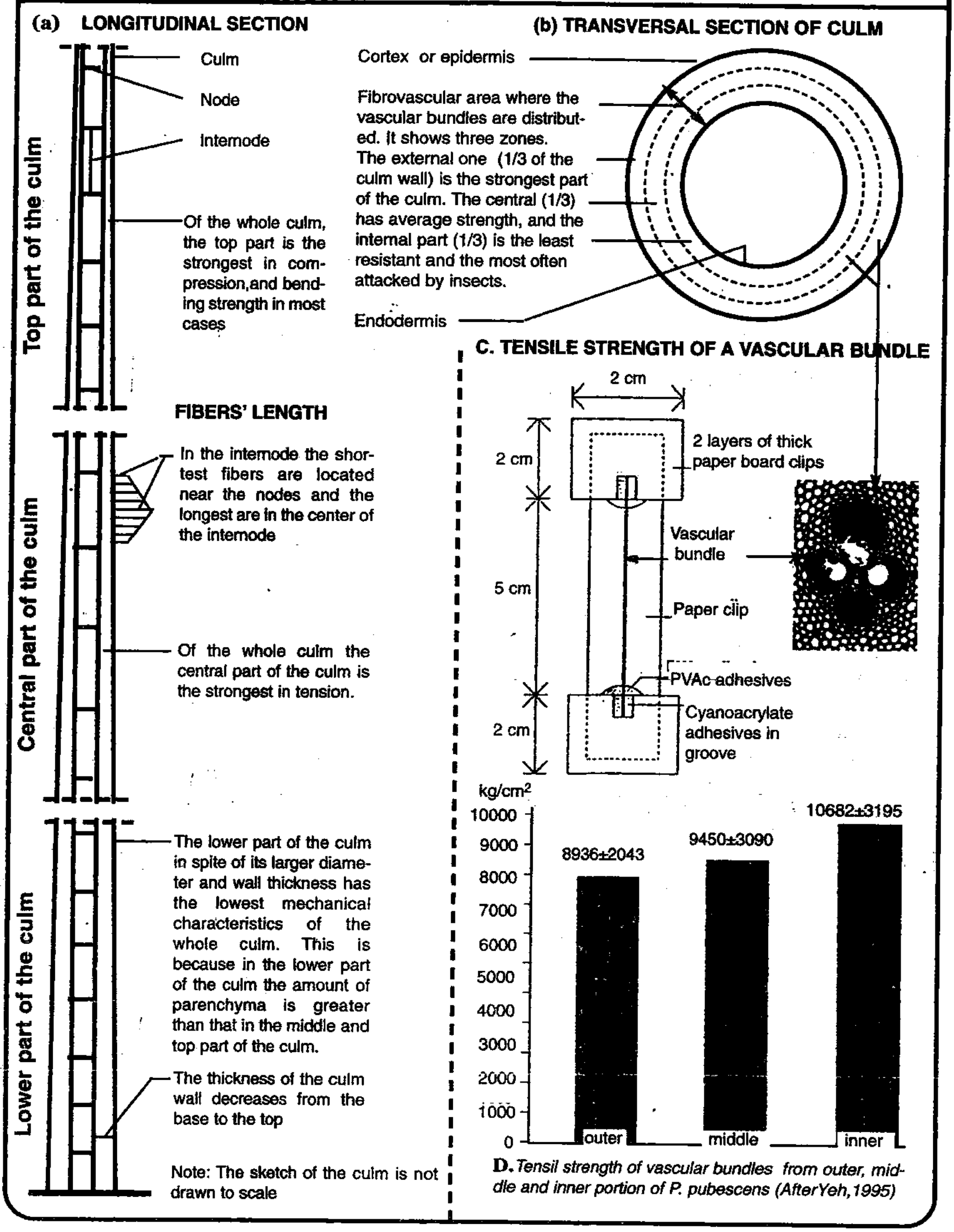
All the split bamboo culm were wrapped with plastic bags to prevent the evaporation of moisture so the fiber remain flexible. The separation of vascular bundles were done mechanically with some skill instead of using chemical process.

Twenty samples of vascular bundles 7 to 9 cms in length were prepared and divided into three portions across the wall thickness by knife, i.e. inner, middle and outer portion, in order to evaluate the strength of vascular bundles from different portions of bamboo wall and all conditioned under 65% RH and 23° C for moisture equilibrium.

The tensile tests were performed in a Shimadzu AG-10 T universal testing machine with a load cell of 50 kgf capacity, and a testing speed of 1 mm/min. was used. The vascular bundle is mounted between two pairs of 1.5 mm thick paper board on both ends and the clear length of vascular bundle between paper board clips is 5 cms (Fig. 6.6 C). The paper board is carved a small groove about 1.5 cm long to accommodate one of the ends of vascular bundle to prevent crash during the test and then glued together with cyanocrylate adhesives.

The plastic PVAc glue was then applied at the junture of bundle and paper board to release the possibility of stress concentration at that particular location.The resulted tensile strength of vascular bundle from different portions of bamboo wall are shown in Fig 6.6 D. (Tensile strenght of the vascular bundle).

Fig.6.6 AXIAL AND TRANSVERSAL BAMBOO STRUCTURE



D. *Tensil strength of vascular bundles from outer, middle and inner portion of P. pubescens (AfterYeh,1995)*

As can be seen in table 6-6 D, there are not significant difference in the tensil strength values for vascuar bundles among inner, middle and outer portions of bamboo wall.

Outer portion = 8936 ± 2043 kgf/cm² ; Middle portion=9450 ±3090 kgf/cm² ; Inner portion =10682±3195 kgf/cm². The average tensile strength value = 9689 kgf/cm²

The average number of vascular bundles is estimated across the bamboo wall from microscopic photos.There seems to be no variation in the number of vascular bundles in bamboos up to a height of 12 feet. However, significant differences in the amount of vascular bundles can be found across the bamboo wall, i. e., about 5.41/mm² for the outer portion, 2.69/ mm² for the middle portion, and 1.97 mm² for the inner portion.

The number of vascular bundles in the outer layer of the culm is twice that in the middle layer, also 2.75 times that of the inner layer. The difference of the tensile strength among the inner, middle and outer layer of strip specimen can be explained by the difference in the amount or distribution of vascular bundles across the bamboo wall mentioned above by.M.C.Yeh (1995).

8.-The mechanical properties of each of the internodes vary along the culm

Table 6-4 show the results of the study carried out by Sjafii (1984),on the mechanical properties of the internodes 1-3-5-7 (including the nodes) which correspond to the lower part of the culms of 4 different species of bamboo.

Table 6-3 AVERAGE MECHANICAL PROPERTIES OF BAMBOO INTERNODES WITHOUT AND WITH NODES (*Phyllostachys pubescens*)

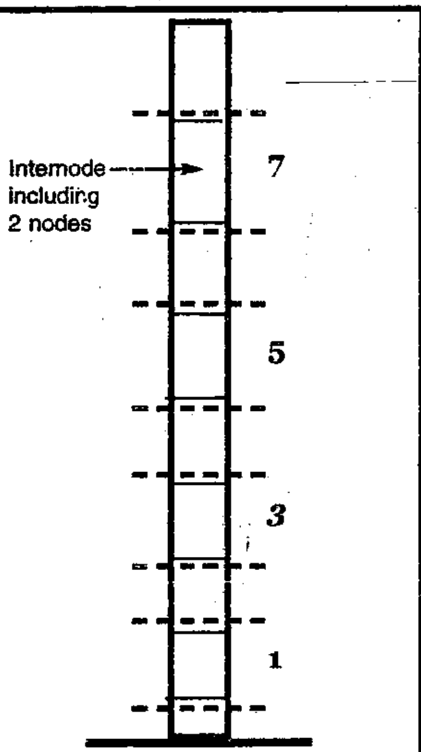
Property	Without node (MPa)	With node (MPa)	Change due to node
Tensile (Longitudinal)	263.4	212.8	-19.2%
Flexural (L)	136.6	131.3	-3.9%
Compressive (L)	62.6	58.6	-6,4%
Shear (L)	13.1	12.2	-6.9%
Tensile (Transversal)	3.0	3.6	+20.%
Cleavage (T)	0.6	0.8	+33.3
Toughness (L) (in kJ/m²	89.6	77.7	-13.5%

Source: Zen, Li, Zhou (1992) in Zhou (1994)

This study concludes that each of the internodes of the whole culm has different mechanical properties, which in some species do not increase progressively from bottom to top. For example, in *Dendrocalamus asper* the compression strength of the 1st inter-node is 639 kg/cm², and in the 7th is 566 Kg/cm².

However, they increase in the center and top parts of the culm, where the compression and tension strength are higher than in the lower part. On the other hand, according to Table 6-3, in most cases, when the internode is tested in compression with the nodes, strength is reduced by 6.9% and tension by about 19.29% compared to internodes tested without nodes, but the transversal tension and cleavage increase by 33.3%.

Table 6-4 Mechanical properties of various bamboos at various internodes of the lower part of the culm.



Species	Internodes of basal part	Modulus of elasticity Kg/cm²	Modulus of rupture Kg/cm²	Compres. strength Kg/cm²	Tensile strength Kg/cm²
Dendrocalamus giganteous	1	172,097	1828	602	1836
	3	122,463	1758	619	1946
	5	147,912	1827	640	1880
	7	130,352	2880	646	1966
	Average	143,206	1823	627	1907
Dendrocalamus asper	1	122,073	1637	639	2145
	3	149,587	1741	592	2040
	5	129,542	1595	622	2220
	7	123,966	1578	566	2104
	Average	131,292	1638	605	2127
Gigantochloa robusta	1	94,208	1384	533	1970
	3	92,367	1294	510	1767
	5	109,217	1398	511	1854
	7	97,381	1345	530	2066
	Average	98,293	1355	521	1914
Bambusa vulgaris var. *striata*	1	60,652	1075	484	1392
	3	71,931	1123	443	1196
	5	88,297	1105	475	1352
	7	83,939	1286	417	1346
	Average	76,205	1147	455	1322

Source:.(After Sjafii, 1984) in Widjaja & Risyad (1985)

9 -The ability of bamboo cells to generate electrical signals when stressed and the influence of their electrical properties in the modeling and remodeling of their hard tissue

Nogata & Takahashi (1995) studied the ingenious construction and strength of bamboo (*Phyllostachys pubescens*), in order to gain an understanding of the principles of design and processes found in biological materials and to apply these findings for the development of new and superior material/structure concepts, such as composites in multiphased and funcionally graded materials, by using and/ or modifying those models which are found in living organisms. (See Biomimetics). This study was published by their authors with the title: *"Intelligent functionally graded material: bamboo"* which is focused on the microstructure, strength and mechano sensing system of bamboo.

According to this study, the authors examined first some biological load carriers such as plant and tree stems, animal bones and other biological hard tissue, and observed that their geometry changes under loading to match mainly stress-or strain-dependent requirements. For example, the interior structure or architecture of a bone exhibits and optimized shape with respect to the principal stress directions and the shear stress magnitude in the body. This indicates that the bone is managed by a self-optimizing system with sensing mechanism (e.g. piezoelectric effect of bone) that detect external mechanical stimuli to control the modelling /remodelling of the skeletal system. Thus it can be inferrred that the shape and ingenious construction of biological hard tissues are the result of a continuous process of intelligent optimization. The basic characteristics of biological hard tissues such as microstructures, functions, and modeling systems are a source of both fascination and inspiration to the designers of engineering structures.

~~On the other hand,~~ the basic difference between biological and artificial structures is that the former have living organisms which can be characterized by multyfunctionality, hierarchical organization, and adaptability (Srinivasan et al, 1991). As result biological structures are complicated and non uniform, which suggests that judicious combination of elements, materials and components of differing strength in the same structure can lead to acceptable and adequate hybrid systems whose properties are managed for specific purposes.

Mechano sensing system and adaptive modelling of bamboo

The Fig. 6.7 (1), shows the enlarged photograph of a vascular bundle located at the center and outside of cross-section of the culm wall. It shows a flower shape and a figure eight shape, respectively. There are two big holes (metaxylem vessels) and two in the center (phloem with sieve tubes and protoxylem). If we replace these holes by one big hole, the meaning of the flower shape will be realized by comparing the stress distributions around a hole in an infinite plate subjected to a uniaxial tension. (2)

Figures 6. 7 (3) and (4) show the photoelastic stress pattern around three holes in a plate model, with similar dimensions to those in a bamboo, which is subjected to two different loading directions, respectively. The best way to reinforce these holes is to set in fibre bundles accorting to the stress distribution. Therefore, it seems that the placement of the fibre bundle indicates a stress situation around the vessels in the xylem and phloem.

Mattheck (1990) and Mattheck and Burkhardts (1990), showed that the contour shape of biological structures such as tree stems, red deer antlers, human tibia, and tiger claws are highly optimized in terms of mechanical strength and minimum weight. This implies that biological structures may have mechanical sensing devices.

Therefore, in order to gather information and examine the sensing ability of bamboo cells, when stress is induced by external mechanical stimuli, the authors tryed to detect a biological signal which may be induced. For this purpose they used an electrocardiograph machine for the human body for a measurement system. A half size diagnostic ECG (electrocardiogram) electrode with adhesive paste was used.

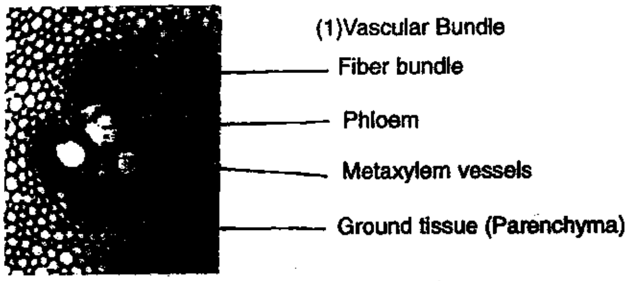
Fig. 6.8 shows an example of the voltage signal curves which were obtained from a bamboo culm subjected to an external bending moment. The curves show the presence of a spike upon loading and upon unloading. The higher voltage signal was recorded on the compression side rather than the tension side of the bamboo culm. These signals may be used as a trigger to organize adaptive growth related to the stress direction. The authors' data, obtained from other plants (ruber and palm tree), showed that the characteristic features of the signals depended on the kinds of plants, and there was no voltage signal induced from specimen boiled in a hot water bath for one hour or from a dried specimen with a weight loss of one half. Because boiling or drying of specimens means the death of the plant cells, it is clear that the voltage signals recorded were produced from live cells in stressed materials This indicates that the lieve bamboo cells have the ability to sense some information induced by external mechanical stimuli.

On the other hand, Fukuda and Yasuda (1957) found piezoelectrical properties in bone which was stressed. There are several reports quoted by the authors which are based on evidence that bone demostrates a piezoelectric effect. This is used to explain the concept of stress or strain -induced bone remodelling which is often referred to as Wolff's law (1870). Thus, bone converts mechanical stress to an electrical potential that influences the activity of osteoclasts and osteoblasts (Hayes *et al*, 1982). It is also known that the interior structure of bone (trabecular architecture) is arrenged in compressive and tensile systems corresponding to the principal stress direction. (Koch, 1917).

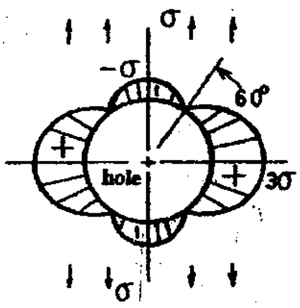
The properties of the voltage signals induced in bamboo may also be similar to the piezoelectric effect in bone. Therefore, it may be shown that the electrical properties of bone and bamboo play an important role in the remodelling/modelling of the skeletal system in biological hard tissues.

Fig. 6.9 shows the enlarged vascular bundle of bamboo which was grown on steep ground. It is clear that the deformed contour shape of the bamboo culm and the asymetric shape of the fibre bundles are a reflection of biased

THE ABILITY OF BAMBOO CELLS TO GENERATE ELECTRICAL SIGNALS WHEN STRESSED



(1)Enlarged photograph of vascular bundle



(2) Stress distribution around a hole in an infinite plate

(3) Photoelastic stress pattern around three holes

(4) Photoelastic stress pattern around three holes. Note the diffrence of load direction between (3) and (4)

Fig.6.7 *Transverse section showing the vascular bundle and photoelastic stress pattern around the 3 holes. Note the difference of vases. (Nogata & Takahashi 1995)*

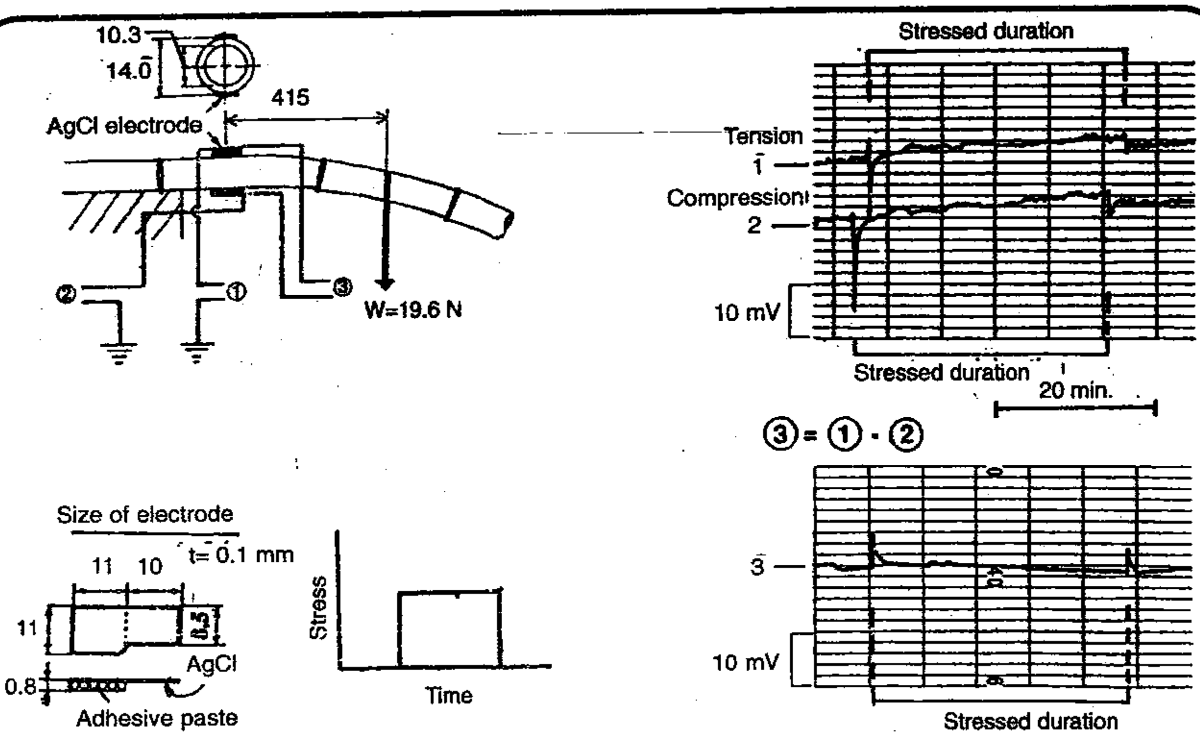
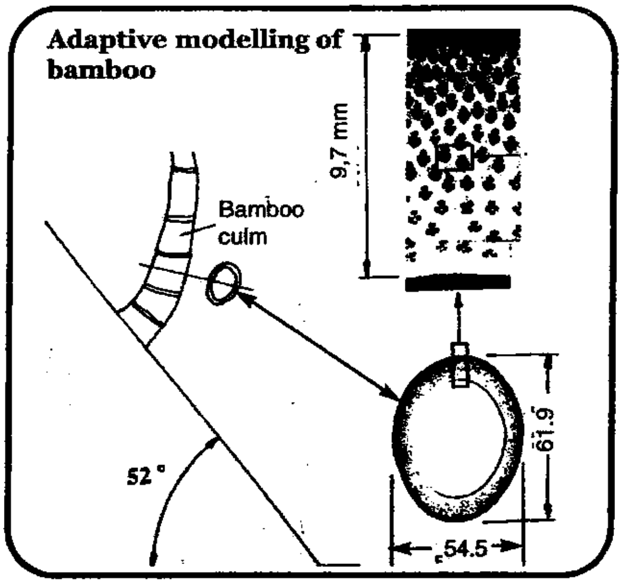


Fig.6.8 *An example of the voltage signals induced by bending moment for a bamboo culm. Nogata & Takahashi (1995)*



loading conditions by their environment. Therefore, the electric signals recorded and the location of the fiber bundle are evidence suggesting that bamboo has a stress/strain-induced adaptive modeling system. This system uses cell-based mechanosensors which may be utilized toaffect or change their shapes (e.g. placement and volume density of fibre, thicknes of stem which can compensate for applied extrnal loads in order to avoid any loclized stress peaks. Thus the characteristic stress/ strain states lead to the modeling of hard tissue and ingeniously customized microstrutures in bamboo.

The above considerations also indicate that the volume density of fibres and their distriution give us important information from the mechanical and morphological points of view.

Fig. 6.9 *Transverse sections showing the placement of fiber bundles on the culm of bamboo grown on steep ground (After Nogata & Takahashi (1995).*

EVALUATION OF THE TENSILE STRENGTH OF THE CULM WALL

As was explained before,the first research about the mechanical properties of bamboo and its application as reinforcement in concrete instead of steel bars, was carried out by H.E. Glenn in 1944 at Clemson Agricultural College in South Carolina during the Second World War.

Due to the lack of technical and scientific information about bamboo which there were at that time , Glenn, like many other researchers, erroneously considered that bamboo was a tree, and he evaluate the mechanical properties of various bamboo species following the norms and shapes of testing samples recommended for the evaluation of the mechanical properties of timber. This was a big mistake because bamboo is a giant grass;and their anatomy, morphology physiology and growing process are quite different from .that of trees. By by the other hand the mechanical properties of the culm varies from the lower to the top part of the culm and transversally from the interior to the exterior part of the culm wall. Consequently bamboo has a different structural behavior of that of timber

Based on the similarity which exists between a metal chain and a bamboo culm (when tested in tension) since the internodes with their nodes serve a similar function to that of a link in the chain; we can apply on bamboo the principle that the maximum tensile strength of a chain corresponds to that of its weakest link, this means that the first thing that we have to fine out (and evaluate) is the location of the weakest and strongest zones in tension ,compression and bending of the transversal section of the culm wall (SeeFig.. 6.10), and vertically from the lower, central and top part of the culm. (See Fig.6.15A)

In the evaluation of the lower , central and top parts of the culm we will find that the top section of the culm is the strongest in compression, and bending strength of the whole culm.The central section, which have the longest internodes is the strongest in tension; and that the lower section of the culm, in spite of its larger diameter and wall thickness, have the lowest mechanical properties of the whole culm.Transversally,the fiber density and tensile strength increases from the inside to the outside of the wall.

At the present time,the most complete and accurately study related to the distribution of the fiber density, tensile and modulus of elasticity along the transverse section of the culm wall, was carried out in Japan by Nogata & Takahashi (1995).(See Fig 6.10) The material tested,was a culm of the specie *Phyllostachys pubescens (P. Edulis).* Two internodes (without nodes) were taken from the culm, the "A" internode was cut at 1 m above the ground and the internode "B" at 5 meters above the ground (See Fig.6.10). They divided the culm thickness in 9 plies and in each one they studied the fiber density and the tensile strength (See Fig.6.10 C-D-E). Two types of specimens as shown in the same figure, were shaped, using a knife, from a single culm of bamboo which was 13 meters long. Tension tests were performed within 48 hours after it was taken from the field, to prevent any change in the mechanical properties due to moisture loss.

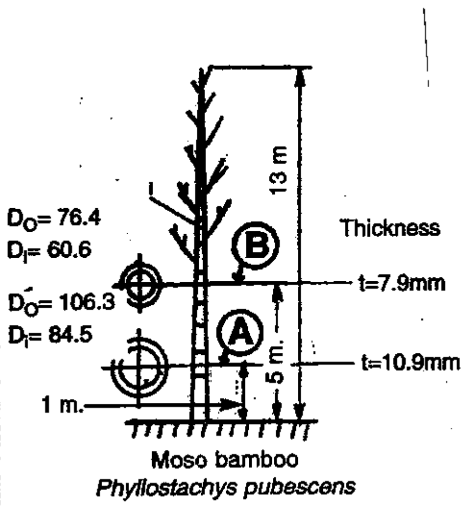
The Fig.6.10 D shows that the fiber density gradually increases from the inside to the outside surface, as well as from the lower part to the upper part of the culm. According to the authors, this graded structure will produce a uniform internal stress distribution in both radial and axial direction. .Tension tests were performed using very small specimens with cross- sectional areas of about 0.25 mm². The specimens were taken from the nine areas arranged as shown in Fig. 6.10 C. The Fig. 6.10 E shows the tensile strength and Young's modulus for A and B specimens along the transverse section of a bamboo culm, which indicates that the strength gradually increases from the inside to the outside, and also that specimen B has higher strength than specimen A. This variation is the same as the variation of volume density of fibres that was mentioned in Fig. 6.10 E. Since the extreme inside, the specimen No. 9 was made of pure ground tissue, its strength was correspondingly about 25 MPa.

Thus, the strength of pure fiber was estimated to be about 810 MPa (using rule of mixtures), which is equivalent to that of steel (600-1000 MPa). Furthermore, Young's modulus of pure fibre was 55 GPa. This value is about one quarter of the value of steel which is 200 GPa. This data shows that the bamboo has high strengh but low rigidity.

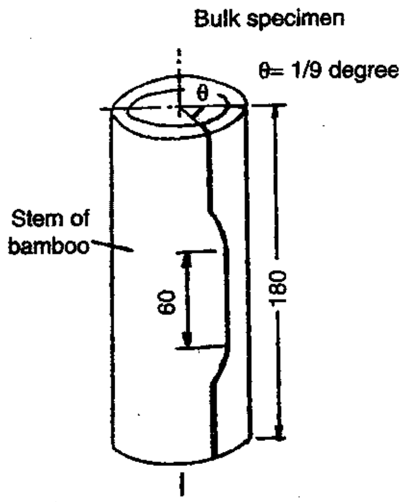
RADIAL DISTRIBUTION OF TENSILE STRENGTH IN THE WALL

Fig.6.10 **SPECIMENS' GEOMETRY FOR TENSION TESTS** *(After Nogata & Takahashi (1995)*

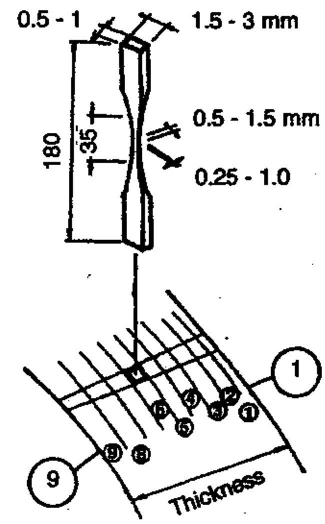
A.-Location of the samples in the culm

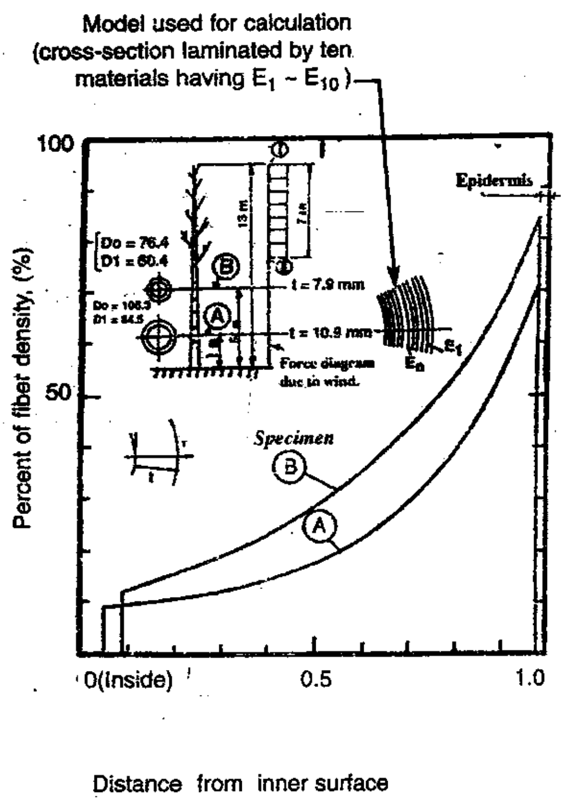


B.-Internode (without nodes)

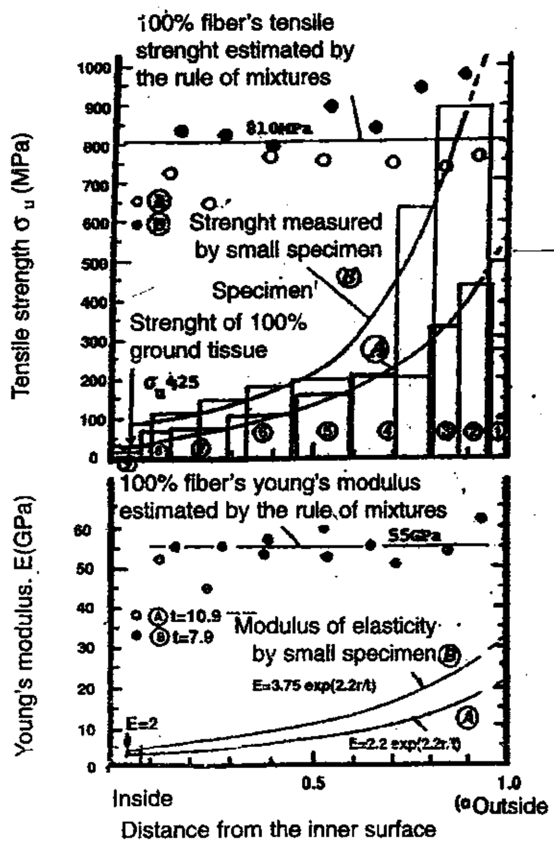


C.-Tensile specimen and location in the culm wall





D. *Distribution of fiber density along the transverse section of the culm.Nogata & Takahashi (1995)*



E. *Distribution of tensile strength and Young's modulus along the transverse section of the culm wall.*

TENSION TEST OF CULMS

Tension tests with round specimens (full cross section of culm) are difficult to carry out because it is not easy to find a method for fastening a round piece in the testing apparatus so that it can be severed by tension. It is therefore preferable to test strips from the culm wall similar to the one shown in Fig. 6.10 C, but including the nodes, and without nodes.

Bauman (1912) was the first researcher to determine the difference in tension between the outer layer of the culm wall and the interior one. He found that the strength in tension for the outer layer of "black bamboo" (*Phyllostachys nigra*) was 3.068 kg/cm²; for the interior layer it was 1594 kg/cm²; and for the entire thickness of the wall it was 2070 kg/cm². In specimens taken from "tonking bamboo" (*Arundinaria amabilis*), he found that the tensile strength for the outer layer was 3,843 kg/cm², and for the inner layer it was 1353 kg/cm².

In Japan, in 1930, Sioti Uno carried out the most complete study that I have seen on the mechanical and chemical properties of several native species of bamboo in which he studied the strength properties only of the outer and inner layer of the culm wall, in the lower, middle, and top part of the culm. In this chapter, I have shown all of the results of his research as a model for future researchers. Nevertheless, I consider that the strength should be studied in 3 layers (minimum) instead of two.

Many authors consider that the tensile strength in bamboo increases with the age of the culm and that the maximum values for tensile strength occur in specimens three to five years old. This could be true for compression and bending strength, but it can not be taken as a rule for tension strength. In the experiments I carried out using the species *Guadua angustifolia* (Hidalgo 1978) to find the strength to tension of bamboo cables used as reinforcements in concrete, about 162 strips taken fromthe outer part of the culm were tested. The maximum tensile strength was 3,213 kg/cm² in a strip taken from the upper part of a three and a half year old culm. The lowest tensile strength was 1,017 kg/cm² in a strip taken from a 5 year old culm. However, I found values as high as 3,018 and 3,206 kg/cm² in strips taken from one year old bamboos.

On the other hand, according to the *Chu pu* book, written by Tai Kaichih in the year 420 A. D., "The Chinese bamboo 'Chin chu' which grows twenty or more feet high and has a circumference of several Chinese inches, is suitable for making bow strings before the shoots become a culm" (less than one year old). This means that very young bamboos of this species are stronger to tension than the older ones.

With the information I got from my research, I realized why the Chinese used strips taken from young green bamboos for the manufacture of bamboo cables (up to 30 cm in diameter) used in the construction of suspension bridges with a span of more than 100 meters. (See supension bridges.) They also manufactured the small diameter cables used by the junk-hauliers in the largest rivers of China.

According to Needhan (1965), on a journey up the Yangtze river in 1908, Esterer made some measurements on the bamboo cables used by the trackers or junk-hauliers and found a tension of 518 kg/cm²., which was of the same order as that normally found in steel wires. Meyer (1937) found that the tensile strength of the bamboo cables used in the construction of suspension bridges in China was about 1,828 kg/cm². Moreover, while hemp ropes lose some 25% of their strength when wet, the tensile strength of plaited bamboo cables increases about 20% when they are fully saturated with water (Needham 1965).

Table 6-5 TENSILE STRENGTH OF BAMBOO AND MODULUS OF ELASTICITY

A. Tensile strengh (kg/cm²)						B. Modulus of elasticity (kg/cm²)				
Species	Layer	Lower section	Middle section	Upper section	Average	Layer	Lower section	Middle section	Upper section	Average
Ph.bambusoides	Inner	1.876,2	1.295,5	2,259.3	1,810.3	inner	219,375	170,461	262,413	224,083
	Outer	4.207,6	3.868,5	3.494.0	3,856.7	Outer	618,765	508,897	443,056	523,573
Ph. nigra var. Henonis	Inner	608,4	2.237,6	940.7	1.262,2	Inner	126,750	329,067	167,982	207,933
	Outer	2.383,2	3.128,3	1,632.4	2,381.3	Outer	590,600	605,442	453,444	549,895
Ph. pubescens	Inner	730,0	1.060,5	887.4	892.6	Inner	24,013	115,272	116,675	85,320
	Outer	3.254,0	3.166,4	2,532.5	2,964.3	Outer	135,583	494,750	381,250	337,194
Ph. lithophila	Inner	639,8	1.885,9	1.891.0	1,472..2	Inner	26,325	235,738	429,772	230,612
	Outer	2.094,9	4.269,4	2.946.0	3,103.4	Outer	84,452	533,675	669,544	429,224
Dendrocalamus latiflorus	Inner	506,5	1.007,3	1,057.9	857..2	Inner	55,054	185,145	154,397	130,865
	Outer	2.336,0	3.633,7	3,163.7	3,045.1	Outer	116,800	807,933	608,404	511,046
Bambusa oldhamii	Inner	1.621,8	2.046,5	2,614.6	2,094.3	Inner	224,694	292,357	344,026	287,026
	Outer	4.221,9	4.846,6	4,757.8	4,608.7	Outer	753,911	683,139	594,700	677,250
B. stenostachya	Inner	697,6	2.649,6	2,377.7	1,908.3	Inner	91,789	378,514	349,662	273,322
	Outer	3.836,0	2.957,5	2,407.3	3,066.9	Outer	532,778	434,926	316,663	428,122
B. vulgaris var. vittata	Inner	1.569,5	1.993,8	2,465.0	2,009.4	Inner	186,846	207,563	----------	197,204
	Outer	4.303,2	4.554,6	3.460.9	4,106..2	Outer	672,375	669,794	----------	671,085

Source: Sioti Uno (1930) Note: The original scientific names were corrected in the translation made by McClure

COMPRESSION STRENGTH PARALLEL TO THE GRAIN

Compression strength parallel to the grain is the capacity of the bamboo fibers to resist longitudinal compression, as is the case of a bamboo used as a column. The harder the fiber and larger the area of fibers, the greater the compression resistance.

The relationship between compression strength parallel to the grain and the moisture content of a bamboo splint is similar to that of wood; this means that there is an increase in maximum crushing stress from the green to the air-dry condition. By assuming that the fiber saturation point of bamboo is 20%, the increase in crushing strength from green to air-dry condition is 4.9 percent per one percent decrease in moisture content. In the testing to compression of 76 specimens of the species *Guadua angustifolia* (Hidalgo 1978), we found that the compression strength of the culm increases with the age of the culm and with its height. A maximum compression strength of 705 kg/sq. cm. was found in the top portion of a 5 year old culm, and the minimum compression strength of 261 kg./sq. cm. was found in a one year old culm. The tensile strength, compression and bending increase with the height of the culm. Bending and compression strengths also increase with age until they are 7 or 8 years old, depending on the species. As mentioned earlier, fiber length has a correlation with the modulus of elasticity and compression strength. A close correlation also exists between specific gravity and maximum crushing strength. The compression strength, as well as the percentage of sclerenchyma fibers, increases vertically from the bottom to the top of the culm, and horizontally from the innermost layers to the peripheral part of the culm. There are cases in which the compression strength of the top is almost twice that of the lower part. In experiments conducted by Uno (1930), he found that the compression strength in the lower, middle and top part of the culm of *Phyllostachys bambusoides* were respectively: 442 - 342 - 835 kg/cm^2 and in *Ph. Lithophila* 644 - 667 - 1,284 kg/cm^2.

Testing of bamboo to compression

In most research carried out up to the present time, the specimens used for the evaluation of compression parallel to the fiber, consist of bamboo cylinders 10 centimeters high (or 10 times the thickness of the wall) taken from the center or from the lower part of the internode. However, most researchers ignores the fact that in the internodes, the fibers near the nodes are short and longest fibers are in the center of the internode. This means that if the specimen is taken from the lower part or top part of the node, where the fibers are short, the value of its compression strength will be lower than that of a specimen taken from the center of the internode where the fibers are the longest. The reason for this is that fiber length has a correlation with compression strength.

Table 6-6 COMPRESSION PARALLEL TO THE GRAIN OF INTERNODES OF *G. angustifolia*

Age of culm sections	Position on the culm	Crushing strength Kg/cm^2	Fiber stress at proport. lim .Kg/cm^2	Modulus of elasticity Kg/cm^2	Moisture content %	Specific gravity
1 to 3 years	Lower section	maximum **381.20**	265.00	85.714	26.58	------
		average 318.34				
		minimum **255.48**	185.00	42.500	63.75	-----
	Midle section	maximum **482.40**	395.00	89.286	16.16	0.686
		average 389.15				
		minimum **295.91**	230.00	84.000	28.88	0.651
3 to 5 years	Lower section	maximum **502.42**	385.00	62.216	42.56	0.666
		average 445.80				
		minimum **389.19**	290.00	55.555	41.50	0.634
	midle section	maximum **629.73**	550.00	124.038	16.06	0.797
		average 491.30				
		minimum **352.88**	270.00	65.909	27.72	0.583
More than 5 years	Lower section	maximum **505.45**	432.50	77.344	37.16	0.612
		average 408.61				
		minimum **311.78**	275.00	58.871	42.57	0.578
	middle section	maximum **549.31**	465.00	130.555	14.13	0.787
		average 438.15				
		minimum **327.00**	255.00	78.333	18.87	0.666

Source: Martin, Mateus-Hidalgo (1981) -Number of tests 90- The top section of the culm was not sended from the farm

From the above we can conclude that in order to study the compression strength of bamboos, it is necessary to test the whole internode including the two nodes) taken from the central part of the lower, middle and top portions of the culm. As mentioned earlier. In order to establish a methodology for testing the mechanical properties of bamboos under compression, I suggest dividing the whole length of the useful height of the culm (after removing the top most-branch) into three sections of equal lengths and taking 2 internodes from the central part of each section, one with the two nodes, for testing the minimum compression strength, and the other without nodes, for testing the maximum compression strength.

Testing in compression sections of 1- 2 and 3 meters long.

From the studies carried out by Sjafii (1984) on the mechanical properties of various bamboos at various internodes of the lower part of the culm (See Table 6-4), we concluded that each of the internodes of the culm has different mechanical properties, which generally do not follow a progressive value from the bottom to the top of the culm. Consequently, the best solution for testing bamboos under copression is to test sections of culms which are one, two and three meters long (these are the dimensions most used in construction, indicating for each one the number of internodes and the wall's thickness and diameters (internal and external). In this way we can get the most exact and safer results from the compression tests.

In 1981, I was the adviser of the thesis of two students from the College of Agricultural Engineering of the National University of Colombia in Bogota (Martin & Mateus). We studied the compression strength of sections 1, 2 and 3 meters long taken from the lower, and middle part of culms of *Guadua angustifolia* with different ages. (The top section was not sent from the plantation). The results are summarized in the Table 6-7.

The purpose of this study was to provide information to the bamboo builders in Colombia on the appropriate use of different length bamboos, as columns and supports for buildings built on sloping grounds and in secondary structures, such as those used for the construction of concrete slabs, in order to use a minimum of bamboo supports and larger spans between supports. At the present time, distances of supports in both directions are 80 cm.The tests were carried out in the materials laboratory of the Engineering Faculty at the National University of Colombia in Bogota.

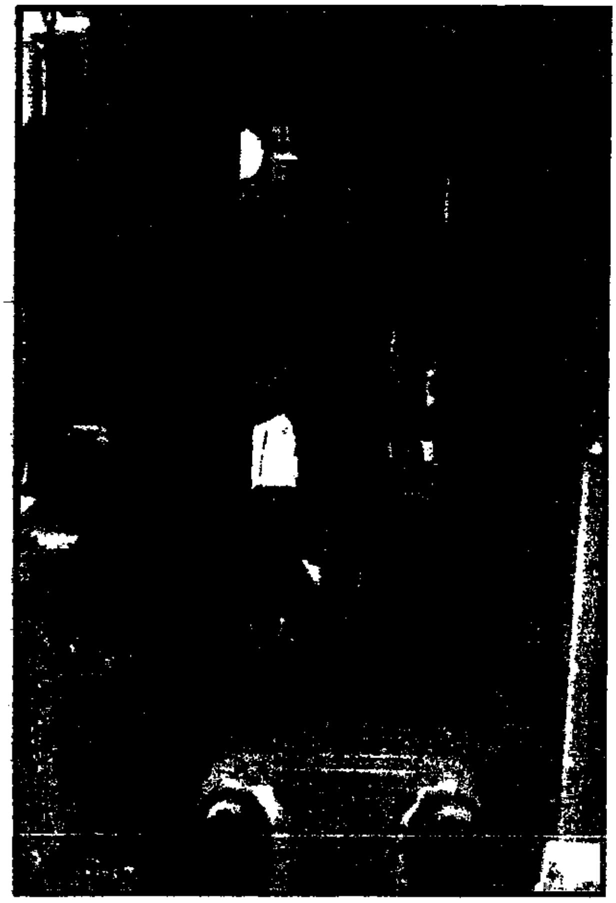
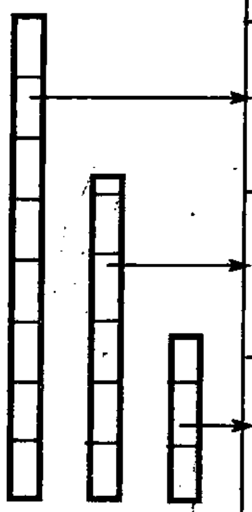


Fig. 6.11 *Compression evaluation of sections 1 and 2 meters long of Guadua angustifolia at the college of Engineering of the National University in Bogota.*

Fig. 6.12 *Compression evaluation of sections 3 m long of Guadua angustifolia.*

Table 6-7 COMPRESSION STRENGTH OF SECTIONS OF 1- 2 AND 3 METERS LONG OF *Guadua angustifolia*



Lenght of culm sect.	Culm age (years)	Crushing strength Kg/cm²		Base Diam Cm	Wall thick. Cm	Number of nodes
3 meters	1 to 3 years	Maximum	4,930	9.08	0.79	8
		minimum	2,740	9,44	0.97	10
	3 to 5 years	Maximum	8,350	10.76	1.58	13
		minimum	2,775	9.04	0.96	9
	more than 5 years	Maximum	16,600	13.09	1.92	13
		minimum	3,200	9.89	0.87	9
2 meters	1 to 3 years	Maximum	10,125	11.33	1.15	7
		minimum	3,830	7.86	0.71	6
	3 to 5 years	Maximum	12,830	11.73	1.52	7
		minimum	5,100	9.53	1.26	7
	more than 5 years	Maximum	22,500	14.33	1.62	7
		minmum	6,600	9.09	0.88	6
1 meter	1 to 3 years	Maximum	14,050	9.27	1.50	5
		minimum	7,350	8.39	0.73	3
	3 to 5 years	Maximum	19,000	11.57	1.72	4
		minimum	8,000	8.28	0.98	4
	more than 5 years	Maximum	23,650	13.50	1.55	4
		minimum	9,910	10.23	1.20	5

Source: Martin, Mateus, Hidalgo (1981) - Total number of tested samples 129

Table 6-8 COMPRESSION STRENGTH AND MODULUS OF ELASTICITY

Species	Section of the culm	Compression strength Kg/cm²	Average com-presion stren. Kg/cm²	Average modu-lus of elasticity Kg/cm²	Area in cross section of wal/ /Area in cross sect. of culm	Average thereof
Ph.bambusoides (Ma bambus)	lower	442.96	540.55	2,242.95	47.6 cm²	38.40
	middle	342.75			37.5	
	upper	835.95			30.1	
Ph. nigra var. Henonis (*Ha bambus*)	lower	411.58	411.28	2,433.61	55.5	51.87
	middle	458.85			34.1	
	upper	363.43			65.4	
Ph. pubescen (Moso bambus)	lower	588.67	610.90	2,395.69	40.4	42.07
	middle	648.84			38.4	
	upper	597.19			47.4	
Ph. lithophila (Seki-bambus)	lower	644.94	862.29	3,527.50	49.8	41.43
	middle	667.09			37.4	
	upper	1,274.85			37.1	
Dendrocalamus latiflorus (Mor- bambus)	lower	272.02	356.86	1,612.86	36.3	45.67
	middle	532.21			29.5	
	upper	266.35			71.2	
Bambusa oldhamii (Tiosi-bambus)	lower	532.48	311.64	2,398.59	67.4	47.10
	middle	542.18			31.2	
	upper	760.25			42.7	
B. stenostachya (Si-bambus)	lower	361.26	341.54	1,487.05	32.7	71.83
	middle	221.60			68.8	
	upper	441.75			64.0	
B. vulgaris var . vittata (Daisan -bambus)	lower	506.24	534.03	1.545,43	45.0	43.20
	middle	515.54			39.7	
	upper	580.31			44.9	

Source: Sioti Uno (1930) Note: The original scientific names were corrected in the translation made by McClure
The Amsler Co.'s apparatus of 30 tons capacity was used.

BENDING STRENGTH

The cortex or mechanical tissue that is arranged around the outer part of the cylindrical culm, performs the function of protecting the culm so it can resist bending forces. When the culm in the clump is bent by the wind or by the weight of the snow in winter time, it becomes elliptic in cross section.

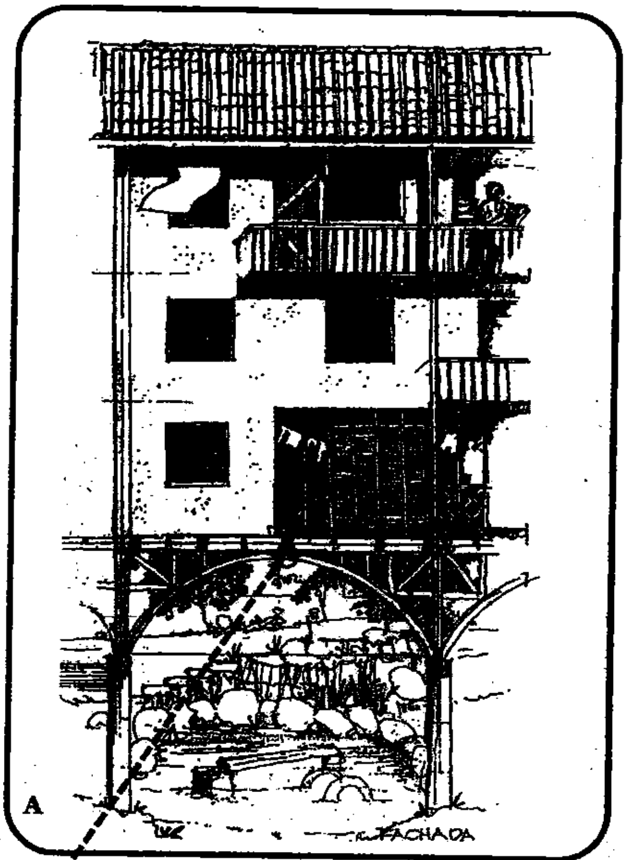
The bending culm is thus compressed along the lower part, and expanded along the upper part. If this force of compression and tension becomes greater than the bamboo wood can support, the culm will break along the center of the cylinder or neutral axis. When the culm, once cut, is used in beams, it has the same structural behavior.

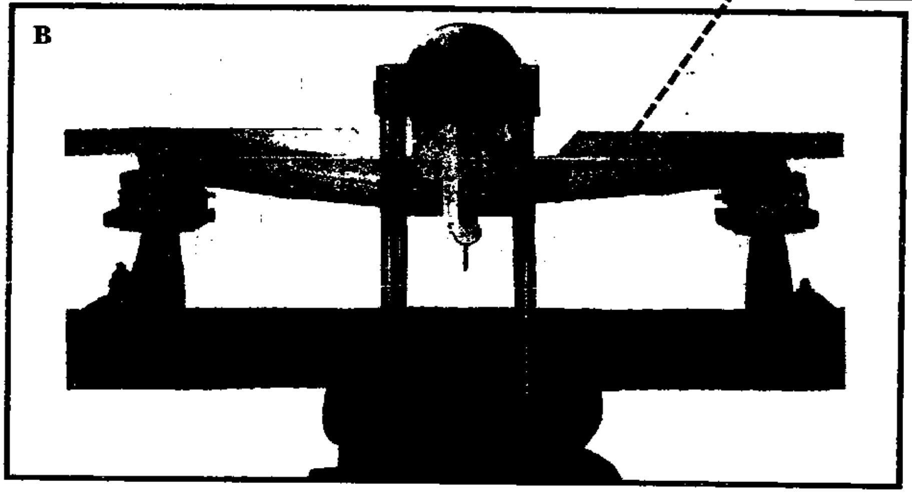
According toTakenouchi (1932), if the thickness of the wall of the culm internode is 1/8 or 1/5 of the diameter of the cylinder, this culm cylinder is, as a rule, much more resistant to bending forces than a solid culm of the same diameter. The culms of *Phyllostachys bambusoides* (Madake) and *P. nigra henonis* (Hachiku) and some others which have a wall thickness of about 1/9 the diameter of the cylinder, can withstand the weight of snow without breaking. But the culm of *Ph. edulis* (*Ph. pubescens*) (Mosochiku) whose thickness is 1/11 the diameter of the cylinder, is comparatively easy to break.

Assuming that the fiber saturation point of bamboo is 20%, the increase in bending strength from green to air-dry condition is 0.05 percent per one percent decrease in moisture content. This value is lower than that of wood, which is approximately 4 percent per one percent decrease in moisture content. According to Bauman (1912), the bending strength of the inner layers is 950 kg/cm², and of the outer layers is 2535 kg/cm².

Bamboo possesses excellent mechanical properties which depend mainly on the fiber content and, therefore, vary considerably within the culm and between species. At the base, for example, the bending strength of the outer part is 2 - 3 times that of the inner part. Such differences become smaller with increasing height of the culm. With the decreasing thickness of the culm wall, there is an increase in specific gravity and mechanical strength of the inner parts, which contain less parenchyma and more fibers, whereas in the outer parts these properties change only slightly. For bending strength and modulus of elasticity, higher values were obtained from the upper part. Bamboo splints with the epidermis downwards have a higher bending strength and modulus of elasticity than those with the epidermis upwards.

Bending tests. Bauman (1912).- The specimens were placed on two supports whose distance apart, as a rule was, in round numbers, 25 times as great as the largest diameter of the bamboo to be tested and a load was placed at the middle between the supports. The failure occurred when there was splitting parallel to the axis of the specimen, as a result of shearing forces. The bending strength of bamboo cylinders varied between 722 and 2760 kg/cm². The thicker cylinders (outer diameter about 8 cm), were weaker than the thinner ones (outer diameter approximately 2 - 3 cm).





Figs. 6.13 (A) (B)
(A).This is a very interesting architectural design that was the winner of a giant bamboo housing project competition in Colombia. The problem is that the architect and the judges ignored the fact that a bamboo culm can not be bent like a metal bar, because it cracks along the neutral axis with the smallest deflection as is shown in the testing machine. (B) The solution is to build a three articulate arch. (See bamboo deformed structures.)

SHEAR STRENGTH

Although trees (hardwoods and softwoods) and bamboos are woody plants, as mentioned earlier, their anatomy, morphology and growing processes are different, as is their structural behavior. Most researchers do not realize that bamboo does not have radial cells like those in timber which increase its shear strength parallel to the axis. This is why bamboo has very low shear strength parallel to the axis and the presence of nodes has only a slight significant effect on shear strength.

This low shear strength of bamboo is an advantage for some purposes, for example, in the manufacturing of bamboo strips for weaving baskets or for making cables, but it can also be a disadvantage in construction, particularly when researchers try to make the same type of bamboo specimens that are used for testing timber. Bamboo specimens generally break very easily in the direction parallel to the axis.

In the experiments we did on the shear strength of *Guadua angustifolia* (Hidalgo 1978), we tested 27 specimens of different ages using stair shaped specimens and dimensions recommended by Motoi Otta (1955). The maximum shear strength was 144 kg/cm^2, the minimum was 45 kg/cm^2, and the average was 93 kg/cm^2. Today, I consider that this very common method of evaluation is impractical and the results are useless; the best method of testing bamboo shear strength is using the whole inter-nodes with the nodes and also without them. The specimens have to be taken from the lower, center and top sections of the culm, and they will have different diameters and wall thicknesses.

Fig.6.14 *The low shear strength of bamboo is an adventage for some purposes, for example in the manufacturing of bamboo strips for weaving baskets and many other articles.*

IMPACT TESTS

Baumann (1912) carried out some impact tests on round bamboos. The work to failure was from 2.2 to 3.3 m kg/cm2; the distance between supports was 25 cms. A pronounced difference due to the place where the impact was applied could not be observed. In contrast, the mode of fracture was entirely different. Whereas in impact on the nodes, the specimen was severed in strips parallel to the axis, in impact on the shaft, the specimen consistently broke through. In this case, the tensile strength of the fibers was exceeded.

In the pendulum impact tests carried out by Jain, Kumar and Jindal (1992) in bamboo strips, the test specimens were 75 mm long and the cross-section was 10 mm x 10 mm taken from the culm wall. Tests were performed on notched and unnotched bamboo fiber, and bamboo mat reinforced plastic composites. Notched specimens had a 2 mm deep 45o notch angle at a distance of 28 mm from the top end. The samples were fractured in a Hounsfield plastic impact testing machine. Impact toughness was calculated from the energy absorbed at the cross-sectional area without notch and at the cross-sectional area at the notch.

Results and analysis. The percentage of cellulose (fibers) and lignin (binding material) in bamboos fibers is higher than in other natural fibers. The microfibril angle of the cellulose fibers is very small and bamboo has a polylamellate wall structure. These are the factors responsible for the higher tensile, flexural and impact strength of bamboo in the direction of the fiber. Perpendicular to the fiber direction, bamboo has minimum strength.

Table 6-9 Impact Tests	**Impact strength (CoV$^{2)}$ (kJm^{-2})**
Bamboo (across the fiber)	3.02 (±1.08)
Bamboo (along the fiber)	63.54 (± 4.63)

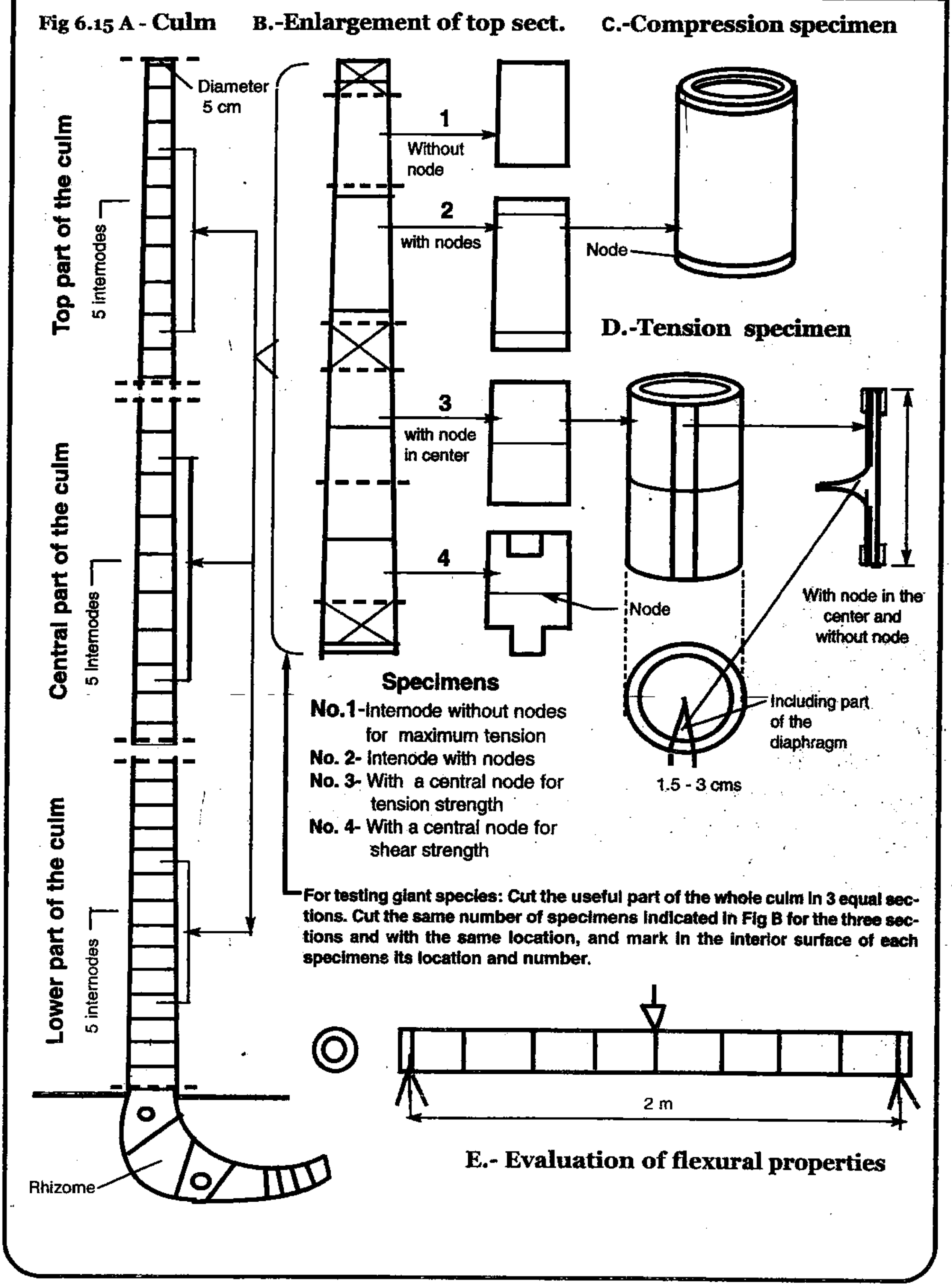
The results of pendulum impact carried out by the same authors on bamboo orthogonal mats are shown in Table 6-9A. Fiber composites have a higher impact strength than mat composites. This can be explained because 50% of the fibers in the mat are in the direction of impact, and the other 50% are perpendicular to the impact. Only perpendicular fibers are capable of arresting and diverting the propagation of the notch by delamination.

Another important fact which has emerged is that the notch has no affect on the strength of the mat (bamboo-fiber reinforced plastic composite-BFRP) (See bamboo composite) The high impact strength of BFRP composite puts it in the category of tough engineering materials.

Table 6-9A. Impact strength of BFRP composite

	V_f (%)	Impact strength specimen (CoV$^{2)}$ (kJm^{-2}) notched	unnoched
Fibre composite	35%	43.71(± 2.92)	45.62(± 3.01)
Mat composite	65%	33.87 (± 2.20)	34.03(± 1.26)

SUGGESTED SPECIMENS FOR TESTING MECHANICAL PROPERTIES OF BAMBOO



HOW TO UPGRADE THE BAMBOO MECHANICAL PROPERTIES (REFORMED BAMBOO)

Reformed Bamboo

The density or specific gravity of wood timber and bamboo culm wood is a measure of its solid wood substance per unit volume and an index of their physical and me-chanical properties. Wood of hight density is stronger and stiffer than wood of low density. Nevertheless, it is possible to increase the strength and the stiffness of wood of low density if the volume of a wood timber piece is compressed or compacted perpendicularly to the axis of the piece with the purpose of reducing its volume, increasing in this way its density per unit volume. This technology was developed in wood timber by Ruyter,& Arnoldy in 1994 when they patented a *Process for upgrading low quality wood* (Eur. Pat. Appl. EP 623, 433-Cl.B27K5/06-09 Nov.1994).

This process comprises: (1) A softening stage, in which low-quality wood is heated to 160-240° in the presence of an aqueous medium and an aqueous pH buffer (pH 3.5-8.0) and at a pressure which is at least the equilibrium vapor pressure of the aqueous medium at the operating temperature, to at least partially hydrolyze the hemicellulose and disproportionate the lignin. (2) A dewatering stage, and (3) A curing stage. Thus air-dry sawn poplar wood was soaked overnight in an aqueous solution containing 6 g/L Na acetate at 95°, heated by steam at 200° condensing on the surface until the temperature in the center of the wood was 185°, cooled to 10° and compressed for 5 minutes, with gradually increasing pressure from 1 to 3 bar to remove the aqueous face. The sections were pressed in a platen press at 195° and 5 bar for 1.5 hours to give wood having Shore D hardness 70 and bending strength 125 MPa compared with 30 and 60 respectively for a sample without the Na acetate

A similar technique called "*reformed bamboo*" has been developed in China at the Academic Sinica by Li, Fu, Zhou, Zeng and Bao (1994) This new technique which aims at changing the form of bamboo from its natural circular cross section into a plate for convenient structural use.

The manufacturing technique covers three major processes after the bamboo culm is separated into several splints longitudinally which were then compressed after a treatment of softening.

The microstructure of reformed bamboo was studied, their mechanical properties were tested and the results show a remarkable increase compared with normal bamboo. According to the different uses, the mechanical properties and comprensive ratio (which is defined as r=(Ho - H1)/Ho, where Ho is the original thickness and H1 the thickness after compression) of reformed bamboo can be designed beforehand and adjusted in the manufacturing process. As a new attempt reformed bamboo was used to reinforce aluminum alloy for the purpose of protecting reformed bamboo itself and substituting some aluminium alloy .(See composite materials).

General structure and properties of bamboo

As mentioned earlier, all bamboos share some common features: they are natural ligno-cellulosic composite and are composed of fibres (bast fibres in vascular bundles) and matrix (parenchyma thin-walled cells around vascular bundles, vessels and sieve tubes in vascular bundles). Natural bamboo can be taken as unidirectional fibre-reinforced composite and its fibre volume fraction has an intimate relation with its mechanical property. The distribution of bast fibres of bamboo along the radial direction shows a gradient trend, and this undoubtedly influences its mechanical properties, as do synthetic fibre-reinforced composites. However in previous works, when the mechanical properties of bamboo were concerned, average values across the thicknes were more often used rather than those of a specific part of the bamboo culm. In fact, the heterogeneity, porosity and anisotropy are important features of bambo.

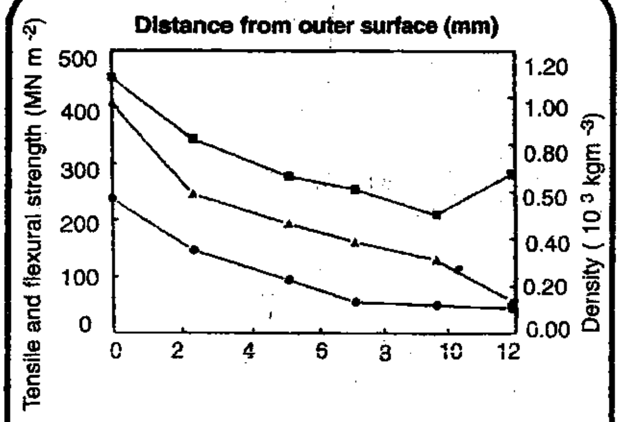


Fig. 6.16 *The radial changing trends of (▲) tensile and (●) flexural strength and (■)density of Ph. pubescens.*

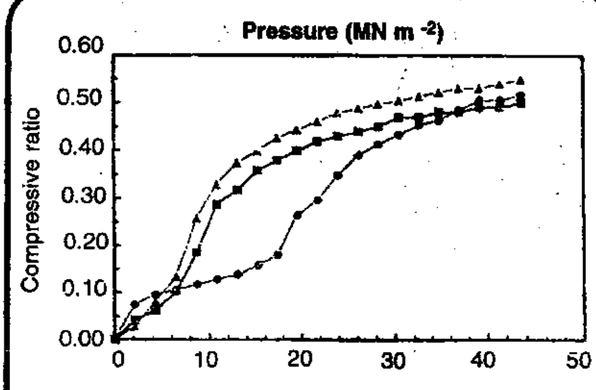


Fig. 6.17 *Relationships between moisture content, compresive ratio and pressure of bamboo. Moisture content (●) 8.5% (■) 22.6%. (▲) 28.9%*
(●) 8,5%, (-) 22.6%, (s) 28.9%

Because the fraction of bamboo fibres is not constant along the radial direction (fibers are denser in the outer part than in the inner part), to make the measurement of mechanical properties more accurate, one bamboo was cut longitudinally into several beams, with the width of each beam being about 15 mm; then each beam was separated into several strips of increasing thickness from the outer surface to the inner surface, and the tensile strength and effective modulus of each layer were measured experimentally. Owing to the gradient of fiber volume fraction in the radial directions, strictly speaking, there will be a coupling between stretching and bending under tension. To weaken the unexpected effect of coupling, each strip was made very thin; therfore, within the thickness of each strip, the modulus can be assumed to be a constant, which is the factual tested data of the effective modulus. End-taped specimens were made for testing tensil strength and effective modulus, of size 120 mm x 12 mm x *h* mm (*h* is the thickness of the specimens. The flexural strength was measured in three-point bending with a span of 40 mm for bamboo strip specimens. Fig. 6.16 shows the changing trends of the major mechanical properties of bamboo (*Phyllostachys pubescens*) along the radial direction.

It is obvious that there are many voids inside and outside the vascular bundles, and the number of voids in the inner part of the bamboo is greater than that in the outer greeen bamboo. The gradient structure of bamboo is optimum to adapt to the living environment, because this structure (a thick-walled circular cylinder with one end fixed) can provide optimum strength distribution and maximum structural stability with minimum material weight.

However, while bamboo is used as structural material, i.e. bamboo fibre-reinforced polymer (BFRP), the inhomogeneity of bamboo is usually an unexpected feature. To make the use of natural bamboo more convenient and more abundant, the microstructure of bamboo is redesigned and reformed to enhance the homogeneity of structure and property distribution.

Manufacture of reformed bamboo

Bambusa pervariabilis from China was chosen for this experiment. The manufacturing procedure consists of three steps: softening, compression and fixture. First , natural bamboo was separated longitudinally into several parts (usually two to four parts) and the diaphragms in the nodes were cut off roughly. Then the bamboo strips were heated in a container to adjust the moisture content to certain value. The strips were then compressed with a compressor to obtain the required compressive ratio. Finally under certain pressure, strips were pressed for 3 hours for the purpose of fixture. During the process, the moisture content of the bamboo is very important. The technological conditions can be determined according to Fig.6.17 which shows the relationships between moisture content, compressive ratio and pressure.

If the moisture content of bamboo is too low (such as 8.5%), as illustrated in Fig. 6.17, the bamboo is too rigid and brittle to be compressed rapidly; the other two curves show similar trends. It should be noticed that when the moisture content reaches 30%, the saturation conten,the water in bamboo will damage cell tissues during the compression process, and this will deteriorate the mechanical performance of reformed bamboo.

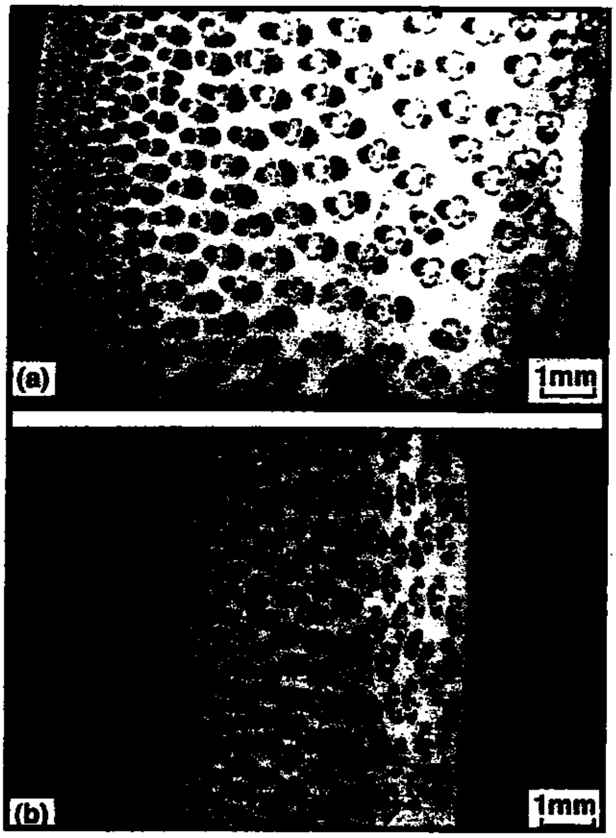


Fig.6.18 *Optical photographs of cross sections of (a) Normal bamboo, and (b) reformed bamboo. (After Li , Fu, Zhou, Zeng and Bao (1994)*

The structure of reformed bamboo

The structural changes of reformed bamboo derive from the distribution of vascular bundles and the vascular-bundles themselves. Fig.6.18 shows optical photographs of cross-section of normal bamboo (a), and reformed bamboo (b). From the comparison of these two photographs, it can

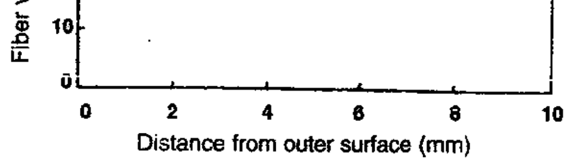


Fig. 6.19 *Fiber volume fraction of bamboo (▲) before and (●) after compresion (Compresive ratio is 0.49)*

be seen than the vascular bundles, or exactly speaking, the bast fibers in the inner part near the pith ring of the culm, became denser, and many voids in the vascular bundles (vessels and sieve tubes) disappeared after compression; the shape of the vascular bundle also changed from circular to elliptical.

To analyze the fiber volume fraction precisely, an Automatic Image Analyzer (Kontron IPS 500) was used to measure the area fraction of bast fibres over the total area. The specimen was divided into six or seven parts along the circumferential direction. The voids in the vascular bundle were taken to be matrix thus the fibre area fraction of each small divided part can be measured and the fibre area fraction along the radial direction was available. Because bamboo is strict unidirectional fibre-reinforced composite material, the fiber volume fraction VF was also calculated, and is shown in Fig. 6.19. The fibre volume fraction V_f of normal bamboo decreases gradiently along the radial direction; after compression (cf.fig.5), the V_f of most parts of bamboo is in the vicinity of 50%, but the fibre fractions near the pith-ring (the inner surface of bamboo culm) remains the same. The mean value of fiber volume fraction of both kinds of bamboo are listed in Table 6-10.

Mechanical properties of reformed bamboo

To obtain a compressive evaluation of reformed bamboo, tests were made of its density, static properties such as tensile modulus and strength, flexural modulus and strength, and shear strength along the fibre direction. The sizes of the bamboo specimens were determined by referring to the testing standards of wood and fibre-reinforced composites, or according to previous work. Experimental material was purchased from Guangdong province in South China. All tests were performed on a Shimadzu-DCS testing machine at room temperature. The geometric configuration and sizes of specimens are shown in Fig 6.20.

For tensile experiments, because the longitudinal shear strength is much lower than the tensile strength, the side-curved specimens were often found to be damage by shear fracture at the specimen end rather than tensile fracture in the working length, so in our experiments, end-taped specimens were used instead of side-curved ones. Owing to the gradient of bamboo structure, the strength and modulus are very different in the radial direction, so measurements should be thought of as "effective" or "apparent" properties or, in other words, they are the average values across the thickness of the specimens.

In all the bending tests, the side with the higher strength was loaded in tension. For shear tests, the direction of the loads is shown in Fig. 6.20; the shear test was performed on the basis of the test standard, using the method for wood. The tests result are summarized in Table 6-10.

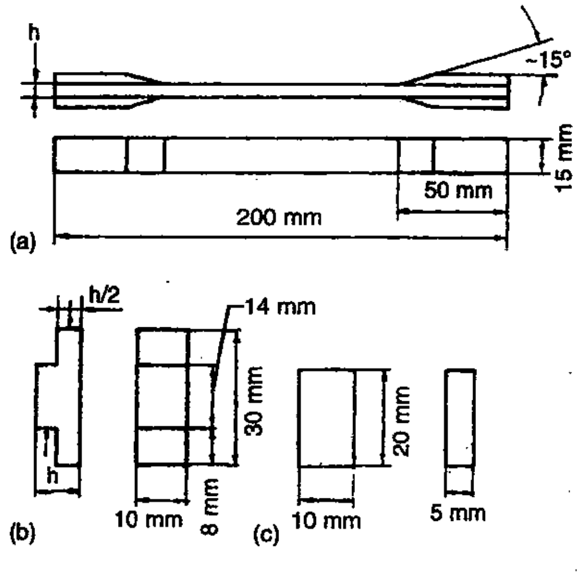


Fig. 6.20 *The shape and size of the bamboo specimens (h is the thickness of the bamboo culm wall (a) Tensile, (b) shear, (c) compressive specimens. (After Li, Fu, Zhou, Zeng and Bao (1994)*

Table 6-10 Comparison of the mechanical properties of reformed and normal bamboo

	Reformed bamboo		Normal bamboo	
	Mean	Dev.	Mean	Dev.
Fiber volume fraction (%)	43.6	13.4	29.2	12.8
Shrinkage coefficient radial	0.252	0.005	0.299	0.02
tangencial	0.184	0.0570.	0.319	0.076
bulk	0.446	0.83	0.663	0.132
Density (10^3 kgm^{-3})	0.87	0.17	0.66	0.07
Tensile strength (MN m^{-2})	271.5	60.6	206.2	24.7
Tensile modulus (GN m^{-2})	29.0	5.6	20.1	3.2
Flexural strength (MN m^{-2})	276.6	22.7	210.3	25.3
Flexural modulus (GN m^{-2})	23.2	4.7	13.1	3.0
Compressive strength (MN m^{-2})	104.7	28.4	78.7	7.6
Shear strength (MN m^{-2})	14.5	2.2	15.1	4.6

Source: Li et al (1994).

Table 6-11. Specific properties of normal and reformed bamboo

	Reformed bamboo	Normal Bamboo
Specific tensile strength (km)	31.84	31.88
Specific tensile modulus (Mm)	3.40	3.11
Specific flexural strength (Km)	32.44	32.51
Specific flexural modulus (Mm)	2.72	2.3
Specific shear strength (km)	1.70	2.33

Source Li et al (1994)

The data in Table 6-10 reveal that many mechanical properties of reformed bamboo are obviously increased, for example, the tensile strength is increased by 31.7%, tensile modulus 44%, and flexural strength 31.5%, at the expense of 32.2% increase of density.

The increase in the static mechanical property of reformed bamboo compared with the normal one can be explained by the following four aspects:

(a) Density. It is well known that the mechanical properties of a biomaterial have a close relationship with density of the material. For wood, usually the wood possesses a higher density, and has higher strength; such a correlation also exists in bamboo between the flexural strength and density of bamboo.

(b) Compressive ratio. For the same bamboo, the higher the compressive ratio, the denser will be the reformed bamboo. The total number of bast fibres in bamboo, which bear most of the load to which the bamboo is subjected, remains the same, so the strength and modulus per unit area will be increased as shown in Fig.6.21.

(c) Fiber volume fraction. According to the mixture principle $\sigma_c = \sigma_f V_f + \sigma_m V_m$ for bamboo, σ_f is much higher than σ_m. thus the relationship between σ_c and V_f approaches a linear form; the increase of V_f of reformed bamboo will undoubtedly increase its strength.

(d) Microfibril angle. The microfibril angle of the plant can dominate substantially its mechanical property. During compression the length and width of a specimen must be increased to some extent, and thus so do the lengths of bast fibers.

For a spirally coiled structure, like the cell wall of a plant, the increase in length must result in the decrease of the microfibril angle with the respect to the fiber axis, and this contributes to the increase of tensile property. The specific property, which is the ratio of the property to density, is of particular importance in composites.

Table 6-11 gives a comparison of the specific properties of reformed an notmal bamboo. From Table 6-11, it is clear that some major specific properties of both materials are very close or even the same. This is easy to understand, because the effect of compression is to assemble the fibers more densely and the increase in the properties was accompanied by an increase in density.

Disadvantages of bamboo

Although reformed bamboo has many advantages over normal bamboo, it does not overcome the defects of other biomaterials. Because bamboo is a unidirectional fibre-reinforced composite, the mechanical properties in directions other than the fibre direction are less than those in the fibre direction, especially those across the fibre. For example, the tensile strength in the fibre direction is usually more than 50 times higher than that across the fibre, and the case in reformed bamboo is the same.

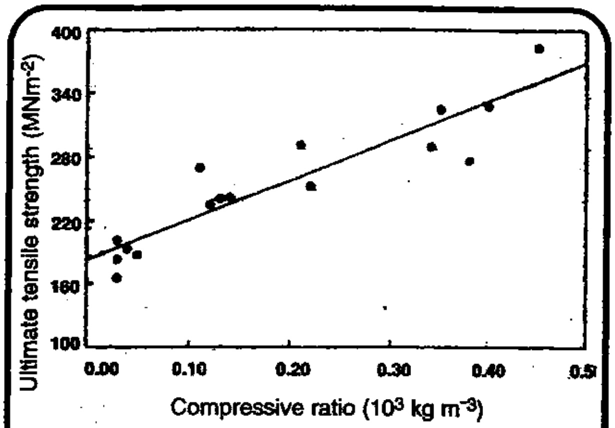


Fig. 6.21 *The tensile strength curve of reformed bamboo versus compressive ratio.*

Another serious disadvantage of bamboo, also suffered by other biomaterials, is hygroscopicity. The shrinkage coefficient of a material represents its ability to absorb water in air and the shrinkage coefficient of reformed bamboo was found to be less than that of normal bamboo (cf Table 6-10); thus the reformed bamboo is superior to the normal one in respect to retaining geometrical stability, in other words under the same conditions, reformed bamboo absorb less water from air than normal bamboo.

After all the moisture content of ligno-cellulosic bamboo will increase due to water in the air and will result in rot during service. The other parameter which describes hygroscopicity is the hygroscopic volume coefficient H, which is defined as H=W/V where W is the moisture content in the specimen, and V is the volume of the dry specimen.

The hygroscopicities of normal bamboo and reformed bamboo composites were measured experimentally for one month. Specimens were placed in a container of 100% relative moisture and a temperature of 20 degree C ± 2°C The moisture content of the specimens were measured regularly (See Reformed bamboo/aluminium alloy composite)

Of the three start points those for reformed bamboo and reformed bamboo/aluminium are lower than that for normal bamboo; this is because the moisture content of reformed bamboo is lowered during the process of heating and compression.

Up to 20 days, the hygroscopic volume coefficient (HVC) of reformed bamboo aluminium remained the lowest. In the other two specimens, without aluminium sheets outside , the HVC of reformed bamboo increased more rapidly than that of normal bamboo; this is also because of the low moisture content in reformed bamboo after treatment. The situation after 20 days is seldom encountered in service, when the relative humidity of 100% in their experiment is taken into account.

C. CHEMICAL PROPERTIES

CHEMISTRY OF BAMBOO SHOOTS AND CULMS

The results of the chemical composition of bamboo shoots carried out by Higuchi (1987) is given in Table 7-1. The sheath of bamboo shoots was peeled off and was cut into the upper, middle and basal portions, respectively. The sample of each portion was homogenized by a Waring blender and the homoginate was pressed to remove the juice. The homoginate was extracted several times with cold and hot water successively to remove the water soluble substances. Bamboos were cut into small pieces which were then pulverized by a Wiley mill.

The samples thus obtained were analyzed by conventional methods based on Schorger's procedure, and the content of lignin was corrected for protein. The contents of ash and the extracts of hot water, 1% NaOH, and ethanol - benzene decreased with maturation of the bamboo shoots, altough they were somewhat larger in bamboos than in shoots.

This may be attributed to the effect of water extractions in preparing the samples of bamboo shoots. The content of cellulose, pentosan, lignin, total methoxyl, and the methoxyl of lignin increased with the maturation of the bamboo shoot; the pentosan content decreased again in bamboos. The proximal chemical compositions of bamboo culms are generally similar to those of hardwoods, except that alkaline extract, ash and silica contents are higher than in hardwoods. High silica content causes scaling during evaporation of the spent liquor for recovery of the chemicals in pulping.

A. Hemicelluloses

Hemicellulose of bamboos have been investigated by several researchers. Maewaka and Kitao isolated a xylan from Madake (P. reticulata) culm by extraction with aqueous alkali of the chlorite holocellulose followed by precipitation of the alkaline extract as a copper complex with Fehling solution.

The xylan thus obtained comprised more than 90%of the bamboo hemicellulose. The structural studies by means of methylation analysis and periodate oxidation (Smith degradation) of the xylan gave evidence supporting a B-1, 4-linked linier polymer with attachments of single unit side chains such as the residues of L-arabinose and D-xylose in a molar ratio of 1.0:1.0-1.3:24-25, respectively.

It seems different from arabino- (4-O-methyl-D-glucurono) xylan found in the wood of gymnosperms, with respect to the degree of branching and the molecular properties.

Some properties of the bamboo xylan are similar to those hardwoods, but the most of the properties are in common with that the *Gramineae*.

It was further found that bamboo xylan isolated by extraction of bamboo holocellulose with DMSO contain 6-7% acetyl group. These results indicate that the bamboo xylan has unique feature of *Gramineae* different from gymnosperm and angiosperm xylans.

In addition, from the water soluble fraction of bamboo shoot-hemicellulose extracted with DMSO, a xylan which

Table 7-1 Chemical composition of bamboo shoots and mature bamboos (Percent of the water-free material)

Species		Ash	Hot-water extract	1% NaOH extract	Alc.-benzene extract	Cellu lose*	Pento-san	Lignin	Metho-xyl	Metho-xyl in lignin
Phyllostachys pubescens	h. p	1.61%	16.16%	45.44%	4.72%	31.69%	25.40%	2.25%	1.21%	5.17
	m. p	0.70	15.78	34.17	3.60	35.44	31.62	6.21	1.34	7.76
	l. p	0.88	14.72	32.86	2.33	38.48	36.20	7.80	1.91	8.27
	m. b	1.31	19.96	32.19	4.63	49.12	27.70	26.06	6.69	14.48
Phyllostachys nigra MUNRO var. *Henonis*	h. p	2.15	19.26	58.14	6.32	43.89	25.56	2.14	1.39	4.26
	m. p	0.88	12.02	46.02	3.35	41.53	27.18	6.93	1.20	5.86
	l. p	0.68	14.14	39.28	2.38	45.41	42.97	7.08	1.62	7.47
	m. b	2.00	21.47	34.03	3.35	42.31	24.13	23.82	6.45	17.06
Phyllostachys reticulata	h. p	1.39	10.84	57.49	6.64	34.36	24.94	3.84	1.47	3.36
	m. p	0.85	8.58	46.18	3.66	37.30	29.58	4.85	1.99	4.78
	l. p	0.78	8.31	34.87	1.21	38.39	49.74	9.17	2.38	6.46
	m. b	1.94	23.24	36.17	3.37	40.97	26.54	25.33	7.02	14.68

h. p: higher portion of bamboo-shoot m. p: middle portion of bamboo-shoot
l. p: lower portion of bamboo-shoot m. p: mature bamboo
*Cellulose content was determinated by modification of JENKINS' $NaClO_2$ method by S. HONDA and was calculated for the pentosan free basis.
Source: Takayoshi Higuchi 1987.

gives no copper complex with Fehling solution, an arabinogalactan, and a-glucan were isolated. The yield of the arabinogalactan was 0.3- 0.4% and was found to be different from conventional plant cell wall arabinogalactan which usually contains D- galacturonic acid.

The structural analysis by methlation and Smith degradation indicated that the arabinogalactan is composed of 1, 3- linked D- galactopyranosyl residues similar to the arabinogalactan from plant seeds and the sap of sugar maple. The molecular weight of a-glucan was 8000.

Kato et al recently found that ferulic acid is esterified to arabinofuranosyl residue of arabinoglucuronoxylan in sugar cane cell wall. Ferulic acid occurring as an ester component of bamboo cell wall may be linked to the hemicellulose as well, altough p-coumaric acid is confirmed to be linked to the side chain of bamboo lignin.

B. Lignin

Lignins are generally classified into three major groups based on their structural monomer units. Gymnosperm lignin is a dehydrogenation polymer of coniferyl alcohol. Angiosperm lignin is a mixed dehydrogenation polymer of conifery - and sinaply alcohols, and grass lignin is composed of mixed dehydrogenation polymer of coniferyl-, sinaply- and p- coumaryl alcohols. In grass lignin p- coumaric acid is esterified to the side chains of the lignin polymer.

1) p- coumeric acid

Grass lignin including bamboo lignin gives absorption bands at 315 nm and 280nm in the UV spectrum. However, when grass lignin is treated with aqueous NaOH and then lignin is precipitated with acid the precipitated lignin gives an absorption bans at 280 nm and p-coumaric acid is isolated from the filtrate. An absortion band at 1730 cm^{-1} in the IR spectrum, which is attributed to the p-coumaric acid ster, also ~~disappeared after saponification of the~~ grass lignin.

On the basis of spectral analyses before and after alcaline hydrolysis and acidolysis of bamboo lignin and model compounds such as veratryl p-coumarate and 3-(3,4 - dimetoxy phenyl) propyl p-coumarate we found that about 80% of the p-coumaric acid in bamboo lignin is sterified to γ-hydroxyl group of lignin side chains, specially of α, β-saturated ones in lignin molecules; α- linked ester of the acid was estimated to be less than 20%

2) Alkaline Nitrobenzen

By alkaline nitrobenzene oxidation gymnosperm lignin gives about 25% vanillin with a small amount of phydrobenzaldehyde ; angiosperm lignin 40-50% of a mixture of vanillin and syringaldehyde with molecular ratio of 1:1-3 and grass lignin 20-30% of a mixture of vanillin ,syringaldehyde and p- hydrxybenzaldehyde with molecular ratio 1:1-2:1.

About two third of the hydroxybenzaldehyde yielded by alkaline nitrobenzene oxidation of grass lignin is derived from the esterified p-coumaric acid of the lignin. the products and the ratios of the aldehydes reflect aproximate composition in the monomeric components of these types of lignins. These aldehydes are derived from uncondensed aromatic units of lignin and determined by gas liquid chromatography .(Higuchi , 1987)

The main chemical elements entering into the composition of bamboo culms

The main chemical elements entering into the composition of bamboo culms, forming the cell walls are cellulose, hemicellulose and lignin. Minor constituents, enclosed in the cell cavities, are tannins, resins, waxes and inorganic salts.

In the study conducted by Ma & Han (1993) in 26 bamboo species, they pointed out that the cellulose content is 35.86%- 45.76%, averaging41.80%.According to Karlsen *et al* (1967), in trees it can be assumed that softwoods are composed, on the average, of 48-56% cellulose, 20-30% lignin and 23-26% hemicellulose ardwoods contain slightly less cellulose and more hemicellulose. The experimental results indicated that the chemical composition of bamboo culms was similar to that of hardwoods in general, except that alkaline extract, ash and silica contents are higher than in hardwoods. The xylan obtained from culm extraction and precipitation comprised more than 90% bamboo hemicellulose (Higuchi T. 1987).

Liese (1992) points out that bamboo consists of about 50-70% holocellulose, 30% pentosans and 20-25% lignin. This chemical composition varies according to the species, the conditions of growth,the age of the bamboo culm and the part of the culm. Since bamboo completes the maturation of culm tissue within 2-3 years, when the soft and fragile culm becomes hard and strong, the proportion of lignin and carbohydrates changes during this period. However, after full maturation of the culm, the chemical composition tends to remain rather constant.

Cellulose and hemicellulose, also called holocellulose, are the solid residues of the polysaccharide fraction that remains after extraction of minor components and lignin by mild oxidation. The hemicellulose is extracted from holocellulose with a 17.5 NaOH solution, the residue being cellulose, which is difficult to isolate in a pure form because it is closely associated with the hemicellulose and the lignin. Cellulose is sometimes referred to as alpha-cellulose, which is the principal component in the manufacture of useful products such as paper, explosives, plastics, synthetic textiles, etc., which can be manufactured using bamboo as a raw material, as will be explained in another chapter of this book.

Pentosans are the main constituents (80-90%) of bamboo hemicellulose. In cold water, some dyes and tannins can be dissolved, while hot water extracts more substances from bamboo culms, such as starch and some others.

Alcohol-benzene 1:2 (1/3 ethanol and 2/3 benzene) is used to extract almost all substances not belonging to the cellulose group or lignin. Ether is used to extract alkaloids which do not dissolve in water (PROSEA (1995).

The nodes contain less water-soluble extracts, such as pentosans, ash, and lignin, but more cellulose than the internodes. The season influences the amount of water-soluble material, which is higher in the dry season than in the rainy season. The starch content reaches its maximum in the driest months just before the rainy season and sprouting.

The ash content (1-5%) is higher in the inner than in the outer part. On an average, the silica content varies from 0.5 to 5%, and it increases from bottom to top. Most silica is deposited in the epidermis, "the skin zone", whereas the nodes contain little silica and the tissues of the internodes almost none. The silica content affects the processing and pulping properties of bamboo.

Lignin: After cellulose, lignin is the second most abundant constituent in bamboo and great interest has been placed on its chemical nature and structure. Liese (1985) points out that bamboo lignin is a typical grass lignin, which is built up from three phenyl-propane units, p-coumary, coniferyl, and sinapyl alcohols, which are interconnected through biosynthetic pathways.

Bamboo grows very rapidly, reaching its full size within a few months. The lignification within every internode proceeds downward from top to bottom, whereas transversally it proceeds from the inside to the outside. During the height growth, lignification of epidermal cells and fiber precedes that of ground tissue parenchyma. The full lignification of the bamboo culm is completed within one growing season, showing no further aging effects.

Bamboo has been chosen as one of the suitable plants to study the biosythesis of lignin. Initially, these investigations were almost exclusively based on feeding experiments with radioactive precursors and it was found that lignin is synthesized from glucose formed by photosynthesis via the "Shikimic acid pathway" (Higuchy 1969 in Liese 1985).

Probably, the first and most complete research related to The study of the mechanical properties and chemical composition of bamboos was carried out by Sioti Uno at the Utsunomiya Agricultural College in Japan and published in 1932. I think that these studies are very important because they can be used as the basis for future research.

For his research, Mr. Uno used eight bamboo species and the following procedures for the preparation of the materials or components of the culm. I include this old information even though today there is better equipment and faster methods for obtaining the components.

Preparation of materials.

The material for chemical analysis was taken from the inner and outer layers of the culm wall of the lower, middle and upper sections of the culm. The materials for the quantitative cellulose analysis were prepared in the form of very thin, hand-planed shavings, and those for the other analyses were prepared in the form of sawdust, sifted through a 1 millimeter sieve.

a) Cellulose. The determination of crude cellulose was made by the Cross and Bevan method, and that of the Alpha, Beta and Gamma cellulose by the following method: 5 gr. of dry material were cooked one half hour with one percent caustic soda, washed and set aside in a wet condition for 30 to 60 minutes in a slow stream of chlorine wash. After washing with water, it was irrigated with 2 percent sodium sulphite solution, and slowly heated to boiling. Then 0.2 percent caustic soda was added, and it was boiled for another 5 minutes. It was washed with hot water and finally bleached with a one percent solution of potassium permanganate in order to remove the last traces of colored impurities.

The remaining manganese dioxide was removed with diluted ammonia (1:50); then the residue was well washed, dried and weighed. This substance is crude cellulose.

For the preparation of Alpha-cellulose, the crude cellulose was treated for 30 minutes with 18 percent caustic soda, 50 cubic centimeters of water was added. Then it was filtered through a Buchner funnel and the alkali removed by washing with cold water, after which the residue was dried and weighed. This substance is Alpha-cellulose.

For the determination of the Beta-cellulose in crude cellulose, the foregoing filtrate was used. Acetic acid was added to the solution and was heated to 100°. Then the precipitate was filtered off, dried and weighed. Next, the sum of the Alpha and Beta cellulose is substracted from the total crude cellulose; the difference is the Gamma cellulose.

According to the results of the research, as shown in table 7-2, in many cases the crude cellulose increases in the culm from the lower to the upper portion. In the comparison between the inner and outer layer, the outer has a greater amount, the difference amounts to 15% on the average.

Of the Alpha, Beta and Gamma cellulose as shown in Tables 7-2 and 7-3, the Alpha cellulose content is the greatest, i.e. from 66.86% to 77.62%. Moreover, more Beta cellulose than Gamma cellulose is detectable and this relationship is the same as in softwoods.

b) Pentosans.-The analysis for pentosans was carried out according to the following method whereby 2 grams of dry material were used each time. One hundred cubic centimeters of hydrochloric acid (specific gravity 1.06) were added to the material and the mixture was destilled until the destillate amounted to 30 cubic centimeters. After the addition of another 30 cubic centimeters of hydrochloric acid, the mixture was again distilled until another 30 cubic centimeters of distillate were obtained. The same operation was repeated until the total distillate amounted to 360 cubic centimeters. To this solution a solution of phlorglucin was added in order to precipitate the furfural-phlorglucide. This precipitate was filtered out, washed, dried and weighed.

The pentosans were calculated from total furfural-phlorglucide. According to the results of these investigations, there is a little difference between the upper, middle and lower sections. But between the inner and the outer layers, the former show a greater total pentosan content, as is evident in Table 7-4.

c) Alcohol extract.-For the extraction with alcohol, 2 grams of dry material were taken and extracted in a Soxhlet apparatus for 16 hours. Then the alcohol was evaporated from the extract by heating over a water bath, and the residue was dried and weighed. It was found that the total alcohol extract is relatively larg in old bamboo culms, especially in the upper section.

d).-Lignin. It was determined using the following method: 2 grams of the dry material were treated for 48 hours with 72 percent sulphuric acid, then 50 cubic centimeters of water were added and the solution was heated to 100°. Upon cooling, it was filtered through a Goech crucible with an sbestos mat. The residue was washed with hot water in order to remove the acid, dried, and weighed. According to the investigations, as shown in Table 7-5, there is more lignin contained in the outer than in the inner layer.

Table 7-2 CRUDE CELLULOSE AND ALPHA CELLULOSE CONTENT IN SOME BAMBOOS

Species	A.-Crude cellulose content of bamboo culm (%)					B.-Alpha cellulose content in crude cellulose (%)				
	Layer	Lower Section	Middle Section	Upper Section	Average	Layer	Lower Section	Middle Section	Upper Section	Average
Ph.bambusoides	Inner	33.10	34.48	43.28	36.95	Inner	68.73	66.50	64.97	63.73
	Outer	46.70	46.00	49.62	47.44	Outer	81.46	64.96	85.57	77.33
Ph. nigra var *Henonis*	Inner	44.15	40.86	39.73	41.59	Inner	64.78	76.22	63.64	66.21
	Outer	45.40	47.95	43.03	45.45	Outer	68.67	68.13	80.08	72.29
Ph. pubescens	Inner	32.00	29.70	36.14	32.61	Inner	72.90	80.36	58.56	70.60
	Outer	37.78	37.18	38.75	37.90	Outer	44.14	74.53	70.69	63.12
Ph. lithophila	Inner	39.22	47.65	47.30	44.72	Inner	73.85	72.56	83.30	76.40
	Outer	46.95	54.88	47.60	49.78	Outer	68.81	79.41	80.31	76.18
Dendrocalamus latiflorus	Inner	23.18	28.28	39.80	30.42	Inner	46.28	61.10	65.51	57.63
	Outer	37.72	36.70	40.48	38.30	Outer	82.97	72.65	72.88	76.16
Bambusa Oldhamii	Inner	47.25	48.48	50.08	48.60	Inner	73.02	57.19	73.89	68.03
	Outer	51.93	50.20	51.18	51.10	Outer	62.25	72.90	71.71	68.95
B. stenostachya	Inner	43.17	46.45	37.88	42.50	Inner	79.76	78.79	77.49	78.69
	Outer	50.05	47.03	44.50	47.19	Outer	81.37	79.21	86.85	75.81
B. vulgaris var. *vittata*	Inner	46.58	43.37	39.20	43.05	Inner	72.87	75.97	71.68	73.31
	Outer	51.26	52.48	50.35	51.36	Outer	84.39	85.21	76.20	81.93

Source: Sioti Uno (1932)

Table 7-3 BETACELLULOSE AND GAMMA CELLULOSE CONTENT IN SOME BAMBOOS

Species	A. -Betacellulose content in crude cellulose (%)					B.- Gama cellulose content in crude cellulose (%)				
	Layer	Lower Section	Middle Section	Upper Section	Average	Layer	Lower Section	Middle Section	Upper Section	Average
Ph.bambusoides	Inner	23.18	28.21	33.60	28.33	Inner	8.09	5.29	1.43	4.94
	Outer	17.43	19.19	7.62	14.75	Outer	1.11	15.85	6.81	7.92
Ph. nigra var *Henonis*	Inner	34.94	22.70	27.27	28.50	Inner	0.28	1.09	8.09	3.15
	Outer	18.12	16.85	13.34	16.10	Outer	13.21	15.02	6.58	11.60
Ph. pubescens	Inner	16.54	17.77	22.67	19.03	Inner	10.46	2.64	18.78	10.63
	Outer	20.78	11.15	20.14	17.36	Outer	35.08	14.32	9.17	19.52
Ph. lithophila	Inner	17.61	24.08	14.96	18.88	Inner	9.04	3.36	1.74	4.71
	Outer	22.90	18.36	10.64	17.30	Outer	8.29	2.25	9.05	6.52
Dendrocalamus latiflorus	Inner	24.92	32.75	23.49	27.05	Inner	28.20	6,17	11.00	15.12
	Outer	14.24	25.71	18.10	19.35	Outer	2.79	1.66	9.02	4.49
Bambusa Oldhamii	Inner	14.13	14.49	22.32	16.98	Inner	12.86	28.82	3.79	15.16
	Outer	17.09	20.87	10.55	16.17	Outer	20.66	6.25	17.74	14.87
B. stenostachya	Inner	17.10	13.29	16.44	15.61	Inner	3.12	7.92	6.07	5.70
	Outer	14.01	15.15	23.20	17.45	Outer	4.62	5.64	9.95	6.74
B. vulgaris var. *vittata*	Inner	23.62	15.28	17.01	15.64	Inner	4.11	8.75	11.31	8.06
	Outer	11.48	12.24	15.50	13.07	Outer	4.13	2.55	8.50	4.99

Source: Sioti Uno (1932)

Table 7-4 — PENTOSANS CONTENT AND YIELD OF ALCOHOL

Species	A. -Pentosans content (%)					B.-Yield of alcohol extract (%)				
	Layer	Lower Section	Middle Section	Upper Section	Average	Layer	Lower Section	Middle Section	Upper Section	Average
Ph.bambusoides	Inner	20.75	23.40	25.20	23.12	Inner	3.80	8.76	4.10	5.47
	Outer	19.60	20.25	24.40	21.42	Outer	4.45	4.50	7.20	
Ph. nigra var *Henonis*	Inner	26.55	27.55	29.10	27.73	Inner	6.63	8.15	6.95	6.85
	Outer	26.00	25.35	26.30	25.88	Outer	6.95	7.74	4.65	
Ph. pubescens	Inner	27.25	29.60	26.00	27.62	Inner	3.70	5.63	3.40	4.27
	Outer	24.30	25.35	26.50	25.38	Outer	3.80	5.26	3.80	
Ph. lithophila	Inner	22.65	23.00	23.65	23.10	Inner	1.45	2.70	3.80	3.42
	Outer	21.45	17.55	23.05	20.68	Outer	4.55	2.75	5.28	
Dendrocalamus latiflorus	Inner	29.70	28.75	23.14	27.20	Inner	6.38	6.25	3.35	5.40
	Outer	25.90	24.06	20.30	23.42	Outer	5.43	6.40	4.58	
Bambusa Oldhamii	Inner	19.95	21.65	19.85	20.40	Inner	8.30	6.85	4.10	5.33
	Outer	17.05	19.75	15.50	17.43	Outer	3.60	5.16	3.95	
B. stenostachya	Inner	21.20	20.30	21.60	21.00	Inner	7.88	5.68	2.52	4.81
	Outer	17.55	18.10	17.65	17.83	Outer	5.30	4.88	2.60	
B. vulgaris var. *vittata*	Inner	21.40	21.40	21.85	21.55	Inner	6.13	3.28	4.65	4.98
	Outer	20.0	18.70	18.60	19.12	Outer	4.70	5.27		

Source: Sioti Uno (1932)

Table 7-5 — LIGNIN AND ASH CONTENT

Species	A - Lignin (%)					B - Ash (%)			
	Layer	Lower Section	Middle Section	Upper Section	Average	Layer	Average of lower, mid. upper sec.	Average thereof	Color
Ph.bambusoides	Inner	23.48	28.39	29.04	26.97	Inner	1.09	1.07	Ash-white
	Outer	27.84	30.05	31.00	29.62	Outer	1.06		
Ph. nigra var *Henonis*	Inner	32.57	19.56	29.85	27.33	Inner	1.22	2.03	Do
	Outer	31.07	29.90	30.58	30.52	Outer	1.83		
Ph. pubescens	Inner	29.58	24.33	21.28	25.06	Inner	1.57		Do
	Outer	36.61	39.26	29.73	35.20	Outer	1.48	1.53	
Ph. lithophila	Inner	24.30	26.86	29.61	26.92	Inner	2.31	2.10	Ash-dark
	Outer	30.10	32.34	32.10	31.51	Outer	1.89		
Dendrocalamus latiflorus	Inner	18.61	34.85	39.12	30.86	Inner	1.74	1.70	Ash-green
	Outer	27.24	37.26	41.95	35.48	Outer	1.66		
Bambusa Oldhamii	Inner	17.72	28.07	20.02	21.94	Inner	2.52	2.09	Greenish-White
	Outer	23.71	29.48	27.16	26.78	Outer	1.66		
B. stenostachya	Inner	25.85	26.52	25.31	25.89	Inner	2.14	1.74	Do
	Outer	29.35	35.91	28.51	31.26	Outer	1.33		
B. vulgaris var. *vittata*	Inner	22.05	25.44	26.00	24.50	Inner	1.44	1.87	Green
	Outer	30.93	25.93	28.93	28.51	Outer	1.29		

Source: Siati Uno (1932)

Table 7-6 CULM CHEMICAL COMPOSITION WITH REFERENCE TO THE CULM'S AGE

Species	Age (years old)	Moisture (%)	Ash (%)	Cold water sol.(%)	Hot wate sol.(%)	Caust. soda (1%)-%	Alcoh. benz. sol. %	Lignin (%)	Pentosa (%	Holocellulose %	Alpha-cellul. (%
Phyllostachys pubescens	1/2	9.00	1.77	5.41	3.26	27.34	1.60	26.36	22.19	76.62	61.97
	1	9.79	1.13	8.13	6.34	29.34	3.67	24.77	22.97	75.07	59.82
	3	8.55	0.69	7.10	5.41	26.91	3.88	26.20	22.11	75.09	60.55
	7	8.51	0.52	7.14	5.47	26.83	4.78	26.75	22.04	74.98	59.09
Ph. heteroclada	1	8.38	1.24	13.57	9.60	30.89	5.38	22.42	20.43	71.98	58.15
	3	10.87	1.27	9.68	15.94	34.84	9.11	22.72	21.83	59.95	38.96
Ph. nigra	1/2	10.31	1.98	6.72	8.30	31.83	4.12	28.49	22.24	70.77	45.38
	1	7.79	1.84	10.69	8.53	33.24	5.29	23.99	22.08	73.61	58.85
	3	11.61	1.71	6.50	8.36	33.65	5.58	25.00	22.39	68.64	43.79
Ph. bambusoides	1/2	10.69	2.22	4.62	5.93	27.60	1.81	24.51	22.69	76.41	48.92
	1	9.14	1.25	10.49	8.97	29.93	7.34	22.39	22.46	72.65	56.74
	3	9.90	0.98	6.11	7.32	31.33	5.86	25.15	22.65	65.39	42.92
Ph. meyeri	1/2	10.70	1.68	3.69	5.15	27.27	1.81	23.58	21.95	78.47	49.97
	1	8.29	1.29	10.79	8.91	38.28	7.04	23.62	22.35	72.84	57.88
	3	9.33	1.85	8.81	12.71	35.32	7.52	23.35	22.19	62.40	39.05
Ph. praecox	1/2	10.64	3.24	6.72	8.57	33.36	2.25	26.74	21.98	72.83	42.23
	1	8.19	1.96	11.21	7.68	32.84	3.80	24.68	22.24	73.31	56.13
	3	11.29	2.28	7.18	9.09	33.26	5.64	25.65	22.39	65.77	40.81
Bambusa textilis	1/2	9.09	2.39	6.64	8.03	32.27	4.59	18.67	22.22	77.71	51.96
	1	10.58	2.08	6.30	7.55	30.57	3.72	19.39	20.83	79.39	50.40
	3	10.33	1.58	6.84	8.75	28.01	5.43	23.81	18.87	73.37	45.50
B. pervariabilis	1/2	8.38	2.16	4.93	6.35	27.71	2.14	20.92	21.47	79.41	52.63
	1	11.66	2.29	7.64	7.71	29.99	2.15	21.43	20.26	73.34	
	3	11.04	2.65	9.51	9.25	30.63	6.42	22.07	19.22	69.14	48.15
B. sinospinosa	1/2	9.17	2.69	7.29	8.23	29.98	4.23	19.90	21.84	78.29	52.58
	1	11.49	1.92	8.98	9.91	30.25	5.49	20.54	20.72	74.46	49.15
	3	11.13	1.84	9.07	9.29	26.92	5.88	24.17	19.27	72.77	47.10
L. chungii	1/2	9.21	2.73	8.10	9.70	35.17	4.16	17.58	23.91	79.00	47.63
	1	10.33	2.10	8.07	9.46	29.97	4.35	21.41	18.72	73.72	47.76
	3	10.2		6.34 -	9.24	30.57	3.98	22.70	18.88	71.70	
Source: Youdi et al (1985)											
Bambusa vulgaris	—	—	2.40	—	5.10	27.90	4.10	26.90	21.10	66.05	43.6
			4.10		3.80	22.30	5.40	25.50	19.60	61.30	—
			5.30		4.40	28.30	3.20	24.20	18.80	62.9	

PART 3

BAMBOO HANDICRAFTS

Portable basket made with bamboo. (Sellier's drawing) Geografia Pintoresca de Colombia in 1869.

7 MANUFACTURE OF BAMBOO WARES

PRELIMINARY TREATMENTS

1.-RESIN OR OIL EXTRACTION

The purpose of this treatment used in Japan is to give to the bamboo surface a lustrous, ivory color and also to prevent the material from being attacked by insects and mold.

According to S.Takeuchi (1968), at the Kiushu branch of the Industrial Arts Institute in Japan, two ways of extracting the resin, also known as oil extraction, are applied: the dry process and the wet process:

1.-Dry process.- In this case, the round surface of a green bamboo culm section is heated evenly at a distance of about 5 centimeters or more over the burner of an electric stove at a temperature of 1200 -1300 C for about 20 minutes, while turning the culm section, and wiping off the emerging resin and water with a cloth. This process is very expensive, due to the cost of electricity, and is useful only for the treatment of very few pieces. Bamboos treated with this process become so hard that they were used in the thirties for the manufacture of slide rulers, record player needles and knitting needles.

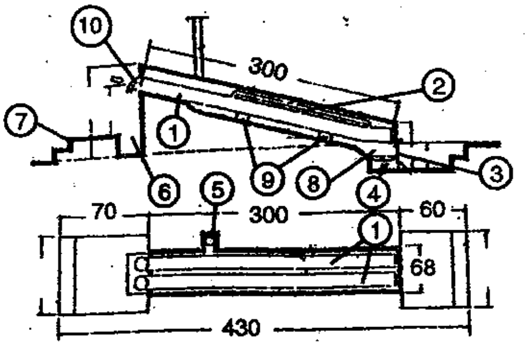
2.-Wet process. In this case, two types of treatments are used, one using water and the other one using chemicals.

2.1)- With water.-In this case, the green bamboos are put into boiling water to boil for 1-2 hours, and are wiped immediately after they are removed. With this treatment good materials can be obtained because there are no chemical reactions.

2.2)-With chemicals.-In this treatment, the following chemicals are used: caustic soda, sodium carbonate, calcium oxide, soap, sodium sulfite, sodium bicarbonate, dye and borax. Caustic soda and sodium carbonate are the most commonly used. Bamboos are boiled for 10-15 minutes in a solution of 0.3% to 0.8% caustic soda, or of 0.3-1.2% sodium carbonate. Each percentage can be changed depending on the materials' condition. Moreover, by also using soap, stains on bamboo can be removed. When many materials are treated at one time, the relationship between the density of the chemical solution and the boiling time should be examined beforehand on test pieces because the boiling time has a great influence on the color of bamboo. Materials treated in this way are more flexible and suitable for weaving.

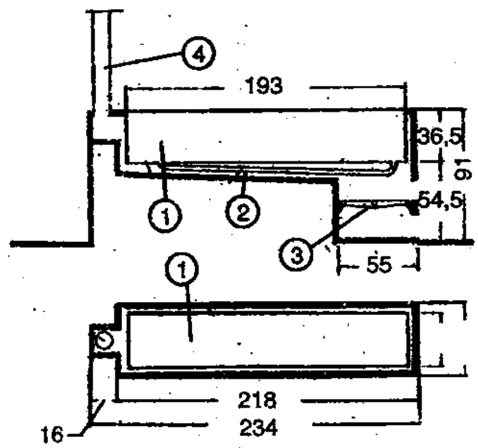
Equipment. The resin extracting equipment used in Kyushu consists of a boiler with a length of 5-6 m. and a diameter of 30 centimeters for a bundle of small bamboos. The slope, 15°, for the convenience of boiling and cleaning operations. Double boilers are arranged to carry out this operation continuously and efficiently, counting 10 minutes as the basic time of resin extraction. The fireplace is rather big because waste bamboos are often used as fuel. Besides a thermometer, a water level measurer and a sweeping hole should be arranged at each place.

Fig.8.1 RESIN EXTRACTION EQUIPMENTS



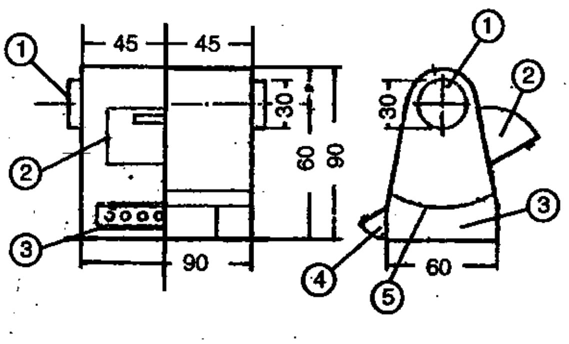
1.-Boilers	6.-Water pool
2.-Convection pipe	7.-Stand
3.-Fire door	8.-Fire place
4.-Loaster	9.-Boiler stand
5.-Chimney	10.-Entrance for bamboo

A.-*Resin extracting equipment type No 1 for industries- Angle of the boiler slope 15°*



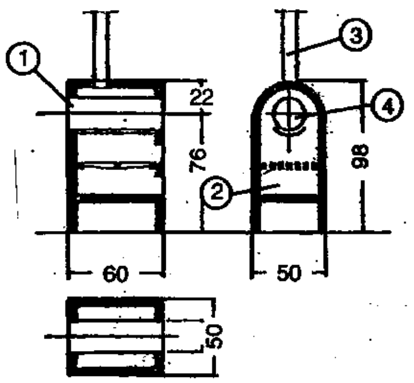
1.-Boiler
2.-Convection pipe
3.-Loaster
4.-Chimney

B.-*Equipment for laboratory (Takeuchi.1968)*



C.-Resin extraction equipment -Direct fire style for small industries

1.-Entrance for bamboos
2.-Entrance for charcoal
3.-Air entrance
4.-Ash exit
5.-Loaster



D -Resin extraction portable direct fire style for very small industries (Takeuchi, 1968)

1.-Heat transfer plate
2.-Loaster
3.-Chimney
4.-Heat separating plate

DYEING OF BAMBOO

Clearness of color and durability in sunlight are required of dyed bamboo products. The dyes are classified into three kinds, namely: basic color, direct color, and acid color, which have been used to dye bamboo materials, but these fade in the sunlight. The outer surface and the inner of bamboo wall have different degrees of dye acceptance. The outer surface is difficult to dye, and some acid dyes and direct dyes are less effective for this purpose.

Dyeing method

Initial treatment. Before dyeing bamboo it is necessary to extract first the resin or oil from it previously, through boiling the bambo in a solution of 0.2% caustic soda or sodium carbonate for 3- 5 minutes. After the extraction of oil, bamboo must be washed fully with water and dried completely to make dyeing effective. It is the key for good coloring to choose bamboo without any scratches on the surface of the crust, and to shane its crust thinly and make the surface as smooth as possible, before dyeing.

Table 8-1 DYES USED FOR BAMBOO

	Acid	Basic	Direct
Red	Rocelline acids of Eosine, Red P.G.	Magenta,Kinds of Rhodamine	Diamine Scarlet
Orange	Orange II, German orange	Chrysoidine, acridine orange NS Conc.	Direct fast Orange, direct Orange, RCon
Yellow	Metanil Yelow	Aureamine	Chrysofenine Cotton Yellow
Green	Brilliant Milling Green B	Malachite green Green bamboo Brillant green	
Dark green		Malachita green Auramine	
Blue	Water blue	Janus blue Methylene blue	Diamine sky blue
Violet	Acid violet 5B	Methyl violet Saframine	
Brown		Extra brown	
Red brown	Resorcine brown	Bismark brown B.G.R.	Direct brown K.G.G. direc
Black	Nigrosine	Janus black	Direct black

Usually an iron kettle, a zinced iron kettle or an enamelled pot is used for dyeing bamboo. If possible it is recomended to use a separate kettle for each color, in order to save the dyes and for good coloring effect. In case the same kettle is used for several colors. The process is the following:

1) Cold water is poured into the kettle with the dye which previously is dissolved in a small quantity of hot water. The mixture is then stired.

2) After heating and boiling the dye solution, the bamboo is put into it and boiled again. The time and temperature for boiling varies between 20-60 minutes at 90º C in accordance with the materials.

3) When dyeing is finished, the colored material is taken out and wash with a weak solution of acetic acid, so as to make the color fast, then is dryed completely to protect it from being moldy.

Precautions.- It is necessary to bear in mind the following precautions with the three kinds of dyes:

Acid dyes

1) Hard water must not be used.

2) Acetic acid and sulphuric acid is used for co-chemical. Example (1,000 cc of water), 2-15 g of dye; 2-5 cc of acetic acid, or 2-15 g of dyes; 2 g of sodium acetate and 1 g sulphuric acid.

3) This kind of dyes is more difficult to dye than basic dye, so about 30 minutes of boiling are necessary.

4) As for brown, orange and blue colors, acetic acid must allways be used.

5) It is recommended to use hydrochloric acid or formic acid at about 1% for silk-scarlet (red) and orange II.

Basic Dyestuff

1) Hard water which contains too much calcium, magnesium and other minerals must not be used for dyeing since the dye and the salts combine with each other to form an insoluble precipitate.

2) If the bamboo material is alkaline, it will produce precipitate.

3) Acid dyes must not be mixed with direct dyes. In this case, it is necessary to apply another dye solution for the material which has already been dyed and dried.

4) Auramine is less durable at high temperatures, so the temperature must be kept below 80° C.

5) When the dye is difficult to dissolve, it is necessary to make a dyeing solution in which the dye has been dissolved with an equal quantity of acetic acid.

6) Dye which is not soluble in water, e.g. Victoria blue, may be made into a solution after it has been dissolved with some kind of alcohol.

7) Acetic acid is used to make the color fast, but it must be noted that it is soluble and the color may occasionally fade.

8) When the process of dipping the material in a 4-6% solution of tannic acid for 3 hours, or a 1-2% solution of tatar emetic for 30 minutes has been carried out before dyeing, the bamboo will receive the color more readily. When the process is carried out after dyeing, the water resistance of the material increases.

9) The time for dyeing should be 10-20 minutes and the proportion of dye in the solution should be 0.05-1.00%.

Direct Dyes

1) It is recommended that salt be used as a co-chemical. Sometimes sodium sulphate or sodium carbonate is also used as a co-chemical. For example: (1,000 cc of water) 2-15 g of dye; and 5g of salt.

2) Bamboo material should be boiled for about 30 minutes.

Special colors and mixing dyes

Single colors are seldom used for industrial arts. As a general rule, dyes are mixed before use.

1)Smoked bamboo color.

a) Dye with 1-1.2 g of Bismark brown (1,000 cc of water) and after drying, dye again with 0.6 g of malachite green (or use 0.4 g of methyl violet and 0.2 g. of malachite green).

b)Dye with a mixture of 1.2 g of Bismark brown and 0.6 g of methyl violet.

2) Dark brown: The mixing ratio is 1 Janus black to 2 Bismark brown.

3) Hot chocolate color: Add an adequate quantity of Malachite green and auramine to Bismark brown.

PAINTING OF BAMBOO

Coloring methods other than dyes

After the outer skin has been shaved off or polished off using sand paper, dilute nitric acid or dilute sulphuric acid is applied on the surface of the bamboo and immediately it is heated evenly over a charcoal fire or in a coke furnace. Then an ammonia solution is applied on it, followed by washing in a dilute soda solution to neutralize the ammonia, and finally it is washed with water. Otherwise, after heating bamboo over a fire, it is sometimes soaked in a solution with a ratio of 1,000 cc of water and 20 g of ammonia for about an hour.

With regard to color, nitric acid treatment makes it brown or red-brown, while sulphuric acid treatment makes it black or dark brown. In this case, dilute sulphuric acid (diluted about 9-10 times with water) is applied on the original surface of bamboo culm. Numerous spots and lines of various sizes appear on the surface, because bamboo oil forms a chemical reaction with sulphuric acid, and when it continues to be heated, the spots and lines are fixed on the surface; consequently artificial sesame bamboo is obtained. Old bamboos contain less oil, so in this case oil should be previously applied on the surface.

Painting is practiced to protect the bamboo or its products from moisture and noxious insects and to add beauty to the material by means of coating the surface with paints or pigments. It is difficult to make paint or pigments stick fast on the surface of the bamboo culm, so the outer skin of bamboo must be shaved or sanded off beforehand.

Varnish, enamel, paint, Japanese lacquer, lacquer, perssimmon shibu and logwood are used for painting on bamboo. Recently acrylic paints and other new paints made from synthetic resins have been invented, and they have been widely applied on bamboo.

Kinds of paints.

1) Varnishes, such as volatile varnish, (solvent is alcohol), include shellac varnish, clear lacquer and high solid lacquer which is one of the best.

2) Enamels, such as volatile enamel which is a compound of volatil varnish and pigment, include: resin enamel, synthetic resin enamel and lacquer enamel. The oily enamels include: outside coating enamel, frosted enamel and aluminium enamel.

3) Paints include: oil paint (a compound of drying oil, pigment and solvent); mixed paint, water paint, and emulsion paint.

4) Japanese lacquers include Kishome urushi or raw lacquer; Sejime urushi or Sejime lacquer; and Gensai urushi or Gensai lacquer. The refined lacquers include black lacquer, clear Japanese lacquer and colored lacquer.

5) Cashew lacquer paint.

Painting methods.

The following methods are used for painting bamboo a) Brush painting; b) Dip painting; c) Roller painting and d) Spray painting. Most paints can be applied with a brush, but lacquer enamel which dries in a short time is exceptionally difficult to apply with a brush, unless the drying time can be prolonged by using specially chosen solvents.

The smoke-finishing of bamboo handicraft products.

According to Ahmad, Ashaari and Grewal (1997), brown-smoked bamboo handicraft products have had a better demand and price than unsmoked products. Tests conducted by the Malaysian Handicraft Development Corporation have shown that the time taken to achieve the desired color ranged from 8 to 144 hours. It has also been observed that the color of the smoked items is uneven. This problem is probably attributable to uneven smoke flow and distribution, and the use of inappropriate fuel. Two charges of splints (8 x 1.5 x 350 mm) from the bamboo *Gigantochloa scortechinii* were smoked in a kiln built at the Forest Research Institute Malaysia at Kepong. The fuel used was air-dried coconut shells. Color assessment was made with the aid of the Munsell Soil Color Chart. Details are given of the colour characteristics obtained after 1 and 2 hours of smoking in the top and bottom tiers, and in the first and second charges. Two hours of smoking at a temperature of 16° C was found to be sufficient to achieve the desired color.

Conservation of the characteristic green color of bamboo

Moso bamboo (*Phyllostachys edulis*) culms have an attractive green coloured epidermis skin which once harvested turns yellowish. In addition, bamboo culms, containing a vast amount of materials such as starch and protein, are easily infested by insects and microorganisms, which reduces their values and durability.

The following experimental studies related to the conservation of the green color of bamboos after they are felled have been carried out in Taiwan and Japan:

1.-Effect of microwave treatment on the green colour conservation and durability of bamboo.

In order to conserve the original green colour of bamboo and enhance the durability, Chang-Hui Tin; Chang-Shang Tzen; (1994) studied in Taiwan the effect of microwave treatment of the green color conservation and durability of bamboo. For this purpose they used the species Moso bamboo and Ma bamboo (*Dendrocalamus latiflorus*) Their culms were treated with inorganic salts such as Boliden K-33, copper naphthenate and copper sulfate and then dried in a microwave oven. The results revealed that bamboo treated with microwave had the better green colour conservation and durability than those dried in an oven. The microwave treatment has been shown to improve the mildew resistance of bamboo during outdoor weathering. However, the best green colour conservation of bamboo epidermis in this study was obtained by consecutively treating with inorganic salts and then with microwave..

2.-Treatment with inorganic salts

Later on, Chang-Shang Tzen; Lee-Hong Lin; (1996) experimented the treatment with inorganic salts such as chromates, nickel salts, and copper salts. After these treatments, the colour change of the bamboo skin was evaluated with a colour and colour difference meter.

The results demonstrated that the protection of the green colour of moso bamboo skin was obtained by treating alkali-pretreated bamboo with Boliden K-33, or nickel nitrate, or copper sulfate, individually. When moso bamboo was treated consecutively with nickel nitrate (or copper sulfate) and then with Boliden K-33, the effectiveness of the green colour protection definitely was improved.

The best result was obtained by treating it with a mixed solution of nickel nitrate and copper sulfate. In addition, based on the results of the durability evaluation, moso bamboo treated with Boliden K-33 possessed the best green colour fastness and durability against weathering..

3.-In 1997 Chang-Shang Tzen tested three species of *Dendrocalamus* (*D. latiflorus, D. giganteus and D. asper*) with several inorganic salts as protection of the green color. The best result was obtained with Boliden K-33 which possessed the best green color fastness.

4.-Treatment developed in Japan for the preservation of bamboos' greenness.

Kubo Sueyosi (1989) developed the following formulation for treating bamboo materials for woven arts and crafts, chopsticks, etc. They are impregnated with a solution of 0.1-0.2% vinegar, and 0.1-0.2% table salt in a closed container at low temperature and under darkness to preserve their original color prior to use.

GLUING OF BAMBOO SURFACES

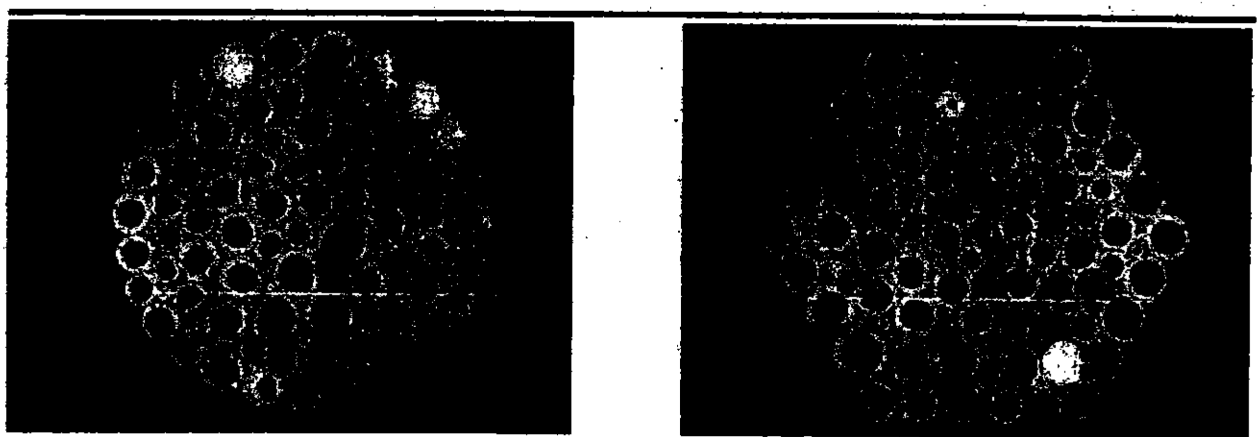


Fig. 8.2 A *and* **B** *shows decorative figures made with small dry sections of internodes glued together after removing the surface or skin of the cortex as shown in Fig. 8.3A.*

BAMBOO LACQUER WARE

In China and Japon the tradicional lacquer is made from the resin of the *urushi* tree (*Rhus vernicefera*).This tree has been cultivated by royal order for hundreds of year in Japan. In Thailand and Burma the resin of the *rak tree (Melanorrhoea usitata)* is used for this purpose. The *rak* tree grows in dry deciduous forests fron near sea level to about 1200 m. The resin is obtained by making 20-30 "V"-shaped incisions in the bark of the tree, a bamboo internode to receive the resin which flows from them being stuck into the bark at the bottom of the "V". The resin continues to flow for 7 or 8 days when the bamboo internodes are taken down. A thin layer of water is poured over the surface of the resin to keep it from drying up. When fresh the resin is of a reddish black colour, when dry it is a pure glistening black.

Three qualities of resin, depending on the season of collection are recognised, they are:

1) *Rak kikwii*, a poor quality resin collected in the rains

2) *Rak deng*, a resin of good quality, collected at the end of the rainy season.

3) *Rak nam nai*, considered the best resin, collected during the hot season.

Adulterants are some times used, the commonest are water and the oil of the *vang* tree (*Dipterocarpus alatus* and *D. turbinatus*). One method of testing the resin is to thrust a stick into it; if there are not impurities the stick comes out evenly coated with a smooth glistening layer of resin, if on the other hand ,.the stick comes out only coated in patches, or without the smooth glistening appearance, it is adjudged that adulterants have been used.

Rak resin is chiefly used for making lacquer ware,but it is also employed for waterproofing bamboo-woven vessels intended to hold water. The resin sometimes produces inflamatory skin-eruptions on those who handle it. It may be mentioned here that a mixture of rak resin and teak sawdust, besides it is used to allay the irritation caused bay handling the resin, it also has some reputation among the Laos as a remedy for leprosy.

The manufacturing process

Finely woven bamboo baskets provide a fine light-weight base for lacquer ware. The bamboos used for this purpose are *Cephalostachyum pergracile* and *Bambusa tulda*. The basket is woven while the bamboo is wet, on a wooden mold cut to the shape of the utensil required. The ribs of the plait are made of very thin bamboo strips 1/4 to 1/2 inch wide while the actual plait is done with fine bamboo strands, 1/16 inch or less in diameter. When the plaiting is finished a rim, about a 1/2 inch wide, of *rak* resin is painted round the edge of the plait, this keeps it from unravelling in the subsequent processes. After the rim of *rak* is dry the article is smeared, inside and outside, with a thick emulsion formed by the mixture of *rak* with water, the exces of the emulsion being taken off with a broad, short-bristled brush. the article is then laid aside to dry for two or three days. The main object of this treatment is to keep the plaiting firmly in place during the next process, the emulsion being less likely to crack and splinter under the knife than pure *rak* would be. When dry the article is shaved smooth with a sharp knife, any irregularities in the plating being removed by this process. If the article is round the shaving is done on a lathe. A mixture of *rak*, ash of paddy husk and very fine earth, well mixed and made into a thick paste, is now spread over the article with broad brush. This paste fills up all interstices in the plaiting. The earth used must be very fine and quite free from grit or sand, otherwise it is impossible to get a good surface on the finished article.

After this application another drying is necessary and then the surface is smoothed down on a lathe if posible, with a fine grained stone, the surface rubbed being kept constantly wet. the article now receives three coats of pure *rak*, being allowed to dry, in a cool shady place, between each coat. This process takes from 5 to 15 days according to the weather. In very hot weather, drying is difficult; it is usual than to dry the articles in underground pits ; this is not necessary in the rains or cold season when drying can be done in a shed. As soon as the third coat of *rak* is dry the surface is smoothed down this time with the rough leaves of a tree (*Ficus cunia*).

Before this last polishing the article, if a round one ia tested on a small lathe to see if it is truly round ; if not it has to have further applications of the ash paste and revarnishings till it is so. This seldon has to be done as considering the rough methods used, the round boxes are wonderfully aqurate both in their roundness and in the fitting of their lids. The article is now ready for the engraver who cuts the pattern with a fine steel style, going through the outer coats of *rak* to the ash mixture beneath. the pattern followed is usually a conventional one of small flower and leaves or animals.

When the pattern is to be red, the whole suface, after engraving is painted over with a mixture of red lead, rak and *mak mu* oil, an oil expressed from the seeds of the *mak mu* tree *(parinarium albidum)*. This is allowed to dry an then the surface is rubbed down with *nawt* leaves which take off all the red except that in the engraved lines , the final treatment is a coat of varnish made by mixing pork fat and *rak*.

When a pattern of gilt lines is desired a slightly different procedure is followed in the latter stages. After engraving a coat of *rak* is painted over the article and while this coat is still wet gold leaf is laid on and spread smoothly over the surface being pressed well down so as to enter the engraved lines and the gold leaf except that on the lines

A bolder desiggn in gilt and black, often representing conventional lotus buds is obtained by still another method. The article goes on to the third coat of rak as already described, but, instead then of engraving a pattern the design is maked out with a yellow pigment in watery solution. The pigment is painted over those portions which are to be black in the finished product . When the pigment is dry gold leaf is spread evenly over the whole surface and a coat of rak given. After allowing this coat to dry the article is washed and gently rubbed till all the gold leaf over the pigment , together with the pigment itself comes away, that over the unpigmented portion remains.

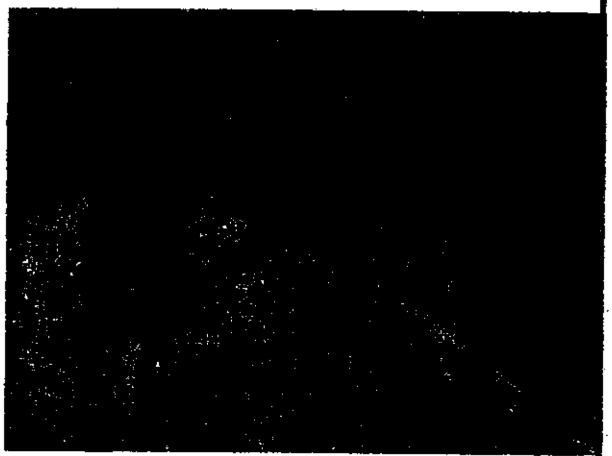
The above methods are followed in obtaining the three chief types of Chienmai lacquer.

Fig.8.3 MANUFACTURE OF STRIPS AND ROUND STICKS

A. *Removing the surface of the culm by hand*

B. *Removing the surface of the nodes with a machine*

C. *Bamboo splitting machine*



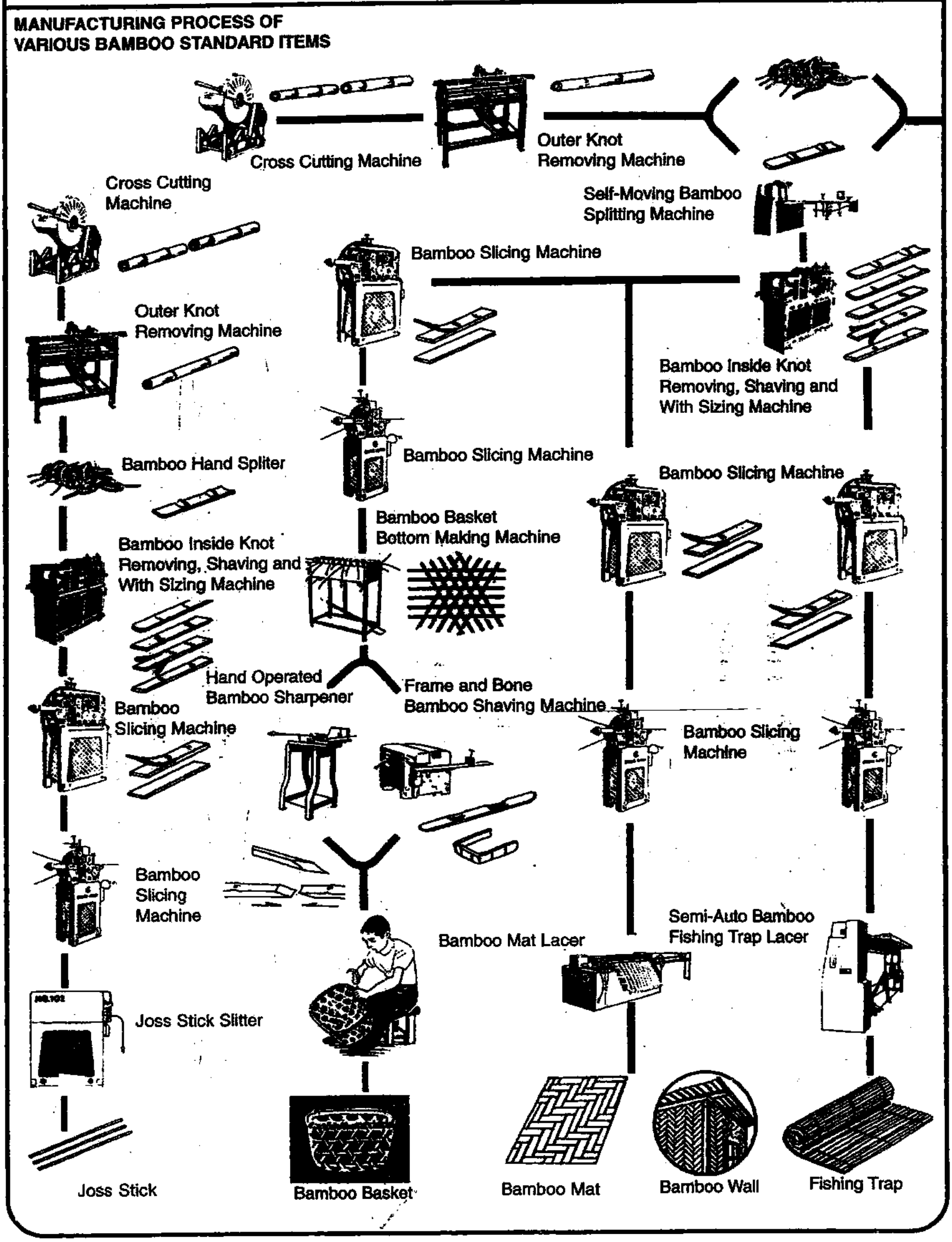
D. *Removing the skin and checking the width of the strips.*

E. *Checking the strip's thickness*

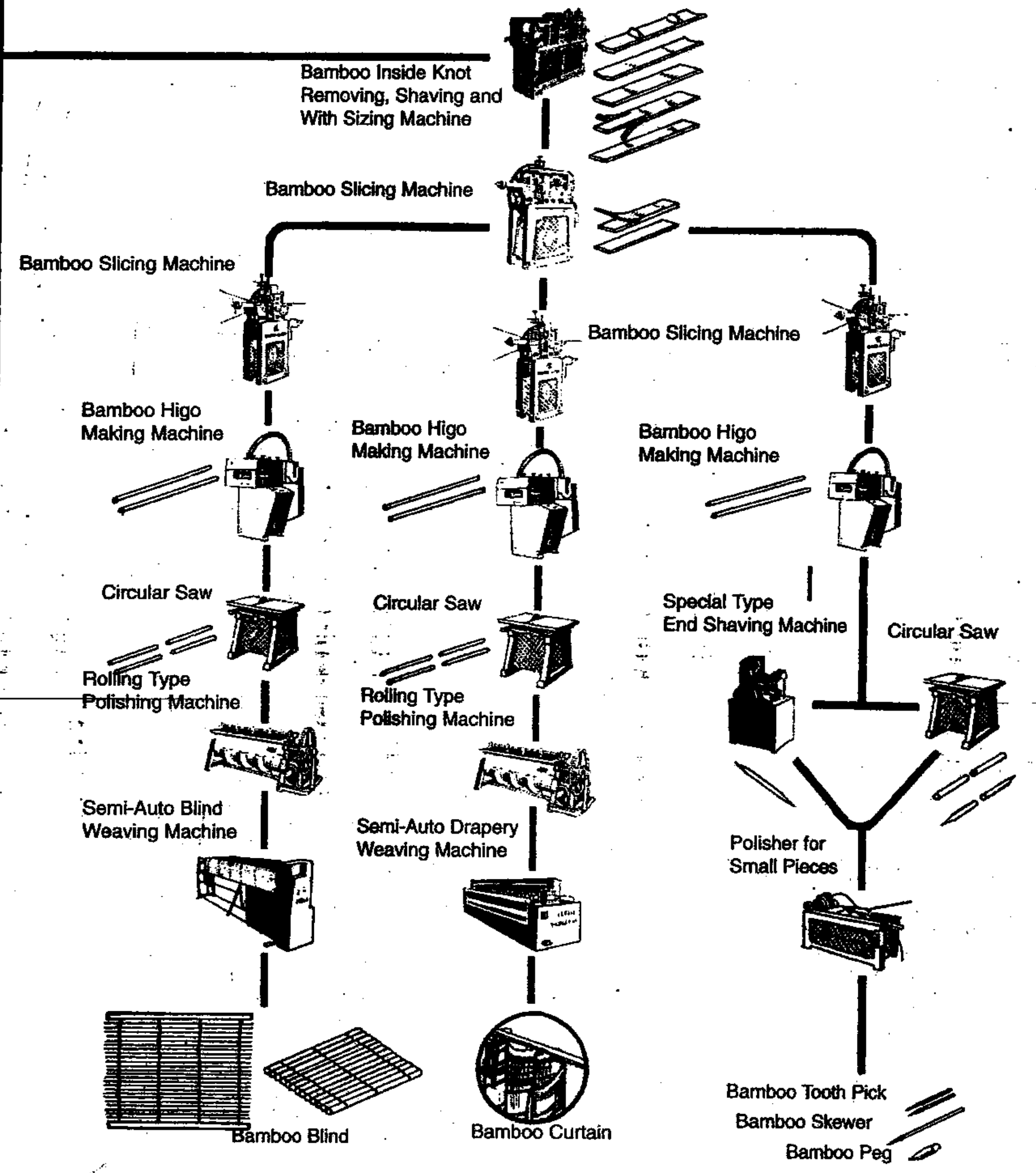
F. *Manufacture of round sticks using a metal shield with different diameter holes.*

Fig 8.4

BAMBOO PROCESSING MACHINERY (1)



BAMBOO PROCESSING MACHINERY (2)



Source: Takahashi, Japan

MANUFACTURE OF BAMBOO WEAVING AND BASKETS

BAMBOO WEAVING

The making of bamboo wares in China and Japan can be traced back to 5 or 6 thousands years ago. Bamboo wares include three main groups: bamboo weaving, bamboo carving and bamboo articles of every day use. Most of these articles could be made using machinery or by hand.

Bamboo woven products are made from bamboo threads and strips. There are more than 150 methods of producing bamboo weaving and some new methods frequently come out. The main methods are: cross-stitch work, threading, fluffing, inserting ribs, bleaching. The steps of the weaving process are: material selection-raw material treatment-weaving-assembly-decoration-package-storage. The main points of the weaving techniques are as follows:

1.-Material selection: Bamboo material is tough, flexible, straight, pressure resistant, tension resistant and corrosion-resistant. However, culms of different bambo species, of different age, or under different site conditions have different mechanical properties.

According to Ho & Xu, the main material for Chinese industrial bamboo weave are *Phyllostachys pubescens, Ph. heteroclada, Ph. meyeri* and *Bambusa textilis*. So proper material for certain bamboo woven products should be selected in accordance with the design requirement. In recent years the main bamboo species used for bamboo weaving are:

1)-*Sinocalamus affinis* .-The tissue is dense with a fine smooth surface which fragments easily and is bright yellow. It is suitable for producing thin strips and making high quality goods.

2)-*Phyllostachys heterocycla* var. *pubescens*. The tissue is tough and tensile with straight grain, it is elastic, with insignificant and fragmented easily, culms with flat nodes and thin wall used for weaving.

3)-*Phyllostachys congesta*. The culm wall is thin, tough and tensil, soft and wareproof, with fine veins and flat nodes, suitable for making middle grade goods

4)-*Bambusa distegie*-Internodes long, flat nodes, tough tissue, insignificant shrinkage, suitable for producting fine strips and making fine goods.

5)-*Phyllostachys henonis* Mitf. Culm straight, tissue not very tough, fragile and breaks easily, mostly used for making middle and low grade goods or articles for every day use.

6.-*Phyllostachys praecox*.- Internodes long, culm wall slightly thin, grains straight, fragmented easily, suitable for producig extrafine shreads and making woven handicraft.

Proper age for cutting is 2-4 years for *Phyllostachys pubescens*, and 1 -2 years for the others. Culms should be straight, free of mechanical damage and disease, and should bee cut in claudy days, at the end of the spring season. Strong sun shine should be avoided. The culm's skin should not be damaged while cutting and transporting.

Treatment: The treatment operations are as follows:

1.- Remove waxy epidermis and nodal flange from culm surface timely, preferable in the same day of cutting, to guaranty the brightness and smoothness of culms. At first remove the nodal flange and then fix culms on a frame, remove waxy epidermis with a sharp knife quickly, slighly and evenly, without any damage to the surface appearance.

2.-Disect bamboo culms. This operation can be carried out manually or on a machine.The culms should be vertically splited into 2 equal parts. Close attention should be paid mainly to the smooth pass of nodes through the edge of knife.

3- **Drying:** Dissected bamboo parts should be put on frames on open air to be dried under the sun with skin side upward. The air- drying process continues until the bamboo skin turns slight yellow or yellowish white. The bamboo parts should not be exposed to the rain for retaining the natural beauty of bamboo surface.

4.- How to produce bamboo strips and threads: Split bamboo parts vertically along the radius of the cross section into bamboo bars. Split bamboo bars vetically along the chord of cross section into bamboo strips. Cut bamboo strips into bamboo threads according to the requirements of the final products. All the bamboo strips should be of same width and same thickness.

5.- Weaving.-Bamboo weaven goods are made of bamboo strips or threads by interlacing them in different directions, while bamboo mats, curtains are made of bamboo strips.

6.- **Bamboo thread weaving method** is mostly used for making such articles as baskets, boxes, bottles, jars, dolls. All these goods are being woven from their bottom part, after the bottom is finished, the weaving goes in spirally.

Weaving for bamboo objects

There five important fundamental weaving methods for bamboo objects that we will see in the following pages are:

1) Square weaving (*Yotsume-Ami*); -2) Hexagon weaving (*Mutsume-Ami*);- 3) Ajiro weaving it is used for hand boxes since old times.- 4) Trunk part weaving (*Do-Ami*), is adapted for weaving the trunk part of bamboo basket, and it is suitable named according to the weaving patterns.

5) Bottom weaving (*Shihizoko-Ami*) includes pentagonal or octagonal shapes and not normal hexagonal shape.

In these five weaving methods, the weaving patterns will vary with the size and width of the bamboo splits used for weaving and in application of dyed bamboo. For example, in some weaving methods one bamboo weaving split is composed of two slender, natural colored splits and one dyed split. These weaving patterns are used not only for many kinds of baskets but also for wall decorations.

Fig.8.5 **SQUARE WEAVING (Yotsume-Ami)**

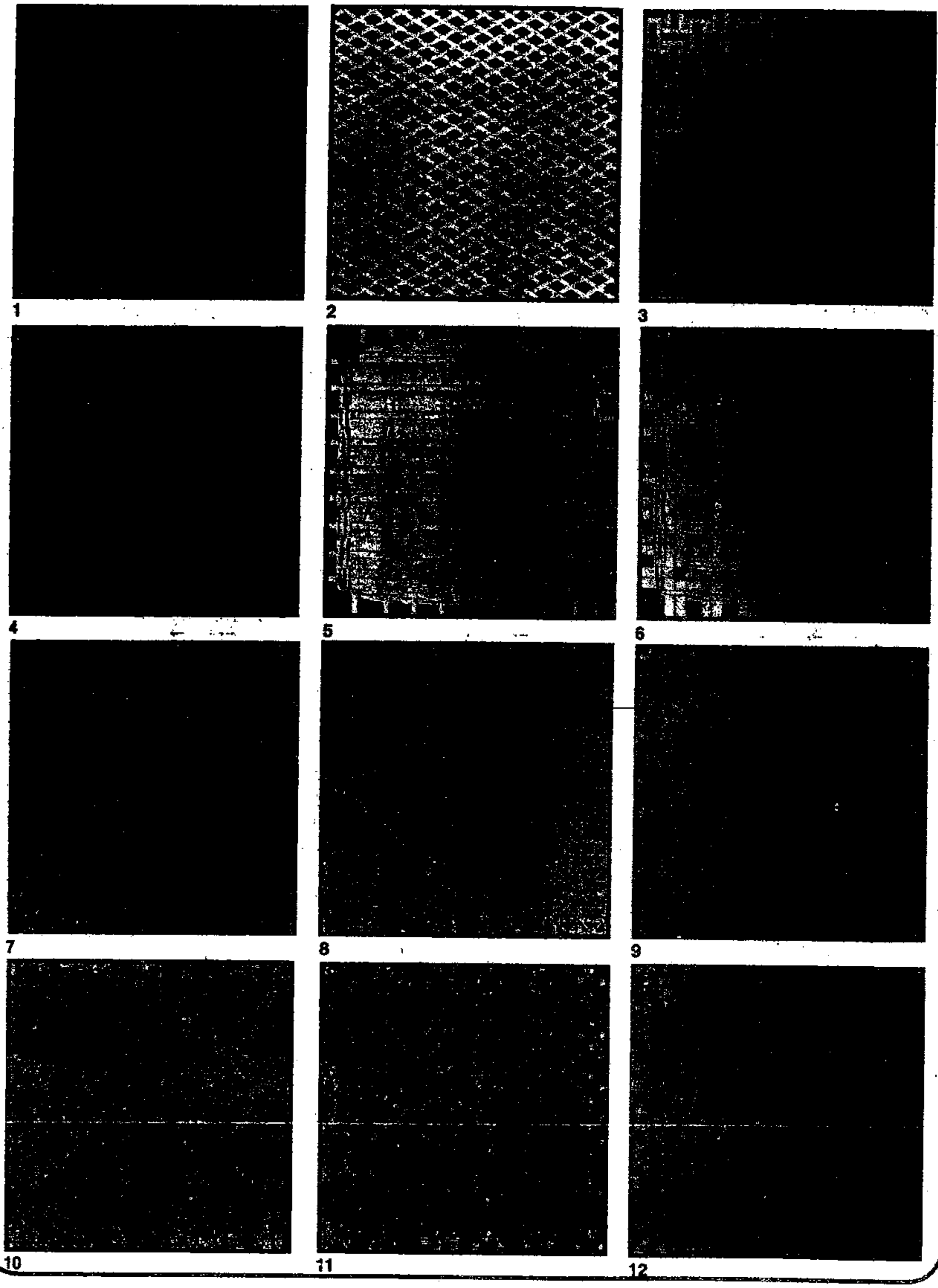


Fig.8.6 **HEXAGON WEAVING (Mutsume-Ami) (1)**

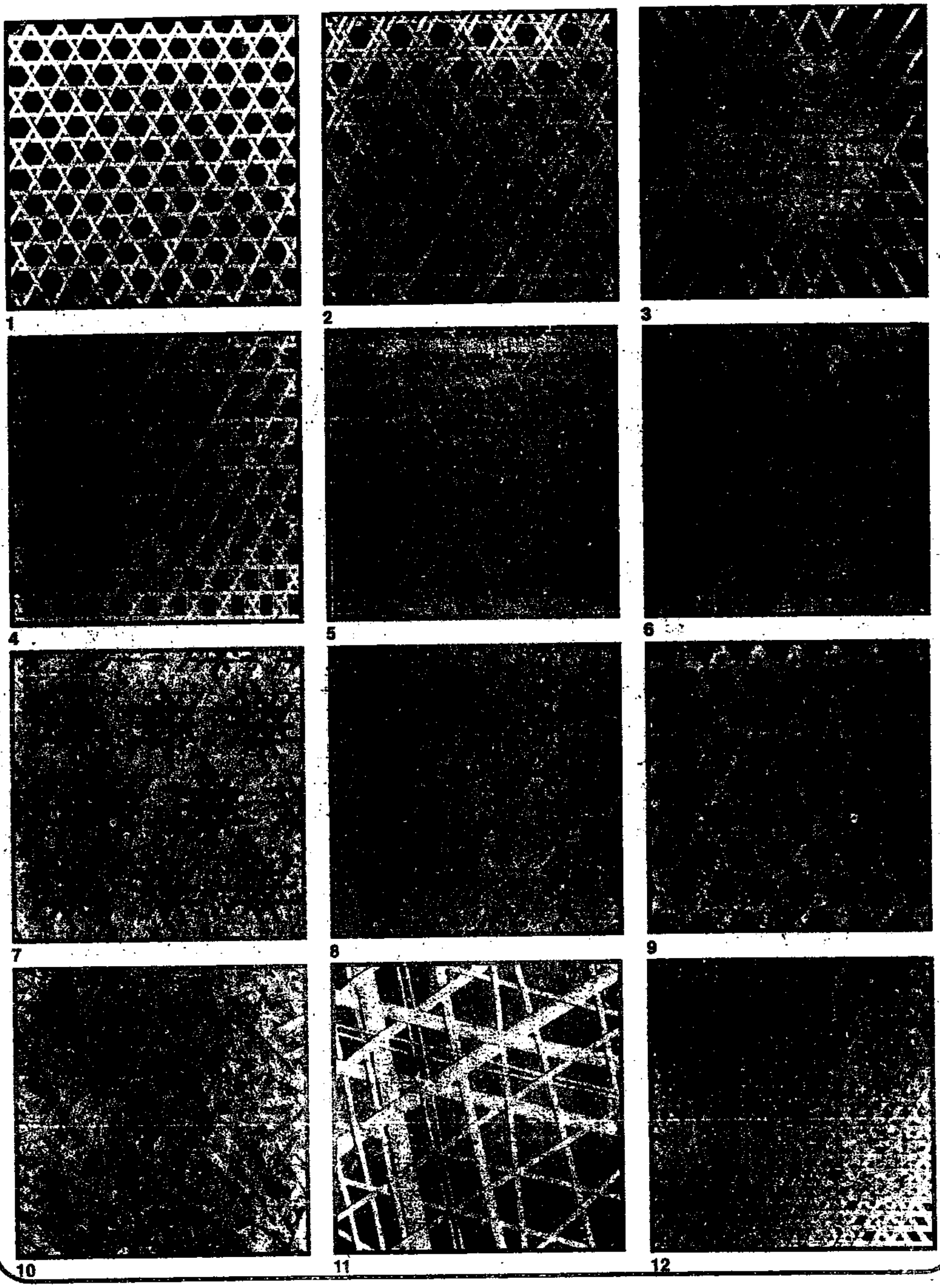


Fig.8.7 **HEXAGON WEAVING (Mutsume-Ami) (2)**

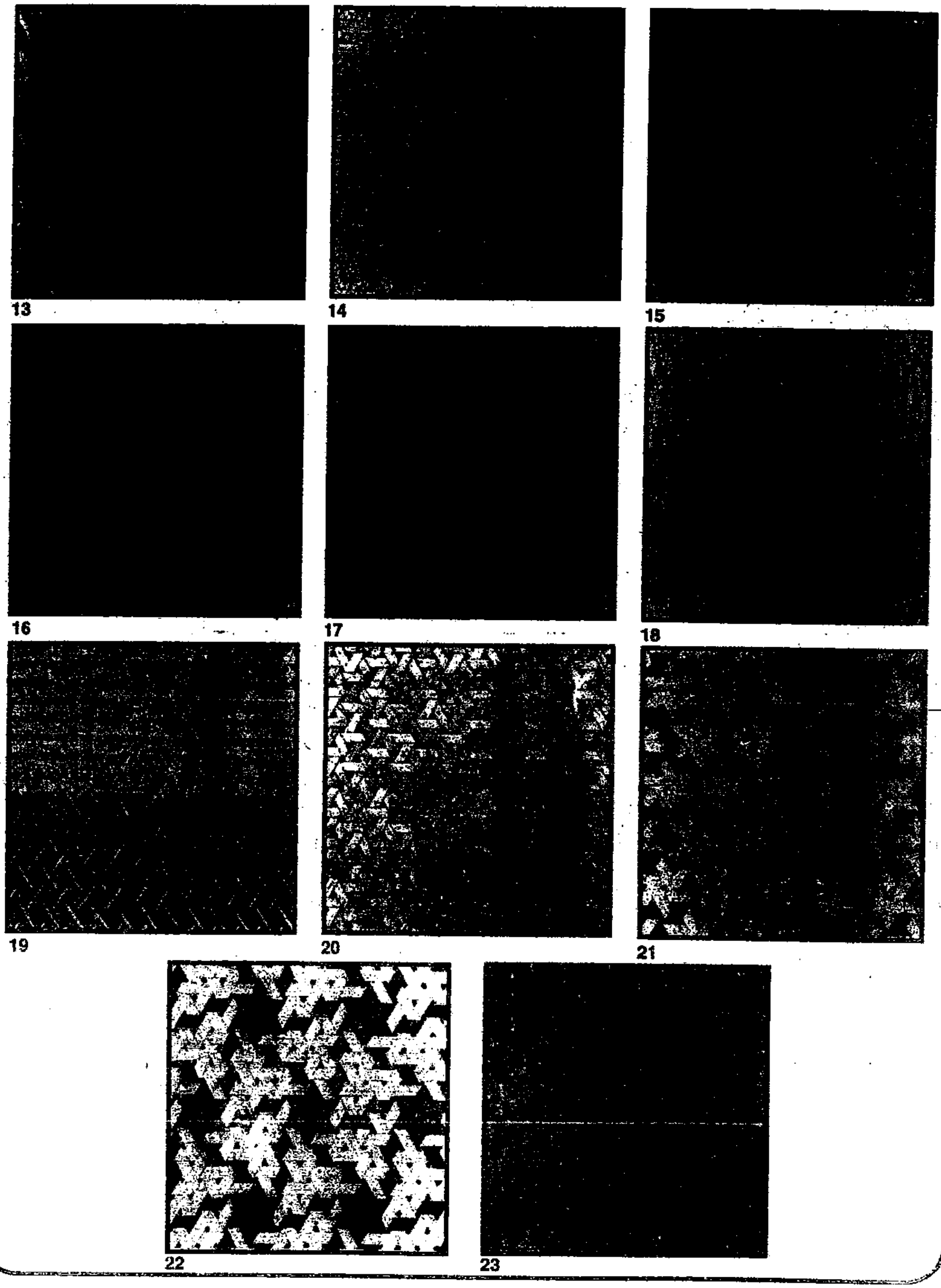


Fig.8.8 **HEXAGON WEAVING (Mutsume-Ami) (3)**

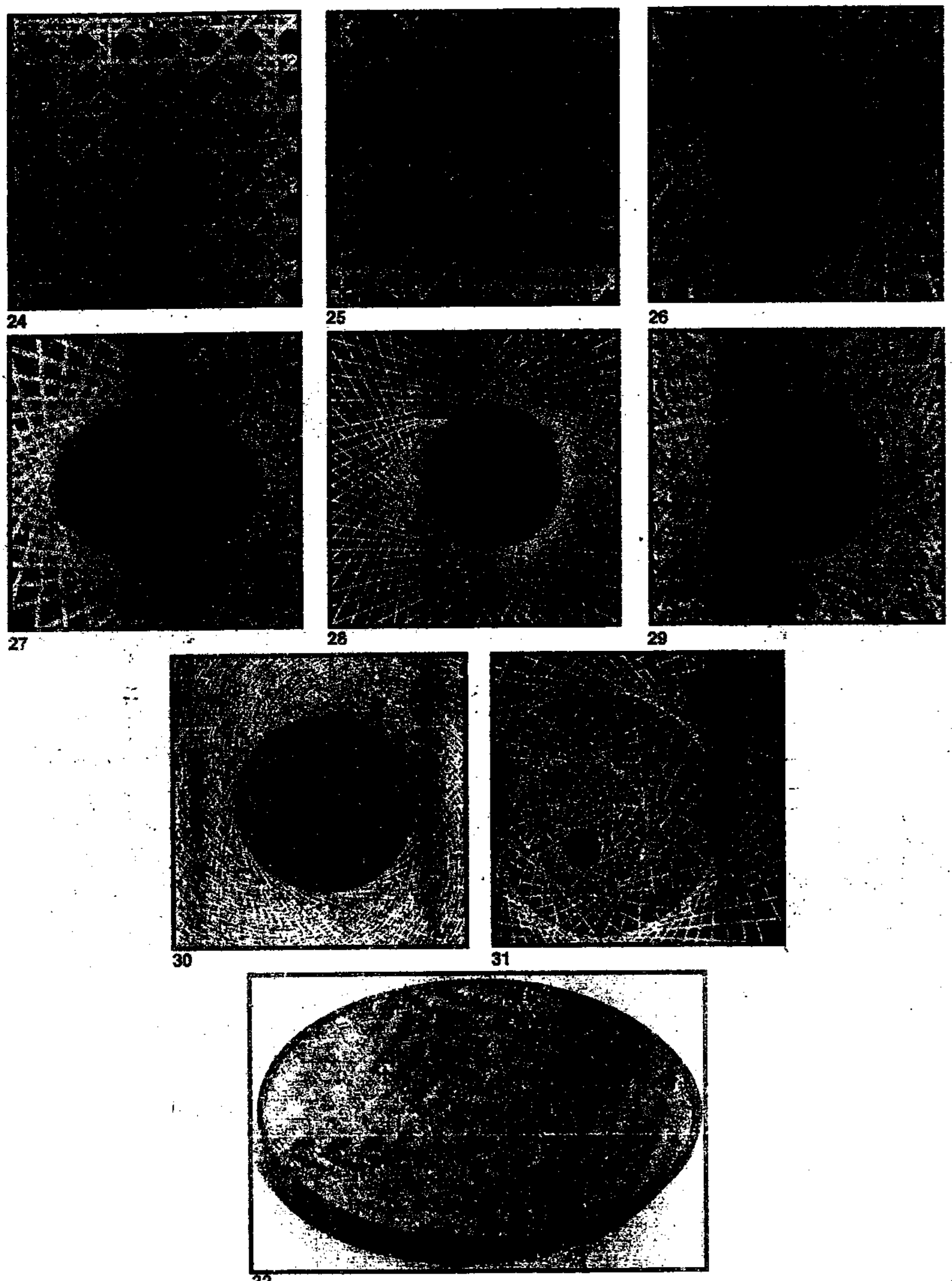


Fig.8.9 **AJIRO WEAVING (1)**

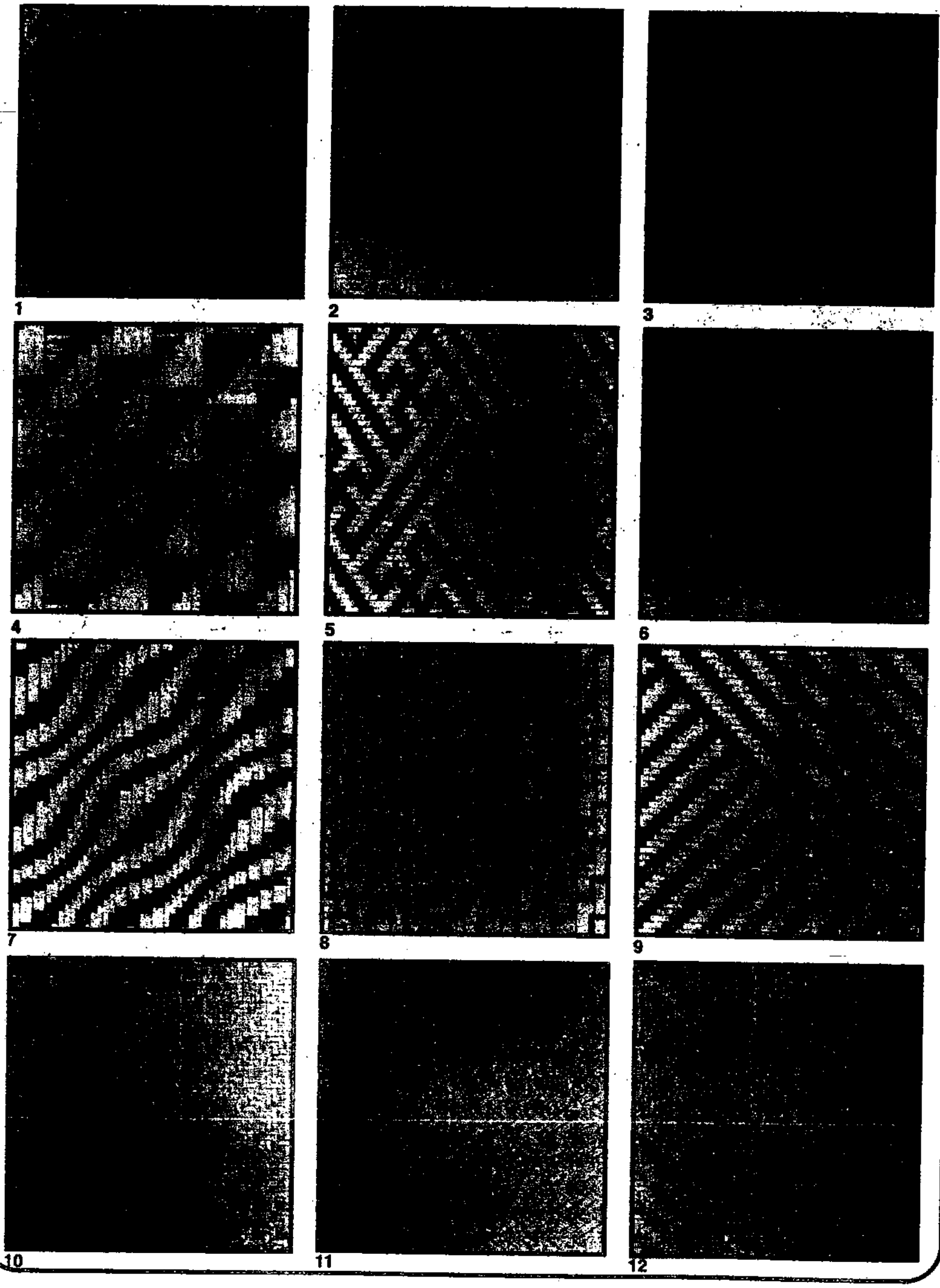


Fig.8.10 **AJIRO WEAVING (2)**

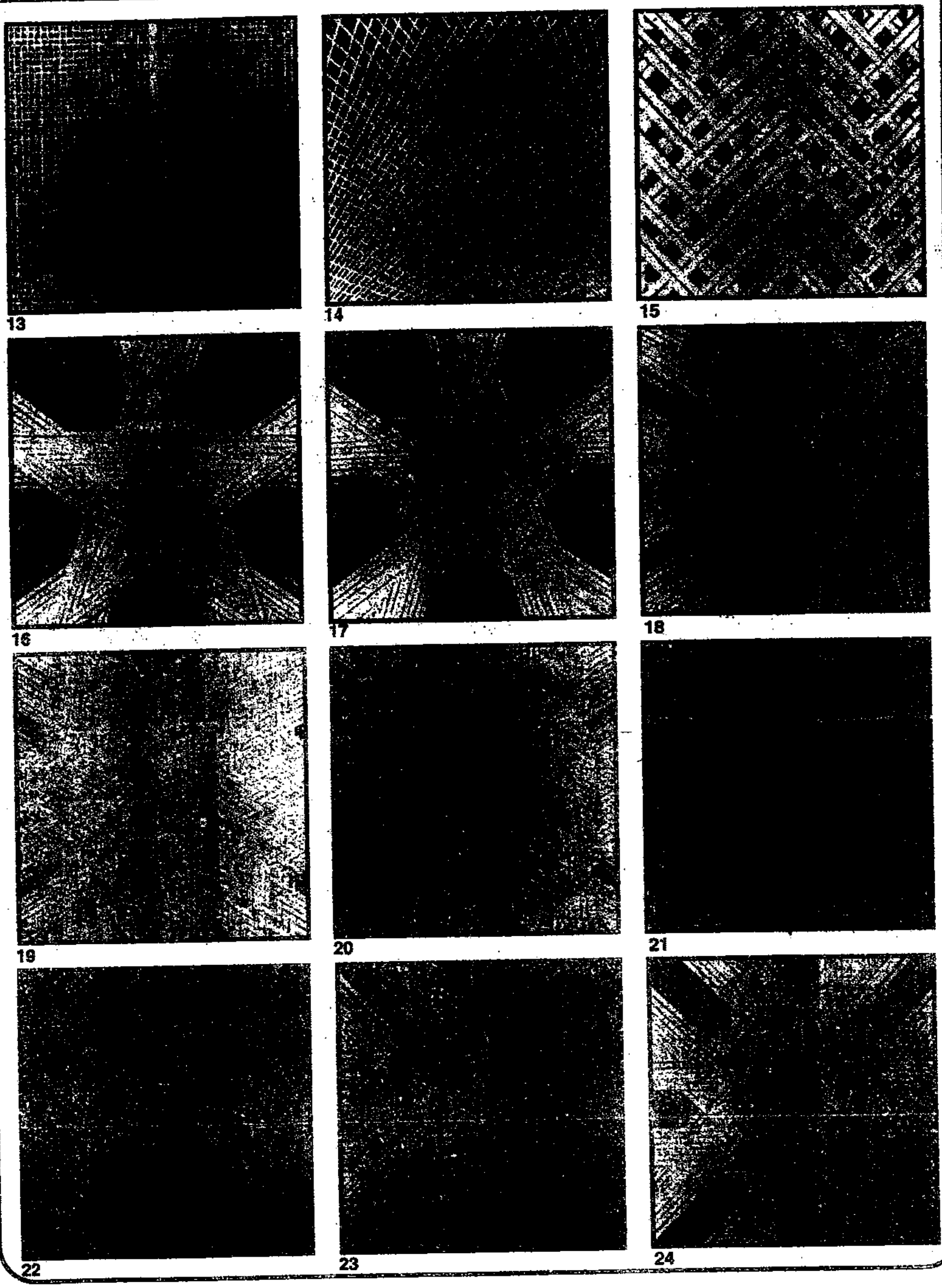


Fig.8.11 AJIRO WEAVING (3)

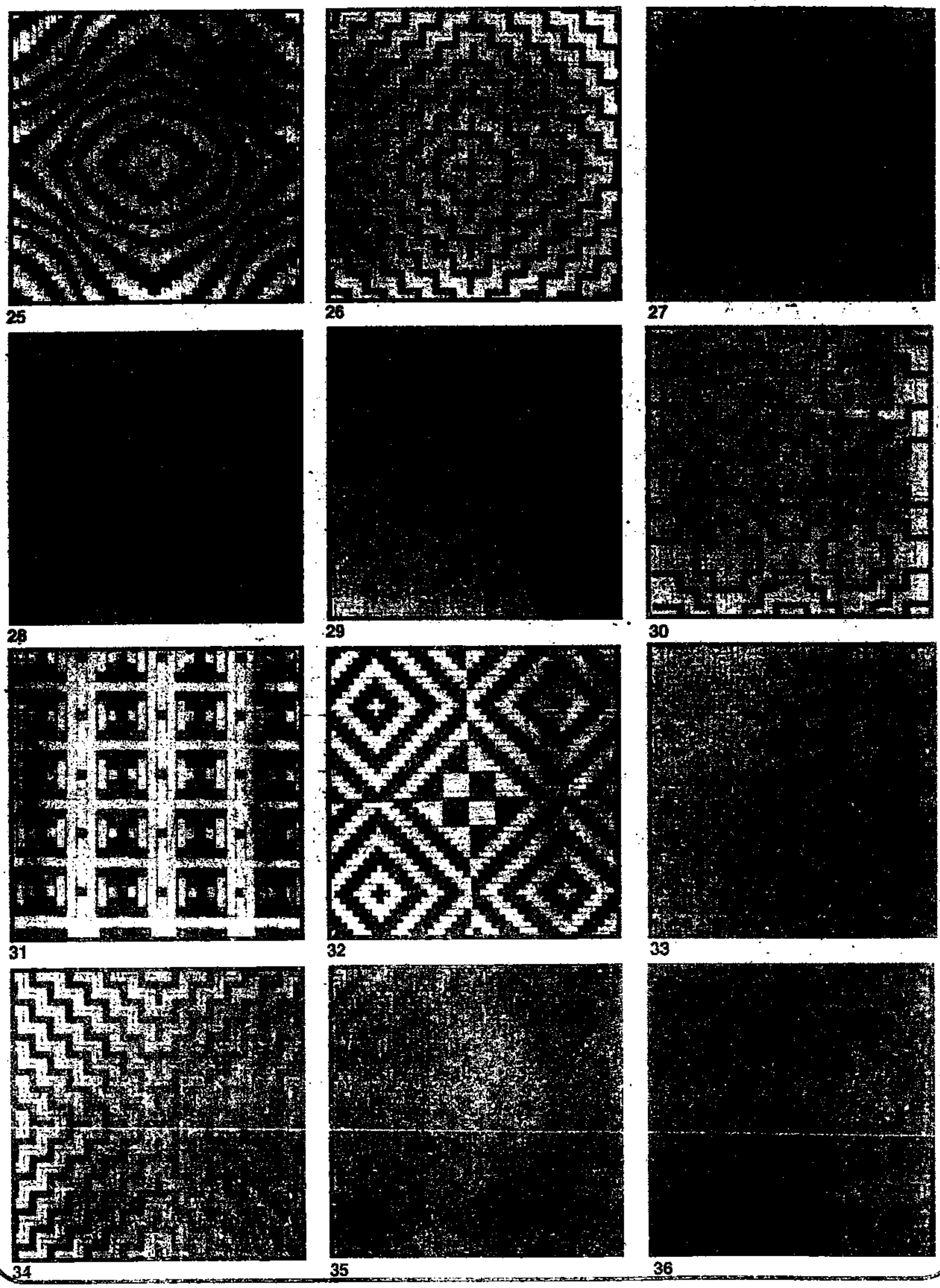


Fig.8.12 **AJIRO WEAVING (4)**

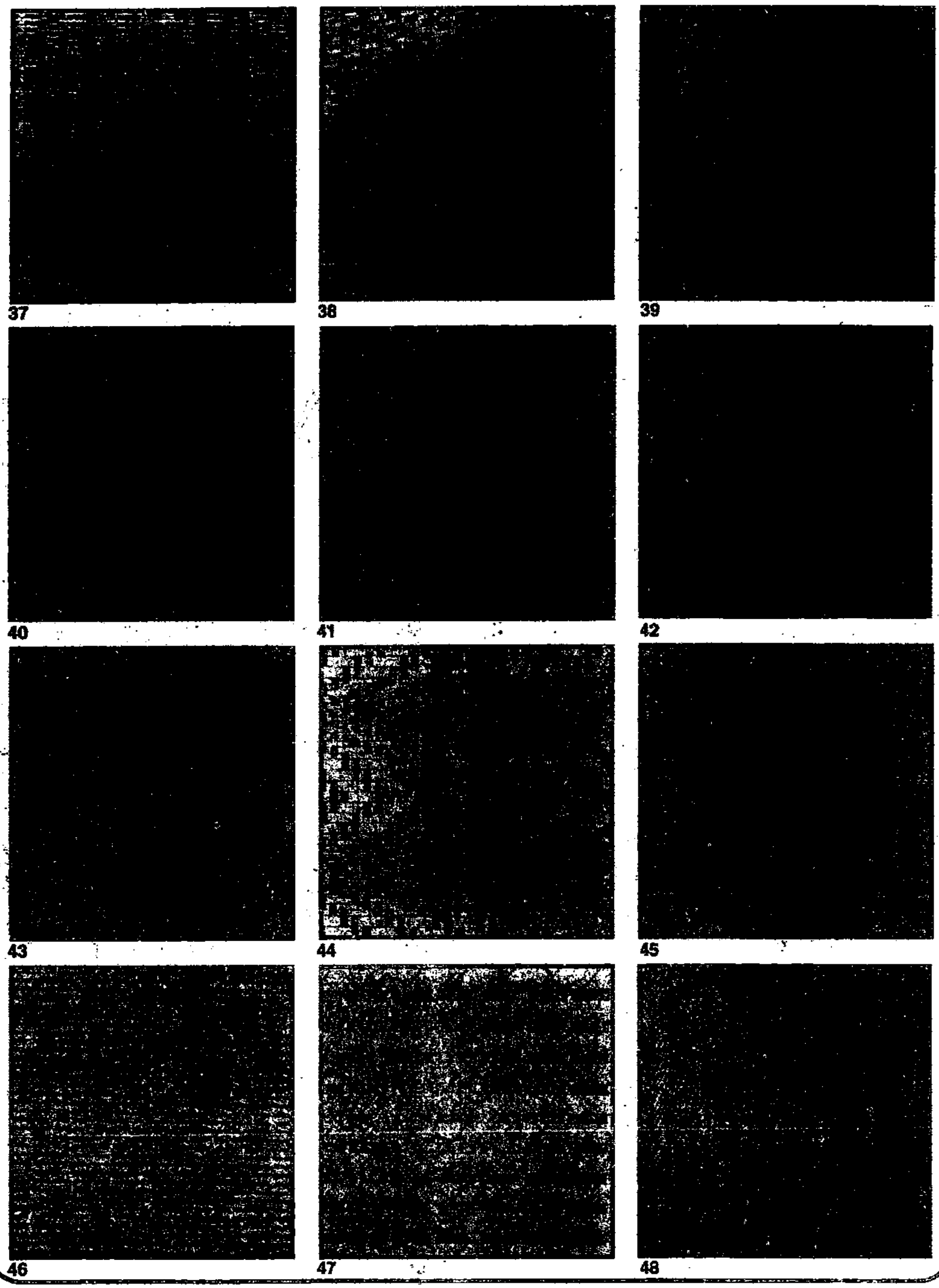


Fig.8.13 **AJIRO WEAVING (5)**

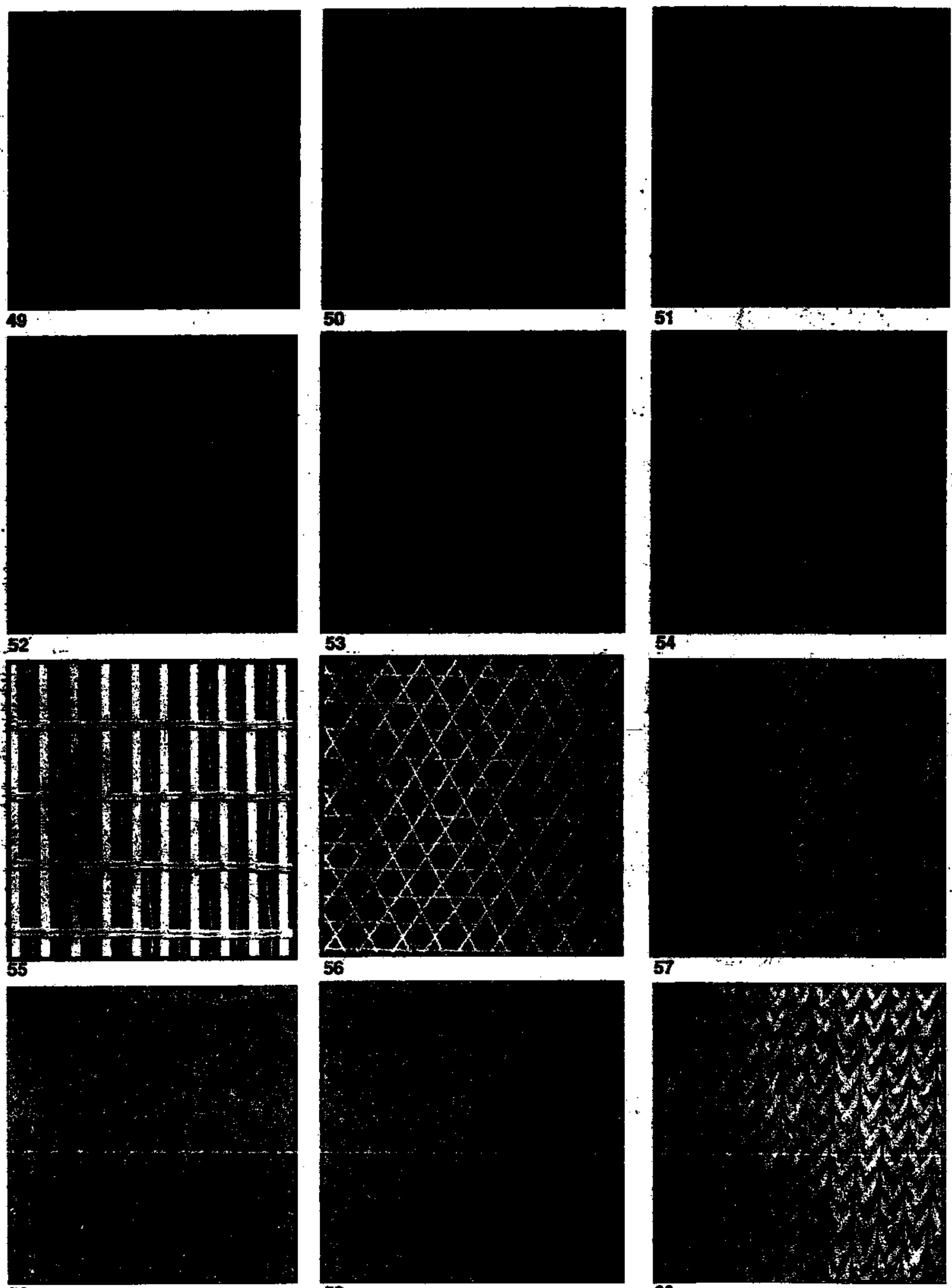


Fig.8.14 **BOTTOM WEAVING**

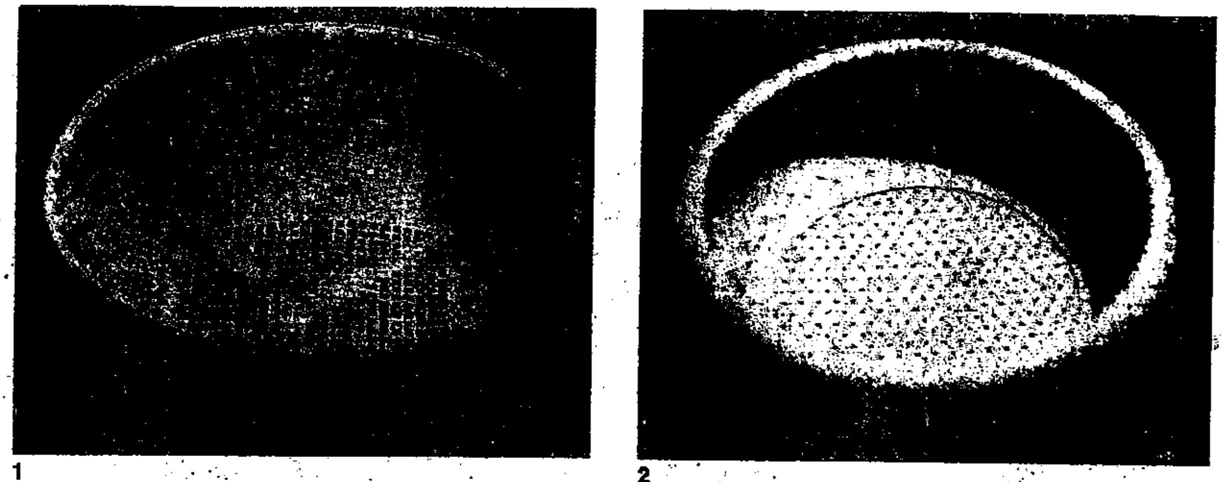


Fig.8.15 **BOTTOM WEAVING**

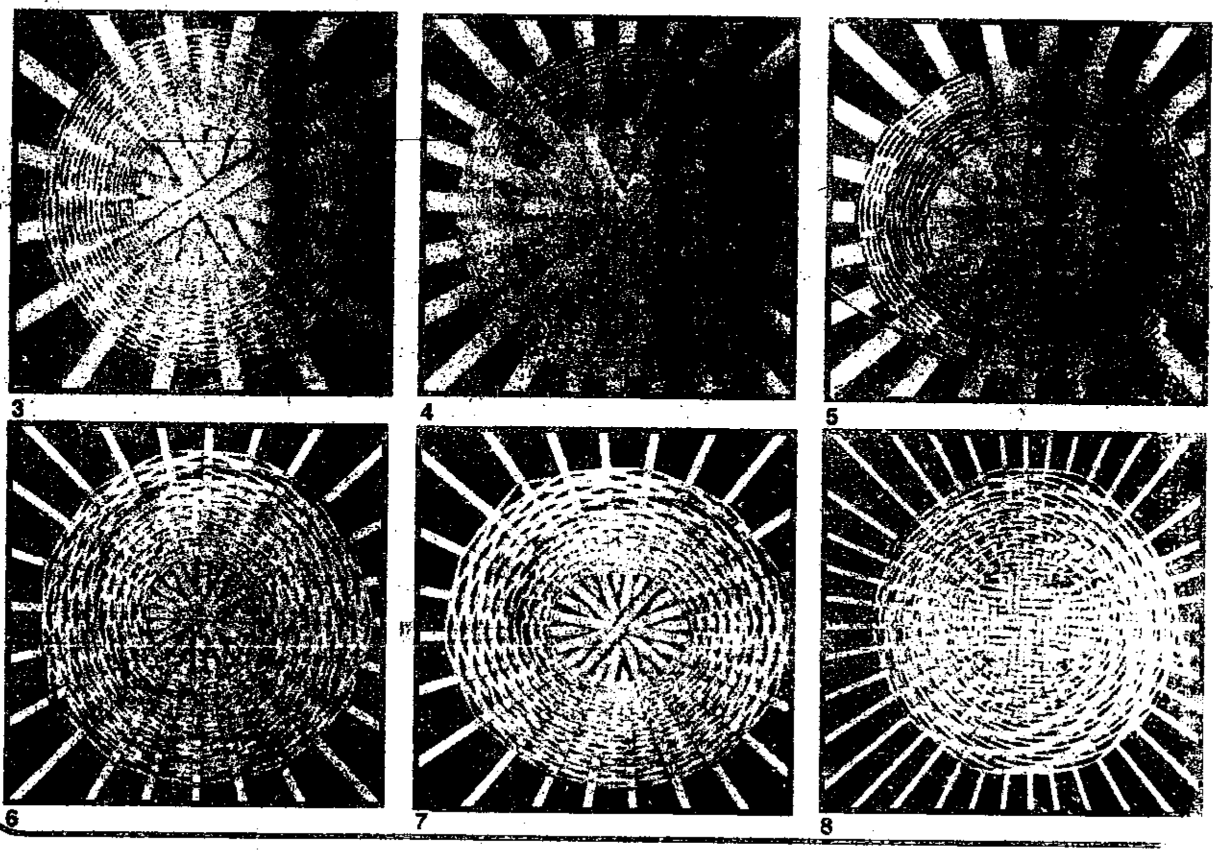


Fig.8.16

BORDER WEAVING (1)

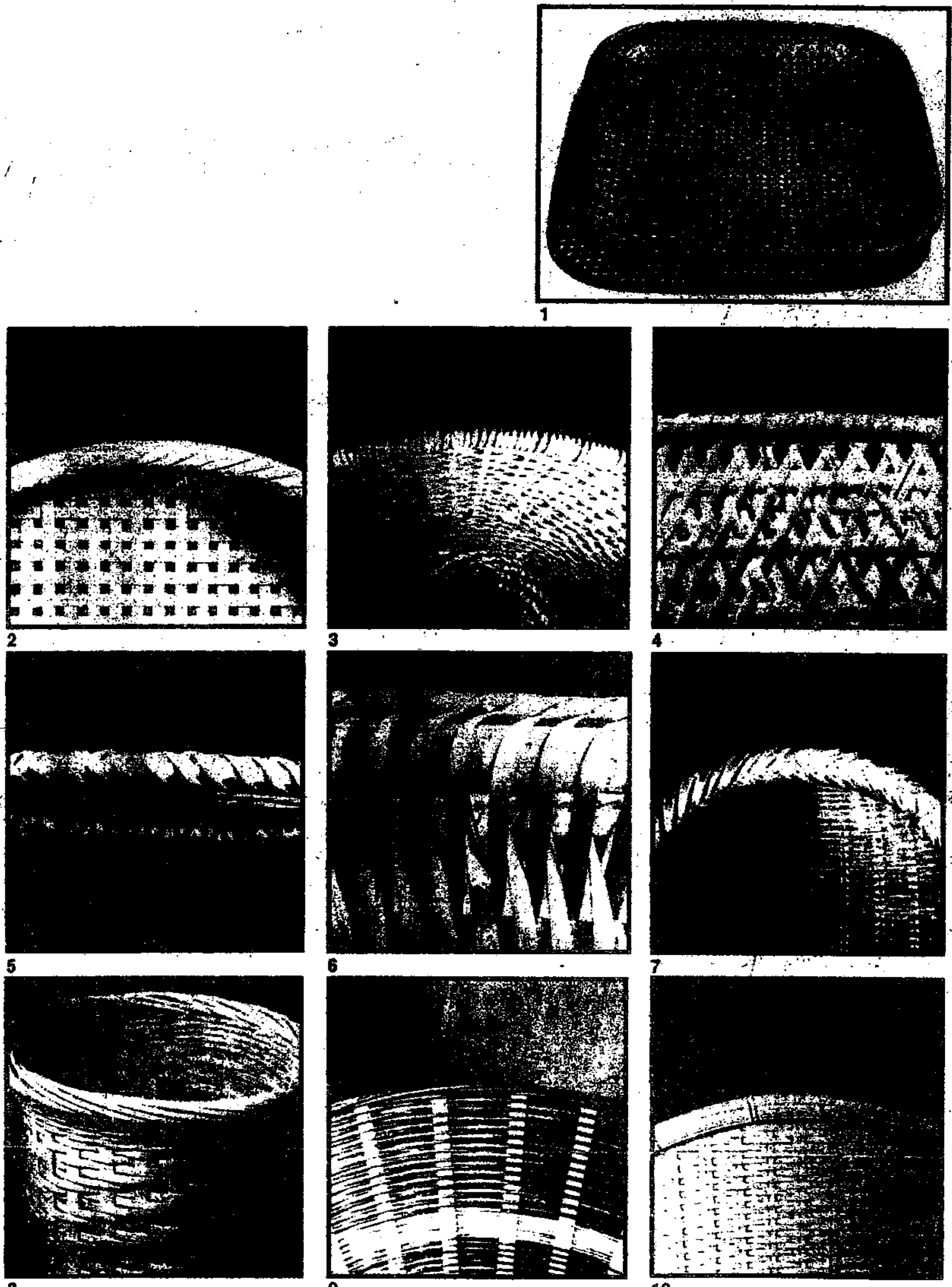


Fig.8.17 BORDER WEAVING (2)

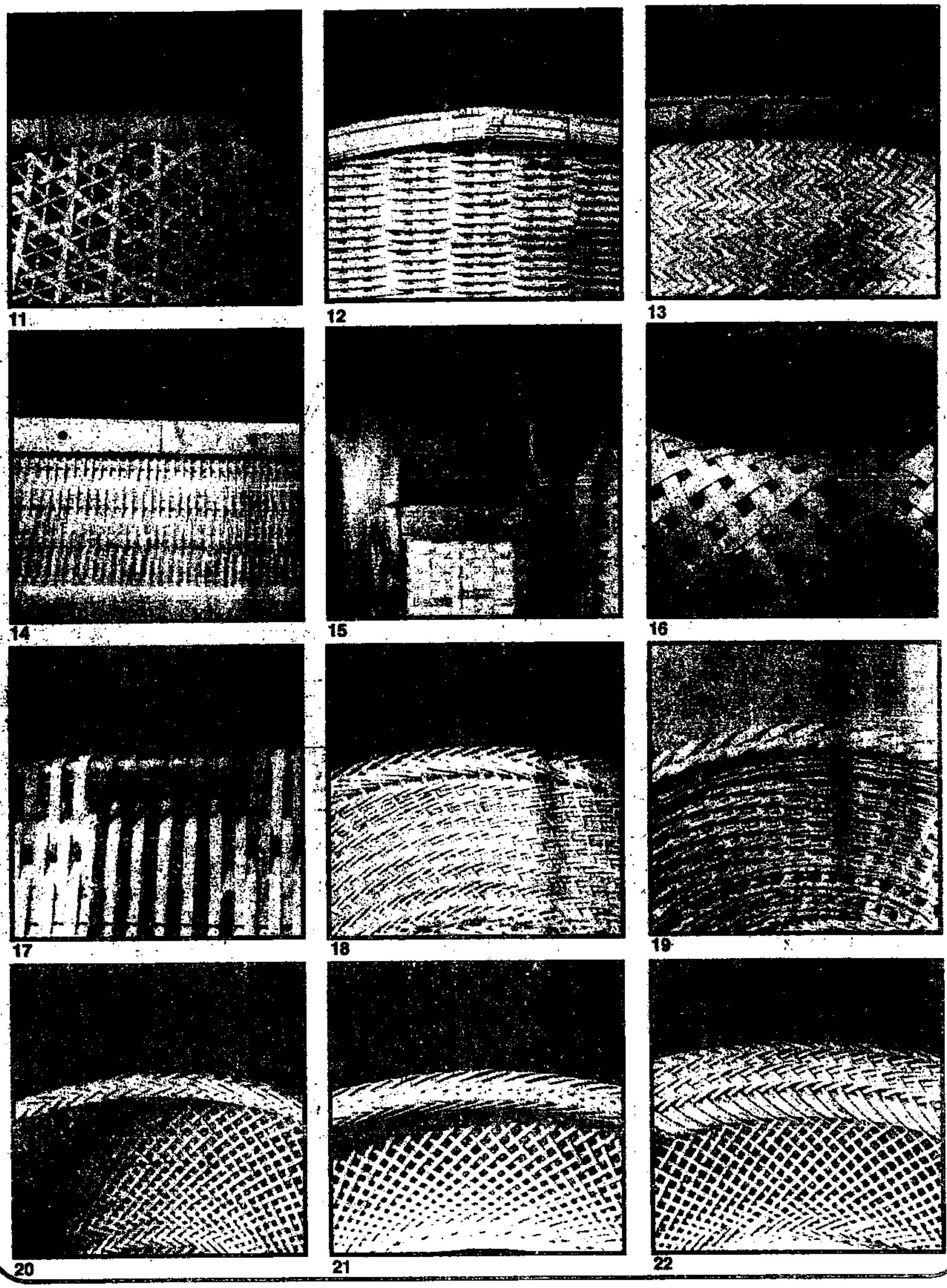


Fig.8.18 **BORDER WEAVING (3)**

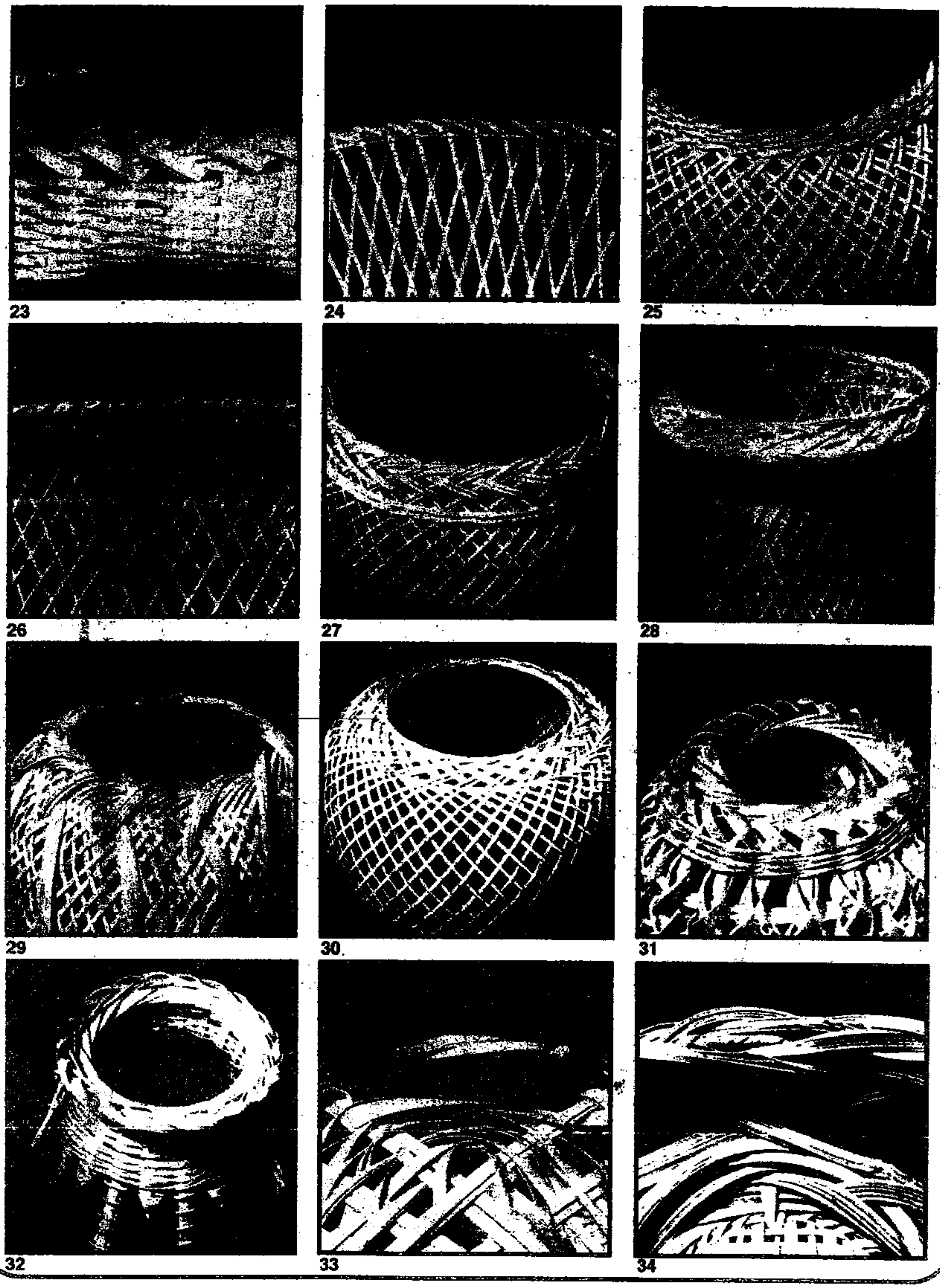


Fig.8.19

BORDER WEAVING (4)

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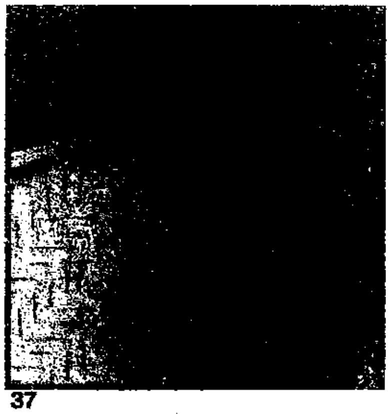

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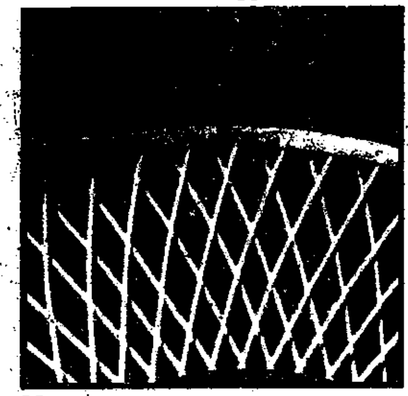

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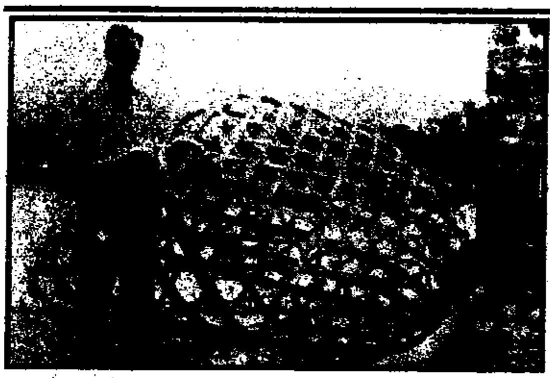
SOME OF THE MANY APPLICATIONS OF BAMBOO BASKETS



A

B

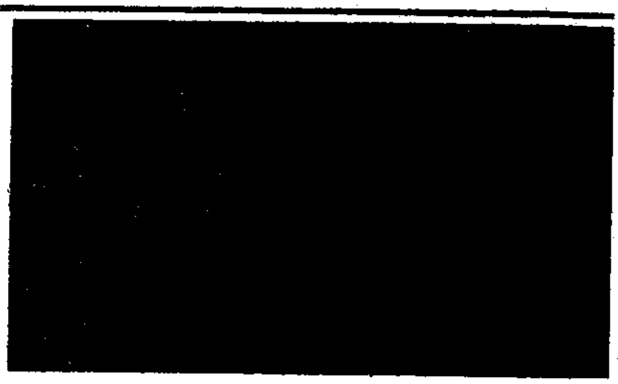


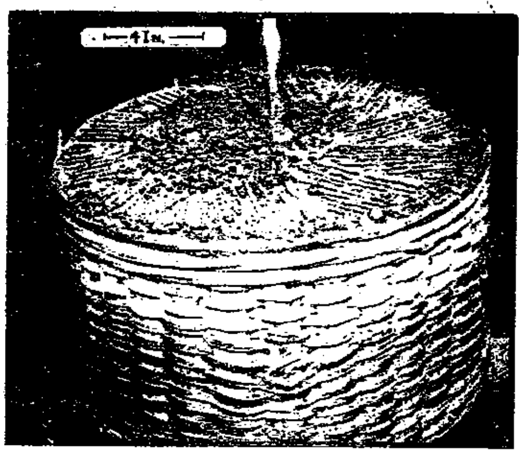
Fig. 8.20 A-B. *Bamboo and wooden bridges supported by one or several giant bamboo gabions.*

C. *Basket boats in Viet nam.*

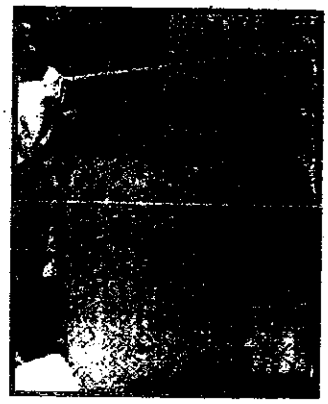
D. *Small bamboo gabions made with bamboo baskets used in river banks as protection from erosion.*

E.-*Woven houses in Etiopia, Africa.*

F. *Water tanks baskets used in the manufacture of bamboo and cement water tanks, toilets etc, are plastered internally or internally and externally with cement mortar.*



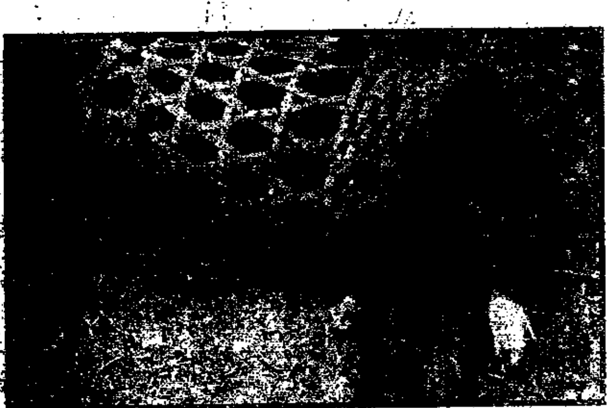
G. *Giant sawale baskets used for transportation of grain in Asia .*

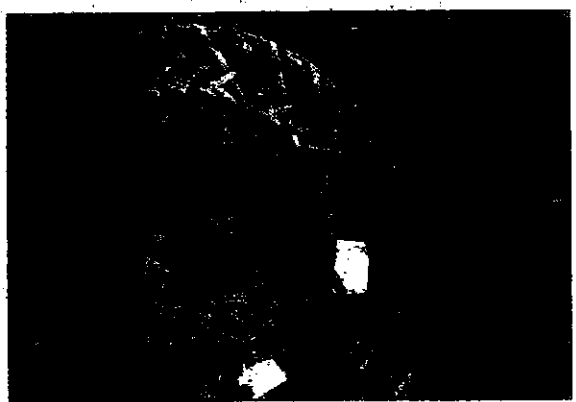


H. *Chinese rotary mills. The lung, of baked clay, used for hulling grain and husking rice.*

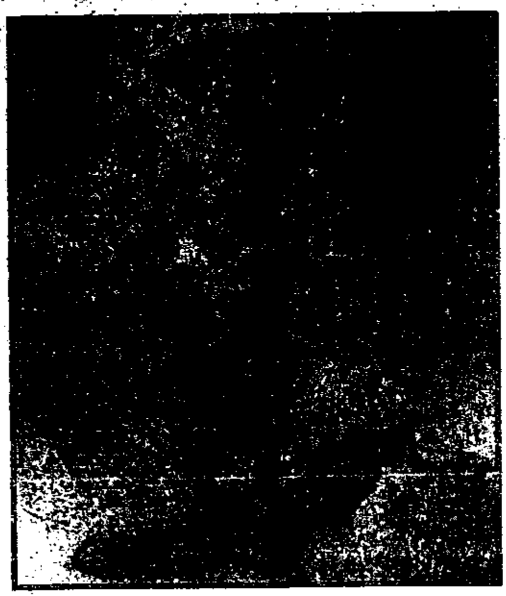
Fig. 8.20 I-J *Basket for the transportation of children. (After Ranjan et al 1986)*

K. *Conical basket known as Khoh used by the Khasi tribe for general-purpose marketing.(After Ranjan et al 1986)*





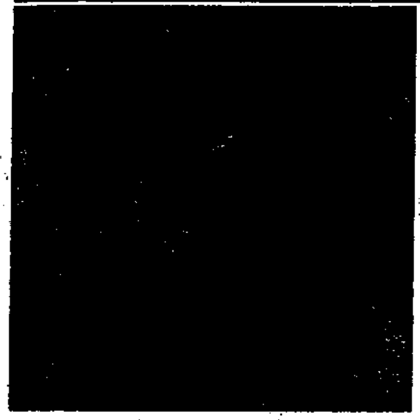
L-M.-*Baskets used in India for the transportation of one or several pigs. (After Ranjan et al 1986)*



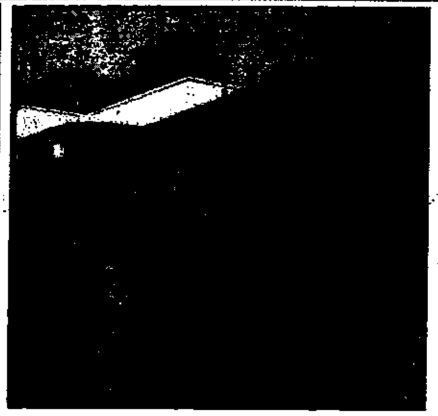
N. *Baskets for the transportation of fighting cocks.*

O. *Baskets for the transportation of owls and domestic animals (After Ranjan et al 1986).*

Fig. 8.21 **SOME APPLICATIONS OF WOVEN BOARDS**

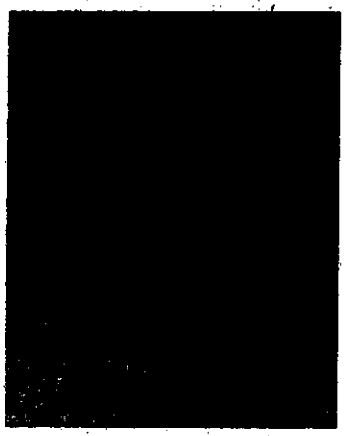


A. *Manufacture of the sawale mats.*

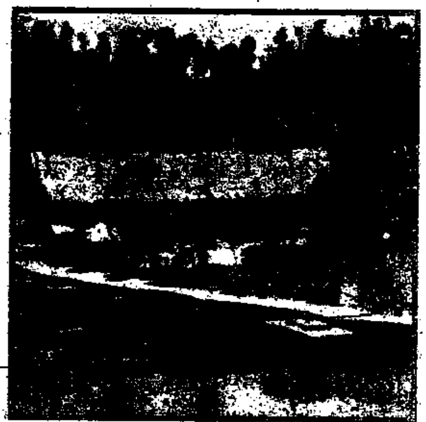


B. *Larger mats are manufacture for the construction of ceilings, walls, floors and road surfaces, etc...*

C. *The mats are used in doors, windows and walls as shown in the picture*



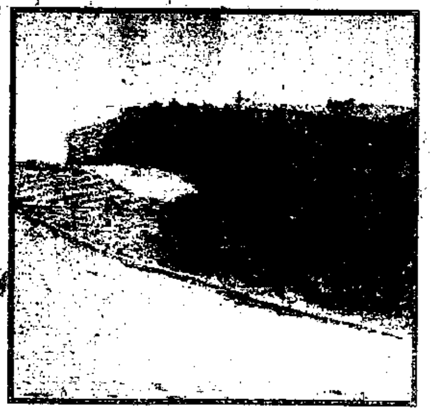
D. *Bamboo mat used as flooring.*



E.-F.-G.-H. and **I.** *Bamboo mat used as a surface on pontons and bridges*

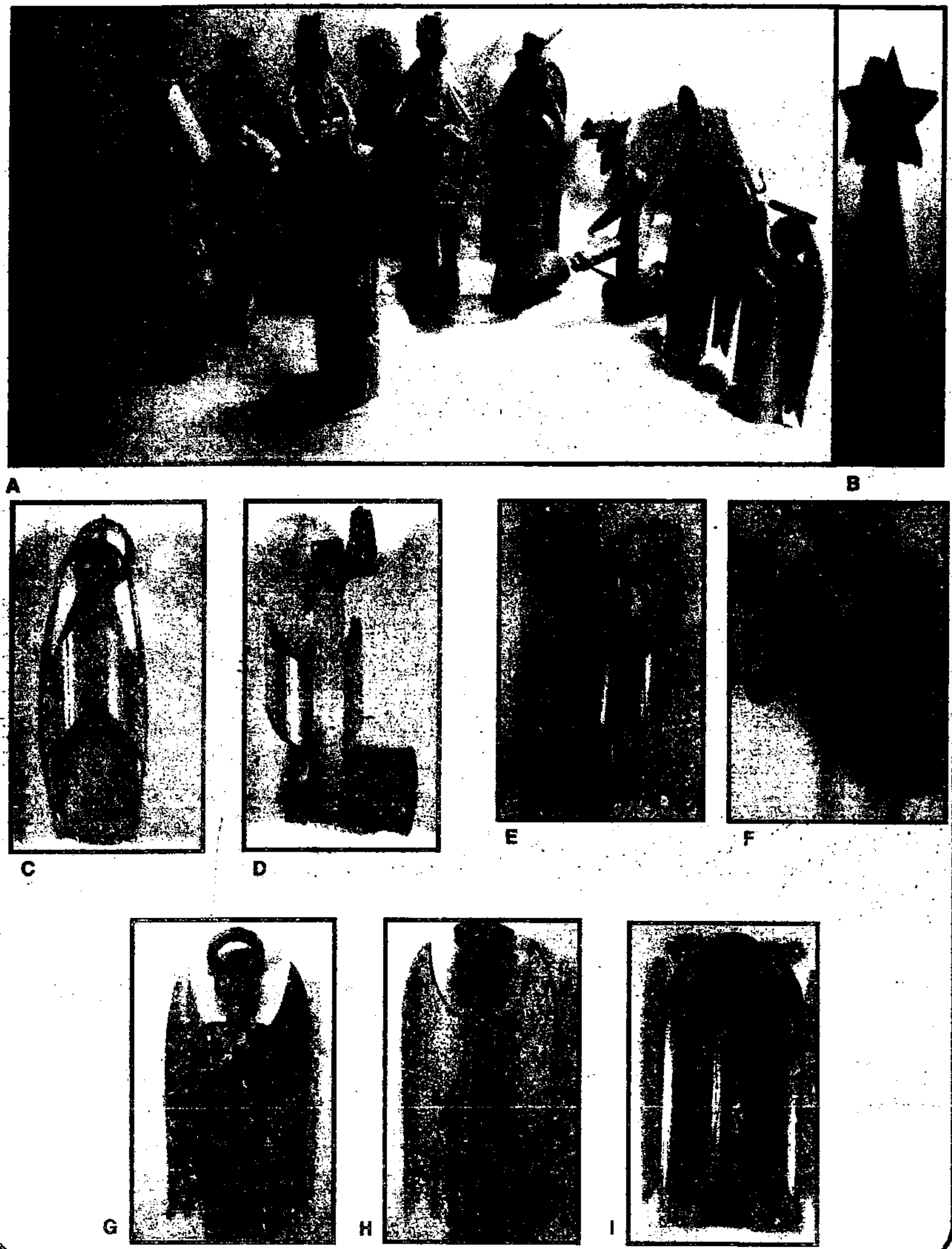
G.

H.

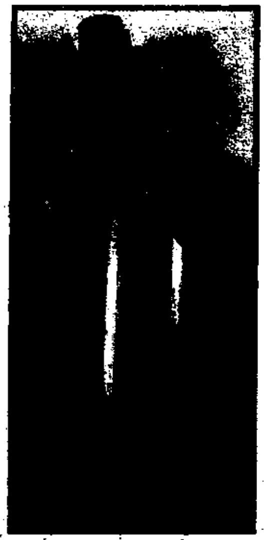


I.

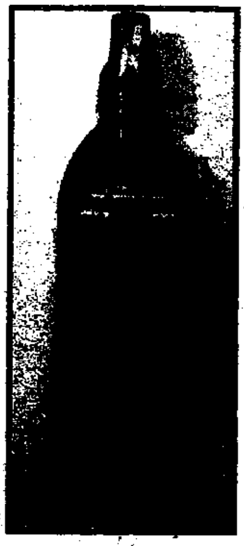
Fig. 8.22 **MANUFACTURE OF A CRECHE**



J



K



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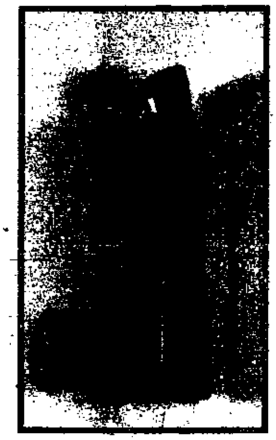

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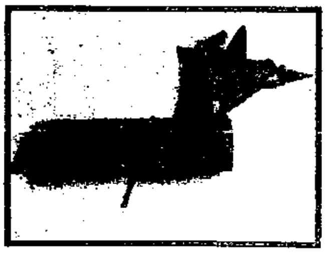


R

Fig.8.23

BAMBOO CULM - BASE CARVING

The culm-base, (Fig. C), the subterranean part of the culm of some giant species with leptomorph rhizome is used in China for carving. This part of the plant has thick wall and is comparatively fine and tough, and on it may be wrought a fairly fine and delicate work of sculpture. Actually throughout this country there are elaborate and exquisite scultures of human figures such as those shown on this page taken from the marvelous book *Chinese Bamboo Handicrafts*, edited by Zhang Qisheng and Cheng Weishan (as Chief editors) and published by China Forestry Publishing House in 1997.

Once cut the piece is put vertically in ventilative shade, avoiding direct sun shine. The green cuticle is removed from the surface, and treated with chemicals to prevent the damage from fungus and borers.

A. *An old fisherman in a bamboo cap (Ningpo, Zhejiang, Yang Gucheng)*

B. *General Zhang Fei (Xiangshan, Zhejiang, Zhang Dehe)*

C *Shows the lowest part of the culm, the culm-base, the roots (which have been removed from the front part), the rhizome neck and the rhizome itself. The roots are used as the hair and beards of human figures.*

Fig.8.24 BAMBOO INTERNODE RELIEF SCULPTURE

The bamboo internode relief is a kind of carving in which the image stands out from the surface of the internode; depending on the depth of the objects depicted, relief sculpture can be divided into low relief, as shown in Fig. A; mid relief and high relief (as shown in Fig. B). In this case, certain parts of the carved images are hollowed out, which makes the carving more vivid.

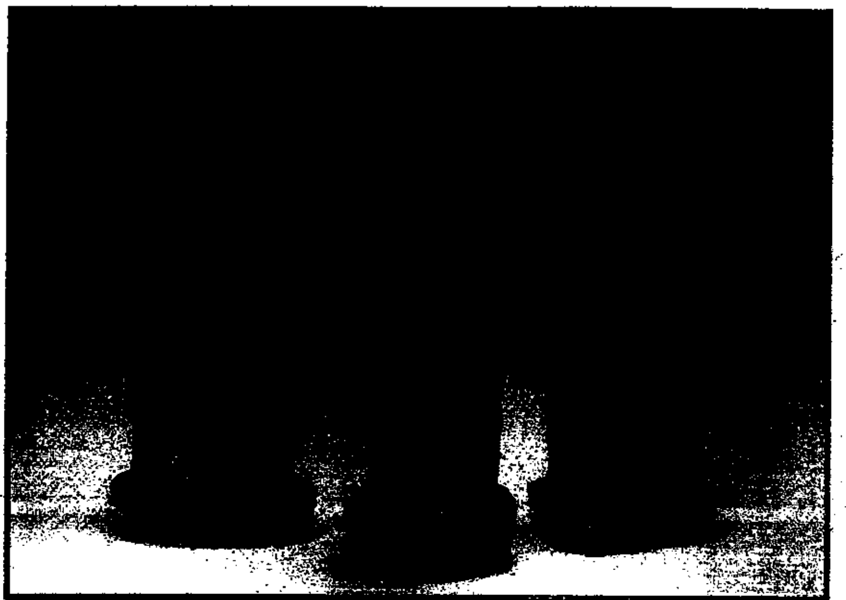
Cuticle removing. Drawings are expressed on the surface of the internode by means of removing cutilise from certain parts of the drawings.

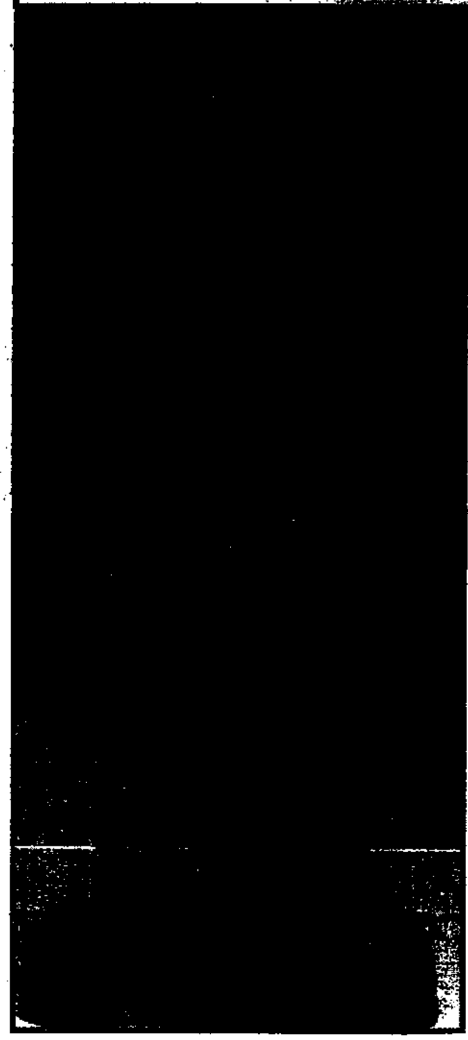
In carving on the bamboo surface layer of certain articles, the inner part of the internode is segmented, softened, flatened, smoothed, and glued to certain articles as a surface layer, and the carvin is carried out on this bamboo surface layer.

Material selection. In China the specie *Phyllostachys pubescens* is selected as row material for carving. While selecting the culms, attention should be paid to the age, size and shape of culms. The selected culms should be free from damages, and should be cut in the period from november to January in temperate zones. During this period the moisture content of culms is low, which benefits their storage. It is desirable that the culms for carving be taken from sunny slopes with comparatively poor soils. They should be be 6-7 years old, which guarantees high quality of final goods. The quality of final goods are affected by the water content of the raw material, which in fresh bamboo culms is about 60%. The culms should be cut into pieces according to the size of final products. Put the bamboo pieces vertically in ventilative shade, avoiding direct sunshine. Remove the bamboo green cuticle from the surface, then treat them with chemicals to prevent the damage from fungus an borer.

The bamboo carving knife is very important. Carbon tool steel 18A and 17A are usually used for the knife. The hardness should be HRCbo-64 or 65-62; high carbon steel and alloy also can be used.

After the pattern drawn well on the surface, use a sharp knife to make the contour of the pattern, then use the carving knife to express the relief.





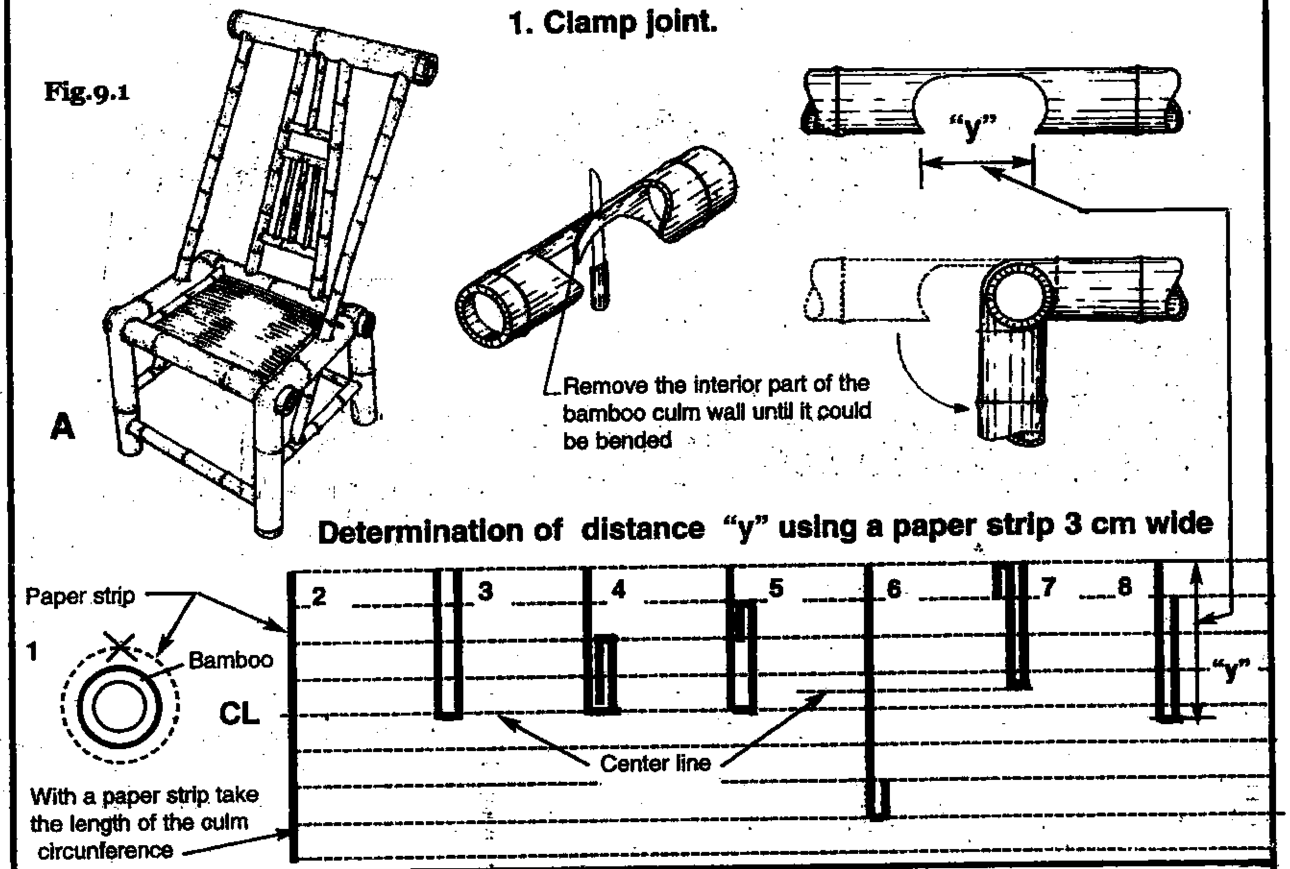
Beautiful samples of bamboo internode relief sculpture from the book *Chinese Bamboo Handicrafts*, edited by Zhang Qisheng and Cheng Weishan (as Chief editors) and published by China Forestry Publishing House in 1997.

A. *A brush pot of square bamboo culm (Chengdu, Sichuang).*

B. *A country of soccer (Meixian, Guandong.*

BAMBOO FURNITURE

TYPES OF JOINTS USED IN THE MANUFACTURE OF FURNITURE



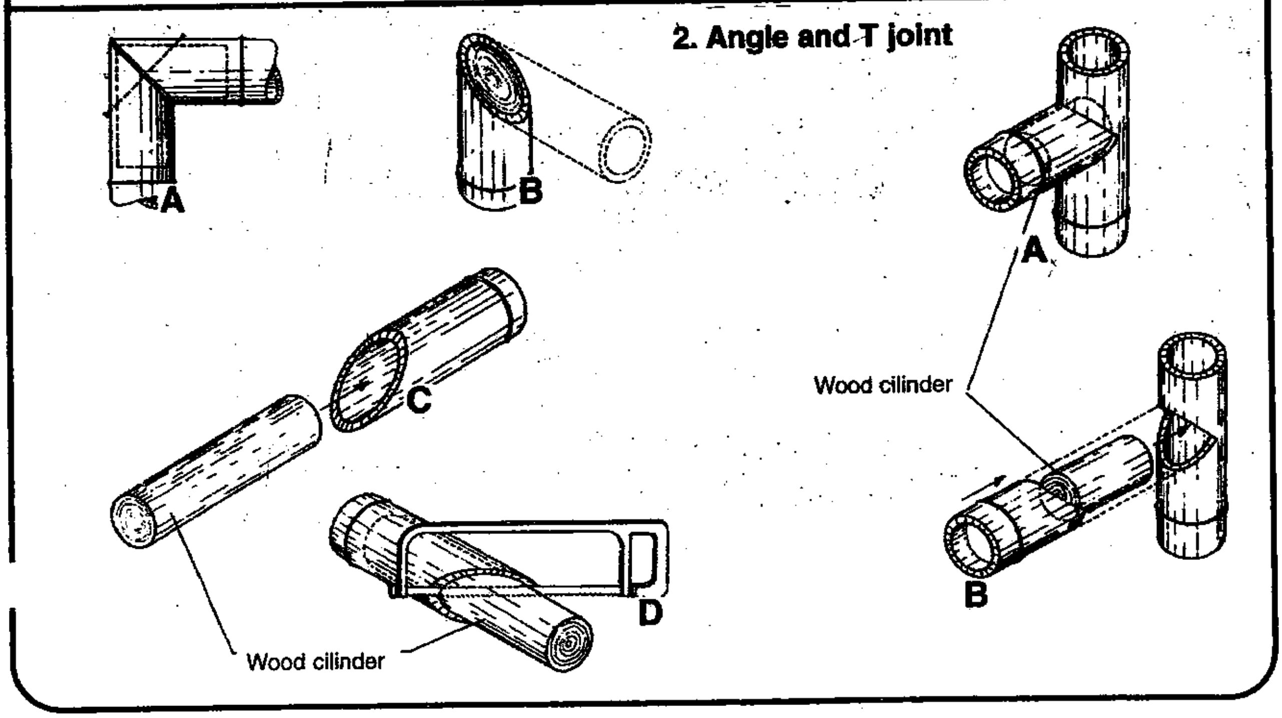
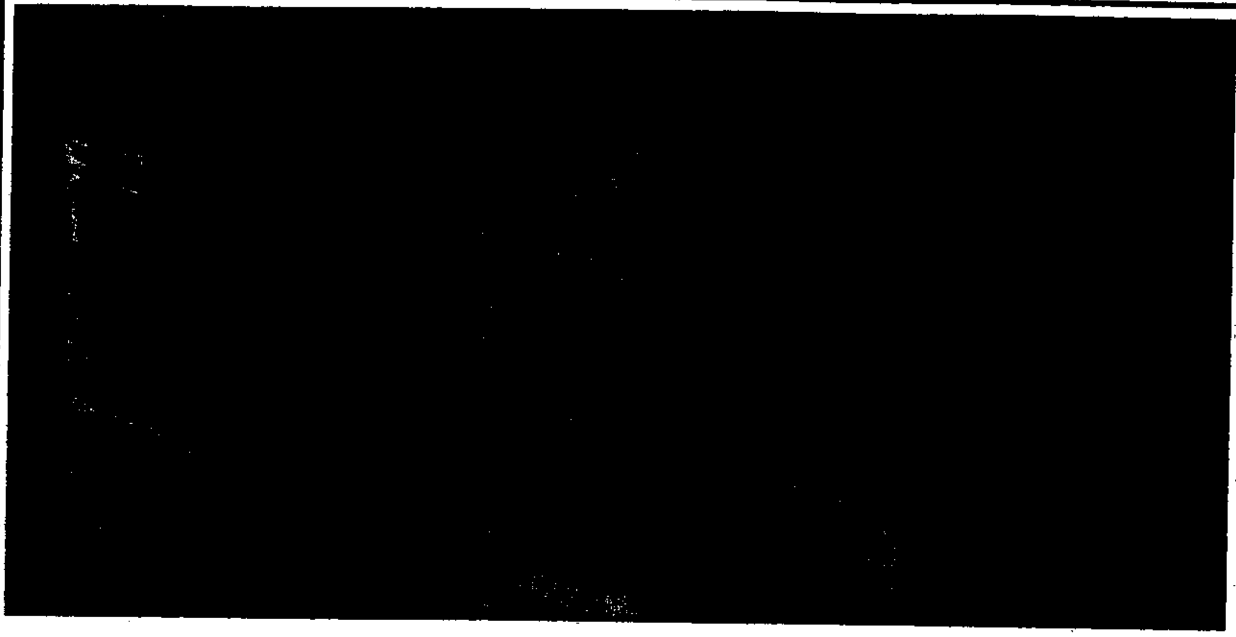
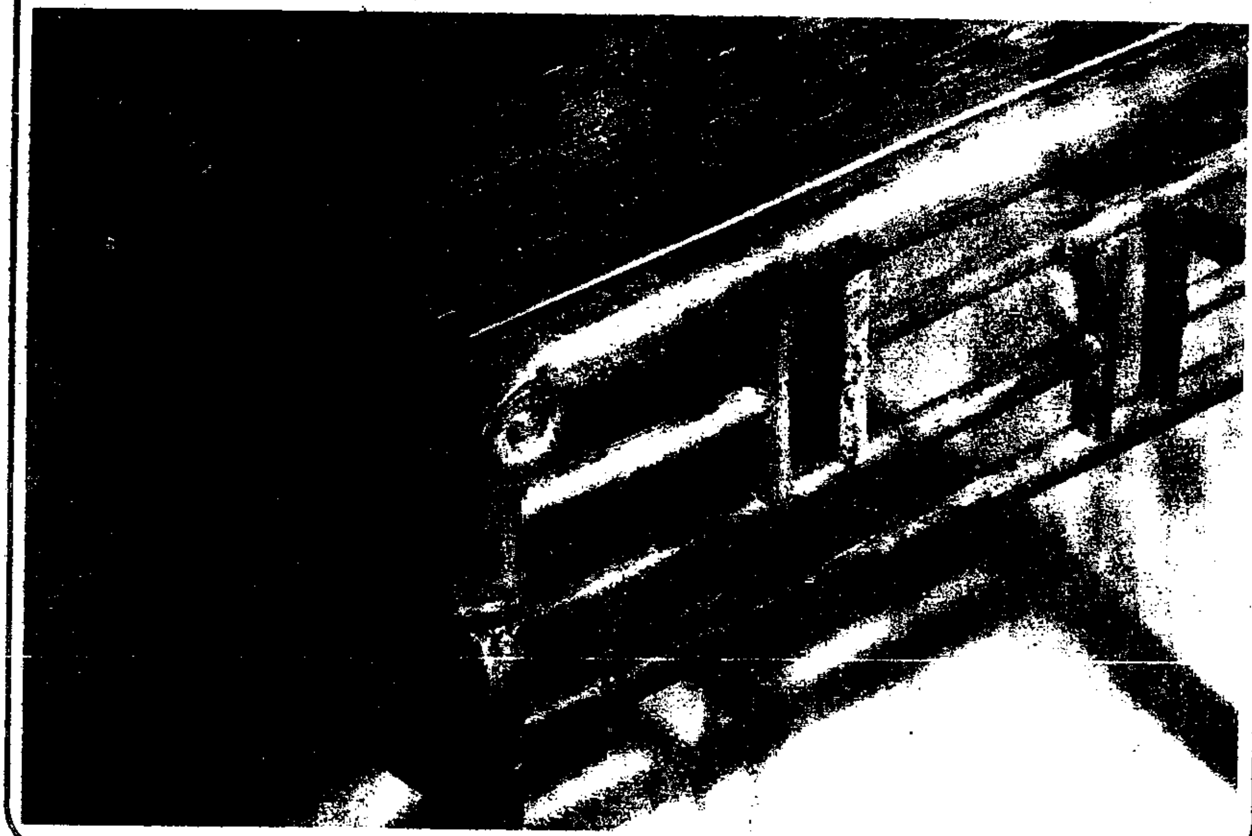


Fig.9.2 **SOMES TYPES OF CHAIRS WITH CLAMP JOINTS**

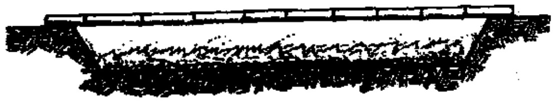


TABLES



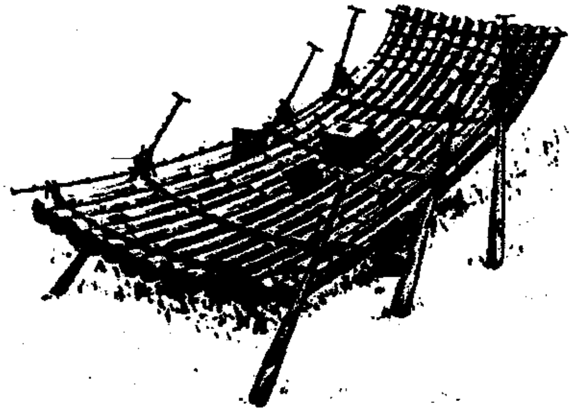
BENDING OR STRAIGHTENING OF GIANT BAMBOO CULMS WITH FIRE

Fig.9.3



A. *Straightening or bending giant bamboos up to 30 degrees with fire.*

B. *In the try boats of T'ai Wan which are simply small rafts, measuring 12 to 40 feet long, a dozen large bamboos are lashed together and the tapering ends forwards are hardened and bent over a slow fire as shown in the drawing.*



C *Bamboo raft 9 to 12 feet long used in Formosa for threecrew members.*

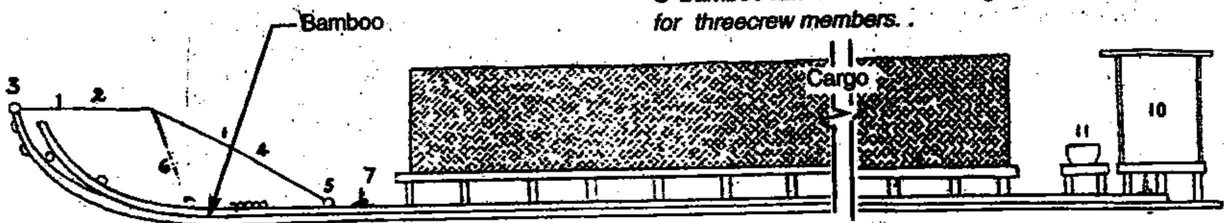
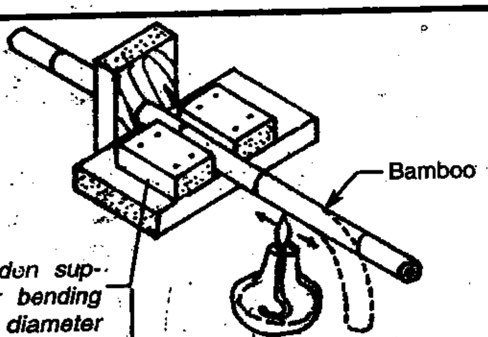


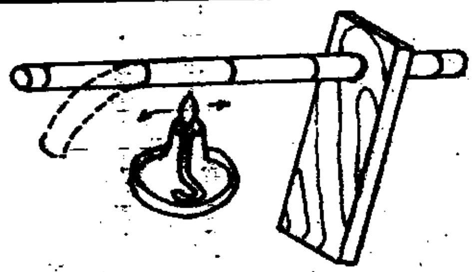
Fig. 9.4 METHODS FOR BENDING SMALL DIAMETER BAMBOO CULMS AND STRIPS WITH FIRE

A

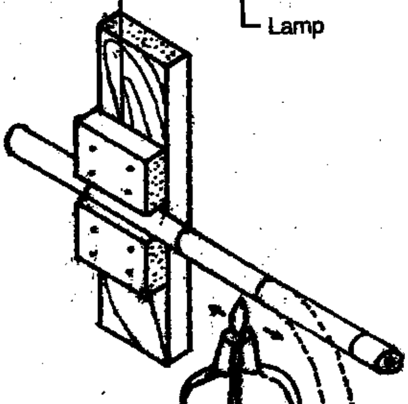


1). *Wooden supports for bending small diameter bamboo culms.*

B



C



D.- *Bending of bamboo strips.*

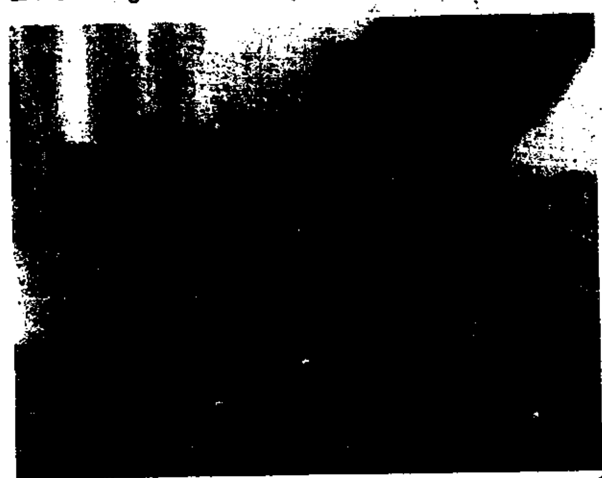
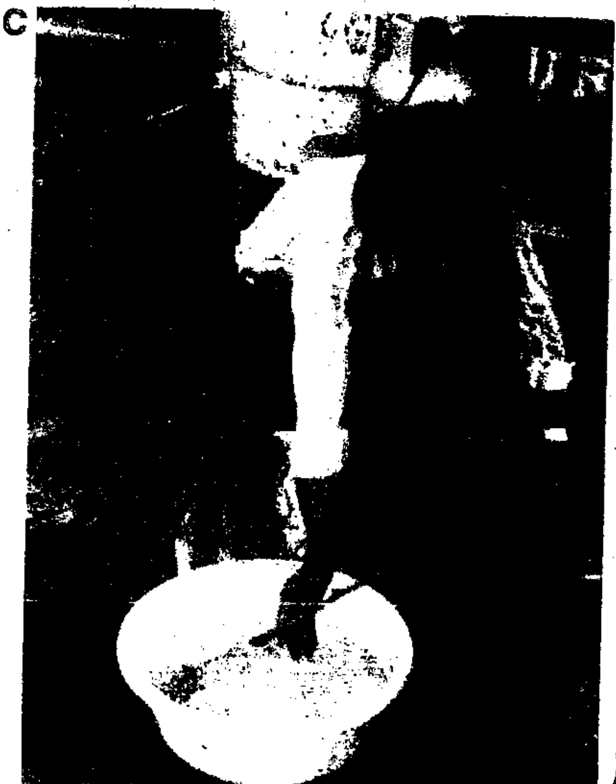


Fig. 9.5 BENDING OF SMALL DIAMETER CULMS WITH FIRE

A

B

C



The most important requirement, in selecting bamboo culms of small or large diameters which are going to be bent or straighten is that they be mature or in other words that they are at least 3 years old.

Bending or straightening.

This can be done by the suitable application of heat and pressure. Heating may be done : 1) over a charcol fire, see Fig 9.3.A

2) By means of a carefully applied blow torch or Bunsen burner to a temeperature that does not cause scorching.

3) Heating with steam for 10-15 minutes. If facilities are available and specially if much straightening is to be done, is undoubtedly to be preferred. A bend whether short or long, most be heated and straightened through a large part of the area to give satisfactory results special wooden straightening tool must be used (See Fig. 9.4).

While the bamboo culm is still hot and the waxy coating on the surface is soft, this coating should be wiped off thoroughly with a coarse cloth. This brings the culm to a pleasing and uniform yellowish color. After straightening and cleaning the culm, the coolin g can be hastened by the application of cold wet cloths, or inmersing the bamboo piece in water as shown in this page.

PART 4

BAMBOO TREATMENTS AGAINST INSECTS AND FUNGI

Water's sellers in bamboo sections (Riou's drawing) Geografia Pintoresca de Colombia in 1869.

8 RULES FOR IMPROVING THE NATURAL DURABILITY OF BAMBOOS

THE DURABILITY OF SOME SPECIES

Natural resistance of bamboos and timbers to insects and other biological agencies is invariably attributed to physical and chemical properties of the culm wood. Generally the natural durability or service life of most of giant bamboo species is very low. Investigations carried out in India at the Forest Research Institute, Dehra Dun, and in China, Indonesia, and Phillippines, have indicated that bamboos of these countries, under ordinary conditions have an average life of only 1- 2 years when used exposed to atmosphere and in contact with the ground; while a service life of 3-5 years can be expected from bamboos used under cover, and out of contact with the ground.When used indoors from 6-8 years. However, bamboos "cured" in kitchens in rural homes where they are exposed to fumes of burning fuel, have a service life extending from 10- 15 years.

In China, for example, many year ago bamboo was the material must used in the construccion of houses (See Chinese Architecture), but due to the low durability of their species,bamboo was replaced by wood and latter by adobe and brick. I was very surprised when in 1992 I visited the Botanical Garden in Nanjing, China,where I saw a very nice buildings (See figs. 10.1-10.2) which from afar looks like made with bamboo, but really the whole building including beams, columns and the roof were made of reinforced concrete imitating bamboo. Between the concrete columns (which painted looks like ~~bamboos) were located vertically~~ natural large bamboo culms that they replace for new ones every 3 or 4 years.This is the way as the Chinese are trying to preserve their bamboo architecture in places where it is very expensive to build the same building every 5 years due to the low durability of their native bamboo species.

It appears that in most of the species the top part of the culm has a higher durabillty than the botton and midle portion due to it has less amount of parenchyma and consequently less starch. The inner and soft part of the culm wall is attacked faster by the insects than the outer one (when the culm is younger than 1 year). Split bamboo and bamboo boards are more rapidly destroyed than round ones.

In Puerto Rico, Plank (1936) worked out susceptibility studies of various species. Exploratory tests indicated that *Bambusa vulgaris* was the most suceptible of all bamboo species to infestation by *Dinoderus minutus*, and it was more heavily attacked than any otherspecies. It was found to contain more starch than any other bamboo tested. For this this reason, its use is not recommended for construction. The highest degree of natural durability in bamboos used in construction is found in *Guadua angustifolia* Kunth, native to South America, as long as it is cut when the culm is mature (three or more years old). In Manizales, Colombia, known as "the cradle of bamboo architecture in the the Americas", there are still bamboo houses that were built in 1890 using mature specimens of *Guadua angustifolia*, and "guadua cebolla" (still unidentified), that up to the present time are used without any type of physical or chemical treatment. This has been confirmed by Varmah and Bahadur (1980) who said that "all species of bamboo, except *Guadua angustifolia*, have been found to be non durable".

In China, there are small diameter bamboos, such as *Pleioblastus amarus* and *Arundinaria amabilis* (tonkin cane), that, according to Li (1992), are not injured by insects. There are also differences in durability between species of the same genus: for example, *Dendrocalamus strictus* appears less resistant to termites than *Dendrocalamus longispathus* (Liese 1985). Also, in the genus Guadua there are several species having very poor resistance and durability.

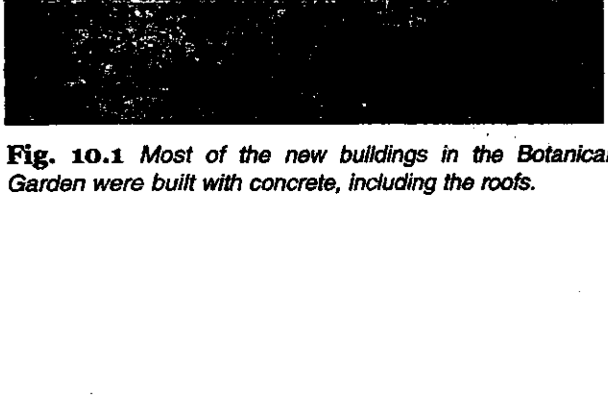


Fig. 10.1 *Most of the new buildings in the Botanical Garden were built with concrete, including the roofs.*

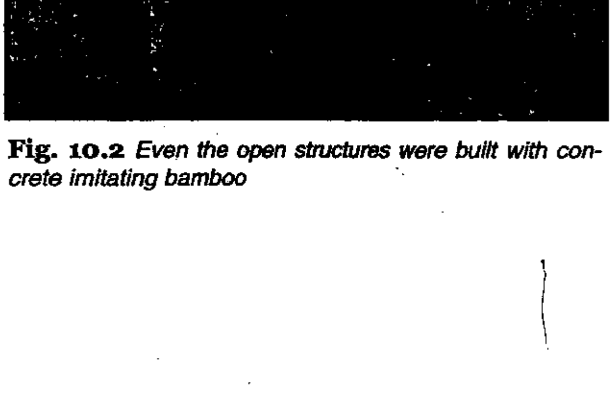


Fig. 10.2 *Even the open structures were built with concrete imitating bamboo*

Fig.10.3 *This is probably the most ancient bamboo house in Manizales, Colombia. According to information I got from Mr. Robert Velez in 1980, this house was built with Guadua angustifolia in about 1890.*

Rules for felling bamboos for construction and other uses

The natural durability of bamboo, or natural resistance to the attack of fungi, insects, and deterioration caused by bioclimatic conditions, particularly in tropical areas, can be increased if we bear in mind several rules before felling bamboo culms that are going to be used structurally in permanent or temporary constructions, or for the manufacture of ply bamboo, laminated bamboo and other composite materials, and handicrafts.

1.- For construction, or for the manufacturing of composite materials, only those species which are known to be less susceptible to insect attack should be used. As I mentioned earlier, the incidence of attack, particularly of the insect *Dinoderus minutus*, is found to be directly proportional to the starch content in the bamboo culm. Some species, such as Bambusa vulgaris, generally have more starch content than any other bamboos, and consequently are more susceptible to insect attack. For this reason this species is not recommended for construction.

In South America, and particularly in Colombia, the species *Guadua angustifolia*, "guadua cebolla" (onion guadua), and "guadua de castilla" (still unidentified), are the most commonly used in construction because they are considered to be less liable to insect attack, as long as they are cut when they are mature and during the proper season of the year.

2.- The best time or season for harvesting giant bamboos, is when the liability to attack by borers is least, and this occurs during the rainy season, at the end of the sprouting period of the shoots, when the starch content of the mother plant is minimum in the culms. According to Liese (1985), the starch content reaches its maximum level in the driest months before the rainy season and sprouting.

The season for felling is confirmed by Channingaraya (1939), who points out that in India, in the Bhadravati division, bamboos of *Dendrocalamus strictus and Bambusa arundinacea* collected during summer are more liable to beetle attack than those felled during the rains, but he explains that "the reason for this is that the beetle population dies down with the advent of the rains". Also, Deogun (1936) comments that the attack of *Dinoderus minutus* may be controlled by cutting the culms in winter "when the sap is low and the insects are probably hibernating".

According to Sulthoni (1985), in Indonesia, the rural Javanese cut bamboos of the species *Gigantochloa apus* and *G. atter* used for construction, during a certain season. They have their seasonal calendar which they call "pranatamangsa" (the rule of season). It is actually a solar calendar system. During the year, there are two main seasons: dry and rainy, which are further divided into four detailed seasons (marengan, katiga, Iabuh, and rendengan).

Each detailed season is divided in three "mangsa". The relative population level of the borers *Dinoderus minutus* and *D. Brevis* has a tendency to decrease in "mangsa tua", and it is the lowest in "mangsa XI" (April 20 to May 11), which is the best season for the Javanese to cut the bamboos for construction. In terms of the biological process of the bamboo culms, "mangsa XI" is at about the end of the sprouting period of the shoots. Felling the mother bamboo at this time is not damaging to the shoots.

3.- How to cut bamboos. Culms are cut at the base, over the first node located above the ground, using a chain saw, machete or a hatchet (the use of a large ax is not recommended). Once the culm is cut, it is necessary to make a cut in the stump leveling with the surface of the node. If the culm is cut above the level of the node forming a cup with the lower part of the internode, with the rains, the cup fills with water, which produce the decay of the rhizome.

4.-At what age should bamboo culms be cut depending on their final use?

a) -Bamboos for permanent or temporary constructions, and for the manufacture of composite materials, such as ply-bamboo and bamboo laminated structural pieces, should be felled when they become "mature", that means once they have completed 3 or 4 years in the grove.

Mature culms have less moisture, and are stronger and less susceptible to the attack of fungi and insects than younger ones. In order to know the approximate age of the bamboo culm, see "Determination of the Culm 's Age" in the first chapter of this book

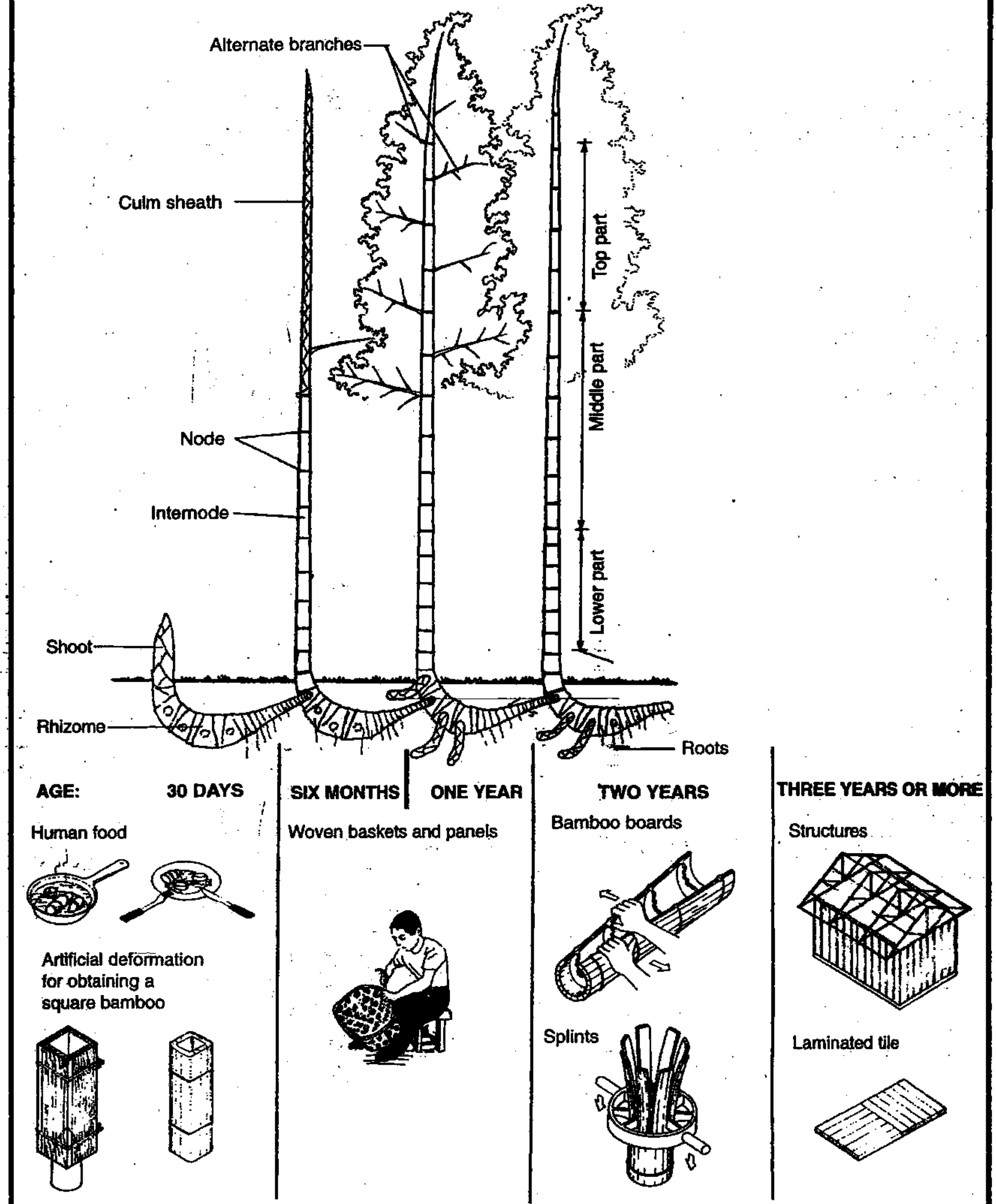
b)- For the manufacture of bamboo floor tiles or parquet flooring, it is recommended that giant bamboo culms which are 4 to 5 years old (no older than 6 years) be cut. At this age, the fiber is stronger.

c)- If giant culms are going to be formed into strips for the manufacture of baskets, mats or any other weaving article, the culm has to be cut after it has finished its entire growth proccess and before the culm reaches its first year of age. At this time in the formation of the plant, the strips taken from the outside part of the culm wall are very flexible and apt for making weaving products. Some artesans recommend for fine weaving that the culm be cut when it finishes its growth process, but before it starts the development of branches. When the strips are taken from very young bamboos, they are very susceptible to the attack of insects and fungus, and they have to be treated.

5.-Bamboos culms which are going to be used in permanent constructions and in the manufacture of composite materials must be seasoned prior to use. Seasoned or dried bamboos are stronger and more resistant to the attack of fungus and insects than green or just felled bamboos. Also is easier to cut and plane dry bamboo boards than green ones.

USES OF BAMBOO CULMS ACORDING TO THEIR AGE IN THE CLUMP

Fig. 10.4



6.- The use of appropriate construction technologies for protecting the bamboo structure. In most of South East Asian countries, houses are built following traditional technologies in which generally are used weaving bamboo panels fixed externally to a wooden structure and exposed to atmosphere. Due to this reason the natural durability of this weaven panels is very low in all the countres where thes type of panels are used; whereas in Colombia bamboo boards are used in both sides of the wall and plastered with cement mortar, which protects the bamboo structure from moisture, attack of insects, and fire .This is why in Manizales, Colombia, there are still houses which were built more than one hundred years ago with *Guadua angustifolia* and at the present time they are in excellent conditions. Without a doubt, the durability of these houses in Manizales is due not only to the kind of bamboo employed, but also to the technology used in the wall construction.

The moon and its effect on felling bamboos.

In some countries, particularly in India and Colombia, it is believed that there is a correlation between the phases of the moon and borer attacks on bamboo. Stebbin (1906) makes a reference to a paper read by Mr. Ernest R. Woakes before the American Institute of Mining Engineers in 1899, in which the author stated that "in Colombia, South America, not only bamboos but all trees, are felled during the waning moon only and not during its increasing phases.

It would appear that in that country the effect of the moon phases is treated as an accepted fact". This is true. Up to the present time, most of the rural people in Colombia believe that the culms of bamboo are rapidly destroyed by borers if they are not felled in the waning moon, and that the felling of the culms has to be done before sunrise, between 4 and 5 am, when it is still dark. This is based on the belief that during the waning moon, the sap flows downwards leaving the wood dry, whereas the waxing moon is supposed to draw the sap upward. Contrary to this belief, Deogun (1936) quotes that in Bihar, Orisa and other places in India, it is commonly believed that if bamboo is felled in the bright phase of the moon it is less susceptible to insect attack than when it is felled in the dark half. Who is right?

Kirkpatrick and Simmonds (1958) quote the experiments made in India by Beeson and Bhatia with *Dendrocalamus strictus*, felled at different phases of the moon. They found that there was a cycle of moisture percentage increasing from full to new moon, and decreasing from new to full moon. If there were any truth in the local belief, this should have resulted in increased liability to borer attacks in bamboos felled during the waning moon, the opposite of the belief commonly held in Colombia. They concluded that there was a definite positive correlation between starch content, which varies seasonally, but not according to the lunar phases, and borer attack.

The experiments carried out at the Forest Research Institute in Dehra Dun, India, have failed to find any connection between the moon phases and the insect attack on felled culms. From the experiments done in Puerto Rico by Plank (1950), it may be assumed that *Dinoderus minutus* infestation cannot be avoided by harvesting according to the phases of the moon.

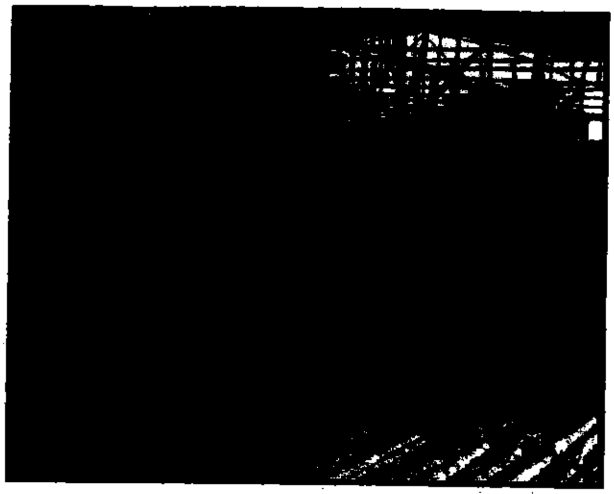


Fig. 10.5.A. *About 850.000 mature bamboo sections 2.50 mt. long, after cut were stacked horizontally in a large shed and only 1% of separate sections were attacked by Dinoderus minutus*

In 1987, I made the following observations near the city of Armenia in Colombia, related to the attack of *Dinoderus minutus* in *Guadua angustifolia* and another variety known by the common name of "guadua cebolla" (still unidentified).

We cut about 850,000 sections of bamboo, 3 meters long from mature culms (more than 3 years old). These sections were going to be used as structural support in the planting of pitahaya, a tropical fruit. For several months, we felled bamboos all day long from 7 am to 5 pm. This means that we felled bamboos during all phases of the moon. After felling, the culms were divided into sections and then transported and stacked horizontally in a large shed open on all sides. It is important to point out that we did not use any prophylactic or preventive treatment during storage.

Six months later, before treating the sections by inmersion in a solution of pentaclorophenol, I checked all of the 2 meter high stacks and found that *Dinoderus minutus* had attacked only 1% of the culm sections, which is a very low proportion.

From this experience, I came to the following conclusions: a) There is no relationship between the phases of the moon and insect attack. b) When mature culms are felled, they are less susceptible to insect attack.

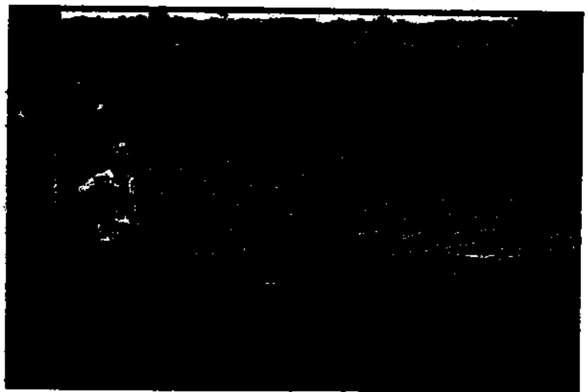


Fig. 10.5.B. *All the bamboo that were cut were used as supports of pitahaya plantations.*

PHYSICAL AND CHEMICAL TREATMENTS AGAINST INSECTS AND DECAY FUNGI

PHYSICAL TREATMENTS (CURING)

There are two methods for the treatment of bamboo culms: the physical and the chemical methods.
The physical treatment is also known as curing; it has the purpose of removing, destroying, or reducing the starch in the culm and, consequently, reducing the attack of the insect *Dinoderus minutus*. However, it does not protect bamboo from the attack of termites and fungis. It is the most inexpensive treatment and, for this reason, it has been used traditionally in the rural areas and villages, particularly in many Asiatic countries, although not much is known about its real effectiveness. This type of treatment is not used in Colombia. There are several methods for curing bamboos.

1-Curing in the clump

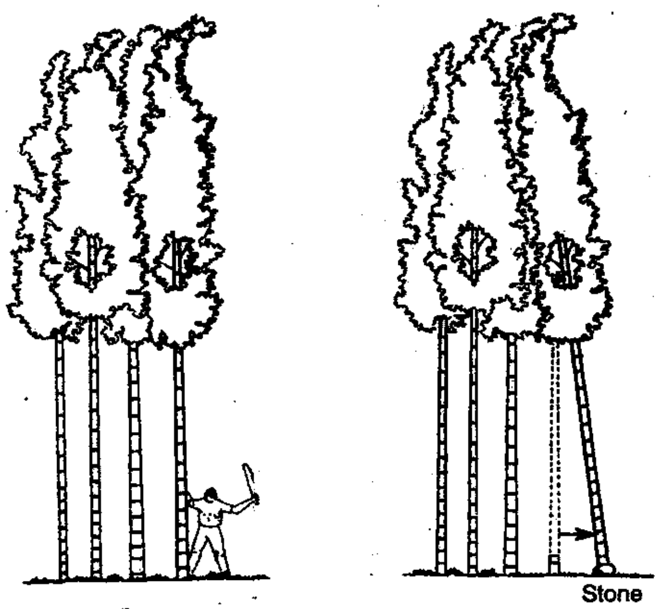
Culms are cut at the base of the culm above the first node above the ground, and left vertically with all their branches and leaves for 4 weeks leaning against other culms at the site. The base of the culm has to be separated from the ground by a stone; thus the starch content in the culm is reduced. As a result, the resistance to infestation by borers is believed to increase, but there is no influence on the resistance to attack by termites and fungi.

On the other hand, this type of treatment can also be used for chemical treatment. In this case, the bottom part of a freshly cut green bamboo with branches and leaves is placed in a barrel containing the preservative. The transpiration of the leaves, still in progress, draws the solution into the vessels of the culm. The preservative must be replenished regularly in order to mantain the desired level. This method requires a lot of time, and often the vessels do not absorb enough liquid to preserve the fibers and parenchyma cells sufficiently through subsequent diffusion.

2- Curing by immersion

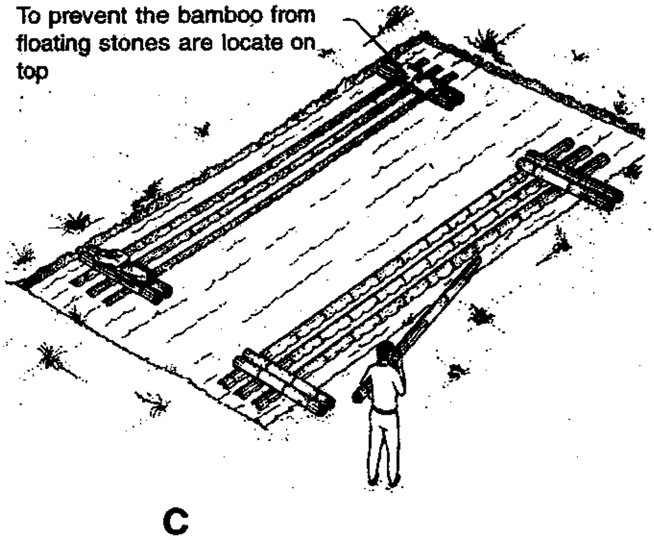
The fresh culms are put into stagnant or running water for a period of several weeks. Stones have to be put on the bamboos to keep them under water. During soaking, starch and sugar in the parenchyma cells are leached out or degraded by bacteria so that the resistance to borers may be improved. This method does not increase the durability against termites and fungi, and stagnantion may lead to staining of the culms. Such ponding increases the posterior uptake of preservatives by diffusion and pressure processes. However, if the culms are inmersed in water for more than 45 days, they become brittle.

Fig.10.6 Curing in the clump



A B

Fig.10.7 Curing by immersion (ponding)



C

3-Curing with heat.

Curing by heat can be done using a ditch dug in the ground to a depth of about 30 or 40 cm with red-hot coals as can be seen in Fig. 10.8, or using a small gas furnace (Fig. 10.9). In both cases the culms most be turned by their ends by hand. This method is also used for straightening curved culms.

Fig 10.8 **Curing with heat** (red-hot coal)

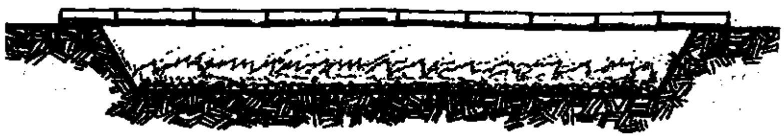
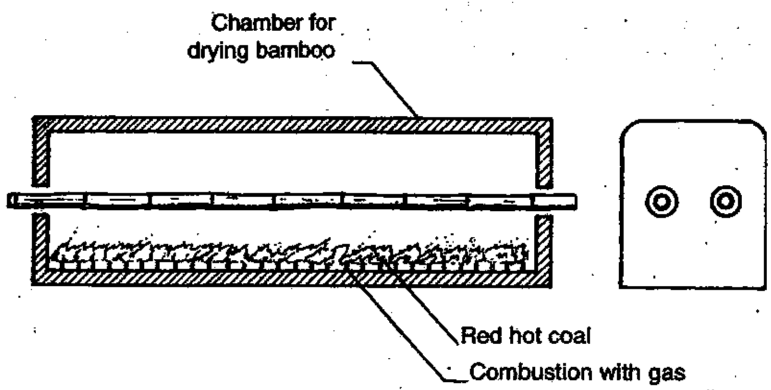


Fig. 10.9 **Curing with heat** (with gas)



4-Curing by smoking.

Bamboos stored above fire places in kitchens in rural homes, where they are exposed to fumes from cooking stoves or burning fuel, have a service life extending from 10-15 years. Toxic substances may be deposited, which leads to some resistance. Due to heating, the starch within the parenchyma cells may also be destroyed.

According to Ishibashi (1990), smoking of the cut bamboos can also be done by gas generated from charcoal kilns from the beginning until it reaches the carbonization state. This treatment makes bamboo more resistant to rot deterioration, and cracking, and extends the life of bamboo used to build underwater frames for growing seaweed.

5-Curing with mud.

Freshly cut bamboos are soaked in a muddy pond (Latosol) for 1-8 weeks and then are slowly dried in the shade. This reduces the starch content which passes from the bamboo into the muddy water, reducing the food for insects and fungi; thereby increasing the durability of bamboo. This process is mostlly practiced by the rural people in Bangladesh (Chowdury 1992).

Suhirman (1987) carried out a laboratory study on the effect of mud-submersion treatment on the durability of two bamboo species: *Dendrocalamus asper* and *D. giganteus*. Test blocks were submerged in mud with latosol and grumosol soils for 1, 2, 3 and 4 weeks prior to 6 months' exposure to *Pycnoporus sanguineus*.

Results showed that mud submersion treatment increased the durability of the bamboos, and that the relationship between the duration of submersion and weight loss due to fungal decay was linear.

6.-Curing in beach sand.

The bamboos used by Father Diego Cera in the construction of the bamboo organ of Las Piñas, Parish of St. Joseph in the Phillipines that lasted so many years, were buried under beach sand at the seashore at the end of 1816 and were unearthed in 1817, when the construction of the bamboo organ began. (The bamboos were probably buried for about 2 or 3 months.) By 1821, the famous instrument was almost finished (Samson 1977).

7.-Curing by sea-water supernatants.

Bamboo and wood products are treated by immersion in sea water supernatants containing 2-7% salts, or in electrolyte solutions containing water and NaCl, or in acid solutions, containing acids and seawater. The two solutions are prepared at 0 -14 ° C and are mixed at a ratio of 1 : 0.0025 - 0.004 and pH 0.2 - 3 and a specific gravity of 1.007-1.057 (Li et al 1987).

8.-Protection by white washing.

Bamboo culms and bamboo mats for housing construction are painted with slaked lime, CA(OH). Besides the ornamental effect of the white color, a prolongation of service life is expected. It seems possible than water absorption is delayed by this treatment, leading to a higher resistance to fungi, but specific investigations are still to be carried out. In Indonesia, bamboo mats are tarred and later sprinkled with fine sand. When the sand clings to the mat and the tar is dry, up to four coats of white wash are applied.

CHEMICAL TREATMENTS

What we have to know before treating bamboo with chemicals.

Bamboos are anatomically different from both hardwoods and softwoods in their tissue organization. Due to these differences in anatomical structure, bamboo behaves entirely differently from timber during treatment with preservatives. As was mentioned earlier, unlike timber, bamboo culms are generally hollow and possess hard outer and inner membranes which protect them from damage and water loss. If round bamboos are subjected to the high pressures and high temeperatures used int he treatment of wood, the air inside the chambers of the internodes will expand, producing cracks along the culm. For this reason, the use of high temperatures and high pressures in the treatment of round bamboos is not recommended.

On the other hand, it is important to point out that when green bamboo dries up after felling or when it overmatures, resistance to penetration of the water solution is offered along its length through the vessels, but it may not be so great in the case of penetration through the diffusion process.

The main characteristics of an ideal bamboo and wood preservative are:

1).-High toxicity against fungi and/or insects and/or marine organisms. 2).- High permanency under all service conditions, i.e. resistance to leaching by water or to rapid evaporation due to heat or chemical transformation due to oxidation, etc. 3).- High penetration. The effectiveness of a preservative also depends on its penetration into the treated material. It should penetrate as much as possible. 4).- Safety in use, meaning low toxity to humans and animals, and absence of objectable odor and color. It should be cheap and commercially available, and it should not corrode the metals used along with the treated bamboos.

The preservatives are divided in two general groups:

1) Oil-types, such as creosote. The most commonly used is coal-tar creosote, which is applied using the pressure process. It is used for bamboos and woods in contact with soil and water. It is preferable to avoid its use in dwelling houses where its odor and color are objectionable and its defects, such as tackiness, and the unpaintability of bamboo and wood treated with it, are a hindrance.

2) Water-borne salts or water soluble salts, that are applied as water solutions. These preservatives are employed principally in the treatment of bamboo and wood for uses where they will not be in contact with the ground or water and where the treated bamboo or wood requires painting. They are less resistant to leaching, so to prevent the leaching of these preservatives from treated bamboos used in the open, sodium dichromate is generally added to fix them. Copper sulphate, zinc chloride, boric acid and borax, and sodium pentaclorophenate are some of the leachable types. As regards fixed types of preservatives which can be used in both inside and outside locations, Ascu, Celcure, Bolinden salts, copper-chrome-boric composition and chromated zinc chloride may be mentioned. The advantage of these preservatives over the oil type is that timber treated with them can be painted over and varnished. (Purushotham et al 1952, 1953).

3).-The effectiveness of insecticides. A study on the effectiveness of 11 commercial insecticides for controlling the bamboo borers, *Dinoderus minutus* and *D. ocellaris (Coleoptera: Bostrychidae)*, was carried out by Varma, Mathew, Mohanadas, Gnanaharan, and Nair (1998). These insecticides were tested by direct application to the beetles and by application to their food surface. HCH, lindane, cypermethrin and permethrin were the most toxic to the beetles. With the exception of HCH and lindane, organochlorines were less toxic than organophosphorus insecticides, carbamates and pyrethroids. DDT was the least toxic. Boric acid was also tested, but it was ineffective when sprayed over the insect or the food surface; however, it was toxic when incorporated into the diet.

METHODS FOR TREATING BAMBOOS WITH CHEMICALS.

The chemical treatments of bamboo can generally be divided into 2 categories: 1) Temporary treatment, known as prophylactic treatment, used for round and split bamboos, and 2) Long term treatment, which includes a) the treatment of green bamboos (freshly cut), and b) the treatment of dry bamboo. It is very important to point out that all of the chemicals and treatment processes that are used on wood can be used in the treatment of split bamboo, but only some of them are recommended for the treatment of round bamboos.

1.-Temporary or prophylactic treatment of bamboo.

This type of treatment with chemicals is used in round and split bamboo and is advisable for preventing fungal degradation of raw bamboo during temporary storage, particularly in tropical countries where the biodeterioration is very severe. It is recommended for when the bamboo has to be in storage for several months in forest depots, as well as in paper mill yards, and for long transportation of green bamboo in open trucks. It is not recommended when green bamboo (not seasoned) is transported in containers for several days in trucks or ships. In this case, the bamboo should be dried first to less than 19% moisture content.

It is estimated that about 20% of this raw material is destroyed by insects and fungus that produce a change in the chemical composition of stored bamboos, especially in the three major components: cellulose, lignin and hemicellulose. The enzymes secreted by the bamboo and wood destroying fungi degraded these compounds and resulted in the progresive loss of woody material with increased periods of storage. In experiments carried out in the test yard by Kumar & Dobriyal (1988), they found that untreated round bamboo belonging to *Bambusa polymorpha* and *Dendrocalamus strictus* species were destroyed in 19 months by termites and fungi. This destruction can be prevented by simple profylactic treatment of bamboos at a coverage rate of 24 liters per ton, using

1.- Boric acid + borax (1:1) 2 percent solution or

2.-Sodium pentachlorophenate + boric acid + borax (0.5:1:1) 2.5 percent solution

2. -Long term chemical treatments

1)- Stepping method (for green bamboo).

In the stepping method, the bamboo culm is placed in a suitable tank containing the preservative with its butt end dipping in the solution. It is held upright (with its branches and leaves) and supported against a neighboring bamboo or tree.The preservative is sucked up during the transpiration of the leaves.(See "Curing in the Clump").

2)- Open tank method (soaking and diffusion treatment) for round and split bamboo.

The open tank treatment is made by soaking the bamboo culms or split bamboos in a solution of a water-soluble preservative for a sufficiently long time to obtain adequate absorption and penetration. This treatment is considered to be one of the best and most economic treatments of green round and split bamboo by the diffusion process.

The solution enters the round culm through the ends and partly through the sides by means of diffusion by capillarity. The degree of penetration depends on the age, thickness, length, and density of the bamboo, and if they are green (just felled) or air-dried. Penetration and absorption of water soluble preservatives are lower in freshly felled culms than in air dried material. Split culms can be treated more easily than round ones; thus the soaking period can be reduced to 1/3 -1/2. The preservative concentration should be higher when green bamboos are treated. In air dried culms, axial diffusion was found to be about 20 times more than that in the transverse direction; radial diffusion was slightly better than diffusion in the tangential direction.

According to Tewari (1981), generally, the absorption of the solution is fast in the initial stages and it gradually slows down with time. For example, about 50% of the total absorption obtained after immersion of *Dendrocalamus strictus* (round and half split) 3 - 4 years old, for 30 days in a 5% aqueous solution of copper-chrome-arsenic composition (CCA), is achieved in the first three days. Mechanical scratching of the outer skin can speed up the penetration, especially for slow diffusing preservatives.

For effective treatment of short sections of round culms, it is suggested that a hole with a maximum diameterof 5/8" be opened in each of the septas, using a long straight shank drill bit. If the septas are removed or partially destroyed, the culm can not be used structurally.

According to Liese (1985), steam treatment significantly improved absorption compared to simple immersion. The time of treatment can be considerably reduced by using the hot-dipping or the hot cold method. A double treatment, consisting of a 20% solution of coppersulfate and zinchromate followed by 20% sodiumdichromate can also be successfully applied.

In Malaysia, the method popularly used by manufacturers of bamboo products or handicrafts is boiling the cut bamboo in a solution of 0.1% Propylene and 0.8% caustic soda or a solution of caustic soda and water. The proportions are as follows: One gram caustic soda to one liter of water (0.1 %); 2 grams caustic soda to one liter of water (0.2%) etc., depending on the thickness of the bamboo which must be boiled for a duration of 5 to 30 minutes.

3) Hot and cold process for the treatment of bamboo boards and split bamboo.

In this process ,the bamboo boards or the split bamboos are submerged in the preservative which is then heated to about 100° C and maintained at that temperature until the bamboo reaches the temperature of the bath. It is then allowed to cool down to the atmospheric temperature or to any temperature higher than that, determined mainly by the required absorption of the preservative. During the heating period, the air in the culm wall expands and is partially expelled. During the cooling period the residual air in the bamboo contracts, thus creating a partial vacuum into which the preservative is sucked.

In order to overcome the danger of precipitation of the chemicals at high temperatures, the use of two baths it is recommended: the first containing water where the hot treatment is given and the second, a cold bath containing the preservative into which the bamboo is immediately transferred immediatelly.

Fig 10.10. *All of the internal nodes of each 3m culm section were previously perforated with a 5/8 diameter drill in the same side of the culm before the treatment.*

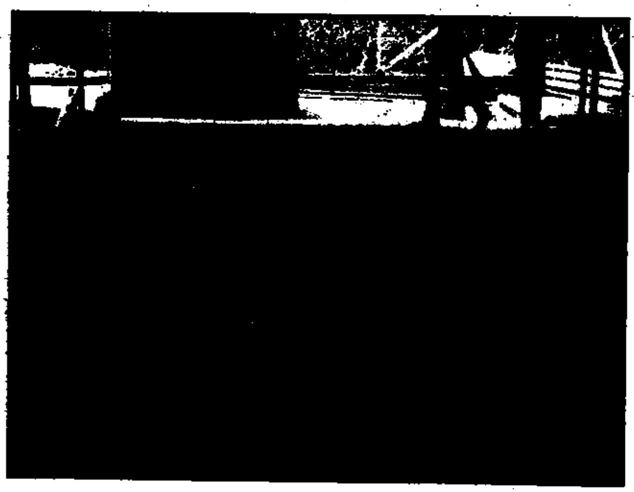


Fig. 10.11 *Sections 3 meters long of Guadua angustifolia were soaked in a solution of Pentachlorofenol (5%) during a week.*

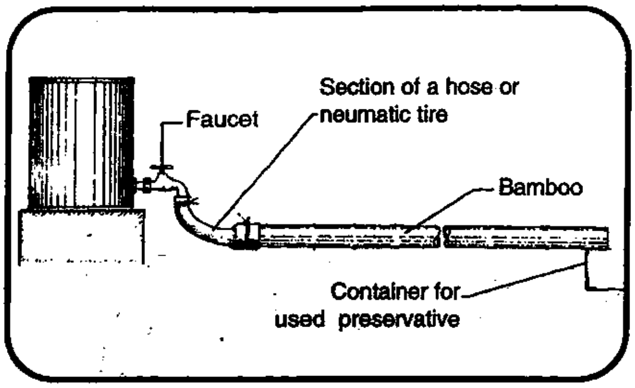


Fig. 10.12 *Boucherie method by hydrostatic pressure*

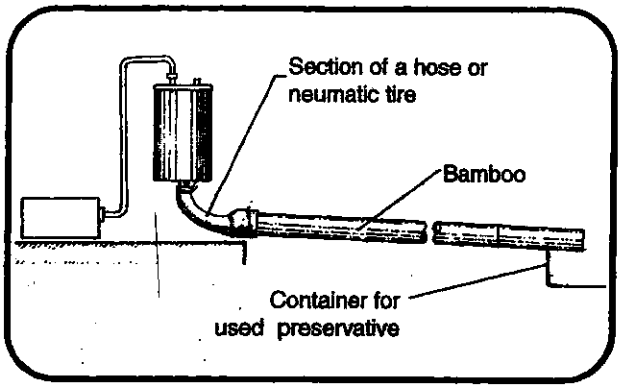


Fig. 10.13 *Modified Boucherie method using pneumatic pressure*

4) Boucherie method for the treatment of round green bamboos.

The Boucherie method is a derivation of the capping method originally used for the treatment of trees. In the capping method, the crown of the tree is cut off and about 6 inches of bark is removed from the butt end. An old rubber inner tube from a car tire is tightly fixed at the debarked place and the tree is either held horizontally to the ground or made to lean on the ground with its butt end resting on a neighboring tree. The free end of the tube, which is held upright, is then filled with preservative which flows down its length under hydrostatic pressure. Where necessary, the tube may be attached to a container for holding greater quantities of preservative. This is known as the traditional Boucherie process, used for the treatment of telegraph poles with copper sulfate, to obtain an average life of about 23 years. This method can be used in the treatment of green or freshly felled bamboos in the following ways:

1.-In the treatment of giant bamboo culms, the butt end of the culm is used as a container or reservoir for the water soluble type preservative. In this case, the top internode has to be incised in the base near the septae, since the inner surface of the bamboo is not permeable. Once the culm is fixed vertically, the top internode is filled with the preservative.

2.-In this case, a suitable metal container, placed higher than the culm or culm section, is used for the water soluble type preservative. At the bottom of the metal container there is a side tube fitted with a stopcock. The bamboo culm is held in a vertical position or inclined at an angle of45° to the ground. The butt end of the culm section is attached to the bottom tube of the container with the preservative with an old tire inner tube. Due to hidrostatic pressure, the preservative displaces the sap which flows out from the lower end of the bamboo culm. The treatmen is stoped when the concentration of the drip is the same as that of the solution in the container. Generally this method is used for treatment individual bamboos and takes several days depending on the length of the culm section, thickness.

4.1-Modified Boucherie method using pneumatic pressure (only for the treatment of round green bamboos)

The above method can be improved by pneumatic pressure (air pump). In this case the metal container have at the top a metal plate soldered to which are attached a bicycle valve and a presure gauge which reads up to 50 lb. air pressure. A ruber tub is then fixed to each metal tubes which-serves to connect the top end of each bamboo to the re-servoir. The connections of the ruber tube to the apparatus and the bamboo can be made firm by winding galvanized wi-re over the joints once or twice and twisting the ends with pliers.

After attaching the bamboo, the pressure gauge is taken out; the preservative is poured through the hole where the pressure gauge is fixed till the container is filled 3/4 its capacity. The valve and the pressure gauge are then replaced and air at a pressure of 10 30 lb pumped in. After about 5 minutes the preservative starts flowing, mixed with the sap. If instead of an small container, a 45 gallon drum with suitable attachments is used, over 10 bamboos can be treated simultaneously, and it is not necessaryt to incise the walls of the bamboo as the cut end itself is sufficient to give entrance to the preservative into the wall of the culmThe preservative which has flown out at the butt end can be re-used after bringing the concentration of the preservative to its original strength.

Using this method, as compared to the classical boucherie method, the time of treatment can be reduced from several days to less than one hour per culm, depending on its length and pressure. Such Boucherie installations are easy to transport and can be used directly in the forest. The duration of treatment and the effectiveness of this method depends mainly on the bamboo species, the moisture content of the culm and the preservative used. Permadi & Sumarni (1995) used the Boucherie method for the preservation of two fresh species from Indonesia, namely andong (Gigantochloa verticillata) and tali (Gigantochloa apus).

They were treated with a borax ($Na_2B_4O_7.10H_2O$) solution with a strength of 5%. The results showed that the penetration of preservative in andong bamboo for 2, 4, 6, 8, and 10 days consecutively was 131.40, 304.92, 308,42, 469.88 and 315.28 cm respectively, while in tali bamboo it was 68.30, 116.83, 141.88 and 128.17 cm, respectively. Maximum penetration of the preservative was achieved after 8 days immersion for andong and 6 days for tali.

According to Xu (1984), an effective anti-borer treatment for bamboo culms was achieved by treating with a pressurized Boucherie process, using 20-25% $CuSO_4$ (copper sulphate) solution at temperatures of >18°C and 3.5 kg/cm pressure 3 h (when bamboos had medium moisture content). Under these conditions penetration of Cu was 2.5-4 mg/cm. Servi-ce life was >3 yr, 3X longer than that of untreated bamboos.

Fig. 10.14 Modified Boucherie method for the treatment of several bamboos

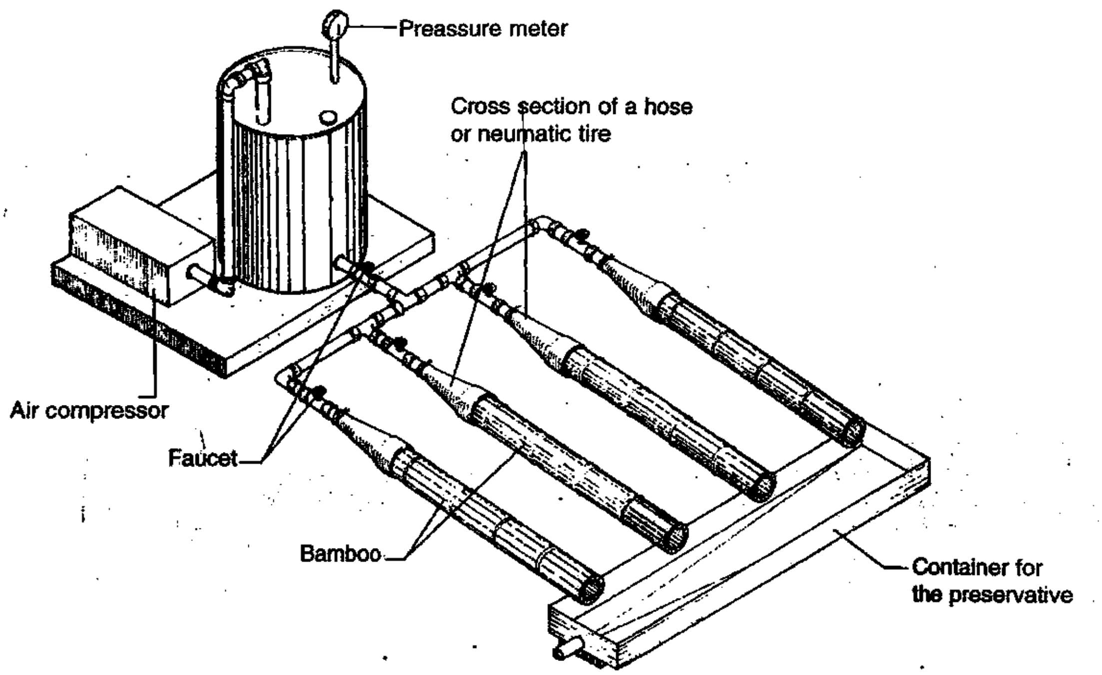


Fig. 10.15 and 10.16 *Boucherie equipment developed by Professor. Marco Antonio Pereira at the University Stadual Paulista, UNESP in Bauru, Brasil. It shows the metal tank with a capacity of 55 gallons , the PVC pieces used for the treatment of various culms at the same time and the joint between the bamboo culm and the PVC pieces.*

5.-Pressure treatment (recommended particularly for treatment of bamboo boards and split bamboo).

Pressure treatment of bamboo is carried out in some countries both with water-borne preservatives but also with creosote. The method gives the best protection for bamboo boards and split bamboo but needs special installations and in most cases, is not economical. For pressure treatment the culms must be air dried in order to obtain sufficient penetration. Absorption and penetration in split bamboo is much better than in round bamboos. During treatment of culms, craks and collapse may occur.

Sonti V.R. (1990) present a report about a workable solution for preserving round bamboo with ASCU (CCA , copper-chrome arsenic compound, using the sap-replacement and preasure treatment methods.

The former has the disadventage of having to complete sap- replacement withing a few hours of felling the bamboo. Bamboo can be preserved quite easily and effectively under preassure if notched in a particular pattern. This neither reduces the bamboo's strength when used in compression or bending . The bamboo were treated with 5 percent ASCU solution (CCA salt), using a vacuum/ pressure cycle of 30 minutes and pressure of 10 kg/cm. The final vacuum was allowed for about 30 minutes to remove as much drip as possible. The bamboos were weighed before and after treatment to arrive to the amount of loading of preservative. It was observed that loading could be controlled between 12 and 27 kg/m3. The entire cross- section was preserved.

According to Lahiry (1997) *Bambusa tulda* was successfully treated with CCA by the full cell pressure method under green and dry conditions in Bangladesh. Dry bamboo gave a higher loading absorption than green bamboo when treated under the same conditions. Higher absorption of CCA was also obtained at nodes than at internodes. Adequate penetration and retention for ground and water use contact was only obtained by treating bamboos predried to 10-15% moisture content, but green bamboo treatment was satisfactory for indoor and overhead outdoor use. CCA treatment increased the service life of both green and dry bamboo by at least twice. Two small holes made in each internode before pressure treatment gave split-free bamboo

Lahiry *et al* (1996)obtained an dequate penetration and retention of copper chrome arsenate (CCA) and copper chrome borate (CCB) in predried Borak Bamboo (*Bambusa balcooa* Roxb.), abundantly grown in Bangladesh, with the Full Cell Pressure Process. The treated bamboo can be used as building materials, the sufficient treatability ensured its long term best utilization at ground contact and indoors. Which will keep the environmental and social economical conditions of Bangladesh more viable and normal.

Lahiry (1997) successfully treated *Bambusa tulda* with CCA by the full cell pressure method under green and dry conditions in Bangladesh. Dry bamboo gave a higher loading absorption than green bamboo when treated under the same conditions. Higher absorption of CCA was also obtained at nodes than at internodes. Adequate penetration and retention for ground and water use contact was only obtained by treating bamboos predried to 10-15% moisture content, but green bamboo treatment was satisfactory for indoor and overhead outdoor use. CCA treatment increased the service life of both green and dry bamboo by at least twice. Two small holes made in each internode before pressure treatment gave split-free bamboo.

Chang-LF; Chen-SW; Chu-CM; Ma-EP.(1979) carried out studies on the biology and control of the beetle *Dinoderus japonicus* Lesne in 1976-77. There was one complete generation a year. Adults and some larvae overwintered within infested bamboos. Adults emerged from such sites in spring and bored into freshly cut bamboos. Females laid a total of 30-142 eggs during their life-span of up to 200 days. The egg, larval, prepupal and pupal stages usually lasted 60, 100, 3-5 and 10-15 days, respectively. Treating infested bamboos with high-pressure steam (at 5 lb and 108 degrees C for 10 min) or soaking them in hot water or solutions of 0.033-0.001% trichlorphon (Dipterex) or 0.0003-0.0005% methamidophos (Tamaron) for 8 h controlled the pest. Infested bamboos should be removed from storage in winter in order to eliminate infestations. in the next spring.

Younus-Uzzaman-M (1994) carried out the preservative treatment of two bamboo species, *Arundinaria falconeri* and *Sinobambusa tootsik*, with CCA (copper-chrome-arsenic) preservative by pressure impregnation, and steaming and quenching methods, and variation in preservative penetration between the two different treatment methods determined. It was found that the pressure impregnation method of treatment was more efficient than the steaming and quenching method.

The Effect of steam treatment and pressure treatment .

Ma *et al* (1980) quoted by Yeh (1994) found that the performance of the mechanical properties of bamboo specimens is weakened with the steaming treatment. On the other hand, the bending strength and impact performance of bamboo specimen is reduced by applying the pressure preservative treatment.

Prevention and control of fungal attack on baskets and handicrafts made of bamboo.

According to Giron, Pablo, Capati (1992): Moulds, stain fungi and decay fungi were observed to infect improperly handled handicraft products made of bamboo, twigs and vines. *Aspergillus niger, Penicillium, Botryodiplodia theobromae, Alternaria tenuissimum [A. tenuissima], Curvularia inaequalis* and *Schizophyllum commune* were the most frequently isolated fungi from samples.

Soaking the raw materials and finished products in 0.1% 2-thiocyanomethyl benzothiazole + methylene bis thiocyanate or 2.5 or 5.0% quarternary ammonium compound for 3 to 5 minutes prevented fungal attack as effectively as NaPCP treatment. Kiln drying prevented the development and re-invasion by moulds, stain fungi and decay fungi. Packing the chemically treated and kiln dried handicrafts in kraft paper eliminated moisture accumulation, thus further arresting fungal development.

Studies on the treatment of green bamboos by different diffusion processes (steaming and quenching and double diffusion), were carried out by Singh-B; Tewari(1981.) Round and half-split specimens of *Dendro-calamus strictus* were treated with the same chemicals by quenching following hot water (85-88 degrees C) or steam treatment, and by double diffusion using combinations of the simple salts. Steam treatment significantly improved absorption compared with simple immersion. All treatments in the entire study gave adequate retention with an appropriate schedule.

SEASONING OR DRYING OF BAMBOO

Generally, bamboo just felled is immediatly used in construction of houses and structures and it dries while the structure is being built. Bamboos that are going to be used in temporary constructions dont need to be dried. The only problem that occurs in temporary structures when green pieces of bamboo are used is that the ties become loose once the bamboo pieces become dry because they shrink and their diameter becomes smaller. This can produce the collapse of the structure.

Felled bamboos that are going to be used in permanent constructions or structures with very fine details must be air dried for at least two months, before making perfect joints in their ends with drills, saws or similar tools. To use thesetools on green bamboos is not recommended.

It is very important to air dry or kiln dry long bamboo boards and splints when they are going to be used in the manufacture of laminated pieces for structural purposes or for furniture or for the manufacture of plybamboo and others composite materials. As was mentioned earlier, the moisture content of the bamboo culms varies widely among species, and among individuals culms. In green bamboos, the moisture content decreases from bottom to top. But after air drying, the moisture content does not vary greatly from the bottom to the top of the culm For example, in the studies conducted by Prawirohatmodjo (1988) in several species from Indonesia the moisture content at the base, middle and top of green *Bambusa arundinacea* was 48.5-38.5-31.6 %. After air-drying it was 15.7-15.6-15.2 %. In green *Gigantochloa atter it* was 94.2-71.8-50.9 %. After air -drying : 14.1-14.5-14.7 %. Seasoning of bamboo is accomplished either by air drying or kiln drying. The moisture content in bamboo and timber is commonly determined using electrical instruments known as moisture meters.

1.-Air drying.

Air seasoning under cover is the most recommended method for drying round culms and transformed culms in longitudinal sections, in splints or in bamboo boards. For air-drying roud bambdos it is recommen-ded to stand them in upright position. If they are laying horizontally, these require double drying time. The air seasoning behavior varies according to the specie. Sharma studied the air seasoning behavior of 9 Indian species and he came to these conclusions: *Dendrocalamus membranaceous* was very easy to season, fine surface cracks sometimes appeared in the inicial stage of drying, but closed subsequently. *Bambusa arundinacea* seasoned without much degradation, mature culms dried rather slowly, very little cracking occurred. *B. nutans* dried fairly rapidly but was liable to crack and collapse. *Dendrocalamus strictus* took a very long time to dry, mature culms dried very satisfactorily without cracking. *D. hamiltonii* dried quite rapidly without much degrade.

Liese (1985) points out that the different seasoning behaviors of bamboo species is chiefly due to the different culm wall thickness, which is the most important factor controlling the rate of drying. The bottom part, therefore takes much longer to season than the top portion. The rate of drying of inmature culms is generally faster than that of mature, ones, but since the former have a higher moisture content they require a longer time. In the initial stages drying occurs quite rapidly, but slows down gradually as drying progreses.

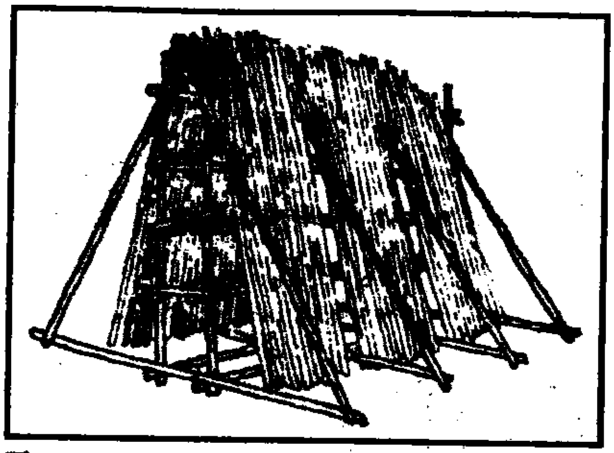


Fig. 10.17 *For air-drying bamboo culms it is recommended that they be stood in an uprigh position. If they are lying horizontally they will require double drying time.*

Seasoning defects. According to same author, several defects may occur during seasoning of round culms. They be may due to the poor initial condition of the culm, excessive sthrinkage during drying or both. End splitting is not so common or severe as in timber.

With all species, surface cracking can occur during drying. Cracks start at the nodes but their extent depends on the species and wall thickness. Thick-walled mature bamboo is especially liable to cracking. A deformed surface of the round cross section of inmature bamboo (less than two years old) is common. Thick walled species evince an uneven outer surface and cracks quite often develop on the inner side of the wall. Considerable shrinkage can take place in the middle part of the internodes, which become concave.

Collapse is a most serious seasoning defect. It occurs during artificial as well as natural drying processes and leads to cavities on the outer surface and to wide cracks in the inner parts of the culm. Green bamboo is apt to collapse due to differential tension during drying. This shrinkage takes place in the early stages of seasoning. The outer fiber bundles are pressed together but the inner ones are stretched and this causes severe stress. Immature bamboo is more susceptible to collapse than mature bamboo. Since drying is more rapid during the dry season, collapse occurs more often than during the rainy season. The lower portion with thicker walls is more susceptible to collapse than the upper portion. Slow drying bamboo species are apparently more liable to collapse than others.

2.-Kiln drying

Kiln seasoning is recommended only for drying splints and bamboo boards. For round culms, kiln drying is considered uneconomical and can be used under controlled condition. As mentioned earlier, rapid drying in kilns may lead to surface cracking and splitting due to excessive shrinkage and, consequently, it is considered impractical.

PART 5

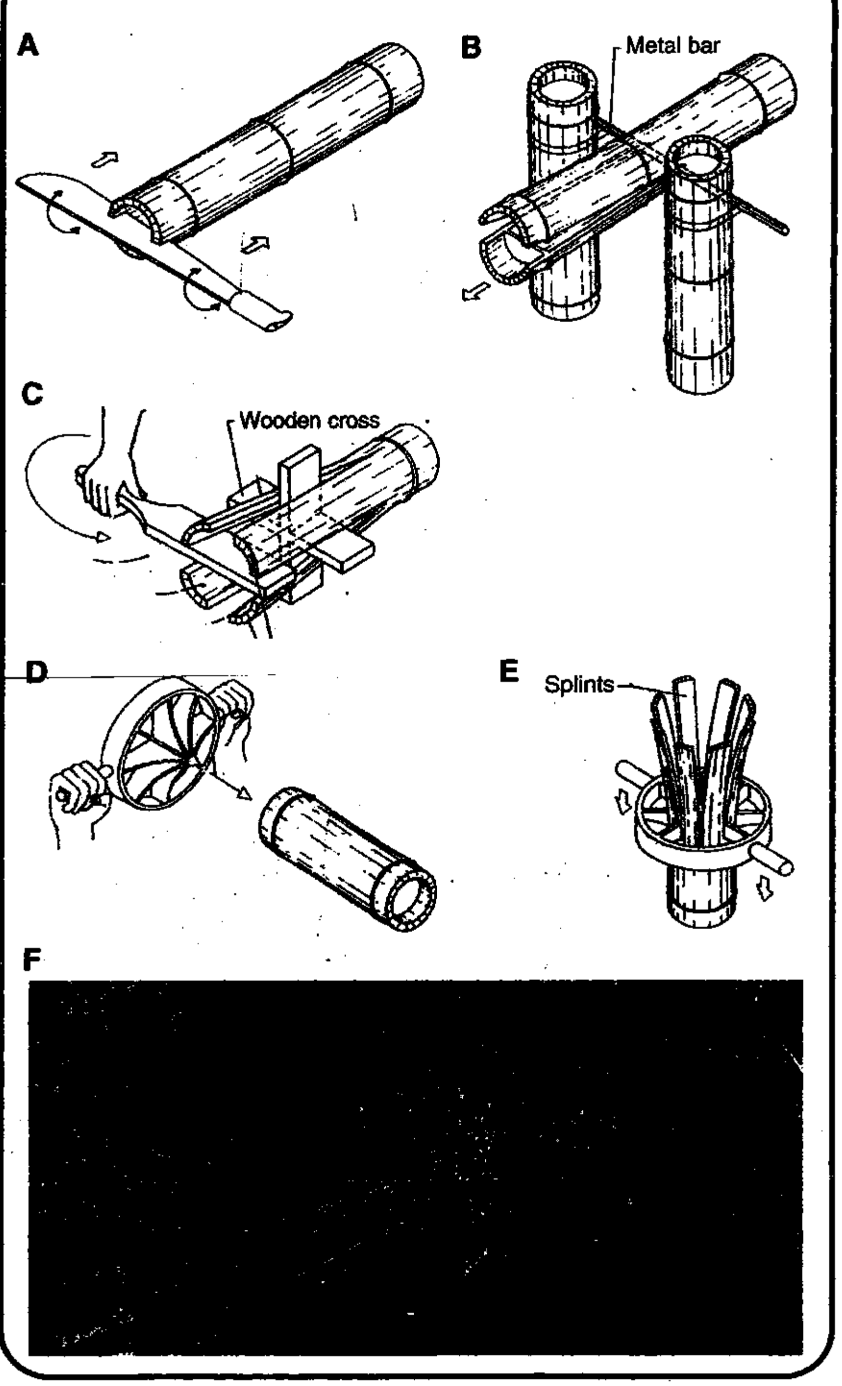
MANUFACTURE OF SINGLE AND COMPOSITE MATERIALS

Bamboo fence (Riou's drawing)
Geografia Pintoresca de Colombia in 1869.

9 MANUFACTURE OF SINGLE BAMBOO MATERIALS

MANUFACTURE OF CHANNELS, SPLINTS AND STRIPS OF THE CULM

Fig.11.1 .-Manufacture of channels and splints



Bamboo does not have radial cells whicht in the case of timber increases its shear strength parallel to the axis. This is the reason why bamboo has very low shear strength parallel to the axis and the presence of nodes does not have a significant effect on shear strength. This low shear strength and the straight fibers parallel to the axis of bamboo is an advantage insome cases for example, in the manufacturing of bamboo channels, dividing a bamboo culm in two longitudinal pieces that can be used as roof tiles, gutters, for the transportation of water in rural acueducts or as a decorative pieces.

On the other hand, short sections of the culm (1 meter long) can be divided radially in splints with the same width (2-3-4 or 5 cm. wide), depending on the number of knives fixed to the radial hand knives tool. The diameter of this radial tool has to be equal to the maximum diameter of the bamboo commonly used plus ten centimeters.

For example, the maximum diameter of the species of *Guadua sp*. that we have in Colombia is 20 cm (guadua de castilla), so the diameter of of the radial tool has to be 30 cm.

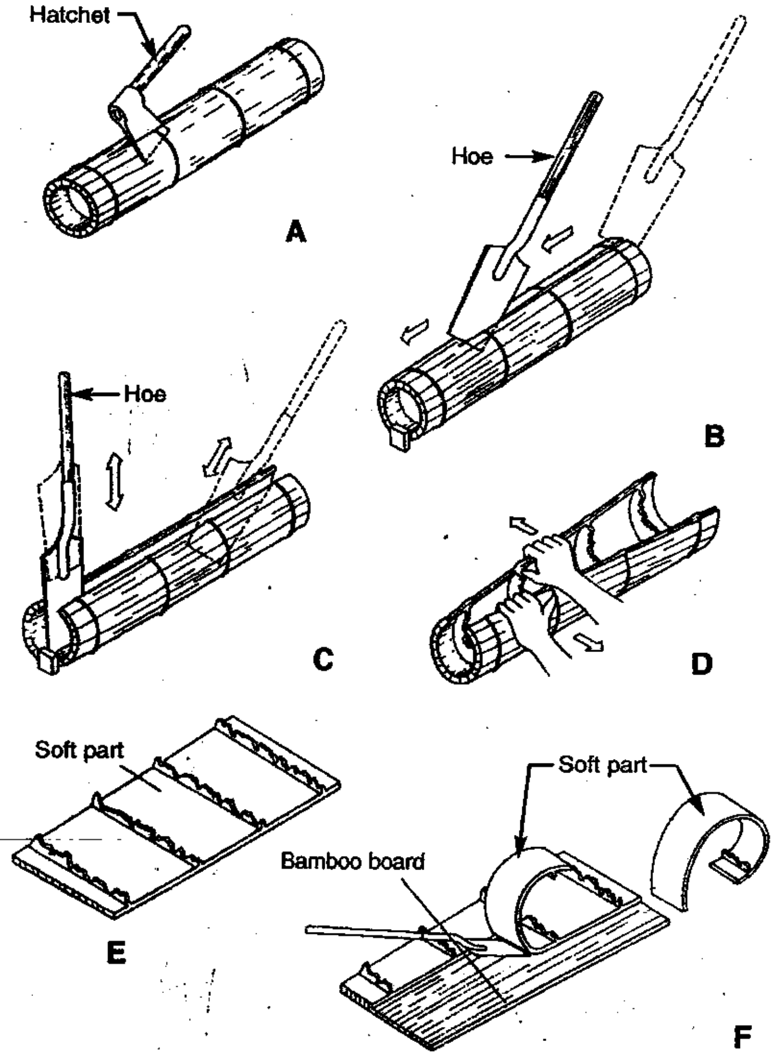
The same radial handknife can be used industrially in a special machine where long bamboos (4, 6 or 8 meters long) are pushed against a fixed radial knife.

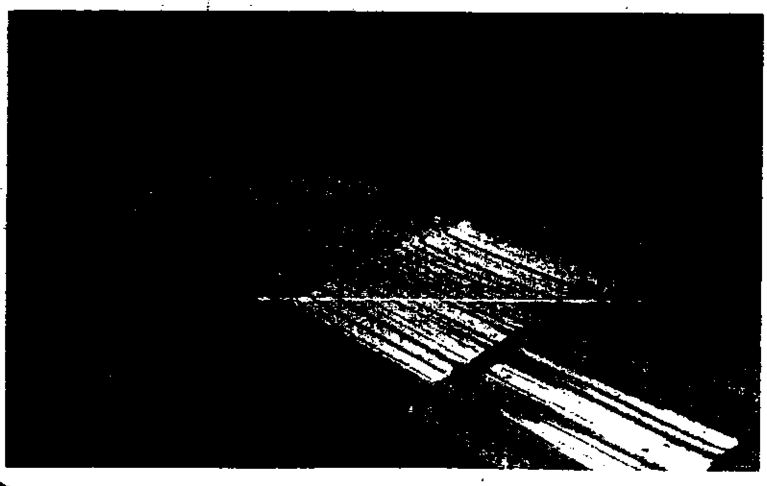
The bamboo splints, 2- 4 cm wide, are used for floors in houses located in very warm climates, in the construction of plastered walls, in hen houses etc. The strips for the manufacture of baskets and mats are also taken from splints.

See manufacture of bamboo cables in the section Reinforced concrete with bamboo cables.

MANUFACTURE OF BAMBOO BOARDS

Fig. 11.2 Manufacturing process





F. *Manufacture of bamboo boards. Removing of the interior and soft part of the culm.*

Bamboo boards are sections of the giant culms that are opened out flat. In Colombia, the complete section of the culm, generally 4 meters long, is opened out flat; following the method explained in Fig. 11.2. But in India and other countries of Asia, the culm section is divided into two longitudinal parts and each of them is opened out flat.

Bamboo board is a construction material with more applications than wood boards or any other material. In the construction of houses, it is used in floors, walls, ceilings, roofs, in concrete forms, in boxes or voids, and as a base for plastered walls and ceilings. It can also be used in the manufacture of excellent plybamboo boards and in the construction of laminated beams or structures or composite beams.

For the manufacture of bamboo boards, the culm section is supported at the ends. With a hatchet or small ax, parallel cuts at a distance of one to two centimeters from each other are made in each of the nodes, with enough force to produce a crack in the node and the two internodes. (A)

Once the above operation has been carried out in all of the nodes, a flat shovel is introduced in the longest crack from one end to the other of the section cutting simultaneously the internal diaphragms. Then the culm is opened with the hands and the diaphragms are removed. With the flat hoe, the soft part of the internal culm wall is removed. (F) which is the part of the wall most attacked by the borers.

Fig 11.3

ROTARY AND SLICED BAMBOO VENEERS

The term veneer is commonly applied to any one of the thin layers or sheets of wood cut or sawed from a log, that are glued or otherwise bonded together to form plywood boards. In the case of bamboo, there are several methods for obtaining different types of veneers. These methods are: rotary, sliced and sawed veneer,which require special machinery, and two handmade methods for the manufacture of bamboo veneer using the external or internal part of the culm.

1.-Rotary veneer (Fig.A).

This type of bamboo veneer is used in the manufacture of non structural plybamboo and for overlaying inferior plywood with decorative purposes. This veneer is peeled from round sections of giant bamboos. Since the bamboo culm is hollow and the diameter and thickness of the wall decrease from the base to the top, it is only possible to manufacture bamboo rotary veneer from sections of giant culms which include 1 to 3 internodes (about 50-60 cm long) with a minimum wall thickness of 10 mm. These sections must be cut with a circular saw from the center part of the culm which has the longest internodes, leaving the 2 nodes at the opposite ends. The culm sections are boiled at 100 degrees C for about 3 hours to soften the material. According to Takeuchi (1968), this treatment produces a high quality veneer and decreases the culm's cracking.

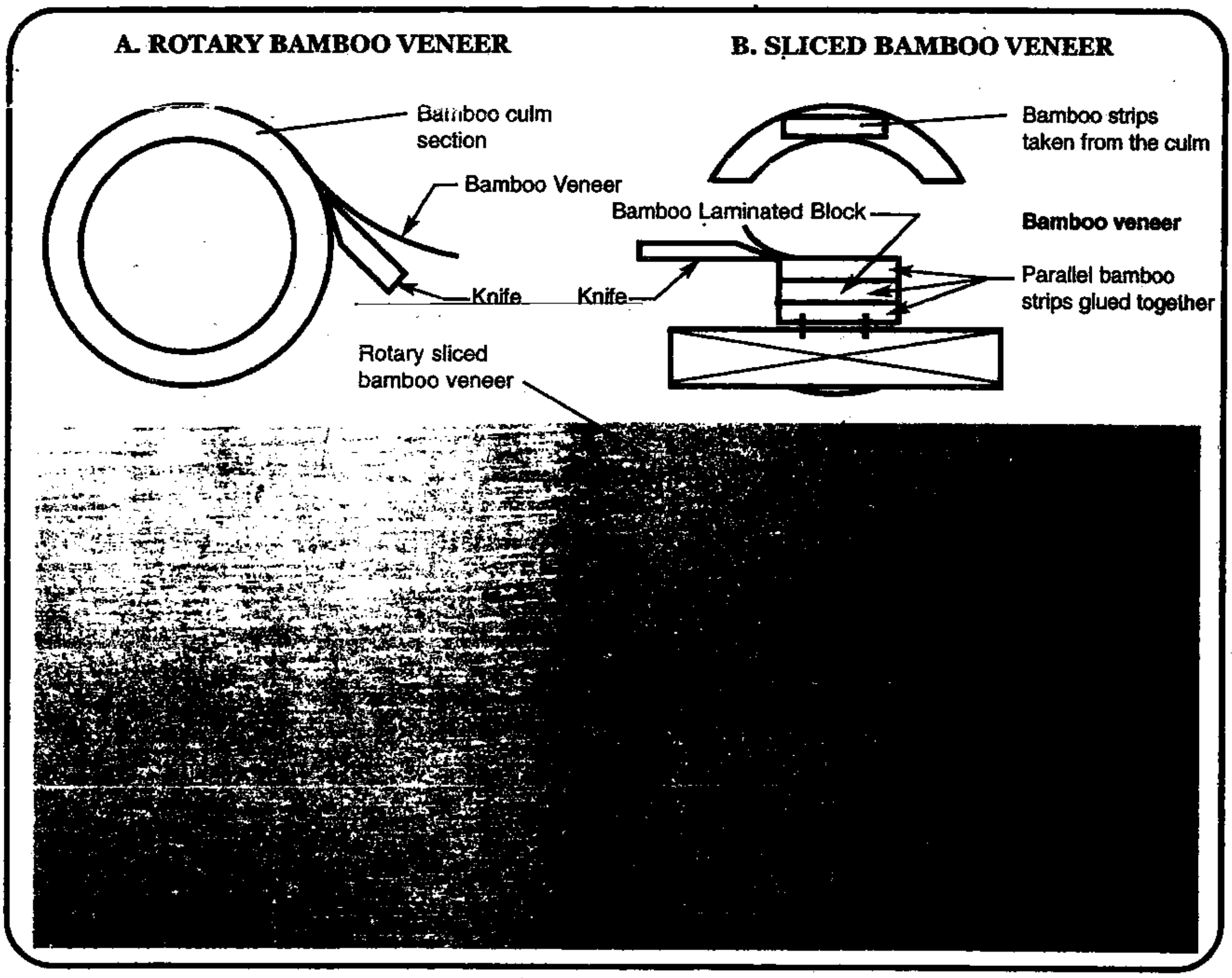
After the sections are softened, the nodes at the opposite ends are removed and the cut is made at right angles. The final length of the section has to be the same as that of the lathe. Then they are fixed to a small rotary cutter which works at a speed of 30-40 rpm. Generally the veneer is 3-4 meters long, depending on the thickness of the culm wall. The bamboo veneer is air dried or dried with hot air to about 12% moisture content. The pressing can be done in a cold or a hot press.

2.- Sliced veneer (Fig. B).

Sliced veneer is produced from large glued laminated bamboo blocks which consist of parallel strips glued together in the same direction. In this case, the main block is also located parallel to the knife.

3.- Sawed veneer.

In this case, the large block which consists of several small blocks glued together in different positions is sawed perpendicular to the block axis in the same way as a loaf of bread is sliced.



INTERNODAL BAMBOO VENEER TAKEN FROM THE SURFACE PART OF THE CULM WALL

Fig. 11.4

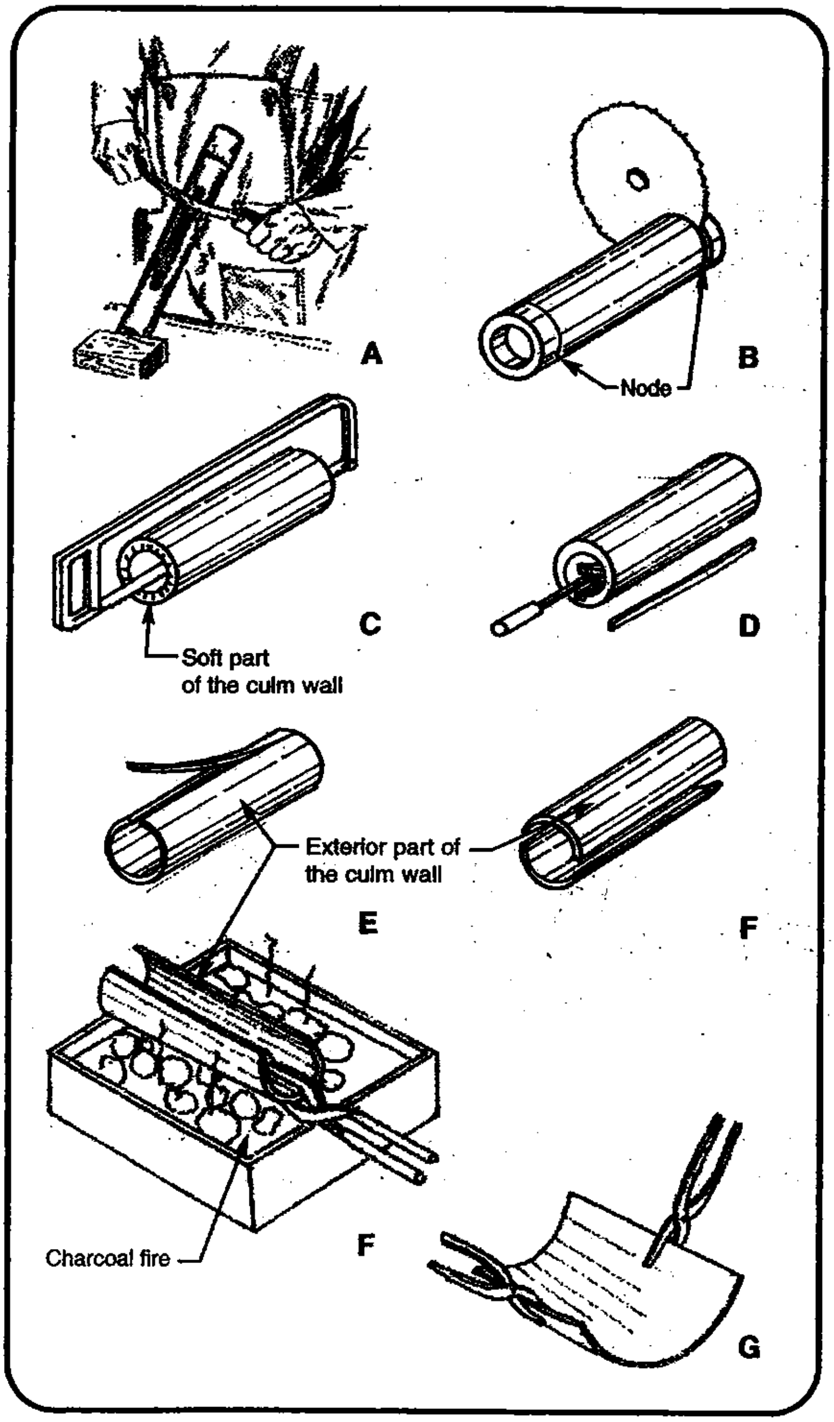
MANUFACTURE

There are two methods for manufacturing veneer from the external part of the culm.

The first method consists of using a small rotary bamboo veneer machine, as explained before. The second method is manual and consists of opening out flat the whole internode or the two longitudinal half sections or channels taken from the internode. Then the soft interior part of the wall is removed, leaving only the external veneer.

As was explained before, the external part of the culm wall of the internode is denser and three or four times stronger than the inner part of the wall. For this reason, the exterior part, which is about 2-4 mm thick (depending on the species), has many applications in the manufacture of furniture, plates, ornaments, floor boards, arts and crafts and particularly in the manufacture of cigarrette and candy boxes, as shown in Fig. 11.6.

For this purpose, internodes from the central part of culms of giant bamboos which have the longest internodes and less parenchyma and diameters from 12 to 18 cms are used. This part of the culm is divided into sections consisting of an internode, with the two nodes, which are cut with a circular saw. Then in each internode the whole cuticule or skin surface (about 0.2-0.4 mm) of the bamboo internodes is removed using a curved knife with two handles (called Sen in Japan). Once the cuticule has been removed, the nodes are removed, and then the soft interior part of the culm wall, about 3/4 of the culm thickness, must be removed manually using a long 1/4" wide chisel or a small radial planer.



APPLICATIONS OF THE SURFACE BAMBOO VENEER

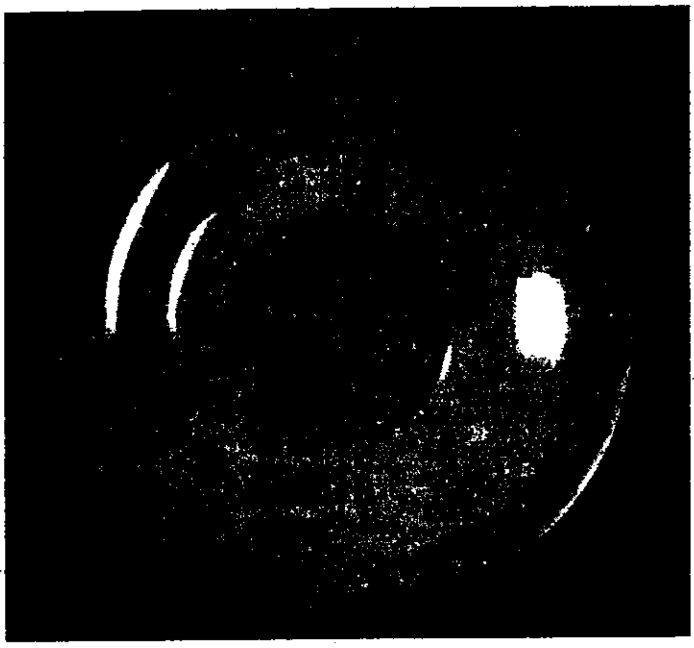


Fig. 11.5 *Plate manufactured with internodal bamboo veneer using a hot plates press.*

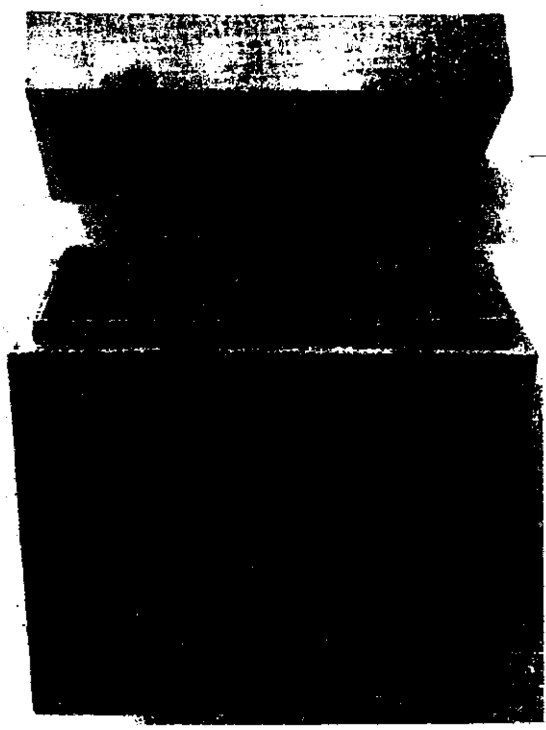


Fig. 11.6 *Cigarret box manufactured in Japan with exterior internodal bamboo veneer.*

Manufacture of plates and boxes

Once 3/4 of the internal part of the cylinder wall has been removed, the whole cylinder can be divided longitudinally into two sections (Fig. F), or if the whole cylinder is going to be opened out flat, a 1 cm wide strip is cut along the cylinder (Fig. E) and then it is dried in the sun. The cylinder or the half sections are heated (vertically) in a boiler with a pressure of 3-4 kg/cm2 for about 1 hour, and then they can be opened out flat and passed through a roller with hot steam or pressed in a hot plate press.

If there is no boiler, this step can be done manually as follows. Heat the materials to a temperature of 130°-150° C over a charcoal fire (Fig. F), placing the exterior part down. Judging the timing by white bubbles on the cut end, press the bamboos between jigs and cool naturally (Takeuchi 1968).

For flattening the internodes with knots removed, Ishii (1990) recommends heating them for about 15 hours at 95-100° C with 100% relative humidity while applying a load to them perpendicular to the fiber direction, and then heating for about 10 hours at 100-140° with 30% relative humidity before returning slowly to room temperature.

It is important to point out that the internodal bamboo is the strongest part of the culm and has better engineering properties than conventional materials. See Mechanical Properties.

INTERNODAL BAMBOO VENEER TAKEN FROM THE INTERNAL PART OF THE CULM WALL

Fig.11.7

MANUFACTURING METHODS AND USES

Ranjan, Iyer and Pandia (1986), in their book *Bamboo and Cane Crafts of Northeast India*, describe the methods used in the manufacture of bamboo containers or boxes of different shapes and sizes depending on their function, using the internal part of the internode wall as veneer. This technology is seen in India in Manipur, Arunachal Pradesh, and Nagaland. For this purpose are used only the internal part of the culm wall of the internodes (without nodes) of the *sondak* bamboo, known as *natt* in Imphal Valley, is a thin walled bamboo with a diameter of about 6cm and an internode length of about 90 cm

FIRST METHOD

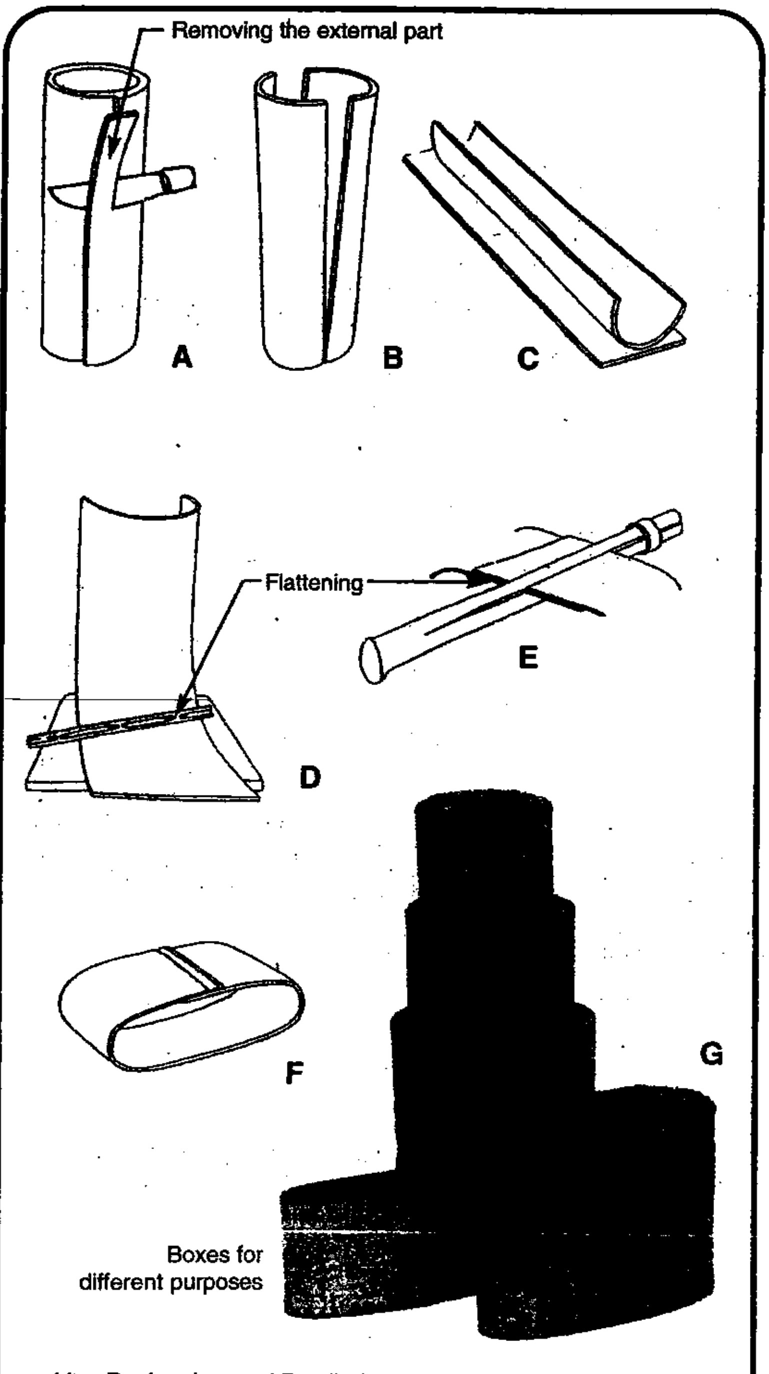
A- The external surface or outer skin of an i nternode section of a freshly-cut bamboo is peeled to a wall thickness of 1 to 1.5 mm.

B- The internode is split along its length in halves. A toxic resin, *kharu*, is collected in small bamboo tubes which are inserted into the trunk of the *kabong* tree. A little of this resin is then mixed with water and aplied on both surfaces of each section of bamboo. According to Khoibu craftsmen, this resin prevents the bamboo from developing cracks while it is beign heated, but the chemical effect of the resin is not clear.

C- Each half is then held over a small fire and heated evenly along the length. This causes it to become very pliable and the circumferece slowly opens out.

D- The curve of the culmis flattened a stick is used to press the bamboo flat on the ground The width of the sheet thus formed is half the circumference of the culm. It is also possible to make a sheet with a width equal to the entire circumference of the culm.

E- While the sheet is still hot it is formed into the desired shape. Traditionally, all boxes were made this way. The length of the heated board is bent and the ends overlapped and held in a split-bamboo clamp, a very simple device made from a length of thick bamboo splint which is partially splt in half along its length. The joint is held between the two splits, the ends of which are held together by a rubber band. The other half of the culm is heat flattened, wrapped around the oval and held in shape. This becomes the lid that matched the box . The overlaped ends are held together by



After Ranjan, Iyer and Pandia (1986)

two rows of stiches made with cotton thread (Fig. F). The container and the lid are arranged so that the overlapping joints on each are on opposite sides of the box.

A piece of heat-flattened bamboo, a flat piece of wood or a tangential slice of a thick-walled bamboo culm, depending on the required size, is cut to fit into each oval to form the base of the container and the top of the lid. A narrow bamboo split is wrapped around the edge of the container at the base and nailed to hold the base in place. The lid is finished in similar manner.

Traditionally these oval boxes had stitched and nailed joints, but they are now made by sticking the joins with adhesive.

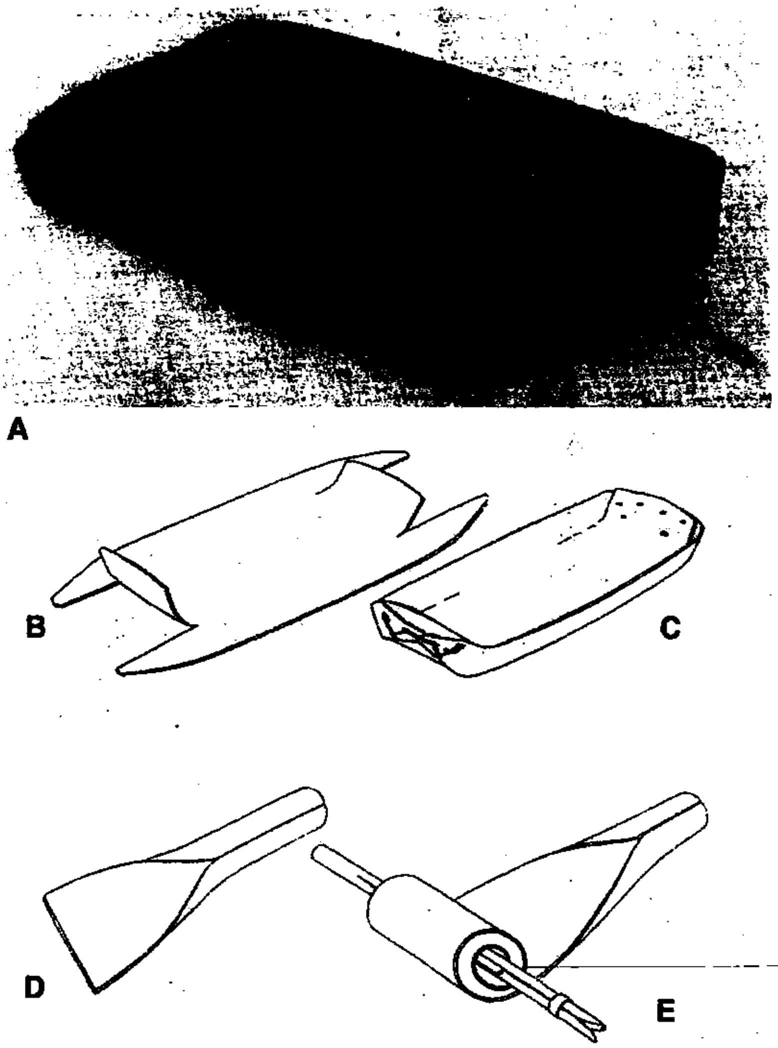
SECOND METHOD

In india, the Chang Naga also have a process of heat-flattening bamboo. they use the *talong* bamboo which must be harvested in December or January " before the top of the culm begins to droop downwards. This means that approximately seven months-old culms are used. A length of internode freshly-cut is peeled and the ends plugged with leaves and grass. The bamboo is evenly heated over a fire till it begins to swell out in the centre due to the expansion of the trapped hot air in the tube. At this point the internode is slit along the length, and a stick used to press the pliable bamboo into a flat sheet

Dao cases, ~~small~~ boxes, rice-plates and large drums are made from a heat flattened bamboo board, and all the forming is done while the sheet is hot and pliable. Shallow rectangular trays made by this process are used as rice plates. They are made by cutting and folding the sheets to form the sides of the tray. The folded ends are are held in place with cane stitches

Large drums used to store rice beer are fabricated from the heat-flattened sheets. A number of pieces are overlapped and stitched with cane to form a cylinder of a required diameter. The base is also made of overlapped pieces and stitched to the cylindrical sides with can splits. The resin, *papoo*, of a tree is used to seal the joints . This resin is not drained from the tree, but the bark is pounded, mixed with water and boiled to form a paste. This is applied in all the joints, and on drying renders the drum waterproof.

Fig.11.8 Manufacturing of rice plates



F. Manufacturing of boxes and drums

After Ranjan, Iyer and Pandia (1986)

MANUFACTURE OF BAMBOO COMPOSITE MATERIALS

10

WHAT ARE COMPOSITE MATERIALS?

Composites offer several other advantages over conventional materials. These may include improved strength, stiffness, weight, thermal properties, corrosion resistance, impact resistance, and wear resistance.

Most man-made composite materials are composed of two materials: a reinforcement material called *fiber* and a base material called *matrix*, in which the fiber is embedded. Examples of composite materials are concrete reinforced with steel or bamboo, and epoxy reinforced with bamboo fibers.

All bamboos are natural ligno-cellulosic composite and are composed of fibers (bast fibers located in the vascular bundles) and a matrix (parenchyma thin walled cells around vascular bundles, vessels and sieve tubes in vascular bundles). Natural bamboo can be taken as a unidirectional fiber-reinforced composite and its fiber volume fraction has an intimate relationship with its mechanical properties. The distribution of bast fibers of bamboo along the radial direction shows a gradient trend, and this undoubtedly influences its mechanical properties, as do synthetic fiber-reinforced composites.

Composite materials are commonly formed in three different ways: (1) fibrous composites, which consist of fibers of one material in a matrix material of another, (e.g. reinforced concrete with bamboo cables); (2) particulate composites, which are composed of particles of one material in a matrix of another (e.g. bamboo particleboard), and (3) laminated composites, which are made of layers of the same material or different materials, including composites of the first two types (e.g. bamboo or wood laminated beams).

Composite materials are usually classified by their matrix (i.e. as metal-matrix, ceramic-matrix (e.g. carbon, SiC, Si3, Si3N4 and Al2O3), and polymer-matrix composites) and their reinforcements (e.g., continuous fibers, discontinuous fibers, whiskers, particulates, and platelets).

The stiffness and strength of fibrous composites comes from fibers that are stiffer and stronger than the same material in bulk form. Shorter fibers, called whiskers, exhibit better strength and stiffness properties than long fibers. The matrix material keeps the fibers together, acts as a load transfer medium between them and protects them from exposure to the environment.

The most important problems in the current study of composite materials are the following: (a) Brittleness of continuous fibers and difficulties in interface design. Most of the reinforcing continuous fibers with high strength and modulus are brittle, especially those made with ceramics (e.g. carbon, etc.). (b) Debonding or pull-out of short fibers from the matrix, causing failures in the reinforcement (Zhou 1994).

Two parameters are commonly used to measure the relative mechanical advantage of composite materials. One parameter is called the specific modulus and is defined as the ratio between the Young modulus (E) and the density of the material. The other parameter is called the specific strength, and is defined as the ratio between the strength and the density of the material.

In nature, we can find that all biological materials are composites, without exception. Examples of naturally found composites include wood, where the lignin matrix is reinforced with cellulose fibers, and bone, in which the matrix made of minerals is reinforced with collagen fibers. Since ancient times, we can find examples of man-made composite materials, which include adobes reinforced with straw, used to keep the clay from cracking, and the use of bamboo culms in the reinforcement of adobe and mud walls in Peru and China.

Advanced composite materials such as graphite/epoxy, Kevlar/epoxy and boron/aluminum composites have been applied in the aerospace industries, and now in commercial industries. However, their high cost prevents extensive civil applications. To lower the cost of composite materials, many biomaterials have been investigated as reinforcements, among them them bamboo, with excellent results.

A bamboo lamina or ply is a typical sheet of composite material. It represents a fundamental building block for composite laminates. A lamina may consist of fibrer, matrix, coupling (chemical) agents and fillers. The fibers can be continuous or discontinuous, woven unidirectionally, bidirectionally or randomly distributed.

Unidirectional fiber-reinforced laminae exhibit the highest strength and modulus in the direction of the fibers, but they have very low strength and modulus in the direction transverse to the fibers. Discontinuous fiber-reinforced composites have lower strength and modulus than continuous fiber-reinforced composites.

A laminate is a collection of laminae stacked to achieve the desire stiffness. For example, unidirectional fiber-reinforced laminae can be stacked so that the fibers in each lamina are oriented in the same or in different directions. The sequence of two or various orientations of a fiber-reinforced composite layer in a laminate is termed the lamination. The layers are usually bonded together with the same matrix material as that of the laminae.

STRUCTURAL ADVANTAGES OF NATURAL BAMBOO COMPOSITES

According to Li,Fu,Zeng, Zhao and Zhou,1994, the tensile strength of bamboo can be as high as 530 MP, equal to or greater than that of most aluminum alloys. If we take density into consideration, the tensile strength to density ratio of green bamboo (442.1 N mg^{-1}) is even comparable with that (401.8 N mg^{-1}) of ARALL (Aramid-reinforced aluminum laminates) (Shu and Tang, 1989). It is reasonable to assume that the biological structures which survive have a successful level of optimization after millions of years of natural selection and evolution. Besides this, bamboo has also been applied in natural plant fiber reinforced composite materials.

Unfortunatelly, however the bamboo node has often either been neglected or evaded, except in the investigation of its anatomical structure. For example, in Shin and coworkesrs' report (1989), only bamboo internode was used as reinforcement. In fact, as an integral part of the bamboo cylinder, the nodes play an important role in preventing the cylinder from structural buckling, in strengthening bamboo's rigidity. the purpose of this paper is to determine the distinguishing features of the macrostructure of bamboo and the function of bamboo nodes.

Analysis of the bamboo internode

Heterogeneity, porosity, and anisotrophy of bamboo are its important features, as far as its mechanical properties are concerned. This usually means that the average values across the thickness direction are quoted rather than those of specific part of the bamboo culm; in fact, its mechanical properties change significantly from the outer green bamboo to the inner surface (pith-ring).

So in this work we separa-ted the bamboo culm into several layers and measured the mechanical properties of each layer separately the changes on bamboo's properties along the radial direction are obvious.

In green bamboos they decrease from the outer to the inner surface but the density curve raises at the inner surface; tha is because of the greater density of the pith-ring compared with that of the near part of the bamboo culm. Bamboo is a natural long- fiber-reinforced compositemateria and its constituents can be classified as follows:

Reinforcement: Bast fiber in vascular bundles, i.e. fiber strand and sclerenchyma sheath
Matrix: Thin-walled cells around bascular bundles
Vessels and sieve tubes in vascular bundles

Among the constituents, only the fiber strand and fibers in the sclerenchyma sheath, i.e. bast cells, have a close relation with bamboo's mechanical properties. By using an automatic image analyzer, the distribution of the bamboo's fiber volume fraction V_f was measured.

It is well-known that, in fiber-reinforced composite materials the V_f of the components controls their mechanical performance. For bamboo, the same regularity does exists, the changing trends in tensile modulus and strength, as well as flexural strength, versus V_f along the radial direction of the bamboo cylinder. There is also a good linear correlation between the mechanical properties and the V_f.

Equations (1), (2), and (3) give the best fit of the flexural strength (σ_F), tensile strength (σ_T), and modulus (E_T) versus the V_f; the coefficients of correlation are 0.9953, 0.9950, and 0.9921 respectively.

$$\sigma_F = 7.99\,V_f - 113.73 \quad (1)$$

$$\sigma_T = 11.88V_f - 121.92 \quad (2)$$

$$E_T = 1.017V_f - 16.93 \quad (3)$$

The reason the linear correlation between bamboo' s mechanical properties, such as tensile strength, and itsV_f, is so good is as follows: For long-fiber reinforced composites, the tensile strength parallel to the fiber direction is governed by the "rule of mixtures", Eq. (4)

$$\sigma_c = \sigma_f V_f + \sigma_m V_m \quad (4)$$

where σ_c, σ_f, and σ_m are the tensile strength of the composites, fiber, and matrix, respectively, and V_f and V_m are the volume fraction of the fiber and matrix. In bamboo, the matrix is composed of thin-walled cells, vessels and sieve tubes, thus σ_m is much lower than σ_f and therefore σ_c approximately equals $\sigma_f V_f$. This is why the V_f of bamboo is the dominant parameter for its mechanical properties.

Another important and remarkable structural feature of bamboo is the non uniformity distributed nodes.

EXTRACTION OF BAMBOO FIBERS AND THEIR USE AS REINFORCEMENT IN COMPOSITE MATERIALS

In India, Deshande, B. Rao and L Rao (2000) investigated the fiber extraction from bamboo strips and the use of these bamboo fibers as reinforcements for polymers. A combination of chemical and mechanical methods was used for the extraction of bamboo fibers. Conventional methods of the compression molding technique (CMT) and the roller mill technique (RMT) were explored for the mechanical separation. The bamboo fibers were characterized and tested for structure and their mechanical properties were evaluated.

The bamboo fibers obtained from CMT and RMT were used to make unidirectional composites. The results demonstrate that bamboo fibers can be extracted consistently and used successfully as reinforcements in polymeric composites. Through this study, quantitative results are available for further and more accurate design of bamboo reinforced composite materials.

Delignification

The chemical constituents of natural fibers can be classified into cellulose and lignin. Lignin plays the role of binding the fibers of cellulose. Alkaline treatment is one of the standard procedures in the pulp and paper industries for lignin removal. Lignin can be dissolved in sodium hydroxide (NaOH) solution and then the cellulose fibers can be extracted with relative ease. NaOH causes the dissolution of lignin by breaking it into smaller segments whose sodium salts are soluble in the medium.

In this investigation, fibers were obtained from commercially available bamboo strips, which were from 1.5 to 1.75 cm wide and in the range of 0.65-0.75 mm thick. At present, very few guidelines are available regarding the alkaline treatment of bamboo and its effect on obtaining bamboo fibers.

The strength of the NaOH solution and the time for soaking have to be chosen on the basis of a series of experiments to maximize the ease of fiber separation. A very strong NaOH solution and a long soaking time will lead to greater lignin dissolution. In this investigation, alkaline treatment was only used as a tool for the facilitation of fiber extraction therefore, the parameters were chosen to optimize separation of bamboo fibers, rather than for maximum lignin removal. The total lignin content of bamboo was found to be 37%, using the analytical.

The bamboo strips were soaked in 0.1 N NaOH solution for different periods. After a series of experiments, 72 hours was found to be the optimum duration of chemical treatment, based on the ease of fiber separation. Weight loss, due to loss of ligneous material, for bamboos strips was 18% after 72 hours of alkaline treatment. After removal from the NaOH solution, the strips were washed with water and dried at room temperature for 1 hour. Then they were subjected to mechanical processes for completion of fiber separation.

Mechanical techniques for fiber separation

A combination of chemical and mechanical processes is used in pulp and paper industries for pulping. After the chemical treatment, discs and rollers are used as the means of supplying mechanical energy to facilitate fiber separation. In this study, two methods were explored for mechanical separation of bamboo fibers from the alkaline treated strips These are CMT and RMT, both of which are widely used to process polymers and composites for a variety of applications. Mechanical separation processes have to be operated so that sufficient stresses are generated to complete the process of fiber separation. However, a very high level of stresses will cause abrasion and fracture of the fibers. In this study, both methods were optimized for ease of fiber separation with negligible deterioration in fiber properties

In the CMT, a bed of strips was placed between two flat plattens and subjected to a constant load of 10 tons. Compression time and the starting bed thickness are important parameters that have to be optimized to obtain good qulaity fibers. After a series of trials, a compression time of 10 seconds was chosen for the bamboo fiber separation. The starting thickness of the bed of alkaline treated strips in the CMT was kept at 1.25- 2 cm.

In the RMT, the bamboo was forced between two rollers, one of which was fixed and the other rotated .The diameter of the rollers was 7 cm, and the separation between the rollers was 0.1 mm for a strip thickness of 0.75 mm. The speed of the rotating cylinder was 60 rpm. Both methods yielded flattened strips of bamboo. These alkaline and mechanically treated strips can be easily separated into individual fibers.

With both methods, strips of varying lengths can be processed. In this study, three different lengths of strips were processed in order to study the relative effectiveness of the techniques with varying strip size. It was found that the RMT was inappropriate for small strip sizes.(< 8.5 cm) due to the limited diameters of the rollers. Similarly, compression mold size was the limiting factor in deciding the maximum strip length that could be processed in CMT. The length of bamboo fibers obtained in this study was in the range of 8-20 cm. This range was appropriate for getting bamboo fibers for applications as reinforcement for chopped-strand mat composites.

Composite preparation

To assess the reinforcing quality of bamboo fibers, unidirectional composites were made using polyester as the matrix. The polyester used was a room temperature curing system with Cobalt Narthanyte as hardener (polyester:hardener, by weight, 2.5:1). CMT was used to process the composite specimens. A bed was prepared as a preform by laying unidirectional bamboo fibers. Subsequently, an appropriate amount of polyester resin was impregnated into the bed. The impregnation and polymerization sequence has to be optimized to obtain void free composites. However fiber deformation and movement should be minimal to yield good quality, unidirectional fiber composites.

Therefore, the time of impregnation, time of curing, and compression pressure are important parameters to be considered to obtain composite specimens for further testing. The setting time for resin was 20 minutes. However, the composite specimens were cured for 24 hours, and the pressure was maintained during the impregnation step. Using the same program, unreinforced polyester samples were also prepared.

Fiber configuration and volume fractions are two of the most important factors that affect the properties of the composite. In this study, the configuration was limited to unidirectional, continuous bamboo fibers, and composite samples were prepared with different volume fractions of bamboo fibers. In addition, fiber populations with different diameters and fibers obtained from both CMT and RMT were used to process the composite.

Fiber and composite testing

It is important to know the properties of fibers, which control the limiting values of the mechanical properties of the composite. The fiber properties are also a good indication of the consistency of the fiber population obtained from different processes. The tensile strength of bamboo fibers was measured to compared different sets of fibers. The objective of mechanical testing of fibers was to calculate the ultimate strength of the fiber and not to evaluate of the stress-strain curves.

Therefore, a simple assembly of fibers was used to evaluate the strength of the bamboo fibers. A set of five fibers of equal length was mounted on a grip and tested at a constant displacement rate of 0.05 mm/min.

The ultimate load carried by the set of fibers and the ultimate extension before failure were measured. The tensile strength was calculated from the ultimate load and the cross-sectional area of the fibers.

The unidirectional composite specimen was made as per the ASTM Standard D790M-86. The length, width, and thickness of specimens were 72, 12, and 2 mm respectively. The volume fraction of fibers in the various test specimens varied from 15% to 30%. A three point bend test with a span length of 50 mm was used to determine the flexural strength and flexural modulus.

Failure load and slope at failure were obtained from the load deflection curves and the strength and modulus were calculated as follows: where w is the ultimate load, L is the length of the specimen, and d is the thickness of the specimen.

All of the tests for fiber and composite characterization were conducted on an Instron Universal Testing Machine.

(Model 4301; Canton , MA).and the fractured surface of composite speciemn was observed using an SEM====

$$\text{Flexural strength} = \frac{1.5\,wL}{bd^2}$$

$$\text{Flexural modulus} = \frac{\text{slope x } L^3}{4bd^2}$$

Results and discussion

The consistency of fibers was examined for geometrical variations, and the variations in diameter for fibers obtained from CMT and RMT were examined. When CMT was used for extraction, the diameters of fiber varied from 0.05 to 0.4 mm. The highest concentration of fiber diameter was between 0.15 and 0.25 mm. Fibers with diameters of 0.05-0.15 and 0.25- 0.40 mm were present in very low concentrations. For the fibers obtained from the RMT, the highest concentration of fibers was in the range of 0.05-0.10 mm. The fibers with a diameter less than 0.05 were found in a low concentration. Finer fibers were obtained from this technique when compared to the fibers obtained from the CMT. There is no significant effect of the initial strip length on the variations in diameter of the fibers obtained after mechanical separation. Since the load application in both techniques was only in the direction perpendicular to length, fibers of the same length as the initial strip length were obtained.

The average diameter of fibers obtained by CMT was larger than that of those obtained from RMT. This result can be explained by the difference between the mechanisms of separation in the two techniques. In the CMT, the compressive stresses exist alone. However, in the RMT, a combination of compressive and shear stresses comes into play. Therefore, for the simple configurations that were used in this study, principal stresses are likely to be higher for the RMT. A spread ratio can be defined as the ratio of the widths of strip before and after the mechanical treatment. The spread ratios of bamboo strips passed through RMT were always higher than those passed through CMT. Therefore. the pressure on bamboo strips passing through rollers is considerably higher than the pressure on the bamboo strips in CMT.

The variation in diameter for a single fiber along its length was higher for fibers obtained by CMT. This can be explained by considering the details of the pressure application in the two techniques. In RMT, the length of the strip passes through uniform pressure conditions. On the other hand, the whole length of the strips was pressurized at once in CMT. The spatial variation in local pressure in CMT would lead to variation in stresses and hence give a higher standard deviation.

The mechanical strength of the fibers was evaluated using the experimental procedure described in the previous section. The tensile strength of specimens from different parts of a bamboo cross section was shown to vary between 100 and 800 MPa by Nogata et al. The calculated theoretical strength of cellulosic fibrils is 810 MPa based on the rule of mixtures. The maximum and average strength for bamboo fibers from CMT was found to be 1000 and 645 MPa respectively. However, the tensile strength of fibers obtained from RMT was considerably lower, with maximum and average tensile strengths of 480 and 370 MPa, respectively. The fibers from RMT have a lower tensile strength as well as lower variations in tensile strength, when compared to the fibers obtained from CMT. It should be noted that fibers from RMT also had a smaller average diameter as well as lower variations in diameter.

The fibers with larger diameters (obtained from CMT) had higher strength compared to the fibers with smaller diameters (obtained from RMT). This behavior is different from what is generally observed in fibers made up of brittle materials, such as glass or metals. The higher strength in smaller fibers in brittle materials is attributed to the lower density of flaws in an otherwise homogeneous material. The opposite effect that was observed in the natural fibers may be attributed to the difference in the structure of natural or polymeric fibers in comparison to the brittle fibers described above. The structure of natural fibers is characterized by a high slenderness ratio, i.e., high surface to volume ratio.

This permits the building of structures with high local curvature (allowing for a greater twist) which allows axial strengths to develop because of high interfiber friction. The probability of interaction between fibrils is higher in larger diameter fibers than in smaller diameter fibers. Higher strength is expected from a fiber with a larger diameter. Thus, the fibers isolated from CMT, which had higher diameters had higher average strength in comparison to the fibers isolated from RMT, which had smaller diameters. The larger the average diameter was, the higher the average tensile strength was.

The surface characteristics of the fibers obtained from the two techniques were examined using SEM. The micrographs of fibers obtained from CMT and RMT at two different magnifications show that the extracted fiber is made up of cellulose fibrils bonded by ligneous material. The size of each fibril is 5-15 μm. The fibers from RMT have organized fibrils along the length of the fibers. On the other hand, fibers from CMT exhibit periodic positions of attachment of resin material and void spaces. The fibers from RMT have a more regular geometry of fibril arrangement than the fibers from CMT. However, the mechanical properties of fibers from RMT are inferior to those obtained from CMT.

One of the factors that can lead to inferior mechanical properties is internal damage due to microcracking in fibrils or ligneous binding material in fibers from RMT despite having an arranged topology. Another set of results, which supports this factor is the effect of fiber diameter on the tensile strength of fibers, regardless of the mechanical treatment used for fiber separation. Since the finer fibers are obtained due to the higher longitude of local stresses, these fibers might have a higher density of internal defects. Hence the fibers obtained from RMT are finer in diameter and more regular in terms of the arrangement of fibrils, but exhibit inferior mechanical properties.

The flexural strengths of composites (75-175 MPa) are significantly higher than those of polyester (20 Pa) in all cases. The flexural strength of polyester can be improved by a factor of 3 to 8 by using bamboo reinforcement. The flexural moduli of composites with CMT fibers increase monotonically with increases in the volume fraction of fibers. However, flexural moduli of composites with RMT fibers were almost the same as that of acetic acid in the samples. Epoxy -coated fibers show an 80.6% weight gain. This is understandable as the crosslinked epoxy does not dissolve in many chemicals but only swells as it is chemically inert.

EPOXY COATED BAMBOO FIBER

As was explained before, the composite material is a combination of at least two chemically distinct materials, created to obtain properties which would not be achieve by any of the components acting alone.

The chemical resistance and tensil properties of epoxy-coated at break of bamboo fibres of *Dendrocalamus strictus*, before and after coating with a high performance epoxy resin (Araldite LY 5052/Hardner 5052 system) have been studied by Rajulu, Reddy and Chary (1996).

The bamboo fibres were soaked in 1 % aqueous NaOH solution for 30 minutes to remove any greasy material and lignin, washed thoroughly in distilled water and dried under the sun for two weeks. The fibres were 22 cm long having rectangular cross-section and thickness varying from 0.1 mm to 0.6 mm. The fibres with a thickness 0.2 mm were selected and cut to a length of 15 cm for studying tensil load at break and to 2 cm for studying chemical resistance.

Glacial acetic acid, conc. nitric acid, conc. hydrochloric acid, conc. ammonium hydroxide, acqueous sodium carbonate (20%) and acqueous sodium hydroxide (60%) were used. The solvents benzene, carbon tetrachloride and toluene were dried using calcium chloride before use. The resin matrix system Araldite was used.

For tensil test, the dried bamboo fibers were soaked in the resin and hardner mixture taken in the ratio of 100 and 38 parts by weight respectively. The soaked fibres were then hanged on a wooden frame in the vertical position and kept in a vacuum oven, maintained at 65° C, for 18 h to complete the curing.

For chemical tests, the short fibers were soaked in the resin mixture. The excess resin was removed by placing the fibres in veritcal position. The fibers were then placed on glazed polyester sheet and cured as described above.

The tensil load at break of the bamboo fibers with and wthout epoxy coating was determined using Michrotech Tensometer employing disc wire chucks. Ten samples were tested in each case and the average tensile load determined.

The chemical resistance of the bamboo fibers with and without epoxy coating was studied using ASTM D543-87 method. In each case, ten preweighed samples were dipped in the respective chemical for 24 h, removed and immediately washed with distilled water and dried by pressing them between the filters papers. The treated samples were the weighed and the % weight loss/gain was determined.

The average tensil load at break of the bamboo fibres before and after coating with epoxy resin was found to be 1.41 kg and 3.4 kg respectively (the average thickness of the coating beiing 100 μm), thus showing an improvement ot 140%.

The percent weight loss/gain for the fibres treated with different chemicals is shown in Table 12-1. It is observed that on acetic acid treatment, both uncoated and coated fibres show gain in weight. Uncoated fiber shows 29 % weight gain indicating the inclusion of acetic acid in the samples. Epoxy-coated fiber shows 80.6% weight gain. This is understandable as the crosslinked epoxy does not dissolve in many chemicals but only swells as it is chemically inert.

In all other chemicals, a decrease in weight is observed for uncoated fibers whereas the opposite is the trend for epoxy-coated fibers, indicating swelling of the epoxy layer because of crosslinking. The weight loss indicates the corrosion of uncoated fibers due to chemicals. In nitric acid treatment, uncoated fibers completely dissolved within 150 minutes.

The above observations clearly indicate that the tensile load at break and the chemical resistance of bamboo fibers increase upon coating them with Araldite LY 5052/ Hardner 5052 system.

In the study, "Development and Testing of Bamboo-Fiber Reinforced Plastic Composites (BFRP)", carried out by Jindal (1986), a composite of bamboo-fibers in Araldite resin (CIBA-CY 230) was developed with the purpose of obtaining a composite with much higher strength and ductility than those of bamboo specimens.

The bamboo used in this study was *Dendrocalamus strictus* cut into smaller pieces, varying from 220 mm to 270 mm, between the nodes (avoiding the portion of the nodes where the fibers are not uniform). Then these pieces were cut into 1 mm thick strips. For facilitating easy separation of the fibers, strips were soaked in water for about 1 hour. These strips were then passed under slight pressure through a rolling mill erating at a slow speed. The rolled strips were again soaked in water for about half an hour and the fibers were separated from the strips using a razor blade. The wet fibers were dried in the sun for two weeks. The fiber section was rectangular with breadth and thickness varying from 0.1 to 0.6 mm.

The results of this study show that the ultimate tensile strength of bamboo is 270 N/mm2 and that of the Ardaldite is 22.7 N/mm2. It can be further observed that the ultimate tensile strength of BFRP composite with 0.8 volume fraction of fibers is 425 N/mm2, which is more or less equal to the ultimate tensile strength of mild steel, the material most commonly used in structural applications. But the density of molded steel is about eight times the density of BFRP composite, showing, thereby, that the specific ultimate tensile strength of BFRP composite is about eight times the specific ultimate tensile strength of mild steel.

Table 12-1 Resistance of bamboo fibers to chemical reagents

Chemical	% change in weight after dipping for 24 h	
	Uncoated fibre	Coated fibre
Acetic acid	+29.0	+80.6
Hydrochoric acid	-14.6	+26.8
Nitric acid	Dissolved	+54.4
Sodium hidroxide	-14.5	+21.1
Sodium carbonate	-36.6	+16.0
Ammonium hydroxide	-10.7	+21.6
Benzene	-35.8	+18.1
Carbon tetrachloride	-36.5	+17.6
Toluene	-19.1	+29.4

EXPERIMENTAL STUDY OF UNIDIRECTIONAL BAMBOO-EPOXY LAMINATE

This study ,carried out by Shin, Xian, Zheng, and Yipp (1989), is an experimental study of unidirectional bamboo-epoxy laminates of varying numbers of laminae, in which tensile, compressive, flexural and interlaminar shear properties were evaluated. The results indicate that the mechanical properties of bamboo-epoxy were comparable to ordinary fiber-glass reinforced plastics. A specific strength 3 to 4 times that of mild steel was recorded. Its mechanical properties were generally comparable to those of ordinary glass fibre composites. The acoustic emission technique was used to predict the occurrence of fracture and critical fracture. These studies indicate that bamboo-epoxy composites can replace ordinary fiber-reinforced composites for construction and other purposes, with the additional advantage of being comparatively lightweight and economical to produce

The bamboo materials tested belonged to the species *Bambusa pervariabilis*. Bamboo strips split longitudinally from internodal sections of the culm were pressed by rolling between a pair of steel cylinders and embedded in an epoxy matrix. Laminates of the composite materials were produced, with each lamina being approximately 1 mm thick.

Test samples were three layers (A3), five layers (A5), and seven layers (A7) thick, all consisting of unidirectional fibers. The tensile, compressive, flexural and interlaminar properties were investigated by means of an Instron 1195 universal testing machine. A crosshead speed of 1 mm min-1 was applied.

Tensile properties.

Partial damage occurred in some specimens when the tensile load reached 85% of ultimate stress. This resulted in slight changes in the actual load and was the point at which maximum acoustic emissions occurred. The tensile strength and tensile modulus of unidirectional epoxy composites were considerable. The average was 203 MPa, modulus Et was 61 GPa, and Poisson ratio was 0.38. An increase in the number of lamina was accompanied by a decrease in tensile strength. This was due to the increasing thickness of test laminates with a corresponding increase in interlaminar voids. Poisson ratio and Young's modulus both increased as number of lamina increased, with E maximum occurring in A5 laminates.

Compressive properties.

Maximum compressive strength was observed in A3 laminates, being 129 MPa. Its compressive modulus Ec was 25.9 GPa which is less than its tensile modulus. The Poisson ratio v was 0.375.

Flexural properties.

Specimens were tested by three point bending. The load-displacement curve showed an early linear segment followed by a non-linear segment beyond 50% of fracture load until ultimate strength was applied.

Interlaminar shear properties. The mean interlaminar shear strength was 14.6 MPa, and the mean interlaminar shear modulus was 823 MPa. This low value is an inherent shortcoming of composite materials, and suggests that future research should focus on improving this drawback.

Acoustic emission testing. Using weighted ringdown as a paramater in the acoustic emission tests the fracture behavior of the test laminates was monitored by recording the acoustic emission (AE) signals and cumulative (AE). With stress levels at 7% of ultimate stress, small fractures in the epoxy matrix cause the emission of low amplitude AE signals. Stress levels at 24% of ultimate stress produced larger AE signals indicating longitudinal cracking in the test specimen. Thereafter, large AE signals occurred at regular intervals between the smaller signals. At 79% of ultimate stress, explosive signals were emitted, corresponding to tensile damage in some laminae. At 95% of ultimate stress, maximum emissions were recorded, due to fracturing of bamboo fibers. AE signals continued to increase in amplitude and frequency until total collapse occurred.

Conclusions

1).-The natural microstructure of bamboo is complex yet logical. The main function of the vascular bundles and fibers is to strengten and transmit stress while the parenchyma form the matrix. When bamboo is pressed and embedded in epoxy, the latter infiltrates the parenchyma and intercellular spaces and further affects transmission. Thus, the tensile, compressive and bending strength of the composite are enhanced. Furthermore, the composite is less suceptible to desiccation induced cracking, deformation under high relative humidity and reduction of mechanical strength caused by insect pest bioerosion.

2).-The variable tensile and compressive moduli of unidirectional bamboo-epoxy composites ,the low interlaminar shear strength, the correlation between mechanical strength and numer of lamina, and the theorical models of their behavior and fracture modes all conform well with those of other laminated composites.

Table 12-2 **Mechanical properties of bamboo-epoxy test laminated specimens**

	Dimensions $w \times t$ (mm²)	Tensile stress σ_t (MPa)	Tensile stress E_t (GPa)	Tensile stress υ	Compressive stress σ_c (MPa)	Compressive stress E_c (GPa)	Compressive stress υ	Bending stress σ_b (MPa)	Bending stress E_b (GPa)	Interlamina shear τ_{13} (MPa)	Interlamina shear G_{13} (MPa)
Three layers A_3	12.6 x 3	243	45	0.30	129	24.9	0.375	255	24.9	10.5	610
Five layers A_5	12.6 x 5	189	76	0.37	59	25.4	-	208	19.3	12.4	768
Seven layers A_7	12.6 x 7	178	63	0.48	90	33.4	-	245	16.4	16.8	877
Mean	63 (mm_2)	203	61	0.38	93	27.9	0.375	235	20.2	13.2	752

Length of testing materials: For tension and flexure 200 mm; For thin plate compresion 100 mm; For direct compression : 25 mm; For interlaminar shear : 40 mm; width =w; thickness =t

CHEMICAL RESISTANCE AND TENSILE PROPERTIES OF SHORT BAMBOO FIBER REINFORCED EPOXY COMPOSITES

Studies on short bamboo fiber reinforced epoxy composites, with varying fiber lengths, have been carried out in India by Varada Rajulu et al (1998). The chemical resistance tests indicate that the composite materials are resistant to acetic acid, hydrochloric acid, nitric acid, sodium hydroxide (60%), sodium carbonate, ammonia, benzene, carbon tetracloride and toluene.

The materials used in this study were: High performance epoxy resin, Araldite LY 5052 (M/S Hindustan Ciba-Geigy) and the curing agent hardener HY 5052 system as the matrix in the composite with bamboo fibers from *Dendrocalamus strictus* from India. The fibers are soaked in 1% NAOH solution for 30 minutes to remove any greasy material and lignin, and then they are washed thoroughly in distilled water and dried in the sun for two weeks. Fibers with a thickness of 0.2mm were selected and cut into different lengths.

For making the composite, a molding box with a 100 mm x 100 mm x 3 mm mold cavity is prepared with seasoned teak wood. The bottom of the cavity and the walls are lined with good quality decolam sheets.

Preparation of the composite and the test specimens.

The mold cavity is coated with a thin layer of an aqueous solution of polyvinyl alcohol (PVA) which acts as a good releasing agent. A thin coating of hard wax is laid over it and finally it is coated with another thin layer of PVA. Each coat is allowed to dry for 20 minutes at room temperature. A 3 mm thick plate is made with Araldite and hardener using a ratio of 100 to 38 parts by weight respectively. Then the molding box is loaded with the matrix mixture and bamboo fibers in random orientation (with varying lengths) and is placed in vacuum oven which is maintained at 65° C for 18 hours to complete the curing. For each length, the weight of the fibers is maintained at 2% of the total weight of the composite. After curing, the plate is removed from the molding box with siple tampering and it is cut into 100 mm x 15 mm x 3 mm samples, having a gauge length of 20 mm and a width of 10 mm, for tensile testing, as described elsewhere. For comparison's sake, the specimens for matrix material are also prepared in a similar form. For chemical tests, the samples (with 30 mm length fibers) are cut into 10mm x 5 mm x 3 mm size pieces.

Results.

It is clearly evident that for the matrix, the weight has increased after immersion. This is understandable as the matrx is crosslinked and as a result swelling takes place instead of dissolution. A similar observation was made by Varada Rajulu et al (1996) in the case of epoxy coated bamboo fibers.

It is observed that the tensile load at break increases with an increase in the fiber length up to 30 mm, after which it decreases. This indicates that the optimum fiber length to get maximum tensile load for the system under study is 30 mm. The tensile load of the composite is found to be less than that of the matrix. It is understandable as the tensile strength of the fiber is very much less than that of the matrix and it appears that the composite is following the law of mixtures.

BAMBOO FIBER-REINFORCED POLYPROPYLENE (PP) COMPOSITES

It has been shown that bamboo-reinforced composites have desirable mechanical properties. However, the polymer matrixes currently encountered in this field are epoxy and polyester in their solid form, which are both expensive and brittle. In order to obtain an economical substitute, Chen, Guo, and Mi (1998) from The Hong Kong University carried out a research project to develop a new type of composite material, thermoplastic bamboo fiber reinforced polypropilene (PP) composites. PP was chosen as matrix resin due to its low price and favorable mechanical properties.

The goal of this research program was to make the composites in the form of boards, rods and thin sheets. Bamboo fiber-reinforced PP composites are expected to have the following properties: lightweight, good weathering ability, good design and manufacture flexibility, and medium strength, which can be used in the furniture and construction industries.

In order to enhance the adhesion between the bamboo fiber and the polypropylene matrix, two maleated poly-propylenes (s-MAPP and m-MAPP) were used as matrixes. In particular, crystallization and interfacial morphology were studied using differential scanning calorimetry (DSC), wide angle X-ray diffraction (WAXD), and optical microscopy.

The materials used as the matrix of the composite were commercial polypropylene (PP) and maleated polypropylene (MAPP). The PP powder, Profax 6201, has a density of 0.920 g/cm3 and a melt flow index of 20. The maleic anhydride-modified polypropylene powder, MAPP, was prepared in the laboratory.

Maleic anhydride (MAH) was purchased and used as received without purification. Benzoil peroxide (BPO), used as an initiator, was purchased and purified by reprecipitation with metanol from chloroform solution. AR grade toluene and acetone were purchased and used as received without further purification. The stabilizer added to the polymer prior to processing was Irganox 1010, a tertiary butyl hydroxyhydrocinnamate.

The bamboo species used in these experiments was *Bambusa paravariabilis.* Bamboo chips were produced by means of a wood planer and were then ground into smaller pieces with a Toshiba MX-301 high-speed laboratory blender, followed by an IKA- Analytical mill. The finer bamboo chips were first dred in a vacuum oven at a temperature of 80° C under a pressure of 180 mmHg for 48 hours. They were then separated with a set of Edecotts test sieves with aperture sizes ranging from 500 microns to 2 mm. Five sizes of bamboo fiber were employed in the BFRP composites (1) less than 500 μm (2) 500-850 μm, (3) 850 μm to 1 mm, (4) 1-2 mm, and (5) a mixture of bamboo chips less than 2 mm.

Grafting Procedures

MAPP employed in this work was prepared by solution surface grafting. The reaction was carried out in a three-neck-round-bottom flask equipped with a condenser, a thermometer, and a dry nitrogen gas inlet. A Cimarec Thermoline hot plate was employed for heating and stirring.

The reaction temperature was maintained at 80° C with an accuracy of (+-)0.5° C by using a contact thermometer in a water bath. Eighty grams of polypropylene powder was dispersed in toluene (600 mL) in the reactor. Nitrogen gas was purged throughout the reaction to remove dissolved oxygen. Eight grams of maleic anhydride, predisolved in hot toluene at 500 C was added to the reactor.

After two min of homogenization in the reaction media, 0.8 g benzoyl peroxide, predissolved in hot toluene at 50° C, was added to the reactor. The reaction was continued for 8 hours with vigorous stirring using a magnetic stirrer. At the end of the reaction, the solvent was separated with a filter, and the product was washed five times with acetone to eliminate any unreacted maleic anhydride.

The grafted polypropylene product was dried in a vacuum oven at a temperature of 60° C and under a pressure of +180 mmHg for 3 hours.

The amount of maleic anhydride grafted onto polypropylene was calculated according to the method reported by Gaylord.

Preparation of BFRP Composites

All raw materials were dried in an oven at 80° C and 180 mmHg vacuum for 2 hours to expel moisture before they were used for compression. A 0.5 wt% stabilizer was added to the polymer prior to mixing. The apparatus used to disperse the fibers within the polymer matrix was a Haake Mixer 3000 equipped with a roller mixer-measure head with precisely controlled temperature and rotation speed. The mixing conditions, such as the ratio of the raw materials, temperature, speed and compression time were scrutinized. The torque, temperature, energy, and other mixing parameters which are related to the viscoelastic properties of the materials and the efficiency of the mixing process were monitored. After mixing, the materials were removed to a compression mold.

Molding procedures

A 200 x 200 mm stainless steel mold was machined. The mold was assembled, cleaned of bamboo chips, PP, and MAPP was homogeneously distributed into the mold, then were compression molded with a hot press (PHI).

After a series of experiments, the optimized molding conditions were as follows: temperature, 210° C; compression pressure during heating and cooling, 5MPa; preheating time, 5 minutes; and heating time, 20 minutes. After compression molding, the molded boards were kept under ambient condition for further tests.

Tensile test.-Tensile tests were performed with a Universal Testing Machine ((UTM), Sintech 10/D tensile tester, USA following ASTM (American Society for Testing Materials standard D639-90. Tensile specimens of bamboo, PP,MAPP, and the composites were machined into dumbbell shapes, following the suggested dimensions of ASTM D639-90 specimen Type I. Five specimens for each sample were tested. The width and thickness of the narrow section for each specimen were measured with an electronic digital caliper. The standard testing conditions were: tensile speed: 3.00 mm/min; load limit HI:50KN; extensometer: 25.00 mm 50% extension.

The stress-strain curve of the specimen was recorded by the attached computer, while the tensile strength, the elongation at break, and the tensile modulus were calculated from the stress-strain curve.

Charpy Impact Test.

A Charpy Impact test was performed with a CEAST pendulum impact tester, England. The testing method consisted of ISO method 179-1982(E). Notched specimens of the composites were in accordance with the dimensions of ISO 179-1982 type 2A. The notch was cut in the middle of the specimen with a CEAST notching machine. A 0.5 J pendulum was used to break the specimens, and the impact energy was recorded. After testing, the crack width of each broken specimen was measured with an electronic digital caliper. The Charpy impact strength was obtained by dividing the impact energy by the cross-sectional area. The unit of the impact strength is KJ/m2. To obtain a reasonable value, 15 specimens for each sample were tested, and the average impact strength for each sample was calculated.

Scanning Electron Microscopy. A ho-el 6300 scanning electron microscope with a resolution of 70 mm was used to study the interfacial morphology of BFRP composites. The interfacial adhesion between fiber-matrix was investigated by examining the tensile fracture surface of different types of BFRP composites. All samples were dried at a temperature of 80° C in a vacuum oven for 12 hours, and then they were sputter coated with a layer of approximately 100 * gold. The micrographs were captured with Polaroid type films.

Results and discussion

Effect of bamboo fraction.-The tensile modulus of the bamboo/MAPP/PP composites increases with bamboo content up to 65 wt %; whereas the modulus of the bamboo/PP composites does not vary significantly with changing bamboo fraction. A tensile modulus of 3.4 GPa is noted at about 50 wt% bamboo fiber in the PP composite; however, at the same composition, the values with MAPP are higher.

The tensile strength of MAPP/PP composites yields a maximum value of 36 MPa at about 50 wt % bamboo fiber. On the other hand, for PP composites, the tensile strength decreases slightly.The above results can be explained by the modified Law of Mixtures equation, which is commonly applied when studuing tensile properties of composites with discontinuous, short fibers.

Effect of MAPP Content.-One of the main factors that affects the mechanical properties of bamboo fiber-reinforced composites is the adhesion between the fiber and the matrix. It is known that the use of a compatibilizer can improve the adhesion, and hence improve the mechanical properties of the composites. Because the bamboo surface is hydrophilic characterized by polar hydroxyl groups and also because PP is hydrophobic polyolefins, the adhesion between the two materials is expected to be rather poor.

Therefore, in this study we used MAPP as the compatibilizer to improve the adhesion because the maleic anhydride strongly associates with the hydroxyl groups on the bamboo surface.

To study the effect of MAPP content on the mechanical properties, the bamboo fraction was kept at 50 wt %, and the ratio of PP to MAPP was changed. Because the maleic anhydride (MAH) content of MAPP is 0.5 wt %, we have therefore converted the MAP content into MAH content in the composites. It has been found that the tensile modulus increases slightly with increasing MAH content; however, one should find a remarkable increase in the tensile strength with the MAH content up to 0.12 wt %, which is equivalent to 24 wt % of MAPP in the composites It is found that the tensile modulus increases slightly wit increasing MAH content.

A continuous improvement in the strength was observed as the MAH content went up to 0.25 wt %. It is believed that the MAPP acts as a compatibilizer in the system, improving the interfacial adhesion in BFRP composites and providing better bonding (e.g., hydrogen bonding) between MAPP and bamboo fiber. As result, the mechanical properties of the composites are enhanced.

Interfacial adhesion of BFRP composites.

SEM photomicrographs of the fracture surfaces of the composites clearly show that there is no wetting on the surface of the bamboo fiber by nonmodified PP. This is due to the fact that the surface energies between the fibers and the PP matrix are significantly different, since the bamboo surface is hydrophilic and the PP surface is hydrophobic. On the contrary, by adding MAPP to polymer matrix, the fiber surface is completely wetted by the PP/MAPP matrix.

One can find on the one hand, that bamboo fiber is not in close contact with the PP matrix, and on the other hand, the PP/MAPP matrix and bamboo fiber are intimately bonded together. It is well known that without effective wetting on the fiber strong interfacial adhesion cannot achieved and the lack of interfacial interactions results in poor mechanical properties for the composites. Therefore, the SEM studies support the tensile and impact testing results discussed in the previous section. Moreover, with the enhanced interactions between the reinforcemen and the matrix, fiber distribution becomes more uniform in the matrix.

The interaction between the bamboo fiber and PP/MAPP matrix can be attributed to the formation of hydrogen bonds in the interfacial region, for instance, between the hydroxyl (-OH) groups of cellulose or its counterpart, lignin, on bamboo fiber with the anhydride groups in the MAPP matrix. Furthermore, it was found that MAPP can crystalllize on the bamboo surface, so that the bamboo fiber acts as both a reinforcing agent and a nucleator for MAPP. The authors believe that the surface crystallization also contributes to better interface adhesion for the bamboo/PP/MAPP composite.

Effect on bamboo fiber sizes

In this work four types of bamboo chips were selected: bamboo fiber sizes (1) less than 500μm; (2) 500-850 μm; (3) 850-1000 μm; and (4) 1000-2000 μm. Both PP and MAPP composites were employed to study the effect of bamboo size on the mechanical properties, while the bamboo concentration was kept at approximately 50 wt %.

It was found that tensile modulus and tensile strength of PP and MAPP composites decrease as bamboo sizes increase. This is probably due to the fact that, at the same composition, a smaller fiber has a relatively larger surface area, which results in better contact between the fiber and the matrix.

Comparison to commercial wood pulp composite.

As one of the objectives of this study was to develope a wood substitute potentially feasible for furniture industrie, the mechanical properties of the present BFRP composites were compearimg with those of the commercial wood pulp composite that is now widely used in making office furniture. It shows that the tensile strength and the stiffness of bamboo fiber-reinforced PP composites are all higher than those of the commerical wood pulp composite and the tensile strength of the PP/MAPP composites is more than three times that of the commercial wood pulp. This indicates that the new composites have a great potential in application as a new wood substitute.

Conclusion.-The MAPP can induce a better distribution of bamboo fiber of 50 to 60 wt % in the PP/MAPP matrix without any difficulty. The maximum values of the tensile strength (32-36 MPa) and the tensile modulus (5--6 GPa) were obtained at about 50 wt % content. Compared to the commercial wood pulp composite, the bamboo fiber-reinforced MAPP composite demonstrates higher tensile strength and lower density (0.920) at a lower cost.

Moreover, bamboo is renewable, which has a special environmental impact, and may lead the new composite to a potential application as a new wood substitute.

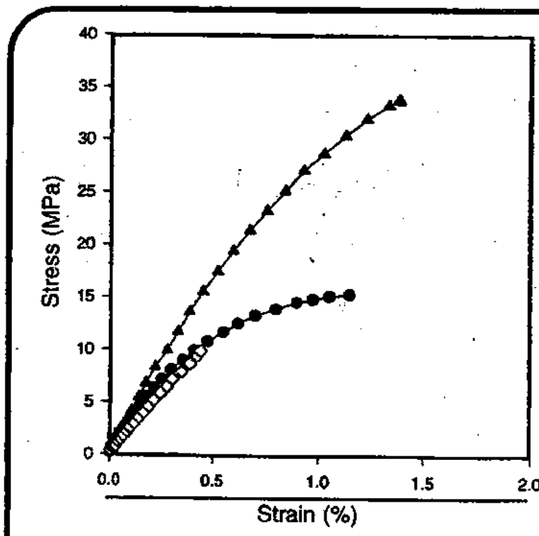


Fig.12.1 *Comparison of the mechanical strength between the BFRP composites with a commercial product (50 wt % BF):● BF/PP;□ BF/m MAPP; ▲ commercial wood pulp.*

REFORMED BAMBOO/ALUMINIUM ALLOY COMPOSITE

In order to overcome the disadvantages and improve the performance of reformed bamboo (See Reformed Bamboo), and to replace some industrial aluminium alloy, in this work, reformed bamboo was applied to reinforce aluminium sheet, i.e. a new super-hybrid composite was designed according to different requirements.

Manufacturing technique

Epoxy resin (E44) was used as adhesive. Aluminium alloy sheet, 0.5 mm thick, is corrosion- resistant aluminium with a tensile strength of 140 MN m-2. In order to improve the adhesive ability, the surface of the aluminium sheet should be pretreated by a chemical or mechanical method: in this experiment, a mechanical method was used. The surface of the aluminium sheets were roughened by sand blasting. The reformed bamboo was adhered together as a plate with epoxy resin, and was then covered with aluminium alloy sheets on both sides. In the present work, the layers of reformed bamboo were placed along one direction; in practice the fibre direction of each layer of reformed bamboo can be designed and adjusted to a certain value, according to different requirements.

Properties of reformed bamboo/ aluminium composite.

Some major mechanical properties of reformed bamboo were tested on a Shimadzu-DCS testing machine at room temperature. For comparison, the data of BFRP and BMC are also listed. The tensile strength of reformed bamboo/aluminium is more that twice that of aluminium, BFRP or BMC. Here, the crux of this phenomenon lies in the compressive ratio of reformed bamboo. In our experiment, this ratio can range from 0%-50% ~~corresponding to the com~~pressive ratio, various mechanical properties of reformed bamboo are widely dispersed. The data for reformed bamboo in Table 6-10 (page 97) are averaged values of all compressive ratio, but in the process of making reformed bamboo/aluminium specimens, only those with higher compressive ratio were chosen, thus relatively higher mechanica l properties were undoubtedly obtained.

Bamboo is a renewable natural source and abundantly available. It is cheaper than wood and aluminium alloy. So reformed bamboo is cheap enough to be a prospective potential substitute for some industrial aluminium alloy. The thin aluminium sheet will protect the epoxy resin from ultraviolet rays and the reformed bamboo from corrosion, while the reformed bamboo can strengthen the aluminum and reduce the total weight of the materia. Besides its mechanical properties, the overwhelming advantage of the new material is its low cost compared with industrial aluminium alloy; in this experiment, the cost is only two-thirds that of aluminium.

While the performance, density and price are considered simultaneously, the ratio of materials performance to its price and density is a comprehensive criterion. They found that the ratio tensile strength to density and price was increased by 717.2%.

Conclusions

Reformed bamboo is a propective potential substitute for industrial alluminium alloy in some applications, specially for civil use, owing to its high performance and low price . On the one hand, alluminium alloy sheets outside the composite can protect the reformed bamboo from absorbing water in air and from rottin ; on the other hand, the reformed bamboo can reinforce the alluminium alloy. (Li .*et al* ,1994)

Impact properties

Li, Zhou, Tang and Zeng (1996) studied the impact properties of normal bamboo, reformed bamboo and reformed bambo/Aluminium composite, and a way of improving the impact thoughness of RB while maintaining the merits of its static properties.

Three-point impact test is a traditional method for evaluating the impact properties of metal materials and some other kind of materials. In this work an automatic Charpy Impact Testing System, designed by Beijing University of Aeronautics and Astronautics was employed.

This system can record and analyse the impact process. Its impact energy can be adjusted according to the experimental materials tested; for this biomaterials 3 kg. m (29.4J) was selected, with a span of 40 mm.

Phyllostachys pubescens, the most abundant bamboo in China was chosen as the experimental material in this experiment. The alluminium alloy sheet used was 0.5 mm thick, corrosion-resistant aluminium with a tensile strength of 140 MPa. The surface of the aluminium sheet was pretreated and epoxy (E44) was used as adhesive.

Since there is no testing standards for natural biomaterials composites, the impact thoughness tests were used only for comparison. The specimens were prepared without a notch on the surface, the size being 12 x *h* x 55 mm, where *h* is the thickness of the specimen. All specimens were tested along the fiber direction.

Owing to the gradient structure of bamboo culm, the impact toughness of the specimen is different dependent on whether the green bamboo side or the pithring side is

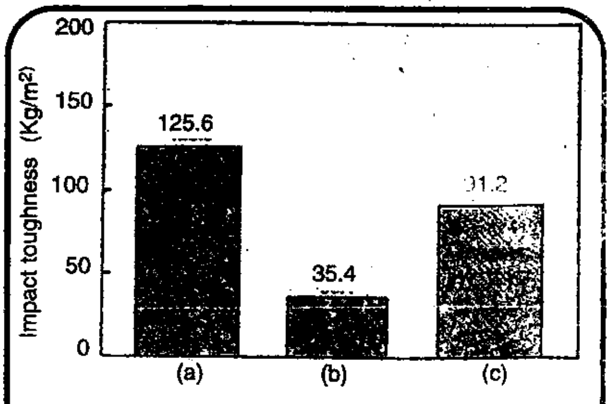


Fig.12.2 *The impact toughness of normal bamboo: (a) green bamboo in tension; (b) pith-ring in tension; (c) without green bamboo.*

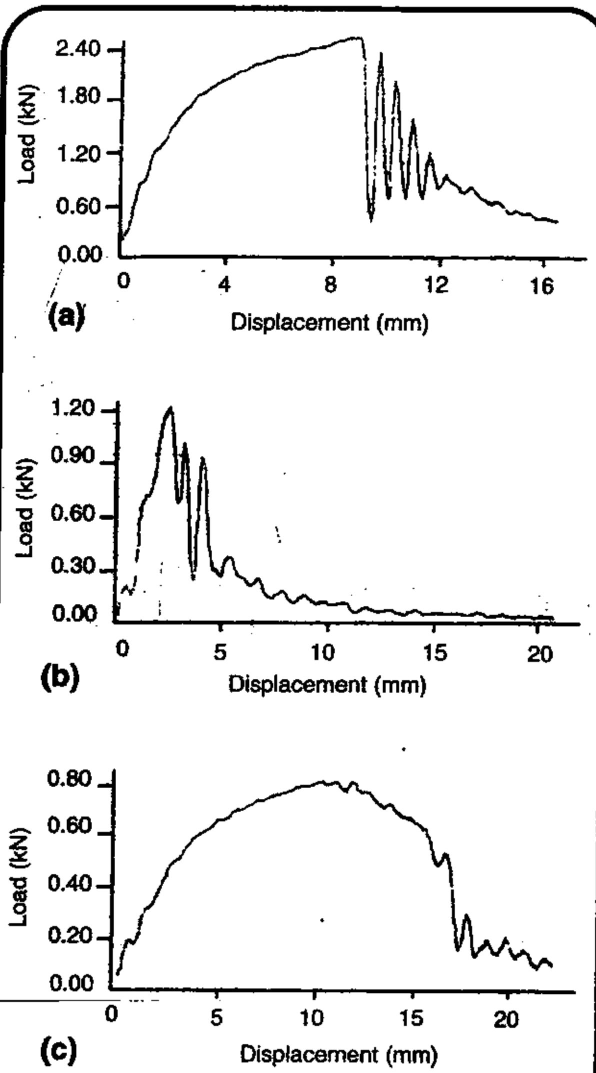


Fig.12.3 *The impact load-displacement curves of normal bamboo: (a) outer surface in tension ; (b) inner surface in tension; (c) outer part of specimen removed and then this side in tension .*

subjected to tensile load. Normal bamboo was tested in the following three modes:

(a) the outer surface (rind system) in tension ;

(b) the inner surface (pith-ring) in tension;

(c) the outmost part of the specimen , green bamboo, was removed and then this side was in tension.

The experimental results are shown in Fig 12.2 and the typical load-displacement curves of these modes of testing are ilustrated in Fig.12.3. As shown in Fig.12.2, normal bamboo has much higher impact when the greeen bamboo side is subjected to tensile stress; this result is in good agreement with the gradient distribution of tensile and comprenssive strength of bamboo.

From the impact curve A in Fig.12.3 he violent vibration curve after the maximun load indicates that in the impact process the bamboo fibers are pulled out bundle by bundle.

When fracture started the first group of bamboo fibers was pulled out and then they fractured, this process corresponding to the first drop of the curve; but the specimen did not fractured completely, the other bamboo fibers which have not fractured began to bear the load and the curve rose again. This process was repeated several times until the specimen finally fractured completely.

The curve B in Fig. 12.3 showing the impact process of the specimen with its inner surface subjected to tension , is very different from curve A. The low strength of the part near the pith-ring makes the specimen fracture at a low stress level, although pull-out of bamboo is still obvious. The advantage of the rind system cannot be fully brought into play, so the absorbed energy is much less than type A. The curve C in Fig. 12.3 is another type; it is more fluent than curves A and B, indicating that little pull-out of fiber occurred. Thus the green bamboo is the major area where fibre pull-out ocurred during the impact process.

The experimental data reveal that the tensile strength of reformed bamboo can be increased by as much as 31.7% compared with normal bamboo. For a specific material, strength and thoughness are always contradictory. In other words it is very difficult to improve both at the same time. For natural composite material bamboo, this contradiction still exists. The scattered points of the impact toughnerss of reformed bamboo whose compressive ratio ranged from 0 to 0.5 gives proof of this.

A meaningful rule can be found: the higher the compressive ratio the more brittle the reformed bamboo will be, although the scatter points show a rather strong tendency to disperse. The mean value of the impact toughness of reformed bamboo is 59.4 kJ/m^2; this is the average value of 30 specimens across the compressive ratio span. Compared with that of normal bamboo, 125.6 kJ/m^2 impact toughness is decreased by 52.7%. Generaly speaking, normal bamboo is a tough material while reformed bamboo is much more brittle.

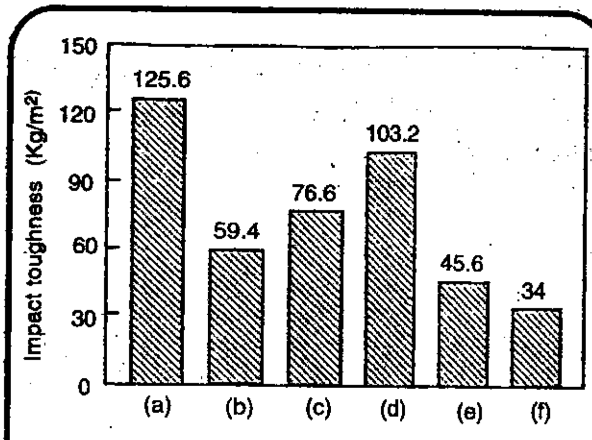


Fig.12.4 *Impact toughness of the specimens tested:* **a)** *normal bamboo;* **b)** *reformed bamboo;* **c)** *reformed bamboo/ Al;* **d)** *(reformed bamboo + glass fabric)/ Al;* **e)** *bamboo fibre composite;* **f)** *bamboo mat composite*

REFORMED BAMBOO/GLASS FABRIC/ ALUMINIUM COMPOSITE

A super-hybrid (natural composite/fibre-reinforced composite/metal hybridization) ecomaterial, reformed bamboo/glass fabric/aluminum (RB/GF/Al) was developed by . Li-SH; De-Wijn-JR; De-Groot-K; Zeng-QY; Zhou-BL (1998)

The addition of a sparse glass fabric/epoxy resin layer between reformed bamboo and aluminum proved to be effective in increasing the compressive, tensile strength of the composite material. In particular, the interfacial shear strength between the reformed bamboo and aluminum was improved by 34%, as well as the transverse tensile strength by 78% with respec to RB. These were the major shortcomings of normal bamboo and reformed bamboo/aluminum composites. The good recyclability of reformed bamboo and aluminum make RB/GF/Al an environmentally friendly material. Extensive use of such an ecomaterial instead of wood would save natural forest resources.

Manufacture of reformed bamboo/ glass fabric/ aluminium (RB/GF/Al)

The bamboo used in this work was *Phyllostachys pubescens*. Reformed bamboo was prepared using the technique reported before. The manufacturing procedure consist of three steps: softening, compression and fixture. First, natural bamboo was separated longitudinally into two to four parts and the diaphragms in the nodes were cut off roughly. the bamboo strips were then heated in a container at 120° C to adjust the moisture content to a certain value. the strips were then compressed with compressor until a require compressive ratio was obtained. Finnally under a certain pressure, strips were pressurized for 3 hours with the purpose of fixture. Furing the process, the moisture content of the bamboo is very important. The detailed conditions were reported previously..

The aluminium sheet used in this work was LY12 with a thickness of 0.3 mm. In tensile strength is 453 MPa. the sparse glass fabric cloth used was purchased in China. There are 300 fibres in one yarn and the diameter of the single fibre is 23 µm. The epoxy resin used was type 618 (E51), made in Shenyan, China.

The surface of reformed bamboo was roughened by sandpaper then the sparse glass fabric cloth was adhered to it at room temperature for 24 hours with epoxy resin at a pressure of 2 MPa.The epoxy resin was used as an adhesive, so only a small amount of resin penetrated into the RB; however, the resin is the matrix of the composite layer of GF/resin. Reformed bamboo/glass /aluminium was manufactured following a similar method to that described previously. The difference is that glas fabric was added between aluminium sheets and reformed bamboo.The relative volume fraction of GF and aluminium in the final composite material are 8.1% and 10.8% respectively.

Mechanical properties of RB/GF/Al

For each property at least 10 specimens were tested and the results were summarized in Table 12-3. In the correlation between the ultimate tensile strength and the density of normal or reformed bamboo, a good linear correlation exists for normal bamboo, but for reformed bamboo there ais not such linear correlation. Usually the linear correlation between tensile strengh and density makes it possible to predict the tensile strength of bamboo by measuring its density.

Fig. 12.5 shows the comparison of the average ultimate tensile strength of various materials used in this experiment. Different from the case reported previously, where low-strength aluminium was reinforced by reformed bamboo, high strength aluminium was selected to improve the transverse strength of the composite.

Table 12-3 Comparison of the mechanical properties of normal bamboo (NB), reformed bamboo (RB), glass fabric (GF), reformed bamboo/glass fabric (RB/GF, aluminium (Al) and reformed bamboo/glass fabric/aluminium (RB/GF/Al). S.D. given in parentheses

	Normal B	ReformedB	Glass Fabric	ReformB/GF	Aluminum	RB/GF/Al
Ultimate tensile strength (MPa)	144.1 (31.0)	187.2 (61.5)	93.0 (3.0)	172 (47.4)	453.8 (48.7)	200.3 43.2
Compressive strength (MPa)	61.2 (14.2)	87.5 (11.1)		85.9 (15.2)		99.7 (20.8)
Flexural strength (MPa)	128.1(NB1) (34.5) 111.1(NB2) (21.5)	183.0(RB1) (17.0) 138.1(RB2) (27.0)		186.4 (14.8)		225.2 (43.3)
Longitudinal shear strength (MPa)	11.6 (4.5)	17.1 (4.0)		21.4 (7.0)		35.0 (6.9)
Transversal tensile strength (MPa)	3.0 (1.0)	4.7 (0.6)		5.7 (0.6)		6.4 (2.2)
Interfacial shear strength (MPa)				7.3 (1.6)		9.8 (2.2)

Source:Li-SH; De-Wijn-JR; De-Groot-K; Zeng-QY; Zhou-BL (1998)

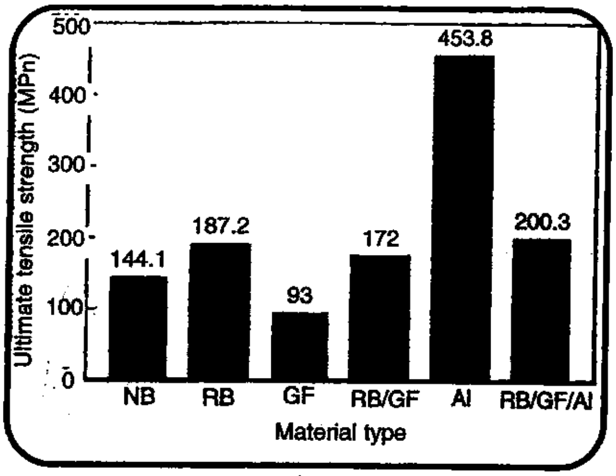


Fig. 12.5 *Comparison of the ultimate tensile strength of the various materials used.*

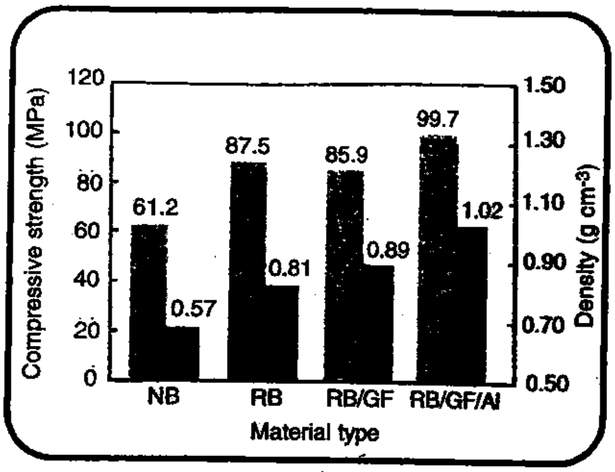


Fig. 12.6 *Comparison of the compresive strength of the various materials used: NB, normal bamboo;RB, reformed bamboo; GF, glass fabric; RB/GF, reformed bamboo/ glass fabric commposites; RB/ GF/Al, reformed bamboo/ glass fabric / aluminium.*

In figure 12.5 RB/GF/Al exhibits the highest tensile strength of all the materials tested. The tensil strength of RB/GF/Al can be designed by adjusting the volume fraction of reformed bamboo or aluminium. In the present test reformed bamboo comprises about 80%(vol/vol) of the composites.

The beneficial effect of adding a glasss fabric layer between reformed bamboo and aluminum is proved by the interfacial adhesion and by the transverse tensile properties. Because bamboo is a unidirectional fibre-reinforced composite, the mechanical properties other than in the fibre direction, are lower than those in the fibre direction, especially those across the fibre direction. For example the tensil strength along the the fibre direction is usually about 50 times higher than that across the fiber direction, the situation for reformed bamboo being similar. Both glass fabric and glas fabric/aluminum layer can increase the transverse tensile strength; RB/GF/Al shows the highest value.

Hygroscopic properties

If the new material RB/GF/Al is to be used in a damp environment, the hygroscopic properties have to be taken into consideration because the uptake of moisture by bamboo will consequently result in a rot during service. The addition of a glass fabric, shows the slowest rate of water uptake and thus RB/GF/Al may be expected to have an improved water resistance, thereby improving the durability and weatherability of bamboo.

The addition of a sparse glass fabric/ between RB and aluminium can increase the interfacial shear strength by 34%, as well as the transverse strength by 78% with respect to RB.

The compressive mechanical properties are increase to different extents compare with those of NB, RB, RB/GF; for instance, ultimate tensile strength, compressive strength, flexural strength, longitudinal and transverse tensil strength. The most important improvement of RB/GF/Al for the practical application is in the aspect of its hygroscopic property : the new composite shows a slower rate of water uptake compared with RB and RB/Al.

Table 12-4 Comparison of the mechanical properties of natural bamboo with other materials.

Material	Density ($g\ cm^{-3}$)	Tensile strength (Mpa)	Specific tensile strength ($N\ mg^{-1}$)	Tensile modulus (GPa)	Specific tensile modulus ($kN\ mg^{-1}$)	Compression strength (MPa)	Specific compres.strength ($N\ mg^{-1}$)
Wood	0.46	104	226	10	22	7	80
Concrete	2.5	4	2	48	19	69	28
Glass	2.5	50	20	69	28	50	20
Aluminium	2.7	247	88	69	25	-	-
Cast iron	7.8	138	18	207	26	120	15
Steel (0.06% C)	7.9	4.59	58	203	26	800	101
ABS	1.1	50	45	3	3	50	45
PVC	1.5	59	39	2.4	1.7	55	37
Polyester	1.8	276	153	18	10	270	150
Epoxy	1.8	1100	611	45	25	400	222
CFRP	1.5	1040	693	180	120	1040	693
Normal bamboo	0.66	206	312	20	31	79	120
ReformedB GF/Al	1.02	200.3	196	-	-	99.7	98

BAMBOO BASED PANELS

TYPES OF BAMBOO BASED PRODUCTS

All bamboo based panel products such as plybamboo, bamboo fiber board, bamboo particle board, bamboo wool board and similar products, are composite materials. That is, they are a composite of bamboo elements such as fibers, veneers, particles, flakes or other lignocellulosic raw materials and some type of adhesive. Depending on the bamboo elements used in their manufacture, the panels or boards have different applications, but most of them are construction oriented. For example, structural plybamboo is manufactured with bamboo boards and is especially used for the construction of walls. Bamboo insulation board is manufactured with bamboo pulp and is used in walls, ceilings and roofs as an insulating material. All the types of wood based panels can be manufactured using bamboo and they will have better mechanical characteristics than wood based panels. On the other hand, the same principles, the same equipment and the terminology used in the manufacture of wood based panels are applied in the manufacture of bamboo based panels. An exception is the type of machinery used for the manufacture of plybamboo, which is different from that used in the manufacture of plywood; however, the pressing is done with the same type of hot plate presses.

Adhesives or binding agents and other materials may be added during manufacture of bamboo based panels to obtain or improve certain properties. The bond can be inherent and obtained by an organic binder as in some fiberboards, such as particle board, or it can be due to an inorganic binder such as Portland or magnesite cement as used in bamboo-wool boards. In general, in the manufacture of bamboo based panels the same type of adhesives used in the manufacture of wood based panels are used. Until about 1930, the adhesives used to bond wood were resinous substances with adhesive properties derived from plants and animals, such as blood, casein and soy beans, that were not waterproof. Since then, many new synthetic adhesive families have been developed, such as urea and melamine formaldehyde; phenol and resorcinol formaldehyde; polyvinyl acetate and copolymer emulsions; elastomer based solution and latex hot melt; epoxy and acrylic. Joints or products bonded with polyvinyl acetate, hot melts and natural resins will not withstand prolonged exposure to water or high moisture content, or repeated high-low moisture content cycling in bonds of high density woods. However, if they are properly formulated, these adhesives are durable in a normal interior environment.

The most common glues used in the manufacture of wood and bamboo based panels are: melamine, urea formaldehyde, phenol formaldehyde, resorcinol formaldehyde and epoxy.

According to the "Wood Handbook" (1987), joints and products made with melamine formaldhyde, melamine-urea formaldehyde and urea formaldehyde resin adhesives have proven less durable than wood, and urea formaldehyde is quite susceptible to degradation by heat and moisture, but it could be durable in a normal interior environment. For this reason, urea formaldehyde is recommended as a type of glue for the manufacture of panels that are going to be used in interior conditions. This adhesive can be cured at room temperature or under high temperatures. Phenol formaldehyde and resorcinol formaldehyde are considered acceptable for structural products. These phenolic resins cure under high temperature and must be hot pressed. They are waterproof and are not be degraded by microorganisms, so they are the most used in exterior conditions.

Phenol formadehyde is a reddish brown resin that is used in the manufacture of some bamboo based panels for exterior use. Resorcinol formaldehyde is used for the manufacture of glued laminated structures, and for exterior conditions; it is the most expensive of the adhesives. The cheapest is urea formaldehyde. At present, it appears that some isocyanate, epoxy, and crosslinked polyvinyl acetate adhesives are durable enough to use in lower density species, even under exterior conditions. Most adhesives will adhere to wood and bamboo, but satisfactory performance depends on careful considerations of these factors: physical and chemical compatibility of the adhesive and the adherents, processing requirements, mechanical properties, durability, ease of use, color and cost. The adhesive's pH is another important factor in wood and bamboo bonding. The adhesive may be acidic, neutral, or alkaline.

Pressure. The strongest joints usually result when the consistency of the adhesive permits the use of moderately high pressures (100 to 250 psi or 7 to 17.5 kg/cm2). Low pressures (100 psi or 7 kg/cm2) are suitable for low density wood because the adherent surfaces easily conform to each other, thus assuring intimate contact between the adhesive and the wood. The highest pressures (up to 250 psi or 17.5 kg/cm2) are required for the highest density woods in order to achieve the desired surface conformation and the adhesive-wood contact.

However, small flat well planed surfaces can be bonded satisfactorily at lower pressures. Because high pressure tends to squeeze the adhesive into the wood or out of the joint, adhesives of thicker consistency are required with denser woods. Usually the thicker consistency is achieved by using longer assembly times with dense woods than with light woods. The longer assembling time increases the absorption of the liquid solvent by the wood and its evaporation into the air. The loss of liquid increases the adhesive's

PLYBAMBOO - TYPES

Plywood is by far the most commonly known structural panel among wood-based panels. Plybamboo is a new material which is manufactured following the same principles and the same terminology used in the manufacture of of plywood, but the equipment employed is different except the pressing machinery. Plywood or plybamboo are panels composed of an odd number (3, 5, 7, 9) of layers of thin sheets of wood called veneers. These layers or plies, which are generally 1 to 5 mm thick, are glued together with the grain of adjacent layers at right angles. The outside plies or veneers are called faces or face and back, the center ply, called the core, can be a veneer, or it can be made of wood blocks or strips of wood of varying lengths laid side by side.

The plies immediately below the face and back, which are laid at right angles to them, are called the cross-bands. The face veneers are oriented with the grain parallel to the long side of the panel, and the *cross-bands* are parallel to the short sides. Plywood is generally manufactured in standard size panels of 1.22 m by 2.44 m (4 x 8 feet).

Wood veneers. Two distinct types of veneer are cut for the manufacture of plywood: The first is the rotary veneer peeled from round logs cut in the rotary cutter, on a lathe that rotates the log against a razor-sharp knife, cutting a continuous sheet just like unwinding a roll of paper. The second type of veneer is the sliced from rarer or valuable logs into face veneer. The slicing machine cuts individual sheets with an up and down or back and forth movement of wood against the knife, or by movement of the knife against wood.

The choice of method will depend on the nature of the wood to be cut and the type of veneer desired. In order to reduce checking and to minimize splitting ahead of the knife edge, the logs are heated in steam or in hot water. This also reduces cutting resistance. In the manufacture of plywood, most of the veneer produced is peeled (rotary-cut) because of its low cost. In the manufacture of plybamboo there are two main groups known as non structural plybamboo and structural plybamboo.

NON-STRUCTURAL PLYBAMBOO

Non structural ply bamboo consists of three plies of very thin rotary bamboo veneers (about 0.5 mm thick), and consequently can not be used for structural purposes but for decorative purposes and arts and crafts. At present, Japan is the country which has taken the best advantages of non structural ply bamboo using the specie *Phyllostachys pubescens*.

Bamboo veneers are used for decorative purposes as face and back of plywood boards or for the top board of tables and trays, and particularly for the manufacture of very thin non-structural plybamboo used in the manufacture of plybamboo plates and other handicrafts (See Fig. 12.7). In this case, the inner side of the bamboo veneer is used as the face, and the convex or cracking veneer as the core. The adhesives used are urea formaldehyde, and a hot or a cold press can be used.

Three types of bamboo veneers are manufactured: rotary veneer, sliced veneer and sawed veneer.

(1) As explained before, rotary veneer is peeled from round sections of giant bamboos (See page 159). Since the bamboo culm is hollow and the diameter and thickness of the wall decrease from the base to the top, it is only possible to manufacture bamboo rotary veneer from sections of giant culms no longer than 2 or 3 internodes (about 50-60 cm long), which have a minimum wall thickness of 10 mm.

The sections must be cut with a circular saw from the center part of the culm (which has the longest internodes), leaving the 2 nodes at the opposite ends. The culm sections are boiled at 100 degrees C for about 3 hours, with the purpose of softening the material. According to Takeuchi (1968), this treatment produces a high quality veneer and decreases cracking.

After the sections are softened, their opposite end nodes are removed and the cut is made at right angles, (having the same length as the lathe); then they are fixed to the small rotary cutter. This machine works at a speed of 30-40 rpm. Generally, the veneer is 3-4 meters long, depending on the thickness of the culm wall. The bamboo veneer is air dried or dried with hot air to about 12% humidity. The pressing can be done in a hot or a cold press.

(2) As explained before (See page 159- Fig. 11.3) sliced veneer is produced from large glued laminated bamboo blocks which consist of parallel strips glued together in the same position or in diferent positions. In this case, the main block is also located parallel to the knife.

(3) Sawed veneer is produced when a large block which consists of several small blocks glued together in different positions is sawed perpendicular to the block axis in the same way that bread is sliced. This method permits the manufacture not only of small veneers 1 mm thick, but also of floor tiles 10 mm thick or more (See floor tiles). Bamboo veneers have to be plastified or covered with a plastic film.

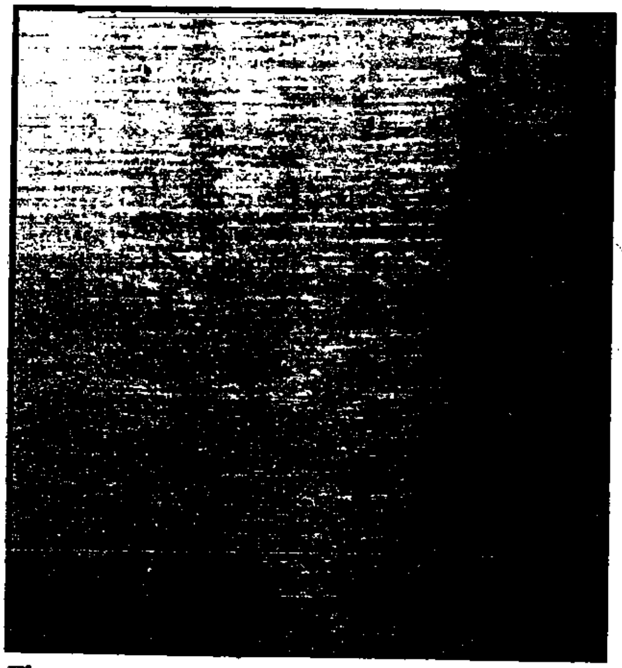


Fig.12.7 *Non- structural Plybamboo made in Japan with 3 plies of bamboo veneer cut in a rotary bamboo veneer machine and pressed with hot plates.*

STRUCTURAL PLYBAMBOO

At present, there are two methods for the manufacture of structural plybamboo panels which use two distinct types of plies. In the Colombian method developed experimentally by the author, thin bamboo boards taken from the the exterior surface, which is the strongest part of the culm wall are used as the core and plies; while in the Chinese method, bamboo slats taken from the culm wall are used as the core and plies.

COLOMBIAN STRUCTURAL PLYBAMBOO

This type of plywood was developed experimentally in Colombia by the author in 1974 at the CIBAM (Bamboo Research Center of the National University), using the species *Guadua angustifolia*. This plybamboo differs from that made in China in that the plies (3 - 5 - 7) consist of bamboo boards (culms opened out flat) which are commonly used in the construction of walls of bamboo houses in Colombia.

For the manufacture of plybamboo boards, mature culms, (three years or older), are cut into 4 m long sections. The sections are transformed by hand into bamboo boards using a small ax or hatchet as shown in the page 158.

Once the bamboo culm is opened out flat and the diaphragms are removed, it can be oven dried or air dried to a content of 12% humidity. Once dry, the soft white surface of the interior part of the bamboo board is removed using a planer machine and about 1 mm of the exterior surface, until it reaches the thickness of 3mm for the plies and 3 to 5 mm for the core. This means that all the plies must have the same thickness.

Finally the 4 meter bamboo board is divided into two pieces of 1.50 m and 2.50 m respectively. These are the dimensions of the two types of plies used in the manufacture of plybamboo boards. All the bamboo plies have to be treated by immersion in chemical preservatives, or the preservatives can be mixed with the adhesive. The panel consists of three, five, or seven plies of bamboo boards, glued together with urea formaldehide resin, or phenol formaldehyde resin, depending on the final use of the plybamboo.

Once the plies are glued and pressed, the edges of the panel are trimmed to the standard dimensions. The final dimension of the panel is 1.200 mm wide, by 2.400 mm long.

The panel can be covered on one or both faces with a wood or plastic veneer or with cement or gypsum plaster if the grooves of the face and back are wider. This panel has the best mechanical characteristics to be used in the construction of plybamboo beams ("I" and box shaped beams) (See plybamboo beams).

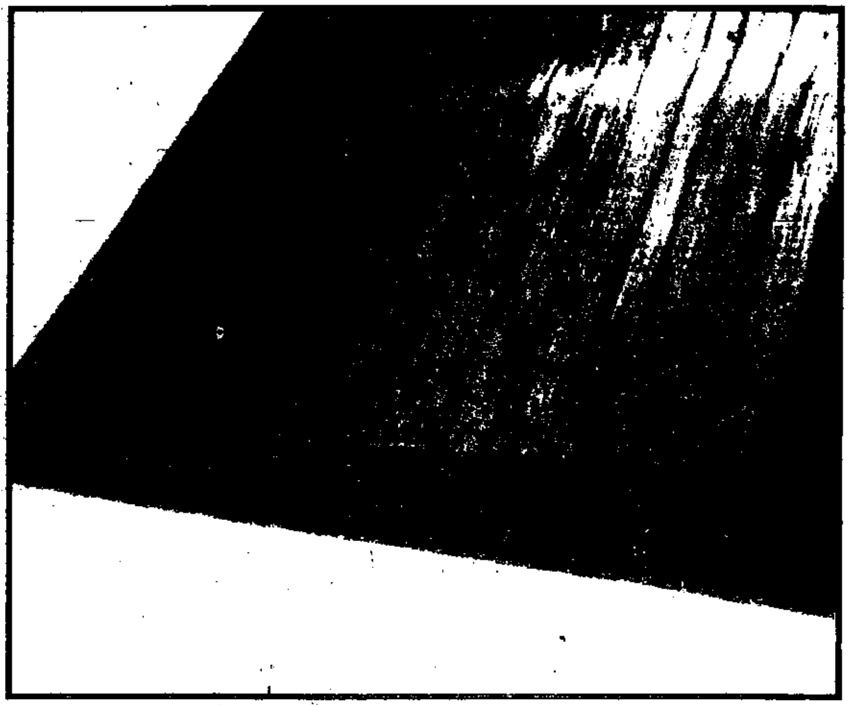


Fig. 12.8 *Colombian plybamboo manufactured with three plies of bamboo boards glued together with urea formaldehy or phenol-formaldehyde depending on the final use. One of the advantages of this material is that it can be covered with a wood veneer or plastered with gypsum or cement mortar. In this case, the grooves can be more open or wider. This material is excellent for the construction of plybamboo beams ("I" and box shaped beams). See ply bamboo beams.*

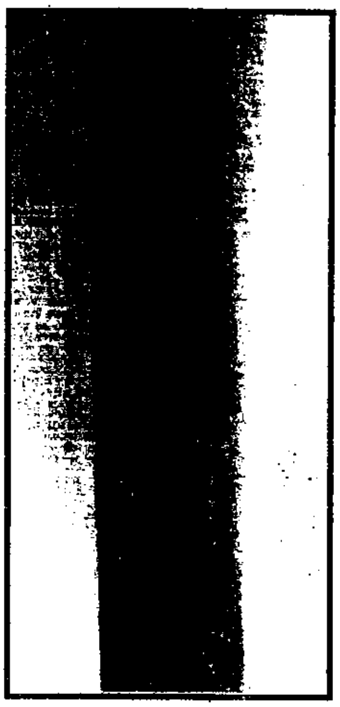
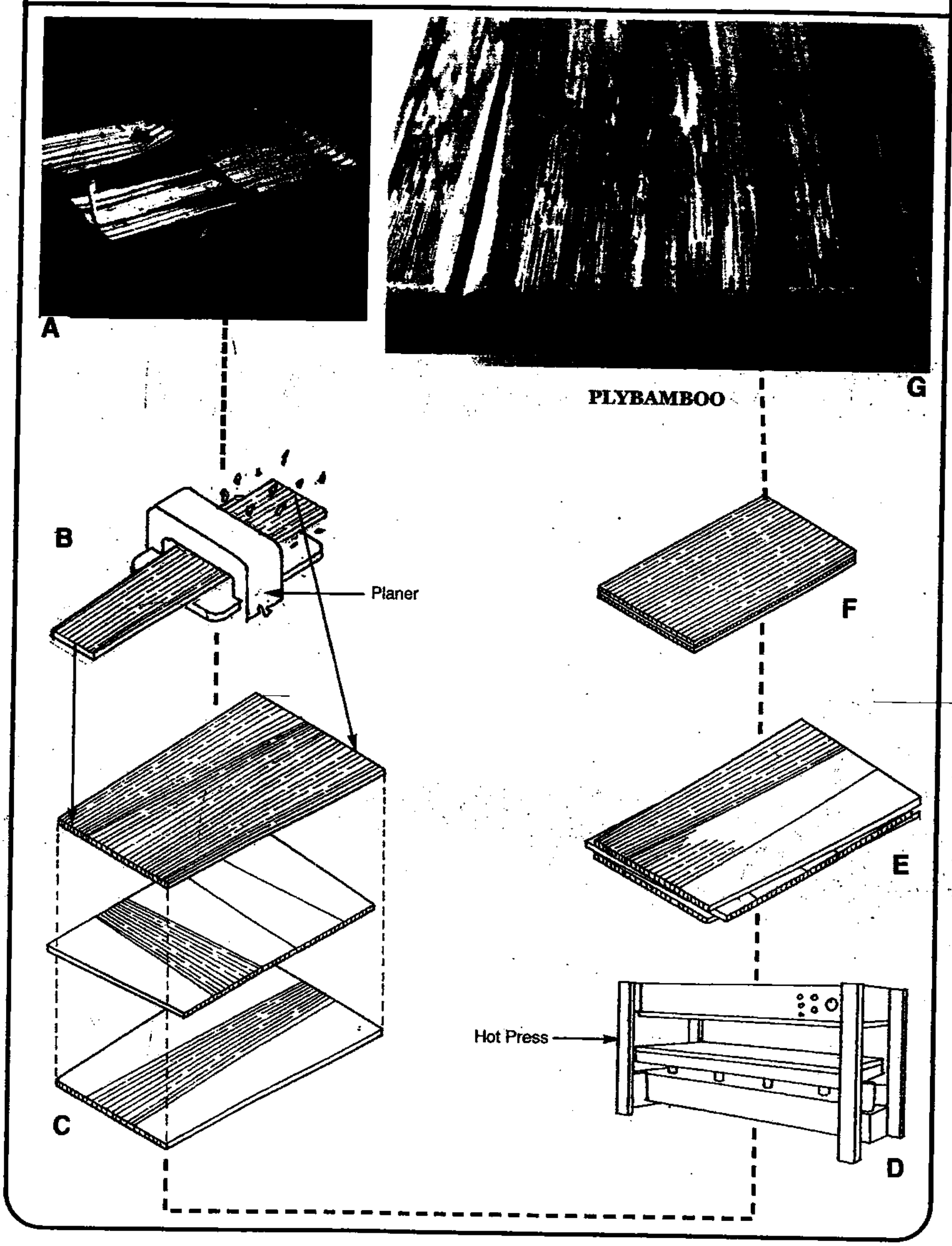


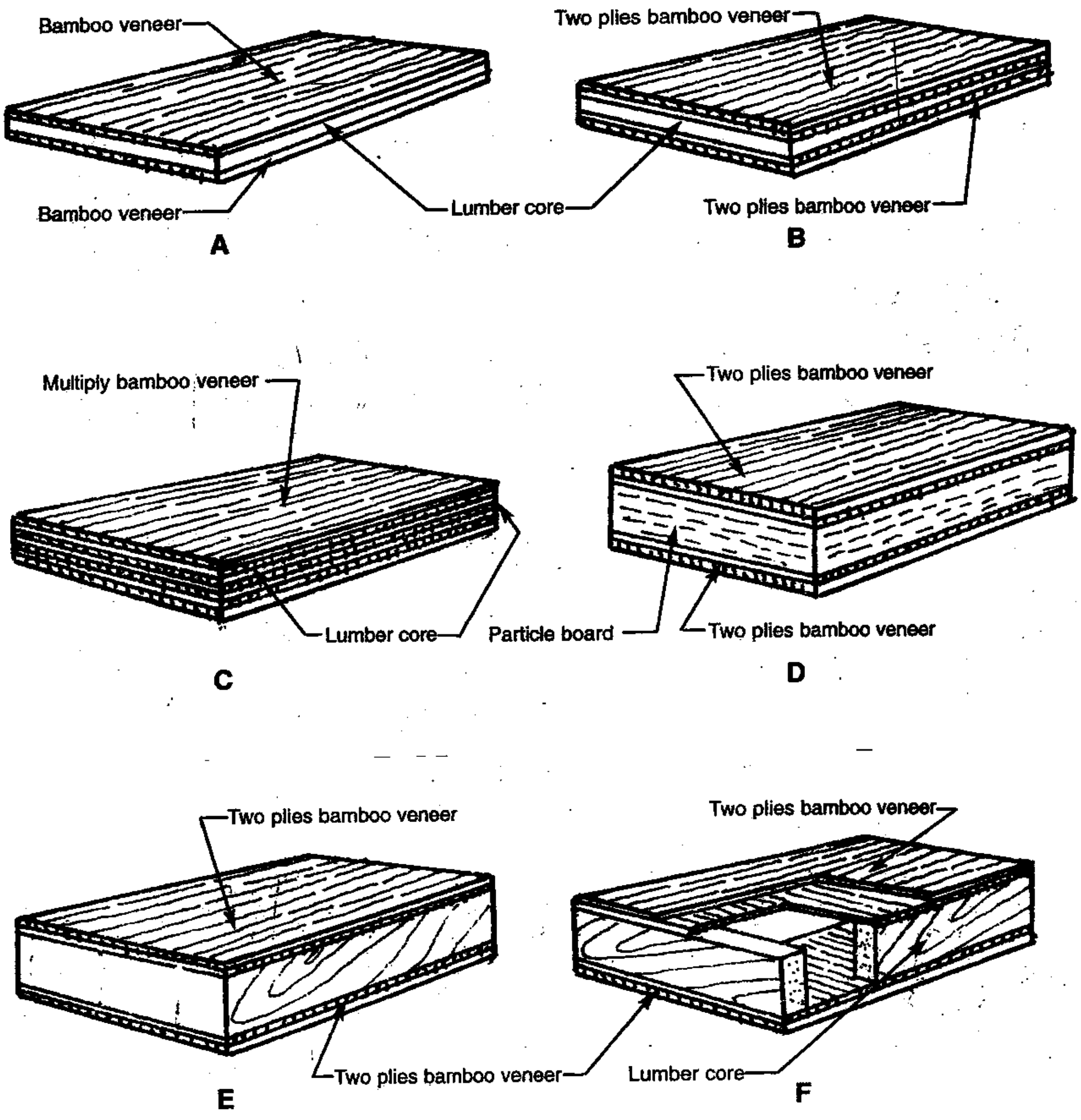
Fig. 12.9 *Cross section of the Colombian plybamboo. This type of plybamboo made with bamboo boards is twice as strong as plywood of the same thickness because the boards include the strongest part of the culm wall.*

Fig. 12.10 COLOMBIAN PLYBAMBOO - MANUFACTURE



PLYBAMBOO WITH WOOD CORE

Fig. 12.11



A. Three ply, bamboo veneer and lumber core construction.
B. Five-ply, bamboo veneer and lumber core construction.
C. Multi-ply, bamboo veneer and lumber core construction.
D. Five-ply, bamboo veneer and wood particle board construction.
E. Five-ply, bamboo veneer and lumber core construction.
F. Five-ply, bamboo ply constructionand lumber banding or railing.

STRUCTURAL PLYBAMBOOS MANUFACTURED IN CHINA

The bamboo based panel industry has been developed in China in the last fifteen years. At the present time, 200 mills have reached an annual production of 100,000 m3 of panels. The major products include plybamboo, bamboo laminated lumber, bamboo concrete forms, bamboo particle board, bamboo veneer faced panels, and bamboo fiber board. This new industry in China has replaced one million cubic meters of industrial timber annually. The bamboo species used as raw material is *Phyllostachys pubescens* which averages 9-10 cm in diameter at breast height. At the present time there are about 2,418,600 ha of *Phyllostachys pubescens* stands in China.

1. CHINESE PLYBAMBOO

The plybamboo developed in China is also called "laminated plybamboo" because all the plies (3 or 5) including the core, are made from slats of bamboo with a thickness of 4 or 5 mm, laid side by side, and bonded together in the direction of the grain, in alternate plies at right angles. An adhesive of phenolic formaldehyde or urea formaldehyde is used. The technology and equipment for the manufacture of plybamboo were first developed at the Nanjing Forestry University in 1982.

Production process

1) The bamboo culm (*Phyllostachys pubescens*) is first cross-cut into four or so sections of the desired length, and the inner and the outer surfaces are scraped out on specially designed equipment. The cuts or sections are then split open in two or three pieces, and the internal nodes of the diaphragm removed.

2) Pretreatment.- The pieces are soaked in hot water (70-80° C) for about three hours, and then softened by steaming at 160° C to thermoplaticize the lignin and hemicellulose more effectively. The treated pieces are then spread out, flattened, dried and stabilized through a heated press, and a breathing drier, especially used for processing bamboo sheets.

3) The pieces are planed smooth and edged straight on both sides. This prepares the material, faces, backs and cross-bands for the manufacture of plybamboo. The forthcoming procedures are just the same as in the manufacture of plywood. This includes the gluing, spreading, assembling, pre-pressing, hot pressing, hot stacking, edging tidyng and end product (Guisheng 1987).

According to Zhao (1987), the amount of urea formaldehyde resin to be applied is 390 - 420 g/ m² and 20 - 60 minutes is the best assembly time when the room temperature is around 20 degree C. The gluing strength is high when the hot pressing temperature is controlled under 115-125 degrees C. The result is good if the pressing is divided into high, medium and low sections in gluing technology, 15-30 kg/cm² for high pressing, 5- 6 kg/cm² for medium pressing and 3-4 kg/cm² for low pressing. Feeding too many or too few materials and shortening hot pressing time and gluing pressure are unfavorable to gluing strength. Hot pressing time can be calculated and determined according to the thickness of the board, 1-1.5 mm = 2 minutes.

Table 12-5 Major properties of laminated plybamboo from China

Density	< 0.9 g/cm³
Moisture content	< 12%
Bonding strength	> 2.5 N/mm²
Static bending strength (longitudinal)	
Thickness <15 mm	>98 N/mm²
>15 mm	>90 N/mm²
>25 mm	>90 N/mm²

Properties.- This laminated plybamboo has extremely high bending strength and very good dimensional stability; it is durable and has wear resistance properties and modulus of rupture (MOR) and it probably ranks as the highest among all of the structural boards and even as good as the solid wood of high density commercial timbers.

Laminated plybamboo has been widely used in China as platform boards in 100,000 trucks at the Nanjing Automobile Manufacturing Co. and in 15,000 trucks at the 1st Changchun Automobile Manufacturing Co., replacing 52,000 m3 of timber and 1,600 tons of steel and reducing the dead weight of the platform by 53 kg each (Zhu et al 1994).

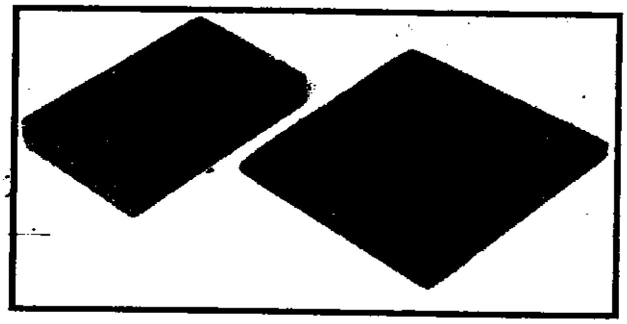


Fig. 12.12 *(A) Chinese plywood covered with a wood veneer .(B) Normal Chinese plywood made with 3 plies of bamboo slats 2 cm wide with a thickness of 4 or 5 mm, lying side by side.*

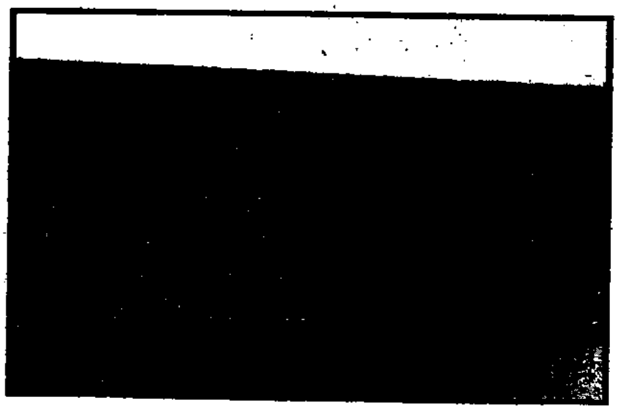


Fig. 12.13 *Cross section of 5 plies Chinese plywood showing the bamboo slats, taken from different parts of the culm wall which make up the plies.*

Wang and Zhang (1993) made a study on the characteristics of expansion of laminated plybamboo (made with urea formaldehyde adhesive) by moisture. When moisture content is increased by 1%, the swelling rate of the parallel board is slightly increased, but the lengthwise swelling of vertical board is a little greater (when plybamboo moisture increases by 1%, the increase of parallel and vertical length is 0.012 - 0.02 and 0.011 - 0.02 respectively). Shrinkage and swelling of plybamboo are the result of interaction of the components in three directions, as the bamboo is split longitudinally, tangentially and vertically.

The lengthwise and cross shrinkage and swelling of plybamboo occur in the position where bamboo is split longitudinally and tangentially. Plybamboo should be strictly protected from drenching and dampness during transport and storage to avoid swelling in length and width that affect loading. Using waterproof paint to coat the surface of plybamboo on all sides can greatly reduce the swelling and increase the dimensional stability of the board.

2.LAMINATED CURTAIN BAMBOO BOARD (with resin impregnated paper).

Laminated curtain bamboo board with resin impregnated paper is an engineering structural material manufactured in China, where it is used as concrete forms in reinforced concrete buildings, bridges, etc. This new composite material was developed in 1991 by Zhao R.J & Yu Y.S. (1992) at the South Central Forestry College, Zhunzhou, Hunan, China. The main materials used in its manufacture are:

(1) Bamboo curtain. This is the basic component. Bamboo culms with a diameter of 6 centimeters or more are cut into strips and woven into bamboo curtains by hand or by using a curtain weaving machine developed by South Central Forestry College. After being spread with adhesive and dried, stripe bamboo curtain is cut into bamboo curtains with specific sizes.

(2) Bamboo mat. This is made as explained in mat bamboo panel.

(3) Primer paper. This is a waterproof kraft paper of 80-120 g/m2 without repellant additives.

(4) Adhesives. Bamboo curtains and bamboo mats are impregnated with water-borne phenolic adhesive, and the primer paper is impregnated with a modified melamine adhesive. Before they are dipped in adhesive, bamboo curtains and bamboo mat should be dried to control the moisture content below 12%. After drying, they are dipped in water-borne phenolic adhesive using special dipping device. The adhesive should be well distributed on all surfaces of both bamboo curtains and bamboo mats. Then they are dried at a low temperature to evaporate any water so as to guarantee the quality.

Before dipping the primer paper in the modified melamine resin, a small amount of diluter, release agent and airing agent should be added to the adhesive in order to reach a certain dipping quantity and to break the film. After being dipped in adhesive and dried to evaporate most solvent, primer paper becomes an adhesive film paper, with a certain resin content and resin condensation degree.

When assembling, the position and number of longitudinal and cross bamboo curtains depends on the thickness of the panel. The position and the number of vertical bamboo curtains and horizontal bamboo curtains in the panel, must be reasonably determined. One layer of bamboo mat and one to two layers of film adhesive are placed on the two surfaces of bamboo curtain panel. Bamboo mat is used for a smoother finish of the planking, while film adhesive on the surface is used to enhance wear-resistance and waterproof qualities. Attention should be paid to symmetry when assembling so as to guarantee concrete form stability of the panel.

The hot pressing procedure is "cold-hot-cold". The procedure of "cold-hot-cold" hot pressing is divided in three stages: preheating, curing and shaping, and cooling. The time for preheating depends on the temperature rising from 50 to 135° C.; the time for curing and shaping is calculated at 1.5 to 2 minutes per millimeter of the final product of the panel; and the time for cooling depends on the temperature dropping to 50 degrees centigrade. The hot pressing cycle is mainly determined by the panel thickness. Generally, the duration of the hot pressing for a 12 mm panel is about 45 minutes.

Bamboo is a thermoplastic material with many holes. Under the action of heat and pressure, as the panel thickness decreases and panel density increases, the longer the hot pressing time, and the more condensation. Therefore, under the premise of guaranteeing panel strength, the technical parameters of temperature, pressure and time should be reasonably determined to enhance output ratio and reduce the hot pressing cycle. A hot pressing time of 1.5-2 min/mm panel thickness is needed for curing the resin. Cool water is then introduced into hot platens to lower the temperature of the panel to 50° C.

After the panel is pressed with heat and sawn, its sides should be coated and sealed so as to enhance the waterproof properties of the panel. This composite panel has the advantages of high strength, good rigidity, little linear dilatation, and wear-resistance and corrosion resistance of the panel surfaces.

Table 12-6 Properties of laminated bamboo curtain board (medium density panel)

Physical properties	
Density	0.82 g/cm3
Moist content	3 %
Linear expansion-Length	0.066 %
-width	0.136 %
Wear resistance	0.053 g/100 revolut.. (300 times)
Retarding combustibility	29.0 Oxigen index
Pollution resistance- Little corrotion under the action of sodium carbonate solut. with 10% solv.	
Mechanical properties	
Bending strength (MPA)	104.5
Elastic modulus (MPA)	11,100
Impact toughness (J/CM2)	6.35
Gluin strength (MPA)	2.73
Modulus of elasticite (MPA)	104.5
MOR (Gpa)	11.1

[Source: Zhao & Yu (1992). Zhu Shillin et al (1994)]

This composite material can be used as concrete forms and can be used repeatedly about 100 times if its surfaces are chemically treated.

3.-BAMBOO PARTICLE BOARD

Particle board is a panel product produced by compressing small particles of bamboo or wood while simultaneously bonding them with an adhesive. The many types of particleboard differ greatly in regard to the size and geometry of the particles, the amount of resin (adhesive) used, and the density to which the panel is pressed. The properties and potential uses of the board differ with these variables.

The major types of particles used for particleboards are: shaving, flakes, wafers (similar to a flake), chips, sawdust, strands (a long narrow flake with parallel surfaces), sliver (nearly square cross section) and bamboo wool (long, slender slivers). Most particle board is produced from residue or leftover bamboos from constructions, or small diameter bamboos that have no other use. Bamboo particle board can be used for ceilings, hollow doors, wallboard furniture, interior decoration, packing and walls in house interiors.

Manufacturing process. Raw material grinding - drying - glue spreading - sorting - forming - hot pressing - final treatment. The processes and the equipment are almost the same as those used to make wood particle board.

Bamboo particles in sizes of 20-30 x 1- 5 x 0,1-0.5 mm, are prepared with chippers and/or ring flakers, and the moisture content is about 25-35%. The particles are dried in a rotary drum dryer at 150-180° C, to reduce the moisture content to 4-6%. After screening, glue spreading, forming, and prepressing, bamboo particle board with a thickness of 4-6 mm is produced by hot pressing at 155-165° C and 1.18 - 1.14 Mpa; the pressing time is about 0.4 minutes/mm thickness of board, and the density of the board is about 0.7 gr/cm3.

According to Wang (1988), the properties of bamboo particle board meet the state standard requirements for wood particle board. The static bending trength is 300 kg/cm2, and the thickness swelling is 3%.

Dimension stability of bamboo particle board made from acetylated particles has been studied by Rowell (1988) using particles of the species *Phyllostachys bambusoides* Sieb et Zucc. The particles were oven-dried at 105° C for 3 hours, and reacted with acetic anhydride at 120° C.

Two kinds of particles with acetic weight per cent gains (WPG) of 14 % and 18%, based on the original oven-dry (OD) weights, were obtained. Control particles and acetylated particles were sprayed with a 43.5% aqueous solution of phenolformaldehyde resin. The resin solid content was 6% based on the OD weights of the particles. They were pressed for 10 min at 177° C into boards with a density of approximatelly 640 kg/m3.

Four specimens were cut from each board, oven-dried and weighed. The rate of swelling in water, thickness changes in cyclic, the water-soaking test, and the equilibrium moisture content (EMC) at 30 % , 65% and 90% relative humidities (RH) were measured for particle board specimens of control and acetylated particles. The results were as follows: During the first 60 min, control boards swelled 10% in thickness, whereas the boards made from acetylated particles at 18% WPG swelled about 2%.

During five days of water soaking, the control boards swelled 10%, whereas the 18% WPG boards swelled slightly over 3%. Control boards swelled a total of 30% in thickness during the five wetting cycles as compared to 10% for the 18% WPG acetylated board. At each RH, both acetylated particles and acetylated particle board had significantly smaller EMCs than control particles and boards.

According to Zhu D.X. (1991), the wood particleboard required 160-180° C temperature and 50-70 kg/cm^2 of high pressure during the hot pressing, but bamboo particleboard does not require such conditions. Bamboo particle board is prepared by the dry method because the fibers are straight and easily matted, so it consumes less power and heat.

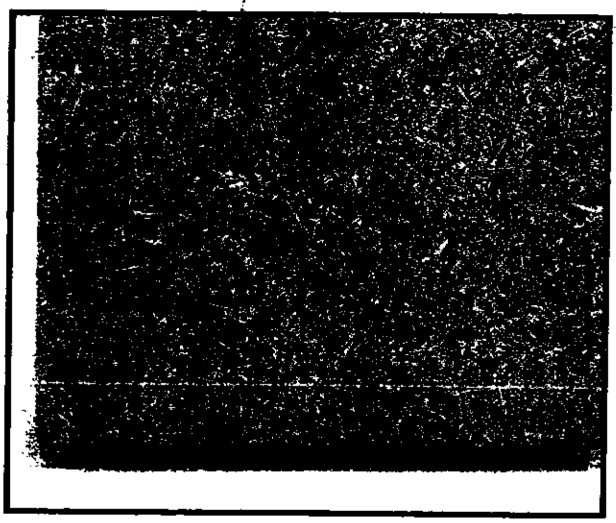


Fig. 12.14 *Bamboo particle board panels made with sawdust (Trevor D. Dagilis.)*

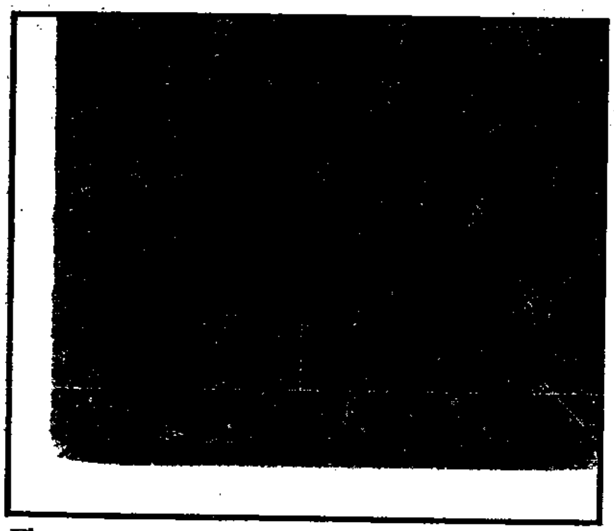


Fig. 12.15 *Bamboo particle board panels made with flakes (Trevor D. Dagilis.)*

4.-BAMBOO FIBERBOARD

Bamboo fiberboard belongs to a group of bamboo-based panel products which differ in appearance, mechanical properties and uses. Its properties are better understood through an understanding of the paper-making process, in which bamboo chips are disintegrated into fibers (pulped) by water-dissolved chemicals penetrating the chips in pressure cookers to dissolve the lignin, the substance that bonds fibers together. The delignified separated fibers are washed and suspended in large amounts of water; the resulting slurry flows onto a fine wire-mesh screen through which most of the water drains, leaving the fiber pulp to form a thin wet mat. Peeled from the screen and dried, this thin mat is nothing less than paper, whose fibers are held together by interfelting and by natural natural bonds without any added binder.

Fiberboard factories fiberize chips and round pieces of bamboo mechanically without lignin-dissolving chemicals, therefore, leaving the lignin in. Hot water or steam softens the wood or bamboo before the attrition mill, a sort of grinding machine, rubs the fibers apart. Defibering is less perfect than pulping with chemicals; fiberboard pulp contains fiber fractions (fines), bundles of fibers, and large fiber aggregates which are not tolerable in pulp meant for good paper.

The pulp must then be washed to remove wood extractives along with other solubles and fines, leaving the fibers suspended in a water slurry, which runs onto a wire mesh screen to drain off water as in paper manufacture. Due to the imperfect defibering and the stiffening effect of lignin, the fibers interfelt and bond less than paper fibers. The board still has sufficient strength for many uses, but some kinds need to be reinforced by adding 2 or 3% binder to the slurry. Finally, the water-drained mat is compressed and dried in various ways, then edged to make square rectangular panels.

In thickness, fiberboard lacks stability, swelling and shrinking like a particle board, even more than solid wood perpendicular to the grain. To retard moisture absorption and swelling, manufacturers add water repellents (sizers), which repel liquid water much more than they do water vapor. Added synthetic resin binders improve the dimensional stability too.

The process for making bamboo fiberboard panels is almost the same as that for wood fiberboard. Chips are prepared in sizes of 20 x 5 mm, and immersed in water to increase the moisture content to 40-50%. The chips are then steamed at 170 degrees C and a pressure of 8 kg/cm^2 for 15 minutes. After defiberation and refining, additives, including PF resin and wax, are added to the pulp, and the PH of the pulp is adjusted to 5 . After forming, prepressing and hot pressing, bamboo hardboard or MDF is made. For making a 4 mm thick, 1.0 g/cm^3 density hardboard, 1% PF resin and 1.0% wax are used, and the pressing time is 7 min at 210 degrees C, 60 kg/cm^2 presssure. For making MDF in a 10 mm thickness with a density of 0.7g/cm3, 5% PF resin and 1% wax are used and the pressing time is about 16 min at 200 degrees C with 35 kg/cm^2 pressure.

5.-WOVEN PLYBAMBOO BOARD

There are three types of woven plybamboo boards: bamboo mat board, corrugated bamboo mat board, and bamboo curtain board.

5.1. - BAMBOO MAT BOARD

Bamboo mat board is a material with great potential. Its modulus of rigidity (MOR) and flexibility are very high and can replace thin plybamboo and plywood in almost any application. In India, bamboo mat board was developed at the Forest Research Institute, Dehra Dun by Narayana-murti (1956). At the present time it is produced in India, Thailand, and China, where there are 16 factories with an annual capacity of 20,000 m3.

Manufacture Process

Bamboo mat is the basic raw material. It is woven from strips cut open from split bamboo culms without any mold stains that have the joints cut flat. It must be woven compactly with an even thickness. Generally the entire process is manual, mostly undertaken by women in rural areas.

Bamboo culms are cut open into thin strips of inner skin in widths of 12-15 mm and a thickness of 0.6-1 mm. Strips from the glossy peripheral epidermal layer should be avoided as they are resistant to bonding. The strips are woven into 2,500 mm x 1,300 mm mats. The moisture content of freshly woven mats is in the range of 40-50%. After drying them in the sun, the moisture is reduced to 8-15%.

If the mats have to be transported and stored for over a month, it is advisable to undertake prophylactic treatment. The simplest and a significantly effective treatment for mats, provided they are not exposed to rain, is spraying with 1% solution of a mixture of boric acid and borax in the ratio of 1:1. Spraying can be done by hand or with a knapsack sprayer. This will not have any adverse effect on bonding. The mats should be air dried after prophylatic treatment.

The air dried mat is spread with 280-320 g/m^2 urea formaldehyde (UF) glue. Soybean flour in quantities of 5-10% is used as a filler, and 0.5% NH_4 CL is used as a curing agent. The glued mats are assembled and then hot pressed into bamboo mat board.

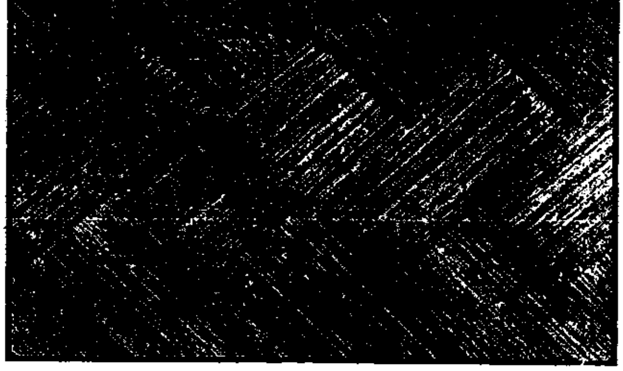


Fig.12.16 *Bamboo mat board.*

Fig.12.17 A. *Plastified bamboo mat board*

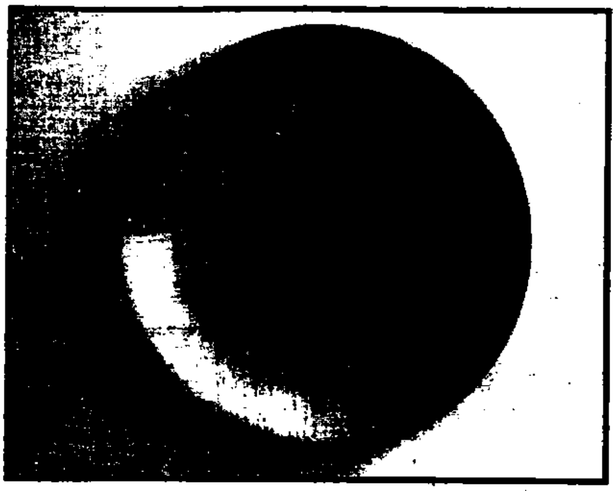


Fig. 12.17 B. *Plate made from bamboo mat*

Yuan & Hua (1988) experimented in China with the manufacture of two layer bamboo mat board. The format for the bamboo mats was 400 x 400 mm, and 1.2 mm thick. The optimum conditions they got were by glue spreading 250 g/m²; pressure on unit area 20 kg/cm²; hot press time 1.2 min/mm thickness; and temperature 130 degrees C. According to the calculated values, the amount of glue is the most important factor influencing the static bending strength of mat plybamboo, followed by unit pressure of the mat and the temperature of the hot press.

Treatments. A suggestion for preservative treatment is Sodium Octaborate Tetrahydrate (SOT) dissolved in water which is poured into the resin applicator. The quantity of SOT to be dissolved is 1 kg in 200 kg water for 100 kg of Phenol Formaldehyde resin. This boron compound penetrates into the slivers along with the resin and gets fixed. The resin treated mats are stacked and kept for at least 2 hours for stabilization.

After the period of stabilization, the treated mats are dried in a simple drying chamber or in a band dryer at a temperature of 90 to 95° C until the moisture content is brought down to 8-10%.

Surface treatment of bamboo mats (plastifying).

Plastifying is adopted for surface treatment of bamboo weaving. Plastifying, as the term suggests, refers to the bonding of adhesives. It is just one more proccess (plastifying) in the routine technology of production, that is surface treatment for the second time in the production.

The technology is: bamboo mat > selection > glue spreading (urea resin adhesive) > assembly > hot pressing > edging > test > soaking (phenol resin adhesive) > air drying > hot pressing > triming > test > storage.

The air dried mats (after being trimmed) can be dipped in a phenol formaldehyde resin solution. About 200 kg of resin is poured into a resin applicator and double the quantity of water is added. It is mixed well to ensure homogeneity. Mats are dipped into the resin solution and kept for 5 minutes. The mats are then lifted and kept in an inclined position for about 30 minutes until excess resin in the resin treated mats is completely drained down to the resin applicator. After a period of stabilization, the resin treated mats are dried in a simple drying chamber or in a band dryer at a temperature of 90-95 degrees C.

The assembled mats are loaded to the hot press (preferably employing a fork lift) and a specific pressure of 16 kg/cm2 (18 kg/cm2 for mats with non uniformly thick slivers) is applied for a period of 6 minutes (for 3 layered panel) at a temperature range of 140°-145° C. The pressing time should be increased at the rate of about 1 minute for each additional mat layer. The hot pressed panels are released from the press and stacked for a period of at least 8 hours before trimming.

Applications: mat plybamboo is used for packing boxes, furniture making, interior decoration, and interior doors, ceilings and walls.

5.2. CORRUGATED BAMBOO MAT BOARD.

The production procedure is similar to that of bamboo mat board. The mat is dried to reduce the moisture content to 12-14%. Phenol formaldehyde (PF) glue is applied to the mat in the amount of 400 g/cm² (single face). A set of 5 layer mats is hot pressed between two corrugated caul plates into corrugated bamboo mat board. With the high strength, low weight and good insulation properties, the product is suitable to be used as roofing material for low cost buildings or houses and for walls (Zhu 1991).

5.3 -BAMBOO CURTAIN BOARD

Bamboo culms are cut into long strips, with a thickness of 1 mm and a width of 10-20 mm, which are woven into curtains. After drying to reduce the moisture content to less than 12%, the curtains are dipped in phenol formaldehyde (PF) glue and then dried and hot pressed into bamboo curtain board with working pressure of 3 - 4 Mpa. The size of the bamboo board is 4,500 x 1,300 mm with thicknesses of 6, 12, 16, 20, and 30 mm.

Bamboo curtain board has a wide range of applications; the thin panels can be used for packing purposes, the panels in medium thicknesses can be used for interior decorations, and the thick panels can be used as structural materials, such as large size concrete forms and platforms for trucks.

BAMBOO MAT AND BAMBOO FIBER MAT USED BAMBOO MAT BOARD AND BAMBOO FIBER MAT USED AS REINFORCEMENT OF EPOXY RESIN

In the last few years synthetic fibres such as glass and carbon has been used as reinforcement in making structural components. Due to the high cost and high energy requirements in their production, these synthetic fibres are not suited for the common applications. For this reason natural fibres such as bamboo have emerged as a renewable and cheaper substitute for sythetic fibers. One of the must important studies carried out in this field in the use of bamboo fiber-reinforced plastic (BFRP) was conducted in India by Jain, Kumar and Jindal (1992). They used bamboo fibers and bamboo orthogonal strip mats (bamboo mats) to reinforce epoxy resin and evaluate their tensil, flexural and impact strengths.

In bamboo mat composites, the fiber volume fraction, V_f, achieve was as high as 65%. The tensil, flexural and impact strengths of bamboo along the fibers are 200.5 MN m^{-2}, 230.09 MN m^{-2} and 63.54 kJ m^{-2}, respectively, whereas those of bamboo fiber composites and bamboo mat composites are 175.27 MN m^{-2}, 151.83 MN m^{-2} and 45.6 kJ m^{-2}, and 110.5 MN m^{-2}, 93.6 MN m^{-2}, and 34.03 kJ m^{-2}., respectively. These composites possess a close to linear elastic behavior. Scaning electron microscopy studies of the fractured BFRP composite specimens reveal a perfect bonding between bamboo fibers and the epoxy. Furthermore, high strength, low density, low production cost and easy of manufacturing make BFRP composite a commercially viable material for structural applications.

The scientific name of the bamboo specie used in the manufacture of the bamboo fiber ~~mats and orthogonal fiber~~ strip mats were not indicated, probably because they were procured in the market from the Tripura Government Arts and Handicraft Emporium, New Delhi, India.

BFRP composite from bamboo fibers. The fibres were obtained by removing the cotton threads; fibers of 0.1-0.3 mm diameter and 40 cms long were chosen and dried in an oven at 105° for 3 hours. Araldite resin CIBA Cy-230 was mixed with hardener CIBA CY-951, 10% by weight of the resin. Dried fibers were soaked in the resin and hardener mixture and kept unidirectionally adjacent to each other in an acrylic perspex mould. The excess resin was squeezed out by applying pressure to the mould. A composite plate of uniformly distributed bamboo fibers in a resin matrix was obtained after curing the resin for 24 hours. This composite plate was inspected for any voids. Using the above technique, none of the plates have more than 0.5 voids

BFRP composite from bamboo orthogonal mat. These mats are available in 60 cm x 60 cm x 0.05 cm size. The cross section of the strips is 4 mmx 0.3 mm. For a single-layered composite, a hand lay-up method was used ; the composite was cured under pressure in the mold used earlier.

For a multilayered composites with different fiber orientation, the mat was cut according to the required fiber orien-

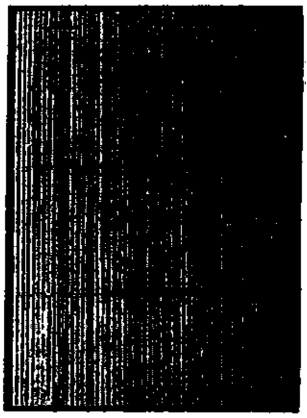


Fig 12.18 -A) *Bamboo fiber mat* -B) *Bamboo orthogonal strip mat*

Fig.12.19 *Surfboard manufactured with epoxy resin reinforced with bamboo ortogonal mats by Gary Young in Hawaii.*

tation and then the composite was made by stacking these one over the other and using the hand lay-up method A composite with 65% fiber volume fraction was obtained by applying a pressure of order of 3.2 k N cm^{-2} to the mould.

The mechanical properties of bamboo and BFRP composites

Bamboo is a natural composite material in which cellulose fibers are reinforced in the lignin matrix along the length of the bamboo culm, providing it with maximum strength in that direction. Because bamboo has minimum strength across the fiber, multilayered composites of different fiber orientation have been developed. Experiments were conducted to determine the tensil, flexural and impact strengths on samples made of raw bambo, unidirectional composite (fibers)(0°), bidirectional composite (mats) (0°/90°), and multidirectional composites from bamboo fibers and ortogonal mats.

Tension and flexural tests were performed according to the ASTM. Three point bend tests were performed to measure flexural strength. Tensil and flexural specimens of bamboo were rectangular strips , 150 mm long, 25 mm wide with a thickness between 2 and 4 mm.

The results show that unidirectional BFRP composit with 50% V_f has 60% grater strength than that of bidirectional BFRP composit with 70% V_f. In unidirectional BFRP composite, V_f is low and the density of the composite is higher as also is its cost, whereas in bidirectional BFRP composite, V_f is 70% but only 50% of the fibers which are in the tensil load direction *(y)* contribute to the tensil strength, the remaining 50% of the fibers are just working as reinforcement in the *x*-direction, thus given a biaxial strength. At the same time the *x*-directional reinforcement reduces the density and also the cost of the composite.

The tensil strength of the multidirectional bamboo fiber composites decreases with increasing number of layers, $B_{5f} > B_{7f} > B_{9f}$, whereas the trend of tensil strength is opposite in the bamboo mat composite. With increasing number of layers, the volume fraction of fibers continues to increase, as does its tensil strength: $B_{9m} > B_{7m} > B_{5m}$.

Table 12-7 TENSILE AND FLEXURAL STRENGTH OF BAMBOO FIBER AND BAMBOO MAT COMPOSITES

	Orientation of fibres (deg)	Density of the composite (10^3 kg m^{-3})	Fibre volume, V_f (%)	Tensile strength (CoV) (MN m^{-2})	Elongation (%)	Flexural strength (CoV) (MN m^{-2})	Deflection (mm)
Bamboo fiber composite (unidirectional)							
Unidirectional (single layer)	(0)	0.975	50	175.27 (± 4.29)	8.9	151.83 (± 3.86)	
Bidirectional (single layer)	(0/90)	-	-	-	-	-	
Multidirectional (5 layer)	(O_2/ ± 45 + 90)	1.030	35	99.34 (± 3.96)	6.2	130.23 (± 5.28)	2.5
Multidirectional (7 layer)	(O_2/ ± 30/ ± 60/90)	1.010	35	82.2 (± 1.72)	7.5	161.1 (± 2.85)	1.75
Multidirectional (9 layer)	(O_2/ ± 22.5/ ± 45/ ± 67.5/90)	1.003	35	70.13 (± 1.65)	8.0	186.38 (± 2.53)	1.25
Bamboo mat composite (multidirectional)							
Unidirectional (single layer)	(0)	-	-	-	-	-	-
Bidirectional (single layer)	(0/90)	0.908	70	110.5 (± 2.49)	7.0	93.6 (± 4.98)	
Multidirectional (5 layer)	(O_2/ ± 45 + 90)	0.936	60	80.5 (± 1.40)	4.09	108.56 (± 1.52)	5.4
Multidirectional (7 layer)	(O_2/ ± 30/ ± 60/90)	0.930	63	87.99 (± 0.31)	5.55	124.52 (± 2.86)	3.6
Multidirectional (9 layer)	(O_2/ ± 22.5/ ± 45/ ± 67.5/90)	0.925	65	92.65 (± 0.70)	6.59	134.59 (± 3.78)	3.2

Source: Jain, Kumar and Jindal (1992) -Note: It is not indicated the scientific name of the bamboo used

In mat composite (B_m), shearing stress in 45° ply are very dominant, whereas in bamboo fiber (B_f) composite shearing stresses are not prominent

For bamboo fiber and mat composites, the flexural strength increases from the five-layered to the nine- layered composites. In the flexural test it was observed that as the number of layers of BFRP lamina/mats increases, the strength also continues to increase due to the fact that specimens have also been tested to failure in the flexural tests. In the tensile test the stress distribution across the section is uniform, but in the case of flexural test the stress distribution across the depth is linear during the elastic stage and nonlinear in the plastic stage. The effect of this nonlinearinity is that as the depth of the flexural specimen increases, flexural strength also increases.

The stress-deflection curve shows a linear segment and then a curved segment from the middle of the curve up to the fracture load. The fracture shows a staggered decrease in load.

For the bamboo fiber composite, tensile strength decreases as the number of layers increases. However it is seen that for the same composite with increase in the number of layers the flexural strength increases.

Impact test specimen

Test specimens were 75 mm long and the cross section was 10 mm x 10mm. Tests were performed on noched and unnoched bamboo fiber and bamboo mat reinforced plastic composites.

Fiber composites have a higher impact strength than mat composites. This can be explained by 50% of the fibres in mat being in the direction of impact and the other 50% being perpendicular to the impact. Only perpendicular fibres are capable of arresting and diverting the propagation of the notch by delamination .

Another important fact which has emerged is that the notch does not affect the strength of BFRP composite. The high impact strength of BFRP composite puts it in the category of tough engineering materials.

Conclusions

Bamboo, a natural composite, has been shown to have maximum strength along the fibers and minimum strength across the fibers.

A composite with good strength in all directions has been successfully developed using bamboo fibers and bamboo mats. The fiber volume fraction achived was 65%.This high fiber volume reduces the density and the cost of the composite. Owing to the reinforcement of fibers in the ortogonal direction s (in the form of a mat) the BFRP composite possesses useful biaxial strength.

This composite is non-corrosive in nature and the layer of epoxy on the surface prevents the natural decay of the bamboo. It has been observed that the mechanical properties of BFRP composite are superior to other known natural fiber-reinforcement plastic composites, as reported in the literature. (Jain, Kumar and Jindal, 1992).

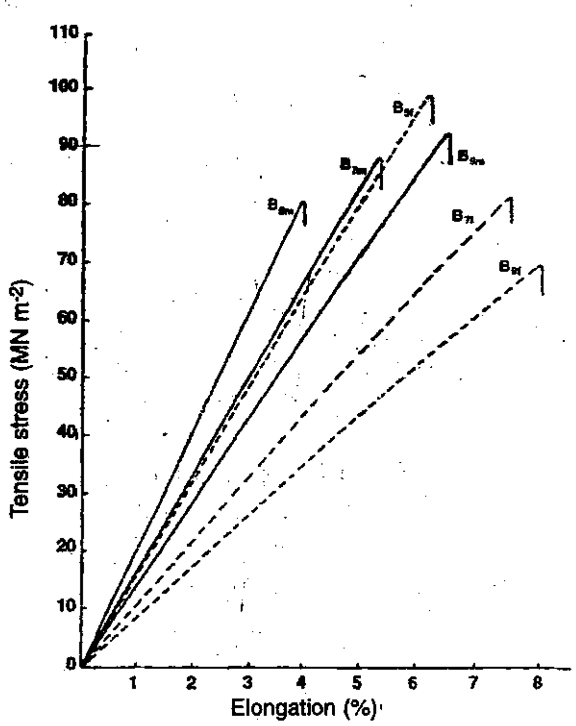


Fig. 12.20 *Tensile strength-elongation curves of bamboo fiber and bamboo mat composites.*

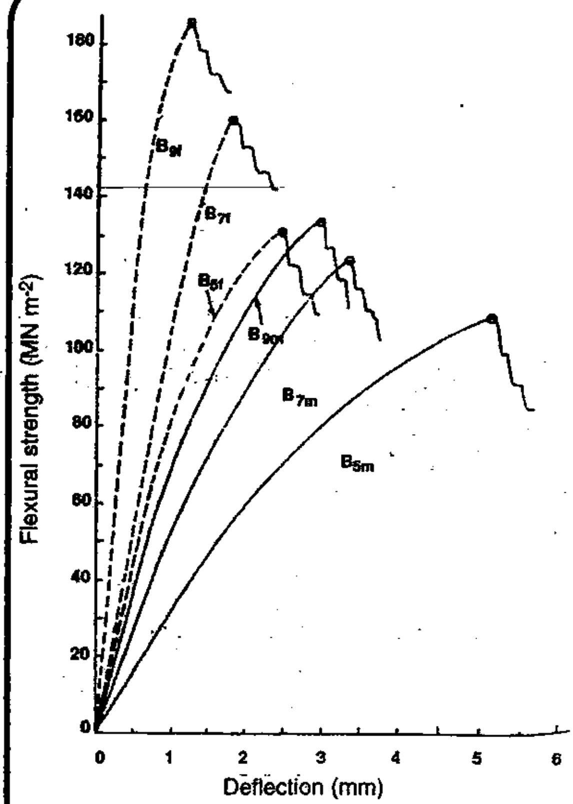


Fig.12.21 *Flexural strength-deflection curves of bamboo fibers and bamboo mat composite.*

GLUED LAMINATED BANBOO FOR THE MANUFACTURE OF SKI POLES AND FISHING RODS

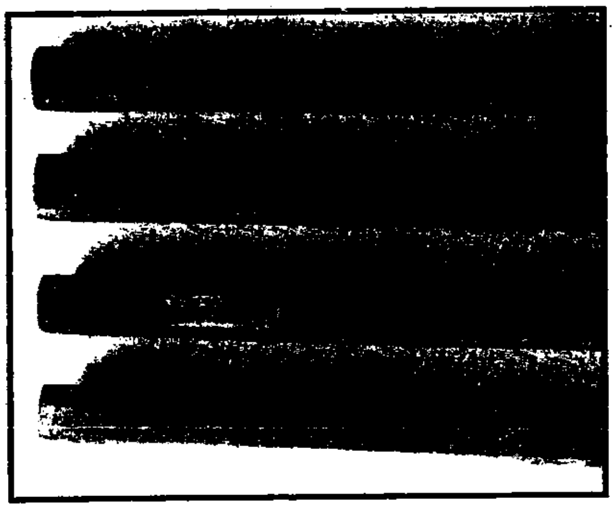
Fig. 12.22

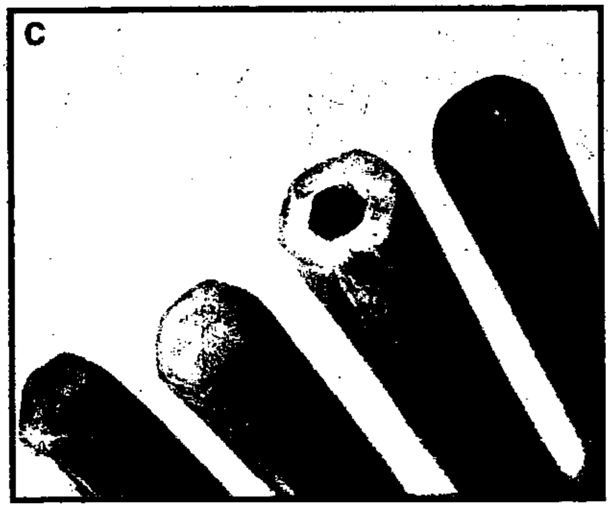
MANUFACTURE OF SKI POLES

In the fourties', during the Second World War, Dr. Alonzo McClure of the Smithsonian Institution of Washington collaborated with the army of the United States in carring out a study related to the use of bamboo in the manufacture of ski poles. With this purpose Dr. McClure traveled by several countries of Central America and South America looking for the most appropriate giant bamboo native species which could be used in the manufacture of ski poles. Most of the species he gathered were from the genus *Guadua*.

The glue laminated ski poles were manufactured by several industries of the United States which at that time were ma-nufacturers of fishing rods. They used 2 types of laminated bamboo sections: equilateral-triangular, as shown in Fig. "A" and equilateral-trapezoidal section shown in Fig. "B". In the former can be seen that the external part of each triangle belongs to the exterior part of the culm that is the strongest part of the culm, due to this reason it is necessary to left the exterior part or skin as nearly intact as possible.

The bamboo strips are planned to an accurate equilateral triangular section in one of a variety of possible jigs which ensures both the the correct shape of the section and the correct taper. Sets of six strips are then glued together into appropriate hexagonal rod section, the skin of each is being placed to the out side, as mentioned above. The wall of some bamboos are thin so there is a limit to the thickness of the poles or rods.



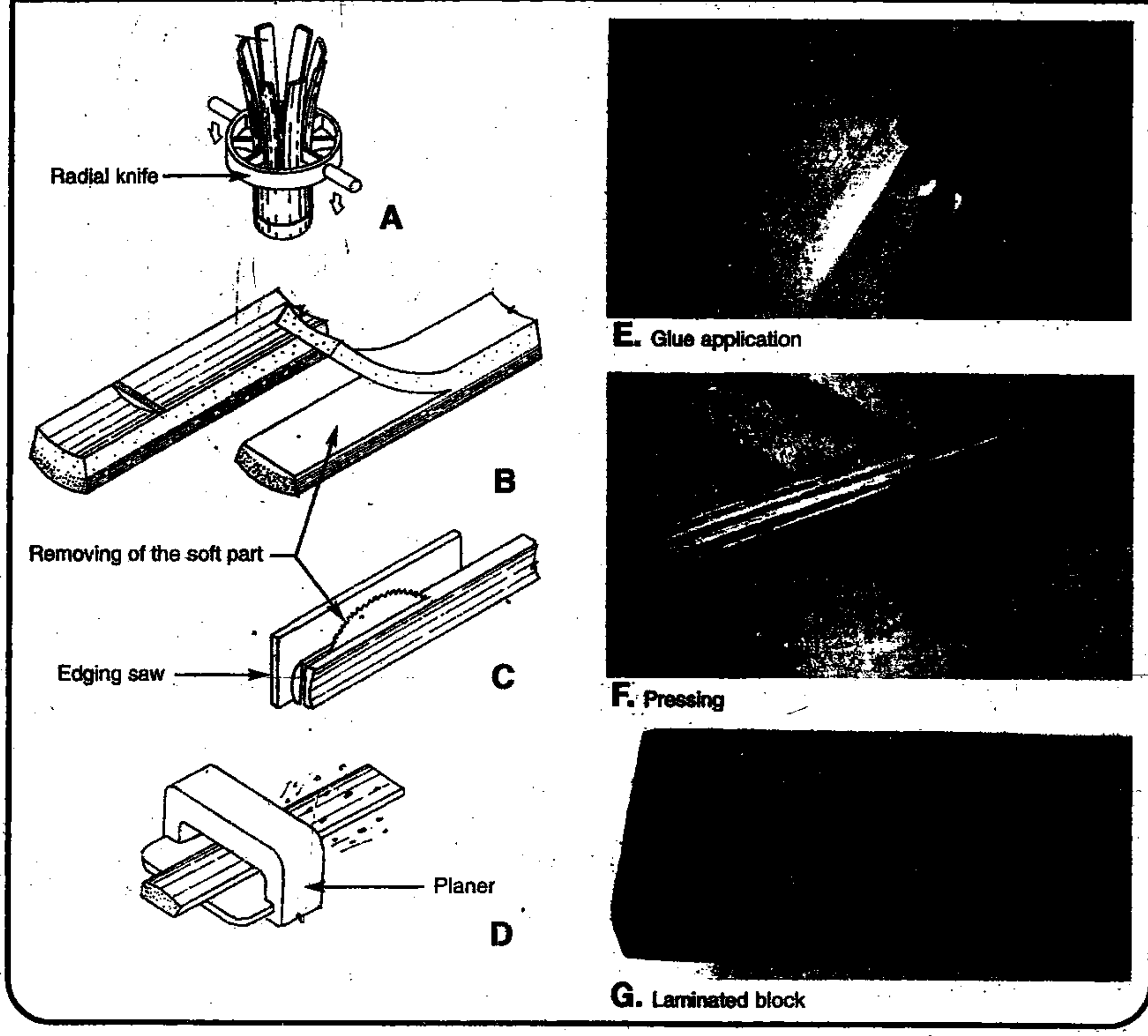


A. *The length of the bamboo ski poles were 122 cm (42") and they are tapered longitudinally The diameter in the top part varies from 15 mm - 18 mm and in the lower part the average diameter is 12 mm.*

B. & C. *Bamboo triangular and trapezoidal strips were used in the manufacture of ski poles.*

MANUFACTURE OF GLUED LAMINATED BANBOO FOR STRUCTURAL, FURNITURE AND FLOOR USES

Fig. 12.23 MANUFACTURE OF GLUED LAMINATED BAMBOO IN COLOMBIA

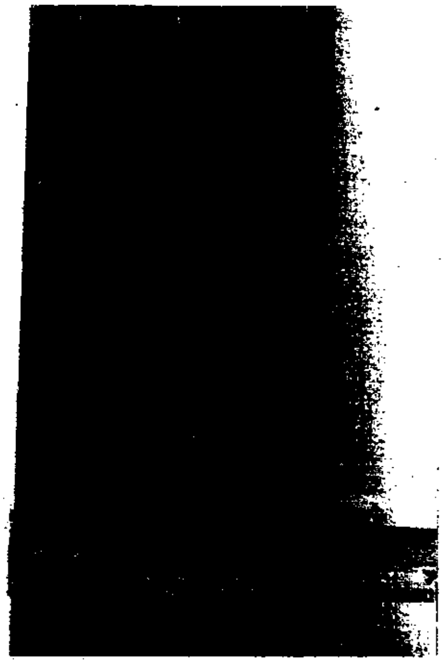


Composite materials such as glue laminated bamboo and glued laminated wood, refers to several layers of bamboo slats or wood boards or slats, glued together with the grain of all layers parallel or in the same direction.

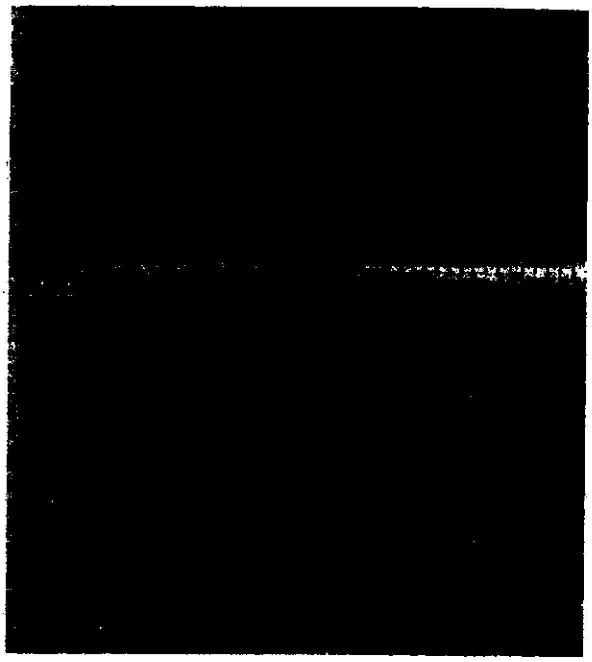
Laminating is a practical means of obtaining a hight degree of control over the properties of bamboo products. By placing the exterior or strongest part of bamboo culm wall in the regions of greateest stress, i.e. the top and botton surfaces and the sections of greater imposed bending moment, performance can be maximize. Likewise, by placing the material with greatest elastic modulus as far as posible from the neutral axis, deflection can be minimized.

In practice the exterior or strongest part of the culm wall is the source of laminations for the top and bottom of the beam where are located respectively the compresion and tension areas of the beam, while the central part of the culm wall supplies the material for the central portion of the beam where is located the neutral axis of the beam, which requires bamboo laminations with lower strength. (See Glue laminated structures).

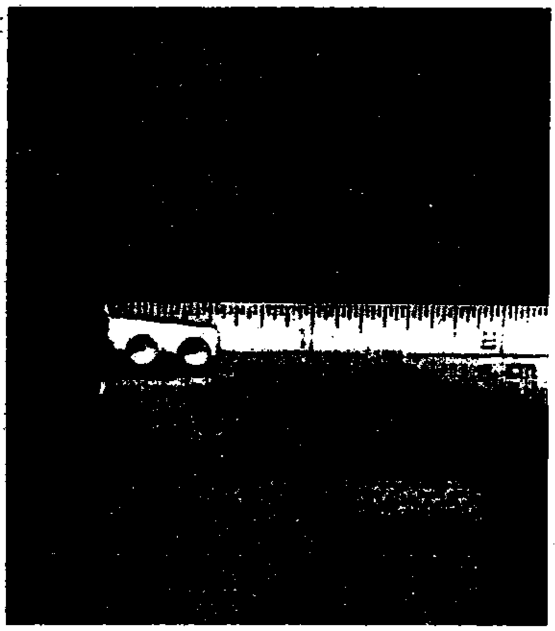
Fig.12.24 DETAILS OF BAMBOO GLUED LAMINATED PIECES



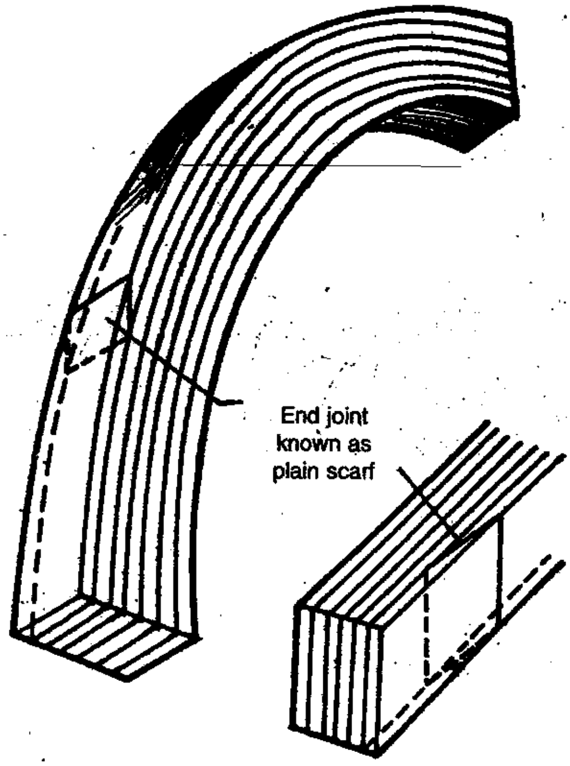
A. *Lamina of Guadua angustifolia taken from the interior side of the culm wall, it can be used only in the central area of the beam nearest to the neutral axis. For the top and bottom of the beam laminas taken from the exterior part of the culm wall most be used.*



B. *Different laminated pieces for beams and forniture.*



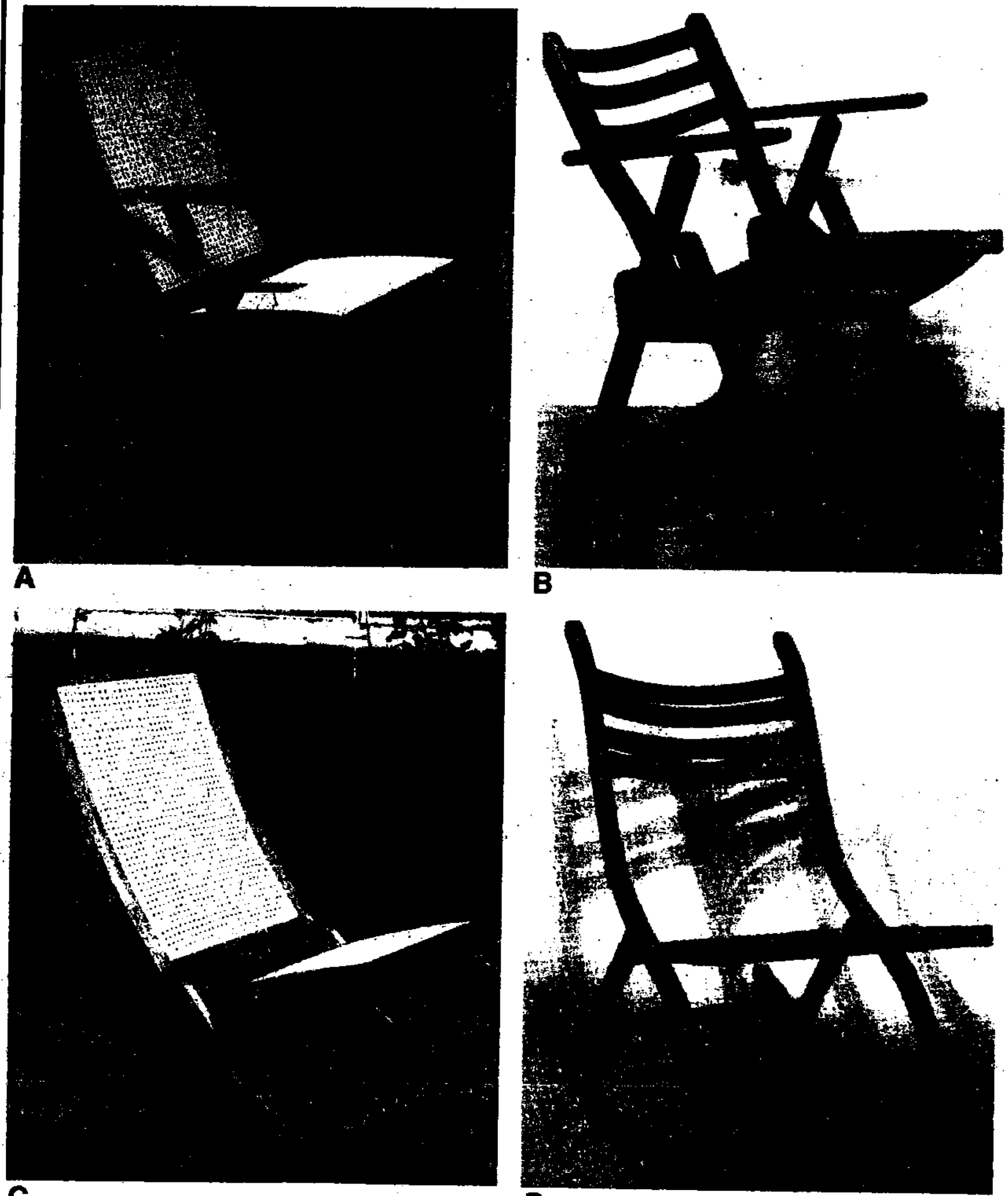
C. *Laminated beam. The width dimension of the beam depends on the diameter of culm*



D. *The scarf splice is the only joint recommended for the construction glued laminated bamboo beams*

GLUED LAMINATED BAMBOO FURNITURE IN COLOMBIA

Fig.12.25 *These bamboo laminated chairs are part of the collection of chairs that I designed and manufactured in Bogota, Colombia in 1994. Unfortunatelly the factory was assaulted and the machinery and the stock of chairs were stolen in 1997.*



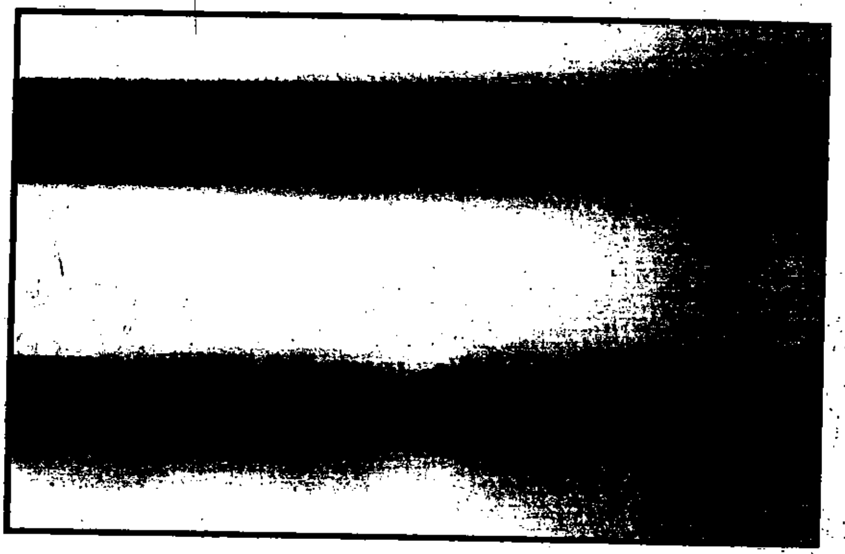
A B C D

MANUFACTURE OF BAMBOO LAMINATED TURNED PIECES

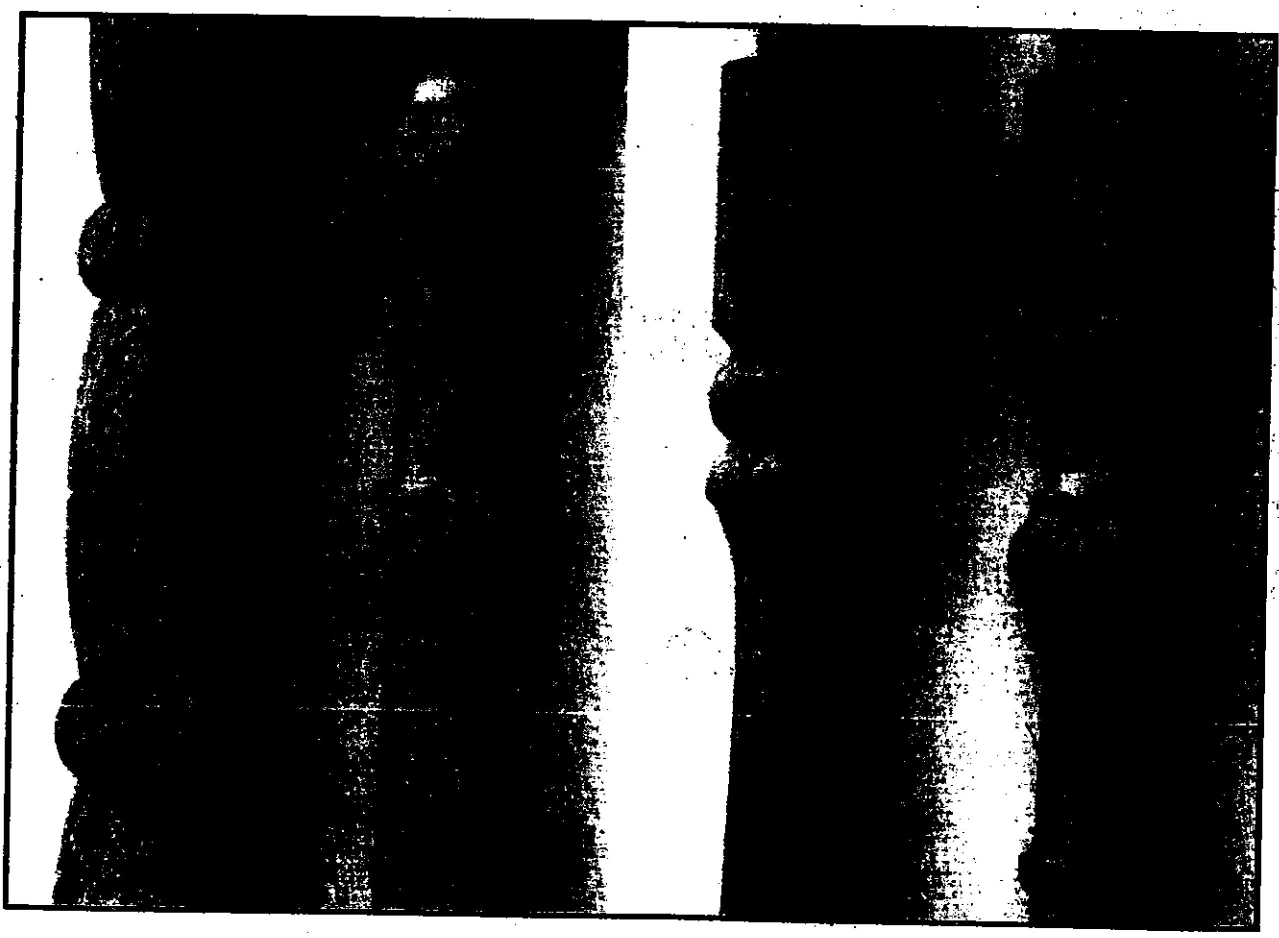
Fig. 12.26 *Bamboo laminated pieces made with slats of Guadua angustifolia were experimented by the author in 1975 at the CIBAM (Bamboo Reseach Center of the National Univesity of Colombia) in the manufacture of bamboo laminated table legs that were turned in a wood turning lathe and then painted with a lacquer.*

The results can be shown in this page. Later on the author used laminated bamboo in the manufacture of chairs and crutches.

A



B



MANUFACTURE OF GLUED LAMINATED BAMBOO IN CHINA

Glued laminated bamboo manufactured in China is known by some authors as "bamboo laminated lumber". It is manufactured in the same way as the plybamboo, with the difference that in the case of the glue laminated the fibres are located in one direction.

Application: This product has good water resistant properties and is used in China as platform for trucks. At present the producsts are availabe in two sizes: 4,070 x 140 x 30 mm, and 5,371x 140 x 30 mm.

Manufacture process:

Bamboo culms are cut in sections. Then the bamboo joints and the outer skin are removed. The skins are 0.5 to 1.0 mm thick. The culm sections are split in 2 or 3 sections which are inmersed in hot water in order to increases the moisture content and their plasticity, because the cellulose, hemicellulose and lignin can be softened, making it plastic with boiling water. The soft cellulose reduces splitting in the cutting off and the widening.

With boiling treatment the bamboo sections will be flattened. The inner part of bamboo is mostly made up of parenchyma with little bamboo fiber, so its strength is very low across. The inner bamboo part of the bamboo sometimes breaks but the problem can be solved by means of cutting a small chunk with 20-40 degrees angle.

The other processes such as drying, spreading glue, matting and hot pressing are almost the same as with the plywood. But if the plybamboo are used for special purpose, such as manufacturing bamboo beating rod or bamboo lateral board, the core is often replaced by the paper board of high quality in order to increase the strength and anti-impact property.

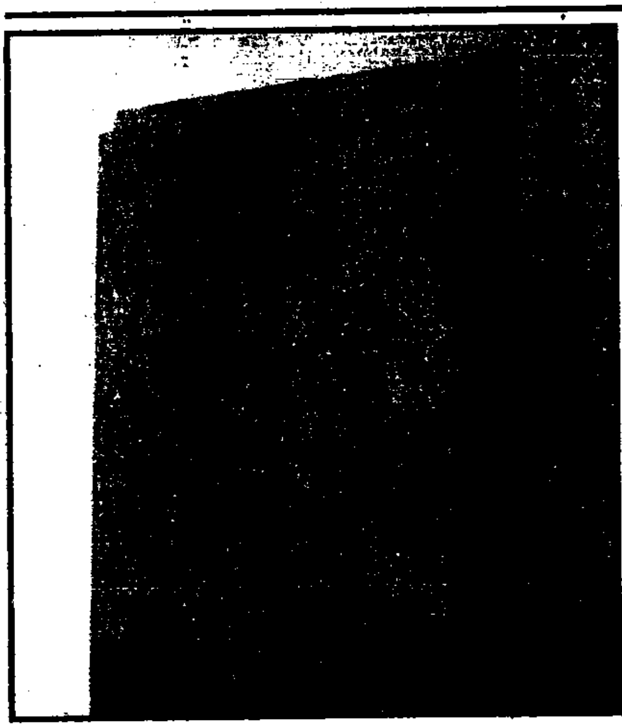
Table 12-8 Properties of bamboo laminated lumber (In China)

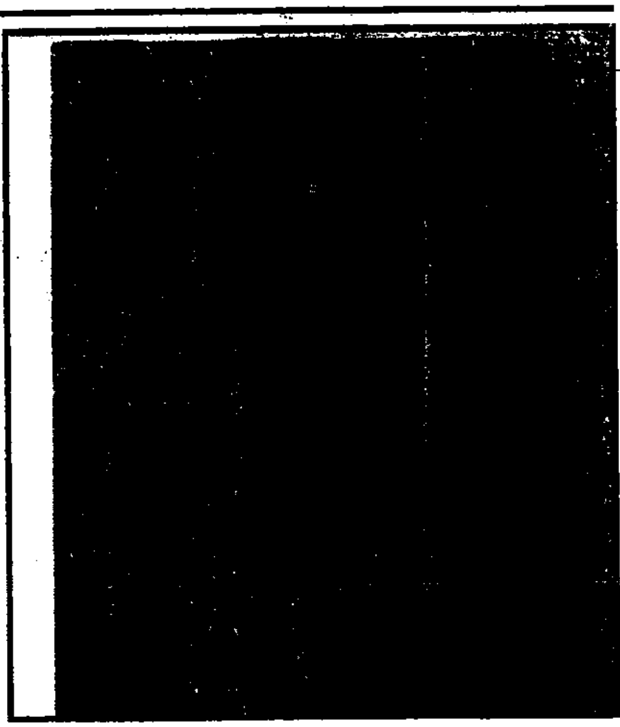
Density	0.99 g/cm3
Moisture content	9.7 %
Modulus of rupture	118.1 Mpa
Modulus of elasticity	32.2 Mpa
Compression strength	62 Mpa
Shear strength	43.5 Mpa
Anti-spliting	20.8 Mpa
Hardness	174.4

In China bamboo culms are cut into long strips with dimensions of 2200/2850 x 11-15mm and 1-2mm thickness, and dried. The strip are dipped with phenol formaldehyde resin and dried in temperature below 100 ° C. The strips are formed into oriented mats in even density and thickness, and then hot pressed at 130 ° -140 ° C. The whole pressing process may need about one hour.

Fig.12.27

MANUFACTURE OF LAMINATED BAMBOO FLOORING

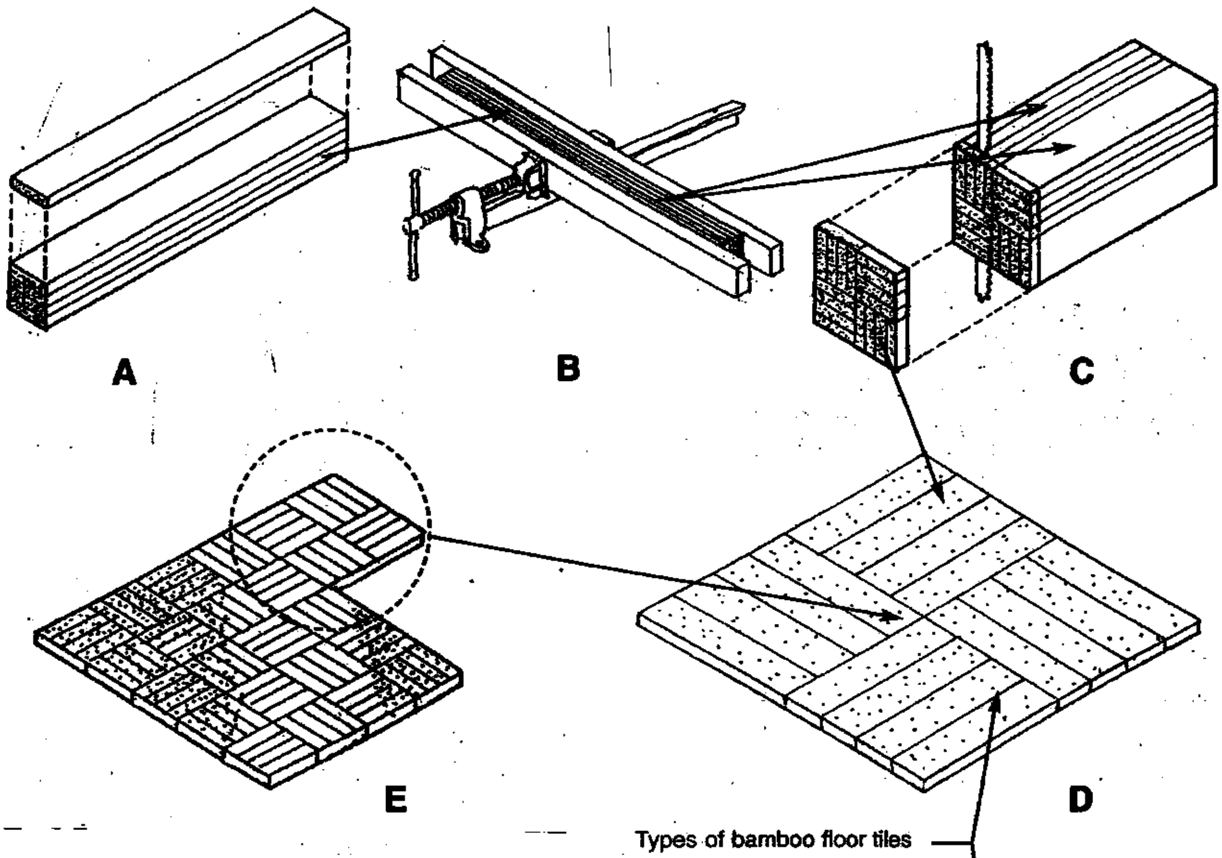


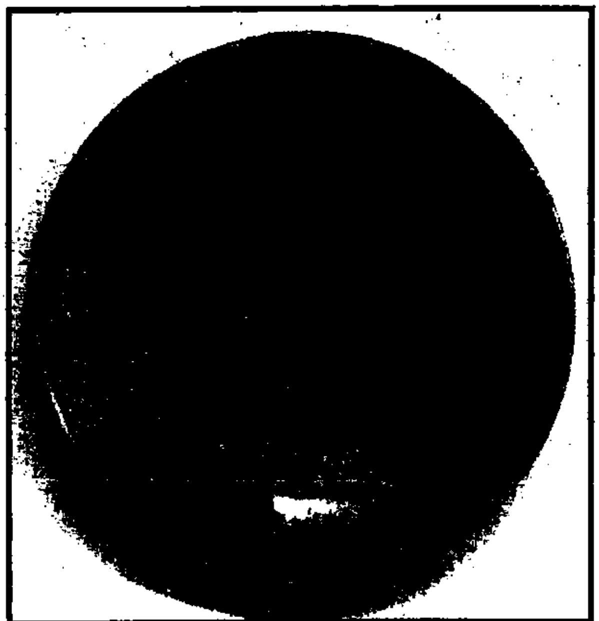


A. - B. *Manufacture of tongued and grooved bamboo laminated board made in Taiwan.*

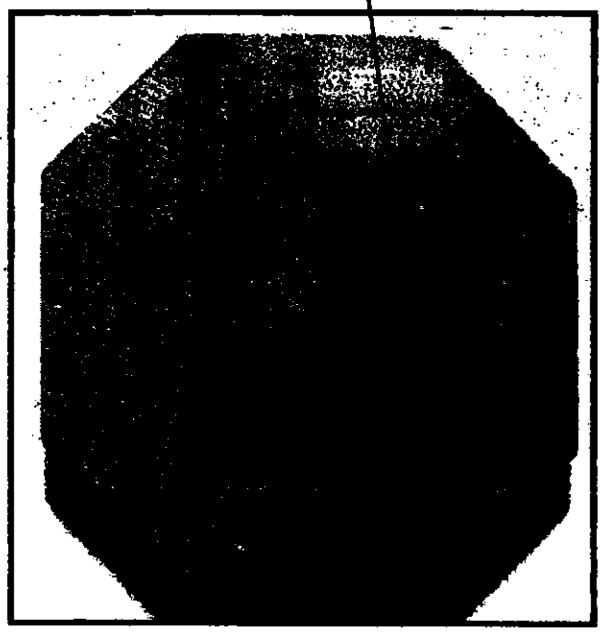
Fig.12.28 **BAMBOO LAMINATED FLOOR TILES AND PLATES**

Manufacture of bamboo laminated floor tiles (with vertical fibers)



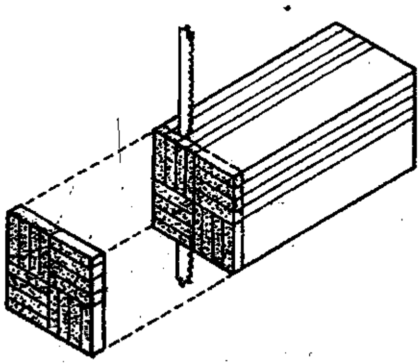


Bamboo laminated plate

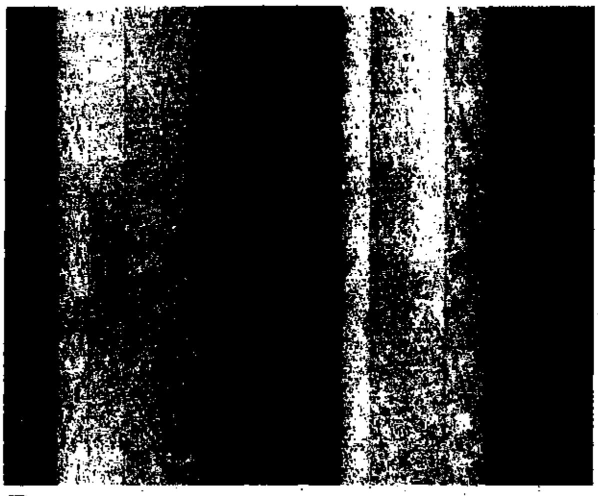


Floor tile

Fig. 12.29 **MANUFACTURE OF LAMINATED BAMBOO PLASTIC VENEER**



A. *The manufacture of laminated floor tiles is similar to the manufacture of plastic veneer.*

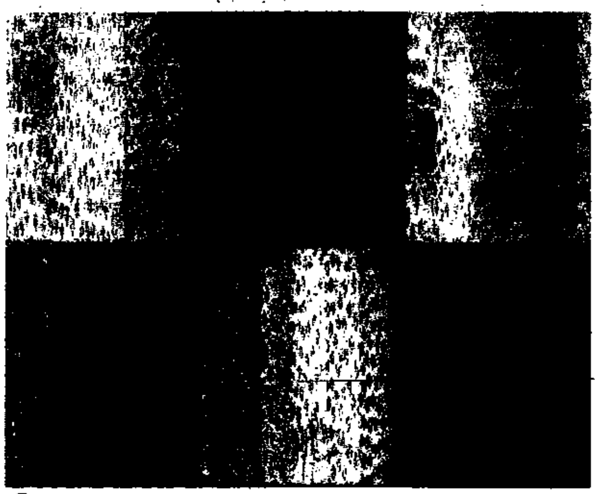


B

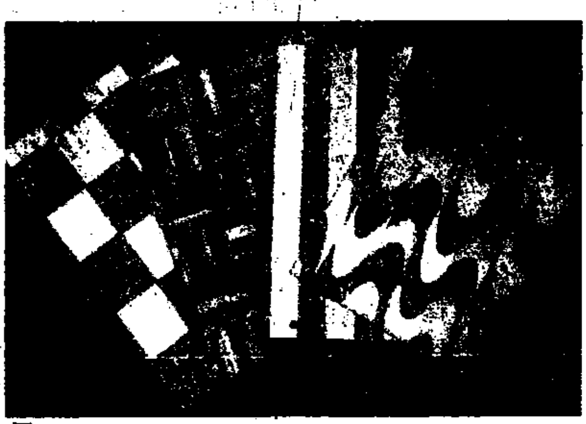
The manufacture of laminated plastified bamboo veneer uses a technology similar to that used in the manufacture of laminated floor tiles shown in Fig."A". The difference is that in the manufacture of plastic veneer the maximum thickness of the veneer is about one a millimeter and the veneer is plastified.

For the manufacture of this type of veneer, it is necessary to make a large block formed of several small laminated blocks, which are made of some dyed laminas and others with natural colors glued together in different positions, as shown in Figs B, C and D.

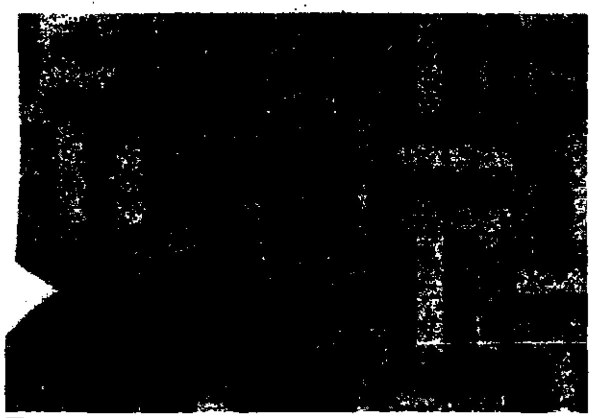
Then the large block is cut transversally as shown above. These square-plastified veneers are used for decorative purposes, such as fixing them on a plywood board or on the sides of boxes.



C



E

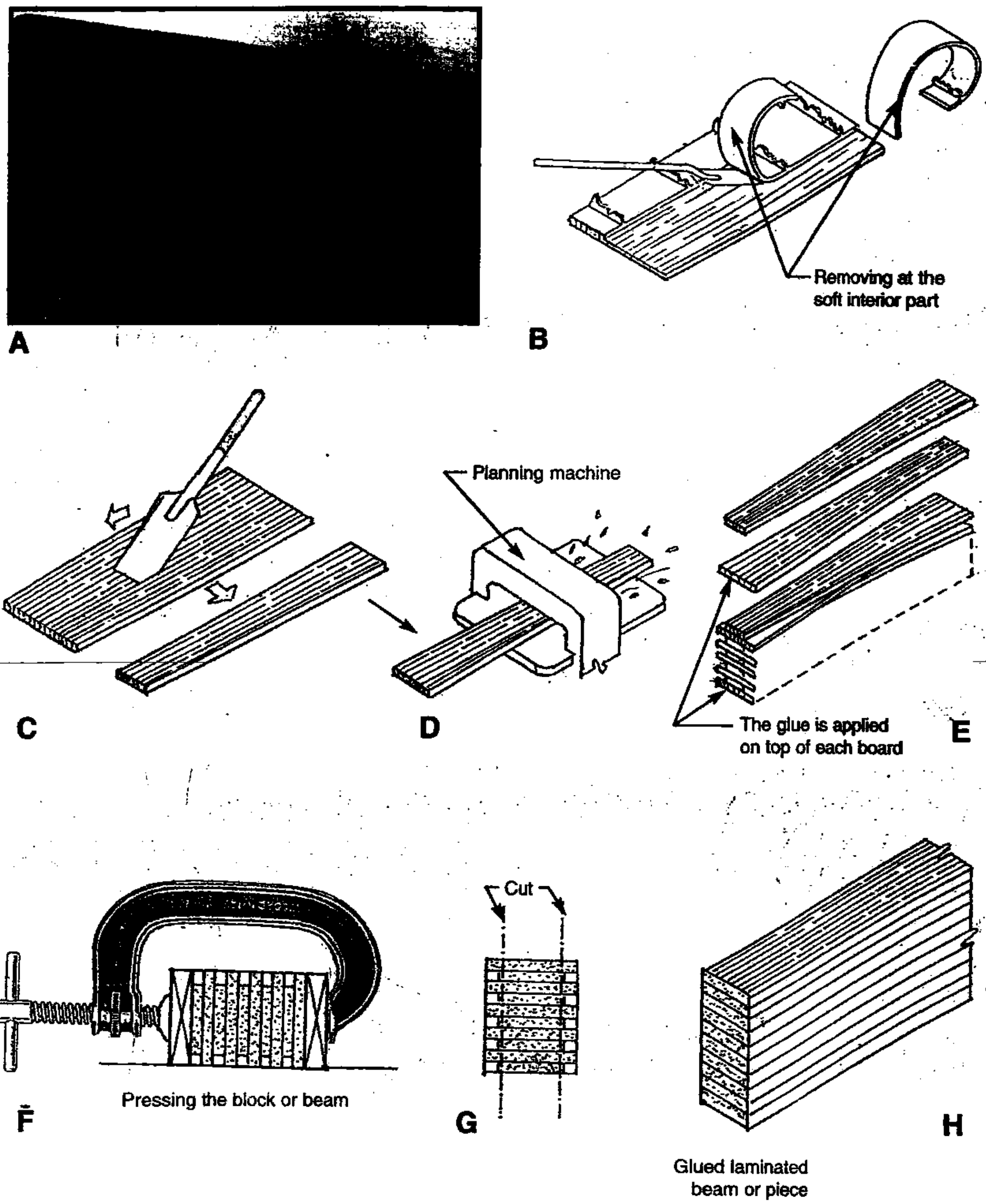


D

E. *Types of plastic veneers,* *made in Japan in the same form than the floor tiles but the veneer thickness is about one mm and covered with a plastic film which permit to bend them as shown in D.*

GLUED LAMINATED BAMBOO PIECES MADE WITH BAMBOO BOARDS

Fig. 12.30



BAMBOO IN THE FIELD OF BIOMIMETICS

WHAT IS BIOMIMETICS

Biomimetics or *Biomimicry*, from the Greek *bios*, life, and *mimesis*, imitation; is the branch of biology that uses information from biological systems to develop synthetic systems. In other words, this new science studies nature's models to solve human problems, e.g., the development of sonar was inspired by the dolphin; the study of infrared sensors owes some of its inspiration to the rattlesnake; a solar cell inspired by a leaf. Biomimetics analyses and biomimetic design and testing are a new direction in the study of composite materials.

I think that biomimetics known also as "bionic" will be the most important biological and engineering science in the design of composite materials, robots and new types of structures in the 21st Century.

Composites imitating bamboo

According to Zhou (1994), an attempt has been made to find a new method of designing structural composites by imitating the optimum structures of biomaterials. Natural bamboo was taken as a kind of composite material to investigate its structure and mechanical properties. The distribution of reinforcement located in the vascular bundles withing the matrix tissue (parenchyma cells) is not homogeneous; it is dense in the outer layer, become dispersed gradually in the middle, and changes to another kind of fine structure in the inner layer.

Typically, living bamboo is subjected to bending loads, such as those produced by wind or snow. According to material mechanics, the maximum normal stress develops at the outer part of the culm. This is addressed by the above mentioned distribution of mechanical properties with the greatest strengthening at the outer part. A schematic derivation based in the optimum design principle has shown that the composite structure of bamboo satisfies the principle of using minimum materials and structures to perform maximum function. Among all the relevant factors, the volume fraction of fibers, the thickness of the fiber wall, and the orientation angle of the microfibrils in the fiber have the closest relationship in the stiffness and strength of biomaterials.

A biomimetic optimum beam model simulating bamboo was carried out with the distribution of fibres symmetrical to the neutral plane of beam. This model was verified using a carbon fiber/epoxy resin composite. The experimental results showed that the bending strength of a composite that simulates the bamboo structure averages 81% higher than a composite with the same amount of matrix and reinforcement distributed homogeneously. The greatest improvement observed was 103%. It is likely that the flexural strength and fracture toughness of other types of composites could be improved by simulating the bamboo structure.

Figure 12.31 (b) shows the fine structure of a bamboo fiber which contains several alternating thick and thin layers. The microfibrils in each layer are distributed in a helical way with different elevation angles, usually 3-10 degrees for thick layers and 30-45 degrees for thin layer with respect to the fiber axis According to the above, an enlarged biomimetic model for the reinforcement of fiber-reinforced composite materials is presented in figure 12.32(a). For traditional fiber reinforced composite, fibers are ussualy arranged in the form of bundles, shown in Fig. 12.32 (b).

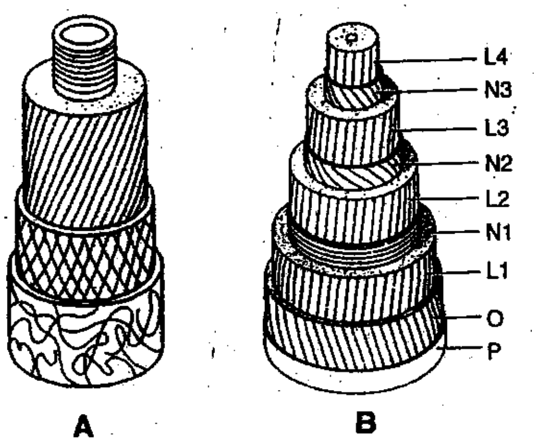


Fig. 12.31 *Schematic diagram of wood tracheid (a), and bamboo bast fiber (b). Primary wall (P), outermost layer of the second wall (O), broad layers (L1-L4), and narrow layers (N1-N3). (After Wai et al) .*

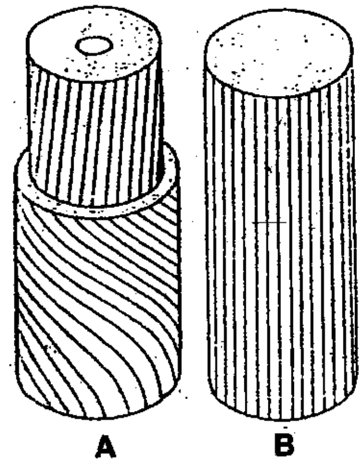


Fig. 12.32 *Schematic drawing of (a) the biomimetic model for fibers in composite materials and (b) the model for a bundle of fibers in traditional composite materials.*

CEMENT-BASED COMPOSITES REINFORCED WITH BAMBOO FIBERS

11

NATURAL FIBERS USED AS REINFORCEMENT

Bamboo and other natural fibers have been used in recent years for improving the strength and ductility of brittle materials like plywood, and cement based composites. In the case of plywood, Xu, Tanaka, Nakao and Katayama (1998) studied the use of Bamboo and jute, added to wood veneer to make reinforced plywood. Three types of material, namely bamboo strips, bamboo woven mats, and jute cloth were placed between veneer sheets at 90 degree and 45 degree orientations, respectively.

Using bamboo or jute in the composite was an effective reinforcement method for the flexural and shear properties. The bamboo reinforcement in the 45 degree orientation showed some good results in some cases. In particular, the shear rigidity was distinctly improved in this orientation.

The jute cloth had good adhesion in all gluelines, but did not improve shear rigidity in the 45 degree orientation as much as bamboo reinforcement. Using bamboo materials in a 45 degree orientation as a component in plywood is advantageous as it improves the mechanical properties. This method could also be used in manufacturing other bamboo composite boards.

According to Sera, Robles-Austriaco and Pama (1990) During this decade, fibers such as bamboo, wood as cellulose fibers, wool or chips, bast fibers, and seed and fruit fibers have been used in cement-base products. Many literatures indicated the ~~following advantages in the use~~ of natural fibers in cement composites:

1..-Increase flexural strength
2.-Post-crack load bearing capacity
3.-Increased impact toughness
4.-Improved compressive strength

However, the long term durability of natural fiber composites remain as problem. To improve durability it is necessary to find ways to stop or slow down the embrittlement process of natural fiber concrete. The best results were obtained with a reduction of alcalinity of the pore water in the cement matrix. This reduction in alkalinity would be achieved by replacing part of the ordinary portland cement with pozzolana such as silica fume, fly ash or rice husk ash.

Natural organic fibers can be divided into vegetable fibers and animal fibers. Vegetable fibers are particularly interesting for reinforcement in cement base-composites. They are :

Wood fibers -e.g. bamboo, reeds, bagasse
Bast or stem fibers-e.g. jute, flax, hemp,ramie.
Leaf fibers-e.g. sisal, henequen, abaca
Seed and fruit fibers- e.g. coconut fiber or coir fiber

Animal fibers include hair , wool, silk etc. but are less recommended if not perfectly clean, as contaminants such as grease weaken the bond between the fiber and the matrix.

Natural fibers can be added to cement in two ways: as as continuous fibers or discrete fibers. Continuous fibers are placed in between layers of mortar and are usually oriented in a given direction, while discrete fibers are added to the mix and are usually oriented ramdonly.

Over the last decade several investigations have been reported on the strength and behavior of concrete reinforced with bamboo and other natural fibers. Since natural fibers are available in abundant quantities in many developing countries. One of the most important investigations were carried out by Sera, Robles-Austriaco, and Pama (1990) at the Asian Institute of Technology, Bangkok, Thailand. They studied the mechanical and physical properties of bamboo, and bamboo pulp, wood, coir, bagasse and palm fiber and their use as reinforcement in cement based.

Table 13-1 **PROPERTIES OF NATURAL FIBERS**

Type of fibers	Wood fibers	Bamboo pulp	Bamboo fibers	Coir fibers	Coir fibers	Bagasse fibers	Fibers
Continuous/Discrete	discrete	discrete	discrete	continous	discrete	discrete	discrete
Orientation	random	random	random	oriented	random	random	random
Matrix	cement	cement	cement	cement	cement	cement	RHA-cem
Length (mm)	40	38-51	2.7	-	37.5	26	-
Average diameter (mm)	-	0.316	0.0275	0.196	0.241	0.240	0.2-0.6
Specific gravity	1.494	1.52	1.53	1.331	1.37	1.25	1.55
Water absorption (%)	141.59	-	-	66.0	67.0	78.5	155.0
Moisture content (%)	20.3	-	-	-	-	12.1	5.0
Ult. tensile strength (MPa)	19.95	442.4	1244.1	71.7	56.0	196.4	251.4
Modulus of elasticity (GOa)	5.65	37.96	123.66	2.04	1.97	16.90	2.0
Bond strength (MPa)	-	1.96	0.98	-	-	0.84	-

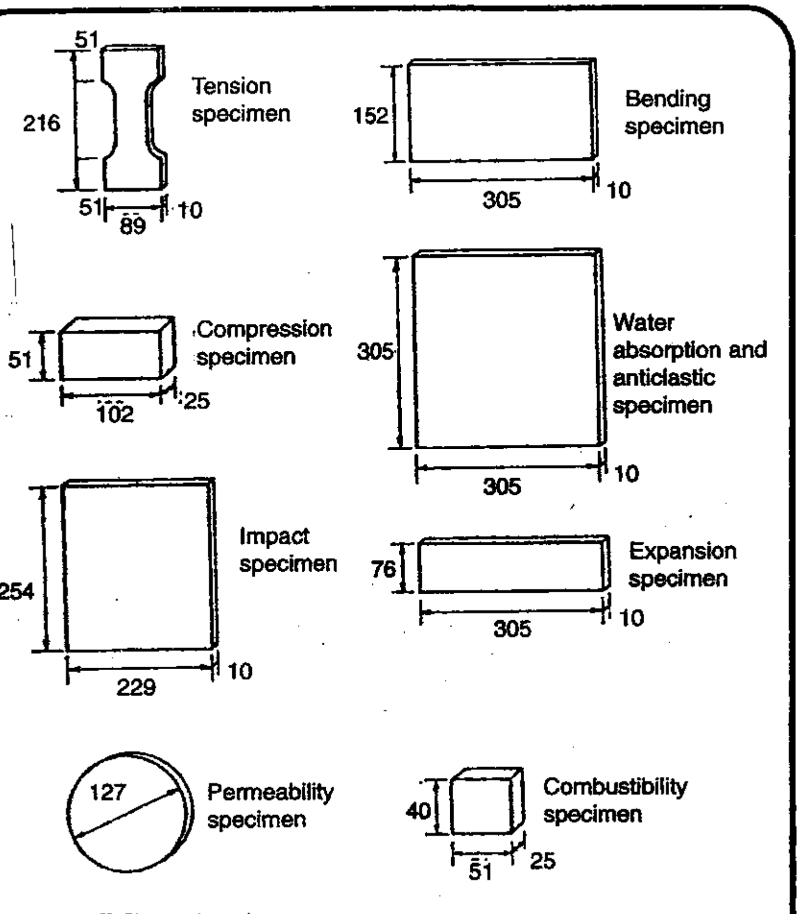
Source: Sera, Robles-Austriaco and Pama (1990).

composites to offer a unique low-cost material for roofing and other structural elements.

Results of the investigation showed that natural fibers can be used as reinforcement in cement-based composites to produce low-cost housing elements. Cost comparisons with commercialized boards showed that the natural fiber boards are not only lower in cost but also offer higher strength, ductility and toughness. It was also found that the durability of natural fibers in cement paste composites can be improved by partial replacement of cement with pozzolanas; the best results in strength were obtained when 40% silica fume or 30% RHA is used. As for natural fibers in noncement composites, results showed that straw-clay composite can be used for grain storage silos due to its strength and good insulating property, although it is not waterproof.

The fibers used in the investigation are shown in the Table 13-1 with their mechanical and physical properties. The fibres are used as discrete fibres of finited length and oriented radomly. The matrix used on the tests included either cement-based pastes or mortars (fine aggregates and cementious material). The cementious material used was ordinary portland cement (OPC) for wood, bamboo, coir and bagase fibres, and rice husk ash (RHA)-cement on palm fibres with 70% OPC and 30% RHA by weight.

Test specimens The cement composites for testing are prepared in the form of boards.The parameters studied for most of the composites are the fibre content (expressed either in fibre-cement ratio or volume fraction). In some tests, the effect of fibre length and the casting pressure were also studied. Typical shapes of the test specimens are shown in Fig.13.1. Detailed descriptions of the test specimens of each type of fiber cement composite are also given.



Note: All dimensions in mm.

Fig.13.1 *Test specimens for determination of mechanical and physical properties of fiber reinforced composites.*

Bamboo fiber cement composites.

The bamboo fibers used in the study was preapared by hammering oven dried short sticks of required length. The pulp fibres used were obtained by heating bamboo chips in 20% NaOH solution at aproximately 170° C with a steam pressure of 0.83 MPa for 6 hours . About 2% of the sulphur by weight was added to increase the efficiency of pulping (pH=14). The pulp was fi nally washed with water before use.

Tests results

The tests results showed that the mechanical properties of the composites can be determined with reasonable accuracy from the law of mixture with the cement/paste mortar acting as the matrix and the fibre as the reinforcement.

The use of natural fibres as reinforcement, either discrete or continuous increase the strength of the matrix, and in particular provides post-cracking ductility. The presence of the air voids heavily influenced the strength of the composites. This depends on the casting pressure applied, and for a given fibre type and fibre content, there exists an optimum casting pressure which will give the highest strength.

From the creep tests results, it was found that the creep deformation occurred during the first 7-10 days of loading. Resistance to creep varies as the amount of cement varies inversely with the amount of air voids. The expansion test results shows that the expansion of fibres composites varies with the fibres volume percentage.

The results of shrinkage tests shows that shrinkage varies with the wood/cement ratio. The behavior is such that initial expansion occur s during the hydration process and shrinkage occurs during the drying process.

Water absorption of the fibre varies with the fibre content. The results of the impact resistance tests show that the wood, bamboo and coir (continuous) boards have a good impact resistance. Wood and coir (continuous) boards tested were combustible whereas the bamboo and coir (discrete boards) are non-combustible.

CEMENT MORTAR BOARDS REINFORCED WITH BAMBOO PULP

BAMBOO WOOL -CEMENT BOARD

Portland cement and other mineral binders are used in several types of wood and bamboo based particle products By far the most important of these is a porous low density product which is used principally for acoustical ceiling panels in commercial and industrial buildings. In international trade this type of product is termed bamboo wool or wood wool..

Wood wool board is about one-fourth to one-third wood by weight, the remainer being Portlan cement or other mineral binder. The product is usually produced in densities from 20 to 25 lb/ft^3. It is well suited to developing countries of the world because it can be produced by very simple hand-forming methods, using the mineral binder that is locallly available

In the case of wood, species selection is extremely important in the production of wood wool. Many species contain wood sugars or other extractives that retard or inhibit the cure of the cement.

This problen can be reduced by long-term storage of the wood bolts prior to shredding and by the addition of chemicals that accelerate the cure rate of the cement. However it is necesary to carefully screen species being considered as raw materials to assess their curing problems. Seasonal variation in sugars should also be considered. be used to be considered..

For making one m^3 bamboo wool-cement board, 150 kg bamboo wool, 220 kg cement and 8 kg CaC_{12} are needed.

Bamboo wools are immersed in water at room temperature for 3 - 5 minutes. The moisture content of the soaked wool should not exceed 25% to facilitate the bonding between bamboo wool and cement. Bamboo wool is treated with 5% CaC_{12} and then mixed with cement. The ratio of bamboo wool and cement in weight is 1: 1.8 - 2.2. For making bamboo-magnesite board, the ratio of bamboo wool and magnesite is 1:1.7 - 1.8.

After forming, the mats are pressed into their final thickness with working pressure of 2 - 3 kg/cm^2 (0.8 - 1 kg/cm^2 is used for bamboo wool magnesite board). The package of pressed mats is dried and cured in panels at 30 - 40 degree C for 24 - 48 hours. The panels need to be conditioned and ventilated at room temperature for 1 - 2 weeks to reduce the moisture content to less than 20%, and then trimmed into final products.

Like low densityfiber board, bamboo wool cement board is very good ifor insulating, is water repellent, has fire retardant properties and is suitable for building applications such as ceilins, partitions etc.

Bambusa vulgaris was used by Chew (1993) in the manufacture of urea formaldhyde (UF) particleboards of varying densities and resin contents. For cement bonded patyicleboards the wood to cement ratios are 1: 1,25, 1: 2.75 and 1:3.00, and the different mineralizing compounds used are calcium or magnesium chlorides, aluminum sulfate, sodium silicate and aluminum sulphate. The UF particleboards had to have a minimum density of 600 kg/m^3 and 8% resin content to meet the requirements of Type I Standard Board (British standard). In the manufacture of cement bonded particleboards with a density of 1250 kg/m^3, fresh bamboo chips of the bamboo had to be pretreated to reduce their total sugar content. The cement bonded particleboards had to have a wood to cement ratio of 1: 2.75 by weght and 2 % of either aluminum sulphate or a mixture of sodium silicate and aluminum sulphate (by weight of the cement) to met the requirements.

Air-cured bamboo pulp reinforced cement

Sinha et al, and Pakotiprapha *et al*, reported that bamboo pulp fibre reinforced cement composites (BFRC) had flexural strength values close to 20 MPa, at a fiber loading of 10% by mass. This letter reports the preparation and mechanical and physical properties of air-cured BFRC.

The bamboo species used in this study was *Sinocalamus affinis* ~~(Rendle) McClure.~~ Bamboo fibers were obtained from kraft pulp unbleached commercial package paper from Change Jiang Paper Mill, China. In conclusion, air-cured BFRC at 10% fiber by weight has flexure strength values of approximately 20 MPa. Unbeaten BFRC has slightly better fracture toughness, at high loadings of fiber, than beaten BFRC.

However, the low value of fracture toughness (less than 1.0 kJm super minus super 2) suggests that the material would be prone to failure by impact and should be used in situations where due consideration has been given to this limitation.

CEMENT MORTAR REINFORCED WITH BAMBOO MESH (BAMBOO-CEMENT)

THE FERROCEMENT STORY

In 1848, the Frenchman Jean Louis Lambot built the first ferro-cement boat using a mesh that he manufactured, impregnated with mortar (Fig.13.2). This was the beginning of reinforced concrete. This boat, in remarkable good condition, can still be seen at the Brignoles Museum in France.

Other boat builders followed Lambot's lead. By the 1930's, engineers had overcome most of the technical pro-blems presented by reinforced concrete, such as excessive corrosion factors of the reinforcing materials and the inefficient weight factor due to the mixture which was far too thick and heavy for commercial use, particularly in the shipping field.

Underestanding these problems, the Italian Professor Luigi Nervi in 1943 began his experiments using many layers of fine wire mesh impregnated with cement mortar. The results were startling. He called the material created "ferro-cement", which did not behave like regular concrete but presented all the mechanical characteristics of a homogeneous material.

Impact tests in which a 580 pounds weight was dropped from heights of up to ten feet showed the very high strength in a slab only 1.1 inch thick. These tests showed, moreover, that even when slab failed, the weight did not break through them.

Even when the cement cracked extensively and the steel yielded, the slab did not desintegrate andit still prevented water seeoing through in great quantities.

Soon after the war, Nervi and Bertolini built their first vessel, the 165-ton motor sailer, *Irene*. The construction of this vessel required no forms. The total weight of the hull came out at five percent less that the weight of a comparative wooden hull and, most importantl, it cost some 40 percent less.

This hull, proved perfectly watertight and, from the inside, the part above the water line could not be distinguished from that below because there were absolutely no moist patches.

After years of hard service in the Mediter-ranean the hull was, and still is, as new as the day it was built and has never required any maintenance.

The advantages of a ferro-cement boat are the low cost of the materials that are used in its construction which include some steel bars, chicken wire, perhaps a little timber and cement.

On the other hand the hull, with a thickness of no more than three quarters of an inch, possesses the strength of steel and is impervious to corrosion, rotting or teredo worms. It is also not damaged by the ultra-violet rays of the sun and, as a one-piece construction, it does not suffer from leaky fastenings or joints. Electrolysis and galvanic action is minimal.

Among the first to adopt the new building method were: New Zeland, England, Canada, USA and China, who are using this technology not only in the manufacture of boats but also in the construction of water storage tanks and even in the construction of houses.

BAMBOO-CEMENT

Due to the extraordinary mechanical and physical characteristics of ferro-cement, and the low cost and advantages that this technology could have in rural Colombia, in 1974 I developed a new technology that I called "bamboo-cement", similar to ferro-cement, in which bamboo mats or bamboo baskets are used instead of the steel bars (which are used for given the form of the final product), which we manufactured with bamboo strips (2-3 mm thick by 1 cm wide) taken from the outer part of the culm wall.

The mats and the baskets were covered outside and inside with a chicken wire, particularly when the holes of the mat were large, and then with cement mortar in proportion 1 : ~~1~~ or 1 :1.5 .The mats covered with mortar were used for building prefabricated walls or for kitchen tables, and the baskets for the manufacture of water storage tanks, toilets, washbasins, etc.

Fig.13.2 *Lambot's original boat built in 1848 now rests in the Brignoles Museum, France. (Samson and Wellens, 1968)*

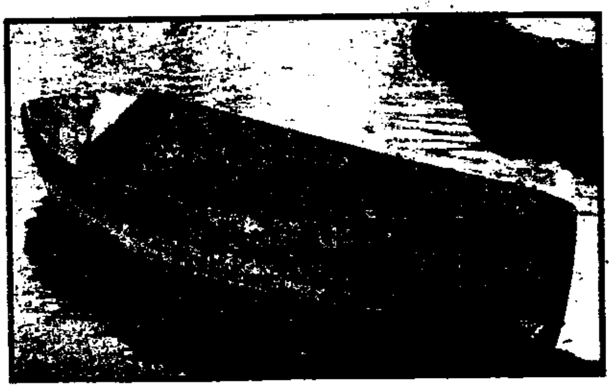


Fig. 13.3 *A ferrocement boat built in 1887 and still afloat. This Duch boat was pictured in a pond at Amsterdan Zoo in 1967 by B.J deRuiter. (Samson and Wellens, 1968)*

Fig.13.4

MANUFACTURE OF SMALL TANKS AND TOILETS

In the construction of small water storage tanks, toilets, latrines, septic tanks, dishwashers etc. the technology of bamboo-cement could be very useful particularly in rural areas.

The materials used for these purposes are a bamboo basket with the shape of the tank; wire mesh (in large tanks) cement mortar in proportion 1:1 or 1:2 by volume (1 part of cement and 2 parts of sand).

The strips of the basket has to be separated at least two centimeters. It is is recommended to cover the interior part of the basket with a half inch exagonal wire mesh before to cover it inside and out side with the mortar.

A

B

C

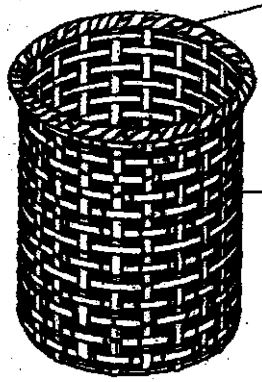
D

MANUFACTURE OF LARGE WATER TANKS WITH BAMBOO-CEMENT

Fig. 13.5

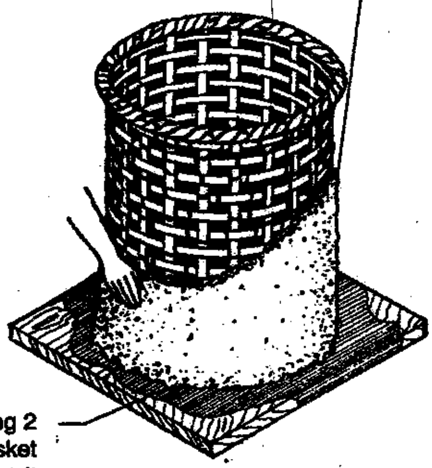
The baskets used in the construction of tanks for water storage have to hava circular form when they are used to store more than half a cubic meter.

Once the exterior surface has been plastered, let the mortar dry before applying the interior plaster.

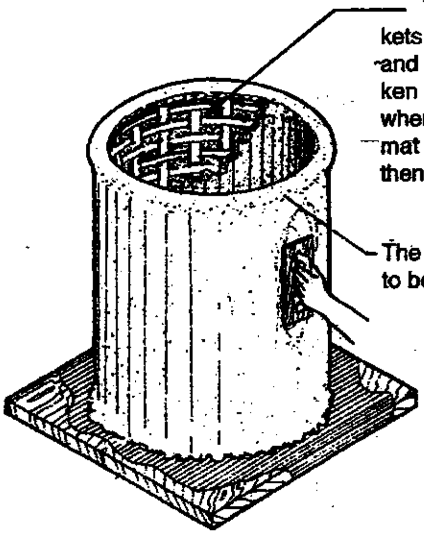


The top ring can be replaced by two strips.

The strips must be separated between 2 to 5 cms.



The application of the mortar starts by putting 2 cm of mortar on wood surface. Then the basket is placed on the mortar and pressed against it The mortar is applyed on the wall starting from bottom to top



The bamboo baskets are covered outside and inside with a chicken wire, particularly when the holes of the mat were large, and then with cement mortar

The mortar has to be 1:2 (cement-sand)

Construction of a cement mortar tank using a bamboo basket in the Saint Lucia Island. West Indies

MANUFACTURE OF PANELS REINFORCED WITH BAMBOO MESH

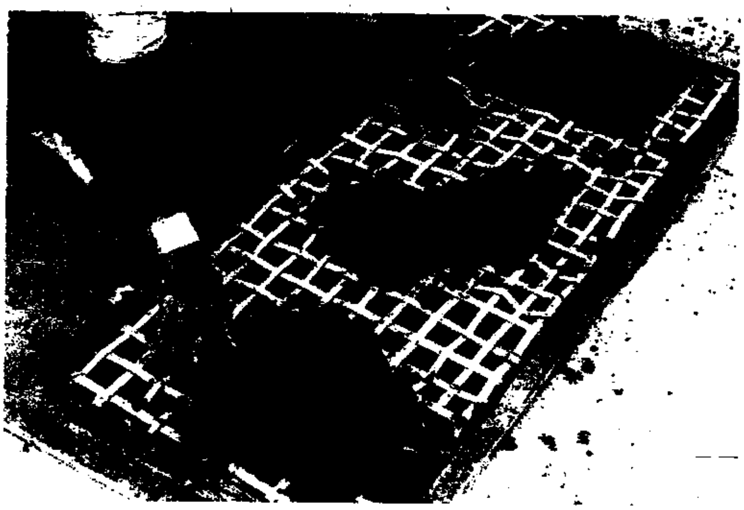
Manufacture of prefabricated slabs

The technology of bamboo cement can also be used in large areas as reinforcement in the construction of floor slabs over the ground or in fundation slabs of small houses or in the prefabrication of slabs of small thickness for using ing as top of counters in kitchens or in walls of prefabricated houses.

In this case the separation of the strips are about 5 centimeters in both directions, and the most recomended is to fix on the top of the bamboo mesh with a half inch exagonal wire mesh before to put the concrete (in floors) or the mortar in prefabricated pieces.

The materials used for these purposes are a bamboo basket with the shape of the tank; wire mesh (half inch), cement mortar in proportion 1:1 or 1:2 by volum (1 part of cement and 2 parts of sand).

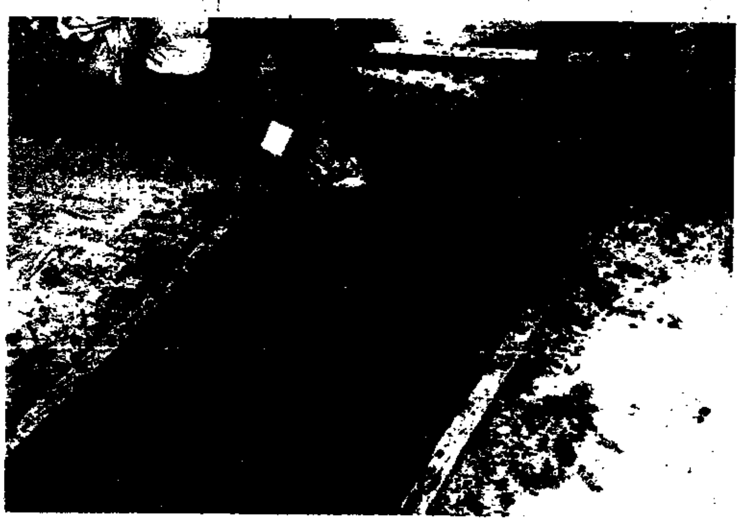
Fig. 13.6



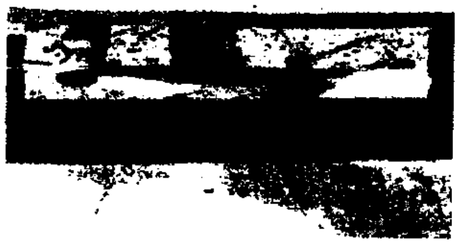
C-D. This prefabricated concrete slabs could be used in the construction of prefabricated walls as a top of counters in kitchens.

A

B



D



CONCRETE REINFORCED WITH BAMBOO

METHODS USED FOR REINFORCEMENT OF CONCRETE WITH BAMBOO

Up to the present time, bamboo has been the natural fiber most used experimentally as reinforcement in concrete due to its high tensile strength, as high as 4000 kg/cm² (in *Bambusa tulda*), and its availability and negligible cost in the tropical and subtropical countries where bamboo is plentiful. It is also the fastest growing and the highest yielding renewable natural resource.

In this chapter, we will study three methods for using bamboo as reinforcement in concrete. The first method consists of using small diameter culms as reinforcement. The second method is the use of strips or splints taken from giant bamboos and the third method is the use of bamboo cables as reinforcement in concrete which was developed by the author, Hidalgo (1974), in Colombia.

The story of the use of small diameter bamboos and splints as reinforcement in concrete goes back to 1914, when H. K. Chow carried out the first experiments in this field as a thesis at the Massachusetts Institute of Technology in the United States. For this purpose, he used small diameter bamboos and splints of the culm as reinforcement. In 1936, the Imperial Forestry Institute in England published Experiments on the *Use of Bamboo in Concrete Construction* containing the experiments carried out in Germany by K. Datta in 1935 at the Technische Hochschule at Stuttgart under the direction of Professor Graf. In this experiment, bamboo splints were used as reinforcement using metal stirrups. (Fig. 13.7) Since then many investigations in this field have been carried out, particularly by students at the engineeringschools of different universities of the Americas, Asia, and Europe (where there are no native species). Many of these studies have no technical value because they do not include the scientific name of the species used in the research, probably because they believed that all species of bamboo have the same mechanical characteristics.

The most important and extensive reseach on bamboo as reinforcement in concrete carried out up to the present was conducted by H.E.Glenn in 1950 at The Clemson Agricultural College of South Carolina. This research was financed by the War Production Board (Contract No 78) and published in the Bulletin No.4 - May, 1950. This study included the construction of several concrete buildings reinforced with bamboo such as the Press Box Building.

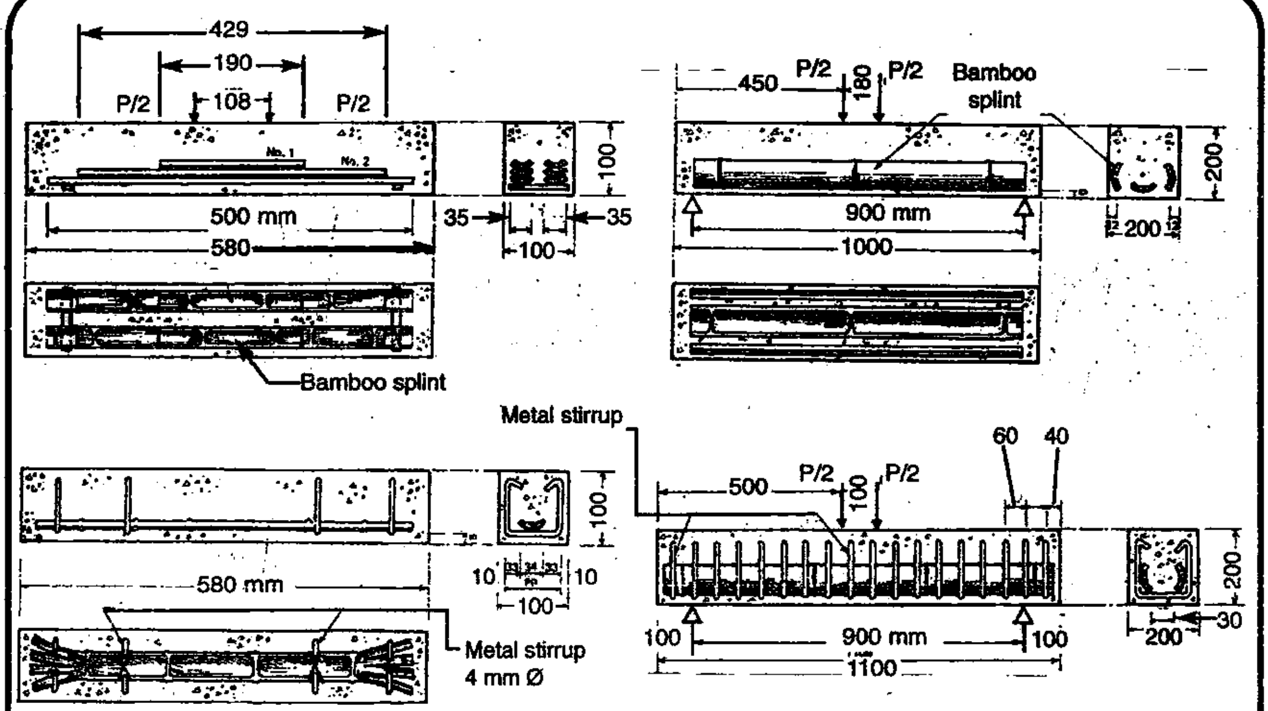


Fig. 13.7 *Types of concrete beams tested by K. Datta 1935) using bamboo splints and metal stirrups.*

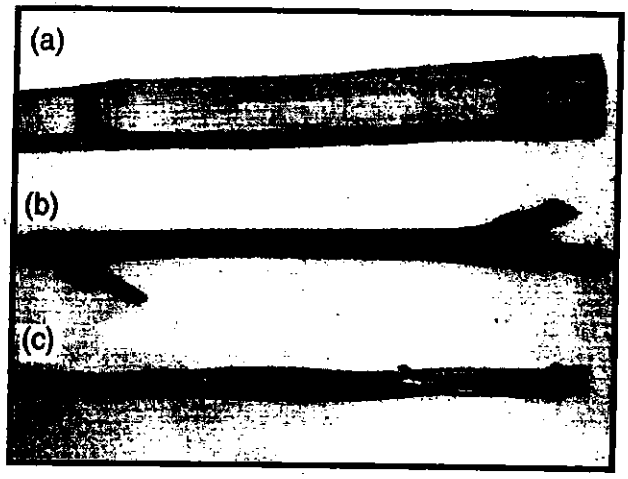


Fig.13.8 *Different forms of using bamboo as reinforcement in concrete: (a) Bamboo splint (b) Small diameter round bamboos with the lower part of the branches for increasing the adherence in concrete. (c) Bamboo cables.*

So far all of the studies carried out related to the use of small diameter culms and bamboo splints as reinforcement in concrete have amply shown that bamboo as reinforcement in concrete is feasible, but it presents the following problems:

(1) The modulus of eleasticity of bamboo is relatively low, usually less than 1/10 that of steel reinforcement. This leads to large deflections and wide cracks when bamboo reinforced flexural members are loaded to capacity.

(2) As a natural fiber bamboo has susceptibility to fungal and insect attack, lack of durability in an alkaline environment, and variability of mechanical properties among the species.

(3) The coefficient of thermal expansion of bamboo can be as low as one-third that of concrete longitudinally and as high as 10 times that of concretediametrically. These differences will also contribute to the development of longitudinal cracks in the concrete surface and to a loss of bond, particularly if the member is exposed to large temperature variations, for example, inprefabrcated beams when exposed to the sun for drying.

(4) The swelling-shrinkage bond problem. As soon as bamboo is immersed in fresh concrete, the interior or softer part of the culm wall absorbs water from the concrete mixture very rapidly, swelling to such an extent as to produce a serious cracking of the concrete surface. (Bamboo culms have been observed to undergo diameter changes on the order of 5% and length changes up to about 0.05 %.) Later on, as the setting progresses, the bamboo contracts more, and more quickly, than the concrete, losing its adherence, and leaving a perceptible play between bamboo and concrete.

In order to solve this problem, researchers have presented different solutions. For example, Glenn recommended the use of seasoned bamboo treated with a brushed on coat of asphalt emulsion.

Other solutions are so sophisticated and uneconomical that it is much less expensive to buy steel bars than to carry out the treatment. For example, Pama et al (1976) recommended previous immersion of the bamboo reinforcement in 2% Zinc cloride, or an adhesive of Neoprene with sand. Kowalski (1974) recommended the application of Polyesteric resins, or epoxy adhesives and silica powder as part of the treatment. Fang et al (1976) re-commended applying first a treatment of sand-blasting and after that a treatment with sulphur. In general, all of these are more expensive than the cost of steel bars.

One can clearly see that many researchers did not take into account that the users of this research are the poor people who live in rural areas of tropical countries where bamboo grows, and where steel bars for concrete are scarce or unavailable.

It is evident that anyone who lives in the city and has the means of paying for the steel bars and their transportation will not use bamboo as reinforcement in concrete.

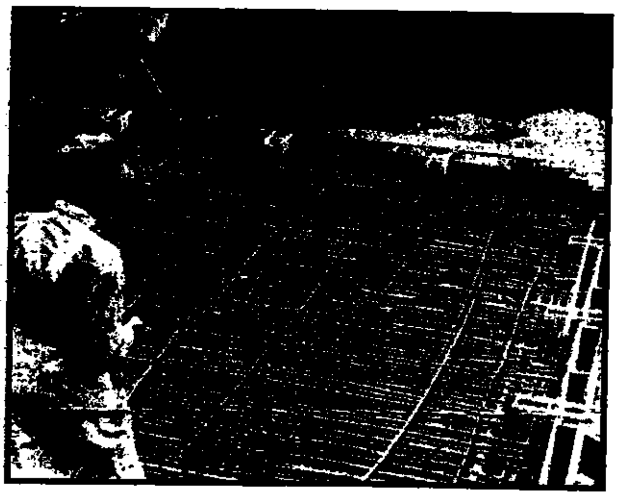
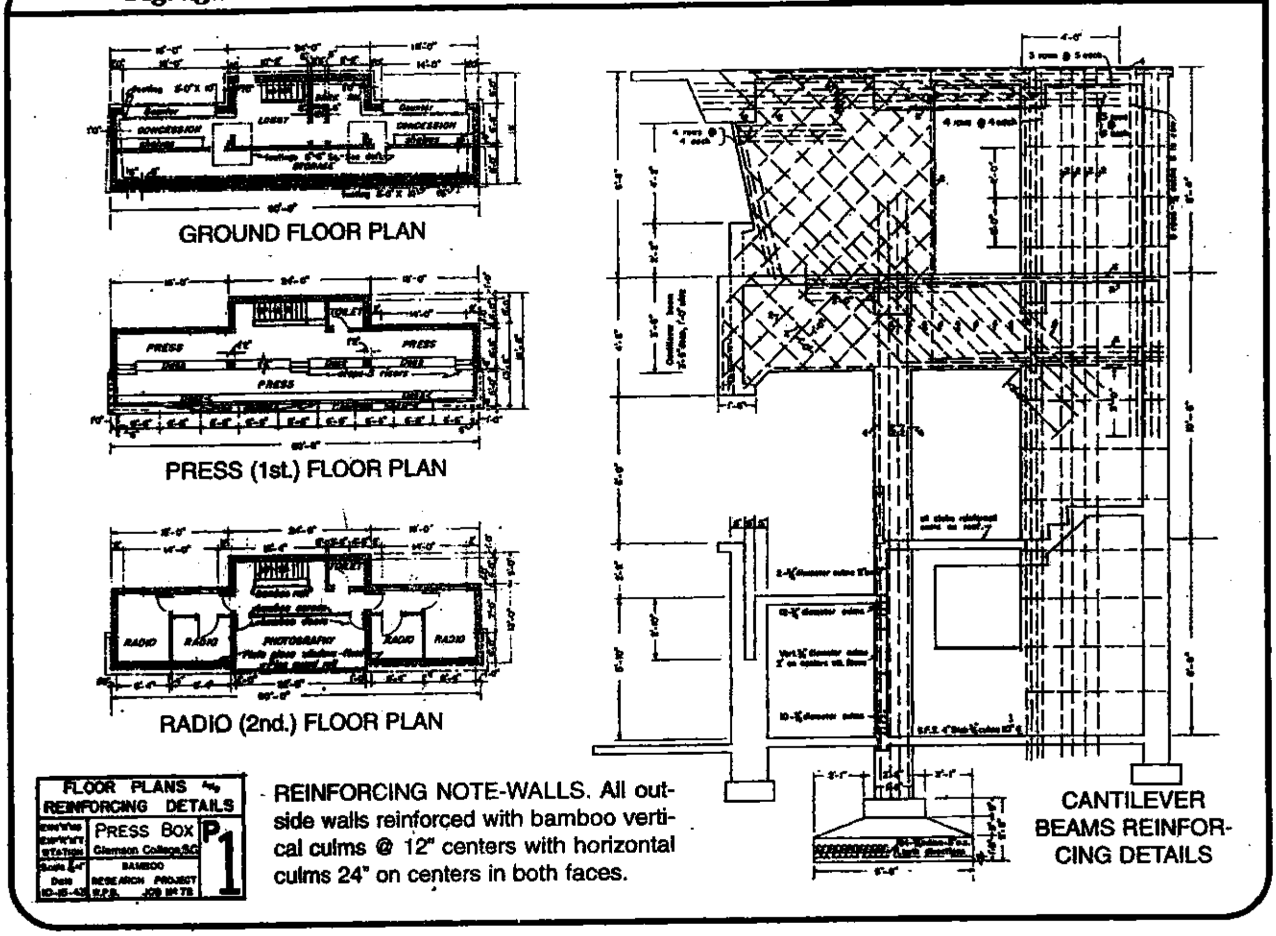


Fig. 13.9 *Bamboo reinforced concrete girders and slab reinforced with small diameter bamboos. (Taken from Glenn 1950).*

Fig. 13.10 *In the Press Box Building, built by Glenn (1950), the walls, floors and roof were made of concrete reinforced with bamboo splints and small diameter culms. The results were not satisfactory.*

Fig. 13.11 Distribution of the bamboo reinforcement in the Press Box building



Summary of conclusions from results of tests on bamboo reinforced concrete beams carried out by H.E, Glenn (1944).

This research. included not only the study of the physical and mechanical characteristics of several bamboo species that he used in the experiments but also the construction of several experimental concrete buildings, in which he use bamboo as reinforcing of foundations, walls, beams, and slabs. As a result of this research conducted by Glen, he published the following summary of conclusions from results of tests on bamboo reinforced concrete beams:

1.-Bamboo reinforcement in concrete beams does not prevent the failure of the concrete by cracking at loads materially in excess of those to be expected from an unreinforced member having the same dimensions.

2.-Bamboo reinforcement in concrete beams does not increase the load capacity of the member at ultimate failure considerably above that to be expected from an unreinforced member having the same dimensions.

3.-The load capacity of bamboo reinforced concrete beams increased with increasing percentages of the bamboo reinforcement up to an optimum value.

4.-This optimum value occurs when the cross-sectional area of the longitudinal bamboo reinforcement was from three to four per cent of the cross-sectional area of the concrete in the member.

5.-The load required to cause the failure of concrete beams reinforced with bamboo was from four to five times greater than that required for concrete members having equal dimensions and with no reinforcement.

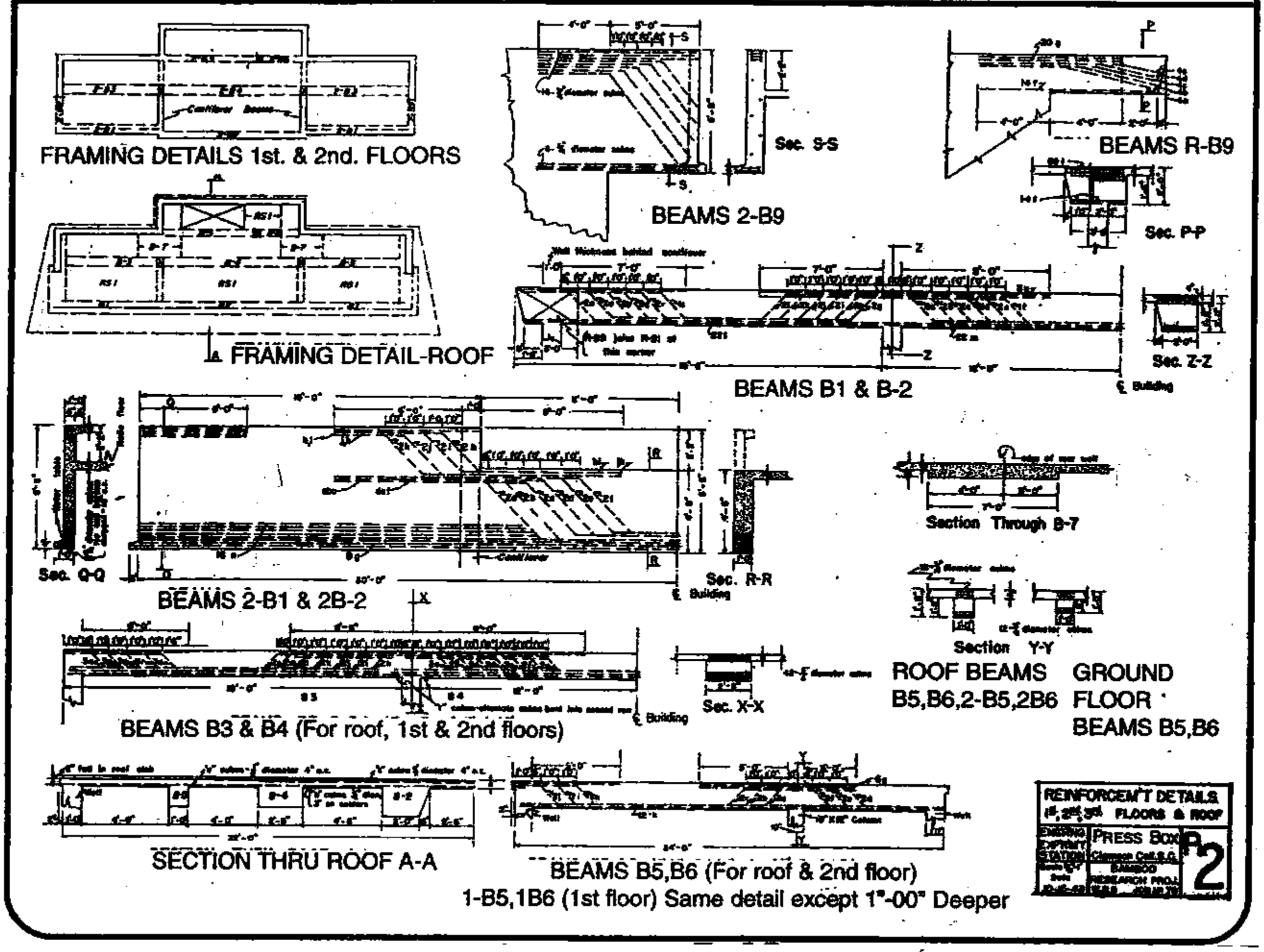
6.-Concrete beams with longitudinal bamboo reinforcement may be designed to carry safely loads from two to three times grater than that expected from concrete members having the same dimensions and no reinforcement.

7.-Concrete beams reinforced with unseasoned bamboo show slightly greater load capacities than do equal sections reinforced with seasoned untreated bamboo. This statement was valid so long as the unseasoned bamboo had not dried out and seasoned while encased in the concrete when the load was applied.

8.-When unseasoned untreated bamboo was used as the longitudinal reinforcement in concrete memembers, the dry bamboo swelled due to the absortion of moisture from the wet concrete, and this sweeling action oftcn caused longitudinal cracks in the concrete, thereby lowering the load capacity of the members. These swell cracks were more likely to occur in members where the percentage of bamboo reinforcement was high. This tendecy was lessened by the use of high early strength concrete.

9.-The load capacities of concrete members reinforced with bamboo vary with the dimensions of the members.

Fig. 13.12 Distribution of bamboo reinforcement in beams of the Press Box B.



10.-The unit stress in the longitudinal bamboo reinforcement in concrete members decreased with increasing percentages of reinforcement.

11.-The ultimate tensil strength of the bamboo in bamboo reinforced concrete members was not affected by changes in the cross sectional area of the members so long as the ratio of breadth to depth was constant but was dependent upon the amount of bamboo used for reinforcement.

12.-Members having the optimum percentage of bamboo reinforcement (between three and four percent) are capable of producing tensil stresses in the bamboo of from 8,000 to 10,000 pounds per square inch.

13.-In the designing concrete members reinforced with bamboo, a safe tensil stress for the bamboo of from 5,000 to 6,000 pounds per square inch may be used.

14.- Concrete members reinforced with seasoned bamboo treated with a brush coat of asphalt emulsion developed greater load capacities that did equal sections in which the bamboo reinforcement was seasoned untreated or unseasoned.

15.-When seasond bamboo treated with a brush coat of asfalt emulsion was used as the longitudinal reinforcement in concrete members, there was some tendency for the concrete to develope swell cracks, especially when the percentage of bamboo reinforcement was high.

16.-Care should be excercised when using asphalt emulsion as a water-proofing agent on seasoned bamboo as an excess of the emulsion on the outer perimeter of the culm might act as a lubricant to materially lessen the bond between the concrete and bamboo.

17.-Concrete members reinforced with unseasoned sections of bamboo culms, which had been split along their horizontal axes, appeared to develope greater load capacieties than did equal sections in which the reinforcement consisted of unseasoned whole culms.

18.-Concrete members reinforced with seasoned sections of bamboo culms, which had been split along their horizontal axes and treated with a brush coat of asfalt emulsion developed considerably higher load capacities than did equal sections in which the reinforcement was split sections of seasoned untreated bamboo.

19.-When split sections of seasoned untreated large diameters culms were used as the reinforcement in a concrete beam, longitudinal cracks apperared in the concrete due to the swelling action of the bamboo. This cracking of the concrete was of sufficient intensity as to virtually destroy the load capacities of the members.

20.-When unseasoned bamboo was used as the reinforcement in a concrete member, the bamboo seasoned and shrank over a period of time while encased in the concrete. This seasoning action of the bamboo materially lowered the effective bond between the bamboo and concrete with a resultant lessening of the load capacities of the members.

21. -Increasing the strength of the concrete increases the load capacities of concrete members reinforced with bamboo.

22.-Concrete members reinforced with seasoned bamboo treated wit methylolurea did not develope greater load capacities than did equal sections in which the bamboo reinforcement was seasoned culms treated with a brush coat of asphalt emulsion.

23.-The load capacities for concrete members reinforced with unseasoned, seasoned or seasoned and treated bamboo culms were increased by using split bamboo dowels as the diagonal tension reinforcement along the sections of the beams where vertical shear was high.

24.-The load capacities for concrete members reinforced with unseasoned, seasoned or seasoned and treated split sections of bamboo were increased by the use of a combination of split dowels and the bending up of the upper rows of the splitt bamboo from the botton of the beam into the top and covering the sections of the beams where the vertical shear was high.

25.-Ultimate failure of bamboo reinforced concrete members usually was caused by diagonal tension failures even though diagonal tension reinforcement was provided.

26.-A study of the deflection data for all the beam specimens tested indicated; (a) That the deflection of the beams when tested followed a fairly accurate straight line variation until the appearance of the first crack in the concrete.

(b) Immediatelly following this first crack, there was a pronounced flattening of the deflection curve (probably due to local bond slippage) followed by another period of fairly accurate straight line variation, but at a lesser slope, until ultimate failure of the member occurred. This flattening of the deflection curve was more pronounced in the members where the amount of longitudinal bambo reinforcement was small.

(c) In all cases noted, the deflection curve had a lesser slope after the appearance of the first crack in the concrete, even though high percentages of bamboo reinforcement were used

27.-No pronounced variations were observed when the behavior of bamboo reinforced concrete members under flexure and having "tee" sections was compared of that of equal members having rectangular sections.

28.-Bamboo reinforced concrete members under flexure and consisting of "tee" sections were not more effective than were equal rectangular sections, provided the breadth of the stem ot the "tee" section was equal to that of the rectangular section and the effective depth of both were the same.

Design and construction principles recommended by Glenn (1950) for bamboo reinforced concrete.

1.-In important concrete members, the use of whole culms of green, unseasoned, bamboo is not recomended as the reinforcing material. In concrete slabs and secundary members, green, unseasoned whole culms may be succesfully used when the diameters of the culms do not exceed three-fourths of an inch. When possible, the bamboo used as reinforcement in concrete members, subject to flexure, should be cut and allowed to dry and season from three weeks to one month before using.

2.-The use of bamboo culms as reinforcement in concrete members subject to flexure cut in the spring or early summer season of the year is not recomended. Only those culms which show a pronounced brown color should be selected for use from a native bamboo grove. This practise will ensure that the culms selected are at least three years old.

3.-When thoroughly seasoned whole bamboo culms are to be used as the reinforcement in important concrete members subject to flexure, some tiype of water proofing is recomended.

4.-When seasoned sections of bamboo split from large diameters culms are to be used as the reinforcement in concrete members under flexure, some type of water-proofing is recommended for the bamboo in all important load carrying members. However, for slabs and secondary members and where the concrete sections are of a size as to allow the placement of the bamboo with clear distance of from one and a half to two inches between the individual bamboo splints and between successive layers, the use of unseasoned sections of bamboo is recomended provided high early strength cement is used. In no case should the split

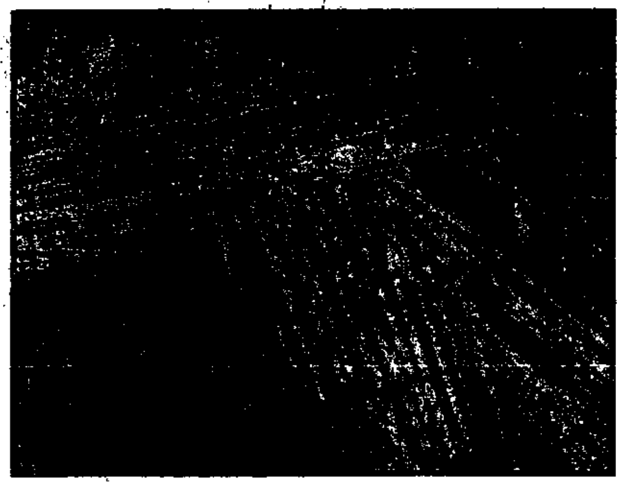


Fig.13.13 *Parts of the bamboo reinforcement with culm splints for beams B-1 and B-9. Press Box.*

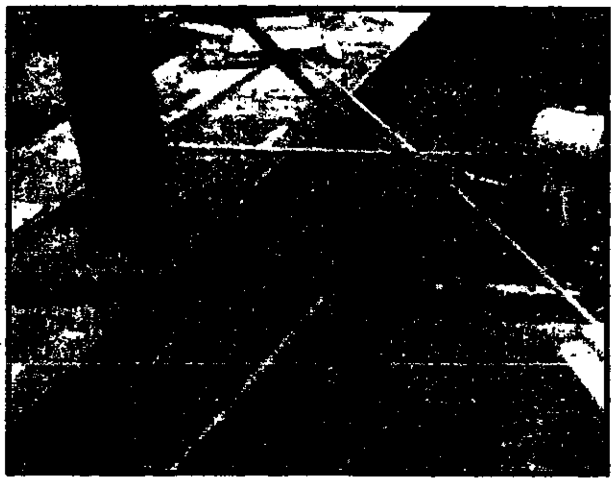


Fig.13.14 *The arrangement of the bamboo reinforcement with small diameter culms in beams 2-B3 and 2B4 of the Press Box Building College.*

bamboo sections have a width in excess of three-fourths of an inch.

5.-The use of vertical split sections of bamboo culms is recommended to provide for diagonal tension stresses in members under flexure covering the portions of the member where the vertical shear is high and where is impractidl to bend up the main longitudinal bamboo reinforcement for this purpose . In continuous members and where otherwise practical, the practce of bending up the main longitudinal bamboo reinforcement at points of heavy shear to provide for diagonal tension stresses is recommended. Also in all cases where it is practical, a combination of the above methods is recomended.

6.-Proper spacing of bamboo reinforcement is very important. Tests indicate that when the main longitudinal bamboo reinforcement is spaced too closely, the flexural strength of the member is adversely affected. Also when the main longitudinal bamboo reinforcement is used in vertical rows and when the top row is near the neutral axis of the member, the area of concrete at this section in horizontal shear may be sufficiently lessened as to cause failure of the member due to horizontal shear. In many of the specimens tested under flexural loads, the cause of failure was attributed to horizontal shear; however in most instances where failure was from this cause, horizontal cracks existed in the concrete due to the swelling action of the bamboo reinforcement.

7.-In placing the bamboo reinforcement, care should be taken to alternate the basal and distal ends of the bamboo culms in all rows. This practice will ensure a fairly uniform cross-section of the bamboo reinforcement throughout the length of the member and the resultant wedging effect that will be obtained will materialy increase the bond between the concrete and bamboo.

8-The design of structural members of bamboo reinforced concrete for flexural loads will be governed by the amount of deflection that can be allowed for the member. In all concrete members subject to flexural loads a high degree of deflection is obtained in the member before failure occurs.

Due to this high deflexion, failure of a bamboo reinforced concrete member usually occurs due to other causes considerably before the bamboo reinforcement reaches its ultimate tensile strength. Design values, not in excess of from 3000 to 4000 pounds per square inch for the allowable tensil stress of the bamboo reinforcement, must usually be used if the deflection of the member is to be kept under 1/360 of the span length. When this low design value is used for a bamboo reinforced concrete member under flexural loads, a high factor of safety against ultimate failure of the member ussualy results.

9.-The same procedure as that used for the design of structural concrete members reinforced with conventional steel is recomended for the design of concrete members reinforced with bamboo. Values have been recommended for the allowable unit bond stress between concrete and bamboo, for the allowable unit tensil stress in the longitudinal bamboo reinforcement and for the modulus of elasticity for bamboo. These recommedded values shoud be used in designing a concrete member reinforced with bamboo for flexural loading. It is also recommended that "tee" beams be designed as rectangular beams ignoring the flange width in the calculations.

10.-Some of the important characteristics of concrete members reinforced with bamboo on which future research should be done include:

(a) Use of those species of bamboo in which the modulus of elasticity is higher than that of the species used in these experiments.

(b) More exact data on diagonal tension reinforcement

(c) Further tests of the use of green uncured bamboo culms as the reinforcement where the conditions are such that the bamboo will be competely seasoned while uncased in concrete.

(d) More exact data on the bond between concrete and bamboo.

(e) The use of other water proffing agents than those used in these tests to insure against the sweling action of seasoned bamboo when placed in wet concrete.

Problems caused by the use of splints and small diameter culms as reinforcement in concrete.

Bamboo as reinforcement in concrete was used during World War II by U.S. and Japanese armed forces in expedient military constructions on isolated Pacific islands and later on during the Viet Nam War where the U.S. army experimented with the construction of concrete vaults reinforced with bamboo based on the studies carried out by Glenn (1950). In the construction of the structure, small diameter bamboos and bamboo splints were used. The results of this experience can be seen in the following photographs.

The results of Glenn's experimental constructions and also the experimental constructions made in Viet Nam for military purposes are the best demonstrations that the traditional use of bamboo using small diameter culms and culm splints taken from the walls of giant bamboos is not recommended in any case as reinforcement in concrete in aerial concrete structures, includingwalls, columns, beams, joists and roofs.

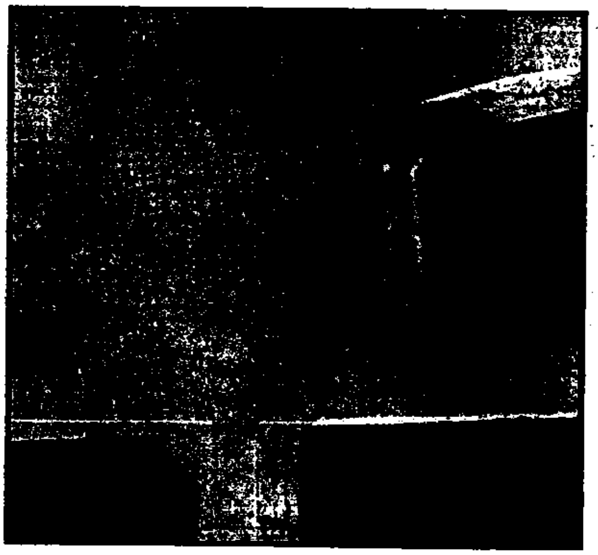


Fig.13.15 *Concrete vaults reinforced with bamboo builted experimentally in Viet Nam*

Fig. 13.16 A. *The bamboo reinforcement ot the vault was exposed and according to the shadows there is not adherence between the concrete and the bamboo reinforcement.*

B. *The collapse of one seccion of the building. There was probably an expansion joint between the two sections.*

C . *There was a lack of adherence between the concrete and the bamboo reinforcement*

D. *The Bamboo reinforcement of the column broke.*

The bamboo based panel industry has been developed in China in the last fifteen years. At the present time, 200 mills

E and F *these also show the lack of adherence between the concrete and the bamboo reinforcement.*

CONCRETE REINFORCED WITH BAMBOO CABLES

When I founded the CIBAM (Center for Bamboo Research) at the National University of Colombia) in 1974, I decided to carry out research in order to look for a new and safer method or technology for using bamboo as reinforcement in concrete to replace the inappropriate technology which had been applied in this field.

For this purpose, we experimented with the use of small diameter bamboo cables, which were made using the same technology developed by the Chinese for manufacturing the large bamboo cables used in the construction of suspension bridges with a span of more than one hundred meters. In this technology, splints two centimeters wide were taken longitudinally from the culm wall using the radial knife tool. From each splint, only the exterior part of the wall (about 3 mm in thickness) was used for the manufacture of the cables because this part is the strongest and densest part of the culm wall and it absorbs a minimum of water. The interior soft part which is about 70% of the culm wall, is disposable. (This is the part that absorbs water from the concrete mixture and becomes swollen.)

For the tension evaluation, we tested 3 types of specimens, each 2 cm wide and taken from the same internode of the culm. One had the whole wall thickness, the second included 2/3 of the interior or soft part of the culm wall, and the third contained 1/3 of the exterior or densest part of the culm wall. The average results were, respectively: 1,175 kg/cm2, 706 kg/cm2 and 2,052 kg/cm2.This means that the exterior part of the culm is almost three times stronger than the interior.

One hundred and sixty three strips, 500 mm long, 100 mm wide and 3 mm thick from different culms with different ages were tested for tension. The maximum ultimate tension was between 3,000 and 3,213 kg/cm2. Some values as high as3,018 and 3,206 were obtained from bamboos between one and one and a half years old. In this way, I learned that the Chinese use young bamboo culms for the

From163 strips that were tested in tension 4.3 % had a strength between 1,017 and 1,249 kg/cm²	4.3% between	1017 and	1249 kg/cm²
	9.2%	1250	1499
	27%	1500	1749
	23.3%	1750	1999
	12.9%	2000	2249
	9.2%	2250	2499
	9.8%	2500	2749
	2.4%	2750	2999
	1.9%	3000	3213

manufacture of the cables since the material is more flexible.

In order to get the adherence of these stronger strips inside the concrete, we prepared and tested two types of cables: one type was braided in the same way that the women braid their long hair, and the other by torsion. The method for manufacturing a cable by torsion using 3 or more strips can be seen in Fig. 13.19. It takes no more than 10 seconds to make a 4 meter long bamboo cable with 3 or 5 strips.

The braided cables have very satisfactory adherence with the concrete, but the problem is that their manufacture takes a lot of time and only 3 strips can be used. In the case of bamboo cables made by torsion, they can have any number of strips. Their adherence in the concrete is good (18.22 kg/cm2) due to the helicoidal shape that the strips of the cable take. The adherence tests of the splints and small diameter bamboos gave 5.09 kg/cm2.

For testing the cables to tension we had many problems fixing their ends in the testing machine .

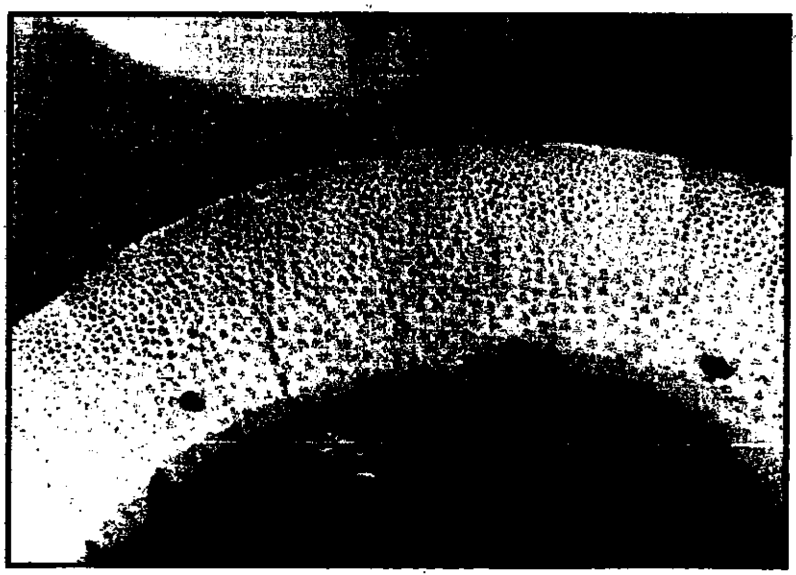
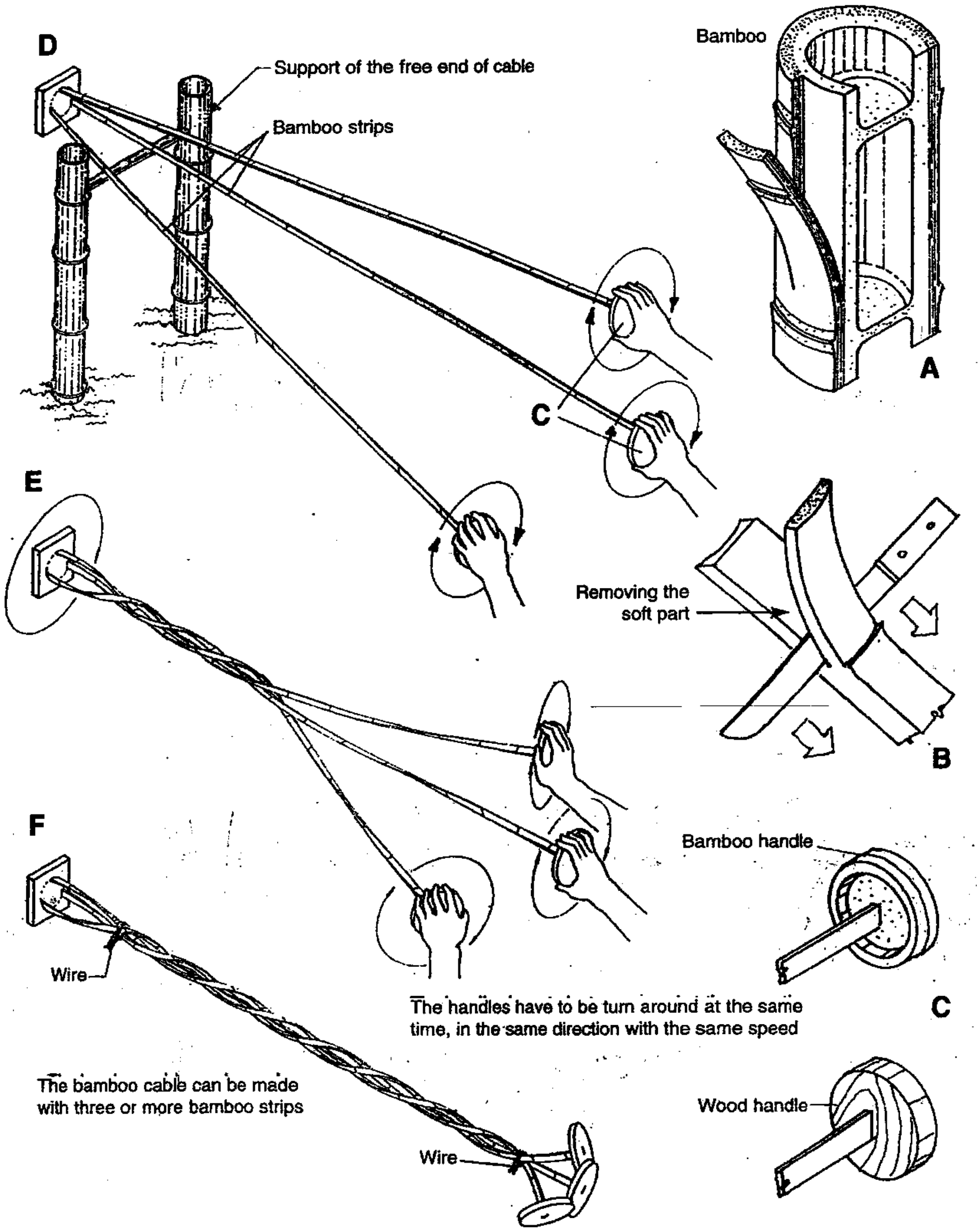


Fig.13.17 *The transversal section of the culm wall of Guadua angustifolia. and the internal zone attacked by Dinoderus minutus.*

Fig.13.18 *The two types of cables used: braided and made by torsion.*

MANUFACTURE OF BAMBOO CABLES FOR REINFORCING CONCRETE

Fig.13.19



MANUFACTURE OF BAMBOO STIRRUPS

Fig.13.20 *The stirrups are made with strips of bamboos 9 to 10 months old at the time of cutting. At this age, bamboo culms are more flexible than older ones, and can be easily bent using a small wooden form with rounded corners. The cables are fixed to the stirrups in the same way as steel bars are fixed to metal stirrups.*

A

B

C

D

E

BEAMS AND SLAB FOUNDATIONS REINFORCED WITH BAMBOO CABLES

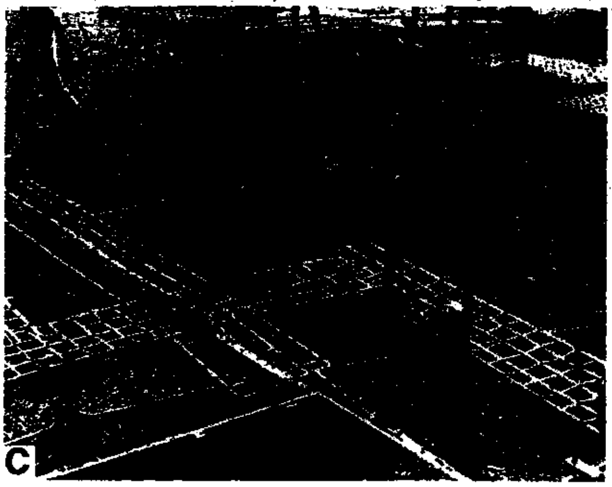
Under no circumstances the use of bamboo as reinforcement in concrete of aerial structures such as beams, columns, walls or roofs recommended, particularly if they are going to be inhabited by humans. Nevertheless, I have had satisfactory results in experiments in bamboo housing projects in Guayaquil, Ecuador. Bamboo cables were used as reinforcement in peripheral and internal concrete beams which support plastered bamboo walls, and bamboo mesh was used in the construction of slab foundations in the way explained in the photographs on this page.

A. -Assembly of the bamboo reinforcement
B. -Placement of the reinforcement of the peripheral beam
C. -Bamboo mesh used as floor reinforcement
D. -Experiment related to the use of small bamboo mesh used as reinforcement inthe lower part of the walls
E.- Pouring the concrete floor


A

Fig. 13.21


B


C


D


E

CULMS AND BAMBOO BOXES USED AS VOIDS. In the construction of concrete slabs in buildings (Colombia)

Fig.13.22 **CULM SECTIONS USED AS VOIDS IN COLOMBIA**

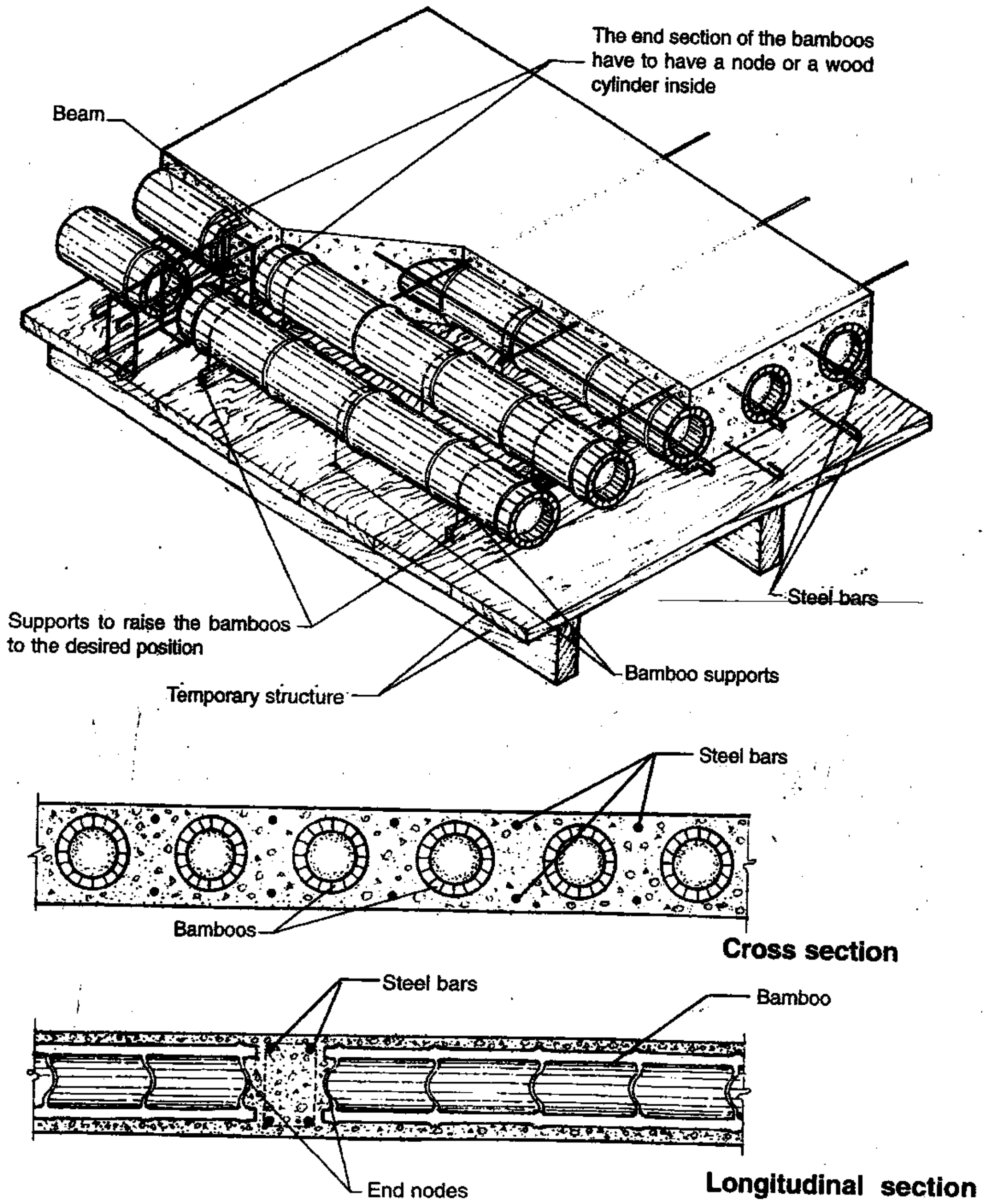


Fig. 13.23 BAMBOO BOXES USED AS VOIDS IN COLOMBIA

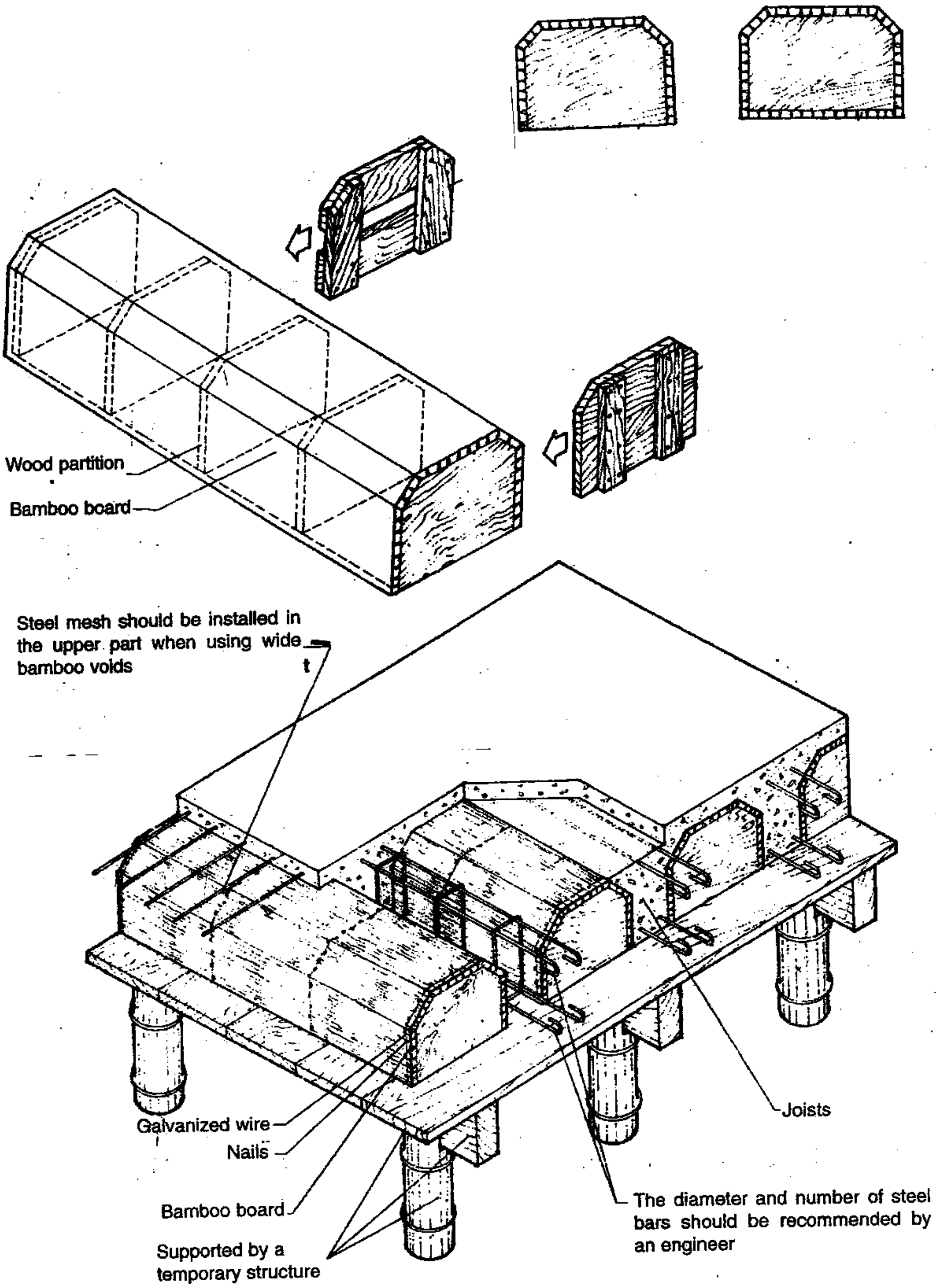
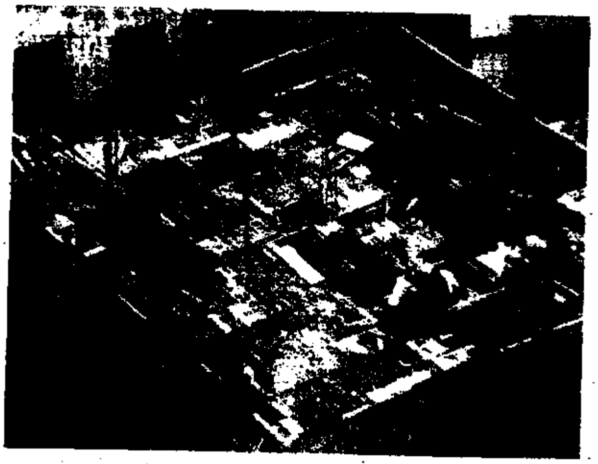
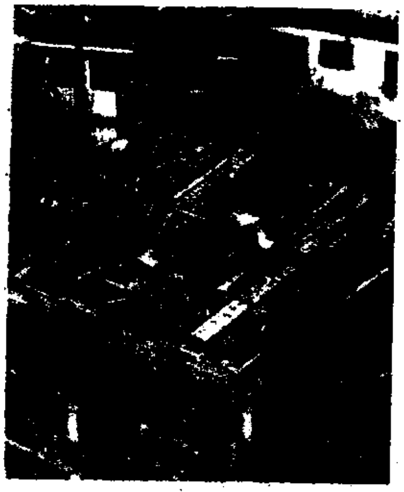


Fig.13.24 **BUILDING CONCRETE SLABS WITH BAMBOO BOXES**

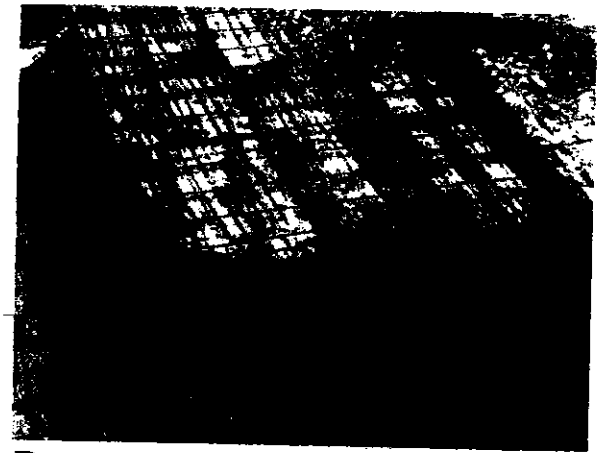
A. *In about 85% of the concrete buildings built in Bogota, Colombia, including high-rise buildings, all of the concrete slabs are made lighter by using bamboo boxes, which reduce the weight and the steel reinforcement.*



B. *First, a steel mesh and then the reinforcement bars of beams and joists are placed on the temporary wooden platform.*

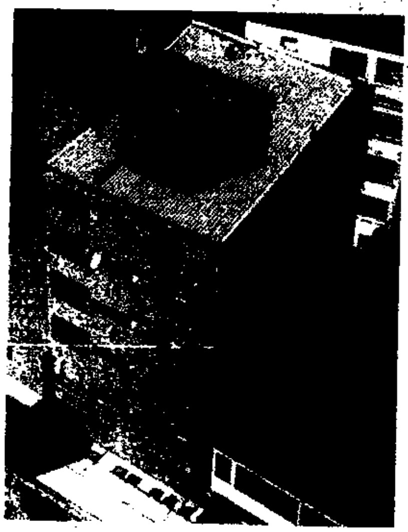


C. *Then the previously manufactured bamboo boxes are placed there.*



D. *Once the boxes and the steel bars are located, the concrete is poured.*

E. *Finishing touches of the concrete slab*



F. *The building once it has been finished.*

Fig. 13.25 CULMS USED AS JOISTS INSIDE CONCRETE FLOORS

In this case, the bamboo culms are not used as voids, but structurally as joists for supporting a concrete slab, as shown in Fig. A.

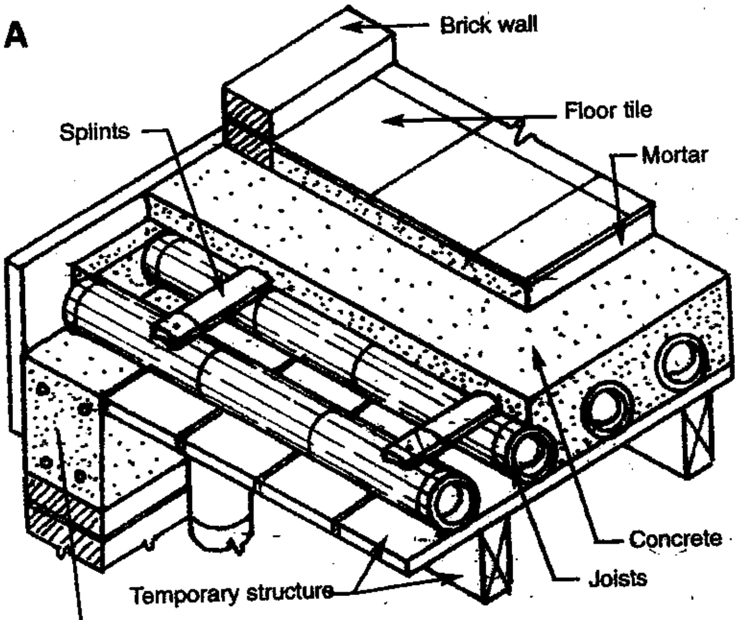
For the construction of the concrete slab supported by culms, it is necessary to build a temporary wooden platform at the level of the upper surface of the beam. Then the ends of the culms are placed on the top of the beams with a lateral separation of 4 cm.

In order to fix the culms with this separation, bamboo splints are nailed perpendicular to the culms with a separation of 1.50 m. Then plain concrete is poured between the culms up to 5 cm above the top part of the culm.

This system is recommended for concrete slabs with bamboo joists supported by brick walls with a maximum separation of 3.50 m.

This technology was used in Cali, Colombia, by Carlos Vergara, and in Popayan, in the southern part of the country by Lucy Amparo Bastidas and Edgar Flores in housing programs, such as the one shown in the Figs. B, C, and D.

A



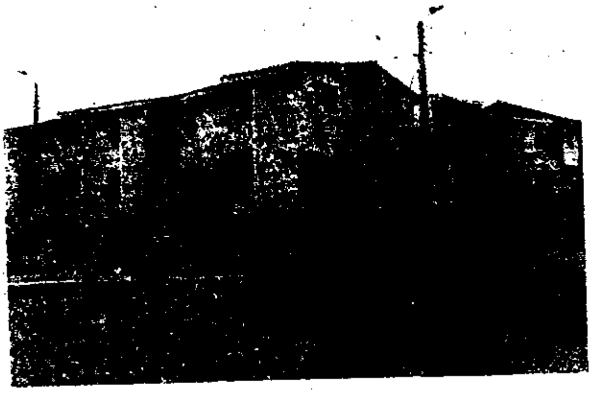
A. *Construction of the concrete slab above a wooden scaffolding.*

B-C *Once located the bamboo joists with a separation of 4 cm the concrete is poured.*

D. *Many houses in Popayan city, in the south of Colombia, has been built with this system which has a low cost.*

B

C



D

CULMS USED AS JOISTS SUPPORTING A CONCRETE SLAB

Fig.13.26 Concrete slab (5 cm) poured on top of bamboo board

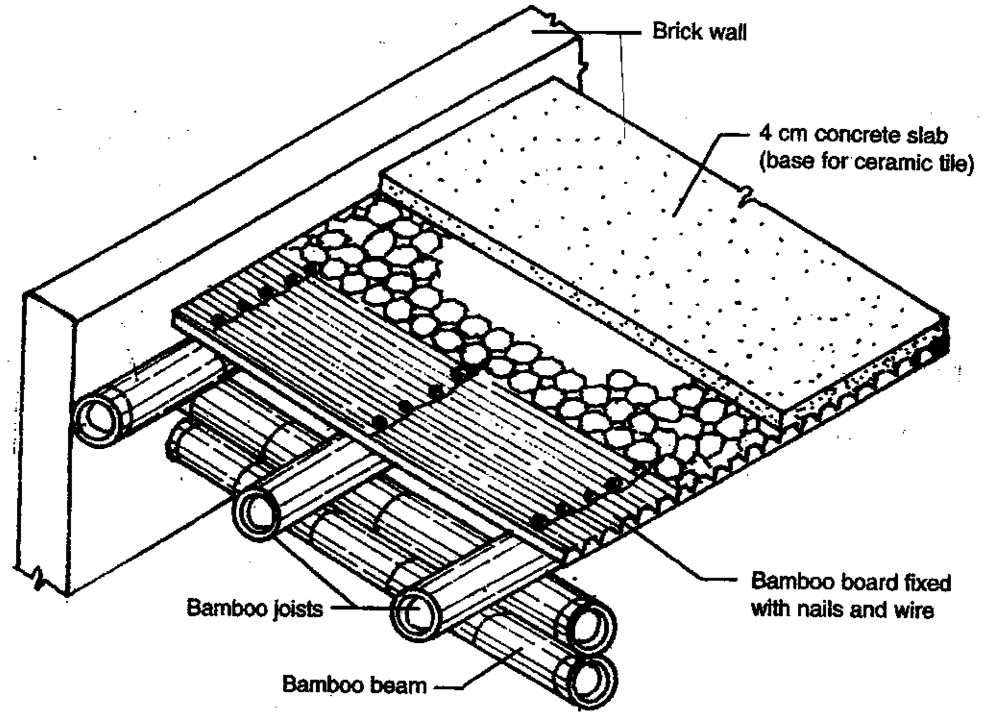
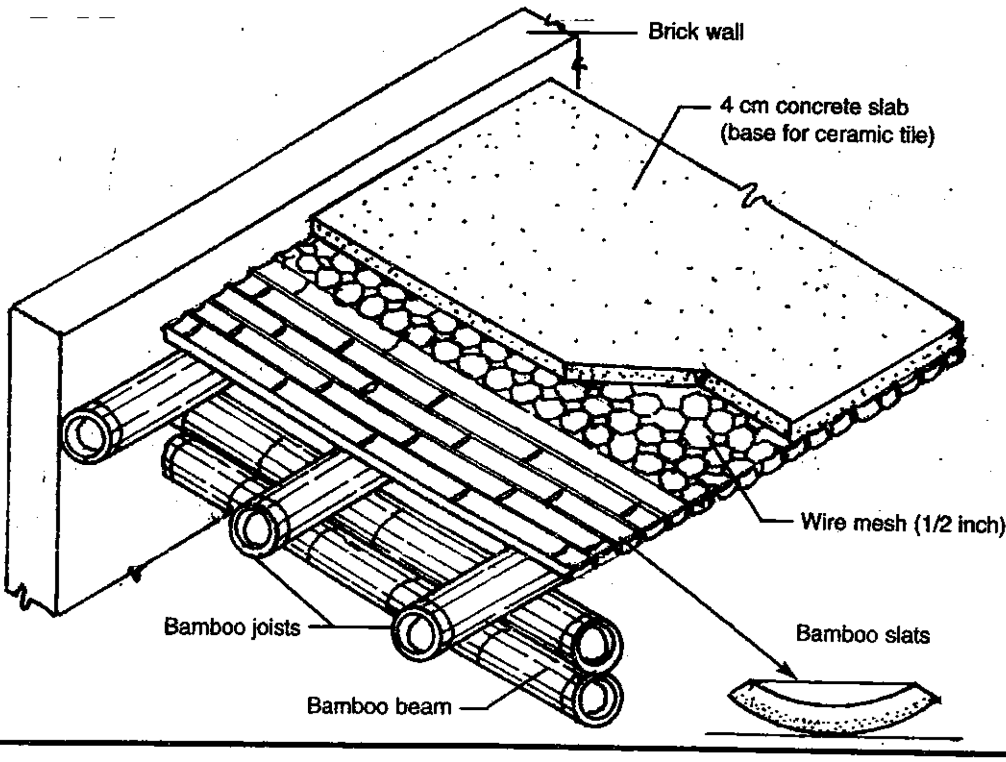
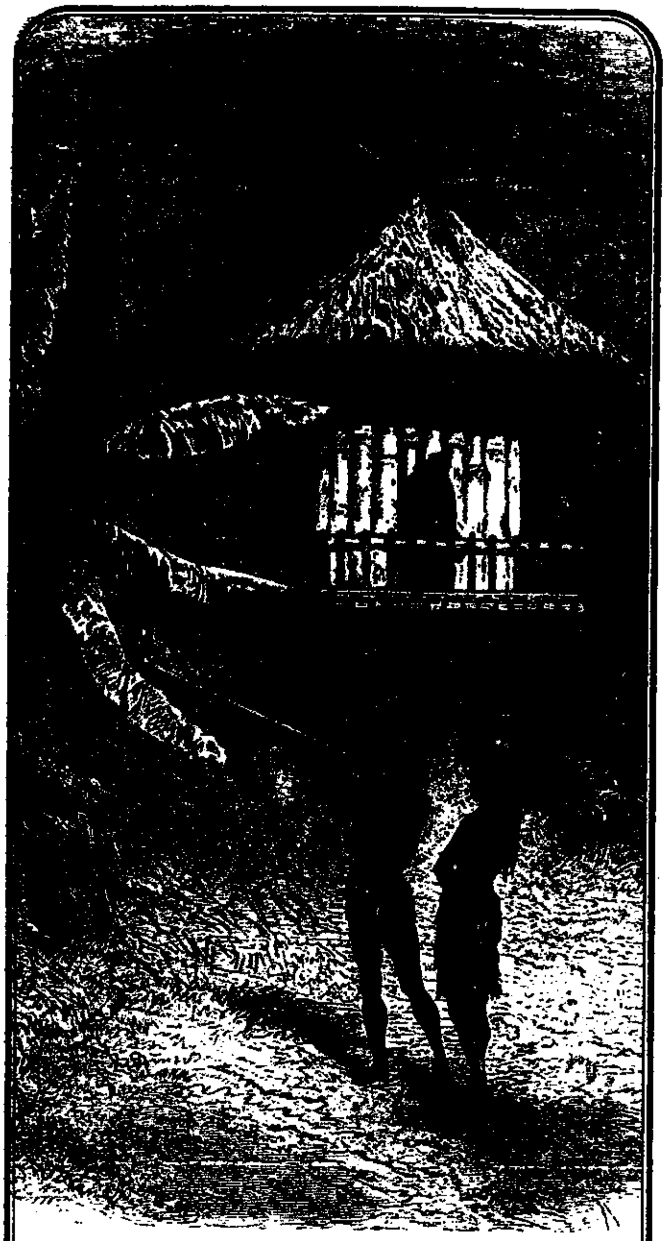


Fig.13.27 Concrete slab poured on top of bamboo slats



PART 6

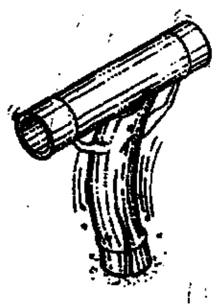
Bamboo Construction Technologies



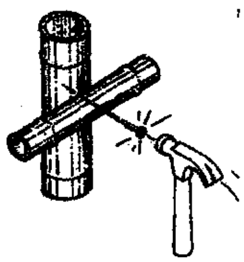
Bamboo house (Neuville's drawing)
Geografia Pintoresca de Colombia in 1869.

12 SOME BASIC RULES FOR USING BAMBOO IN CONSTRUCTION

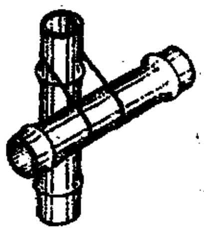
! DONT USE FOR CONSTRUCTION !



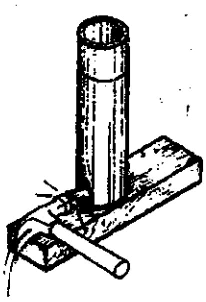
Culms with low compression strength for construction. These include:
1) Young culms less than three years old,
2) Culms which are or have been attacked by insects or fungus,
3) Culms which have flowered,
4) Culms with cracks or which have transversal cuts made by a machete



Nails for fixing lateral culms with smaller diameter, or for fixing joints.

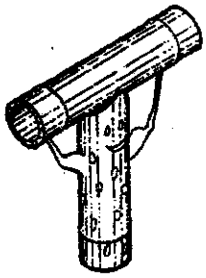


Green bamboos used structurally in permanentm constructions and tied with wire or ropes. When green culms become dry, they shrink and the ties become free

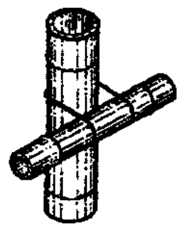


Temporary vertical supports or colums without any node at the lowest end which can present cracks at the moment ofbeing fixed.

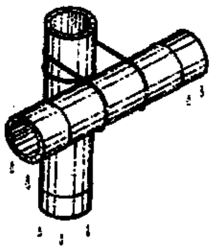
Fig 14.1 ! USE !



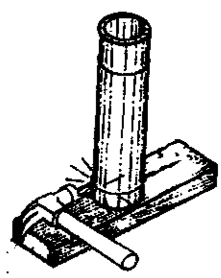
1) Mature cullms 3 years old or older
2)Giant culms with appropriated dimensions and thick walls (more than 9 mm).
3) Culms with appropriate joints



If it is necessary to use nails for fixing small diameter culms (4 to 5 cm) or joints of giant bamboos, it is recommended to open a hole previously with a drill bit sligtelly smaller than the nail"s diameter.
2) For fixing horizontal and vertical structural members in temporary structures use wire ties, nylon or strong vegetal cords.



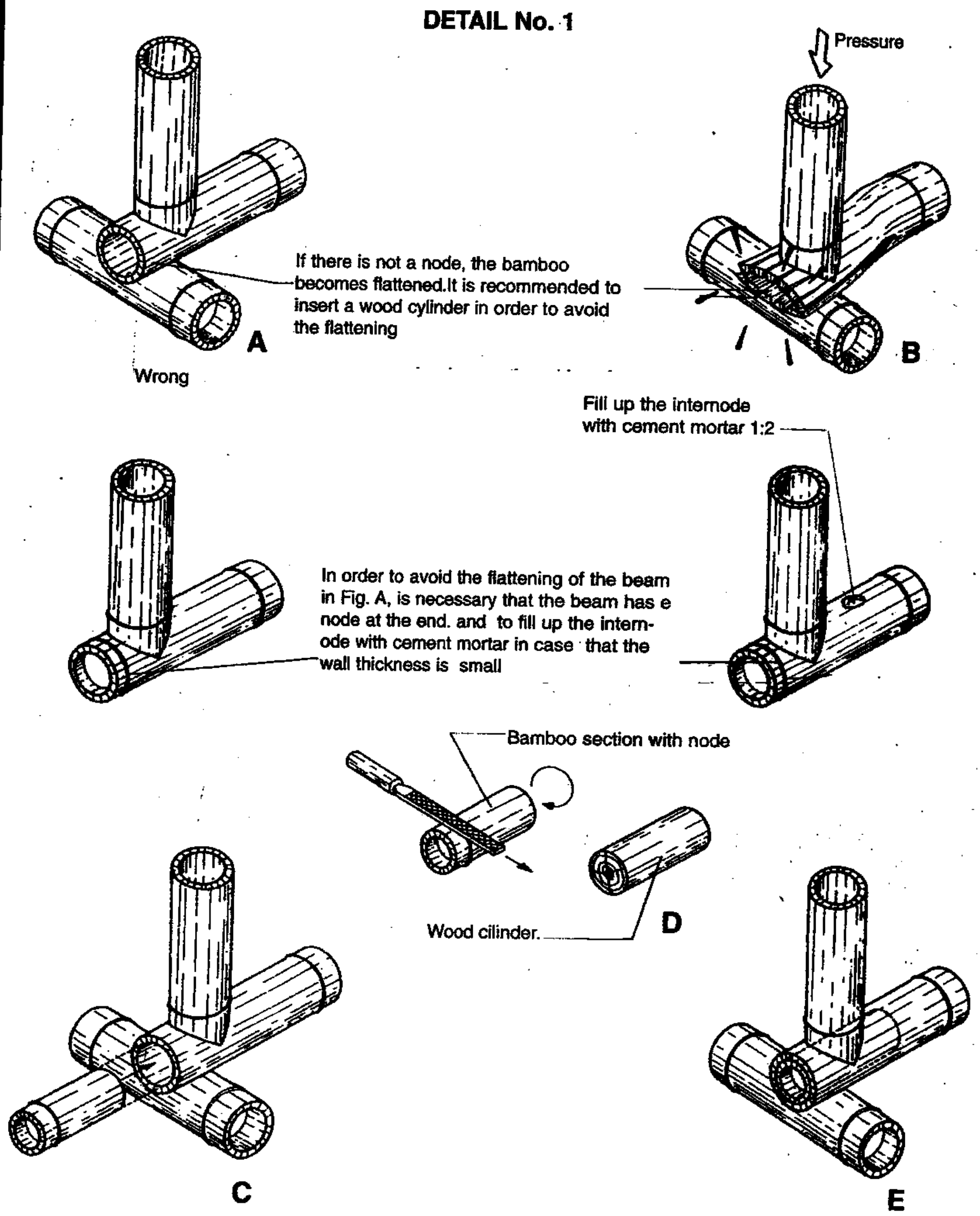
In this case it is convenient to check frequently the ties, or to use dry culms



In this case it is convenient that the temporay column has a node in the lowest end, in order to avoid the craks.

HOW TO AVOID THE CRUSHING OF HORIZONTAL MEMBERS

Fig.14.2



TYPES OF JOINTS USED IN BAMBOO CONSTRUCTION

Fig.14.3 MANUFACTURE OF THE MAIN TYPES OF JOINTS

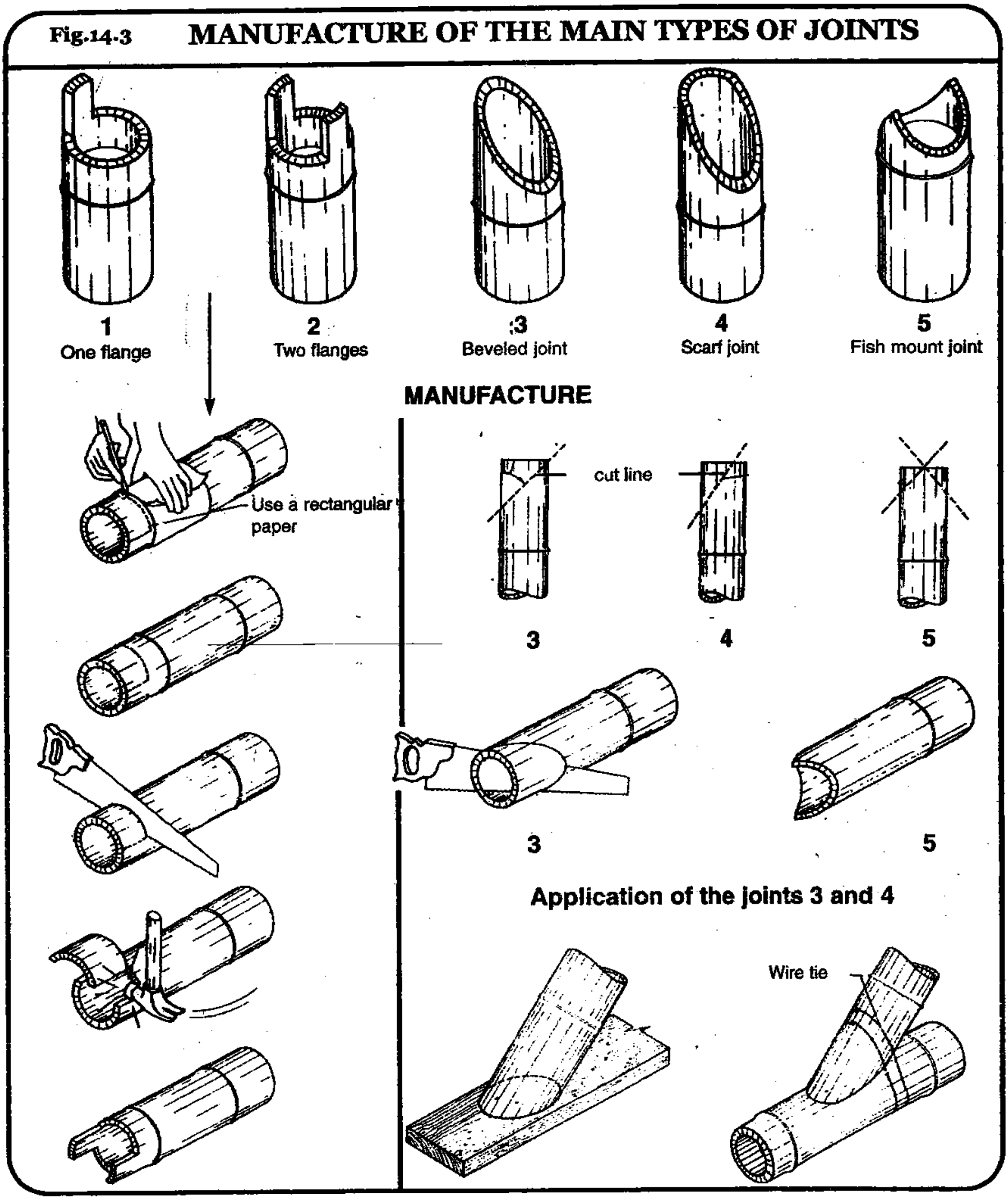
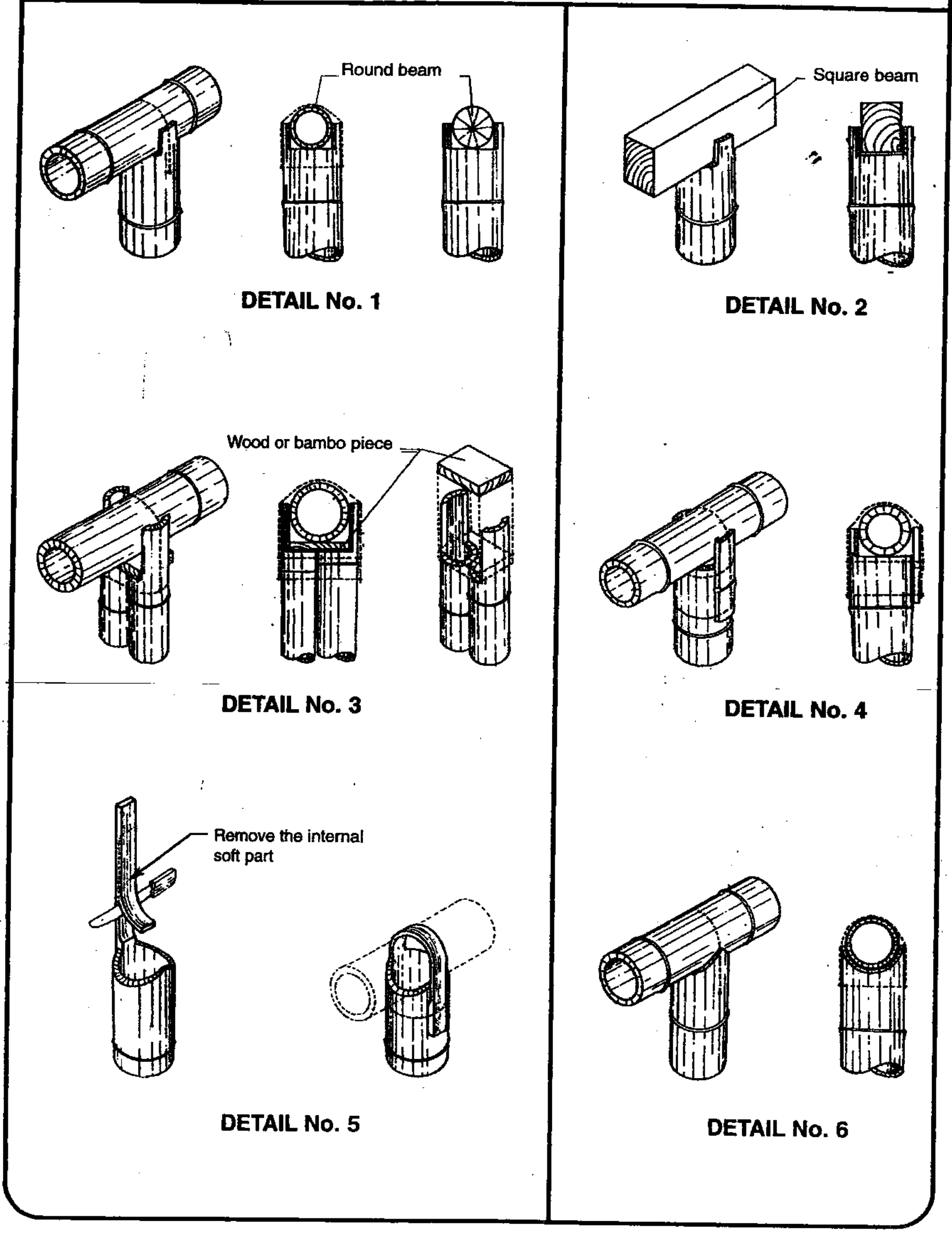


Fig. 14.4 **JOINTS OF HORIZONTAL AND VERTICAL MEMBERS**



FIXING HORIZONTAL AND VERTICAL MEMBERS WITH PINS AND BOLTS

Fig. 14.5

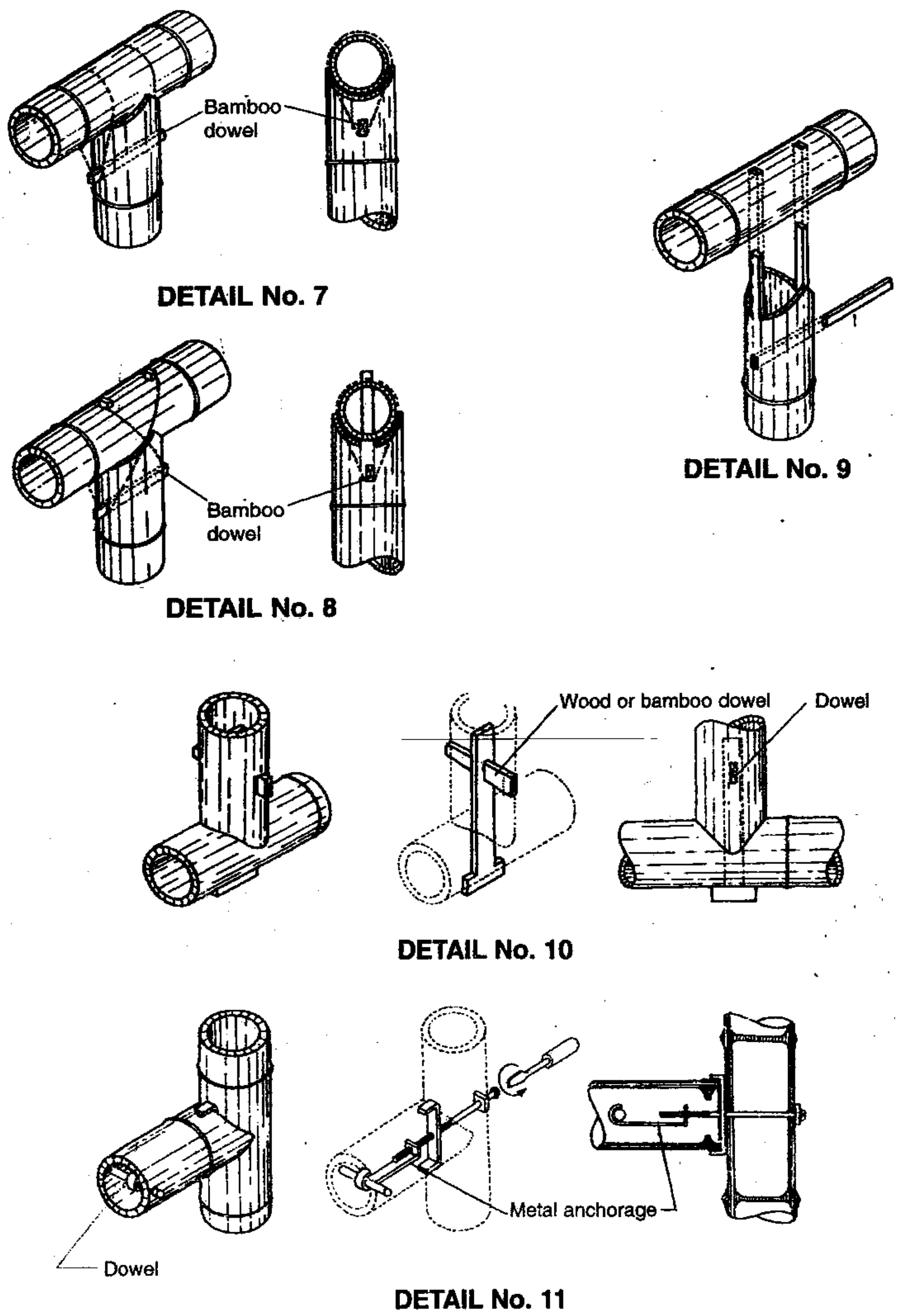
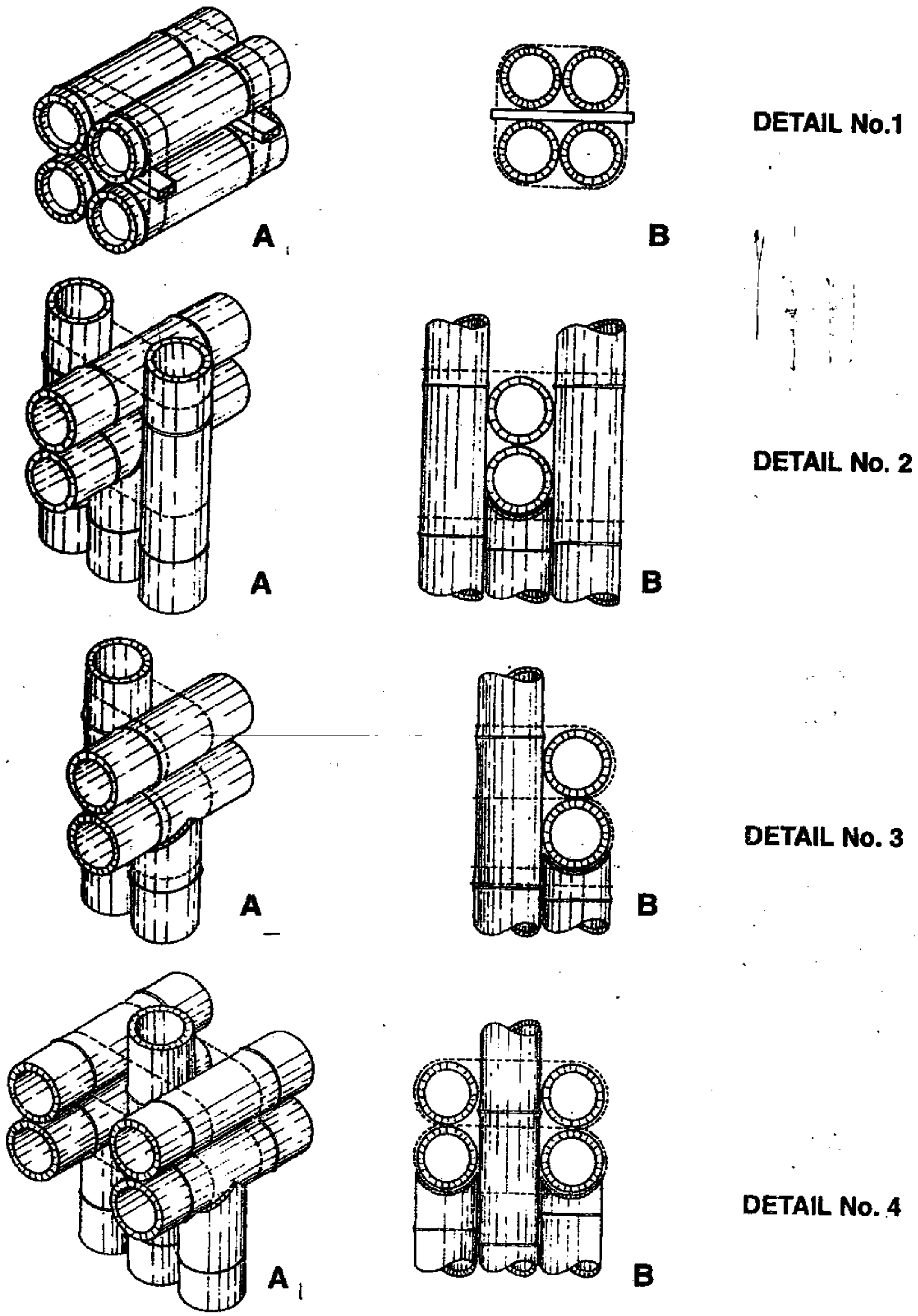
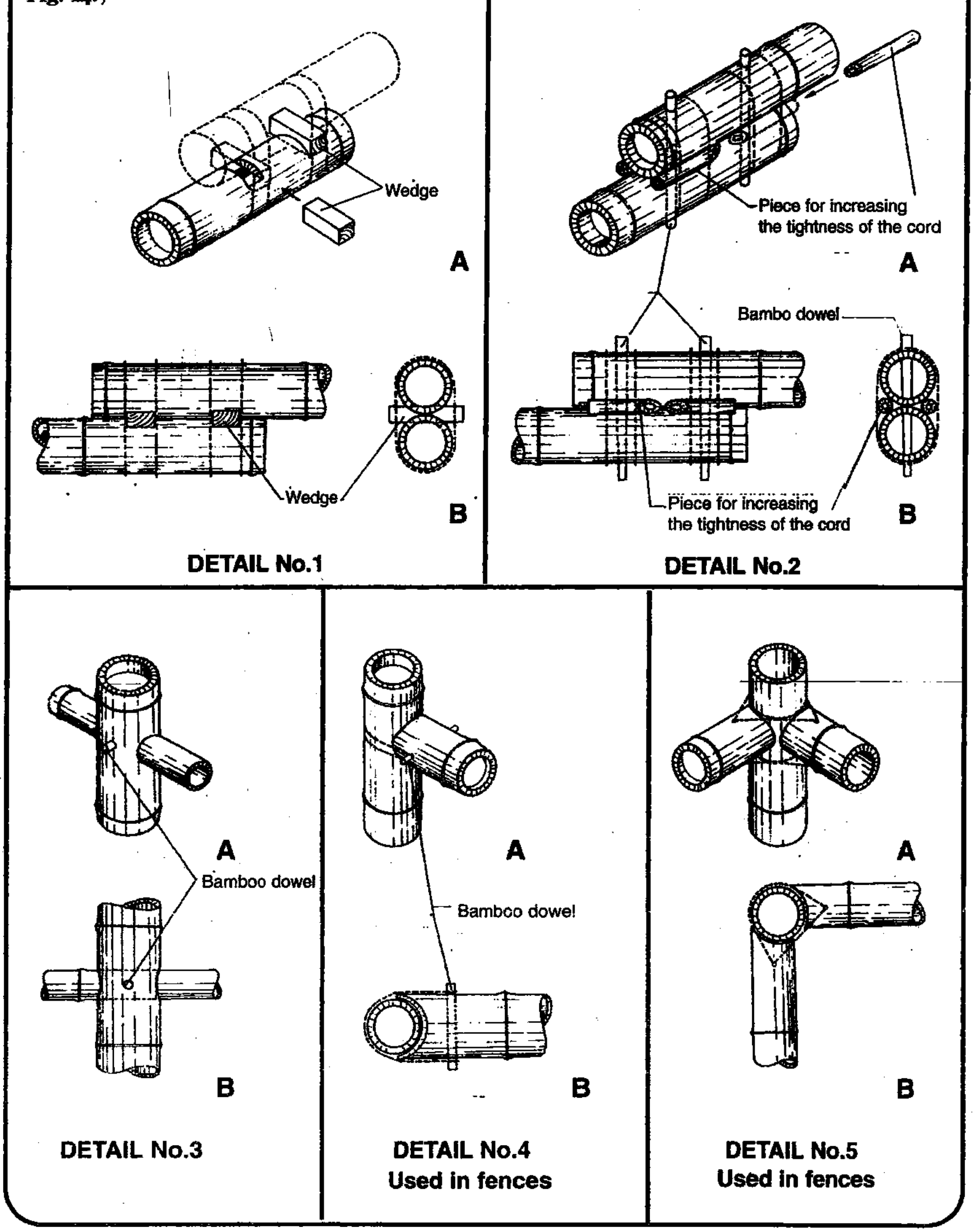


Fig. 14.6 **DOUBLE AND QUADRUPLE BEAMS - SUPPORTS**



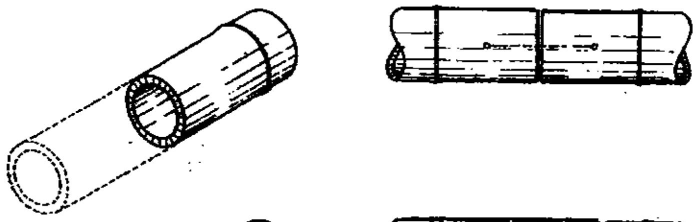
HORIZONTAL JOINTS (NOT FOR STRUCTURAL MEMBERS)

Fig. 14.7

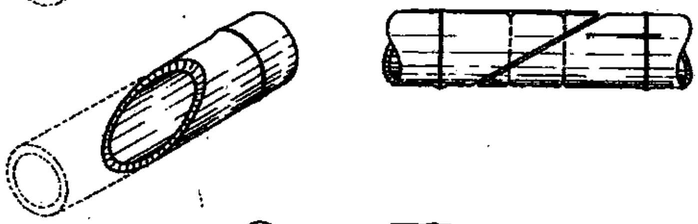


HORIZONTAL SPLICING (NOT FOR STRUCTURAL MEMBERS)

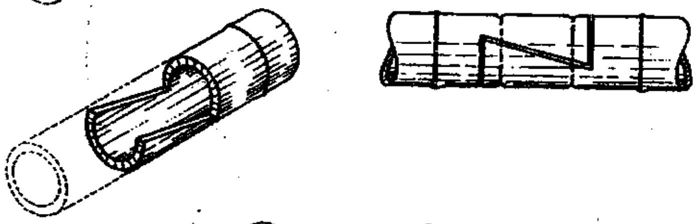
Fig. 14.8



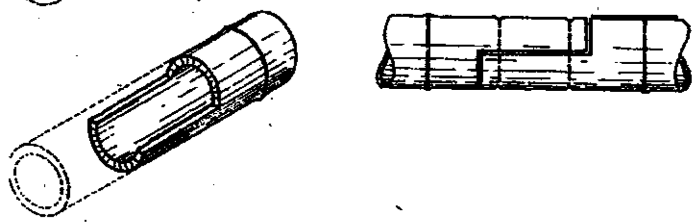
1. Butt joint



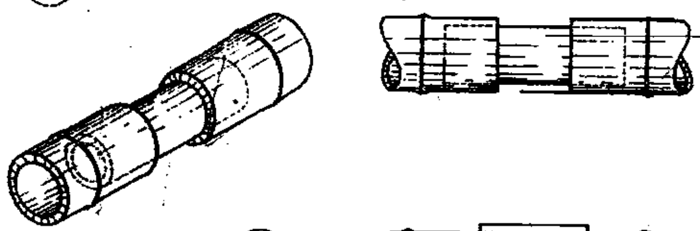
2. Beveled joint



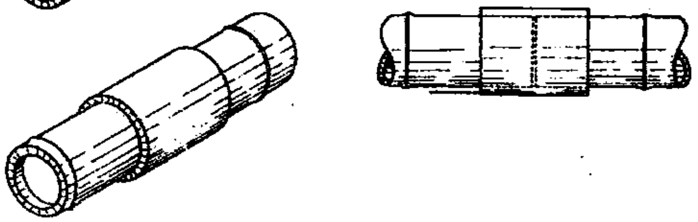
3. Oblique surfaced half-lap joint



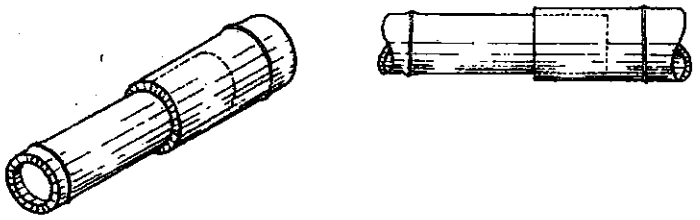
4. Rectangular half-lap joint



5. With internal culm section. It is used for aqueducts



6. With external culm section. It is used for aqueducts



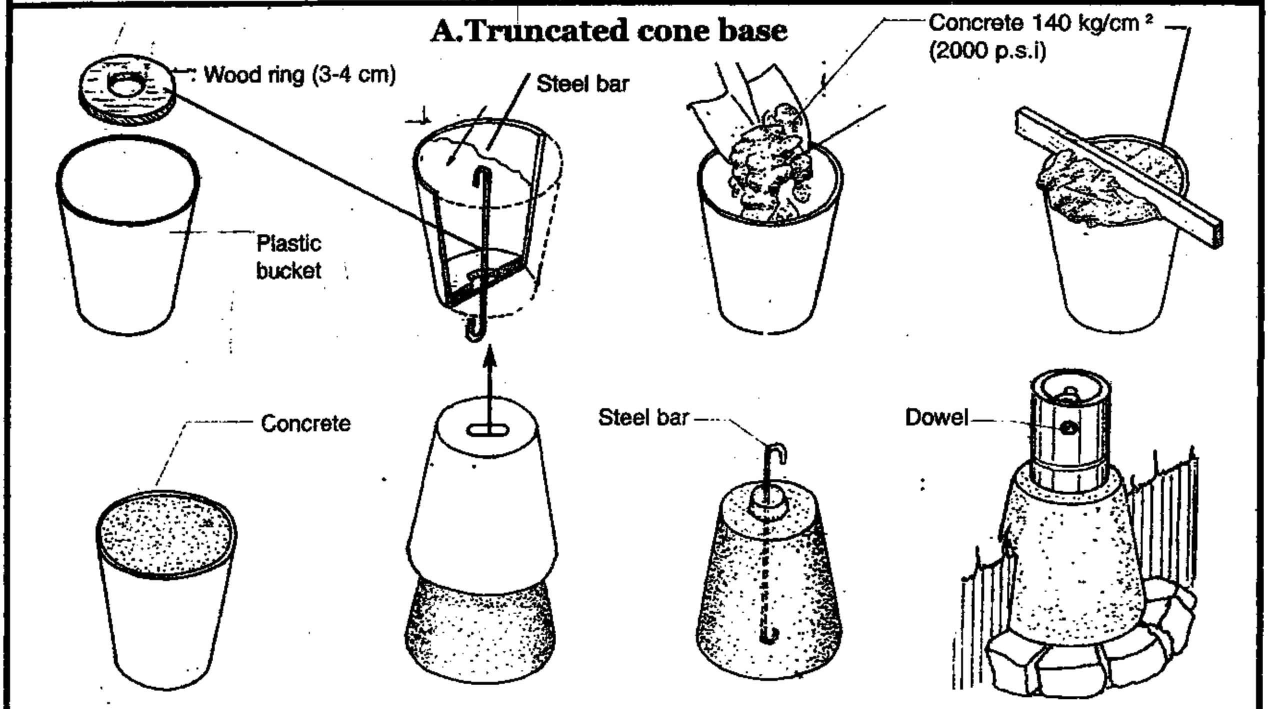
7. Telescope joint it is used for aqueducts

13 HOUSE CONSTRUCTION FOOTINGS

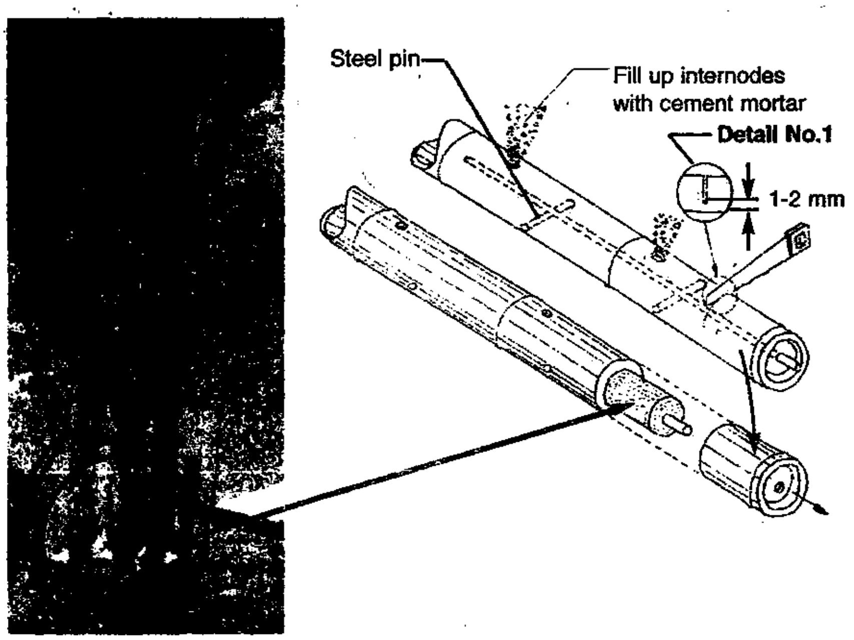
Fig. 15.1

FOOTING TYPES

A. Truncated cone base



B. Concrete cylinder support base

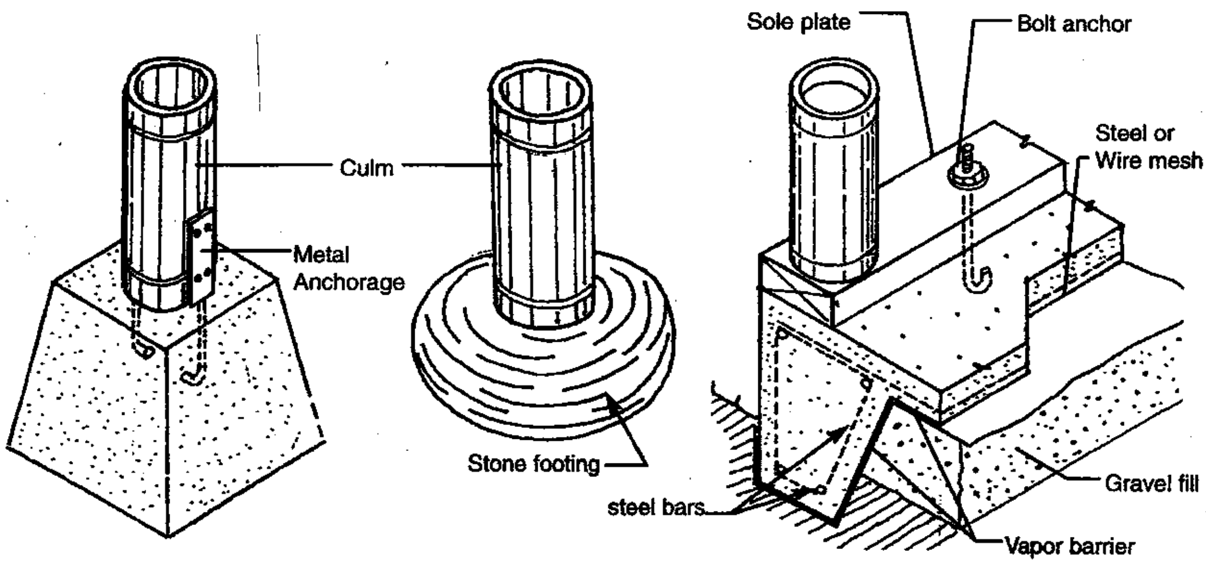


This practical base for bamboo columns was developed by Carlos Vergara. It can be used in the base of bamboo columns, in corridors, but it is not recommended for the foundations of heavy buildings. It uses two internodes with mortar reinforced with a steel bar.

Steel pins or dowels are located in the center of each internode in order to fits the concrete cylinder once it shrinks.

Before filling the internodes with mortar, the bamboo cylinder has to be cut partially, leaving about 1-2 mm from the interior surface around the culm (See detail No. 1). Once the concrete is dry, the rest of the wall is cut in order to remove the end of the culm and the concrete of the base will be exposed.

Fig. 15.2 **FOOTINGS FOR DIFFERENT TYPES OF GROUNDS**

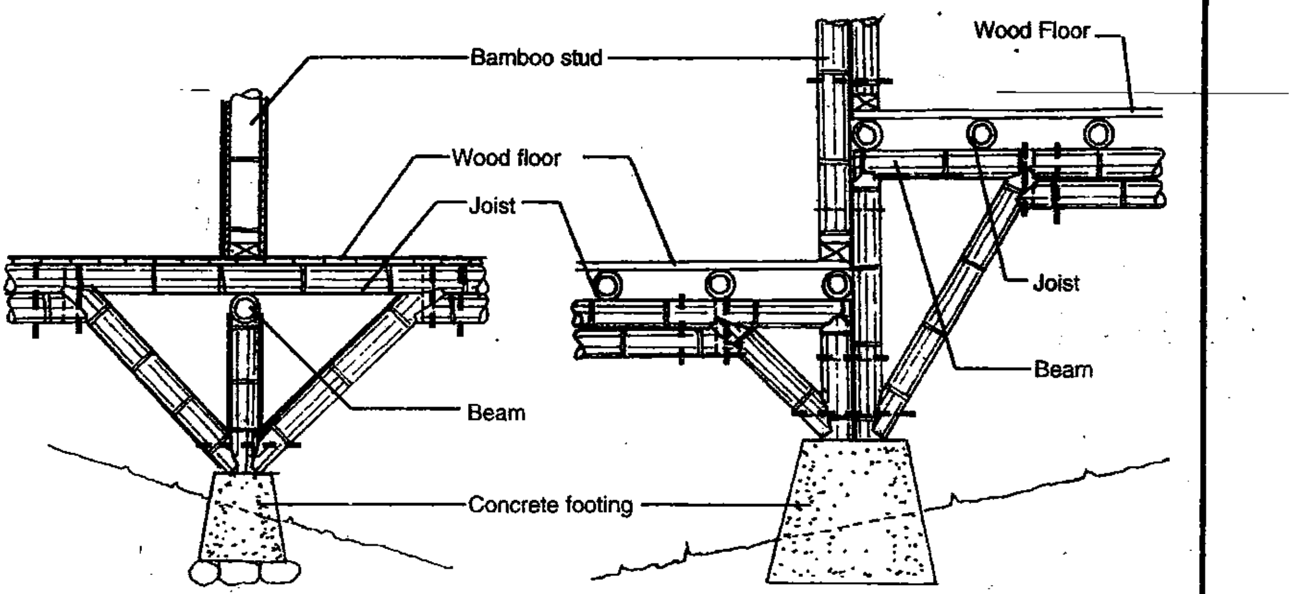


A.-Footing for slope and flat ground

B.-Footstone for slope and flat grounds

C.-Combined slab and foundation for flat grounds

Fig. 15.2A **FOUNDATION AND SUBSTRUCTURES ON SLOPING GROUND**



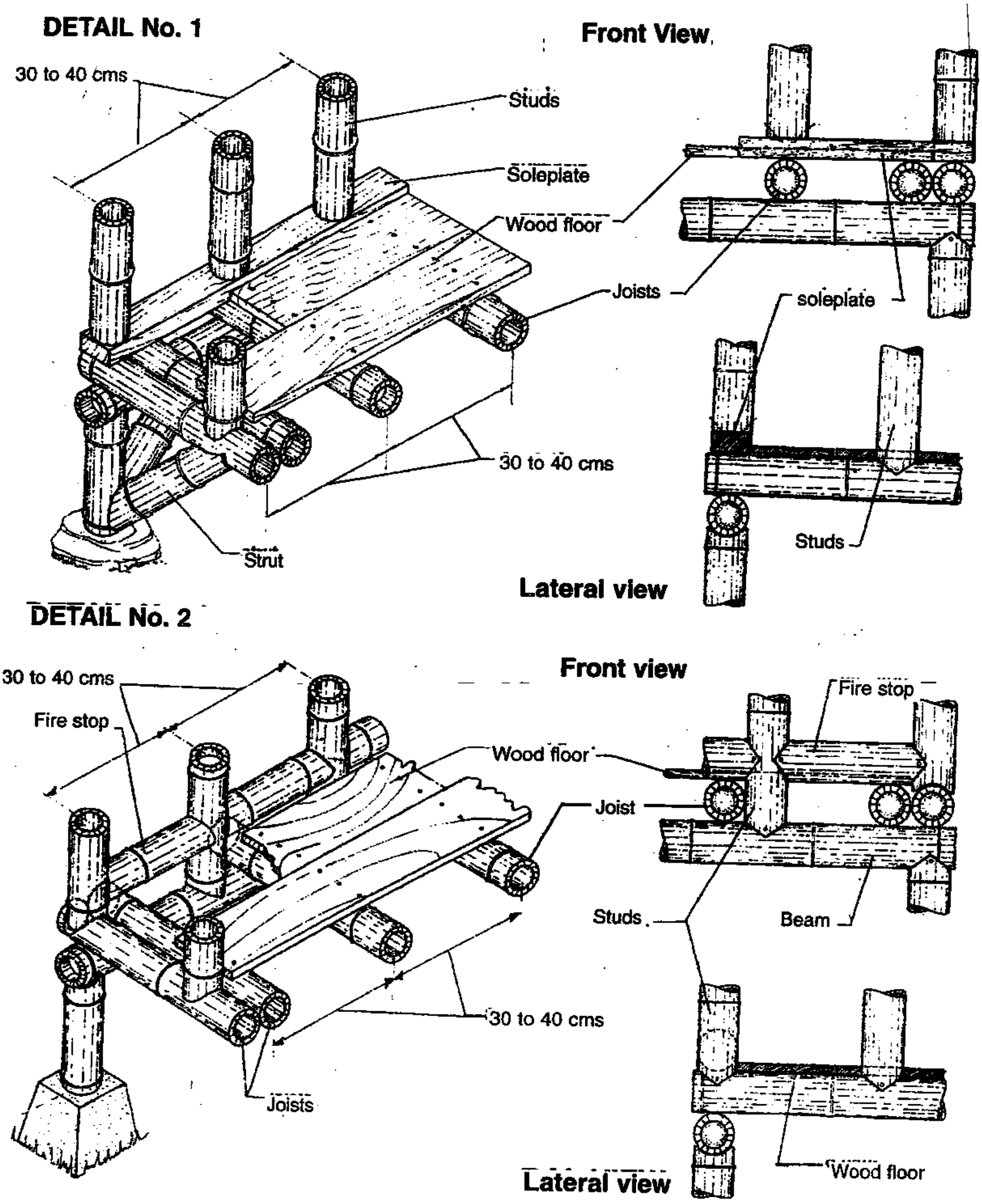
D.-When the floor is on one level.

E.- In the places where there are two floors at different levels.

FOUNDATION AND BAMBOO SUBSTRUCTURE ON SLOPING GROUND

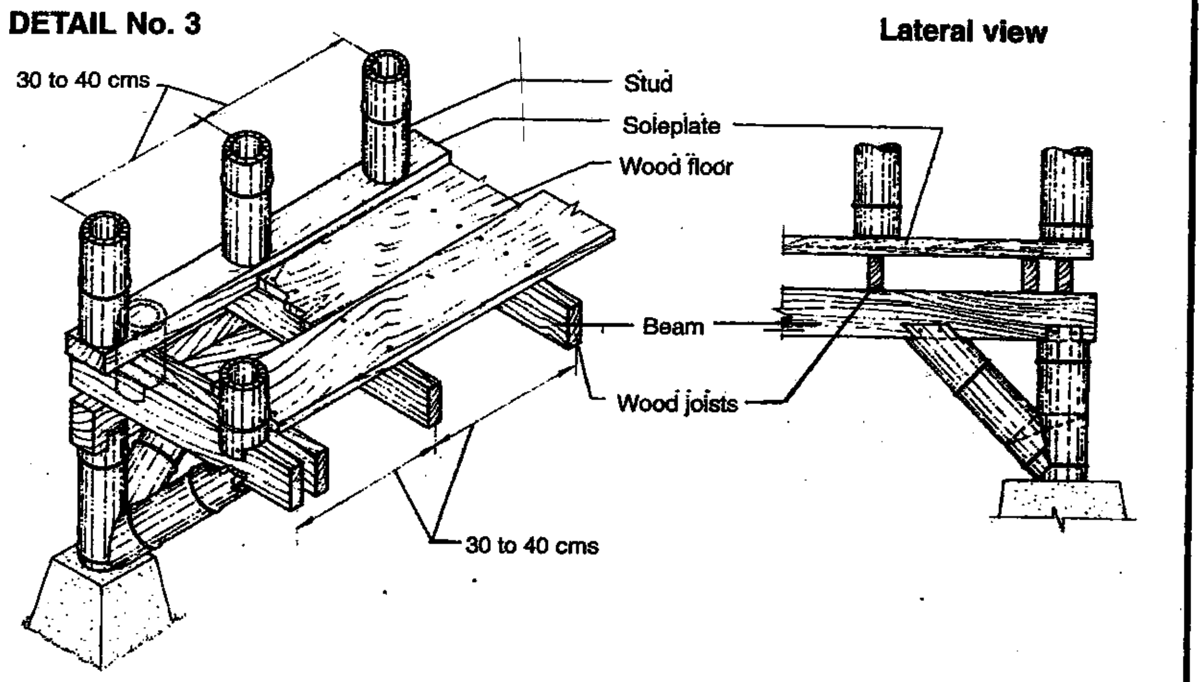
WOOD AND BAMBOO SUBTRUCTURES OF FLOORS ELEVATED FROM THE GROUND

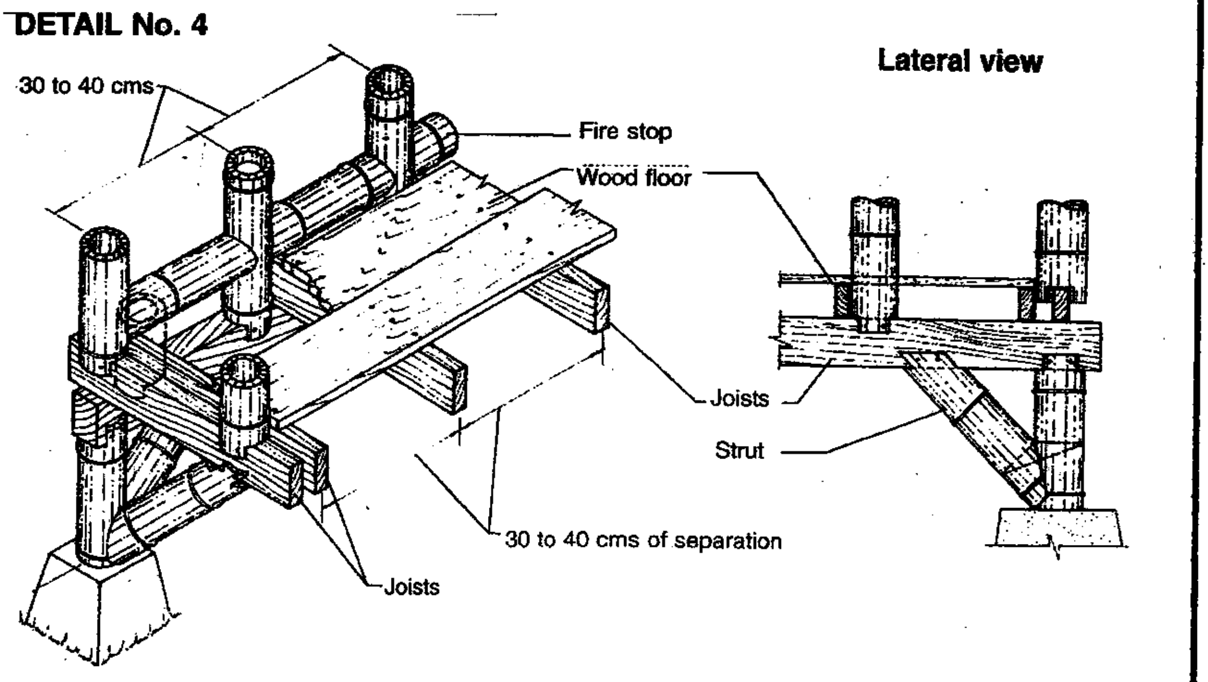
Fig. 15.3



BAMBOO SUBSTRUCTURE OF ELEVATED FLOORS

Fig. 15.4



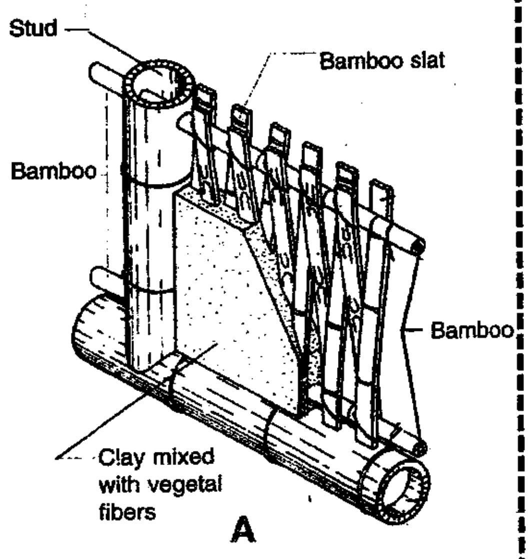


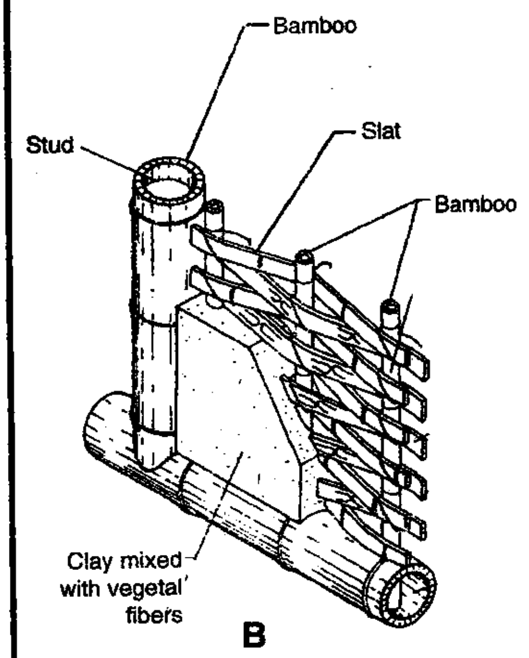
14

BAMBOO WALLS

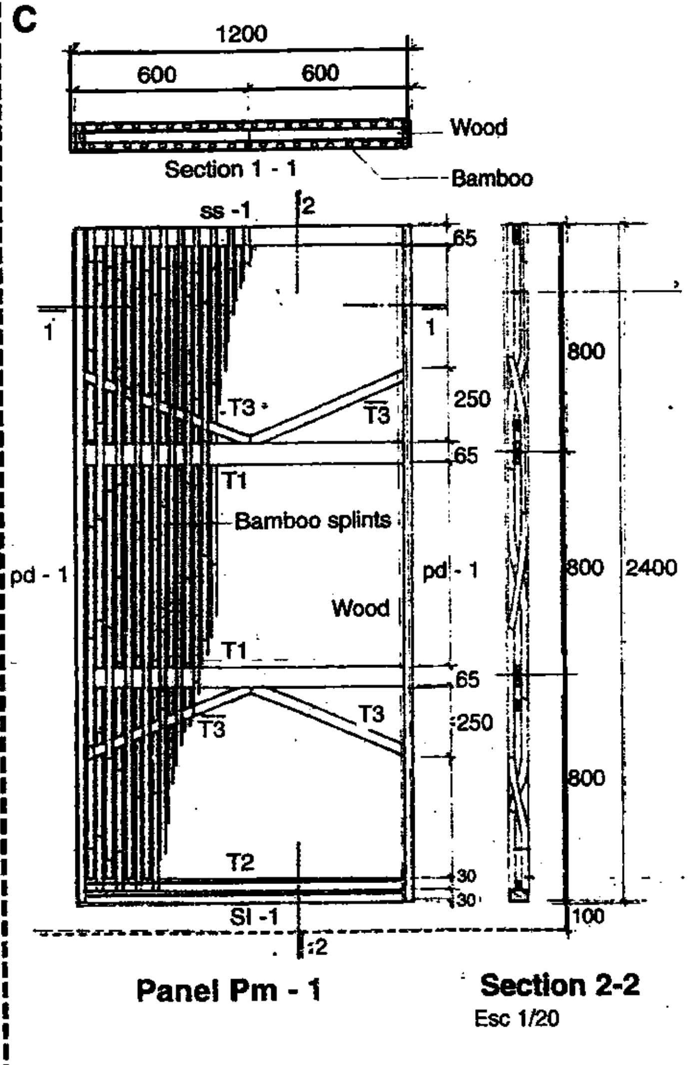
Fig. 16.1 "QUINCHA" WALL - PERU

Bamboo





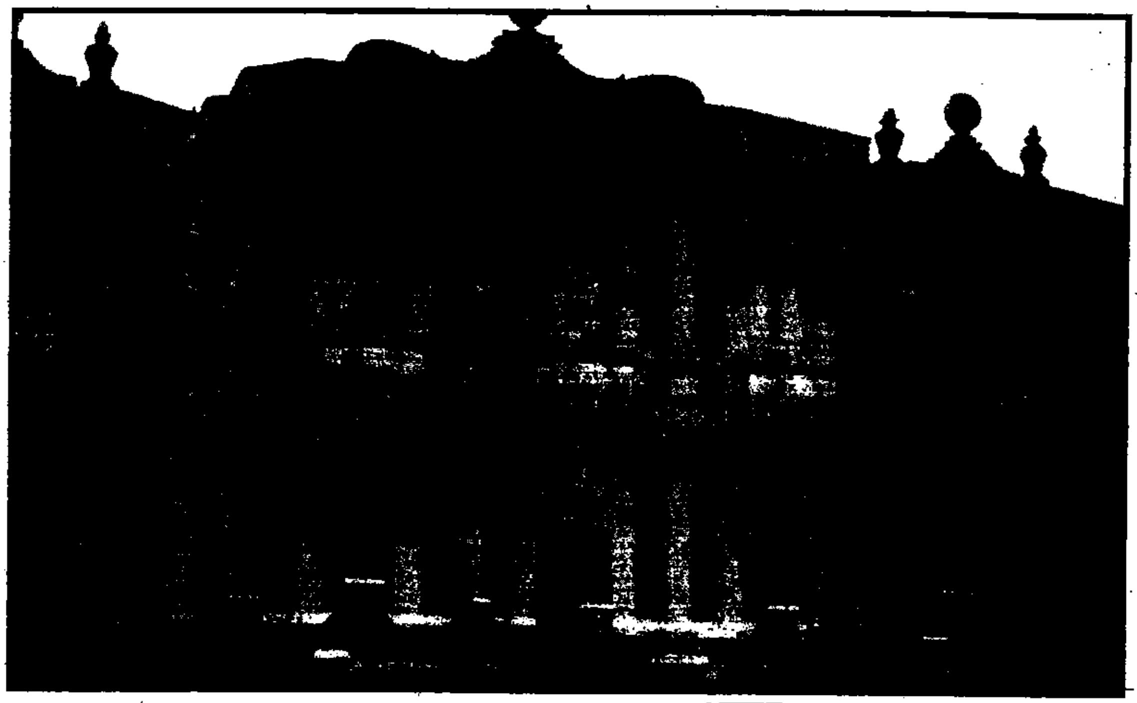
Wood and bamboo - (ININVI)*Peru



*ININVI -*Instituto Nacional de Investigacion y Normalizacion de la Vivienda - Lima. Peru*

TRADITIONAL BAMBOO WALLS IN PERU

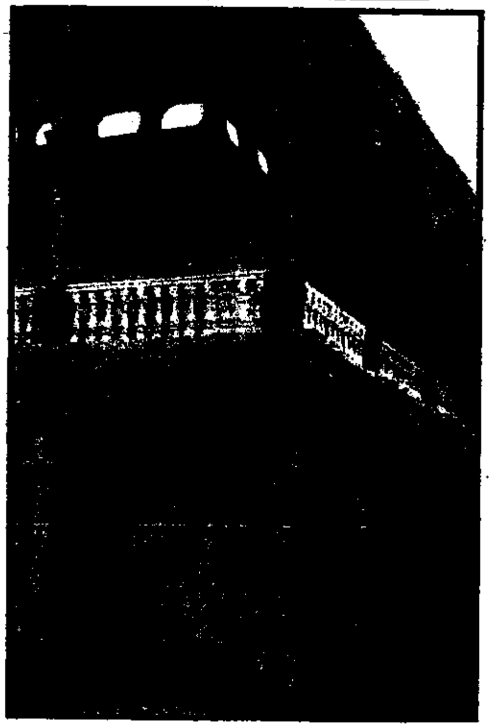
Fig. 16.2 **BAMBOO ARCHITECTURE WITH "QUINCHA"**



A

The Palace of the Viceroy Amat in in Lima, Peru, *known also as the "Mill's house" or "Perricholi's House". (She was the concubine of the Viceroy Amat.) In the nineteen eighties I visited this building while it was being repaired. Bamboo culms covered with plaster were used in the columns, and the ceilings were made of bamboo boards and then plastered. All of the walls and ceilings in this building were made with quincha.*

B



C

BAMBOO WALLS IN ECUADOR

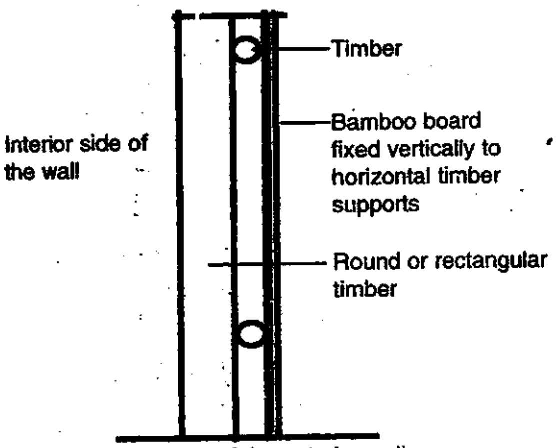
Fig.16.3 ANCIENT AND PRESENT BAMBOO ARCHITECTURE

Figs. C and D show the drawings made by some artists who came to Ecuador in the sixteenth century and later. These two figures show that at that time, the natives were excellent bamboo builders. Due to the floods during the rainy season and the dangerous animals of the jungle, the houses were elevated from the ground. The nice house shown in E are the typical bamboo architecture which can be seen in only a very few towns of the coast.

In the floating houses of the Daule River shown in B, the vertical bamboo boards are replaced by strips of bamboo board 10 cm wide woven diagonally.

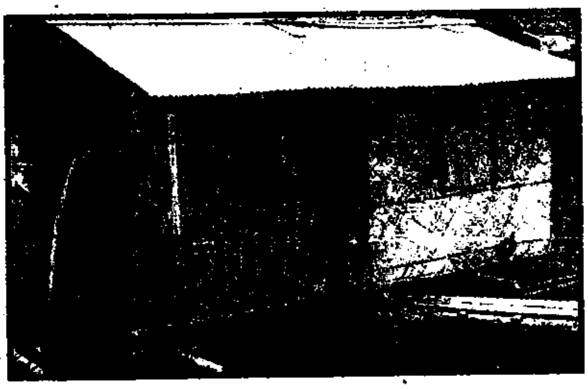
C. *Tipical bamboo and timber house of the Ecuador coast*

A. Detail of the traditional wall



Cross section of the exterior walls

D. *Ancient bamboo house of the Ecuador's jungles*

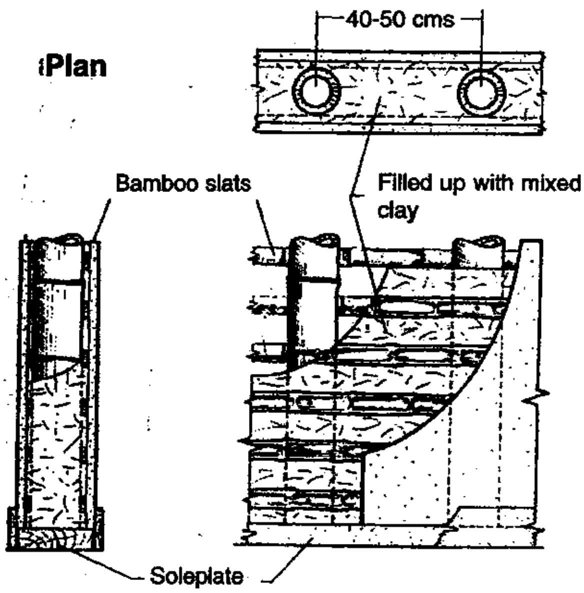


B. *Floating house in the river Daule*

E. *Typical architecture found in few towns of Ecuador.*

CRAMMED WALL WITH CLAY- Colombia

Fig. 16.4 **A.- Construction details**



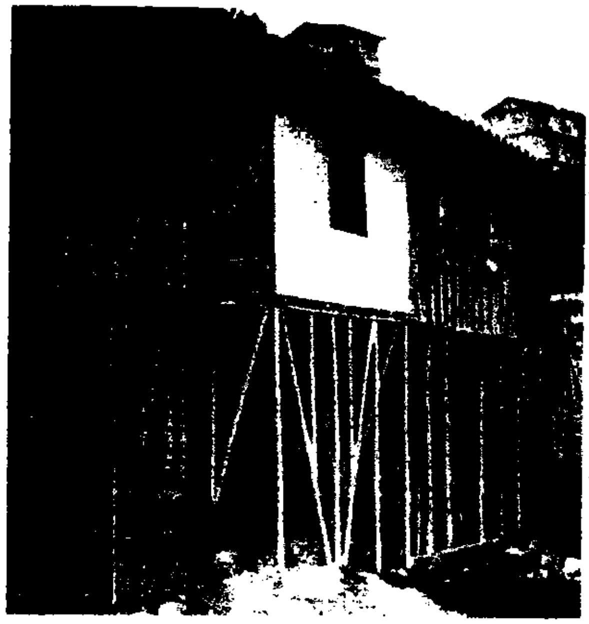


Fig. B *The "cage" (jaula) is built with studs and bamboo slats (3-4 cm wide) which are fixed with nails to the studs with a separation of 7-8 cm. The cage is filled with clay mixed with straw. Once dry (after one month), the wall is plastered with two coats of fine clay,sand and cement. (Photo: Dicken Castro).*

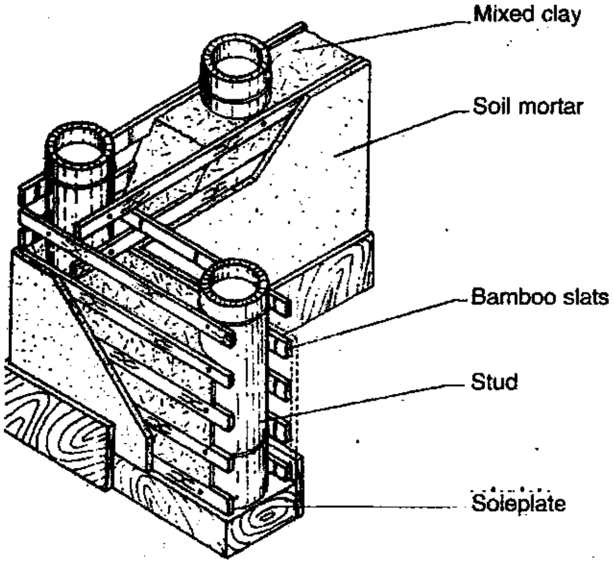
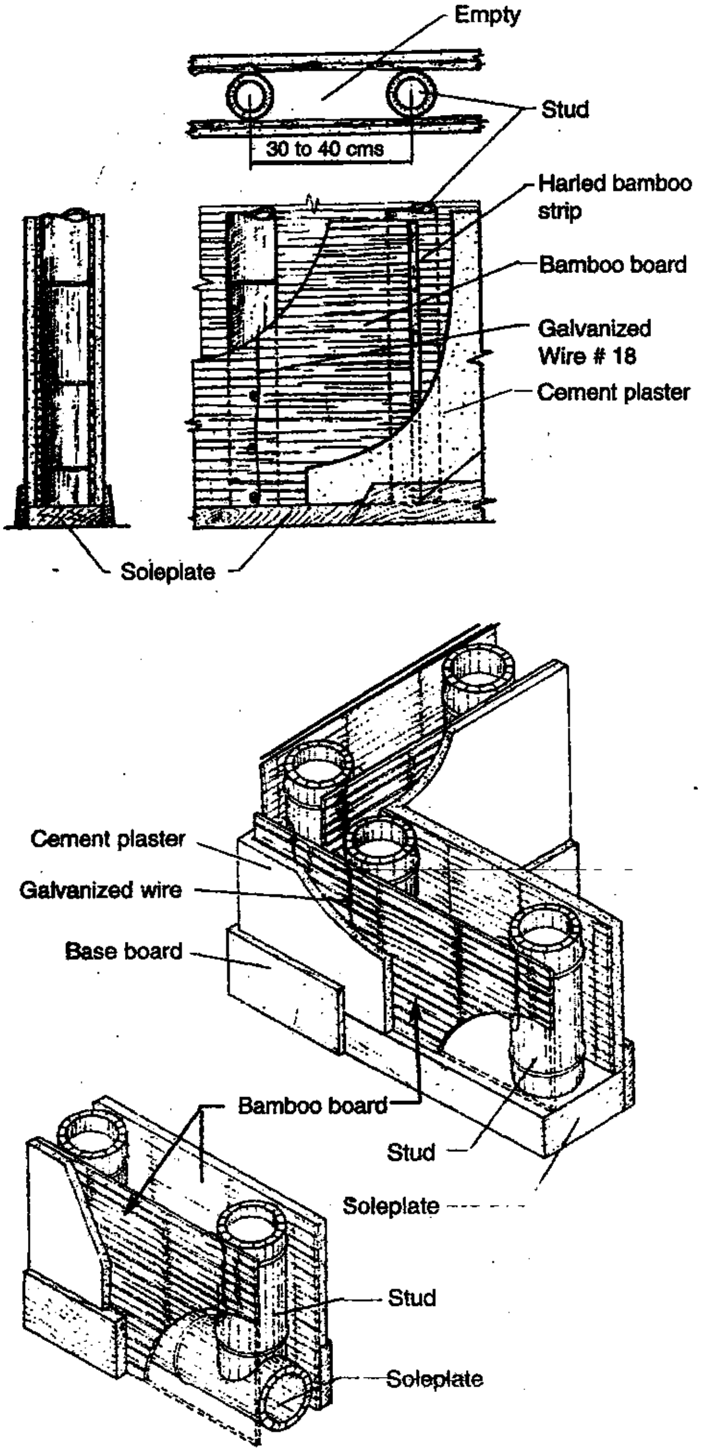


Fig.C *This type of wall is very heavy and generally is used in the construction of the first floor. On the 2nd floor, a double bamboo board wall is used.in most of the cases.*

BAHAREQUE WALL WITH DOUBLE BAMBOO BOARD - COLOMBIA

Fig.16.5 A.-Construction details



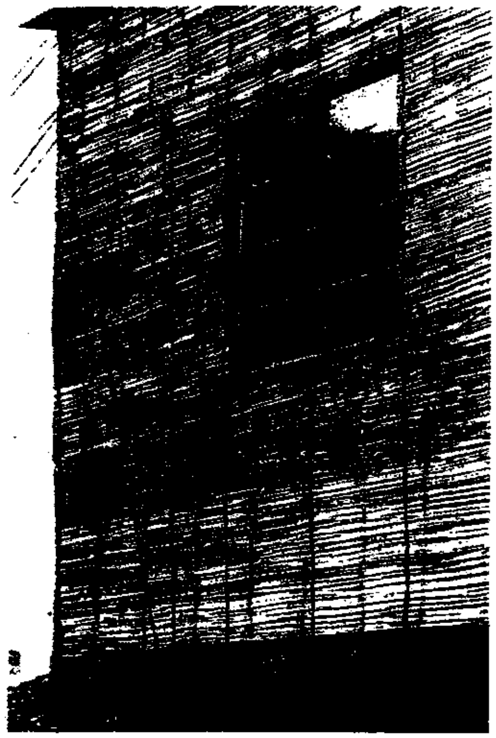


Fig.B *The ends of the bamboo joists and the ceiling of the cantilever must be covered with bamboo boards and plastered.*

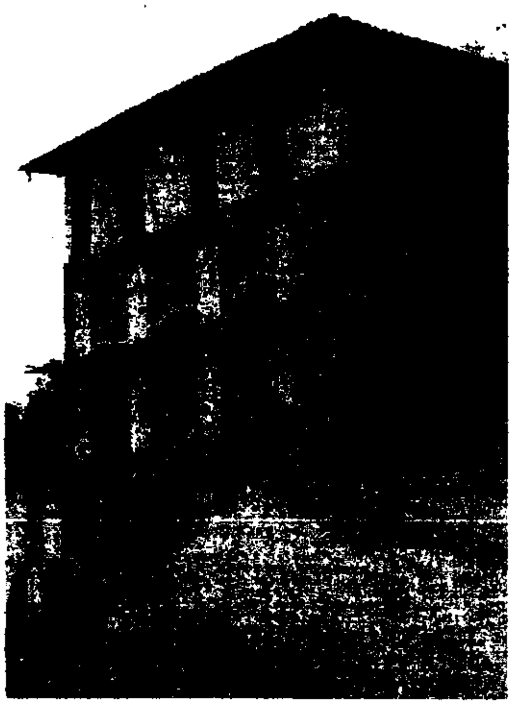


Fig. C *This four floor bamboo house was built around 1930 in Salamina city (Colombia) and in the seventies their bamboo boards were changed and plastered with cement mortar.*

BAMBOO WALLS WITH DOUBLE BAMBOO BOARD

Fig.16.6

A. Cross section of a two story bamboo house with light roof truss

B. Cross section of a story house covered with rafters

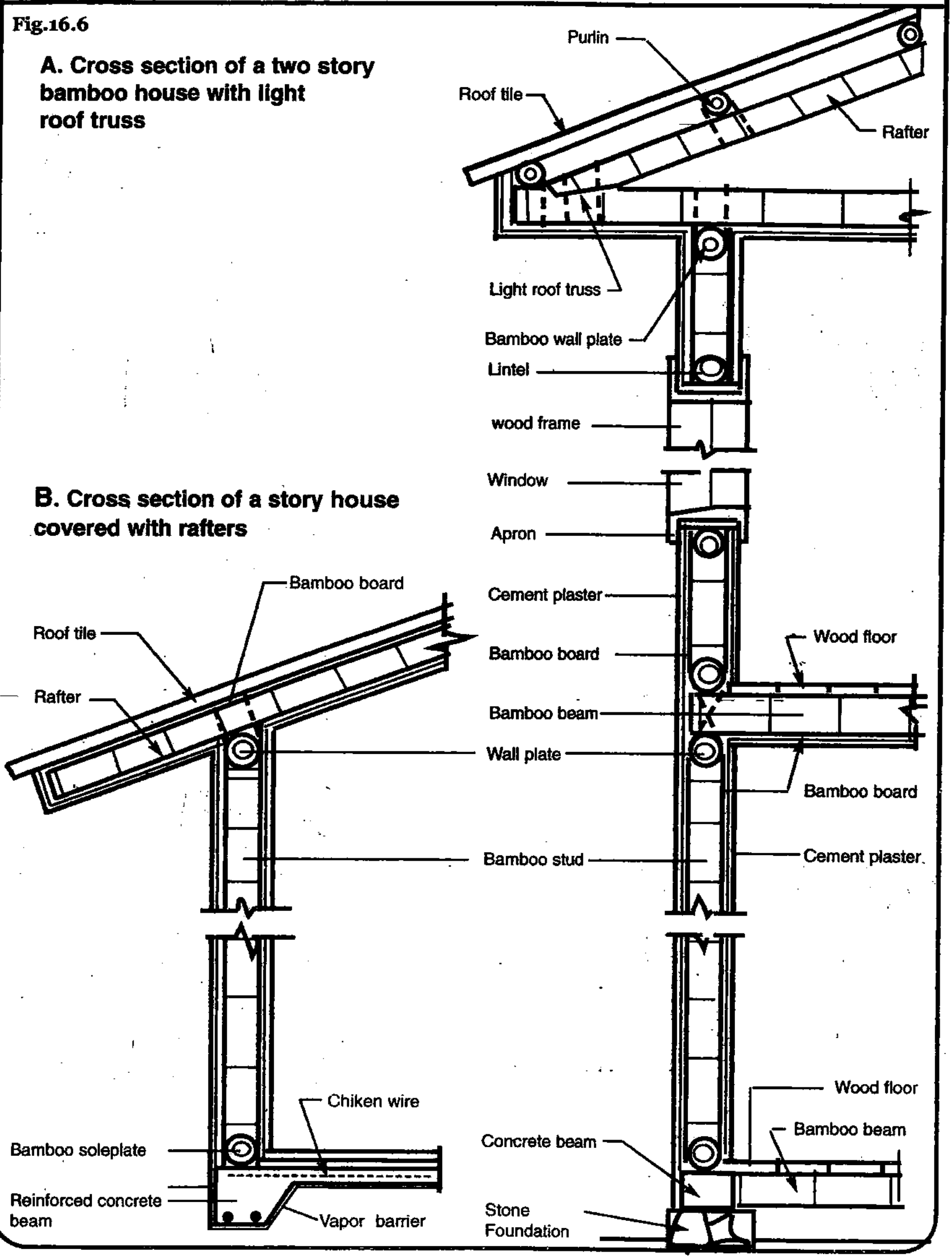
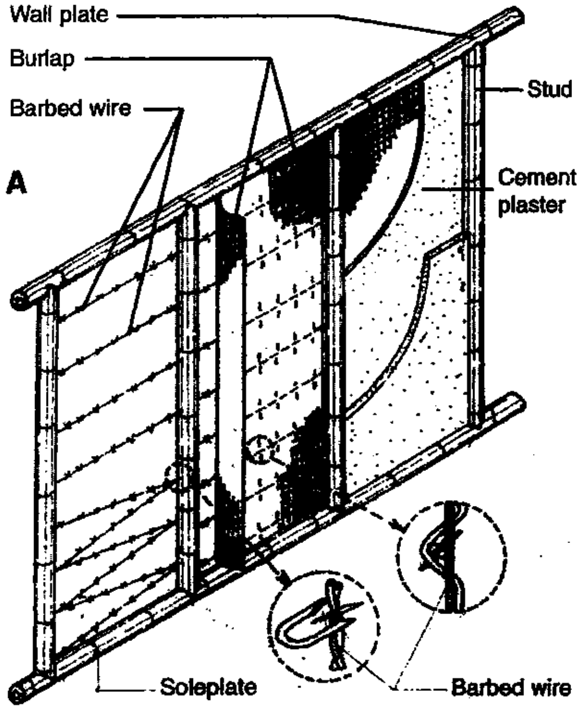


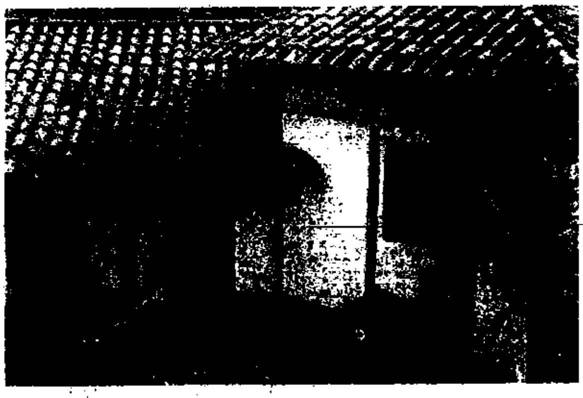
Fig. 16.7

TENDINOUS WALL -INDIA-COLOMBIA

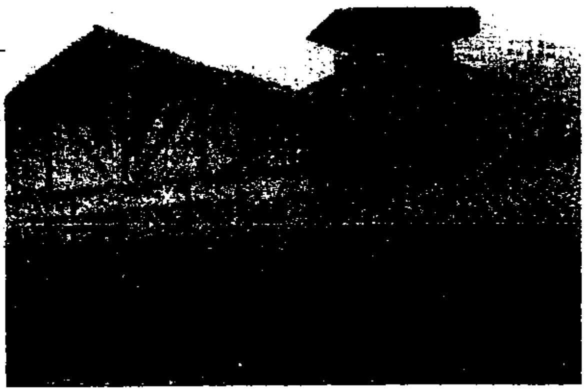
This type of wall consists of a bamboo frame formed by a soleplate, a wall plate and bamboo studs separated by up to 1.20 meters. Barbed wires with a vertical separation of 20 to 22 centimeters are fixed horizontally or diagonally between the studs as shown inFig. A. -Then a piece of burlap (with 4 threads per inch) is hung, and tensed on one side of the barbed wires and fixed to them vertically using galvanized wire No. 18 cut in lengths of about 8 centimeters, as shown in the central frame drawing. Then 2 coats of plaster (1:3 cement and sand) are applied on the surface of the burlap on different days. The barbed wires can be of the minimum caliber. The burlap has to be made with jute or any other strong vegetable fiber. The use of burlap made with synthetic fibers is not recommended.

This technology was originally developed in India many years ago with very poor results due to the low quality of the burlap used. But in 1983, the research group of the School of Architecture of Valley University in Cali, Colombia (Alvaro Thomas, Pedro Supelano, Carlos Vergara and Ricardo Aguilera), improved this technology to the point that today it is one of the best used in the construction of walls. This new technology was used in the construction of houses in Amanecer, a commmunity located near Armenia, Colombia.



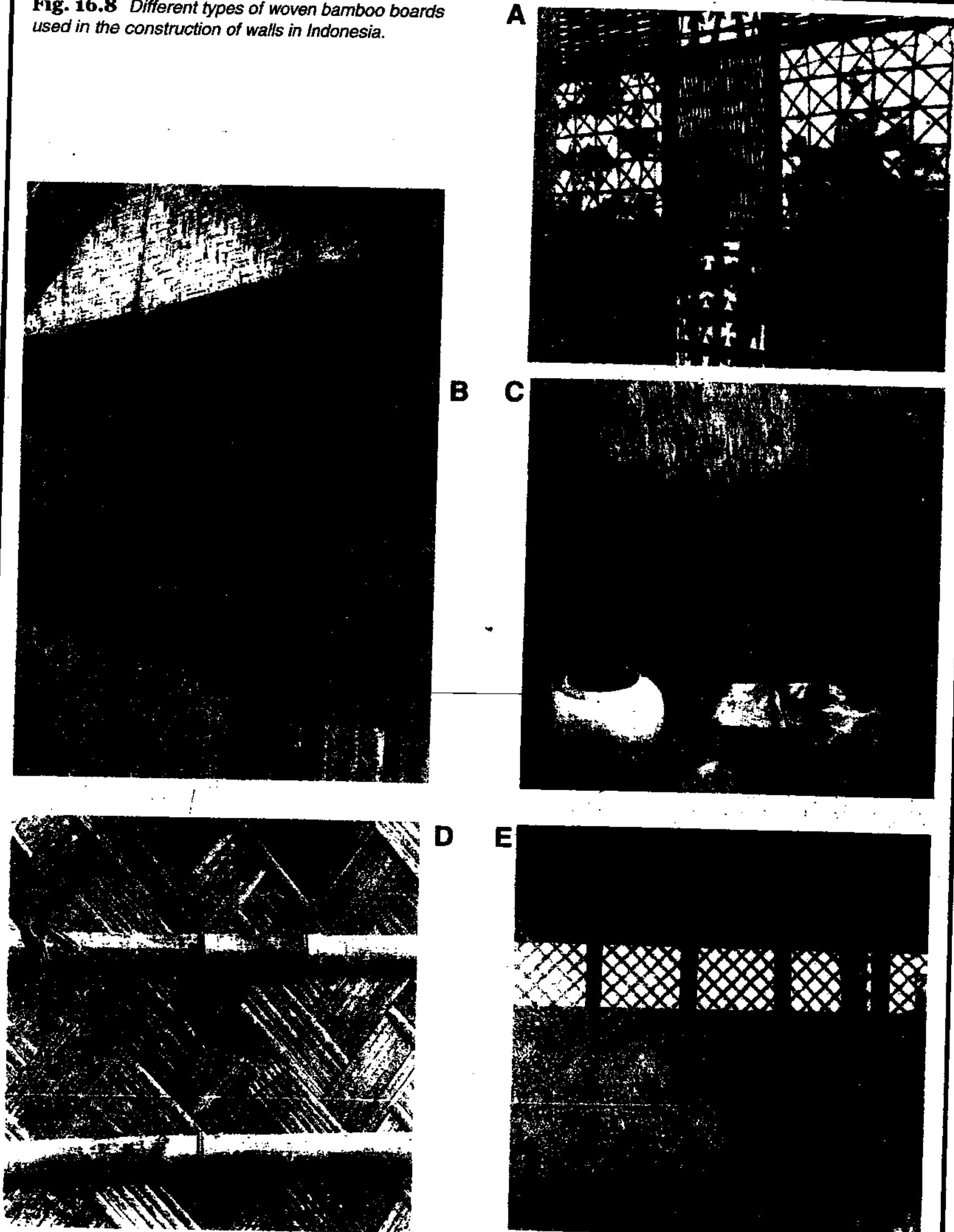


Figs. B,C,D,E. *These photographs show the different types of houses and buildings which were built in "Amanecer" by a Portuguese architect using the technology known as "Tendinous Wall" developed at the Valley University in Cali, Colombia, in the construction of the walls.*



WOVEN BAMBOO BOARDS FOR WALLS AND WINDOWS

Fig. 16.8 *Different types of woven bamboo boards used in the construction of walls in Indonesia.*



BAMBOO MAT BOARD FOR WALLS, DOORS AND WINDOWS -ASIA

Fig. 16.9

Gable ends

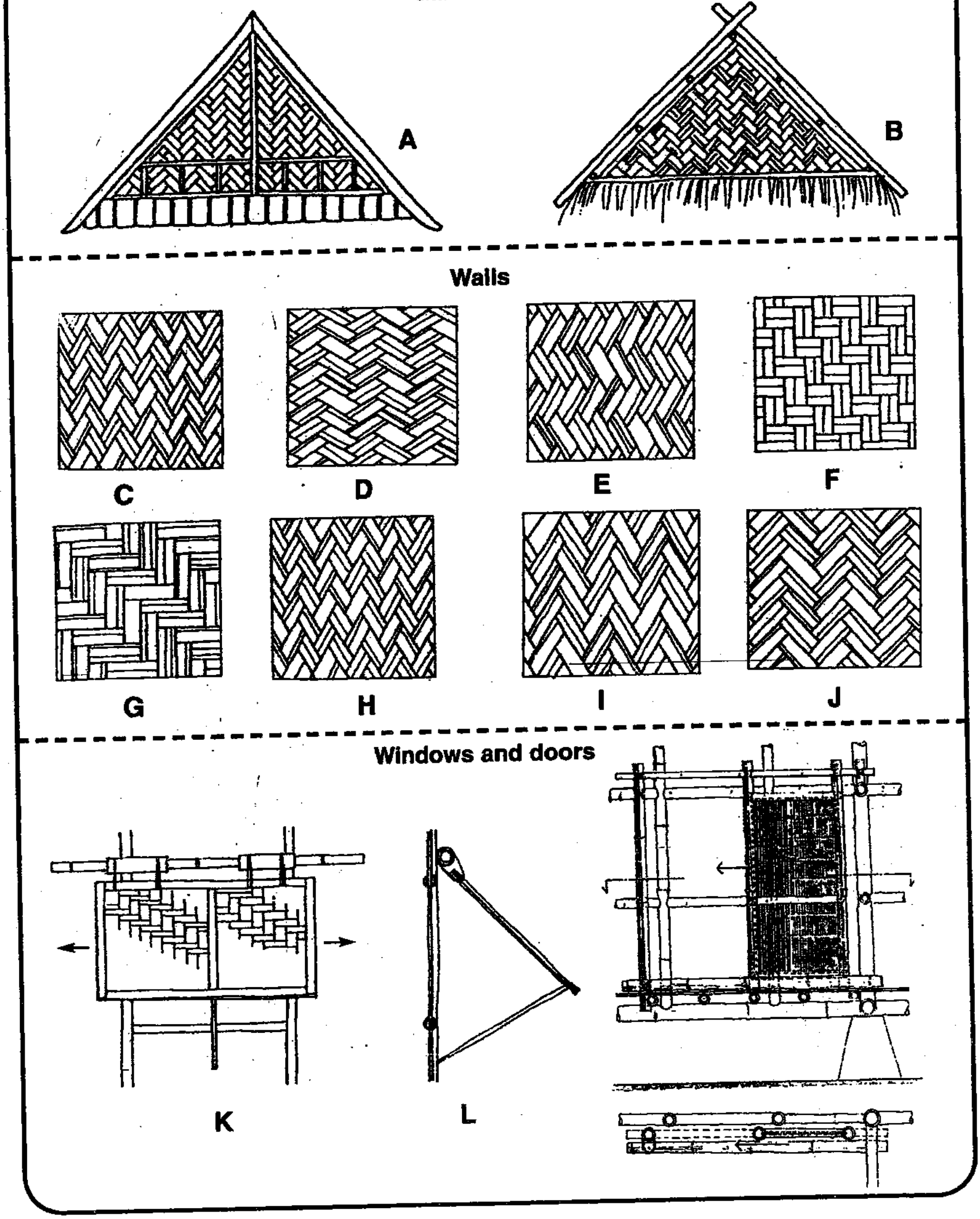
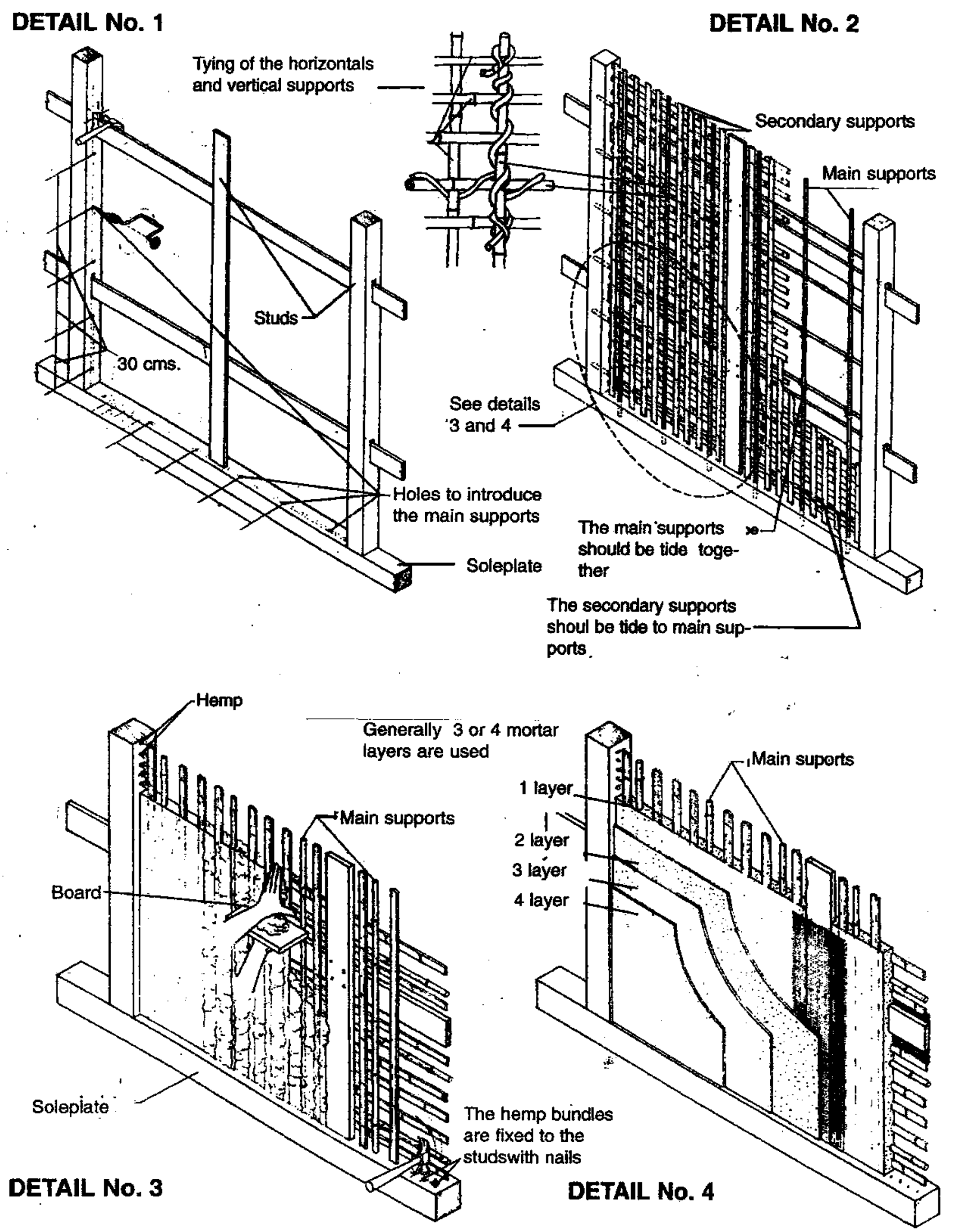


Fig.. 16.10 **JAPANESE BAMBOO WALL**



15 ROOF STRUCTURES

Fig.17.1

LIGHT ROOF TRUSS

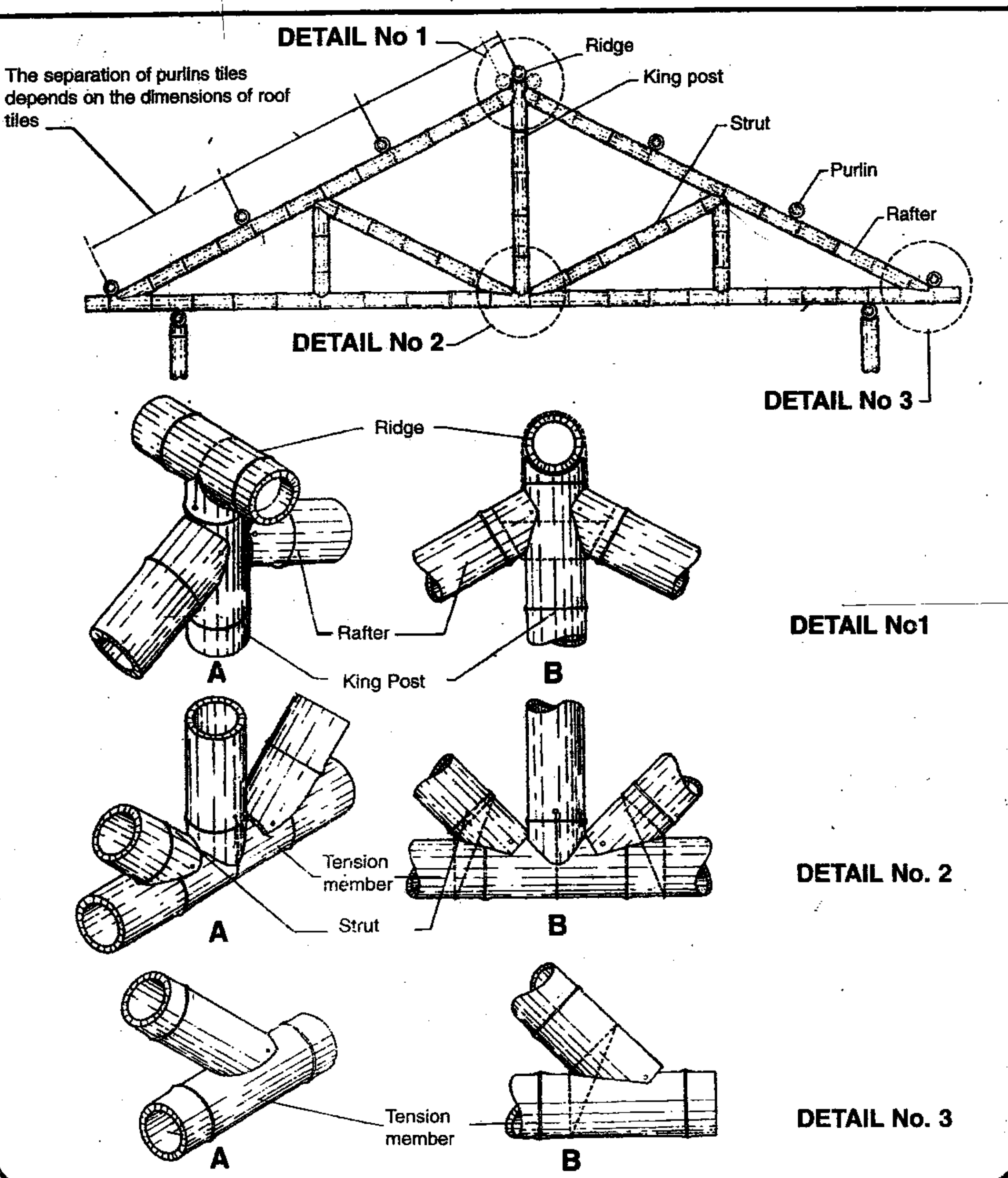
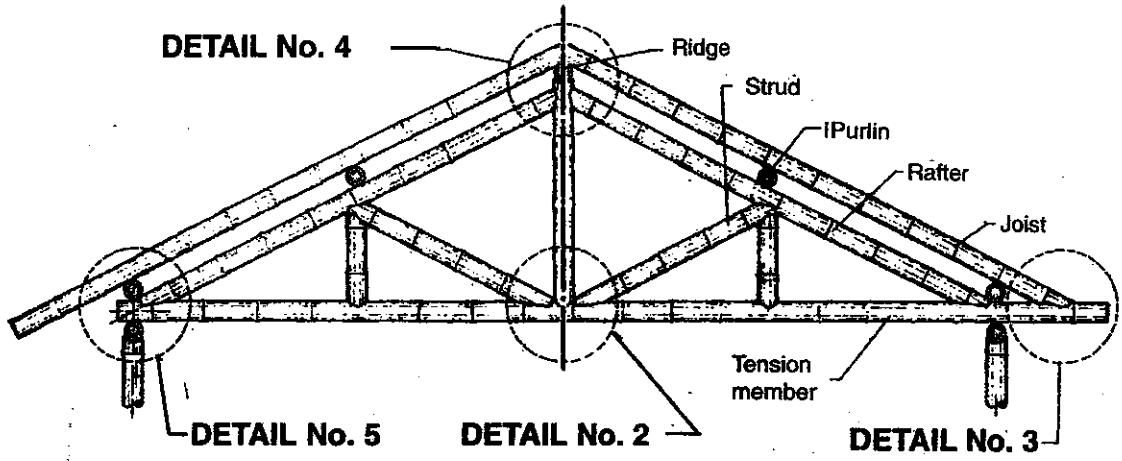
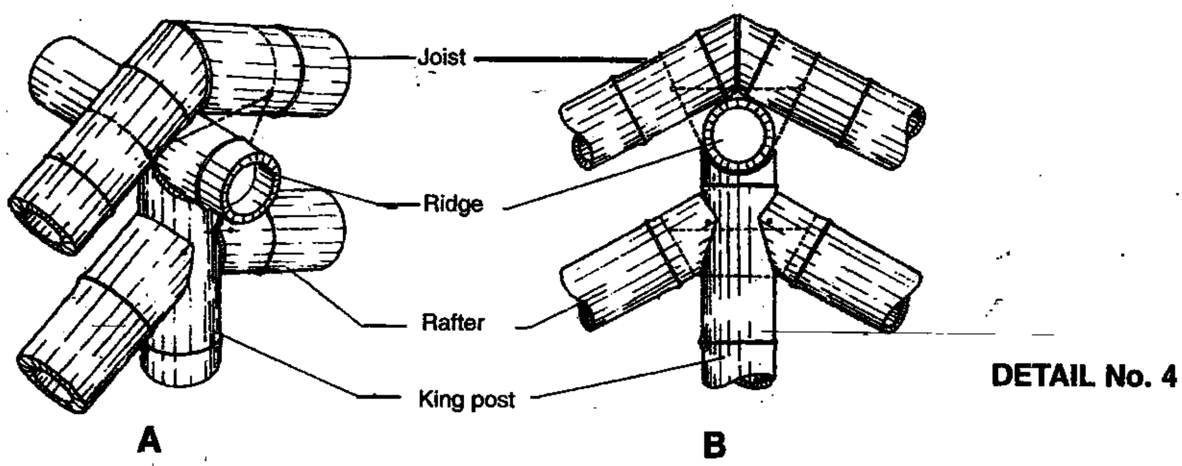


Fig.17.2 **BAMBOO LIGHT TRUSS WITH RAFTERS**





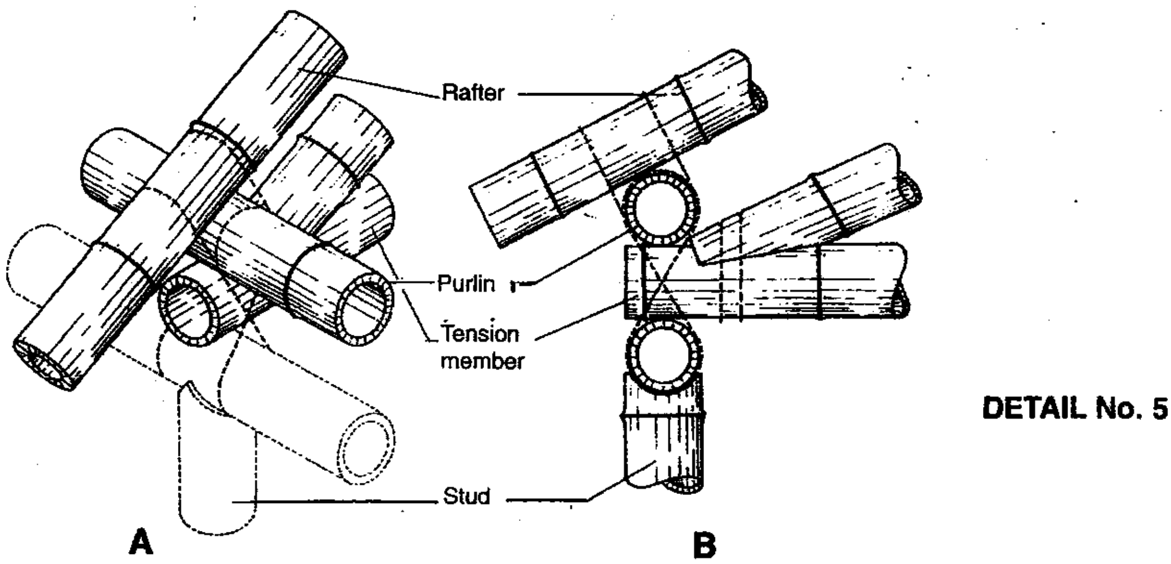


Fig. 17.3 **FASTENINGS OF PURLINS AND RAFTERS**

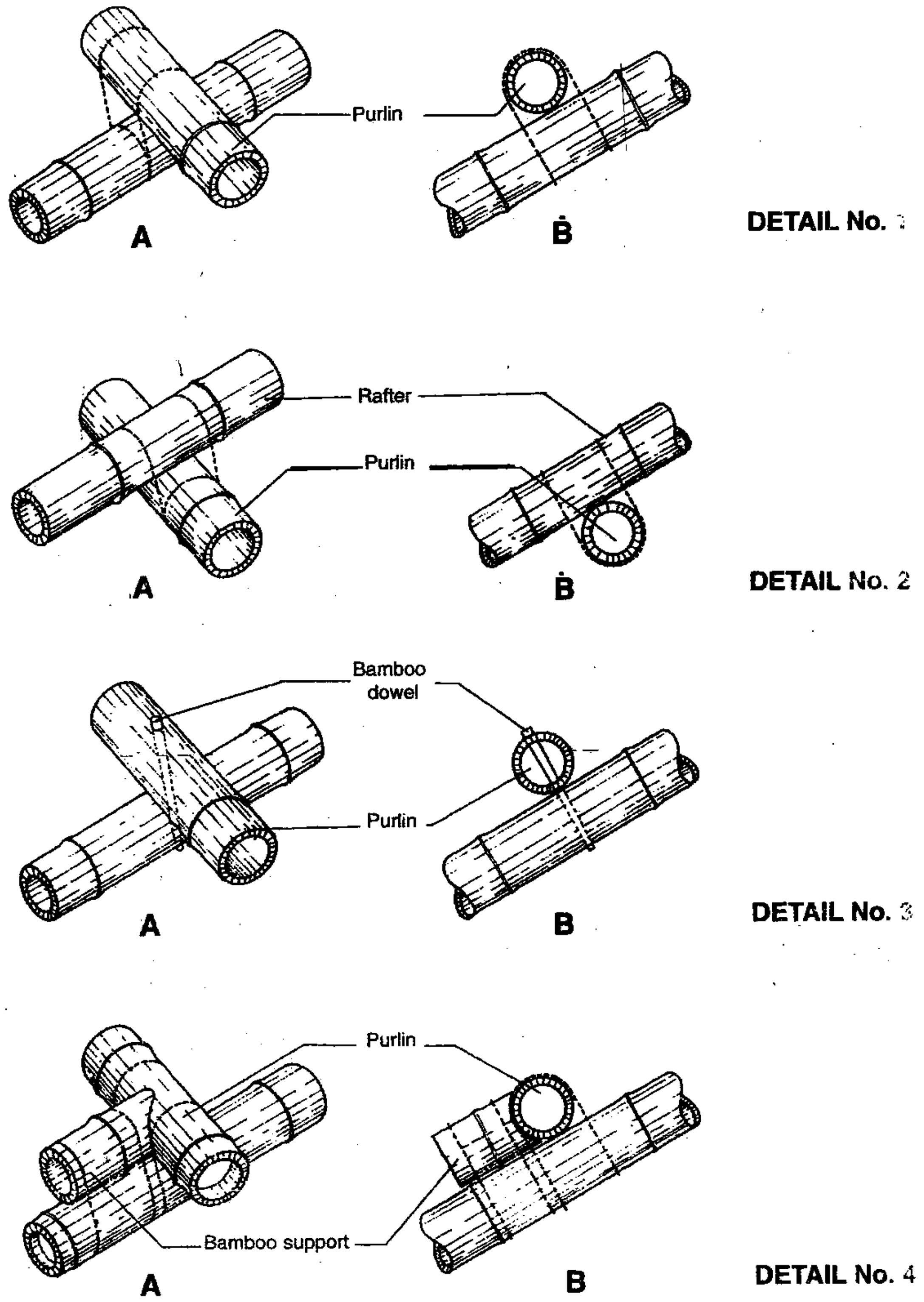
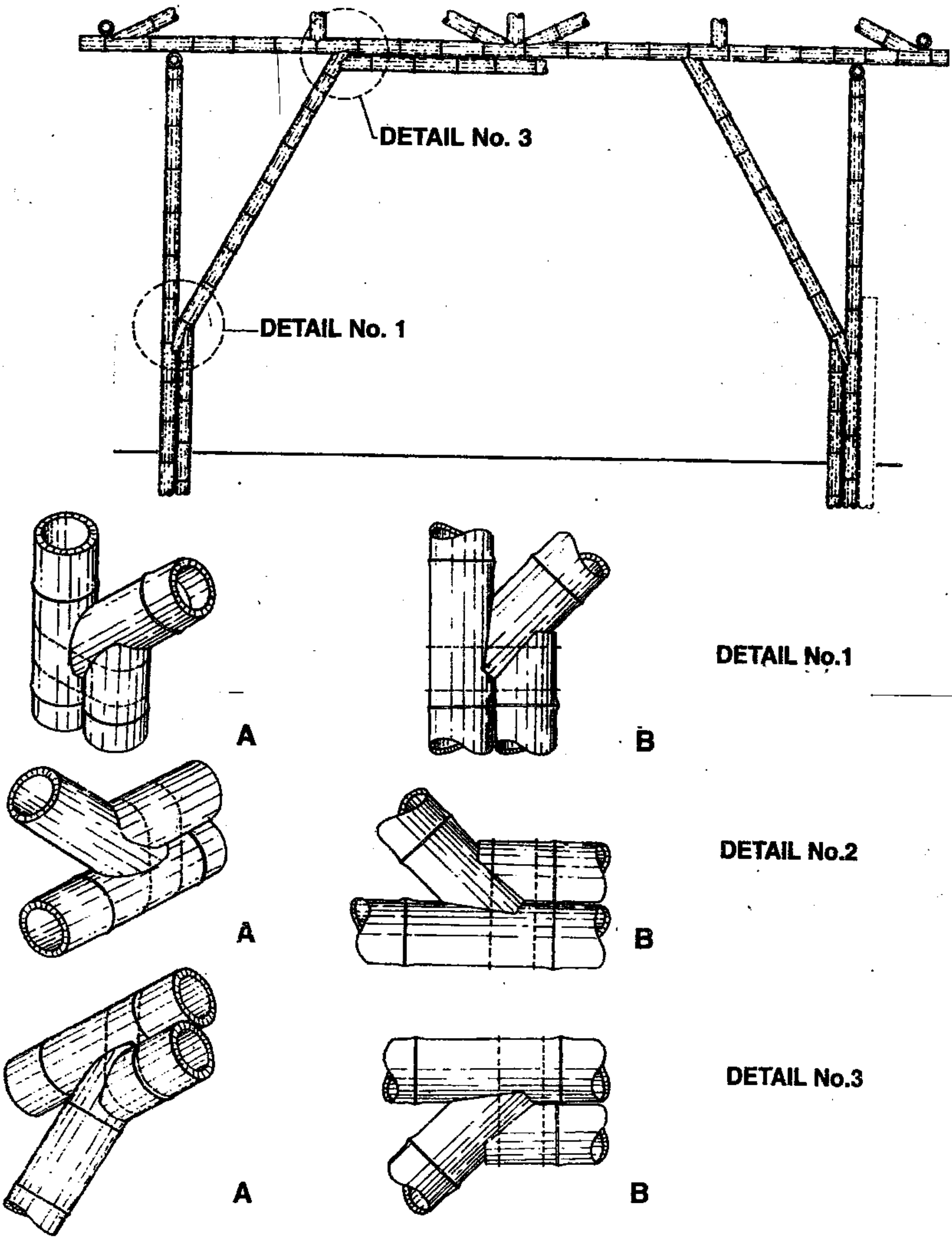


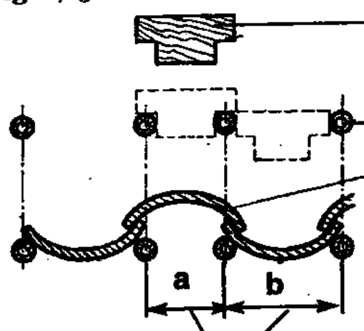
Fig. 17.4

BAMBOO RIGID FRAME



CONSTRUCTION OF PEAK ROOFS WITH SPANISH TILE (COLOMBIA)

Fig. 17.5



Fixing SpanishTiles between bamboo joists

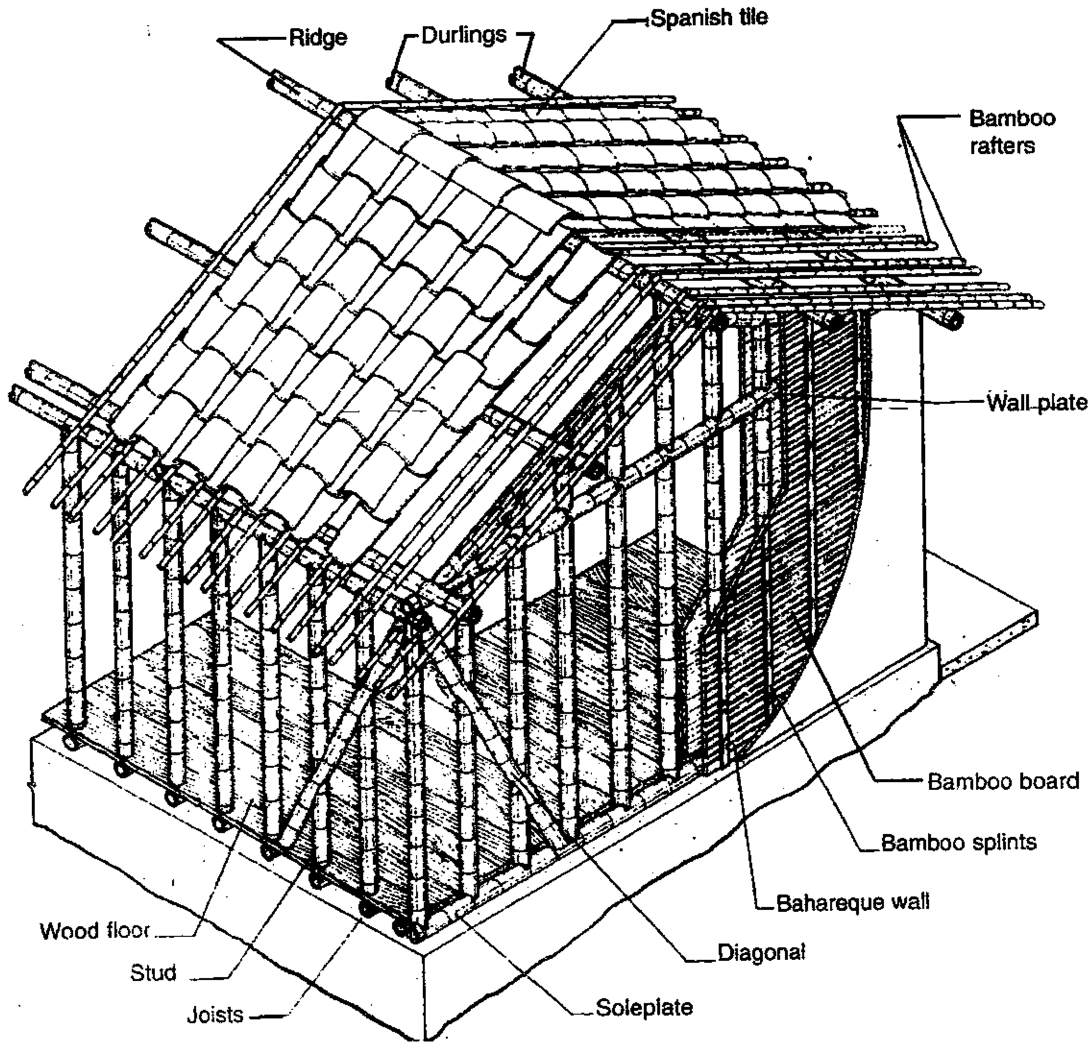


Fig.17.6 PEAK ROOFS WITH CEILING AND SPANISH TILE (COLOMBIA)

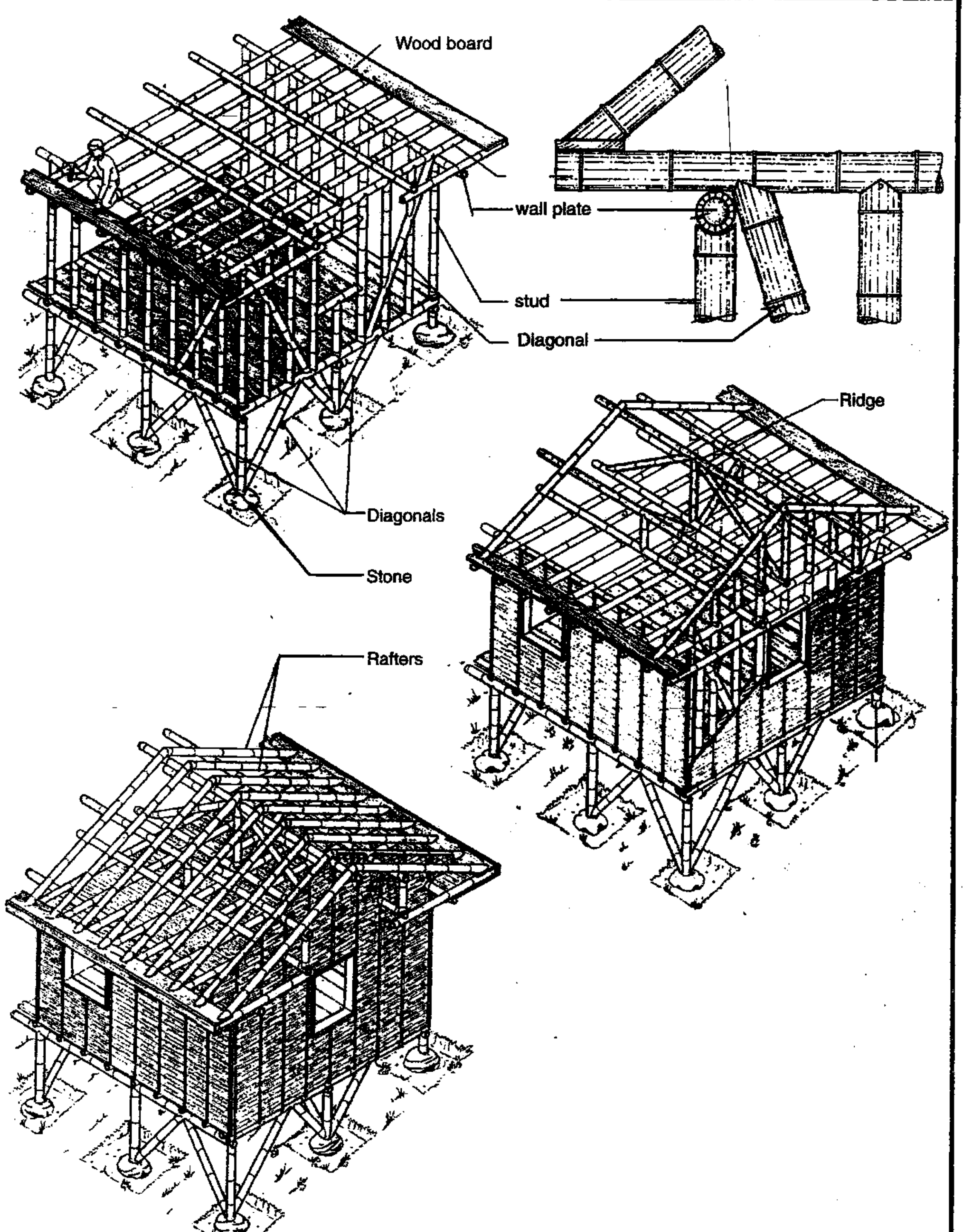


Fig.17.7 **HIP ROOFS WITH CORBELS (COLOMBIA)**

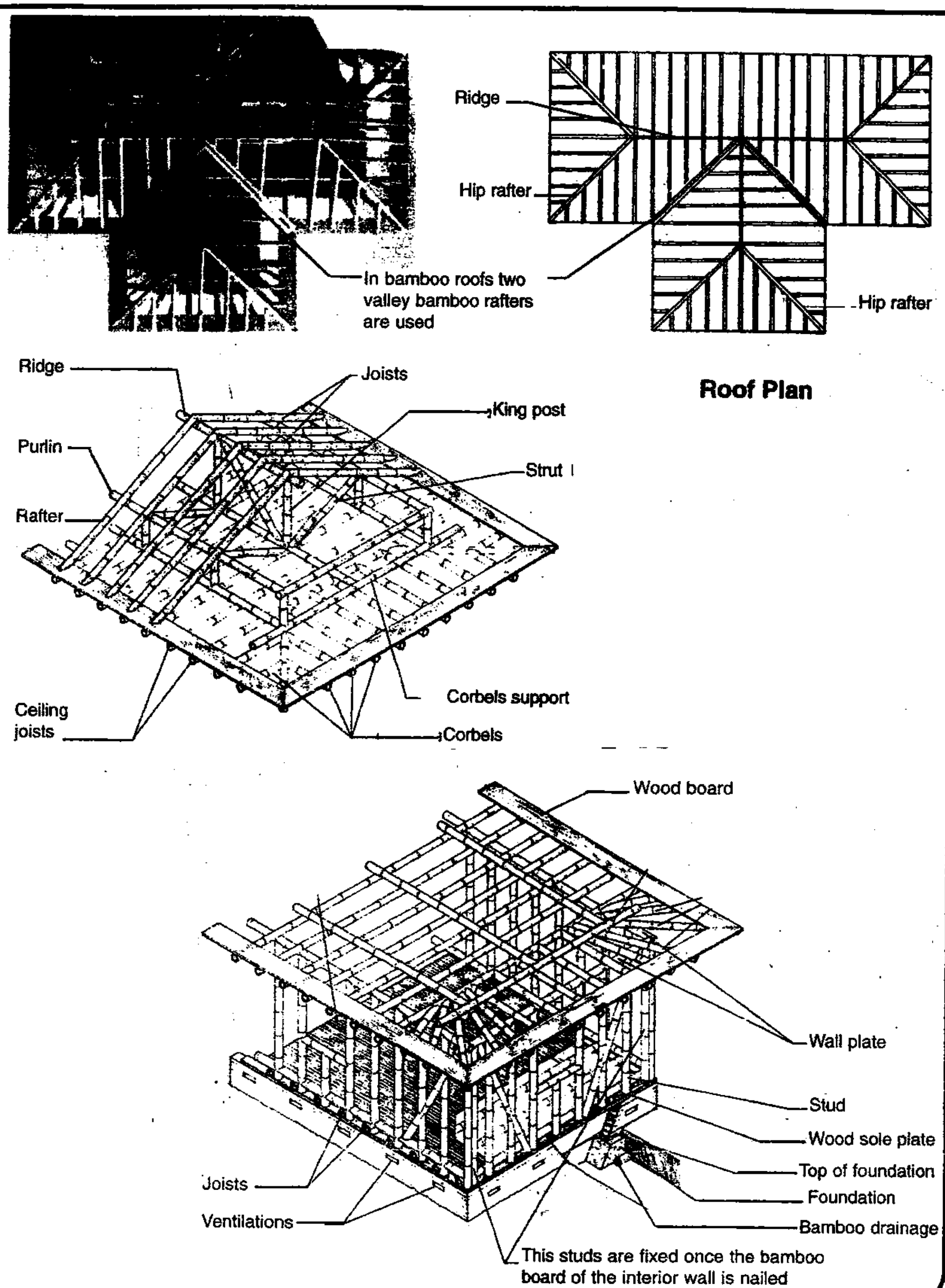


Fig.17.8 HIP ROOFS WITH CEILING AND SPANISH TILE (COLOMBIA) (1)

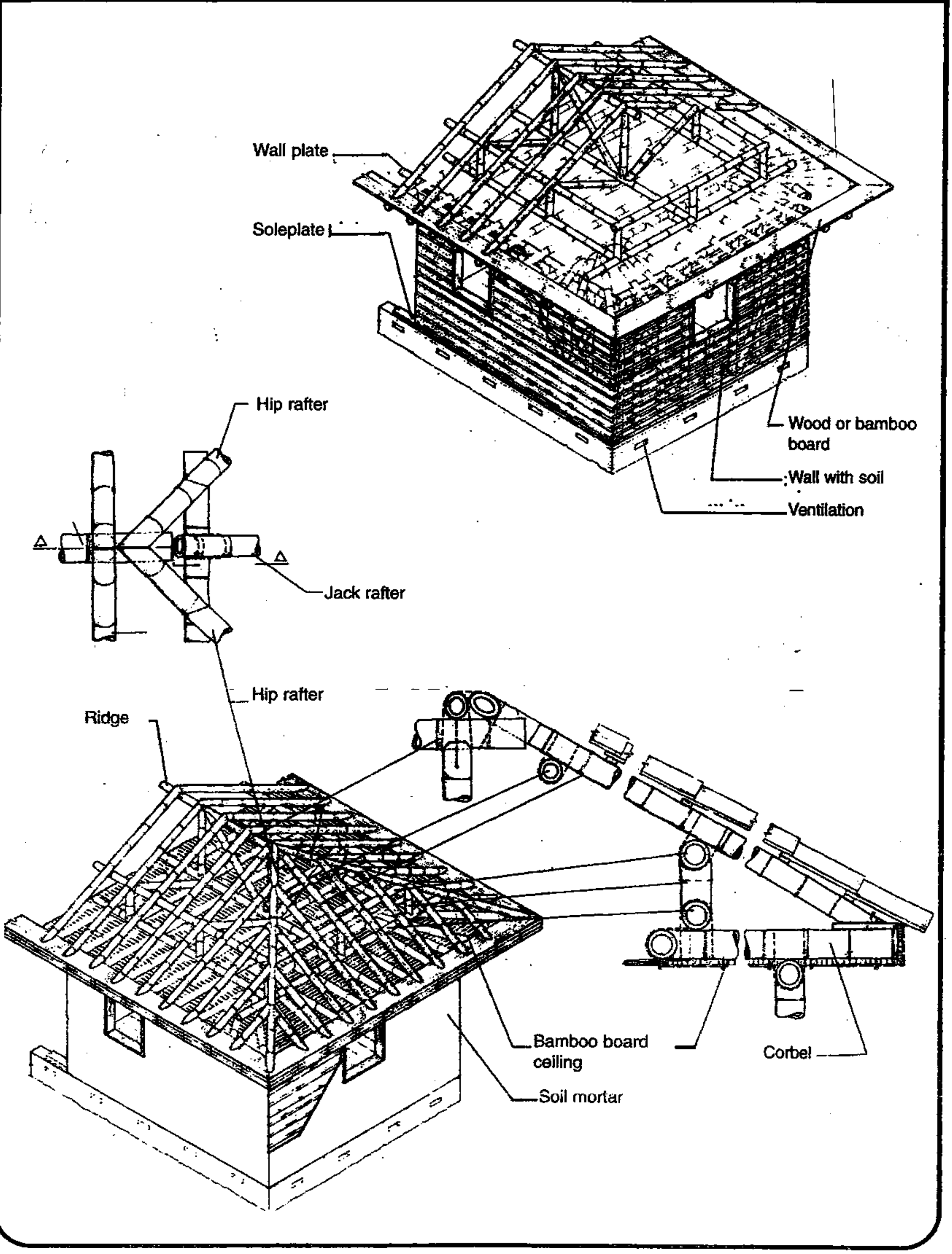
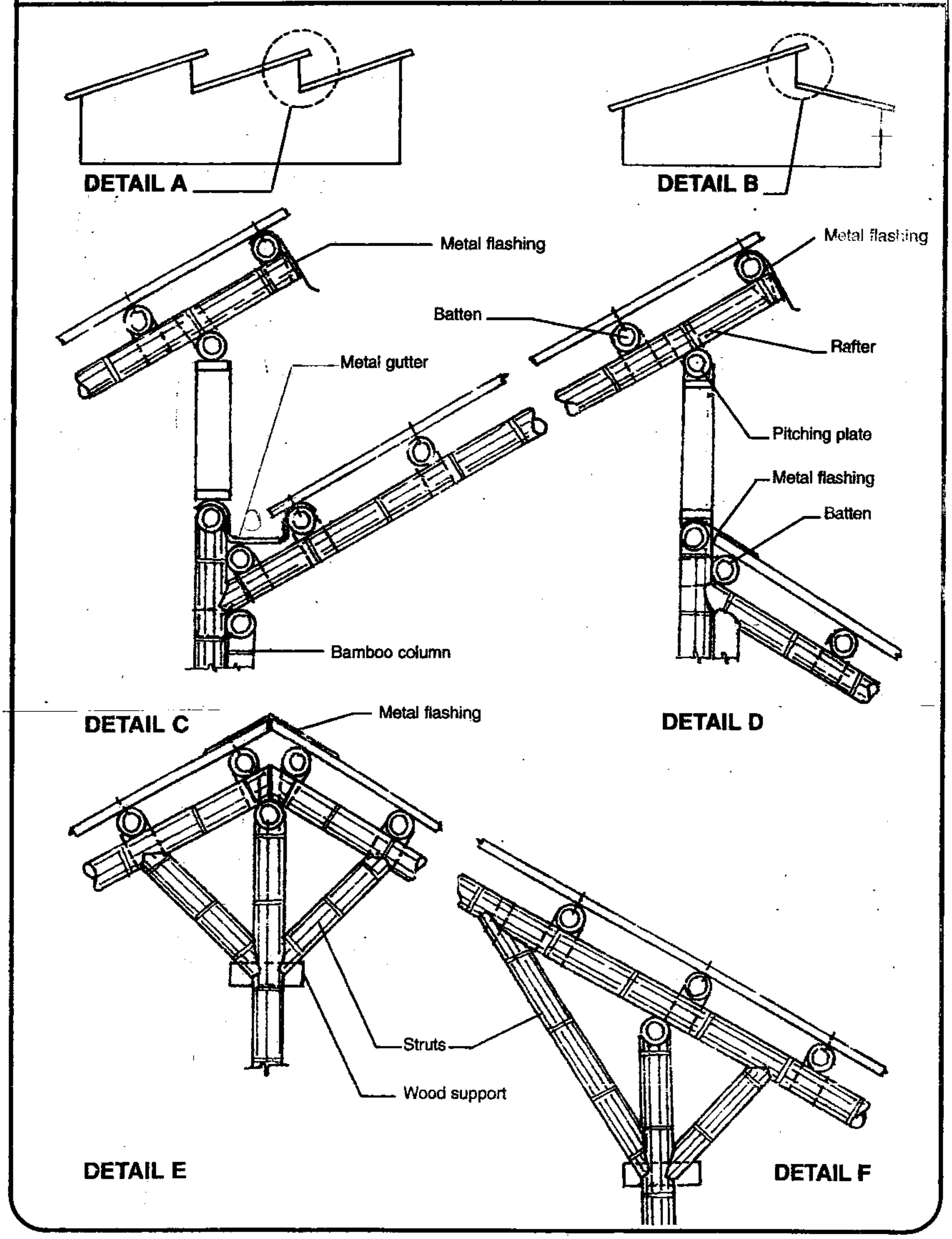


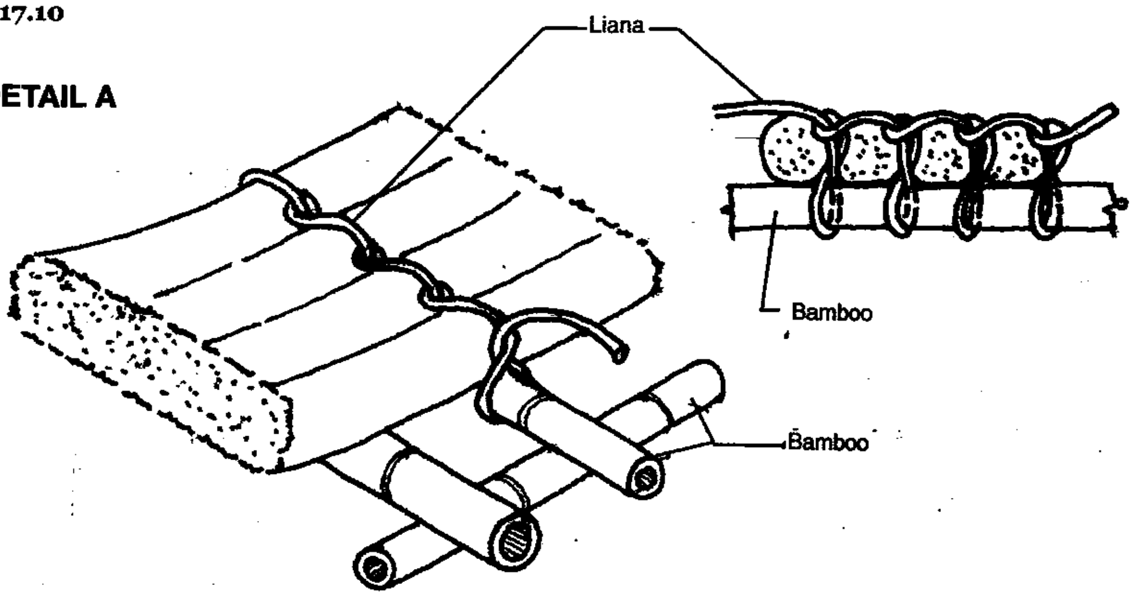
Fig.17.9 DETAILS OF JOINTS ON STOREHOUSE ROOFS



BAMBOO AND GRAIN STALK THATCHED ROOFS

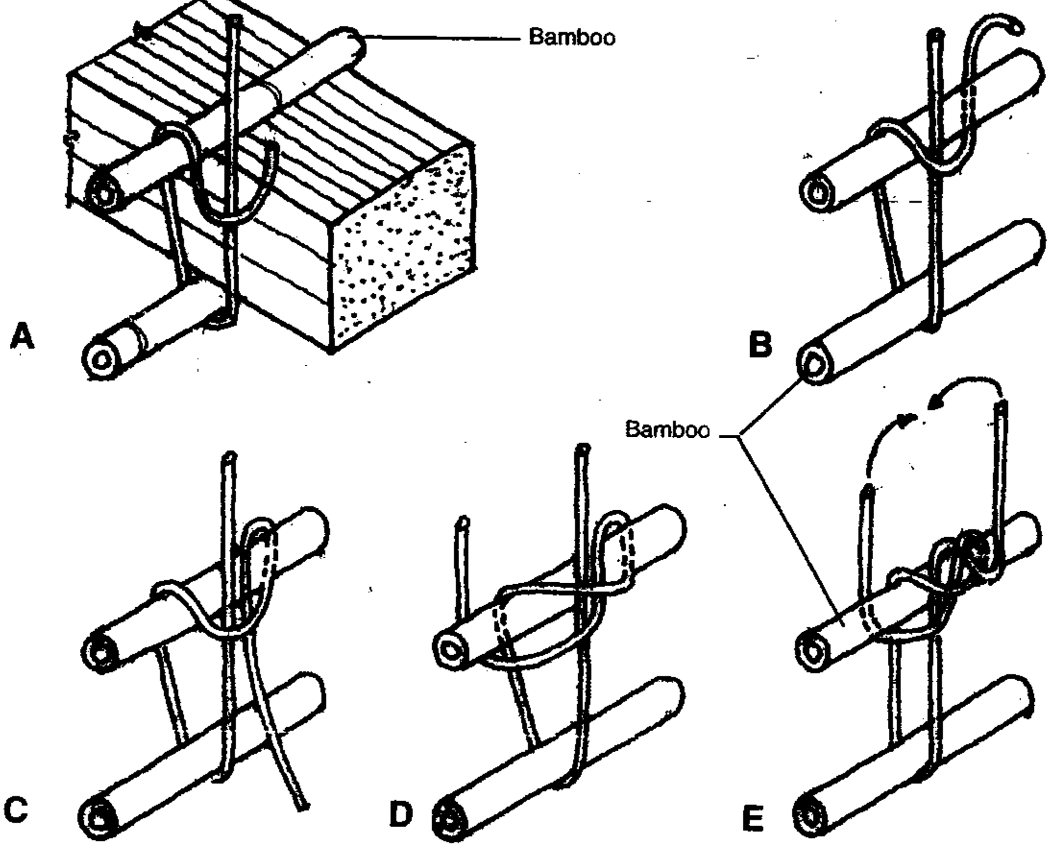
Fig.17.10

DETAIL A



Method for tying up the grain stalks

DETAIL B



BAMBOO AND PALM LEAF THATCHED ROOF

Fig.17.11

Method for tying up the palmleaves

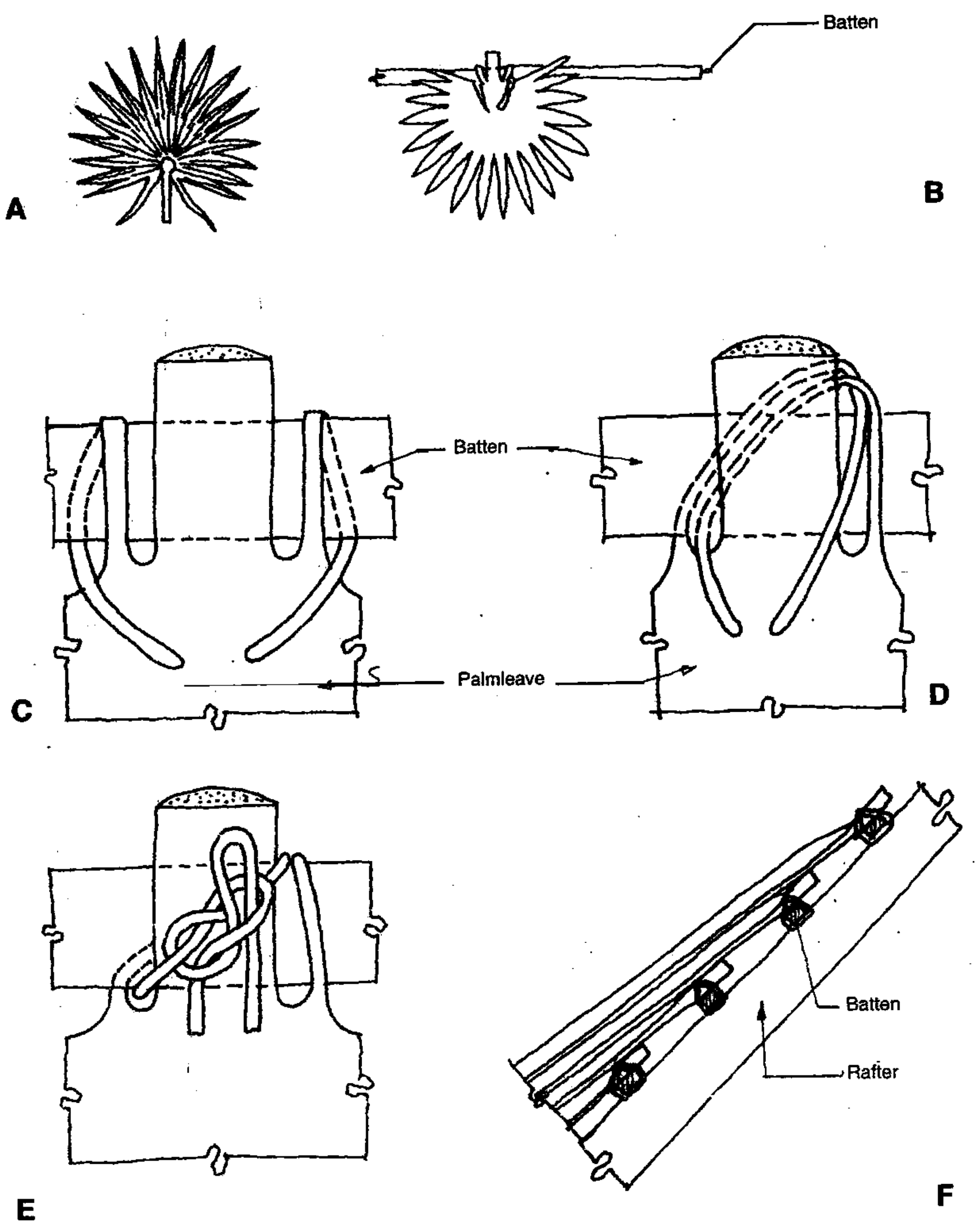
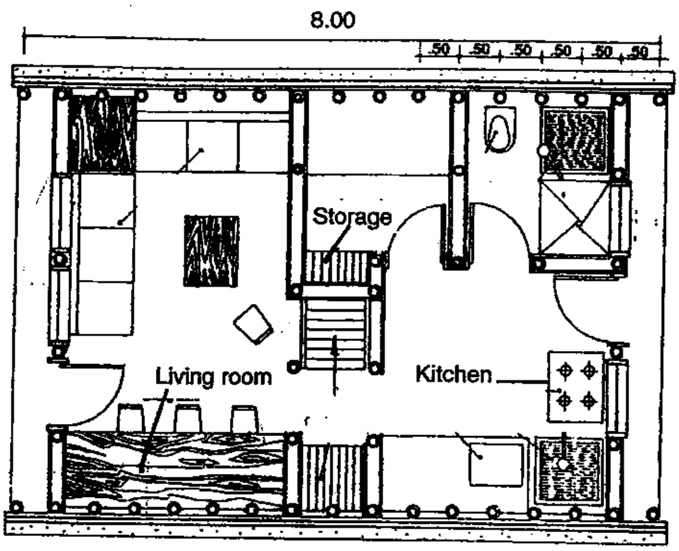
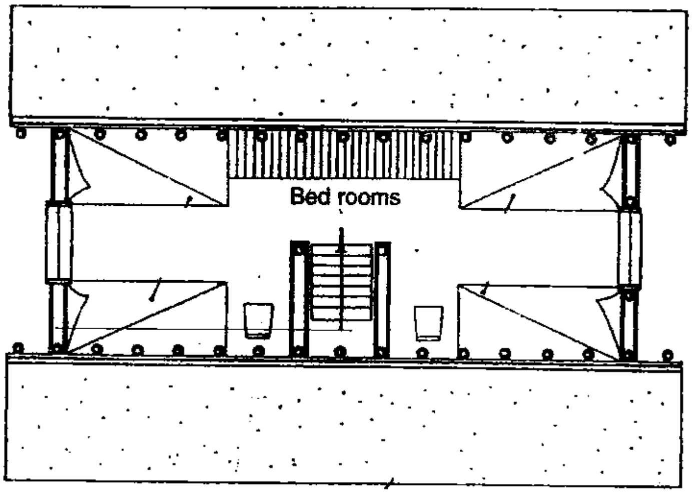


Fig. 17.12

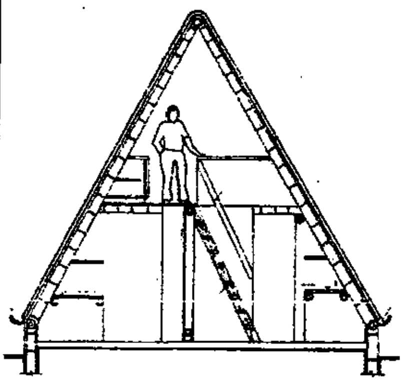
ROOF TYPE "A" FOR A SMALL HOUSE



First Floor



Second floor

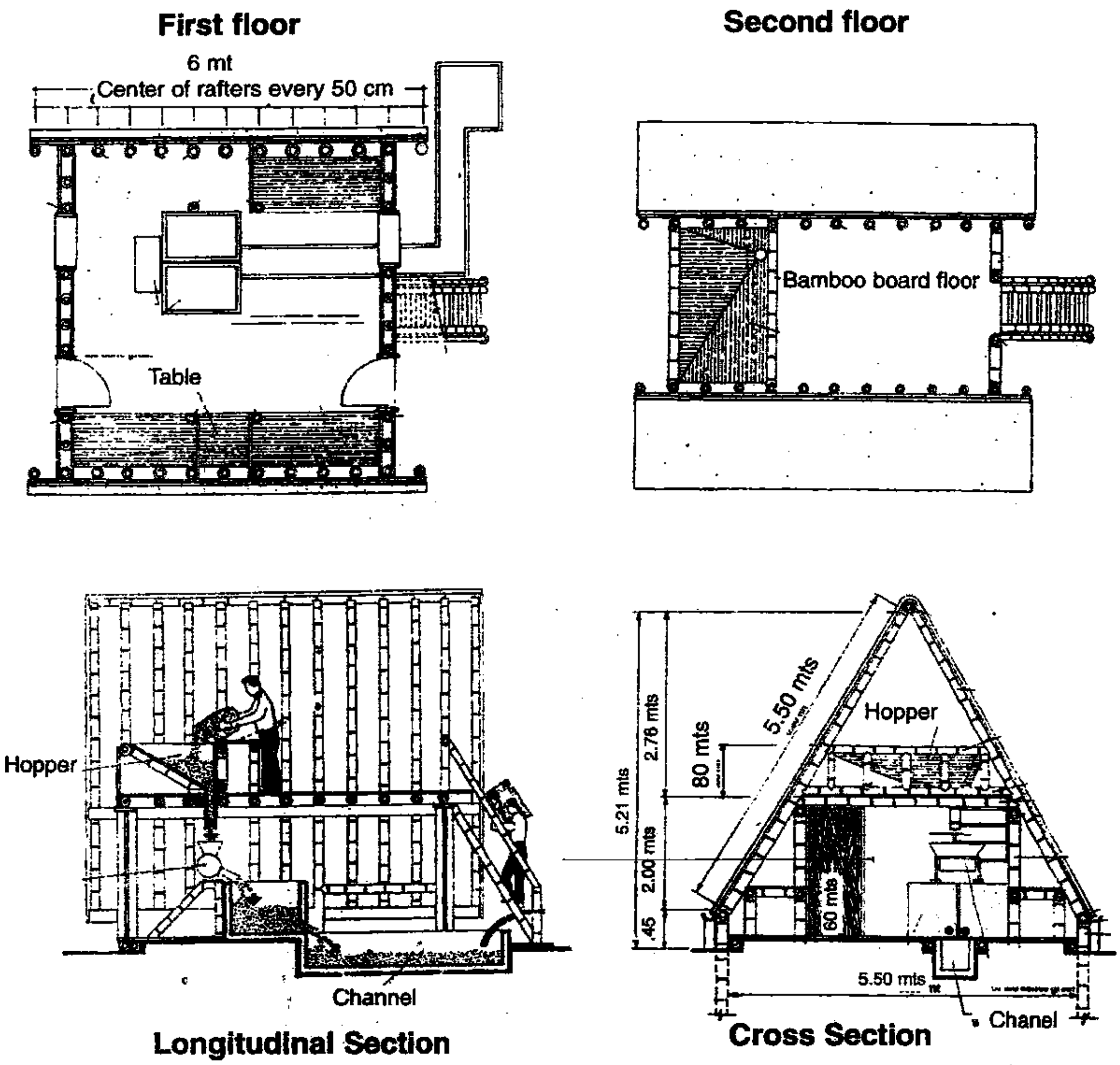


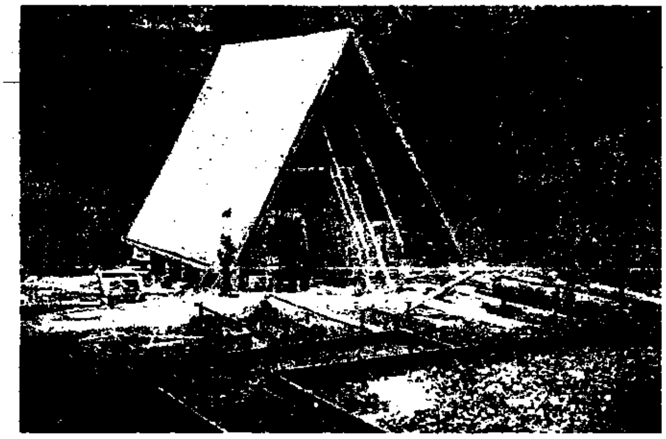
Tranversal section

Traditional wooden house with a thatch roof type "A" built by the poor people in Portugal. It can give an idea of the bamboo house once finished.

ROOF TYPE “A” FOR A SMALL COFFEE BEAM TREATMENT PLANT

Fig.17.13





The coffee beam treatment plant in operation.

Fig.17.14 **CONSTRUCTION OF THE ROOF (1)**

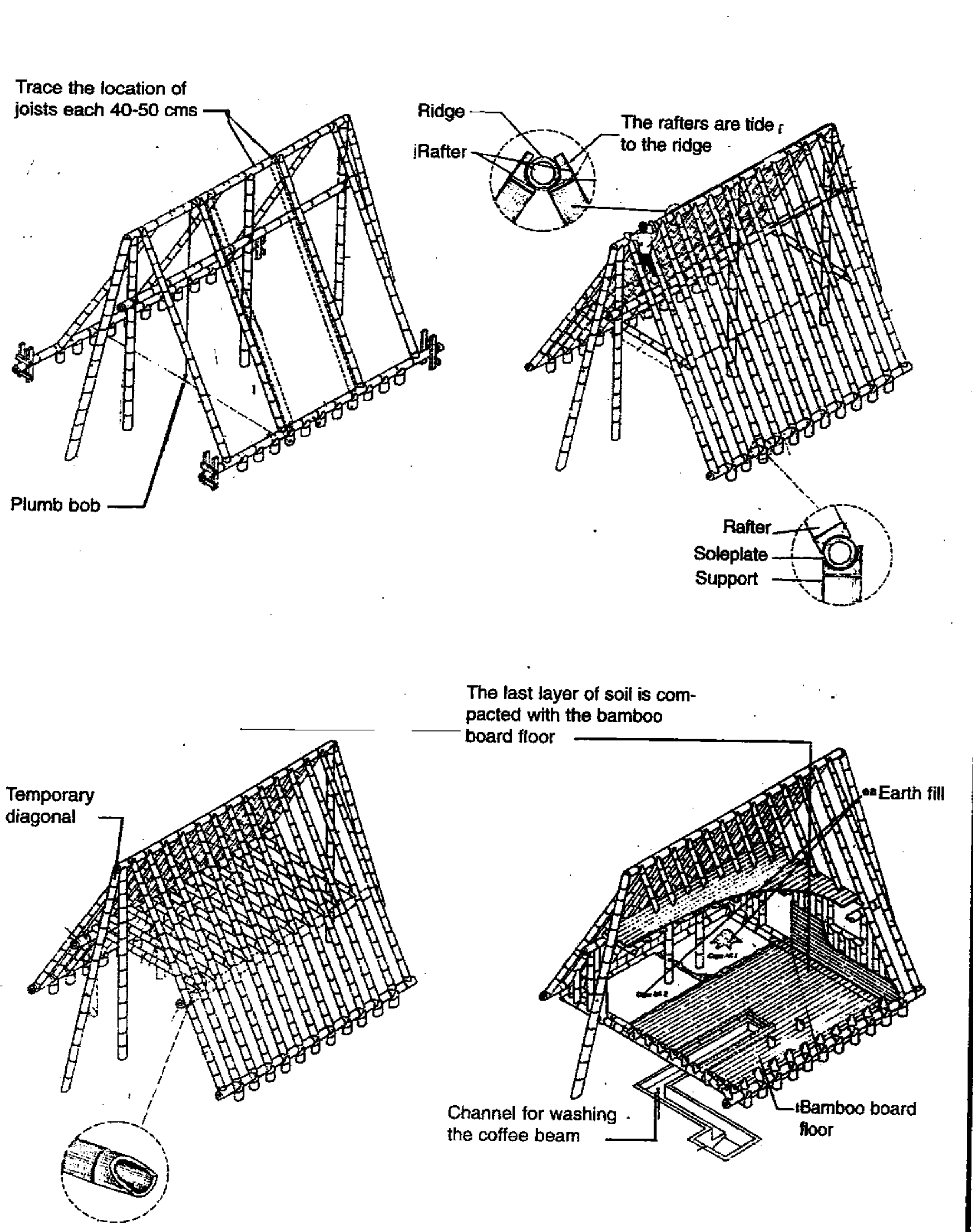
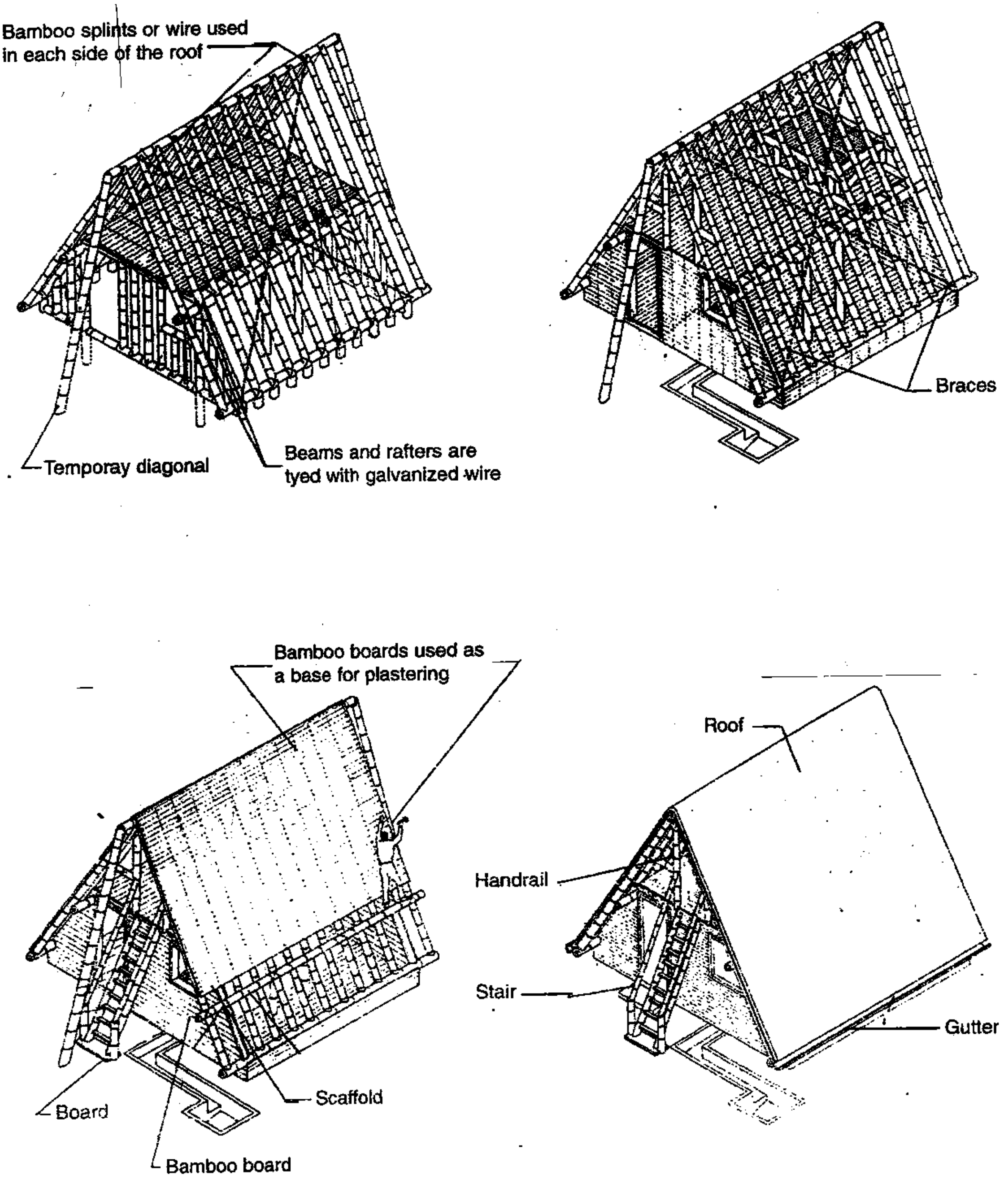


Fig. 17.15

CONSTRUCTION OF THE ROOF (2)



ROOF COVERED WITH HALF SECTIONS OF BAMBOO CULMS (1)

Fig. 17.16

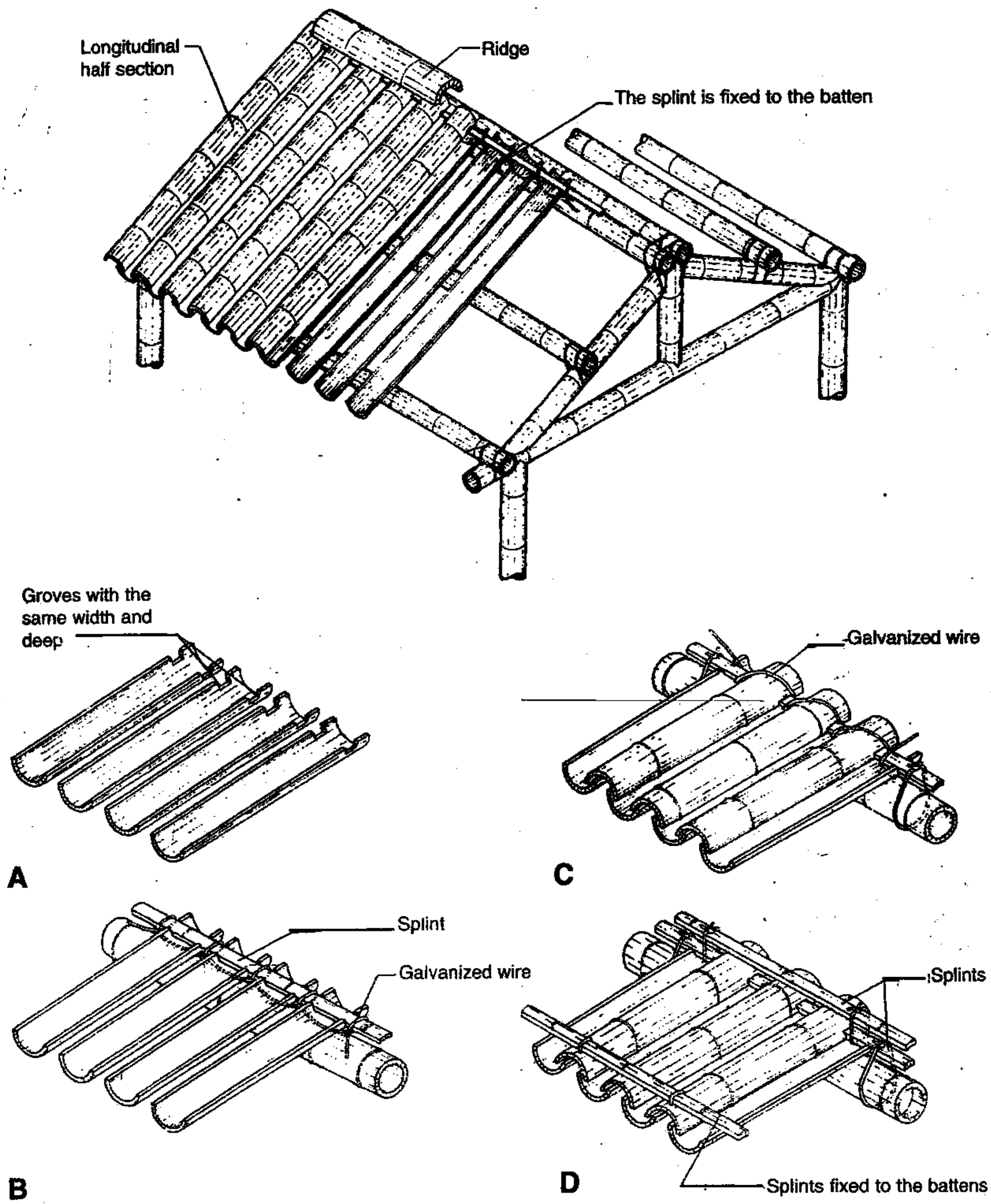
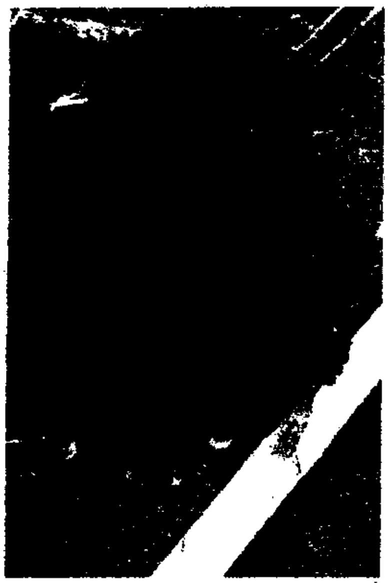
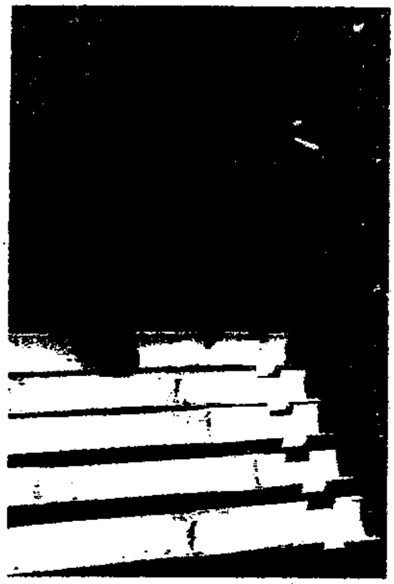


Fig. 17.17 ROOF COVERED WITH HALF SECTIONS OF BAMBOO CULMS (2)



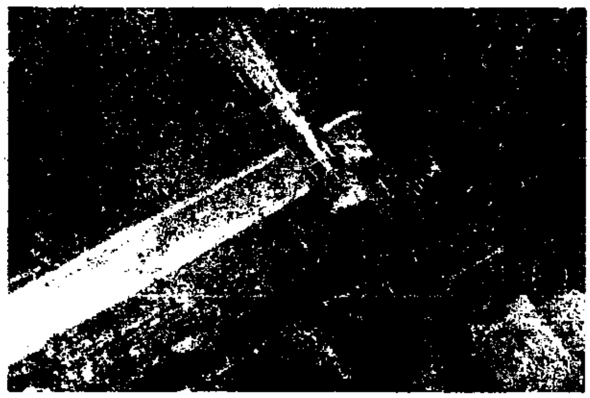
A

B



C

D



E

Roof construction

It is very important to bear in mind that the culms used in the construction of this type of roofs has to be mature (3 or more years old). Never use young culms.

It is convenient to paint with asphalt or similar the surface of the bamboo section used as gutters. or internal nodes

Fig.**A**-Removing the septums or internal nodes

Fig.**B**.-Cutting the lateral sides with the same width and deep.

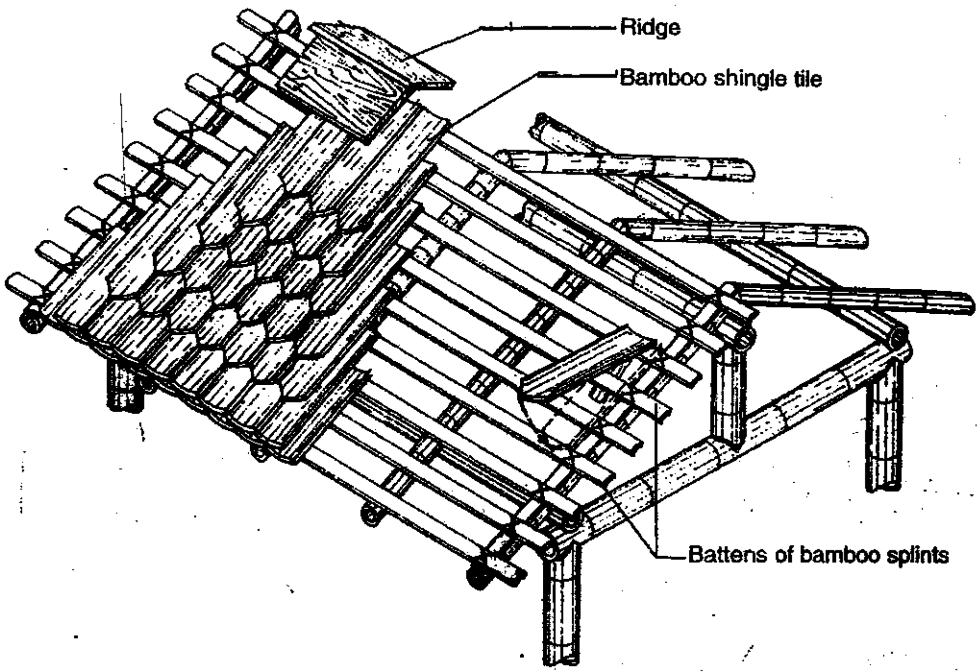
Fig.**C**.-Make a row as shown in this fig. and paint them with asphalt or similar and locate the gutters with iqual distances between borders.

Fig.**D**.-Fix a bamboo splint with a galvanized wire No18.

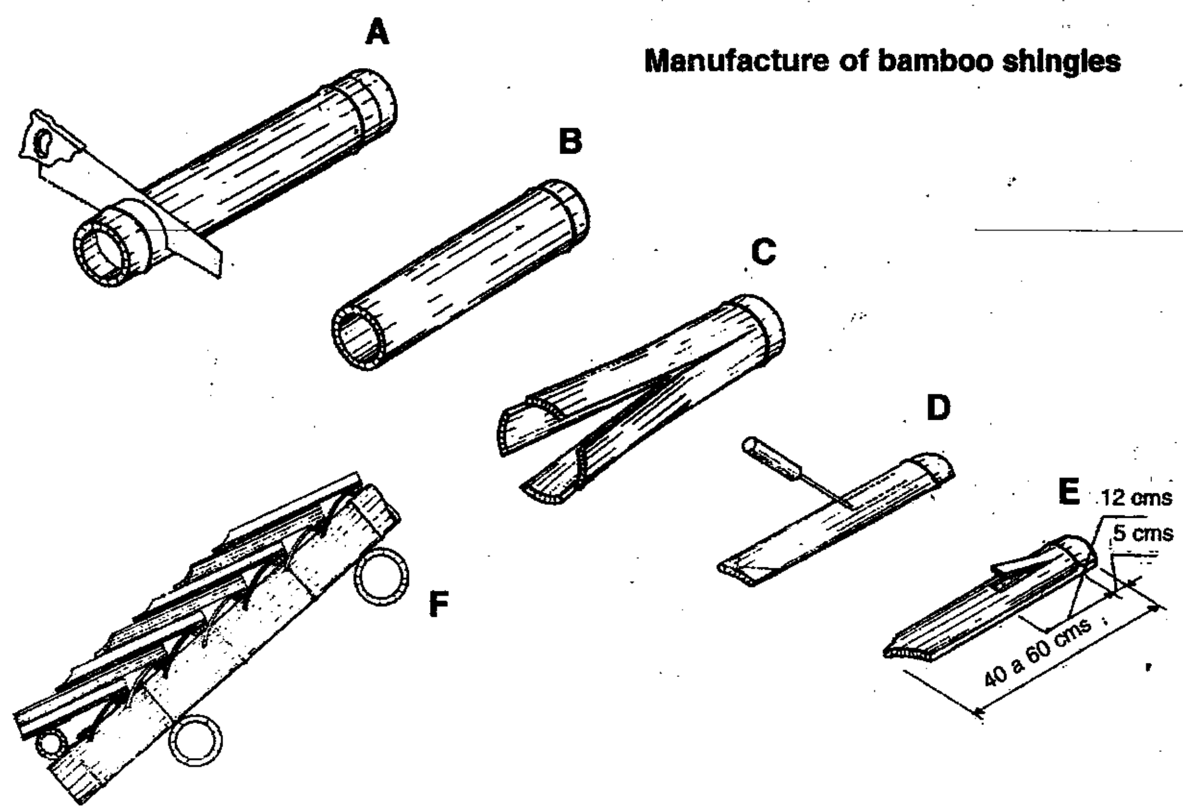
Locate the bamboo tiles with the exterior surface in the upper side.

Fig.**E**.-Fix other splints at the top and lower part of the roof.

Fig.17.18 ROOF COVERED WITH BAMBOO SHINGLE TILES



Manufacture of bamboo shingles



16 PREFABRICATION OF BAMBOO HOUSES

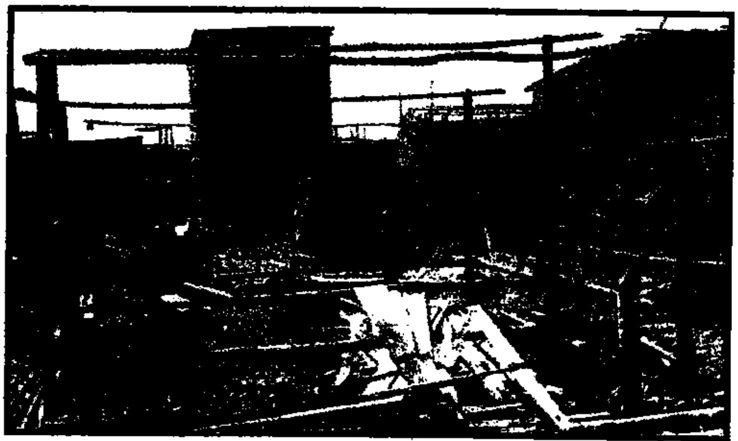
EXPERIMENTAL PROGRAM OF PREFABRICATED HOUSES IN ECUADOR

According to Alcedo y Herrera *"...when the city of Guayaquil was founded in the sixteenth century around the hill of Cerrillo verde or Cerro de la Culata, the structure of the houses were built with timber, the walls with bamboo boards and the leaves of "bijao" palm were used as thatching. In 1812 after the fire which destroyed most of the city, the use of thatching roofs and the bamboo boards in the walls were forbiden and instead of them was recommended the use of ceramic tiles or Spanish tiles for the roofs and quincha bahareque for the walls which at that time were used in Lima, Peru..."*. But later on the quincha walls were replaced again by the bamboo boards which were fixed vertically to the wooden structure. (Fig A)

On the other hand, most of the campesinos of Ecuador who emigrate to Guayaquil looking for a better future, the first thing they do is to participate in invasions of lands where they build a "temporary hovel", (Fig, B) because most of these people believe that once they get a job they will move to a better place but this generally never occurs. On the other hand, there are emigrants which participate in invations in other quartes and for taking possesion of the land they build a hovel using the remainings of other bamboo constructions which later they sell to other people (Fig.C). This is the reason why the aspect of these slums in Guayaquil are very depresive.

Generally the hovels are builted with a very simple structure, made of timber of small diameter as can be seen in the picture. The walls consist of bamboo boards fixed vertically in the outside of the horizontal wooden structure.


A.


B.

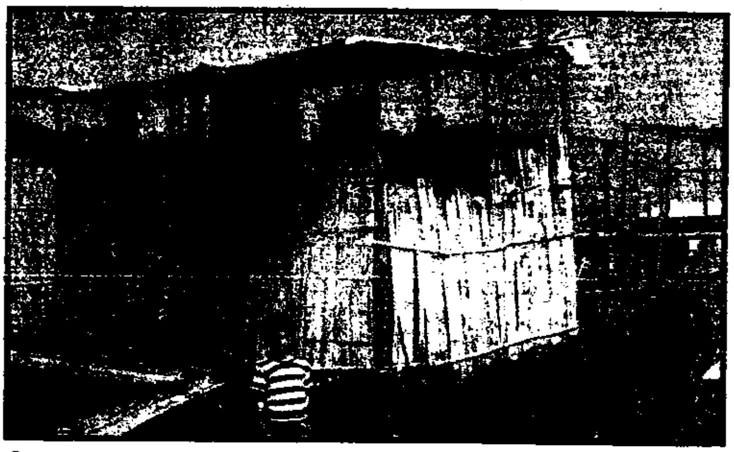

C.

Fig.18.1

A. *Old bamboo houses on the central area of Guayaquil, built with wood structure covered with bamboo boards.*

B. *In the slums of Guayaquil, the bamboo houses are built with a very fragile structure which is covered with bamboo board and as shown in Fig. B, C and 18.2.*

C. *This type of bamboo hovel is commonly seen in the slums of Guayaquil, Ecuador. are built by the invaders for taking poseesion of the land.*

The bamboo wall boards generally are not plastered because the cement mortar increases the weigth of the walls which could not be supported by the small diameter columns. The only advantage which have the use of natural-bamboo boards in the walls and floors is that in the dry season the wind penetrates to the interior of the house throught the cracks of the bamboo boards but also the insects and dust of the roads and water in the rainy season.

In 1981 Guayaquil had a population of about one million two hundred thousands persons of which about 60% of the total population lived in bamboo houses or "cane houses" (as they call them), in the Guasmo and other poor quarters of this city. In these areas about the 80%t of the houses had not acueduct and for solving this problem in each house there were 2 to 4 metalic tanks which were located in front of each house in the street (Fig.18.2) and which were filled up with water by the many private trucks that transported water and that charged at that time 20 sucres for filling up each tank.

In 1984, during several months I worked as consultant of the United Nations in Ecuador at the Junta Nacional de la Vivienda in Guayaquil. This entity was in charge in this country of the construction of low cost howses for families that earn at least 4 minimum salaries monthly.

At my arrival I propose to this entity to carry out an small experimental bamboo housing program in the area of Guasmo, a very poor comunity of Guayaquil, where the people used to live in bamboo hovels as shown in Figure 17.1 B and C. Most of the people which live in this area only earn about one minimum salary or less. My purpose with this program was to demonstrate that was posible that the government could finance the construction of bamboo houses of very good quality and stability for people which earn a minimum salary, if were taking into account the following factors:

1.-Which the family heads of the users group had the same profession or activity. I proposed to make a program for shoe repaired, which are the poorest. This permit me to establish a workshop surrounded by the houses where they can work 3 or 4 hours a day repairing shoes and where they can learn how to manufacture shoes in order to encrease their profits and social level. The money gathered in this form was used for the monthly payments they have make in order to pay to the goverment the loan that they received in materials for the construction of their houses.

2. All the family heads or their representatives have to collaborate in the construction of all the houses.

3. In order to facilitate the construction of the houses, due to most of them have not any experience in construction, we will develope a prefabrication method with bamboo and each one of the parts will be manufactured by the users.

4. The houses have to be designed in such way that they can be builted or enlarged by stages. This permit to the future owners to get a loan for the first stage or for the final stage.

5. The first stage consist of a "basic unit" of 3 by 6 meters which include kitchen, badroom, living room which could be uses as bedroom and a dining room. This basic unit can be increased by the adition of one or two bedrooms.

6.- In order to solve the problem of the water tanks that generaly are located in front of the houses in the street, the house has been designed in such a way that the kitchen and the bathroom were located aside the streed, in the front of the house. This permit to locate the metal tanks below the kitchen table by the exterior side. The kitchen table is extended to the bath room in order to have a water tank in the bath room. All the tanks were interconnected

The program was accepted by the JuntaNacional de la Vivienda from which I received an extraordinary collaboration during the several months that I spent in Guayaquil

From sixty families of shoe repairing we choose 12 families for this program. We builted 4 prefabricated houses with the basic unit plus one room and 8 prefabricated houses with a basic unit plus two rooms. The area of the houses were 36 square meters (6x6 meters) and a patio in the back of the house of 18 squre meters (3x6meters).

The bamboo species used in the construction of these houses were two: *Guadua angustifolia* which is known in Ecuador with the common name of "caña brava" due to its long thorns. And the specie known with the common name of "guadua mansa" because it has not thorns. This specie is the same than in Colombia is known with the vernacular name of "guadua cebolla" which still has not been identified.

Both sppecies are in the brink of extintion because there is not in this country interest in its culture but in their destruction. (See Bamboo Architecture in Ecuador).

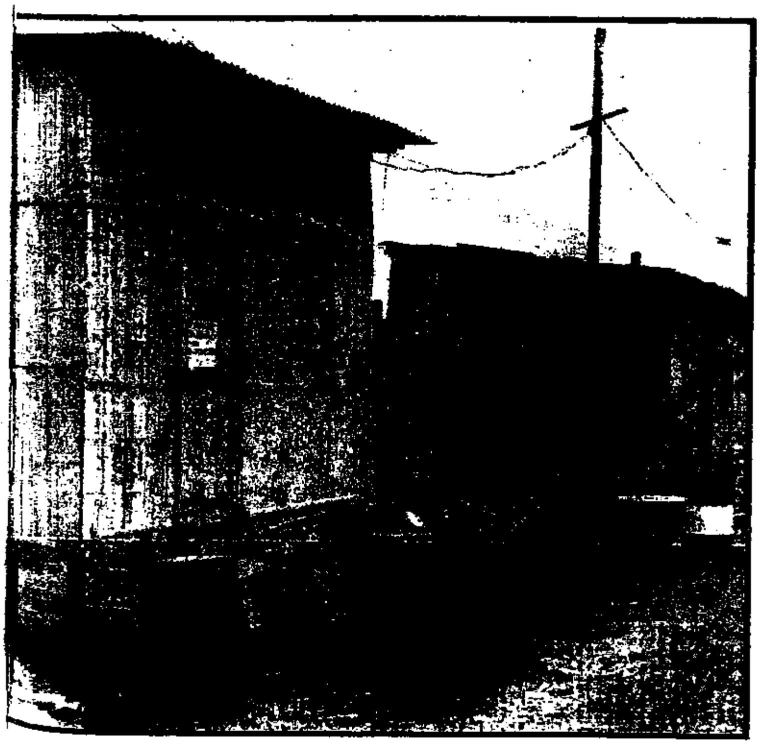
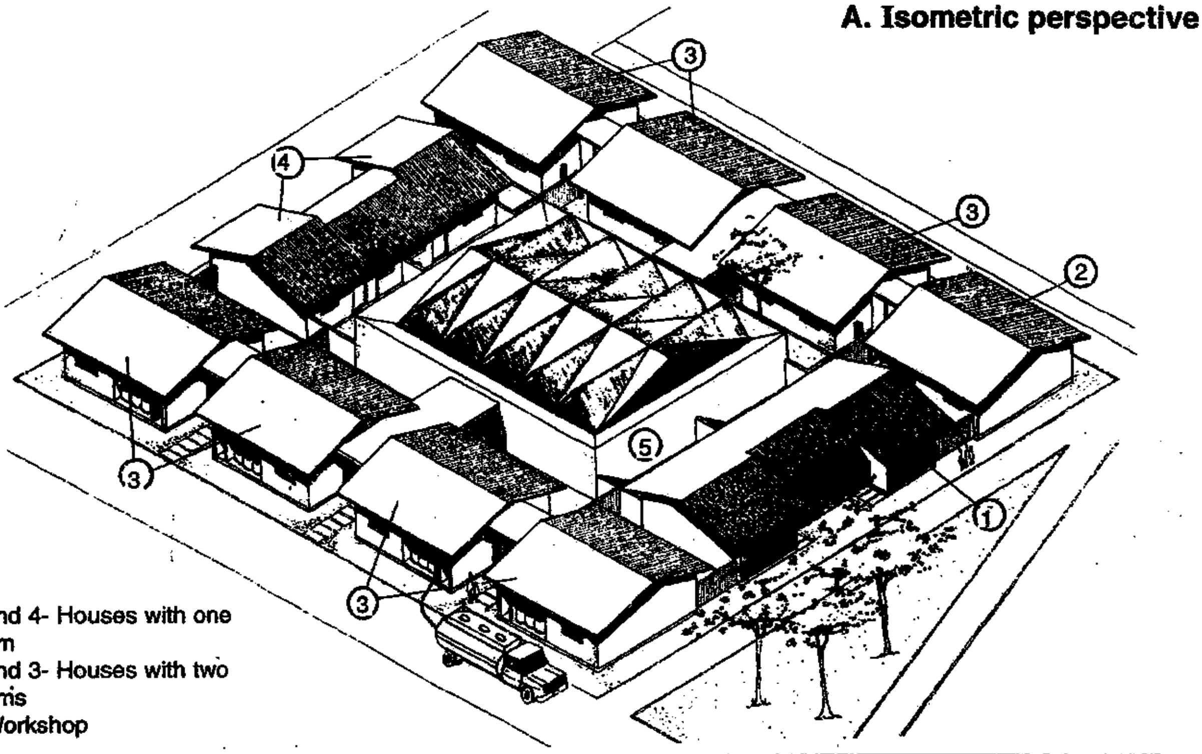


Fig. 18.2 *In the slums where there is not aqueduct, each house has 2 to 4 metal tanks for water storage hat are located in front of the house as can be seen in this picture. In some cases there is only one toilet for several houses.*

Fig. 18.3

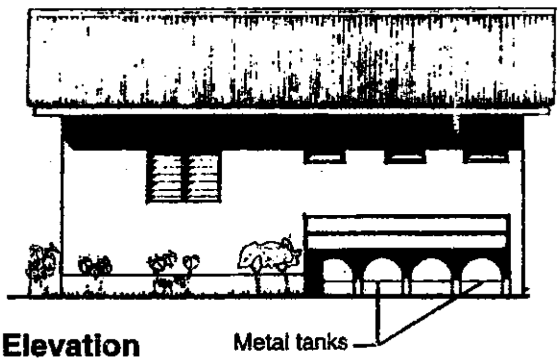
HOUSING PROGRAM

A. Isometric perspective

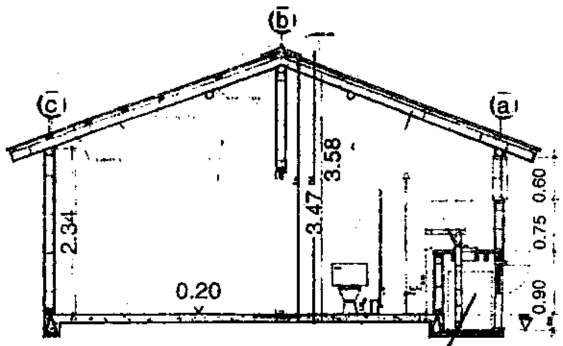


2 and 4- Houses with one room
1 and 3- Houses with two rooms
5-Workshop

B.-Location of the water storage metal tanks in the main elevation and cross section



Elevation

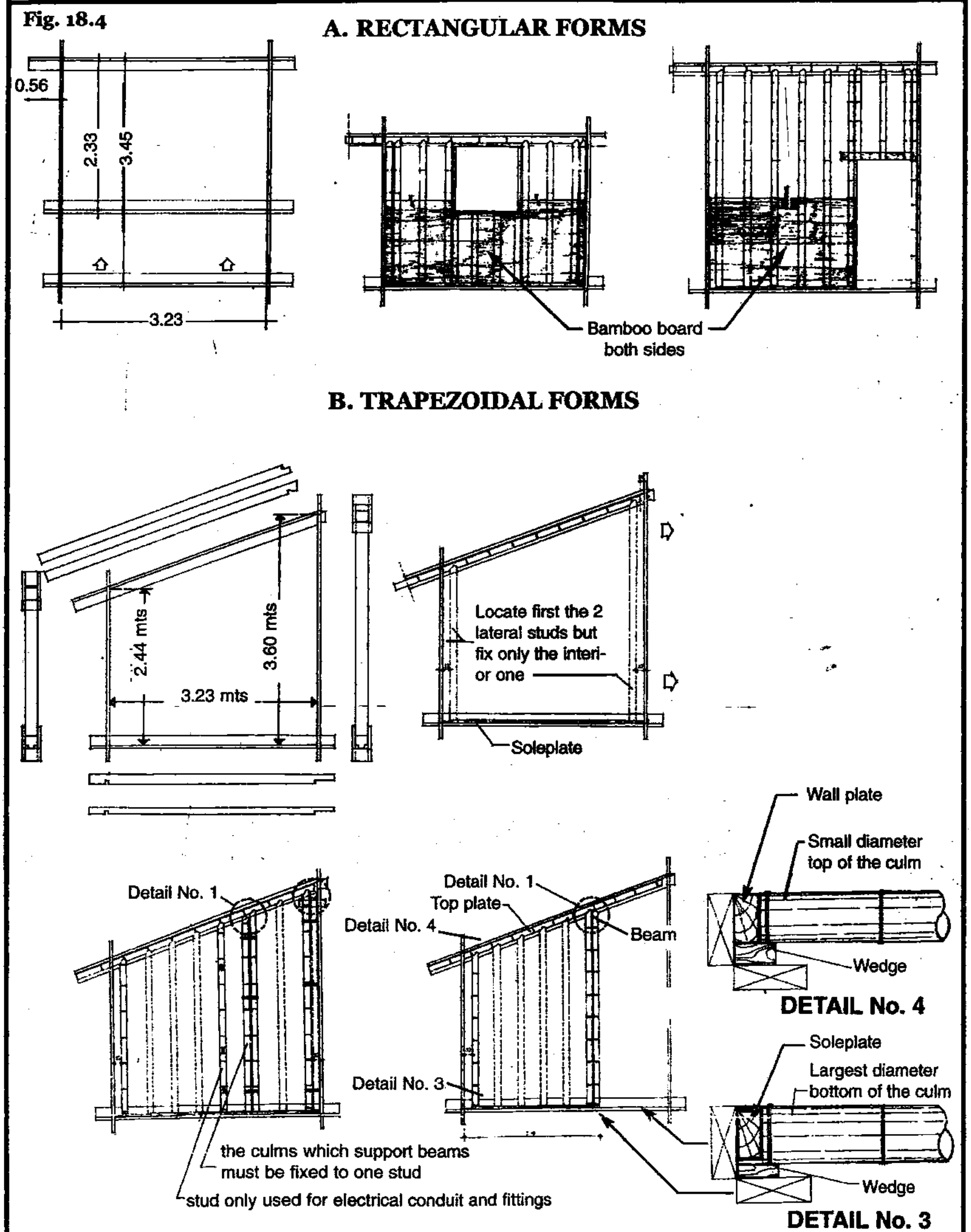


Cross Section

C..*Perspective showing the location of the metal tanks in relation to the bath room and kitchen and the form how they are filled up with water.*

TYPES OF FORMS USED IN THE PREFABRICATION OF WALLS

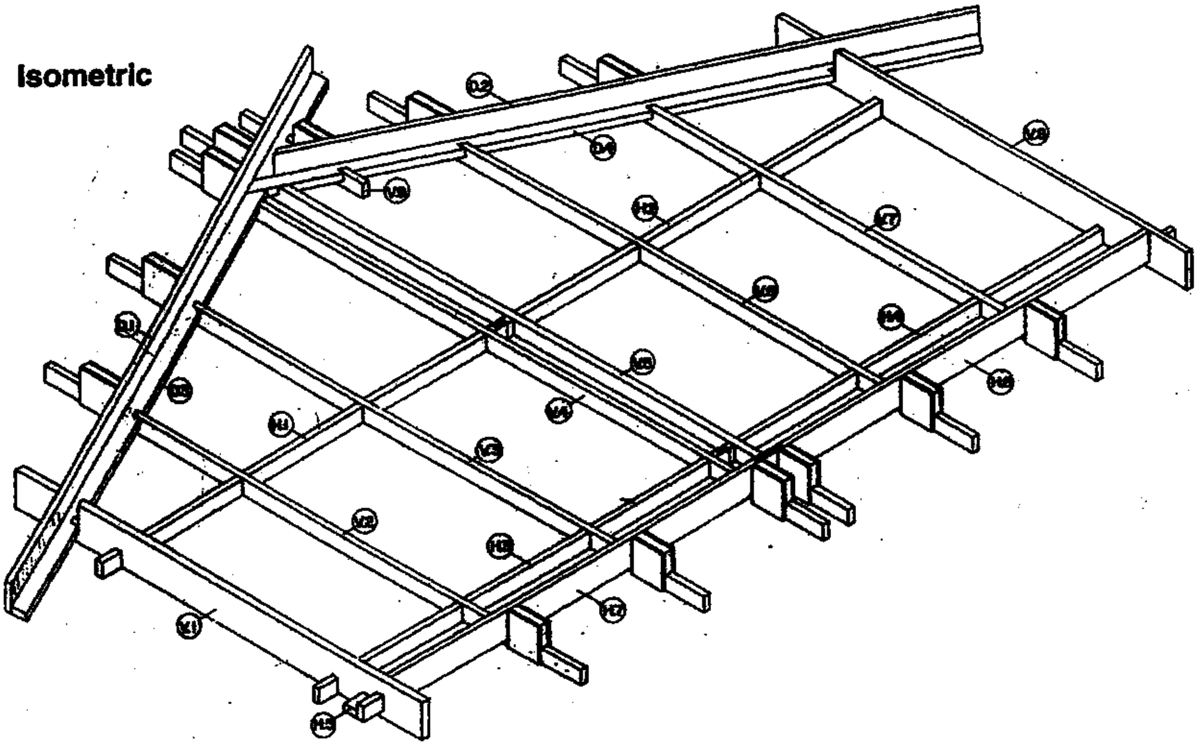
Fig. 18.4



LARGER FORMS USED IN THE PREFABRICATION OF THE WALLS

Fig. 18.5

Isometric



Isometric

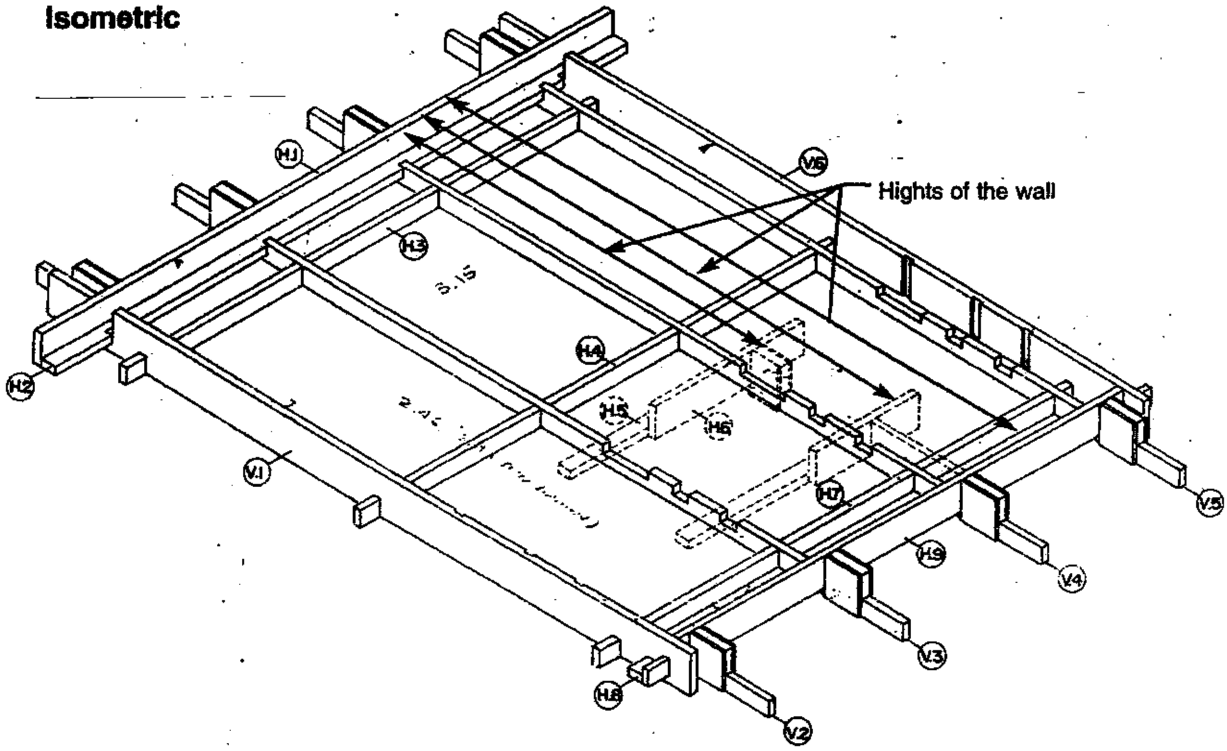
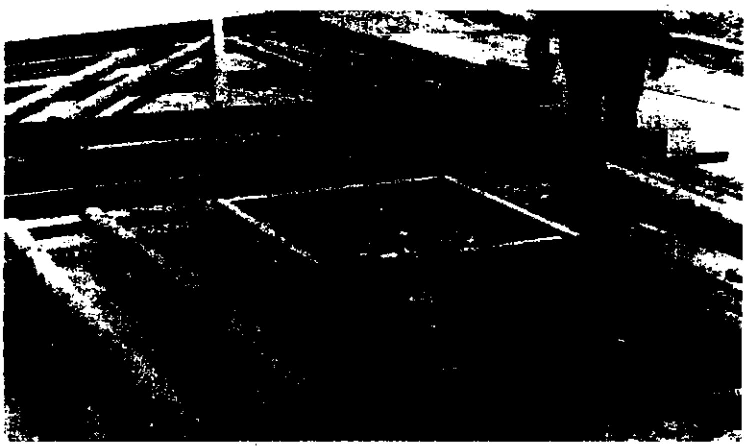
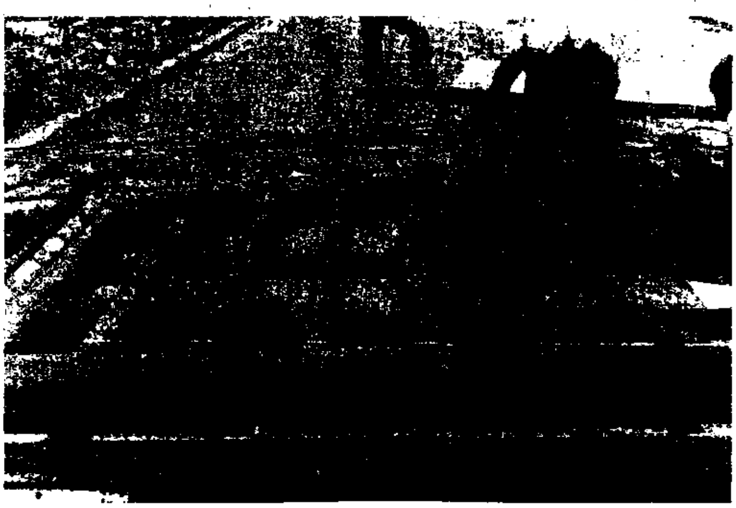


Fig. 18.6 **FIXING THE STUDS INSIDE THE FORMS**

A. *Cutting of the studs. The stud with the holes located in the center is used as a electrical conduit and fittings.*

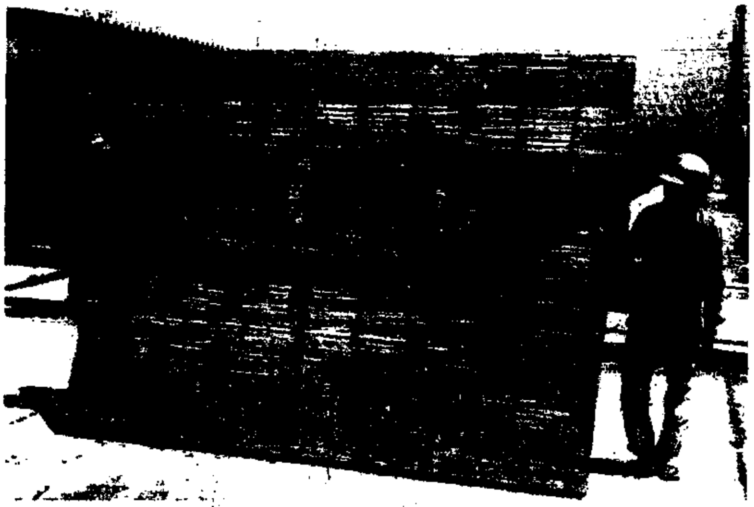


B. *In this wall is used timber for the wall plate and the soleplate. Wood frames are used for fixing the window.*



C and **A** *In this walls are used, bamboo as wall plate and timber as a soleplate. The separation of the studs varies between centers 40 to 50 cm depending on the thicknes of the bamboo board. The lower horizontal wood piece is used for supporting the kitchen table.*

Fig. 18.7 **FURRING THE PANEL WITH BAMBOO BOARDS**



A. *The bamboo board is fixed to the studs with nails 38 mm long with a separation of about 5 cm (3 ginguers) and galvanized wire.*

B. *Once furred the panel by one side can be removed from the form and furred by the oposite side.*

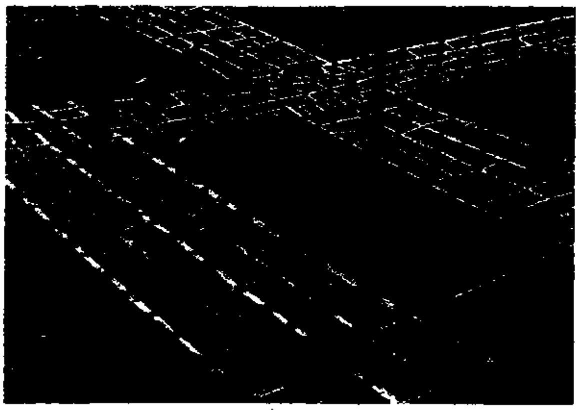
C. *Cutting the borders of the bamboo boards inside the wood frames.*

Fig. 18.8 CONSTRUCTION OF THE SLAB FOUNDATION

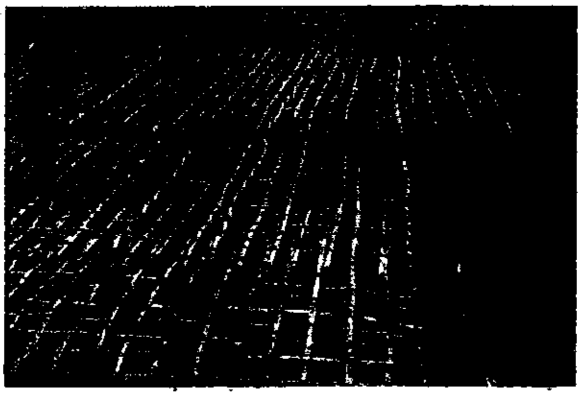
I experimented two types of concrete slab foundations reinforced with two types of bamboo mesh made with bamboo strips 4 cm wide in which were removed the interior or soft part of the strip. In some houses I used a mesh 50 cm wide (Fig. A) which were located only in the axis of the walls. In other houses I reinforced the whole area of the slab with a bamboo mesh (Fig. B). All the fundations have a peripheral concrete beam reinforced with bamboo cables (Fig. C).

The concrete slab had a thickness of 4 to 5 cms. Once finished the concrete slab the position of the walls were traced on its surface (Fig. E).

These houses were builted in the year of 1983 and I visited them in August of the year 2000 and I did not see any crack in the concrete slab or in the peripheral beams.

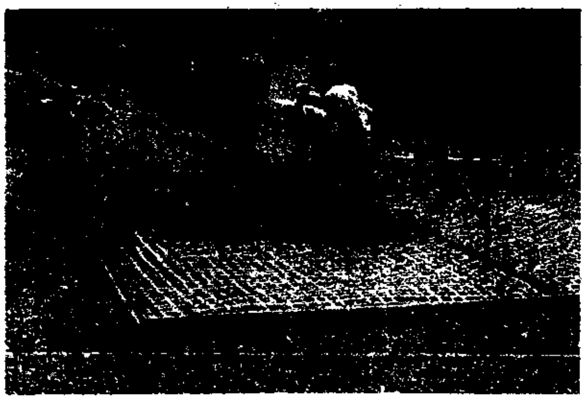


A. *The figure shows a 50 cm. wide bamboo mesh for reinforcing the walls' area.*



B. *The figure shows the bamboo mesh covering all the surface of the house.*

C. *Fixing the cables inside the triangular bamboo stirrups of the peripheral bamboo beams.*



D. *Pouring the concrete in the foundation slab.*

E. *Tracing the lines for the location of walls on the concrete floor.*

Fig. 18.9 **PLAN AND PREFABRICATED WALLS OF TYPE I HOUSE**

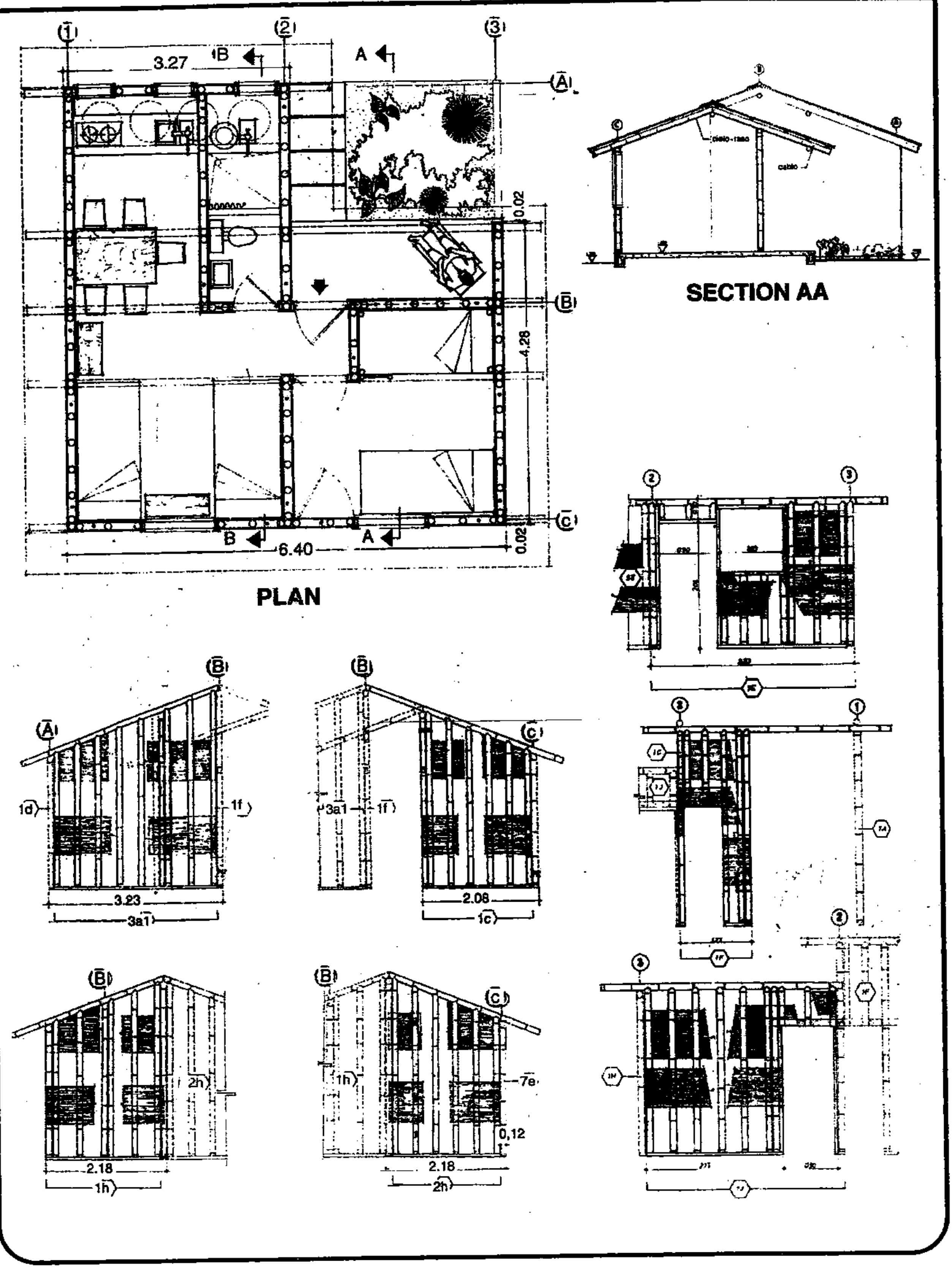


Fig. 18.10 **ASSEMBLING OF THE TYPE I HOUSE**

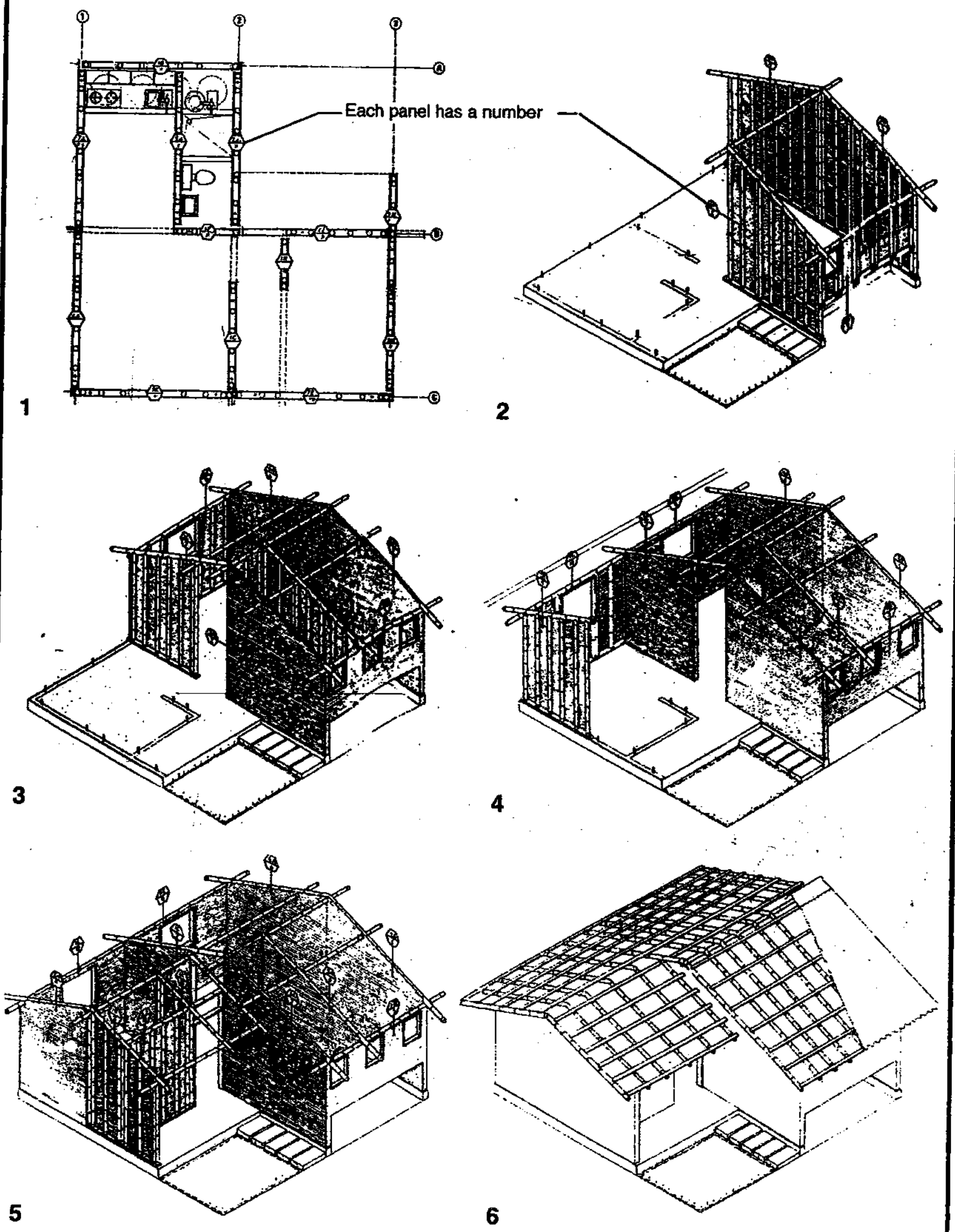


Fig.18.11 PLAN AND CROSS SECTIONS OF THE TYPE II HOUSE

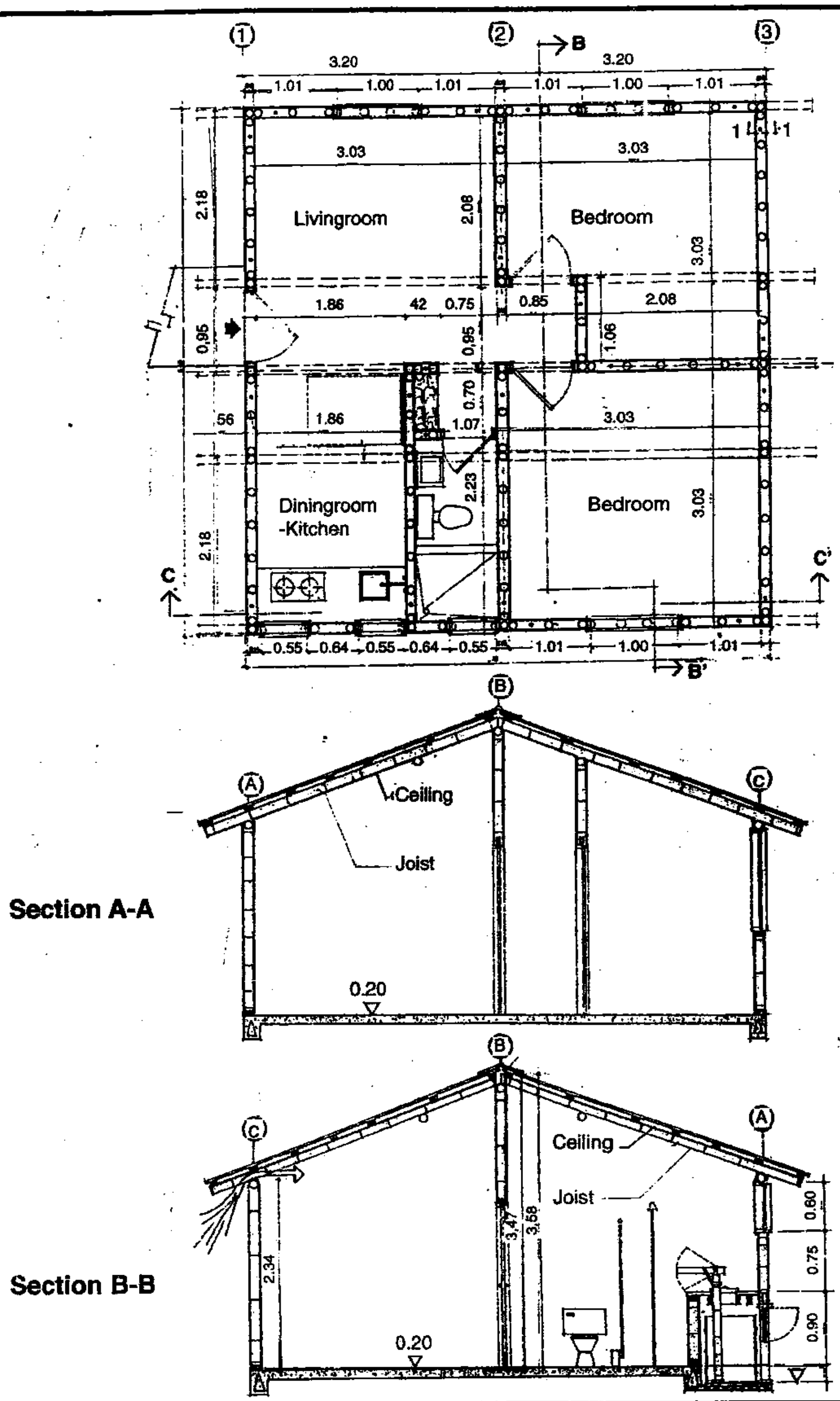


Fig. 18.12 **ASSEMBLING OF THE TYPE II HOUSE**

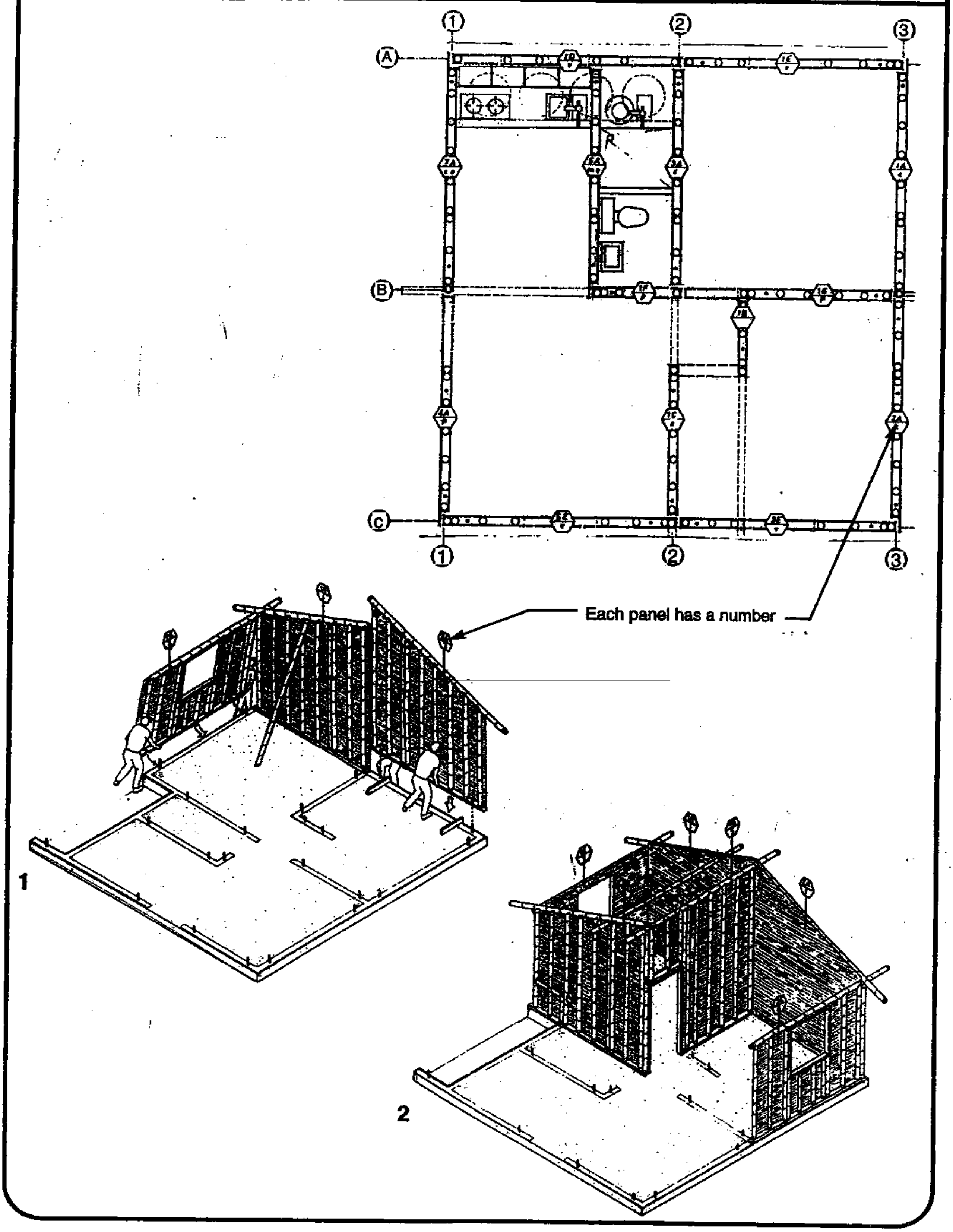


Fig. 18.12 (a) ASSEMBLING OF THE TYPE II HOUSE

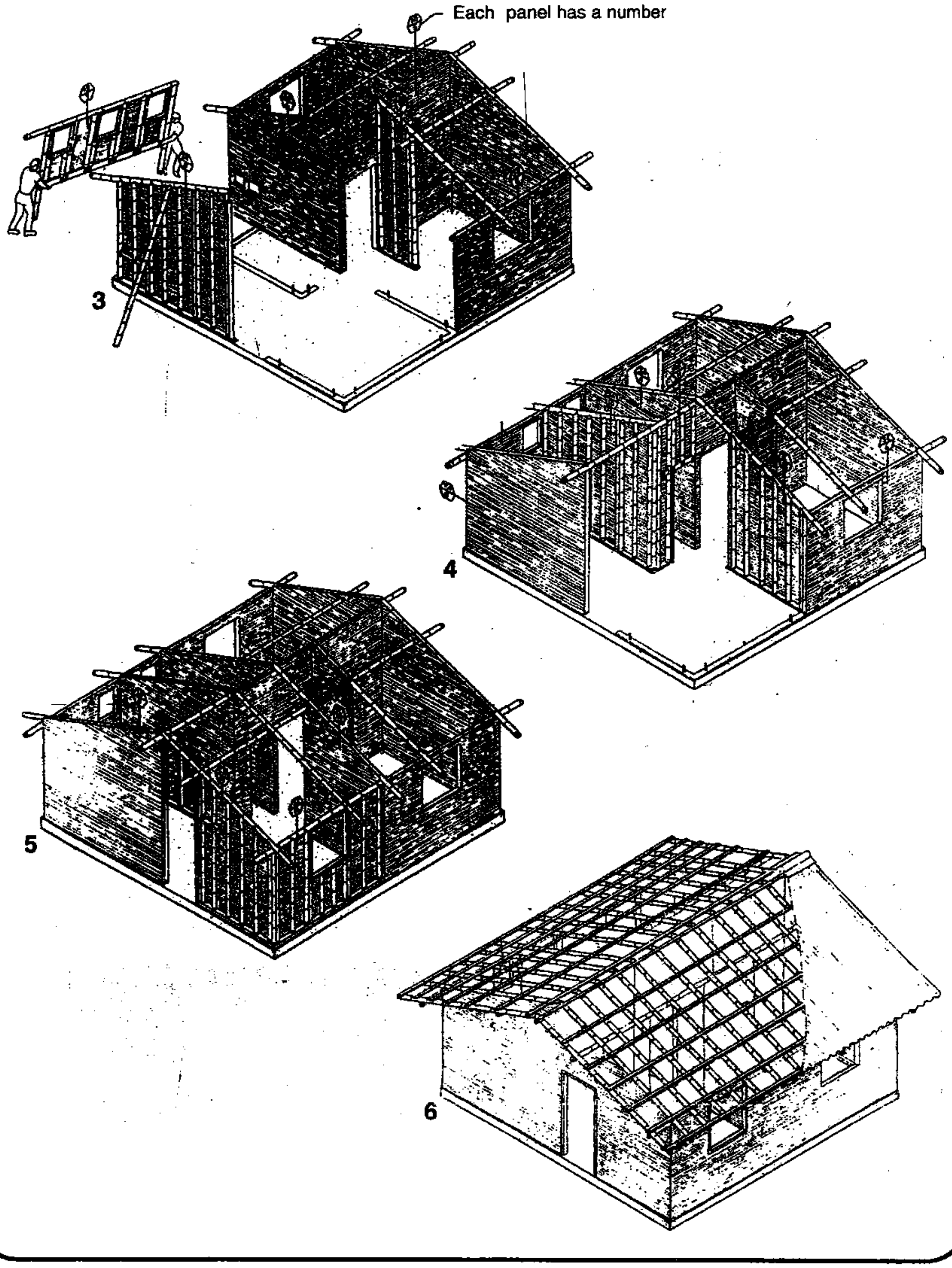


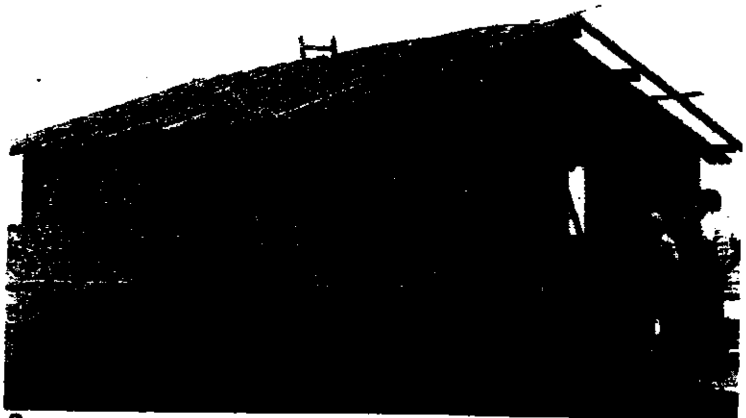
Fig. 18.13 (a) ASSEMBLING OF THE TYPE II HOUSE

1

Locating the lateral wall

2

Once located the lateral wall, are located the girder and stabilization beams and the kitchen external wall



3

Finally the roof structure is built

Fig. 18.13 (b) **ASSEMBLING OF THE TYPE II HOUSE**

A. *The group of shoo-makers pouring the concrete slab of the last of the houses.*

B. *The two type of prefabricated bamboo houses once finished and painted.*

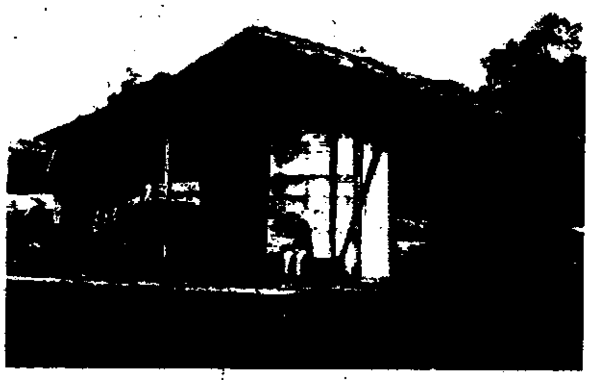
IMPROVEMENT OF DWELLINGS & HOUSING PREFABRICATION PROGRAM IN COSTA RICA

Fig. 18.14 **IMPROVEMENT OF DWELLINGS IN POOR AREAS**

In 1984 I was invited to Costa Rica by Mrs Cecilia Fernandez Saborio with the purpose of collaborating in the organization of the Bamboo National Program of which she was the Director and founder. At my arrival to Costa Rica one month later I found that the new Director was Mrs. Ana Cecilia Chavez with whom I look for a place in order to make a demonstration on the use of bamboo in the improvement of dwellings. With this purpose we went to the town of Atenas, near San Jose, where we visit a poor community known as San Vicente where I choose for the experiment the house indicated in Fig. A and B which was the worst house but with the best wood frame structure.

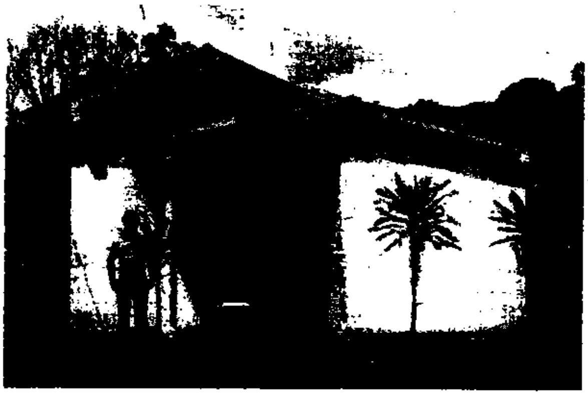
We removed the small wood boards of the walls and replace then by bamboo boards (Fig.C) and then plastered. We fix the tiles of the roof above bamboo boards which were plastered below and painted. The resultS can be seen in Figs. D and E.

A. *The poor aspect of the house.*



B. *All the walls were built with small wood boards.*

C. *The wood boards were replaced by bamboo boards*



D. *The roof tiles were changed.*

E. *The new aspect of the house.*

PREFABRICATION OF BAMBOO HOUSES IN COSTA RICA

Fig.18.15

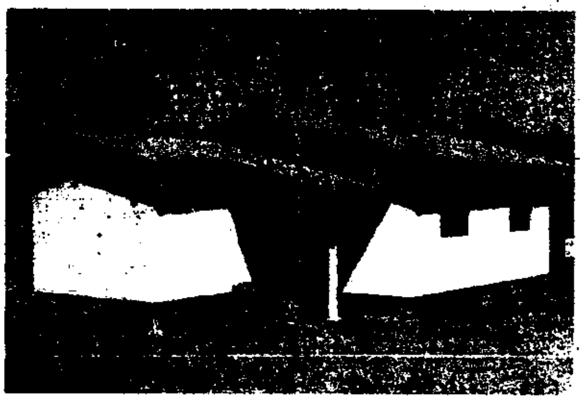
Based on the satisfactory results that we had in the improvement of the dwelling shown before,using bamboo, the government of Costa Rica aproved the Bamboo National program and 5 years later I returned to Costa Rica to teach the bamboo construction technology to a group of 20 students which had finished their studies about construction technologies. With this purpose we builta prefabricated house under my direction. The figures shows several stages of the construction.

A. *In the prefabrication of the walls we followed the same technology which I developed in Ecuador with very satisfactory results.*

B. *Once finished the prefabrication of the walls, the house was assembled by the students.*

C. *The whole structure of the floor were made with timber.*

D. *The group of students after fin shing the construction of the roof.*



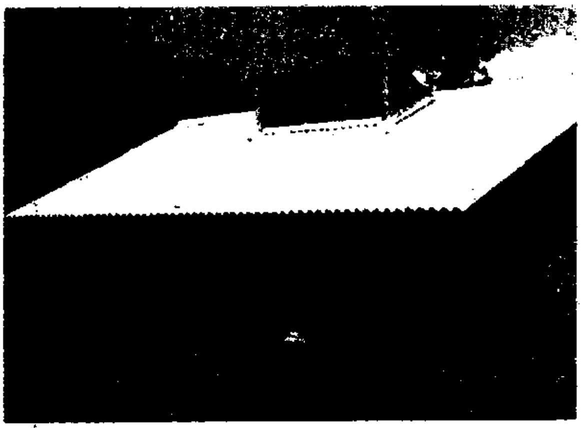
E. *The house once plastered and painted.*

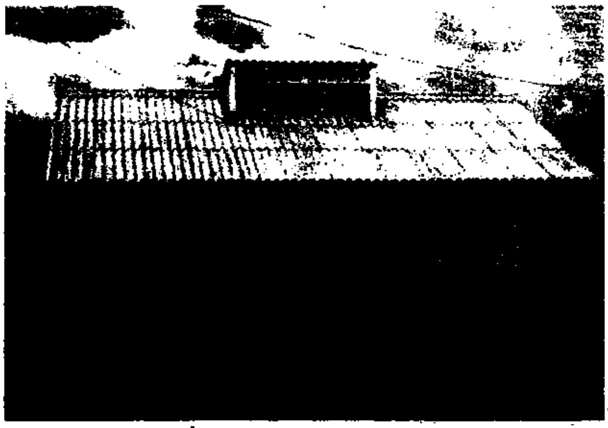
PREFABRICATION OF BAMBOO HOUSES IN COLOMBIA

Fig.18.16 In October of 1985 the eruption of the Ruiz volcano produced in some rivers of the states of Caldas and Tolima in Colombia, huge floods of mood and stones which destroyed and covered the whole town of Armero where 25.000 of its inhabitants died and many small towns and houses located in the border of these rivers were destroyed.

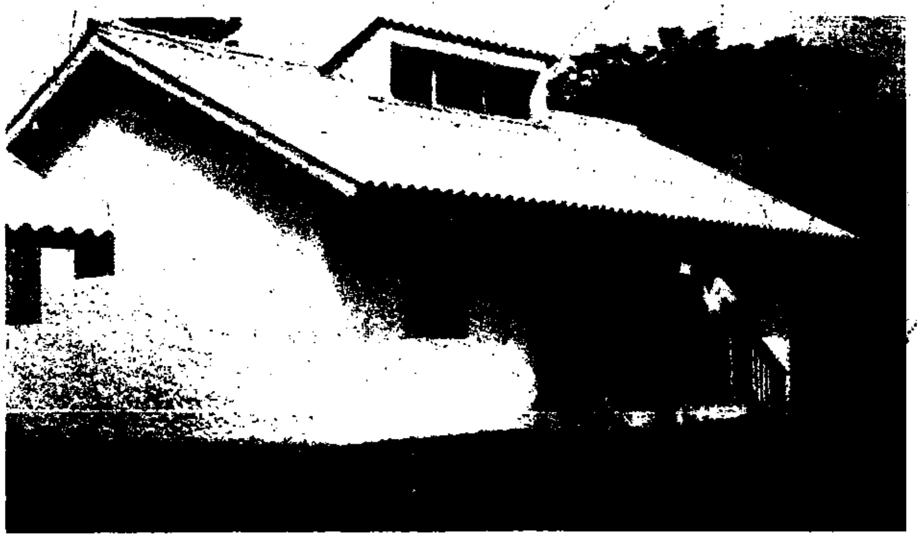
As a consequence many entities develope housing proyects for the people that lost their houses. One of this proyects was financed by the Federacion de Cafeteros in the kilometer 42 between Manizales and Medellin. Three of thes twenty houses were financed by the Acuerdo de Cartagena following the prefabrication system that I developed in Ecuador, In this proyect I participate only in the design and plans of the three houses.

A. *In the first house shown above, the whole structure were built with bamboo and wood.*





B, C.- *In this house the whole structure was made only with bamboo at ground level.*

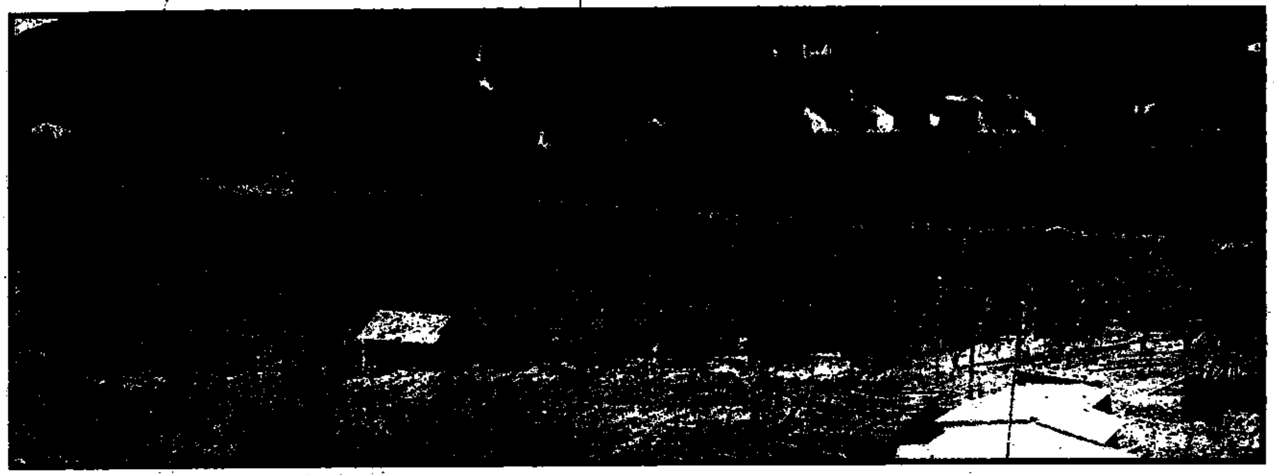


D. *This house was built elevated from the floor and the whole structure were made using bamboo and wood.*

PREFABRICATION OF HOUSES IN THE TOWN " EL PEÑOL"

Fig. 18.17 In 1987 the Instituto de Credito Territorial (I.C.T.) builted in the Town of El Peñol, located in the State of Antioquia in Colombia, 100 bamboo houses for poor people. This proyect was in charge of the architect Ana Lucia Gaviria and I collaborated as consultant.

The prefabrication method employed was the same that I developed in Ecuador. All the houses were located in diferent levels following the slopes as can be seen in the figures A and B.



A. *The 100 houses were built in a beautiful location of the town of El Peñol in the State of Antioquia.*

B, C, D *Details of construction of walls, of the concrete slab and roofs.*

PREFABRICATED PIRAMIDAL BAMBOO CUPOLAS IN PERU

Figs. 18.18

In the rainy season of December 1982 to June 1983 the north of Peru and particularly the district of La Arena was affected by floods and thousand of families had to emigrate to high dunes of the desert. There borned a community of 3.000 people which was known as Las Malvinas.

In September of 1985, a group nown as MIRHAS under the direction of the architect Eliseo Guzman and with the collaboration of the architect Emilio Luisoni and the contribution of the journal La Suisse, from Ginebra, start the construction of houses and schools of the Project Malvinas.

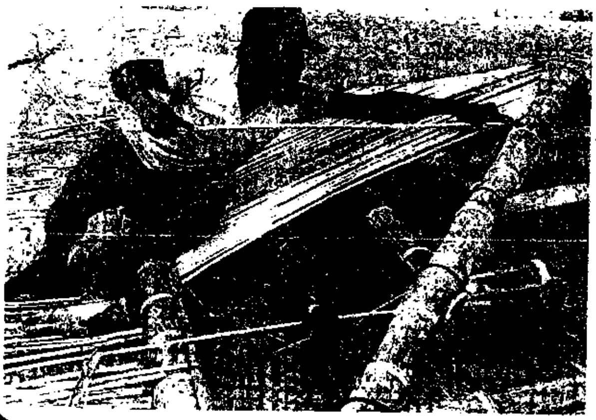
As part of this project was built with bamboo *El nucleo social* or social center, (See Fig. 22.60 A) in which were experimented the construction of prefabricated piramidal bamboo cupolas which gave to the buildings a very nice appearance.

The process of the construction of the bamboo cupolas and their placement are shown in the Figs B,C,D.

A *Shown the social area.*

B.- C. *Prefabrication of the cupolas.*

C.



D.