For my friend Ranjanan with best regards.
New delhi, february 28/004

attari a a
20-02-2011

BAMBOO

THE GIFT OF THE GODS

by

Oscar Hidalgo-López

PART-2

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PART 2 of 2

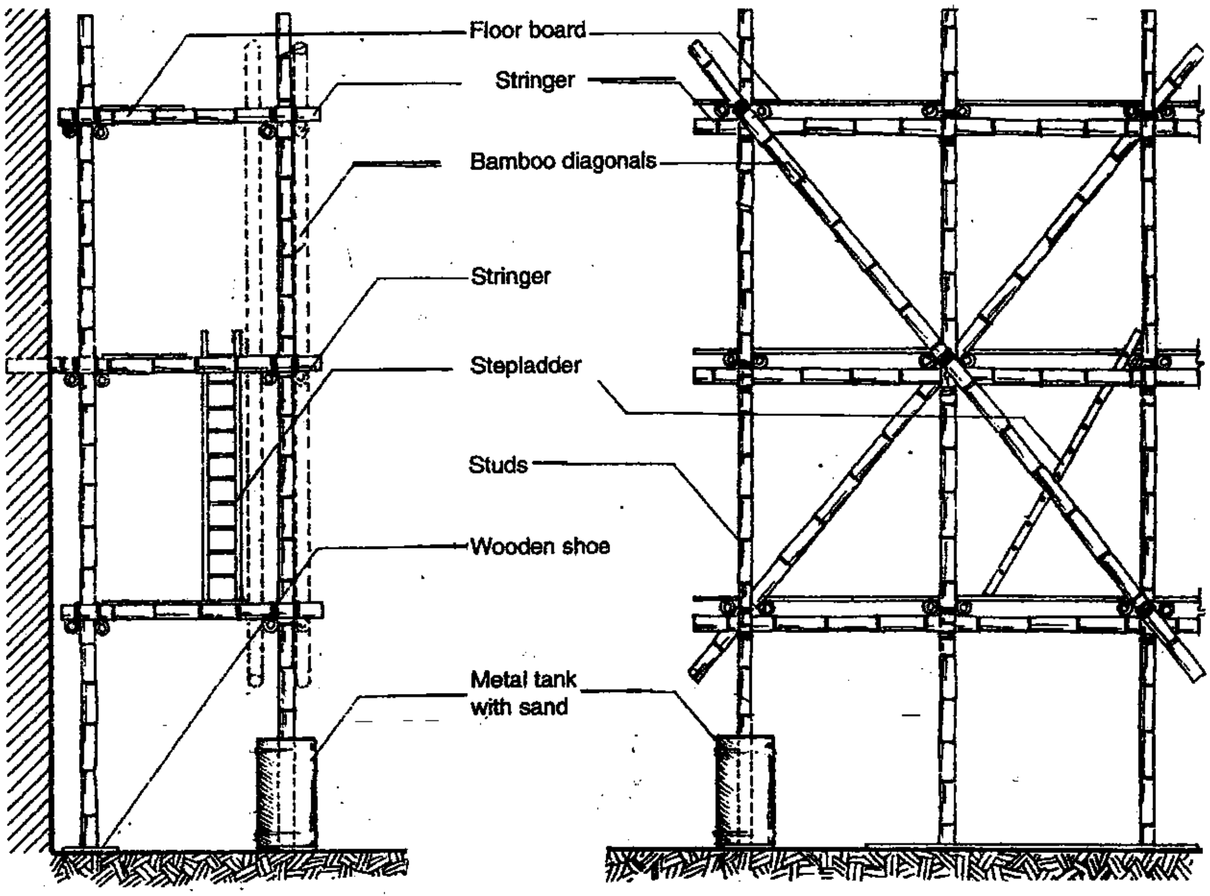
PART 7

Construction of Bamboo Structures

Bamboo bridge (Neuville's drawing)
Geografia Pintoresca de Colombia in 1869.

17 CONSTRUCTION OF BAMBOO SCAFFOLDINGS

Fig. 19.1 **SMALL BAMBOO SCAFFOLDING (Colombia)**

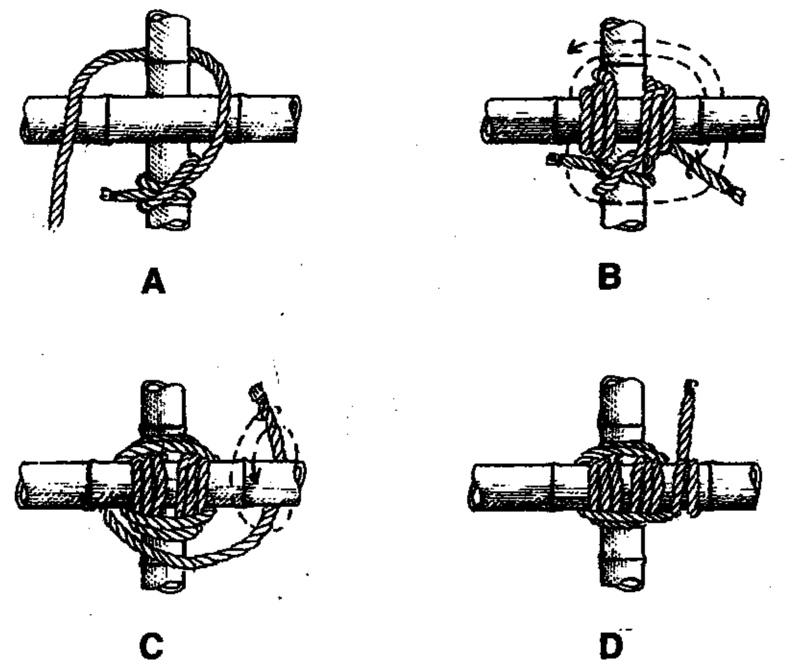


A. Lateral view **B. Front view**

C. *Detail of the wooden shoe. the base of the culms has to have a node.*

TYPES OF KNOTS USED IN THE CONSTRUCTION OF SCAFFOLDINGS

Fig.19.2



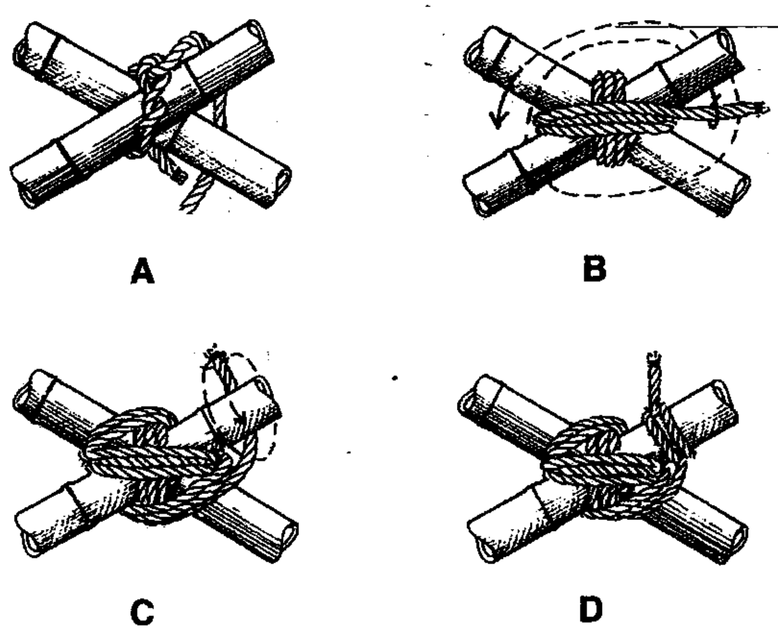
1.-Square or Transom lashing.

(a).-*Start with a clove hitch on the upright. Carry the end up in front of the transom, behind the upright, and down in front of the transom.*

(b).-*Continue in this way, keeping inside previous turns in the upright, and outside previous turns on the transom.*

(c).-*After three to five turns, as described above, conclude with two or three cross turns.*

(d).-*Dispose of the end by tying a clove hitch on the transom.*



2.-Diagonal lashing.

(a).-*Put a tight "timber hitch" diagonally over the crossing.*

(b).-*Continue with three or four tight turns in the same direction as the hitch and the same number at right angles to it.*

(c).-*Put on frapping turns between the spars.*

(d).-*Finish with a "clove hitch" over one spar.*

KNOTS USED IN SCAFFOLDINGS FOR FIXING HAND-RAILS

Fig. 19.3

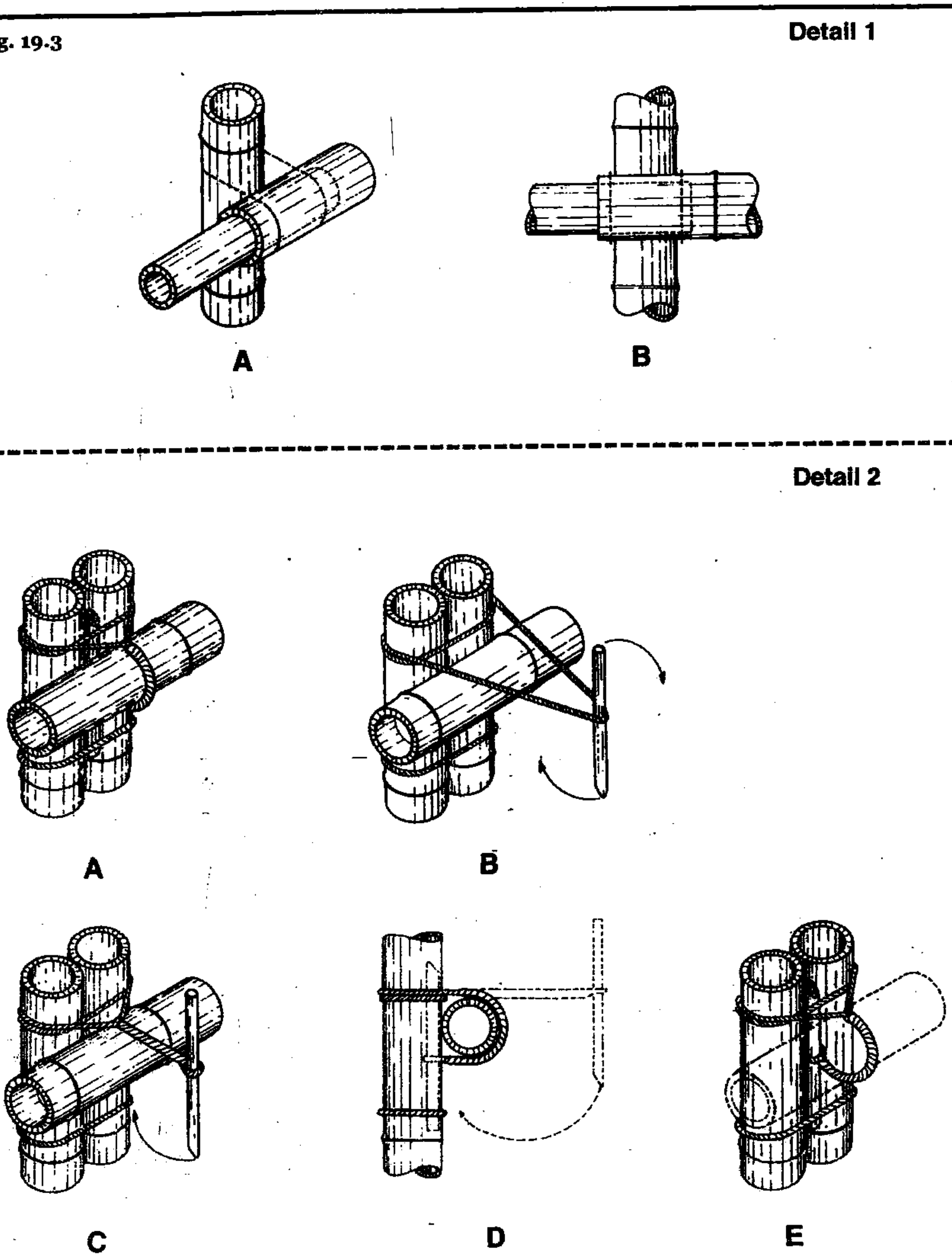
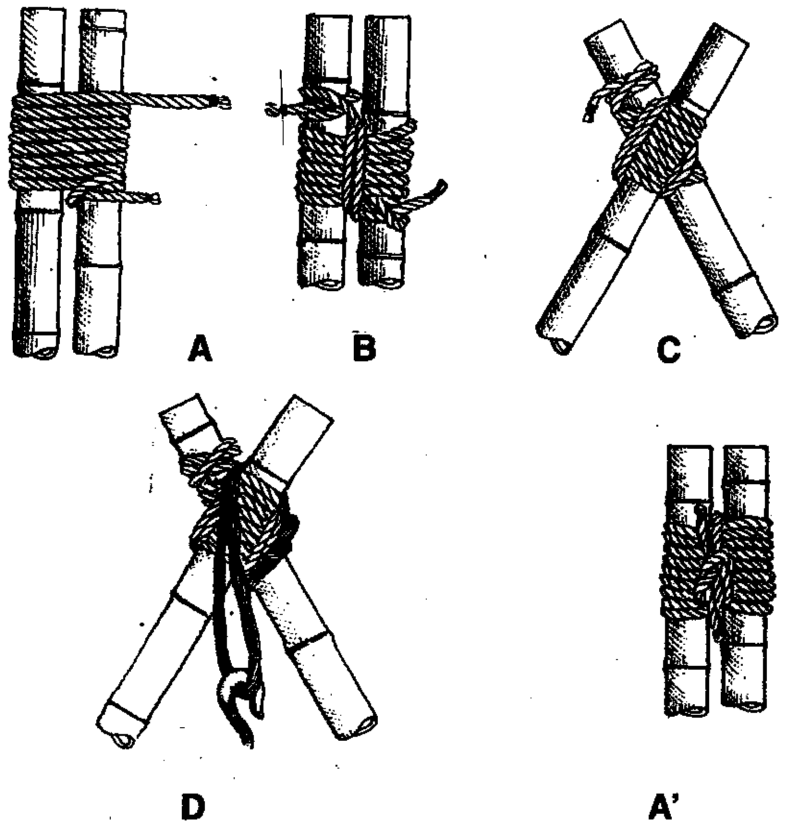


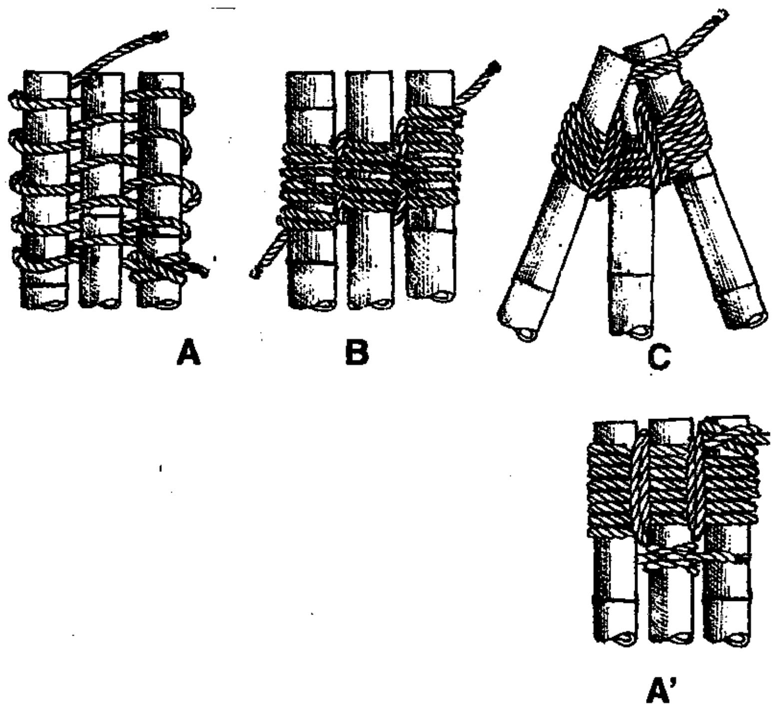
Fig.19.4 BAMBOO BIPOD AND TRIPOD FOR HANGING PULLEYS (CRANE- BOOM)



1. Bipod (Lashing for shears)

(A,B,C,D) First method

(A') Second method

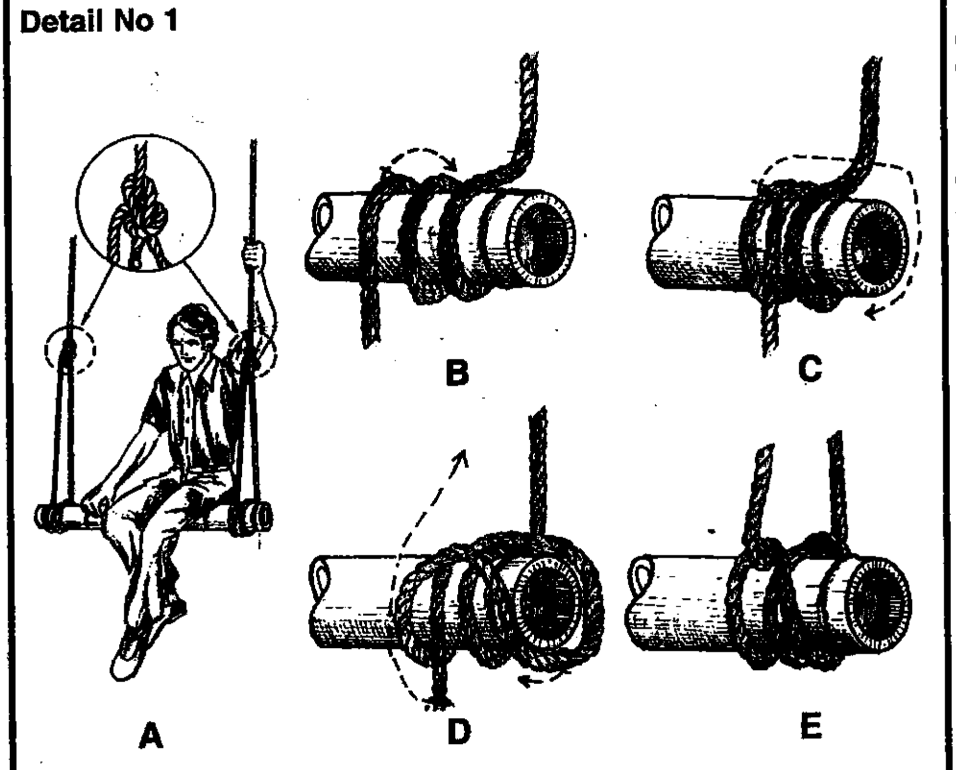


2. Lashing for gin or tripod

(A,B,C,) First method

(A') Second method

Fig.19.5 **HANGING SCAFFOLDS**



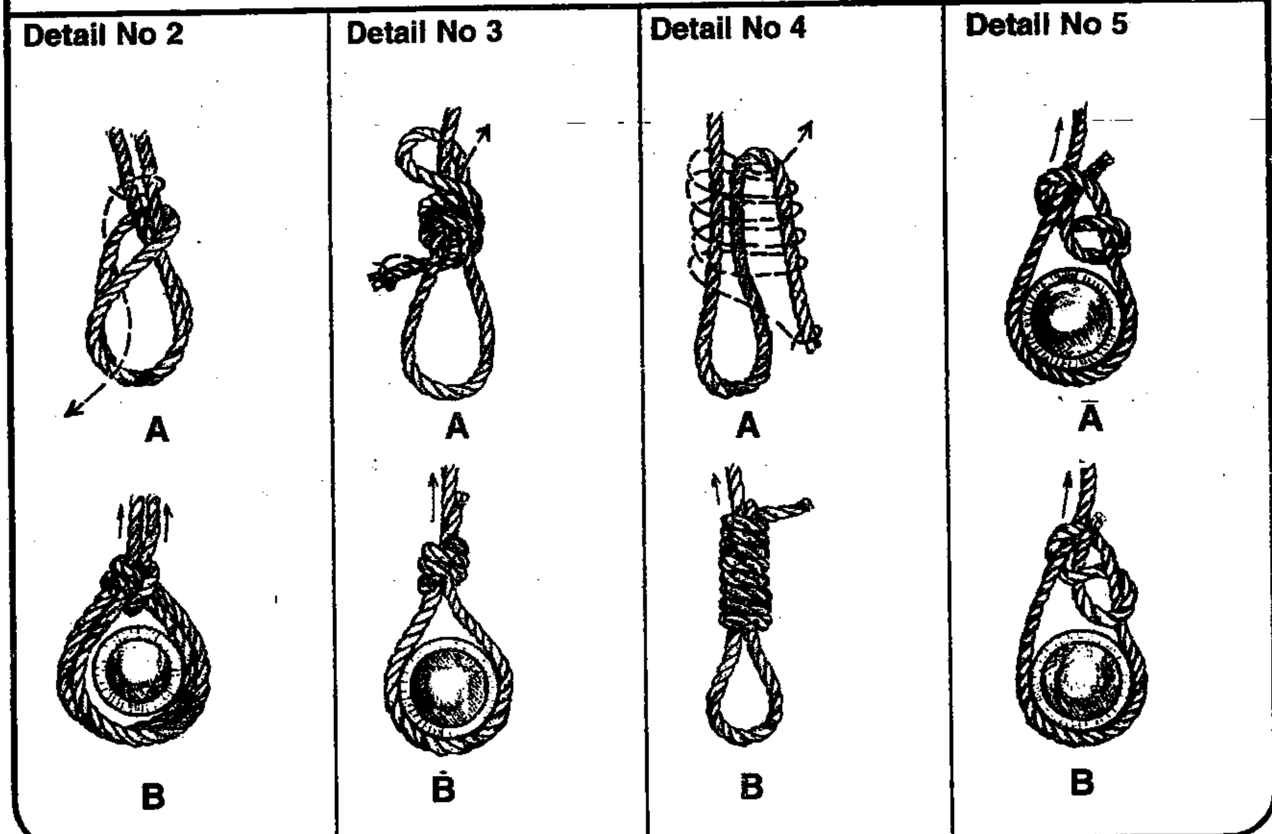
1.Scaffold Hitch
(A) The scaffold once finished
(B,C,D,E) details of the knot

2.-Doble running knot
It is useful when tension comes in on both standing parts
(A First method
(B) Second method

3.-Doble overhand noose
(A,B) Details of the knot

4.-The hangman's noose - knot or Halter.
(A,B) Eight or nine turns

5.- Figure eight noose
(A) First method
(B) Second method

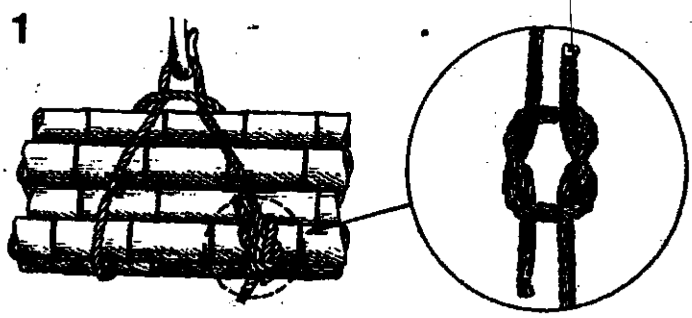


KNOT-TYING FOR VERTICAL TRANSPORTATION OF BAMBOO - Rope ladder

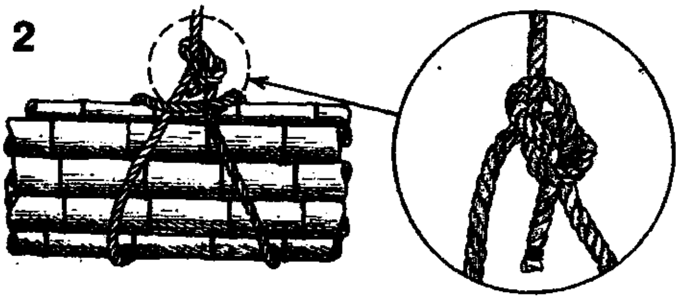
Detail No. 1 -Vertical transportation of bamboo

Fig. 19.6

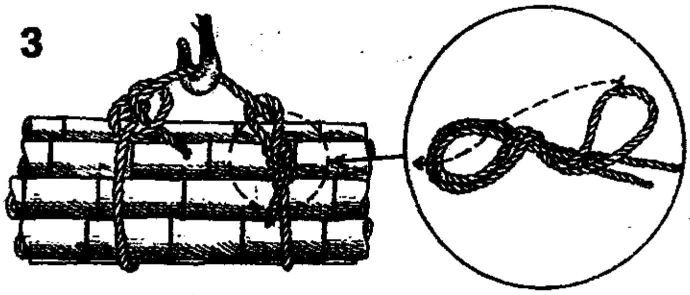
1



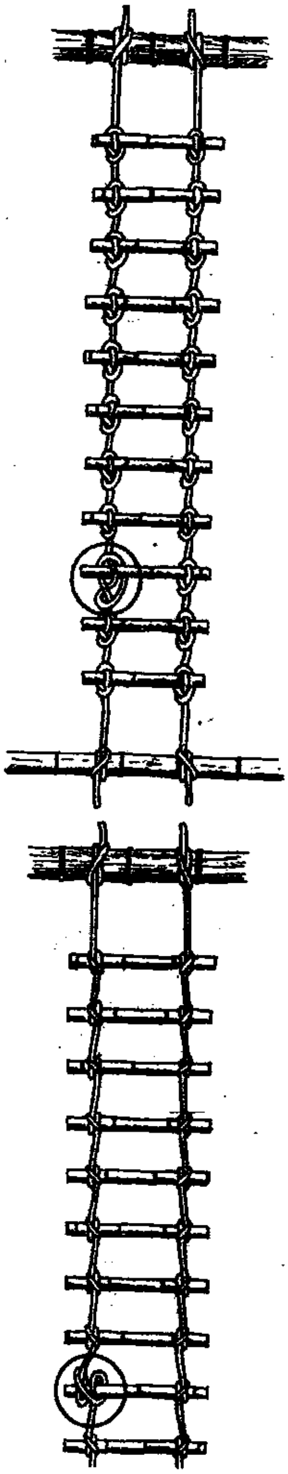
2



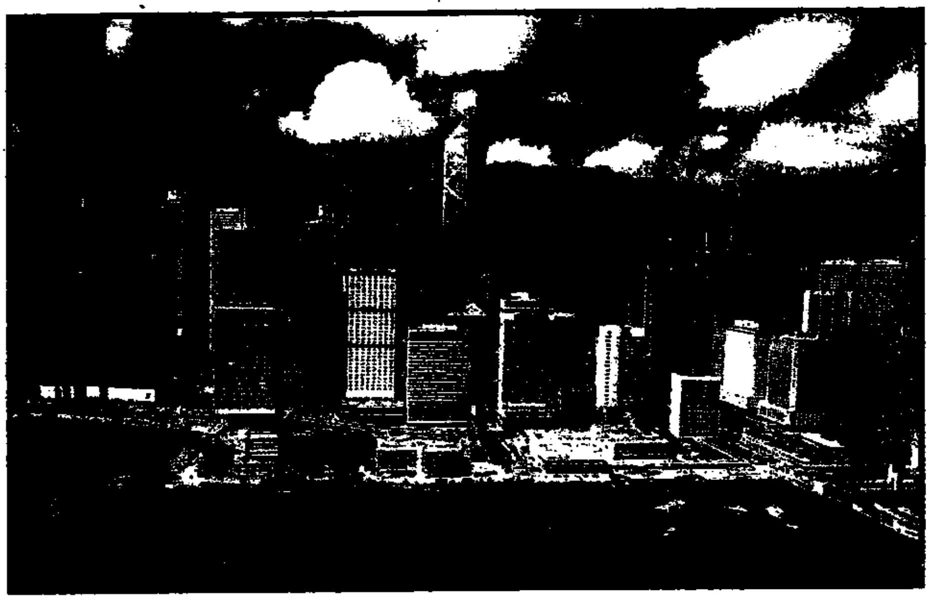
3



Detail No 2- Rope ladder



CONSTRUCTION OF BAMBOO SCAFFOLDINGS FOR HIGH RISE BUILDING IN HONG KONG



Lau (1994) is right when she said that bamboo scafoldings made simple with bamboo poles lashed together, which skirt up the sides of the skyscrapers in Hong Kong, compared with the sturdy metal scaffolds used in construction in all parts of the world, looks like a flimsy lattice-works, which appear about as structurally sound as a house made of toothpicks. Neverthèles in Hong Kong where typhons are frequent, bamboos goes with the wind rather than standing firm against it like metal. In one recent storm, when a half-completed building collapsed, the bamboo scafolding encircling it remained standing. Despite their woobbly look, bamboo scaffolds seldom collapse on their own.

Most of the bamboo poles used in the construction of scaffoldings in Hong Kong belong to the specie *Bambusa tuldoides* Munro, native of Guandong province, in southern China. The following mechanical properties of this specie have been reported in PROSEA (1995): Density 950-970 kg/m^3; modulus of rupture (with node) 79-94 N/mm^2 ; modulus of rupture (without node) 84.0-115.2 N/mm^2; tensile strength (with node) 95.8-112.0 N/mm^2, without node 98.0-140.5 N/mm^2; Shear strength 50.0-59.0 N/mm^2.

The scaffolds are formed by one or two grids of bamboo poles generally 6 meters long with diameters between 7-10 cm.

Fig.19.7 *About 90% of all scaffoldings used in Hong Kong are made with bamboo. It is considered that they are "cheap (one fifth that of steel scaffolding), strong and quick".*

Fig. 19.8 (Top and bottom) *Bamboo scaffolds have been used in Hong Kong in the erection of high-rise buildings like the 78-story Central Plaza tower. Photography by K. Macgregor.*

Horizontal and upright poles are braced by criss-crossed diagonal ones. In some cases are used bamboos with wider diameters in the bottom of the scaffolding which probably belongs to other specie. It is considered that most poles have a life span of about a year.

Until 15 year ago, thin strips of bamboo were used to bind the poles (See Fig. 19.9). The strips were tàken from the outer part of the culm after soaked in water until soft.

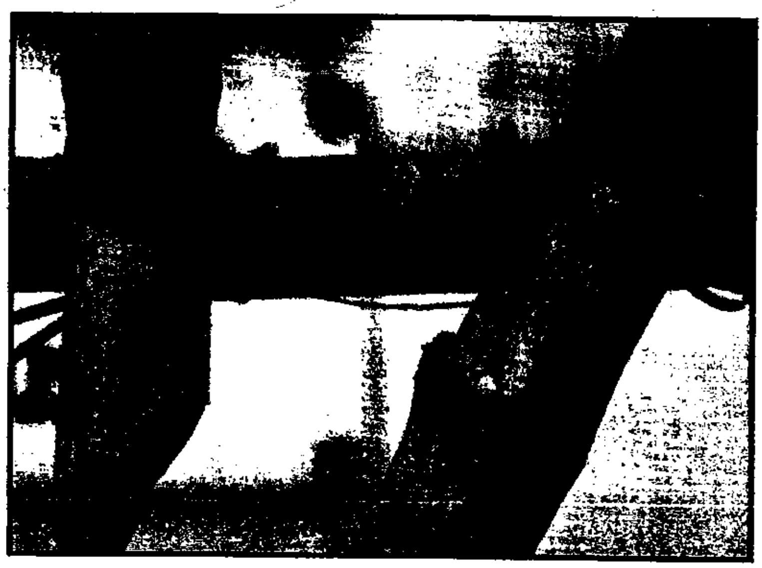
Due to the time taken in the preparation of the bamboo strips and the lack of quality control, bamboo strips were replaced by strips of polystirene (See Fig. 19.10).

Today, most scaffolds are either single-layered or double-layered. The latter type, which allows room for working platforms, is considered safer and is favored in main land China. The former prevails in Hong Kong because it is cheaper; it requires fewer poles to build and is quicker to erect. The down-side with single row structures is that, with no working platform, laborers most carry their tools in waist belts or in buckets, which they tie with ropes to the scaffolding.

Fig. 19.9 *For centuries the craft of erecting bamboo scaffolds has been passed down from generation to generation.*

Compared with metal scaffoldings bamboo has many adventages in the construction of scaffoldings. Bamboo scaffolding can be custom-built according to the shape and size of a given structure, whether it be a gothic cathedral or a Chinese temple. One of its gratest virtues is that it can be tied on to the sides of the buildings in need of upper-story work. Metal scaffolding would have to be built from the ground up, blocking pavements and clogging pedestrian traffic. The cost of a bamboo scaffolding is approximatelly one fifth that of steel scaffolding.

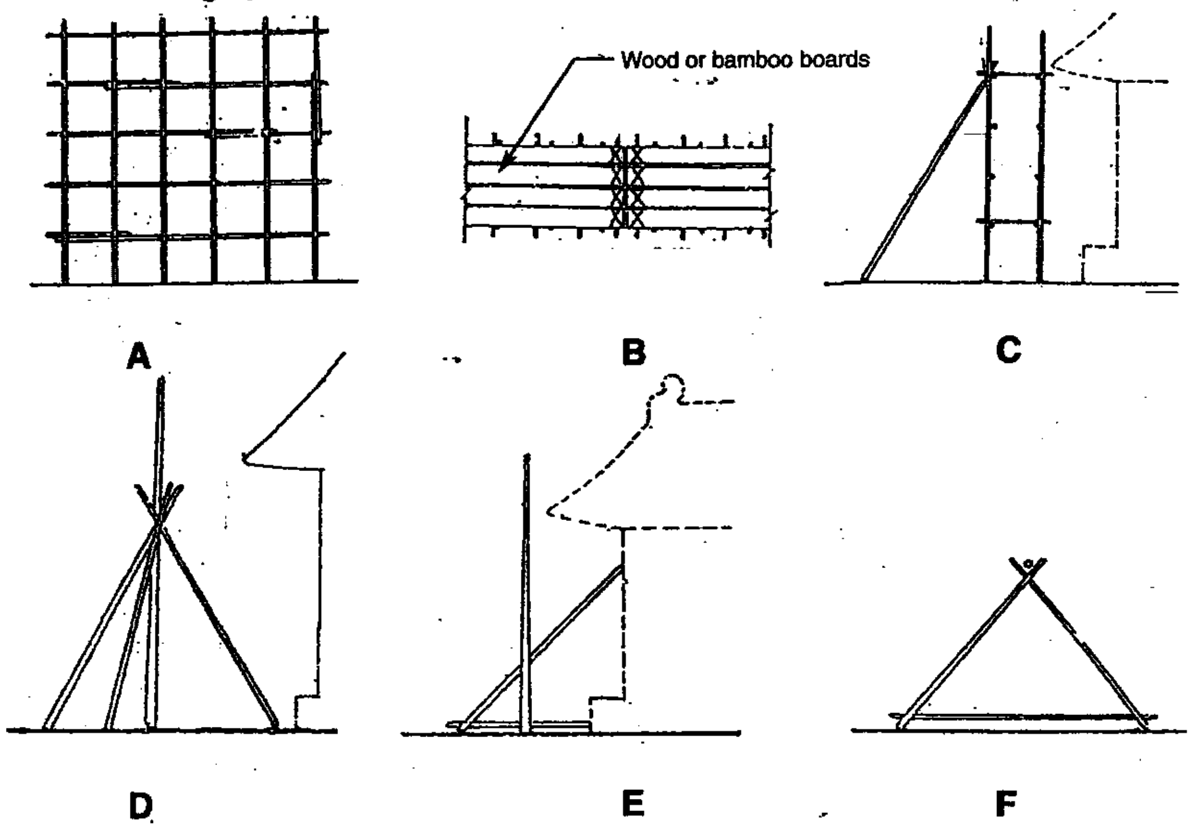
And on those rare occations when the scaffolds do fall, light bamboo poles cause far less damage than heavy metal members, which smash every thing they strike, serioulу hurting buildings, cars, and pedestrian, points out. Lau (1994). Dismantling is a similarly low tech affair. All a scaffolder has to do is cut the ties. Once that is done, the poles are ussually dropped (some times 20 stories or more) along one of the building's side into a batch on the ground. The process, though noisy, is fast and cost efficient. Lau ,(1994)



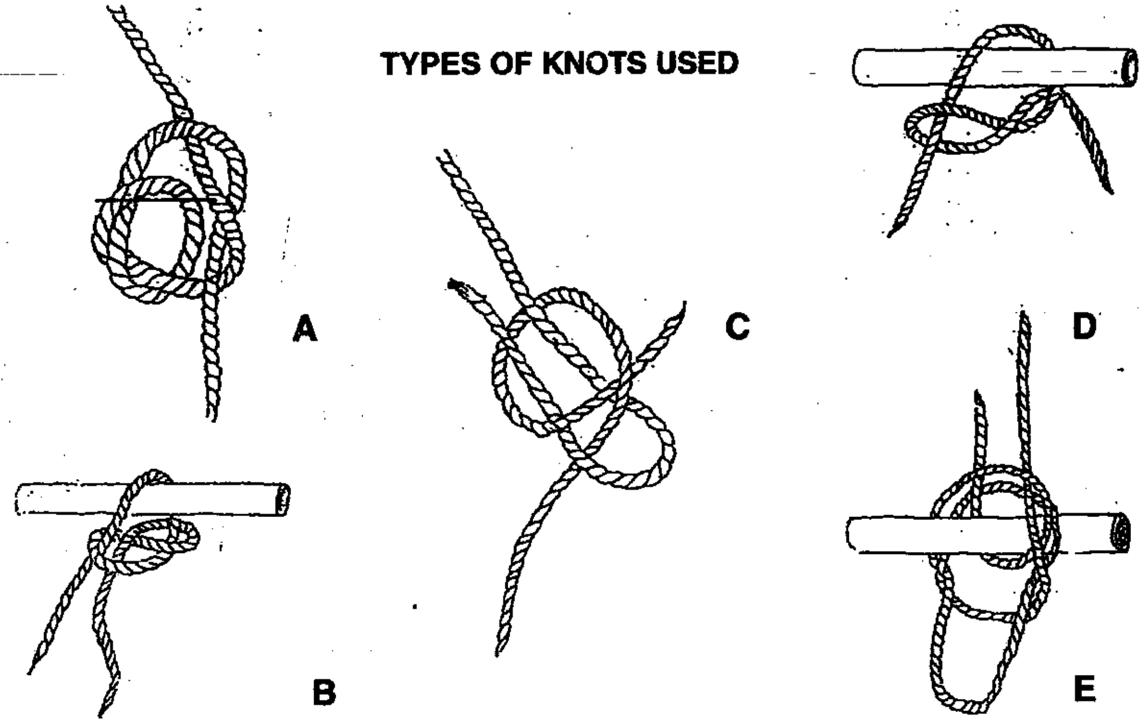
Figs. 19.10 (A and B) *The bamboo strips which were used to bind the poles (A). were replaced about15 year ago by polystirene strips (B)*

SCAFFOLDINGS FOR REPAIR OR BUILDING SMALL STRUCTURES

Fig. 19.11 BRACING OF WOOD AND BAMBOO POSTS

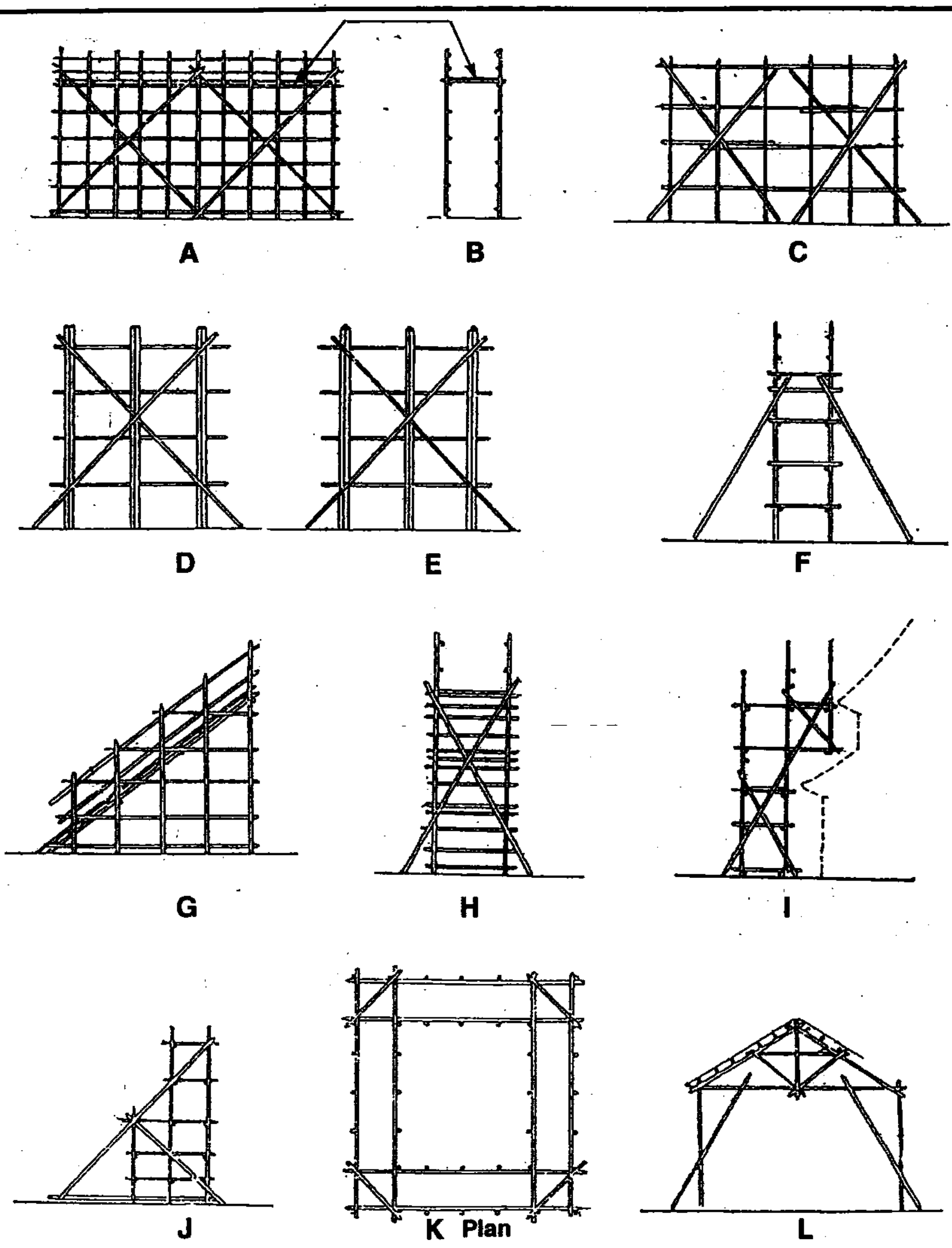


TYPES OF KNOTS USED



Source: Chsui Chingta - China.

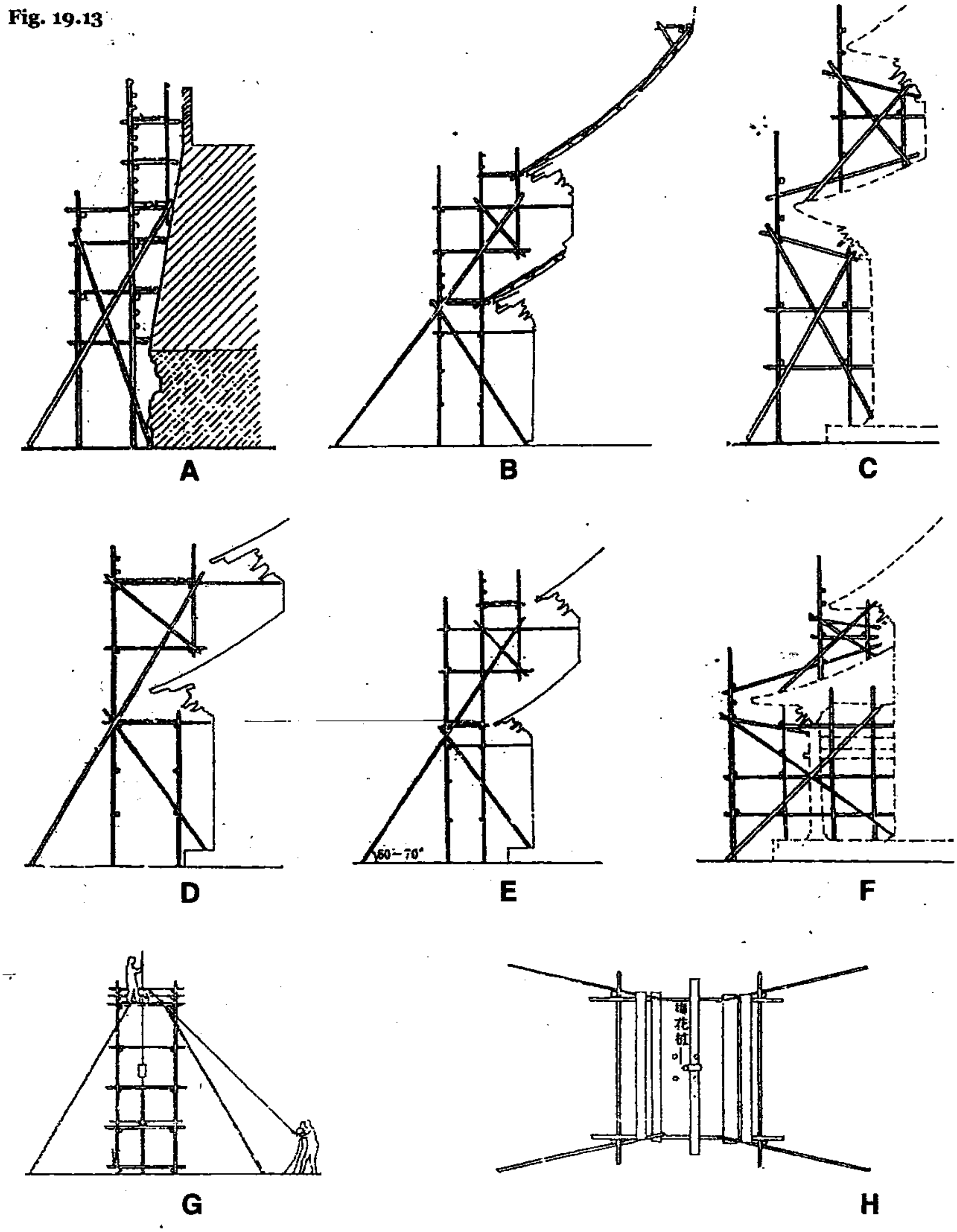
Fig. 19.12 **BRACING OF SCAFFOLDINGS IN CHINA**



Source: Chsui Chingta - China.

DIFFERENT SHAPES OF SCAFFOLDINGS FOR SMALL BUILDINGS (CHINA)

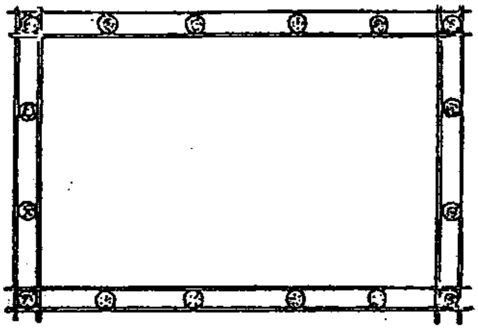
Fig. 19.13



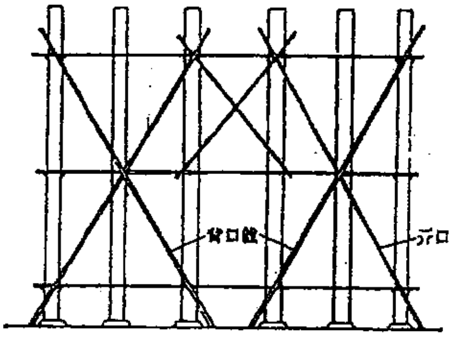
Source: Chsui Chingta - China.

SPLICING AND BRACING OF BAMBOO SCAFFOLDINGS

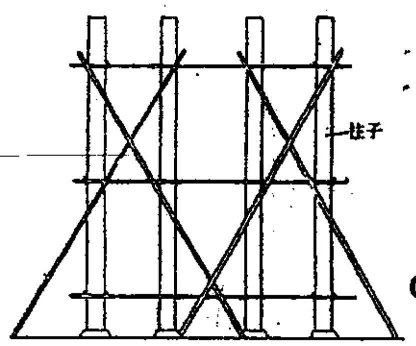
Fig. 19.14 Rectangular scaffoldings



A



B



C

Columns

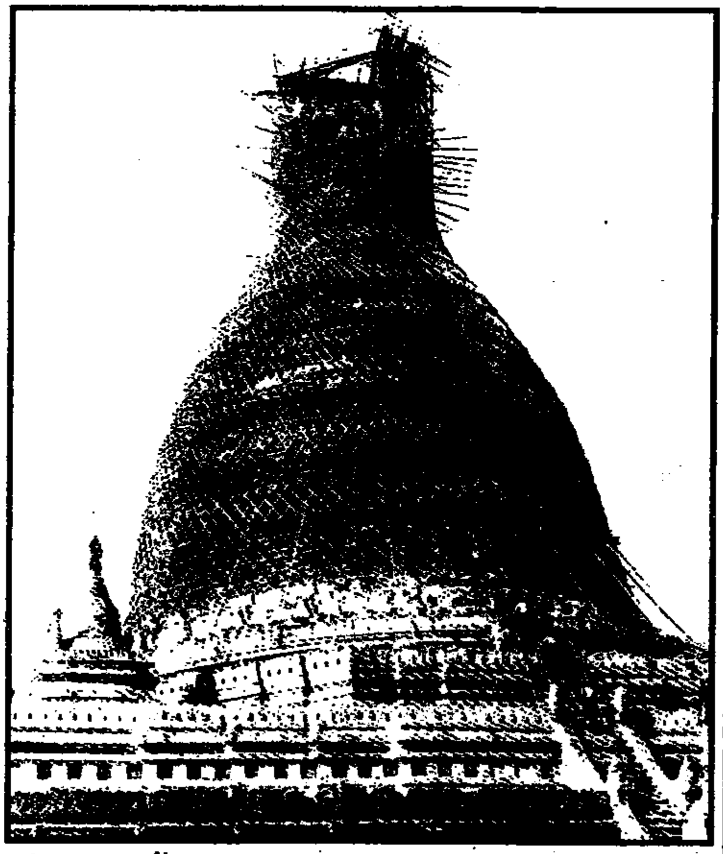
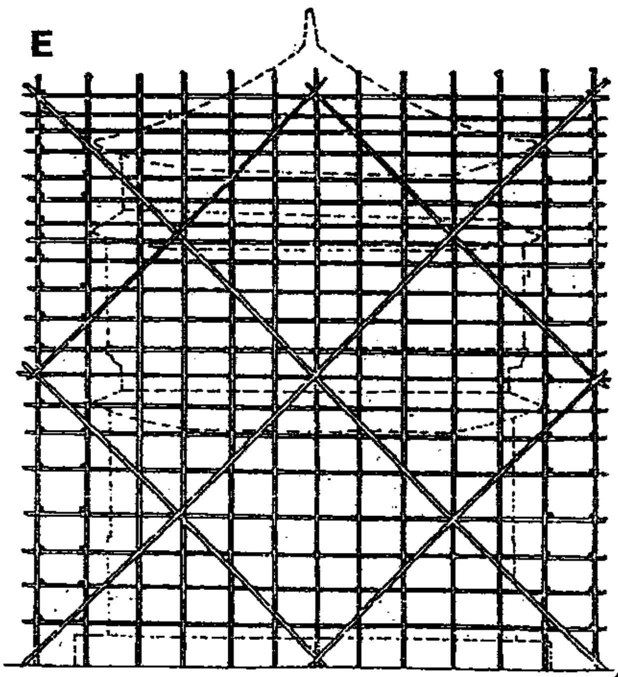
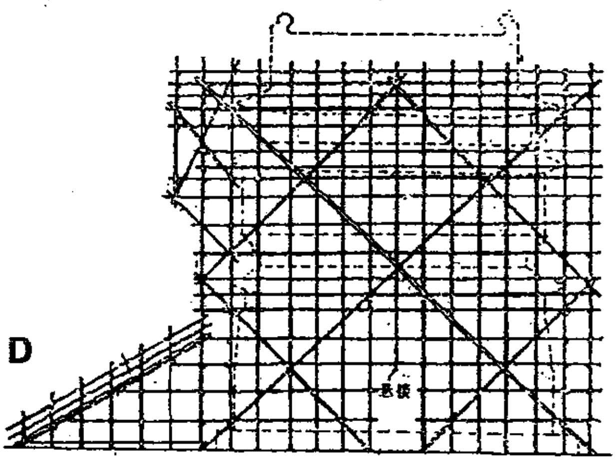


Fig. 19.14 A *Diagonal bamboo scaffoldings are used in the construction or repairing of cupoles of temples like this of the city of Pagan in Birmania.*

E



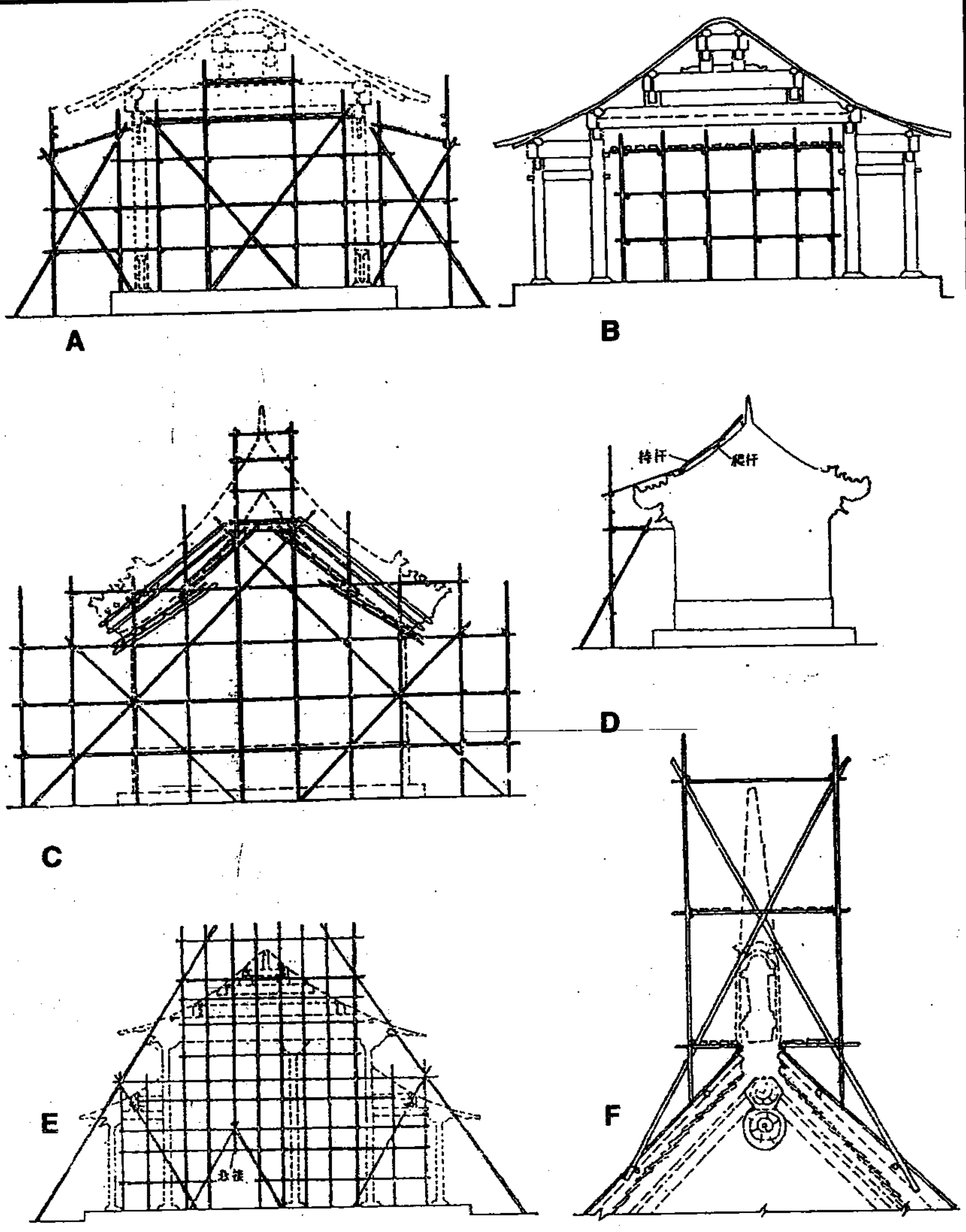
D



Source: Chsui Chingta - China.

Fig.19.15

BRACING OF BAMBOO SCAFFOLDINGS



Source: Chsui Chingta - China.

BAMBOO SPATIAL STRUCTURES

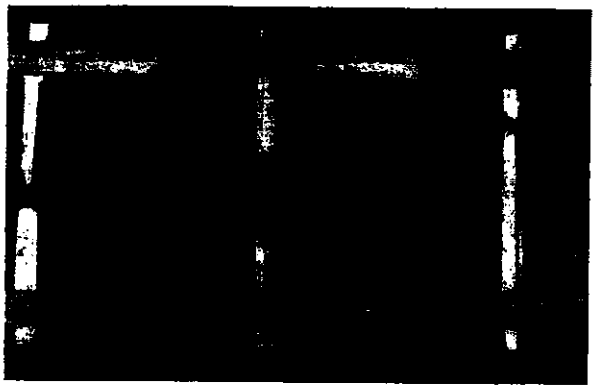
18

Fig. 20.1 TRIANGULAR FLAT BAMBOO SLAT -TRUSSES (WARREN)

The study of the use of bamboo slats in the manufacture of triangular trusses were carried out at the faculty of Engineering of the National University of Colombia as a thesis by W. Carvajal, W. Ortegon and C. Romero (1981). in which I collaborate as adviser.

As can be seen in the photographs this type of trusses offer many posibilities for the construction of very low cost roofs covered with aluminium tyles and spans not longer than 3 meters. Longer trusses present larger deflections the hight varies between 40 to 50 cm.

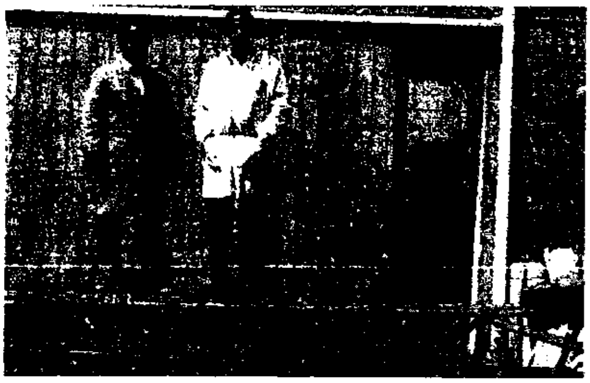
All the structural elements of the flat truss are fixed with low cost screws (Fig. A). The most recomended diagonals are those located with an angle of 60° as shown in the figures B, C and D. In this experiemntes were used the specie *Guadua angustifolia* but is recomended to make tests when are going to be used other species using a pair of trusses as shown.



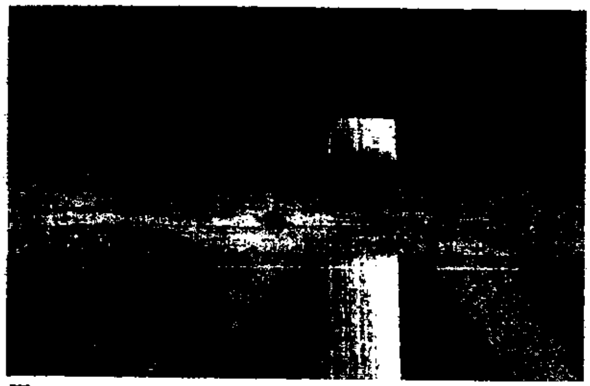
A. *The bamboo slat frame is fixed with screws.*

B. *The truss is very light and its trasportation is very easy.*

C. *Two trusses 3 meters long were experimented.*



D. *The deflection is very small for 150 kg.*



E. *The cost of the bamboo slats and the screws is very low.*

TRIDIMENSIONAL TRIANGULAR BAMBOO SLAT ROOF TRUSSES

Fig. 20.2

This study related to the use of bamboo slats in the construction of tridimensional triangular trusses was carried out as a thesis at the Faculty of Engineering of the National University of Colombia in Bogota, by J.Carrasco, J. Junco and J. Quiroga (1982), with my collaboration. This type of truss is also very useful in the construction of low cost roof s with aluminium tyles and spands from 3 to 4 meters. It consists of two triangular bamboo trusses as can be seen in the Figs. A and B

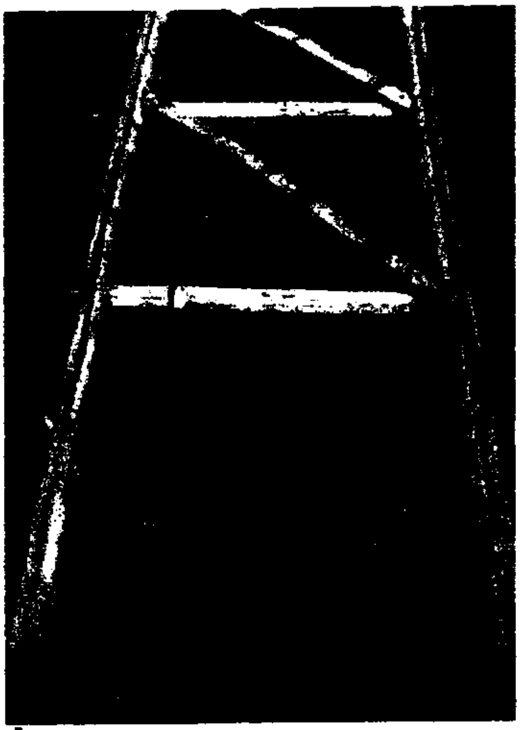
The optimum hight of the truss for lesser deformation was found to be L/8. This means tha if the span is 4 meters the hight of the truss most be 50 cm.

All the joints are fixed with screws and also with galvanized wire. The dimensions of the trusses are shown in the table No.1 (Table 20-1).

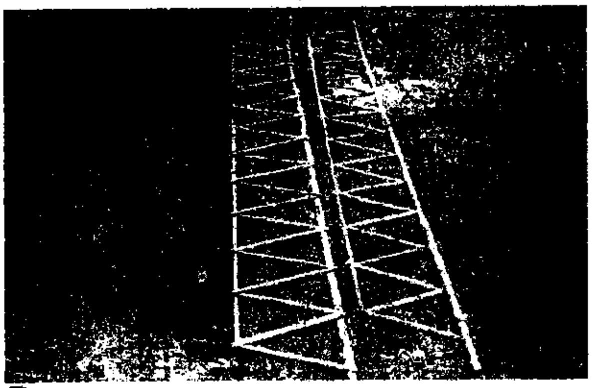
For the manufacture of these type of trusses it is recommended to use mature bamboos 3 or more years old, and for the tension member or lower cord or flange it is recomended the use of slats which are taken from the middle part of the culm.

Tridimensional bamboo triangular trusses can be used in the construction of a double layer bamboo space structure as can be seen in the drawing D.

The bamboo truss design depends on the mechanicanical characteristics of the bamboo specie and these varies according to the place where it grows and the elevation above sea level.

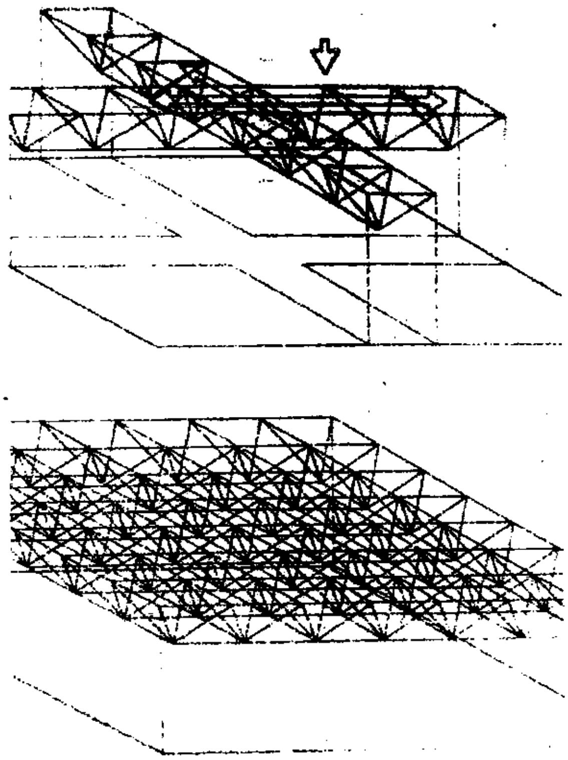


A



B

C. *Trusses with different height.*



D. *Double layer space structure.*

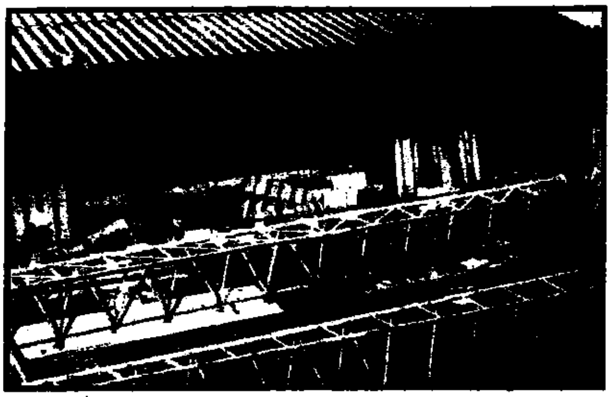
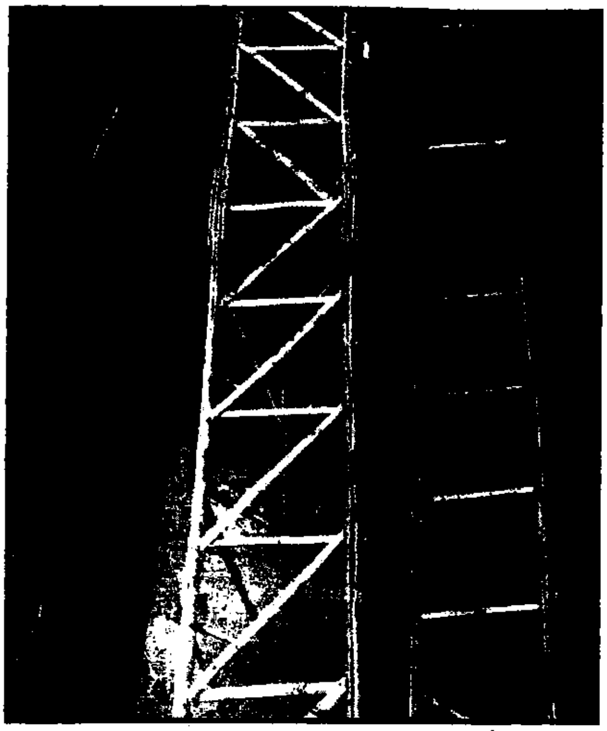


Fig. 20.3 A

B. *This truss could be used for aluminum roof tiles.*



C. *The truss construction.*

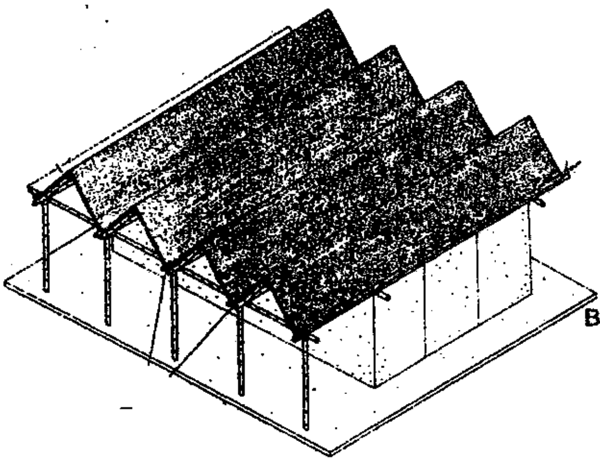
Table 20-1 **PURLINS' GEOMETRY**

Length L mm	LATERAL VIEW dimensions in mm	Separat. chords d(m.m.)	Height of each truss (mm)		
			$h=\frac{L}{8}$	$h=\frac{L}{10}$	$h=\frac{L}{10}$
4000	L= 10 x400; h; Center line	d; h; d=350	500	400	340
5000	L = 10 x 500; h; Center line	d; h; d=420	640	500	400
6000	L = 12 x 500; h; Center line	d; h; d=450	800	600	500

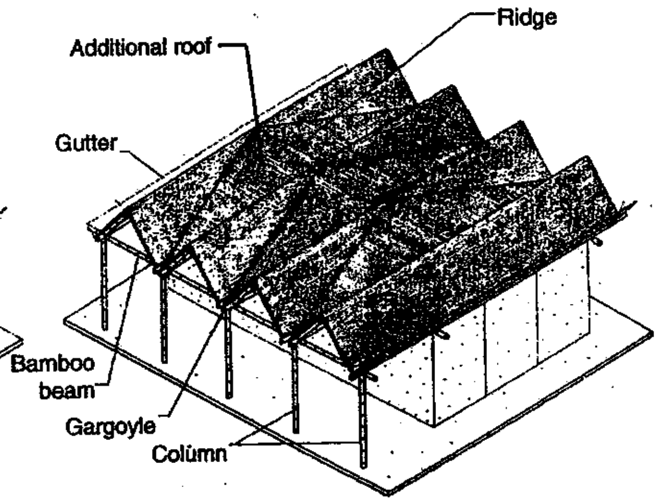
TRIDIMENSIONAL ROUND BAMBOO ROOF TRUSSES

TYPES OF TRIDIMENSIONAL BAMBOO ROOFS

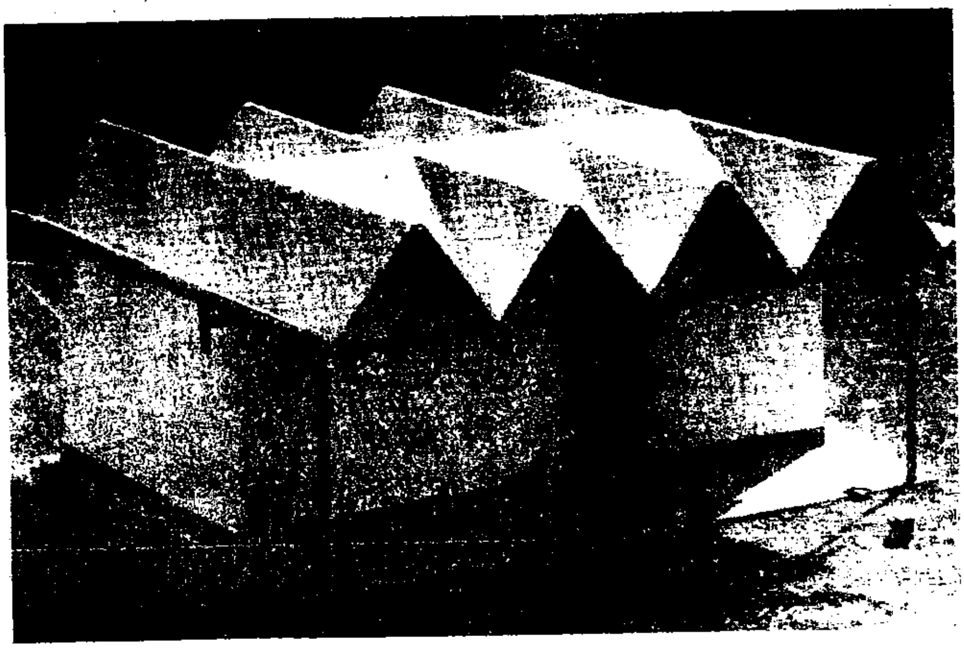
Fig. 20.4



A. With gutters between the trusses



B. With lateral gutters



The picture *shows the school with a roof type B.*

Fig. 20.5 **BAMBOO ROOF TRUSS CONSTRUCTION (1)**

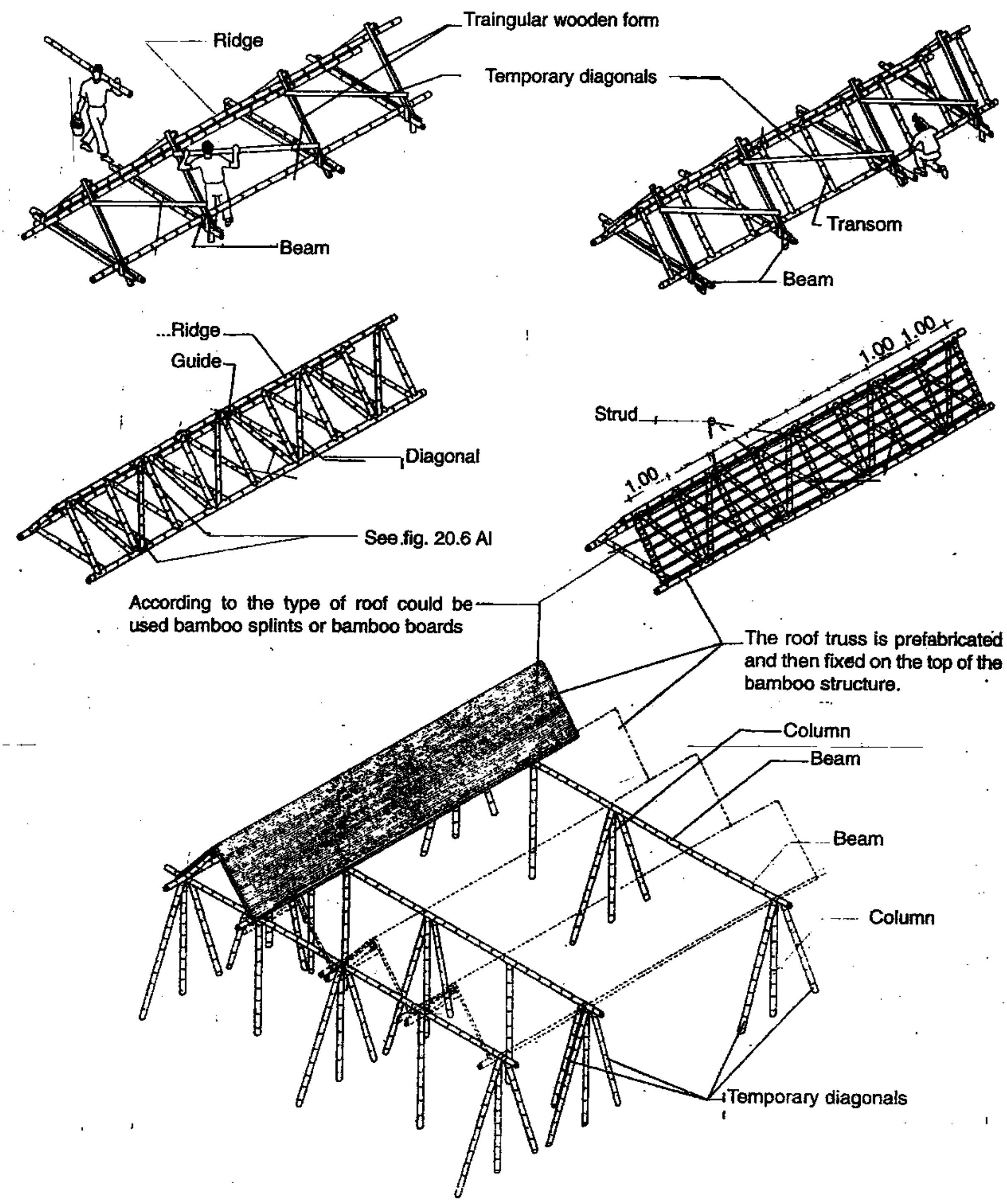


Fig. 20.6 BAMBOO ROOF TRUSS CONSTRUCTION (2)

This is one of the experimental constructions that made in the Bamboo research Center (CIBAM) with the purpose of teaching to the campesinos how to build a low cost rural schools using prefabricated tridimensional bamboo trusses 8 meters long.

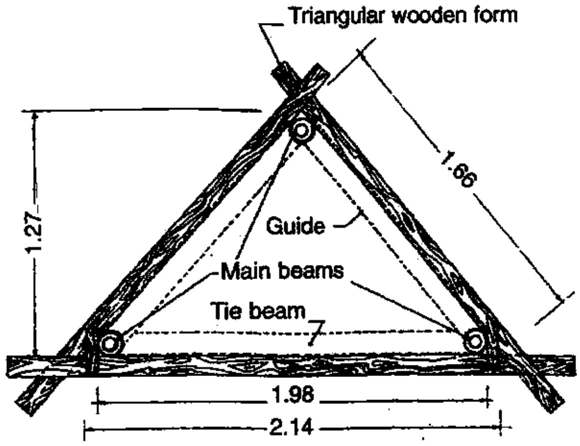
A.-B. The wooden triangles used as guides in the prefabrication of the 6 meter trusses.

C.-Testing the deflection (3 cm)

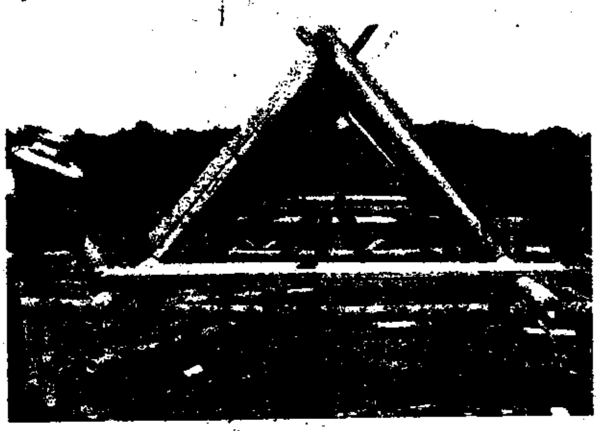
D.-The truss is so light that it can be moved by 4 people.

E.-Once covered the trusses with bamboo boards they were located in the top of the structure by a truck crane which took 20 minute mounting the four roof trusses. The trusses can be also be mounted by 8 persons. It is recomended to build first the walls and then to pumount the trusses. In this case we made the revers while I got the money for building the walls.

Once the trusses are fixed to the wooden beams, are plastered with a cement mortar (1:2).

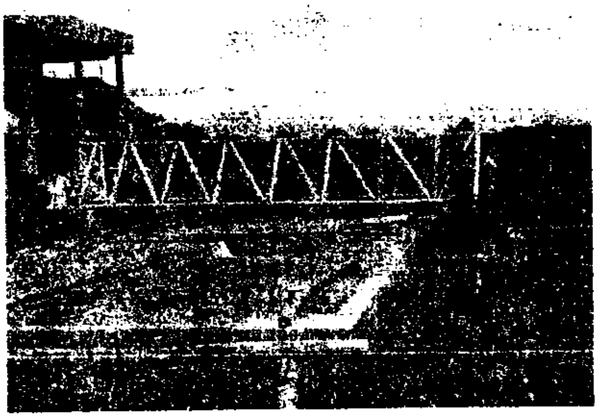


A

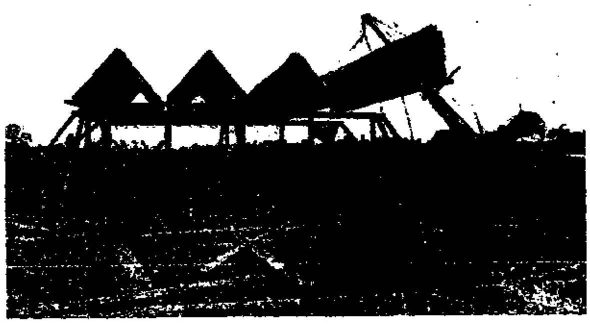


B Show the wooden triangles.

C Testing the deflection.



D The truss is very ligth and could be transported by 4 workers.



E Seventy minutes take in to mount the 4 trusses above the bamboo structure.

STRUCTURE MADE WITH TIED LAMINATED BAMBOO (not glued)

MOSQUE BUILT WITH TIED LAMINATED BAMBOO IN INDONESIA

Village Mosque was builted in Jakarta, Indonesia in 1971 for the international Subud World Congress. (GATE, 1979).

The most interesting feature of this mosque is that its structure was built with tied laminated bamboo not glued.

Fig. 20.7 shows the front elevation and plan of the Mosque built with a tie laminated bamboo structure (not glued).

Fig. 20.7

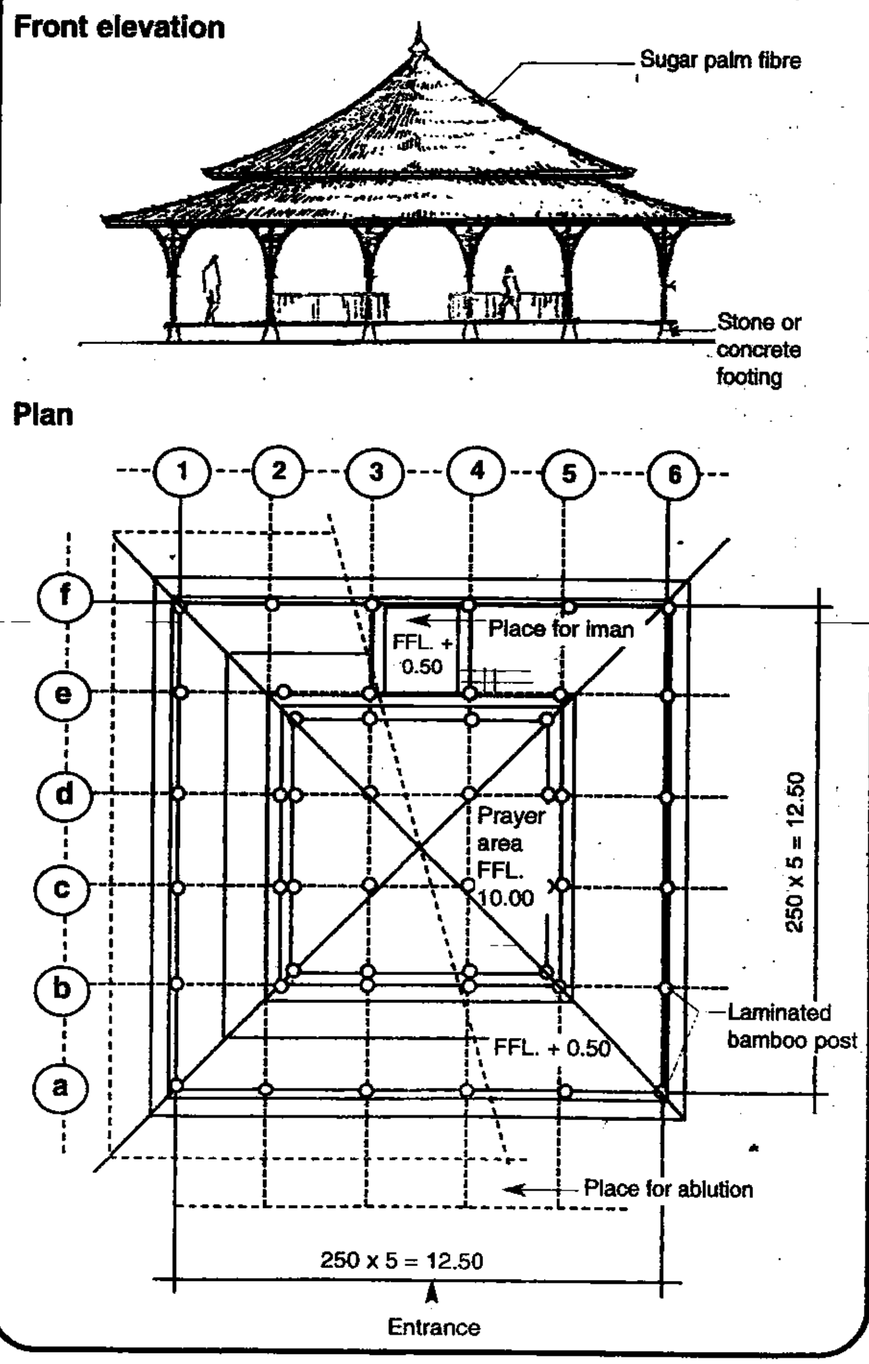


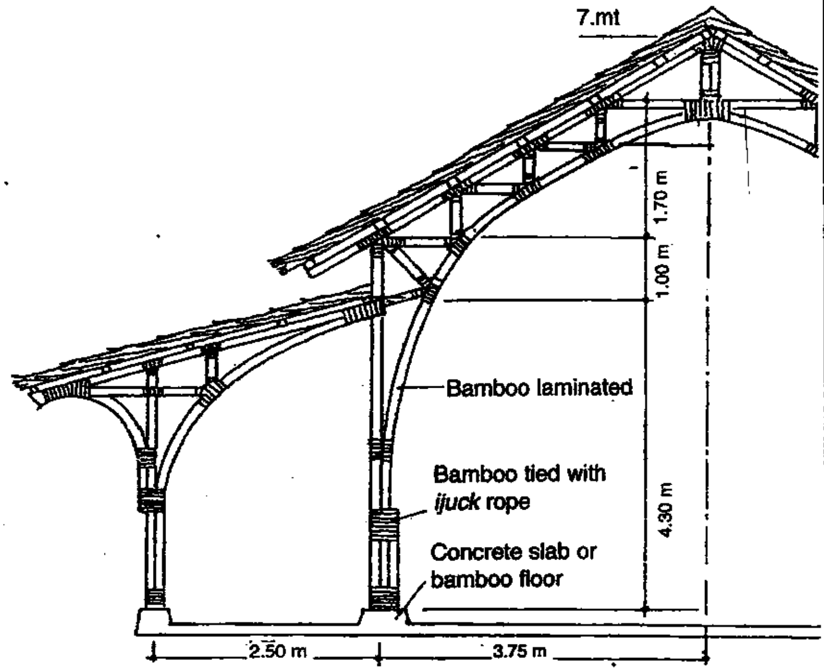
Fig. 20.8

CONSTRUCTION DETAILS

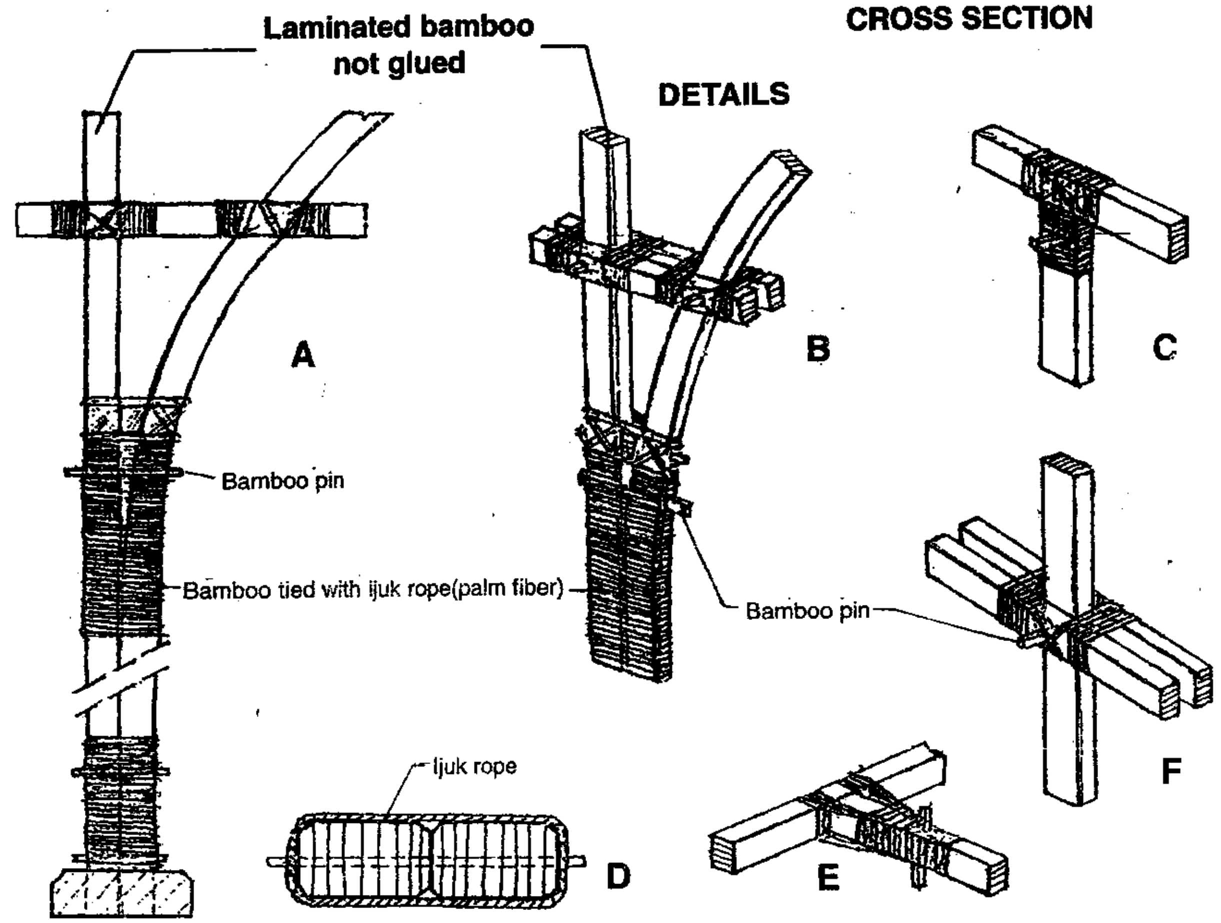
This frame structure was made with bamboo laminated splints, not glued, joined together with bamboo pins and tied with a palm fiber rope known as *ijuck* as can be seen in the details. This palm fiber could last up to 100 years.

The bamboo laminated slats used in its cosmstruction of the structure was not treated and consequently the structure was destroyed by the insects. Probably the bamboo used was less than three years old, or the the interior and soft part of the culm wall was not removed.

This structure has to be made with bamboo slats taken from the exterior part of the culm wall of bamboos three years old or older, following the exterior line of a scale drawing of the structure traced on the concrete floor or using a wooden form of the arches as shown in Fig. 20.9.



CROSS SECTION

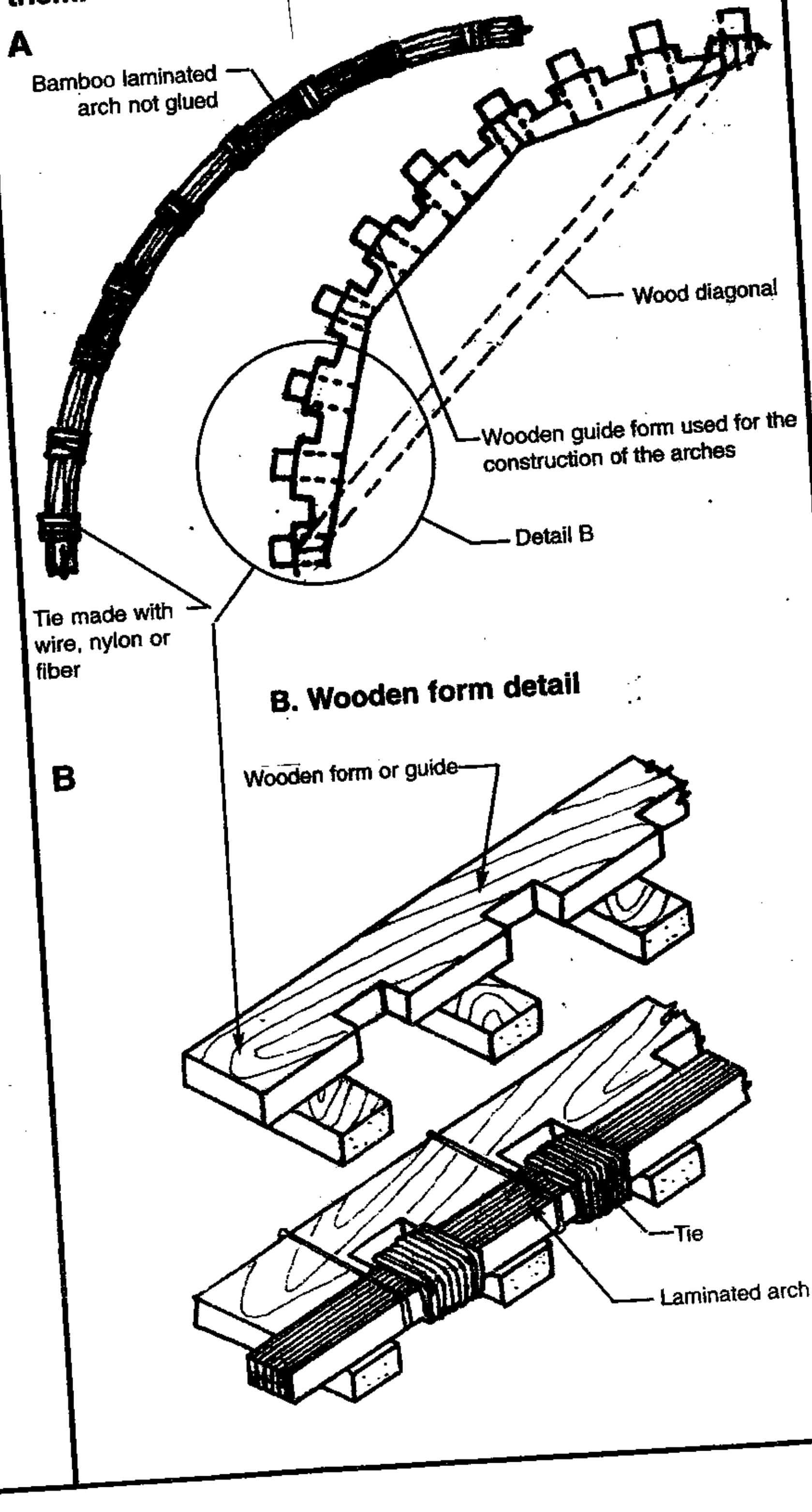


HOW TO BUILD TIED BAMBOO LAMINATED ARCHES

The most simple way for making a tied bamboo laminated arch is drawing a curve with the shape of the arch on the surface of a concrete or a wooden floor and follow this line with the bamboo laminations, but this operation requires a lot of lateral supports or persons for fixing the laminations in their position, unless the floor could be perforated for introducing some vertical bars for fixing the laminations while they are tied.

The best method is to make a wooden form like the one shown in the figures A and B. This form that I designed permit to fix all the laminations and to tie them very easily, because there is enough space below and in the back of the laminated arch for introducing the cords and the fingers as can be seen in figure B.

Fig. 20.9 A.- Type of wooden arch form or guide, that could be used for fixing the laminations before to tie them.



GLUED LAMINATED BAMBOO BEAMS AND ARCHES

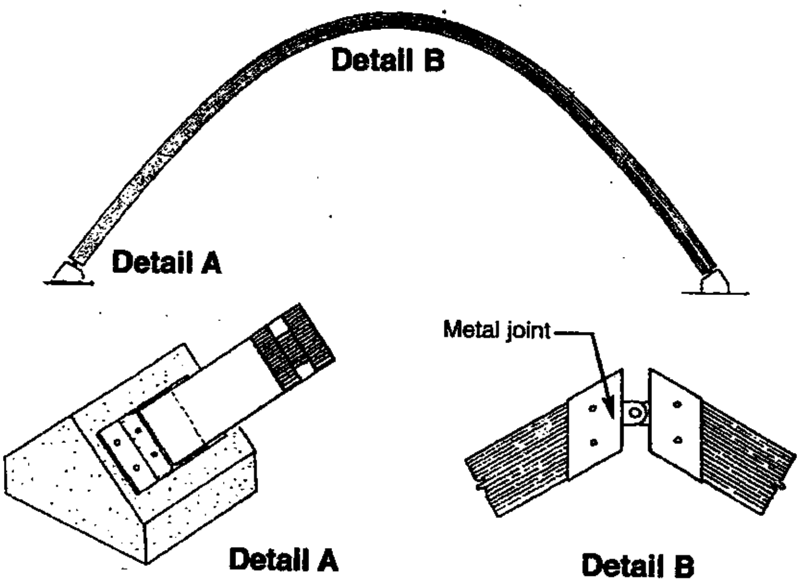
Fig. 20.10 TYPES OF GLUED LAMINATED BAMBOO ARCHES

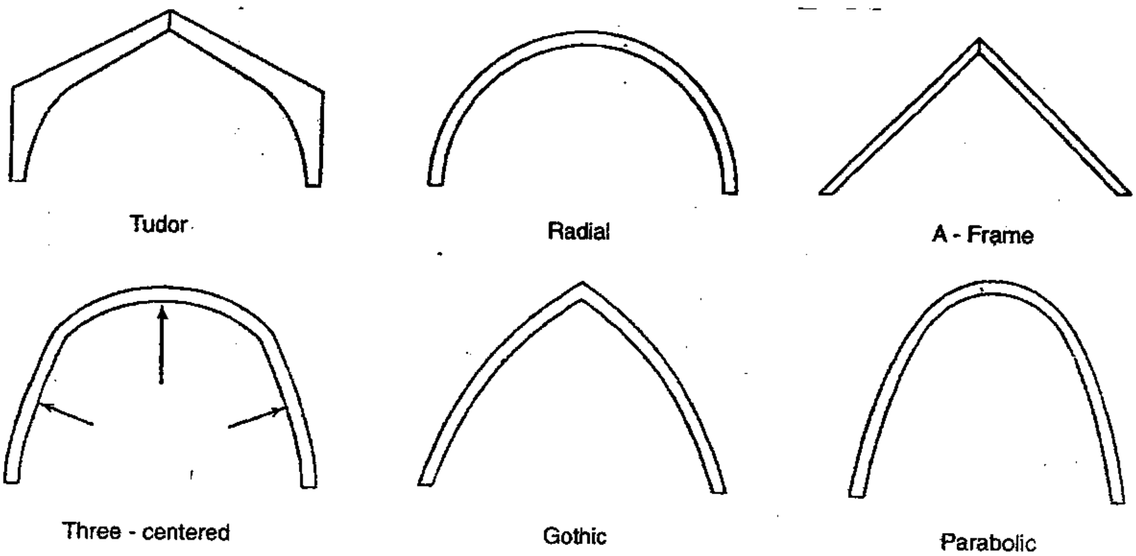
In the manufacture of bamboo glued laminated beams and arches with structural purposes, is followed the same manufacture process indicated for the manufacture of straight and curved glued laminated pieces used for furniture. But there are some differences related to the type of adehesive used and the wide of the laminas used for the manufature of beams and arches

The adhesive used in the manufacture of laminated pieces for furniture is urea formaldehyde, but in the manufacture of bamboo structural laminated pieces must be used fenol-formaldhyde, resorcinol or epoxy.

The width of the beams and arches varies according to the spand or length.

With bambo laminated can be manufactured all types of arches that are builted with wood laminated whic are shown in the drawing below.

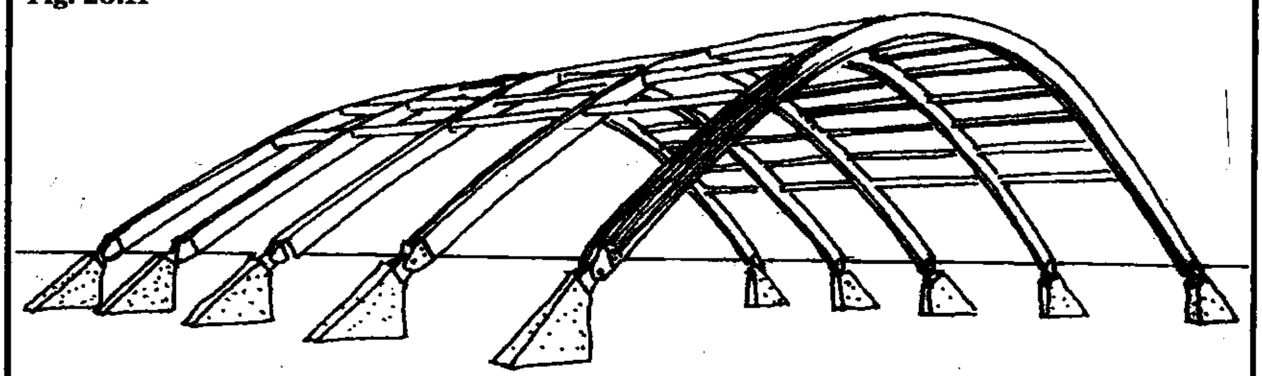




All the above arches can be manufactured with wood laminated or bamboo laminated.

GLUE-LAMINATED BAMBOO ARCHES WITH 2 OR 3 ARTICULATIONS

Fig. 20.11



A. *Glue laminated bamboo arches with two articulations.*

In the manufacture of wood laminated beams there is not a problem with the width of the beams, but in the case of bamboo the maximum width depends on the diameter of the culms. For example if the diameter of the culms is about 10 cm, the maximum width of the laminations that we can get is about 2.5 cm and with a bigger diameter this dimension will increase. We can not make a laminated beam or an arch 2.5 cm wide because of the buckling, but this problem can be solved gluing several arches (2.5 cm wide) in order to increase its width to 5 cm- 7.5 cm or 10 cm or introducing between parallel arches separators or spa-cers, as shown in the Figure 20.10 (detail A). Other solution which takes more time is to make square bamboo culms in order to get bamboo laminations up to 10 cm wide or more depending on the circumference of the culm as shown in Fig. C.

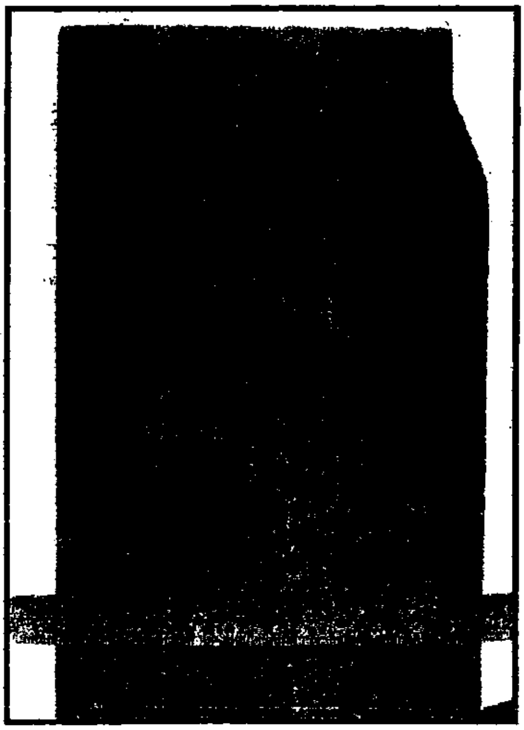


Fig. B. *There is no problem with the hight of the bamboo laminated beam because it could be increased. The problem of the width can be solved as explained above.*

Fig. C. *The four sides of the square bamboo can be used in the manufacture of glue laminated bamboo structures which require laminas wider than 3 cms.*

BAMBOO COMPOSITE BEAMS ('I' and 'Box' bamboo beams)

PLYBAMBOO WEB BEAMS WITH BAMBOO LAMINATED FLANGES

Ply web beams are usualy of "I" or "Box" profile. This kind of beams which are known as laminated veneer lumber (LVL) have been manufactured up to the present time utilising softwood in the laminated flanges and a structural panel product such as plywood or hardboard in the web construction glued into a machined groove in the LVL flangess. Each flange may consist of one or several wood members glued together and hot-pressed with phenol-formaldehyde adhesive.

Work in the 1940's on this material concept was targeted for production of high-strength aircraft structures. Later research studies of LVL were aimed at defining the effects of processing variables and included veneer up to 12mm (1/2 inch) thick The industry presently uses veneers 3 mm to 2.5 mm (1/8 to 1/10 inch) in thickness which are hot pressed with phenol formaldhydeadhesive into lengths from 2.50 to 18 meters (8-60 feet) or more. Joints between individual veneers are staggered along the LVL to avoid gross strength-reducing defects. Common practice in the United States is for these to be butt joints , or the veneer ends may overlap for some distance to provide load transfer.

Some of the first applications of LVL were inspired by rising costs and shortages of high-grade solid sawn lumber for use in parallel-chord trusses and as scaffold planks The first norm related to "prefabrication of wood 'I'- joists" was accepted by the International Conference of Building Officias in 1987 and was the base in creating *ASTM D5055 Standard Specification for Establishing and Monitoring Structural capacities of Prefabricated Wood I-Joists*, in 1990.

Truss manufacturers have found the LVL concept capable of opening new markets. Strength-reducing defects are virtually nonexistent, making possible the feasibility of light trusses and I sections. Current markets for these I section beams are as joists and rafters in light-frame construction. Ply web beams are particularly suitable and economical for roof spans of 6-20 m when spaced at about 1.20 m centres. The closeness of the spacing permits simple, cheap secondary systems of cladding and ceiling to be used.

Scaffold planks are an important LVL product. Uniformity of properties and an extended service life due mainly to splitting resistance are the primary reasons for the succes of LVL in this market. This splitting resistance is atributed to the stress relief afforded by lathe checks in the veneer. Another industry,that has embraced LVL is that of manufacturing housing components because of major weight and material savings on the fabricated components. LVL is considered to be cost-effective in secundary manufacturing operations because of reduced ocurrence of such typical lumber defects as twist, crook, warp, splits, and strenght reducing knots.

Bamboo in the manufacture "I" and box beams represents a new technology in bamboo utilization which up to the present has not being experimented. But due to the extraordinary strength of bamboo laminated pieces and structural plybamboo (developed by the author in Colombia), which are superior to those manufactured with softwood, bamboo will have in a very near future a very important rolle in the manufacture of prefabricated ply web beams and rigid frames structures. Some of the possible variations of bamboo ply web beams are sketched in Fig. J

In plybamboo web beams, the structural interaction between flanges and web or webs is achieved by a continuous glue joint.

Although the glue faces can be held together during curing by pressure clamping. In the case of wood web beams the more common method is to obtain glue-line pressure by either nails or staples (which are not recommended for bamboo). Staples would be used only in fixing plywood to softwood, as with a Box beam, and not for fixing softwood to softwood.

The majority of ply web beams are built with a camber to off-set dead load deflection. This usually requires a camber in the order of 3-4 mm per 2.4 m chord of camber curve. The adhesive used for this purpose is resorcinol or other one with similar characteristics.

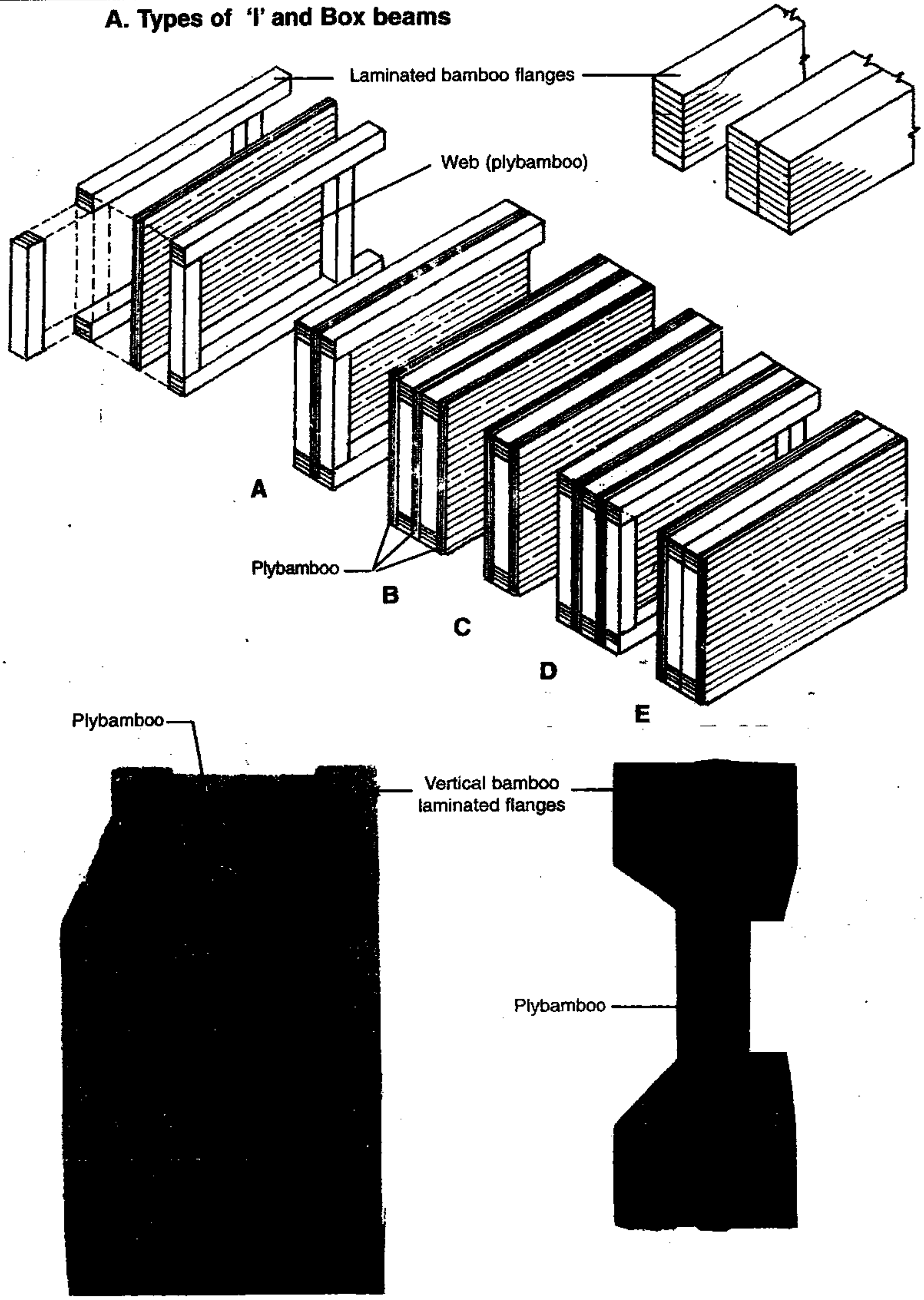
Table 20-2 Allowable design stresses in code approved for laminated vener lumber LVL

Design stress	Range (Lb/in²)
Flexure	2,200 - 4,200
Tension parallel	1,600 - 2,800
Compression parallel	2,400 - 3,200
Compresion perpendicular to the grain:	
Perpendicular to glue line	400 - 600
Parallel to the glueline	400 - 800
Horizontal shear:	
Perpendicular to glueline	200 - 300
Parallel to glueline	100 - 200
Modulus of elasticity	1.8×10^6 - 2.8×10^6

Source: Wood hand book (1987 - Note:These properties are for dry conditions of use and are subject to adjustment for duration of load

Fig. 20.12 "I" AND "BOX" BAMBOO BEAMS

A. Types of 'I' and Box beams



CONSTRUCTION OF FLOORS AND ROOFS WITH "I" AND "BOX" BEAMS

Fig. 20.13 Floors construction

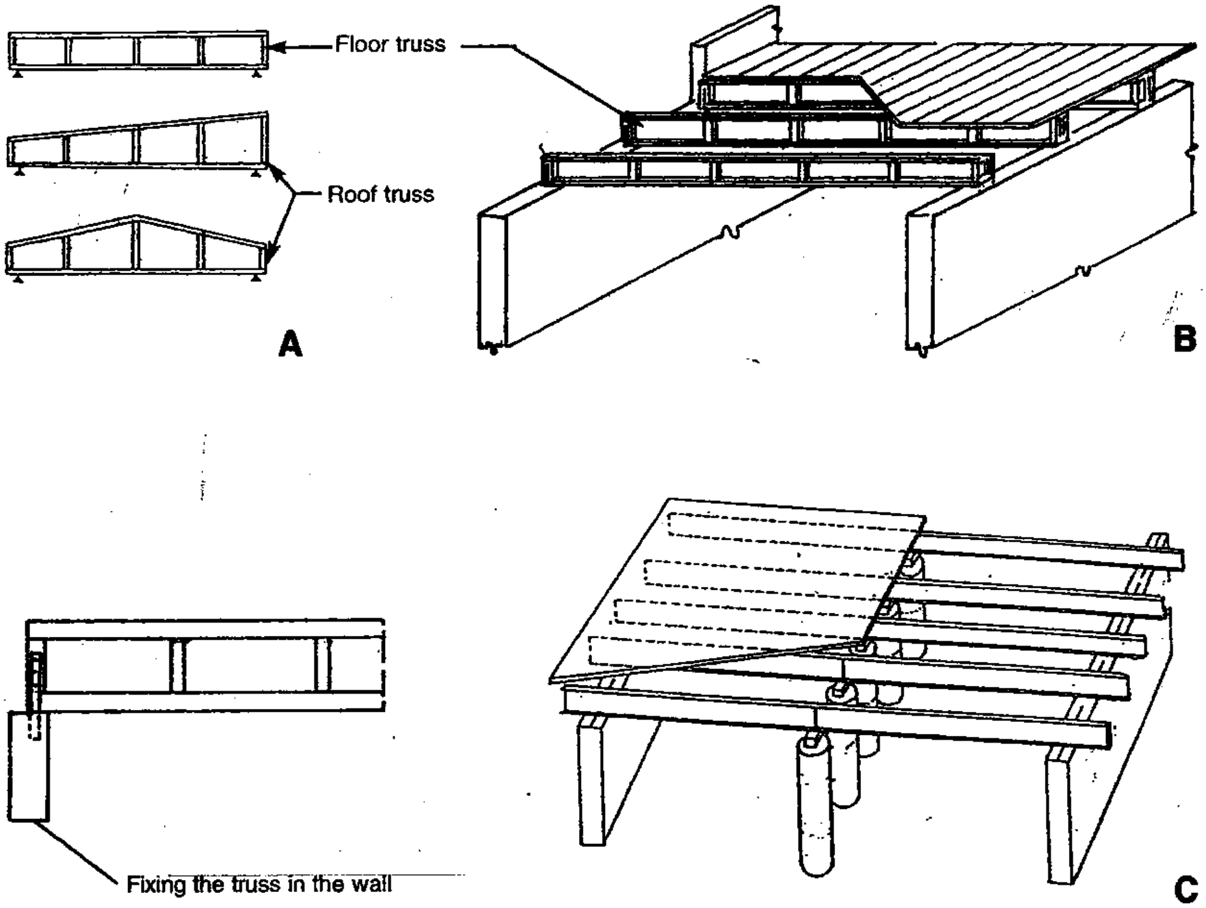
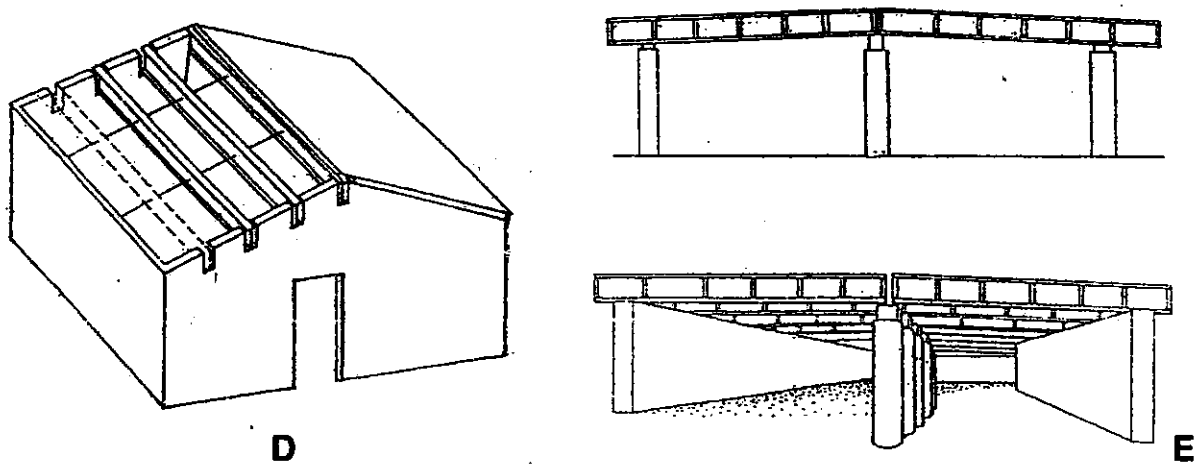


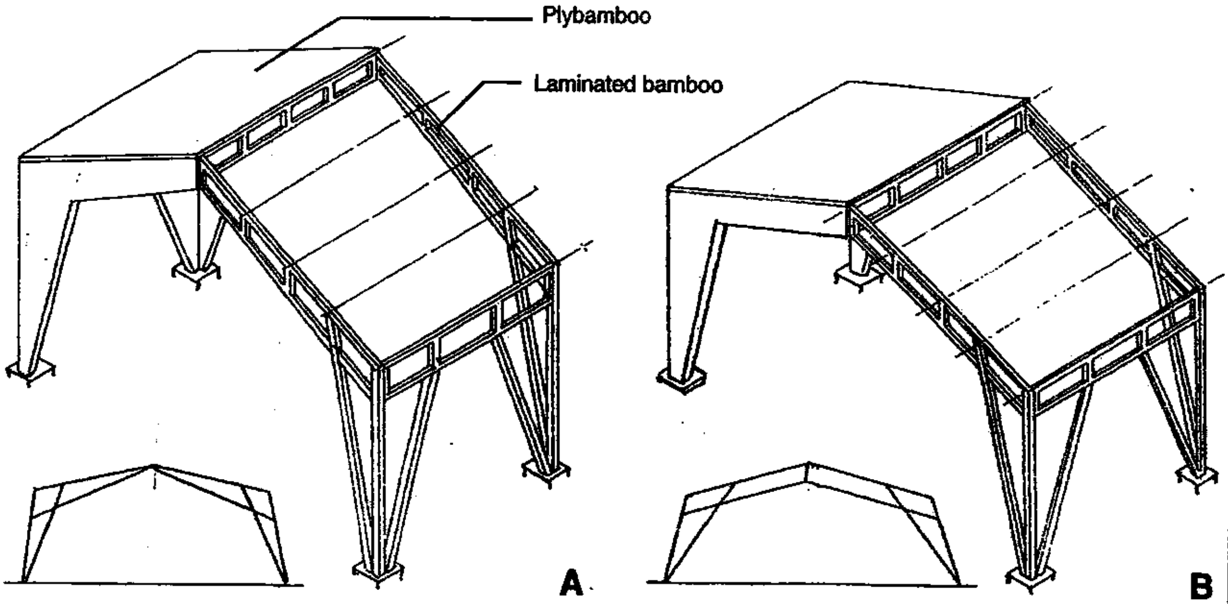
Fig. 20.14

Construction of roofs

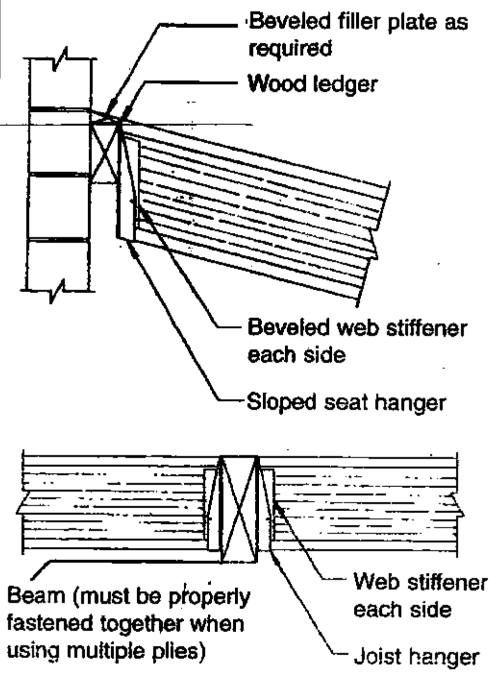


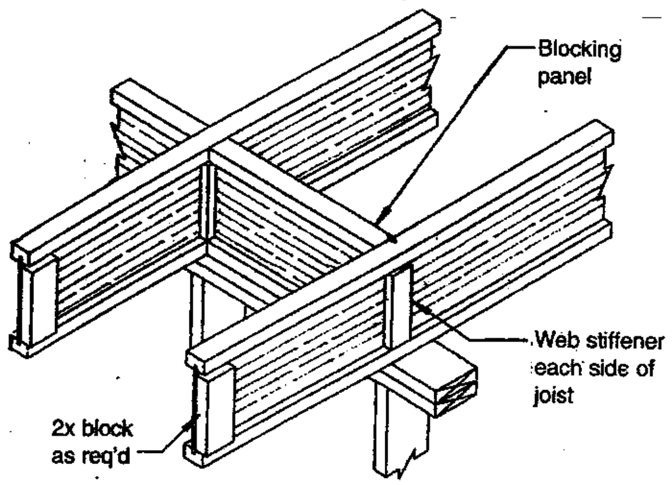
CONSTRUCTION OF RIGID FRAMES WITH "I" AND "BOX" BEAMS

Fig. 20.15



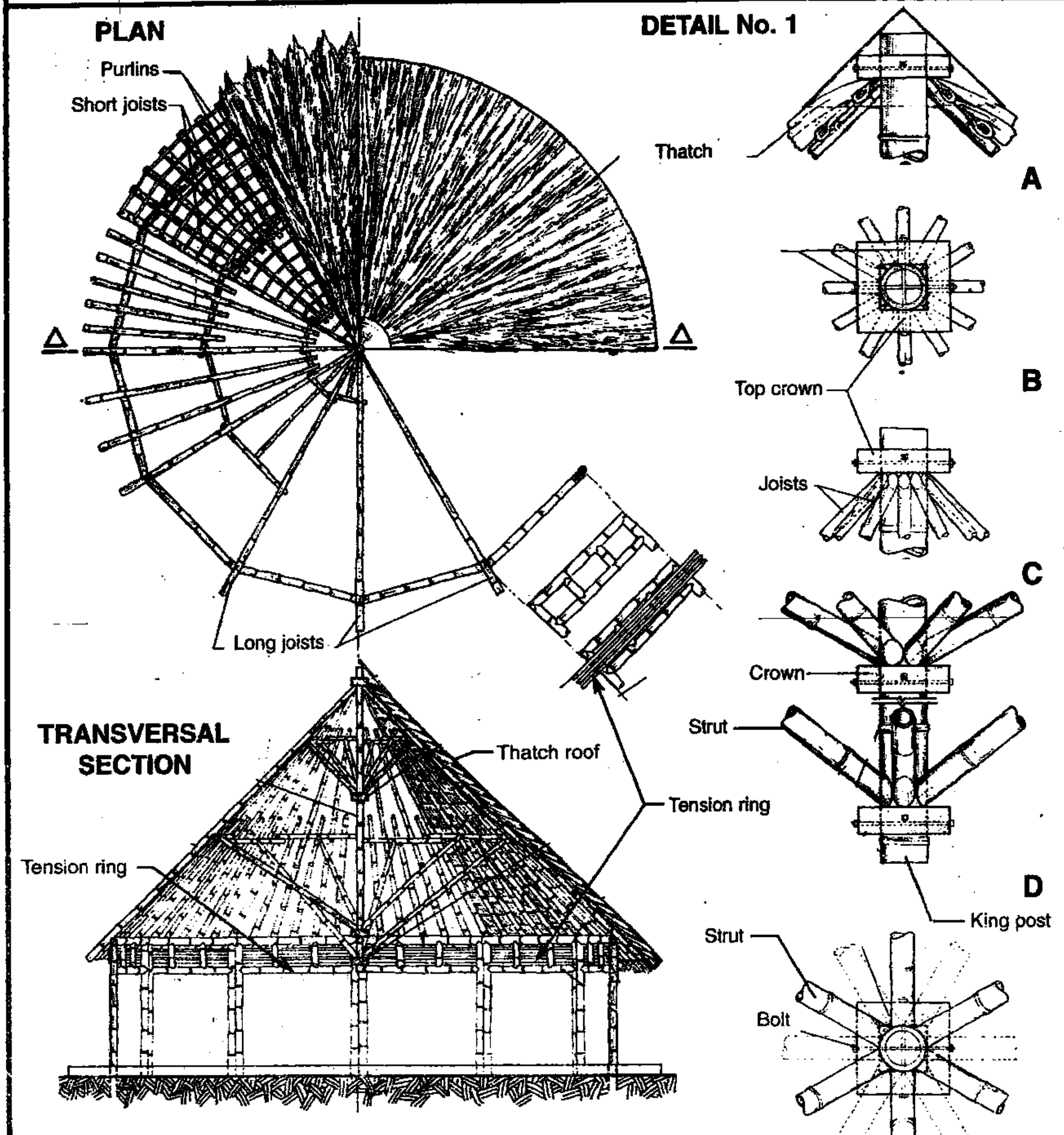
GENERAL CONSTRUCTION DETAILS FOR WOOD AND BAMBOO





CONICAL THATCHING BAMBOO ROOFS

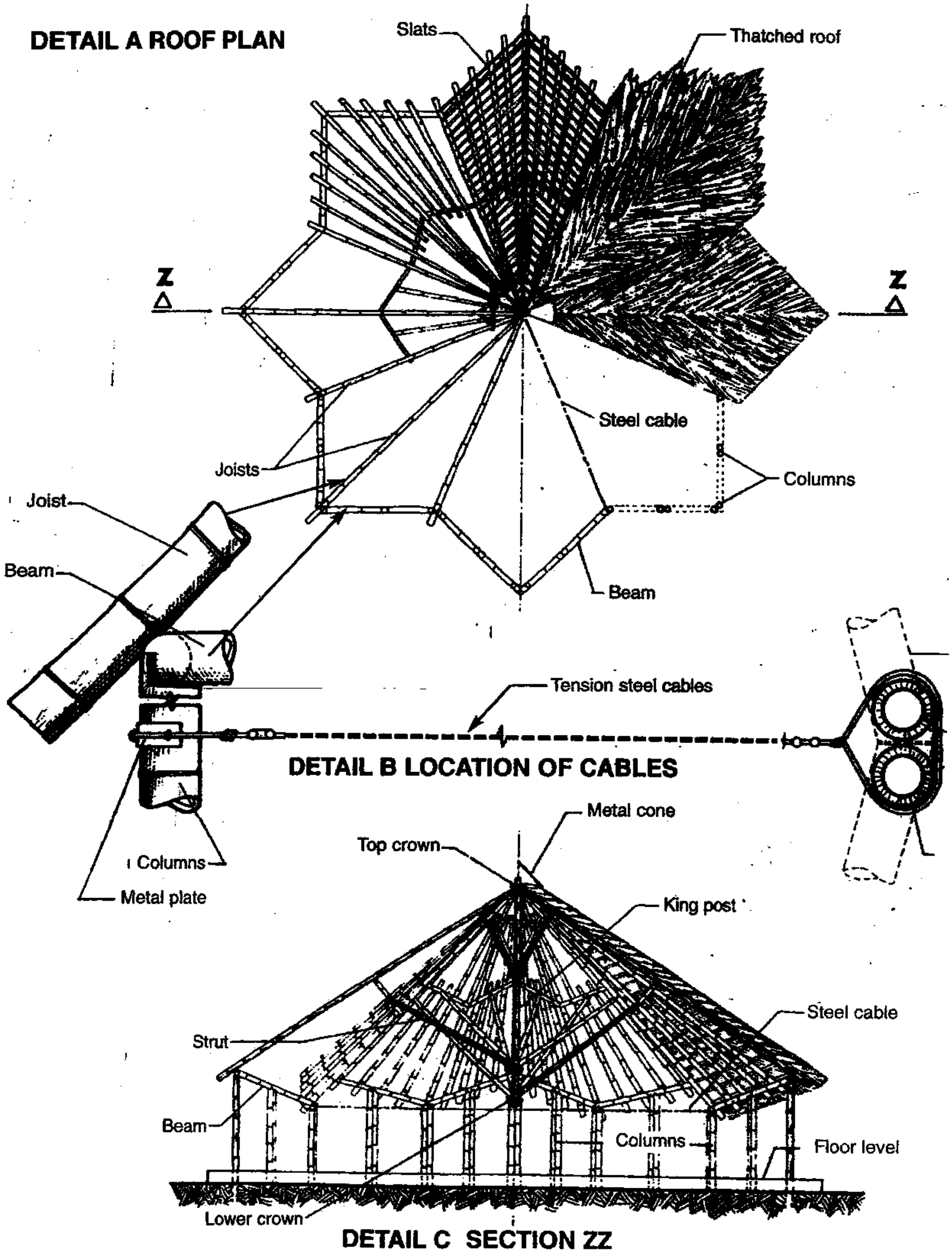
Fig. 20.16 CONICAL ROOF WITH TENSION RING (1)



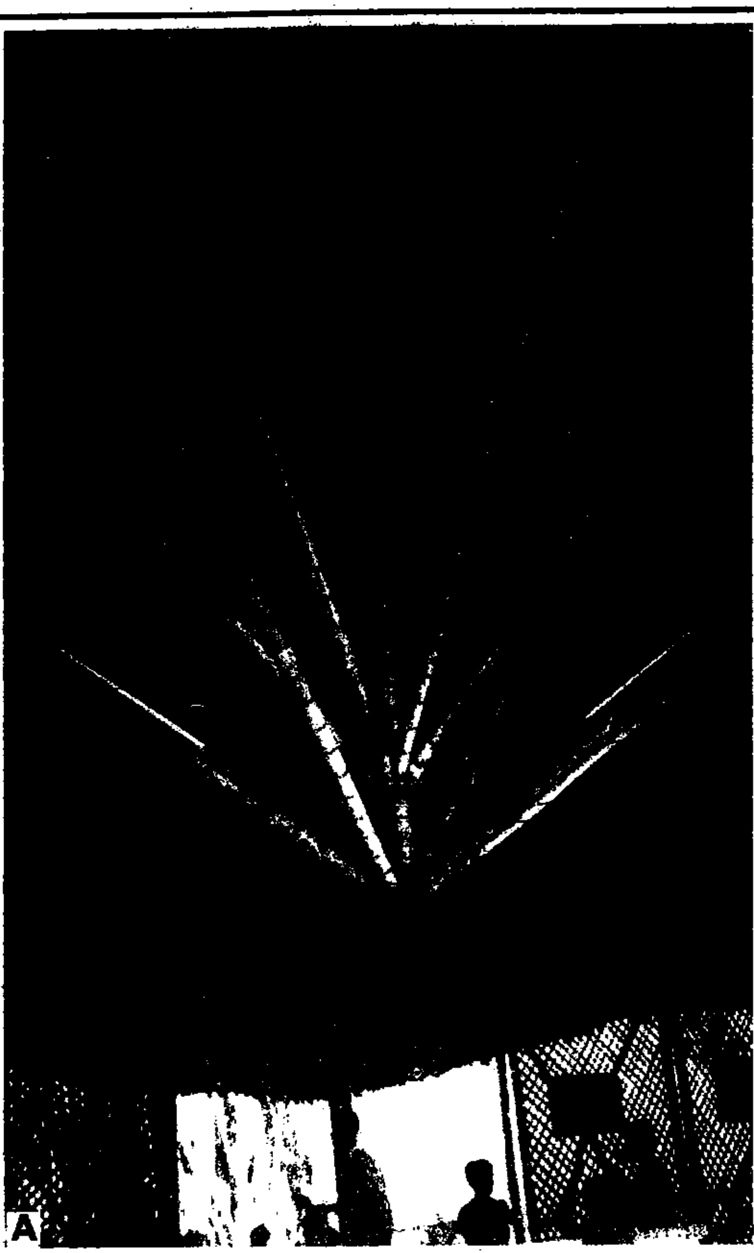
Note: The round conical roof without support in the center must have a bamboo tension ring surrounding the top part of the columns as shown in the transversal section.

CONICAL THATCHING ROOF WITH RADIAL TENSION CABLE S (1)

Fig. 20.17 Due to the shape of the kiosk instead of a tension ring this kiosk has radial tension steel cables



CONICAL THATCHING ROOF WITH RADIAL TENSION CABLES (2)


A


B

Fig. 20.18 *A and B show the kiosk's internal structure which is similar to an umbrella. The king post has four crowns which support the diagonals or struts.*

In 1963 when I finished my studies of architecture at the National University of Colombia, I built this kiosk for the Country Club of Palmira city. This was my first work with bambooand since then " I fell in love" with this wonderful plant. The kiosk had an external diameter of 23 m.

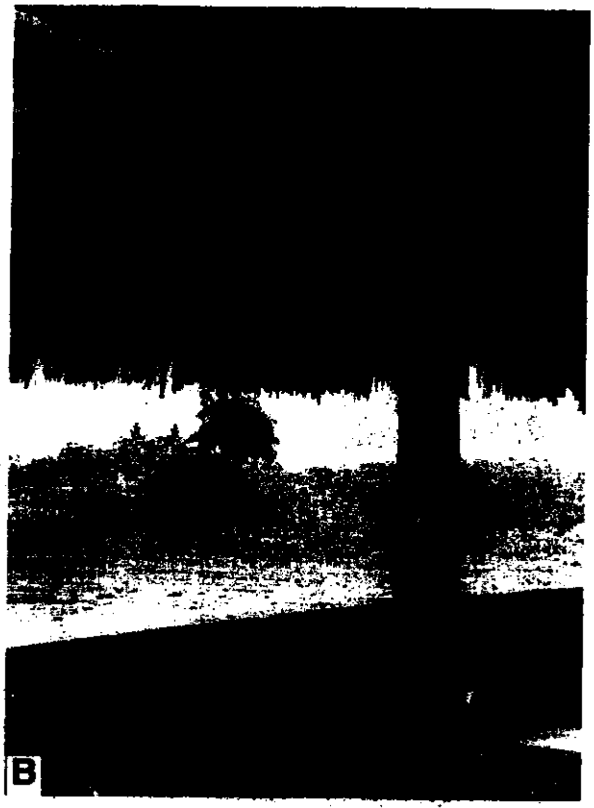
Traditionally the bamboo kiosks were built in the Cauca Valley State, in Colombia with a circular plan with a maximum diameter of 12 m, as shown in the Fig. 20.16. When the lower part of the king post is removed it is necessary to put a bamboo tension ring located in the upper part of the of the columns as shown in the same figure. But in the case of this kiosk which has the shape of a star, it was not posible to use the bamboo tension ring and insted of it I put a radial tension steel cables between opposite columns as shown in Fig. 20.17.


C

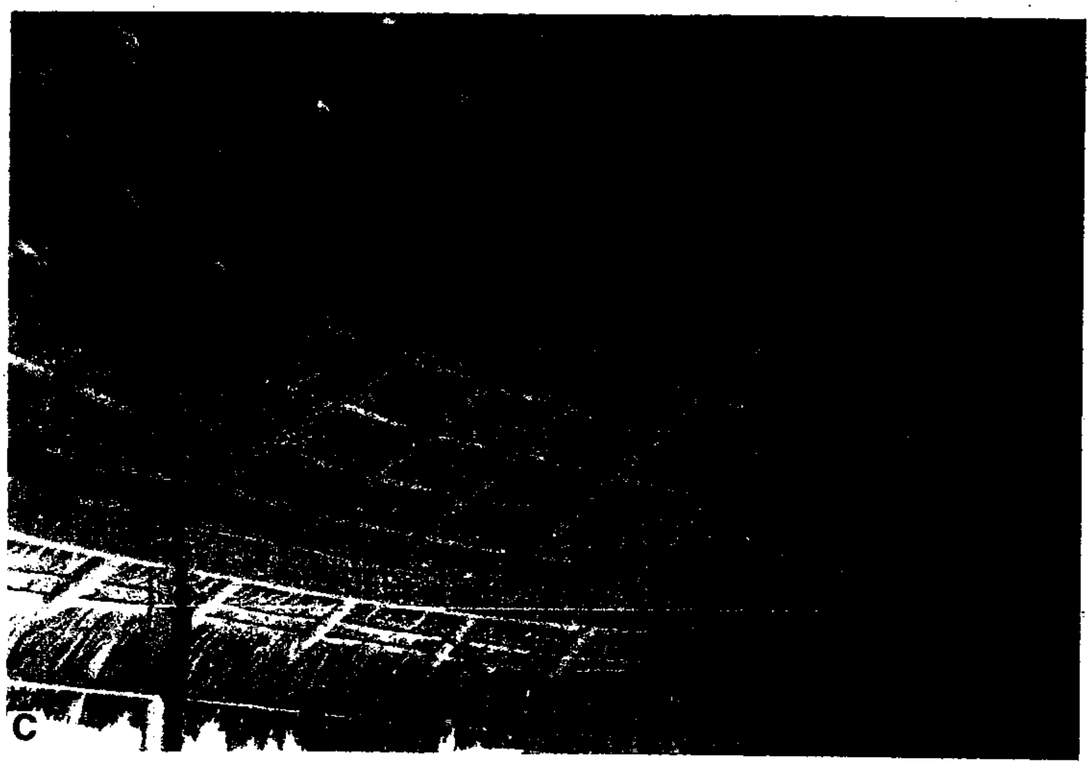

D

BAMBOO CONICAL ROOF SUPPORTED BY A CONCRETE STRUCTURE

Fig. 20.19 A,B, and C *In this kiosk the roof was built with bamboo, but the peripheral beam and the columns were buit with reinforced concrete. In this case the tension ring is replaced by the concrete beam, shown in Fig. B and C.*



The stability of this type of large bamboo kiosks depends on the strength of the bamboo tension ring . In the rainy season the weight of the roof increase and consecuently increase the push of the roof against the ring tension. If this ring can not support the pushing of the roof the kiosk collapse. Due to this reason some kioks' builders replace the bamboo tension ring by a concrete beam.

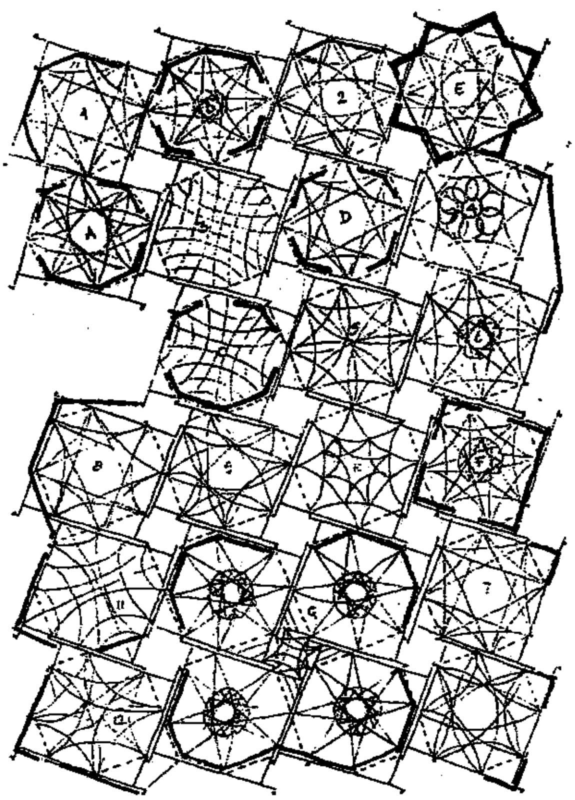


THE BAMBOO DOMES OF Y. FRIEDMAN & E. SCHAUR

Fig. 20.20 CONSTRUCTION OF DOMES WITH BAMBOO SLATS

After the Bamboo World Congress which took place in the Bambuserie de Prafrance in Anduze in the south of France in 1989, Yona Friedman invited me to visit him at his office in Paris.where I spent several hours. I was very impressed with the wonderful work he made in the construction of different types of bamboo domes at the *Museum of Simple Technology*, in Ana University campus in Madras, India, which was completed in 1987. On the other hand he developed the technology of using bamboo rings for the construction of roofs. The domes and the plan and perspective of the Museum are shown in the lower drawing. .But the most important of his program is the way as he and the Comunication Centre of Scientific Knolege for Self-Reliance transfer this technology to the poor people using very simple drawigns that I included in this section.

PLAN AND PERSPECTIVE OF THE MUSEUM OF SIMPLE TECHNOLOGY



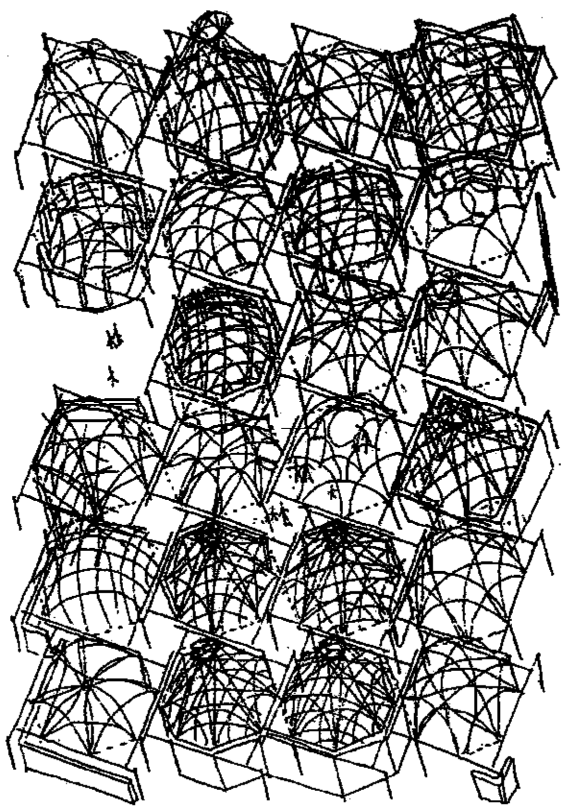
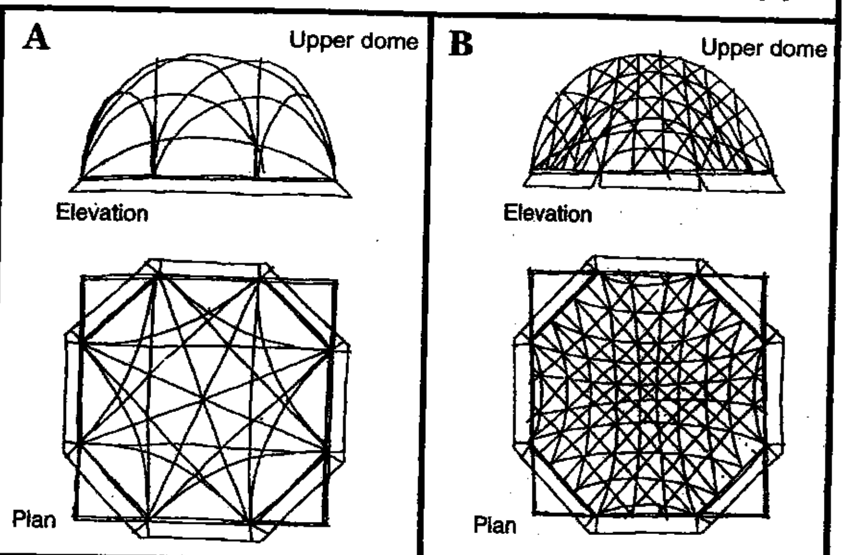


Fig.20.21 TYPES OF DOMES BUILT WITH BAMBOO SLATS (1)

The Museum has been conceived to demonstrate the techniques and methods for self-reliance illustrated in the drawings, which, as was explained before, were prepared by the Comunication Centre of Scientific Knolege for Self-Reliance, addressed to the most disadvantaged people in both town and country.

The prototype domes of the Museum were built by local craftsmen (basket-makers) unacquainted with any building work. They lerned very fast the necessary skills and were soon able to replicate the dome of which they saw the model. The domes were built with bamboo slats (2 slats in each piece).



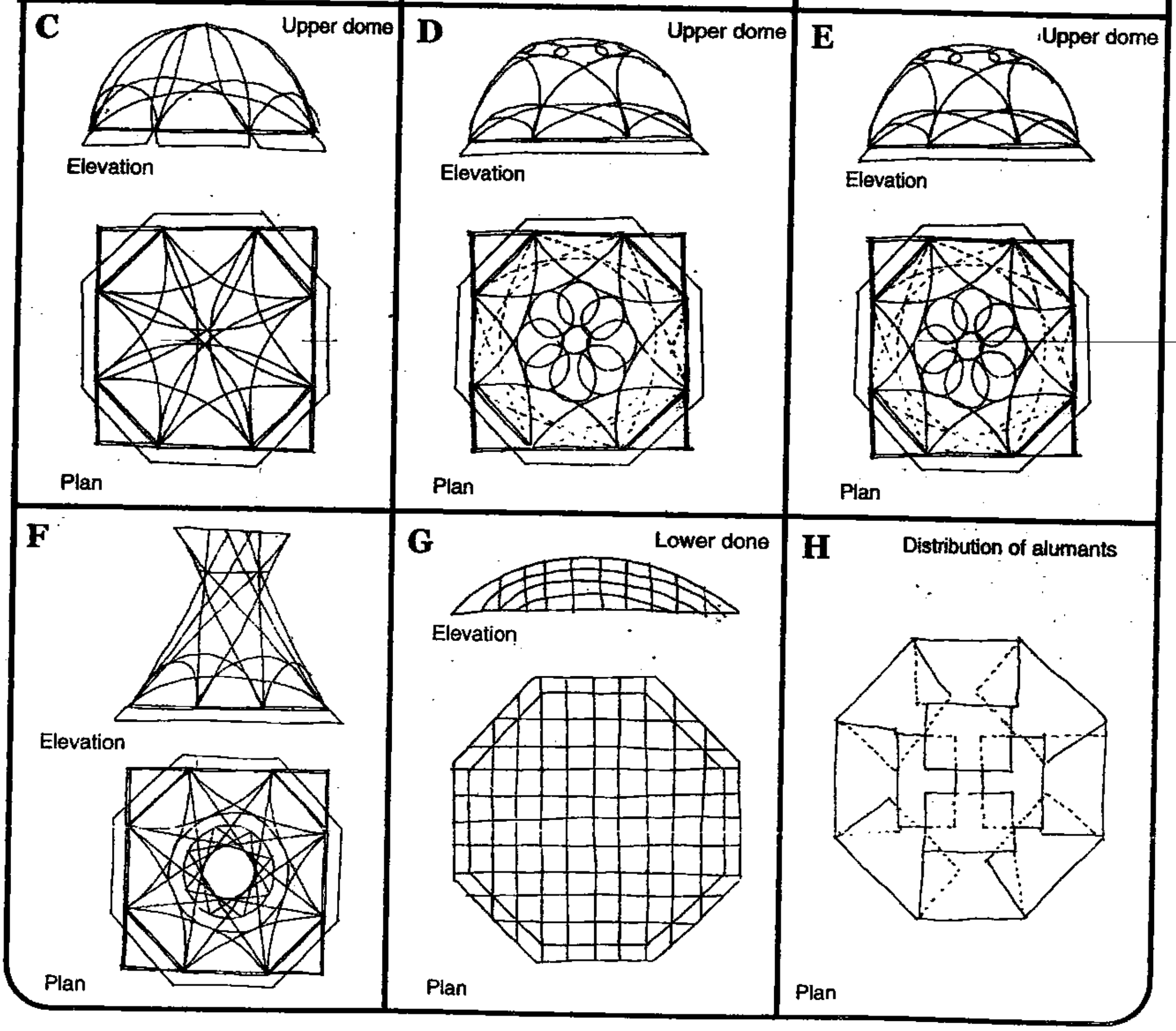
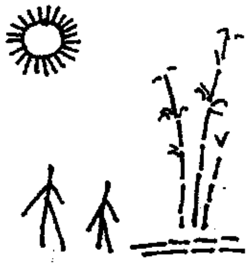
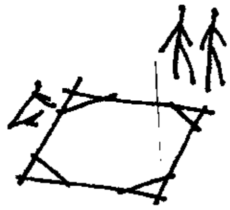


Fig.20.21 CONSTRUCTION OF DOMES WITH BAMBOO SLATS (2)

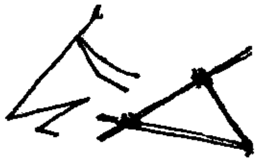


To make a cheap and efficient roof out of bamboo

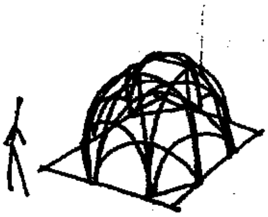
We started by making a frame



A square with diagonal bracing near to the corners



This frame, made of bamboo or of casuerina was made of rods fixed together by ropes

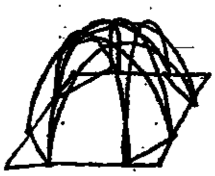


On this frame as a basis we erected a dome

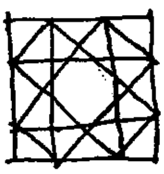
By making archs out of split bamboo or of full round bamboo

These arches were about as high as the half of one side of the frame.

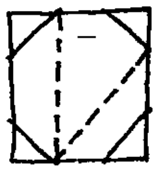
We fixed them standing up between corners of the frame, in various patterns



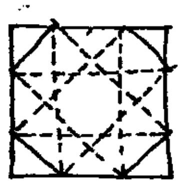
Such archs can be laid out on the frame in many ways:



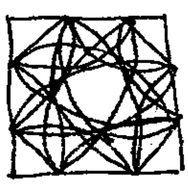
Like this,



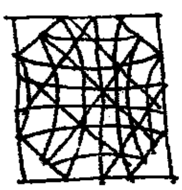
Where they link each corner of the frame to the one 3 modules far.



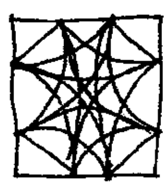
We repeat this operation from each corner



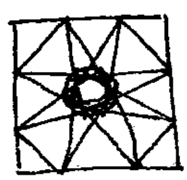
There are many other patterns. like this one,



Or this one, (where some archs start from the sides of the square and not from the corners).

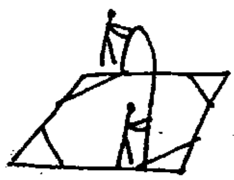


Or this another one



And many more.We made use for this museum of 6 different patterns.

Fig.20.21 CONSTRUCTION OF DOMES WITH BAMBOO SLATS(3)



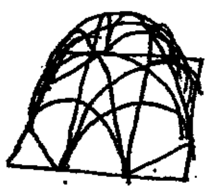
To make sure that the assembled archs keep standing up from the start,

We choose to start with those 2 archs which form a cross, on the octagon of the frame

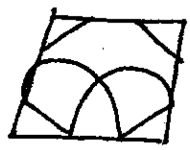
.Or, in another pattern, those which lean on each onto the other, and we tied together these 2 archs.

Then we repeated this operation starting, one after the other, of each corner of the frame. All 8 couples of archs were, at the end, tied together.

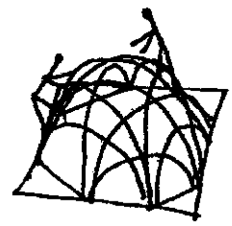
Once these main archs formed the dome - shape we wanted



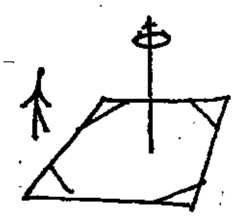
We had to fix that shape. so we made 8 other archs, half as high as the main arches each starting from a corner of the frame



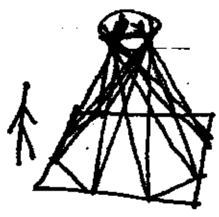
Linking it to the after next one



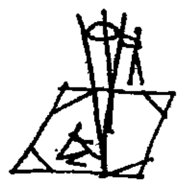
At this stage the dome structure became stable.



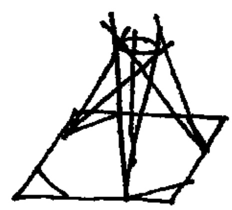
Another type of dome we started with a ring fixed on a pole



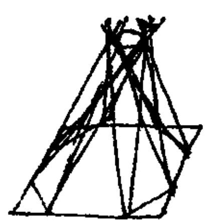
As high as the dome should be



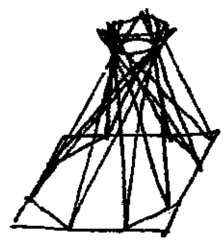
We tied to that ring two bamboo rods linking it to a corner of the frame so that should touch the ring on opposite sides,



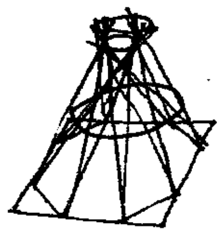
And we repeated this from each corner of the frame.



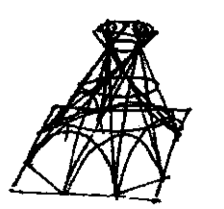
We stiffened that dome, once all the ribs were in place,



With bamboo rings at various heights: one at the top,



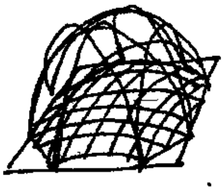
Another at mid - height, and so on.



Once we finished all these, we made low archs between corners of the frame and their after next, and tied these archs to the ribs.

Fig. 20.21 CONSTRUCTION OF DOMES WITH BAMBOO SLATS (4)

These dome structures serve to support

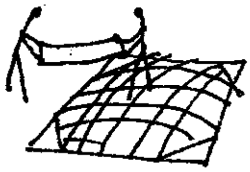


A light lower dome which is more flat,

And which is fastened on another frame, and which hangs on 4 wires from the upper dome.

The lower dome is the support of the roof cladding.

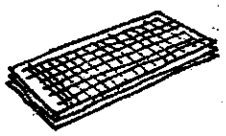
We made the roof cladding with bamboo mats



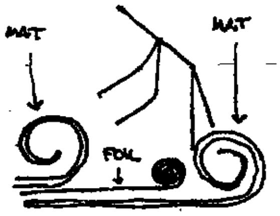
A first layer of which was posed on the grid of the lower dome..

For the second layer we prepared other mats

On which we previously glued thin aluminum foil (on their upper side).



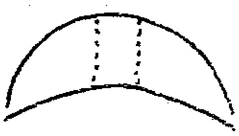
Another kind of cladding (also with aluminum foil)



Can be made by fixing the foil between 2 bamboo mats (wich protect thus the foil).

Such " sandwich" mats we prepared on the ground,

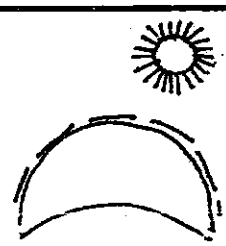
Then we fixed them on the lower dome, as we did with the ordinary mats.



The upper dome has a double task: to support the lower dome which hangs on it

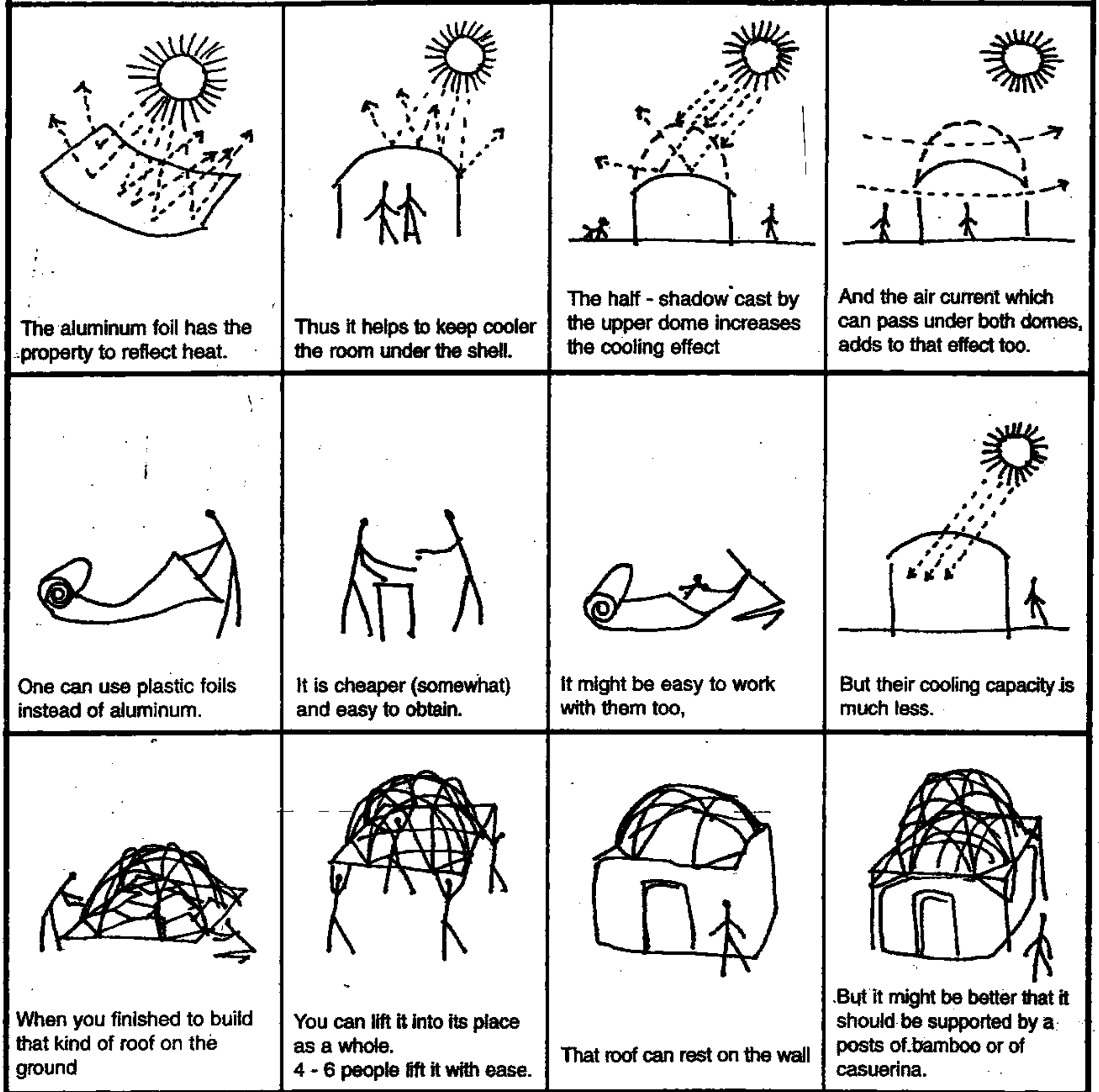
And which would collapse without that support;

And a second task: the upper dome is covered with flat round baskets



Which cast a half shadow onto the lower dome, keeping its shell cooler.

Fig. 20.21 CONSTRUCTION OF DOMES WITH BAMBOO SLATS (5)



The aluminum foil has the property to reflect heat.

Thus it helps to keep cooler the room under the shell.

The half - shadow cast by the upper dome increases the cooling effect

And the air current which can pass under both domes, adds to that effect too.

One can use plastic foils instead of aluminum.

It is cheaper (somewhat) and easy to obtain.

It might be easy to work with them too,

But their cooling capacity is much less.

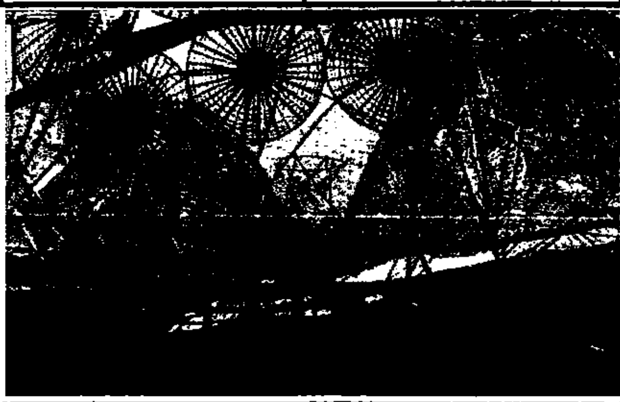
When you finished to build that kind of roof on the ground

You can lift it into its place as a whole.
4 - 6 people lift it with ease.

That roof can rest on the wall

But it might be better that it should be supported by a posts of bamboo or of casuerina.

Fig. 20.22



CONSTRUCTION OF ROOFS WITH BAMBOO SLAT RINGS (Y. Friedman)

Fig. 20.23 *Shows a roof made with bamboo rings. This technology was developed by Yona Friedman at the Communication Centre of Scientific Knowledge for Self-Reliance in Paris.*

Fig. 20.24 ROOFS MADE WITH BAMBOO SLAT RINGS (1)

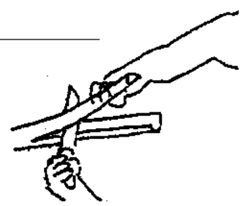
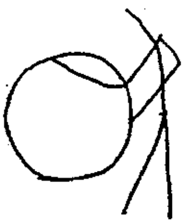
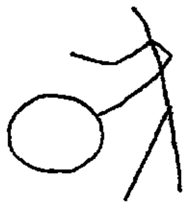
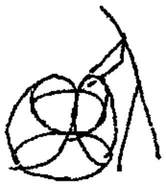
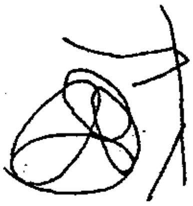
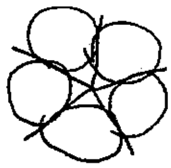
			
You can start making the rings with split bamboo or slats of giant bamboos	Rings with a diameter about one meter	If the bamboo is not strong enough you can choose a smaller diameter	The number of rings will be different according to the model.
			
To start with, you have to tie together 4 rings with wire	You tie them where one ring touches another as shown in the drawing	Then you lift the 3 external rings, leaving the central one on the floor.	Having them in this position you should tie them together

Fig. 20.24

ROOFS MADE WITH BAMBOO SLAT RINGS (2)



You get this rigid structure made with the 4 rings (a sort of tetrahedron)

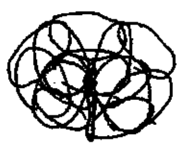


You should make 5 of them and dispose them in the pattern of a flower

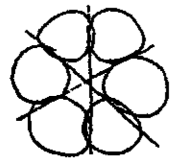
Then tie them together in the center of that pattern where the 5 tetrahedra meet

Then you start to tie together the other rings, first the upside then those down

You obtain by doing so a structure in form of a 'len-til'.

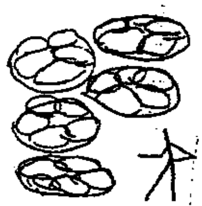


This is a very solid structure

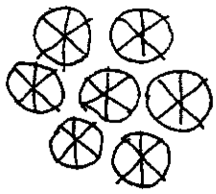


One can build such lentis with 6 tetrahedra as well, disposed as in the drawing

One has to to squeeze them somewhat., in order to tie them together



Let us continue. First, you should make 6 lentils (each with 5 tetrahedra

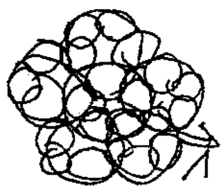


or 7 lentils each with 6 tetrahedra, whichever suits you best)

You take the first lentil which will serve as core, and you fix on each of its and

downside rings, the upside ring of each of the other lentils.

You tie so the 5 lentils onto the core lentil, in every spot



where 2 rings meet. Often one has to draw together the elements of

the elements of that structure to make dissapear the gap between rings.

The tension thus created makes the structure more rigid.

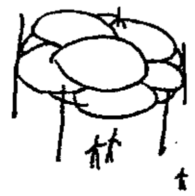
Fig. 20.24

ROOFS MADE WITH BAMBOO SLAT RINGS (3)

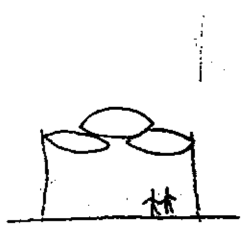
You obtain thus a very solid structure

with a span of about 6 meters (18 feet)

and this with very thin components

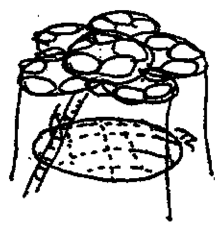


This structure can be supported by walls or by posts

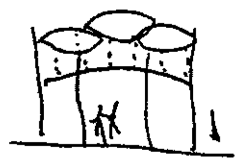


The structure what you built will support the " roof -skin" made with mats,

with mats with plastic foilds or whatever you prefer.

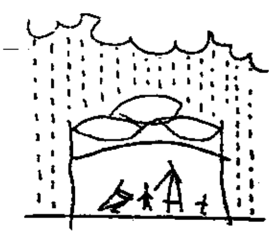


This skin has the form of a flat dome

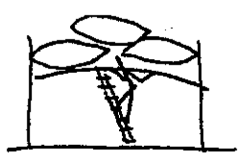


which will hang on the structure you built

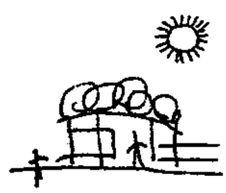
Thus, using little material



you can build a roof which is solid and which protects you ,

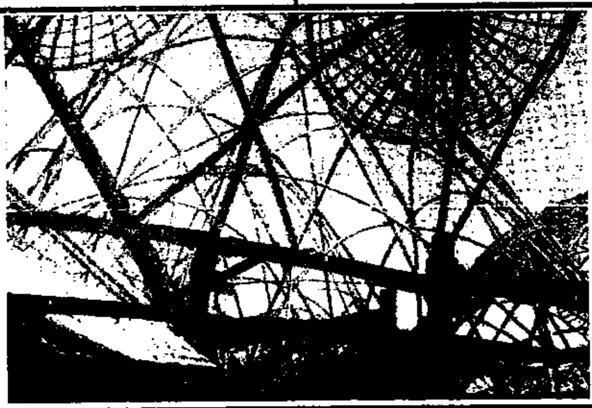


easy to repair



and which will look pretty

Fig. 20.25



THE WOVEN BAMBOO CONICAL DOME (AFRICA)

THE WOVEN BAMBOO CONICAL DOME USED AS HOUSING

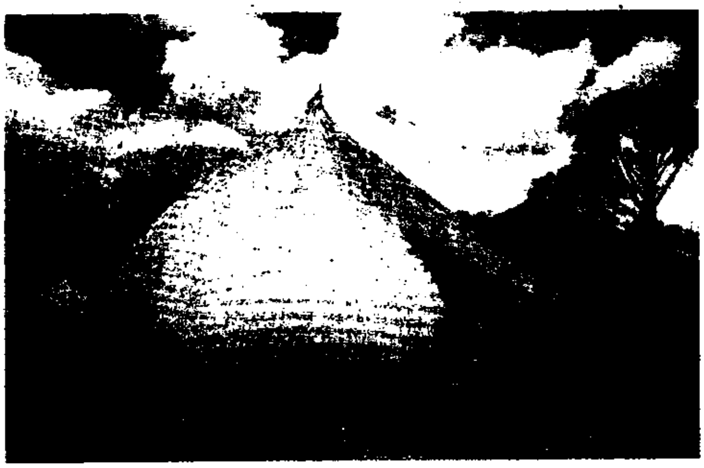
Fig. 20.26

In Ethiopia, Africa, there are two types of woven bamboo conical dome houses which are typical of several variations of this type of hemisferical houses found in this country. They are the *Chencha house* and the *Sidamo bamboo house.*

The *Chencha house* is found in a small relatively high area west of lake Margarita, south of the city of Boroda where is found the Dorze tribe, an industrious people renowened for their skill in weaving. The height of the hut sometimes exceeds 8 m, and is usually not less of 6 m in diameter. Apparently there is a good reason for making it as hight as it is. As soon as the portion which is directly in contact with the soil begins to rot, as indeed it does, the whole house is sunk to an appropriate extent allowing the fresh portion of the wall to come in contact with with the earth, until the hut becomes too low for normal human activities to take place inside it. As a rule the height of the house is reportedly reduced by about 20 cm every four years and then a new house is built.

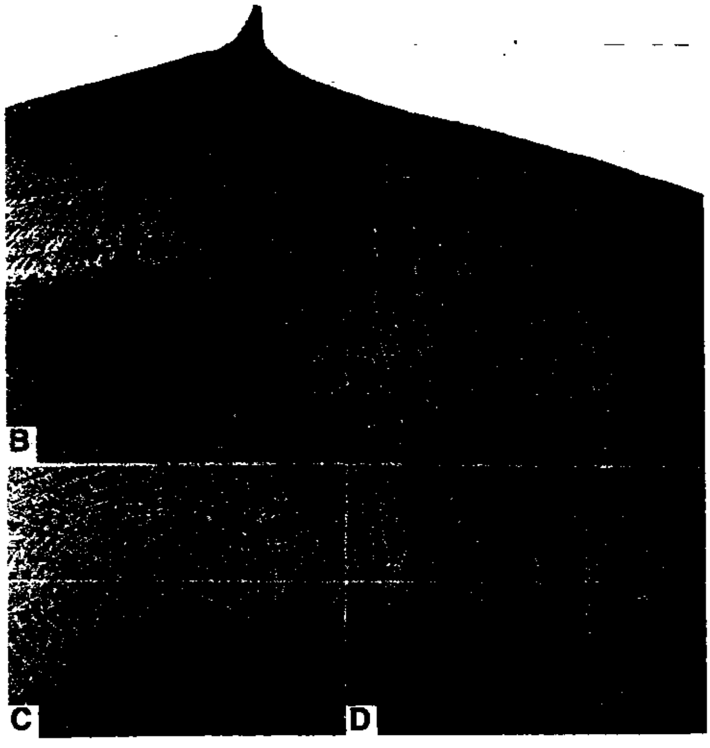
Construction. A circule is drown on levelled grownd outlining the outer section of the wall. On this circle split bamboo pieces are driven into the ground, approximately 10 cm apart. A series of horizontal rings is then interlocked between the vertical pieces, from the bottom to the top. Once the bamboo framework is completed, layer of culm leaves (sheaths) are placed in the exterior surface of outside the frame work of the chencha house

The *Sidamo bamboo houses* are located around the town of Ageresełam, east of lake Margarita. The characteristics of this house are similar to the Chencha house which has just been described, but there are however two importan differences concerning a construction detail:. The Sidamo bamboo house has a central supporting pole whereas the Chencha one does not.. Secondly, the culm leaves that are designed to make the house waterproof are placed in between two layers of bamboo wickerwork forming a sandwich.



A. Chencha house without central support and covered with culm leaves

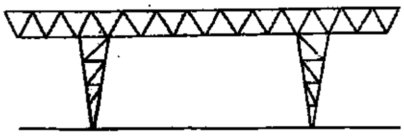
B. Details of the roof construction of Chencha and Sidamo bamboo houses

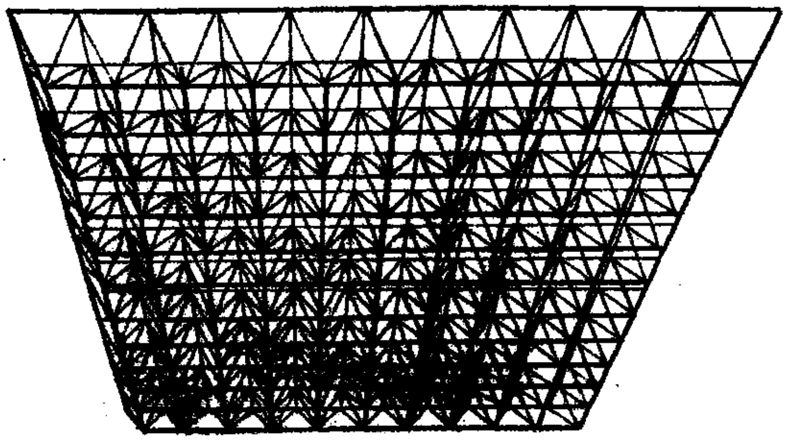


DOUBLE LAYER BAMBOO SPACE STRUCTURE

Fig.20.27

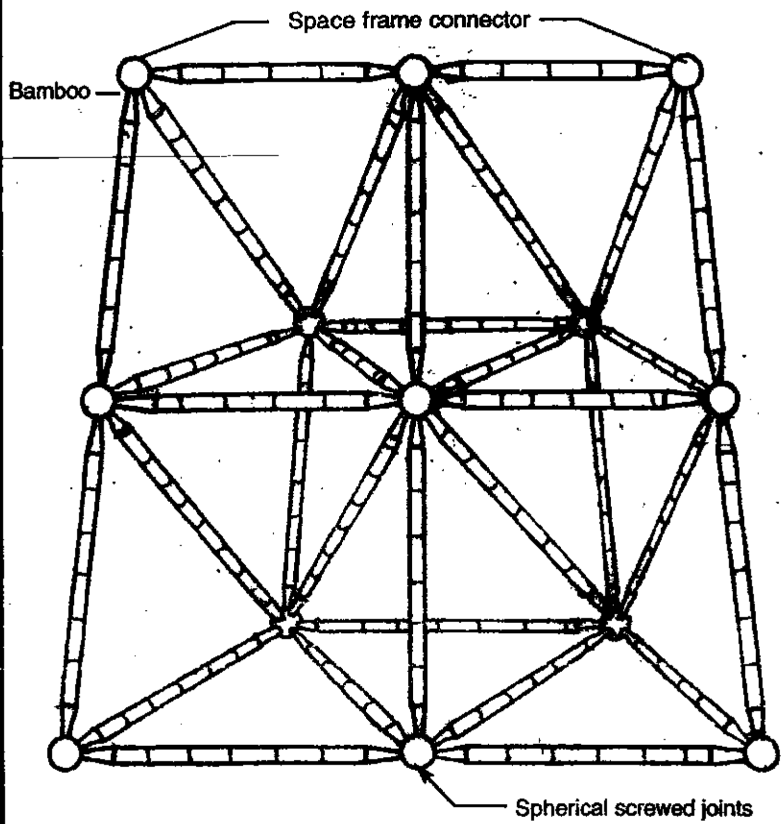
CONSTRUCTION





A. *Underside view of the double layer bamboo space structure.*

UNDERSIDE VIEW

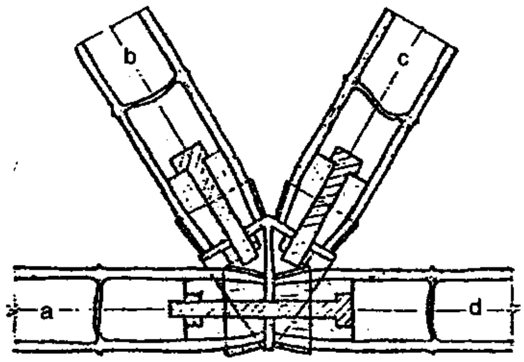


TOP VIEW OF A SECTION

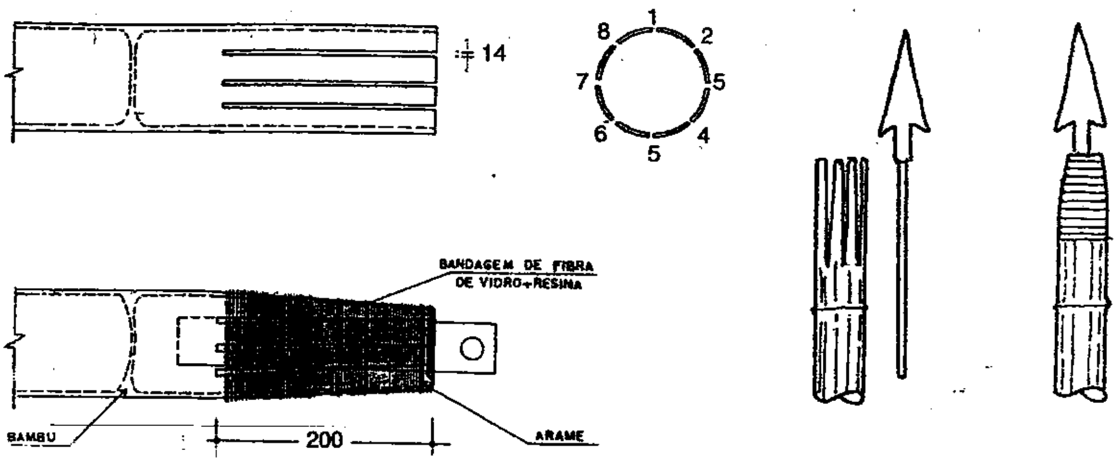
B. *Topside view of the bamboo double layer space structure. The bamboo struts are fixed to spherical screwed joints elements (see Fig. 20.29).*

Fig.20.28

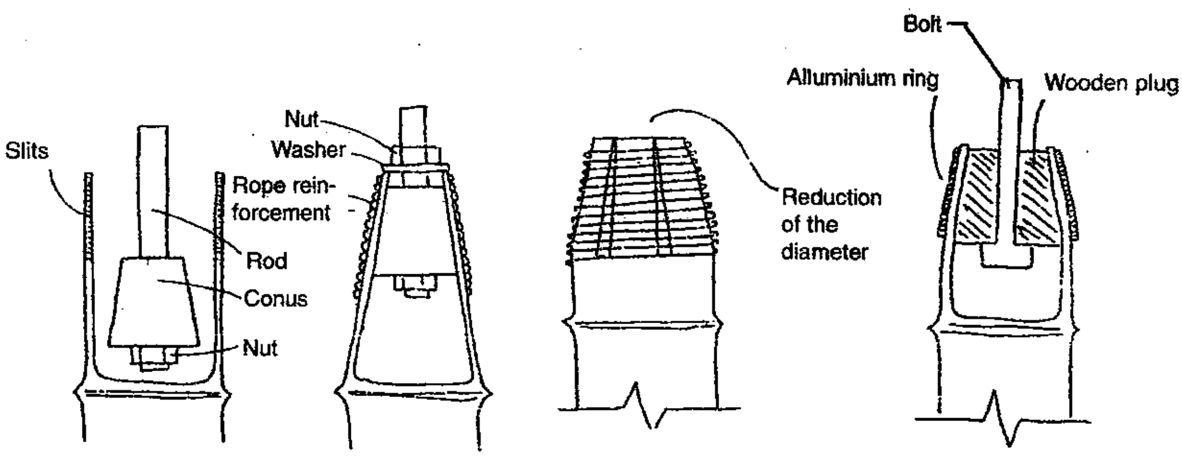
CONSTRUCTION OF JOINTS



A. *In the construction of a double layer bamboo space structures is not posible to use traditional joints as those used in the construction of bambo roofs. It is necessary to use a more rigid joint as this one developed by C.H Duff in 1941 which looks very stiff (After Spoer, 1982).*



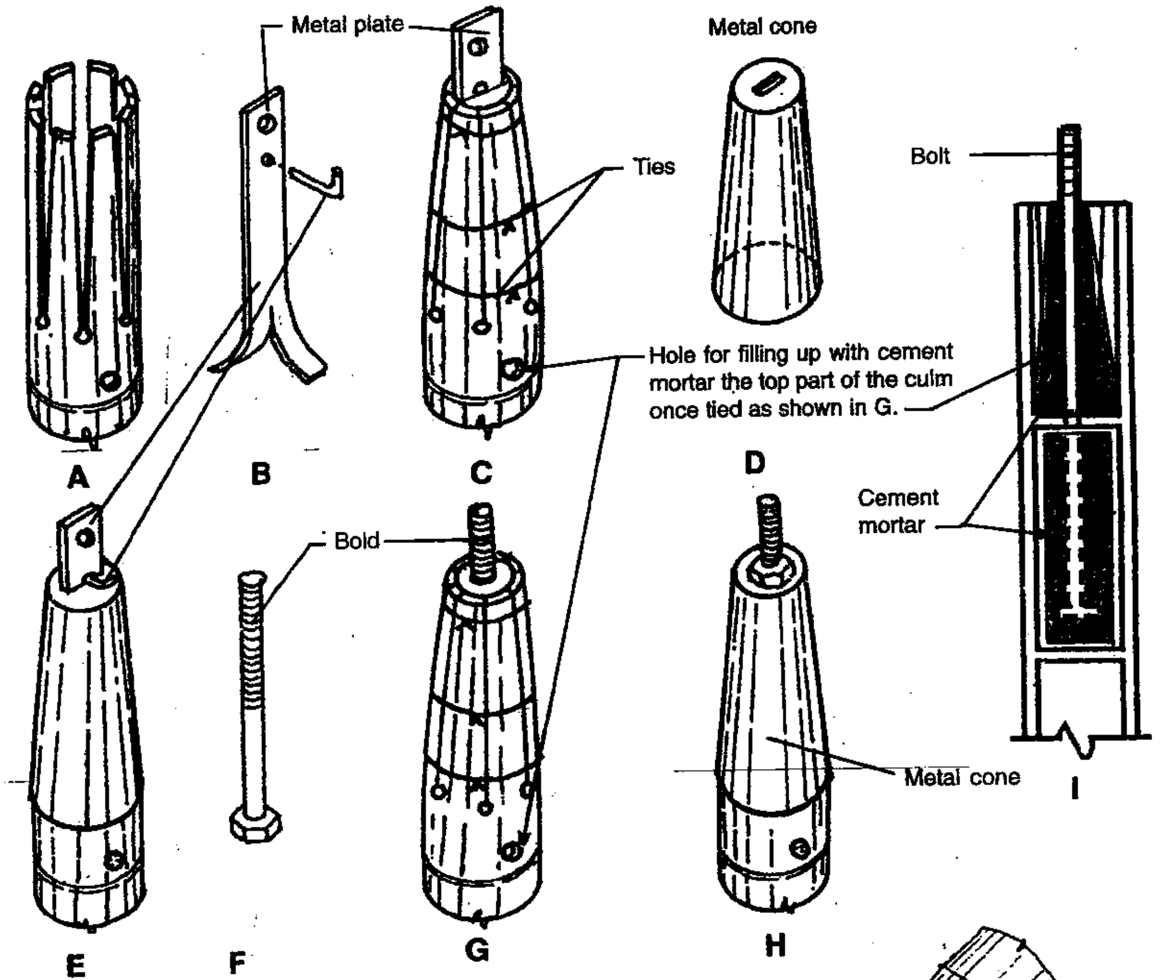
B. *Joint used by Moreira (1991). This type of joint is similar to that used by the indians in Brasil for fixing the metal arrow inside a small diameter bamboo or cane. (Prof. Jose Luis Mendes Ripper).*



C. *Type of joint developed by C.H.Duff (1941) using a wooden cone (After Spoer, 1982).*

Fig. 20.29 CONSTRUCTION OF JOINTS USING A METAL CONE

I designed this type of strong joint in which is used a 1/2" bolt or a sheet metal and two internodes with cement mortar, and a metal (aluminum) cone which replace the cords and gives a better aspect to the tips of the strut. This type of joint can be used in double layer bamboo space structures and geodesic domes. For larger and safer structures is recommended the type of strut shown in Fig. I with an aditional internode with concrete and a larger bolt.



SPACE FRAME CONNECTORS

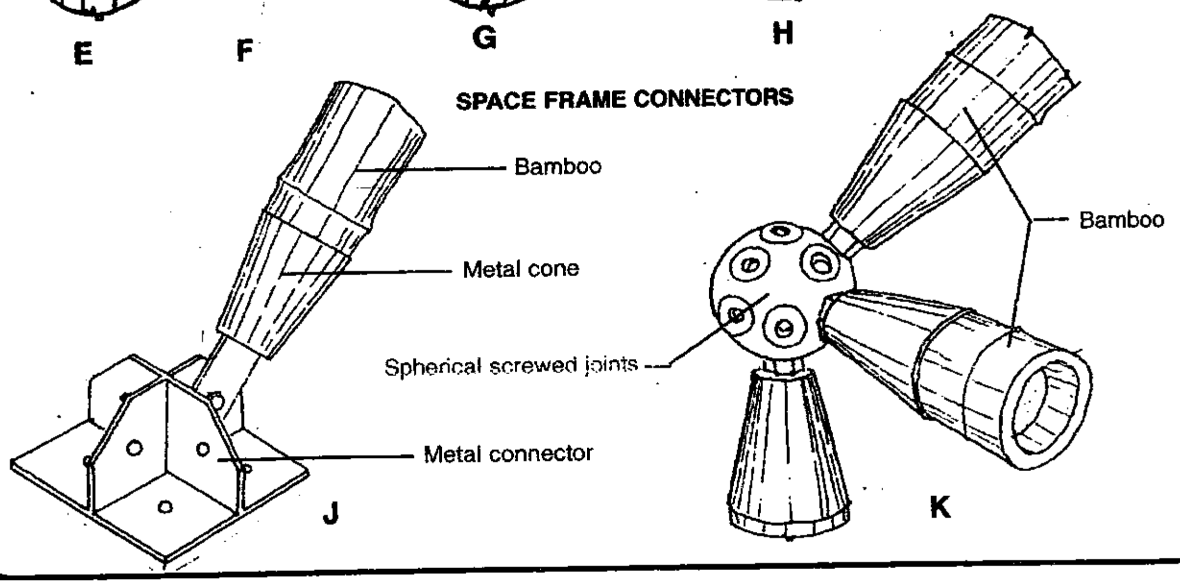
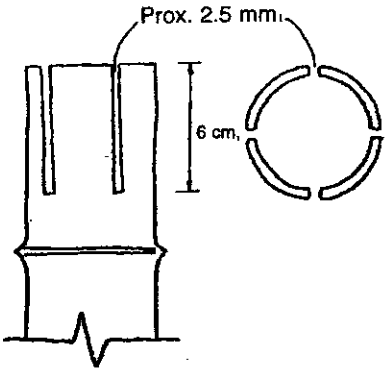


Fig. 20.30

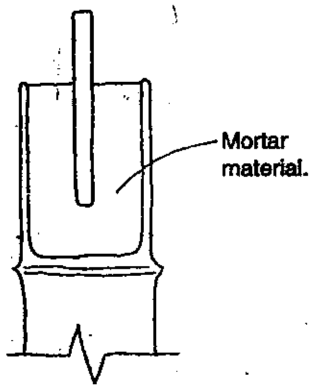
NOT RECOMMENDED JOINTS



A

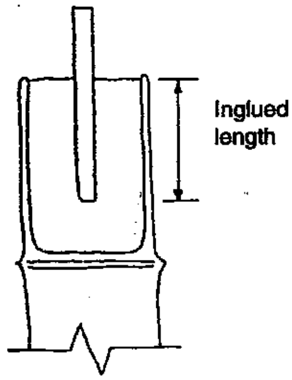
1). The bamboo cylinder must be divided at least in 8 parts. If it is divided in 4 parts is not posible to bend each division after removing the interior soft part of the wall.

2). In each division is necessary to removed a strip in "V" shape as shown in fig. 20.29. if the sides of the strip are parallel the lower part of the crack can not be closed.



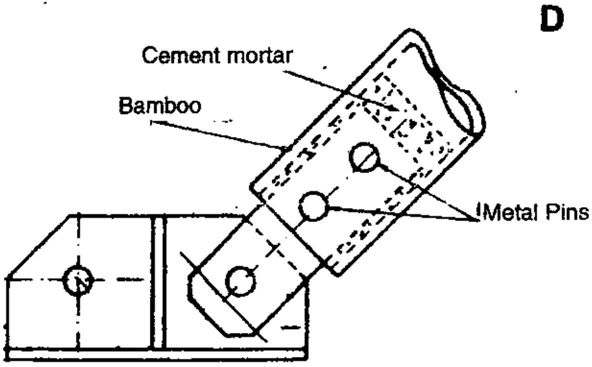
B

After the mortar is poured inside the culm section without the top node, as shown in the figure, it shrinks and lost adherence with the interior of the culm wall and it becomes free inside the internode and can be easily removed pulling the steel bar. In this case is better to use the whole internode, including the membranes.



C

To use any type of glue in the interior wall of the culm section in order to solve the problem explained in "B", will not avoid the separation between the mortar cylinder and the culm wall caused by the shrink of the mortar.



D

In this detail we have the same problem shown in figure B. Furthermore the lower pin is very near of the border of the culm section and due to the low shear strength of the bamboo wall, the pin will tear the wall between the pin and the lower border of the bambooo, once the bamboo pole is tensioned. In this case is recomended to have a complete internode.filled with cement mortar.

BAMBOO LAMINATED GEODESIC DOME
Based on Bucky Fuller's 24- foot in diameter Hexapent dome

Fig. 20.31 **DOME CONSTRUCTION**

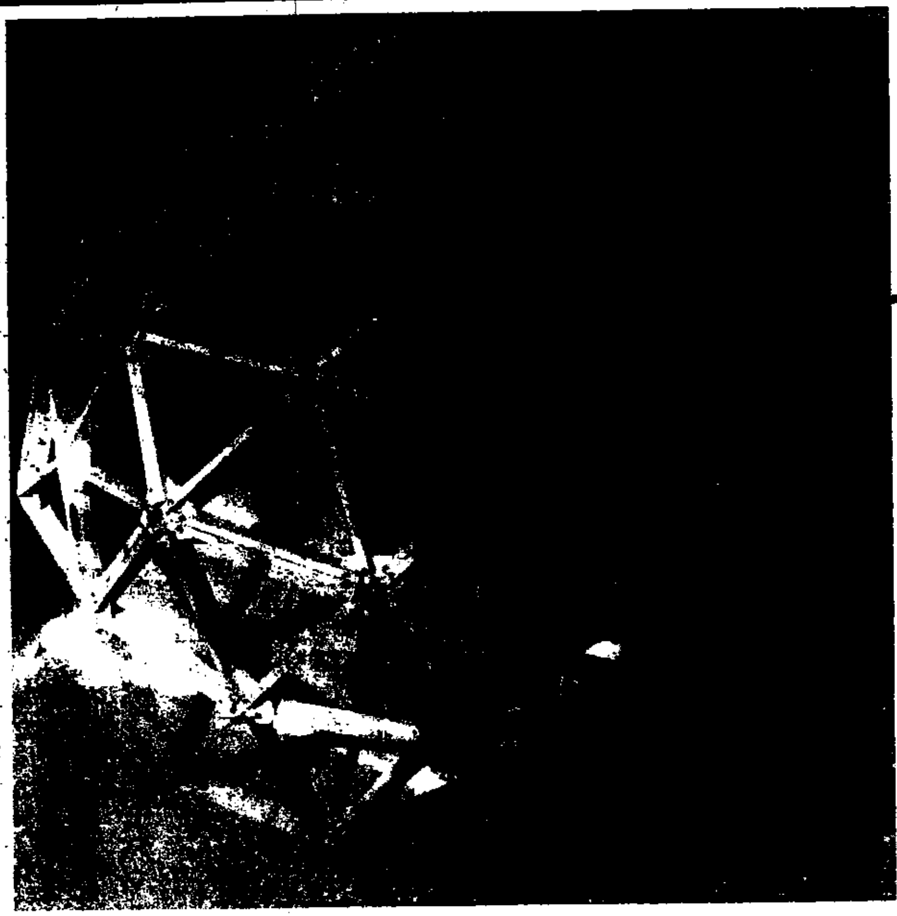


Fig.A. *In 1990 I built the Bucky Fuller Hexa-pent domes with bamboo laminated struts, with a diameter of 3.65 m. based on the 12 feet dome 24 feet diameter designed by Fuller and Sadao (Copyright by Popular Science Publishing Co Inc. 1972).*

Fig. B *Bamboo laminated strut used in the dome construction.*

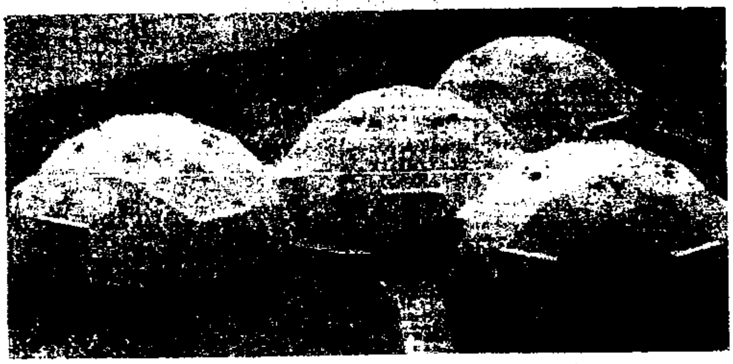
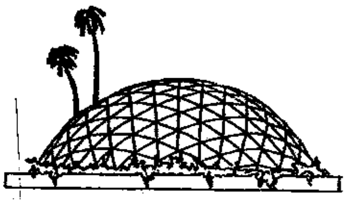


Fig. C. *Fuller has designed cons-tructional forms with the development of his geodesic domes, which are based on the use of simple, easily assembled standard components. In this way, exceptionally economical dome structures which can be used for houses, factories, theaters etc. are produced.*

Domes with hemisfpherical structures have the advantage of a small surface area in proportion with the encolosed volume.

Fig. 20.32

GEODESIC GEOMETRY



The sphere encloses the greatest amount of space with the least amount of material, and the hemisphere which is the basis of the domes encloses more space with less material than any other shape. On the other hand the dome presents the least possible surface to the weather, it conserves heat better than any other shape. The shape of the dome also encourages natural air circulation , making the dome easy to heat and cool. This is the reason why Fuller has drawn plans for domes that would enclose whole cities.

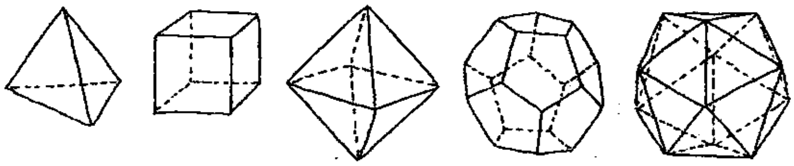
The geodesic dome arises from the study of the regular solids and particularly from the icosahedro. It was invented by Buckminster Fuller who patented in 1951 a method for constructing a spherical surface by subdividing the *faces* or triangles of an icosahedron in smaller triangles.

The icosahedron is the largest solid we could make with equilateral triangles, but if we build in a large scale a icosahedron, the structural members will be very long and cumbersome. The big triangles would sag and require internal bracing. Consequently to be most useful, the bracing would have to form smaller triangles and to give the structure a more spherical shape. The subdivision of large triangles or *faces* into smaller ones is what dome geometry is all about.

The triangle is the only rigid structural configuration. Used in combination they make the geodesic dome the strongest, lightest, most efficient building system ever devised.

Fuller developed two methods for dividing the large triangles into smaller triangles. The first method is known as *triacon breakdown* which consist in dividing two sides of the original triangle in two or several parts and each part is known as *frequency*.

Fig. 20.32 A. THE FIVE REGULAR SOLIDS



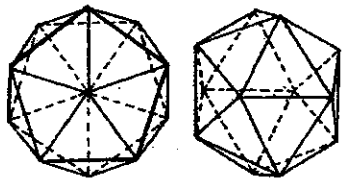
ICOSAHEDRON

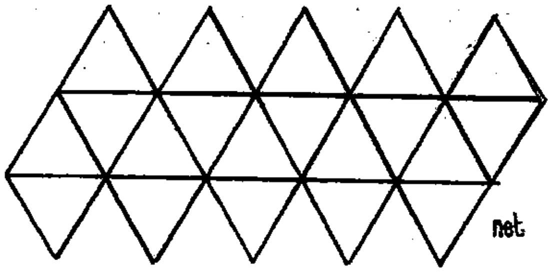
$\frac{\text{Edge}}{\text{Interradius}}$: $\sqrt{5}-1 = 1.236$

Dihedral angle — 138°11'

F	V	E
20	12	30

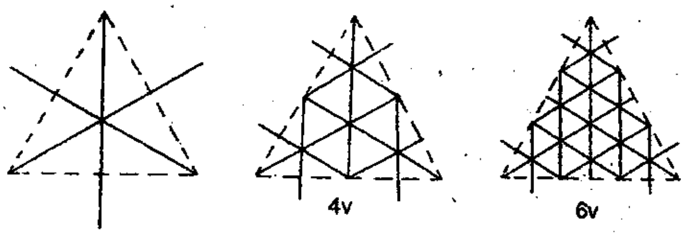
IN:Inter:Circumradius
0.9342: 1: 1.1756

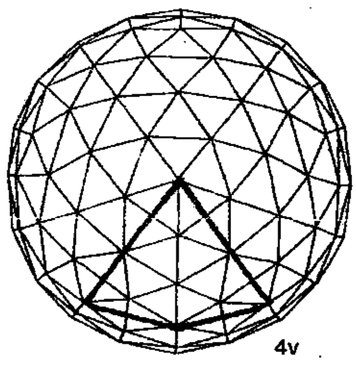




B.- METHODS USED FOR DIVIDING THE LARGE TRIANGLES INTO SMALLER TRIANGLES

FIRST METHOD: Triacon breakdown





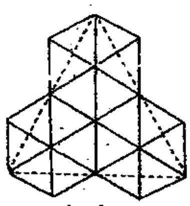


Fig. 20.33

GEODESIC GEOMETRY (Alternate breakdown)

The second method is known as *alternate breakdown* in which the icosa edges remain part of the dome structure. This method is easier and more simple to build than the former In this section we will make reference only to this method.

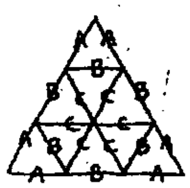
The two subdivisions (2v) shown in the two methods along each edge means that is a two frequency breakdown; three subdivisions means three frequency etc. We will use 3 frecuency, since it is a good frequency for 24 to 39 feet domes. When the *face* is divded it is not done equally, but done so that the faces begin to curve outward. This gives more strength. The more subdivisions of one face of a given diameter icosa, the more numerous and smaller are the triangles, and the closer you get to a sphere.

CHORD FACTORS

There is a set of constants for each *strut* so that using these constants, and some multiplication, yoou can calculate any diameter sphere. The constants are called *chord factors*. A chord factor is a pure number which when multiplied by a radious gives a *strut* length.

There are three different strut lengths, A,B,C. The cord factors for this dome are:

A .3486
B .4035
C .4124



If you want to get the strut length in inches, use inches of radious. For a 24' diameter dome the radious is 12'=144"

A =.3486 x 144 =50.1984 = 50 3/16"
B =.4035 x 144 = 58.1040 = 58 3/32"
C = .4124 x 144 = 59.3856 = 59 3/8"

These are strut lengths for a 24' = 7.31 metros diameter sphere.

The shape of the dome could be 3/8 of sphere, half sphere (hemisphere), or 5/8 sphere.

SECOND METHOD.- Alternate breakdown

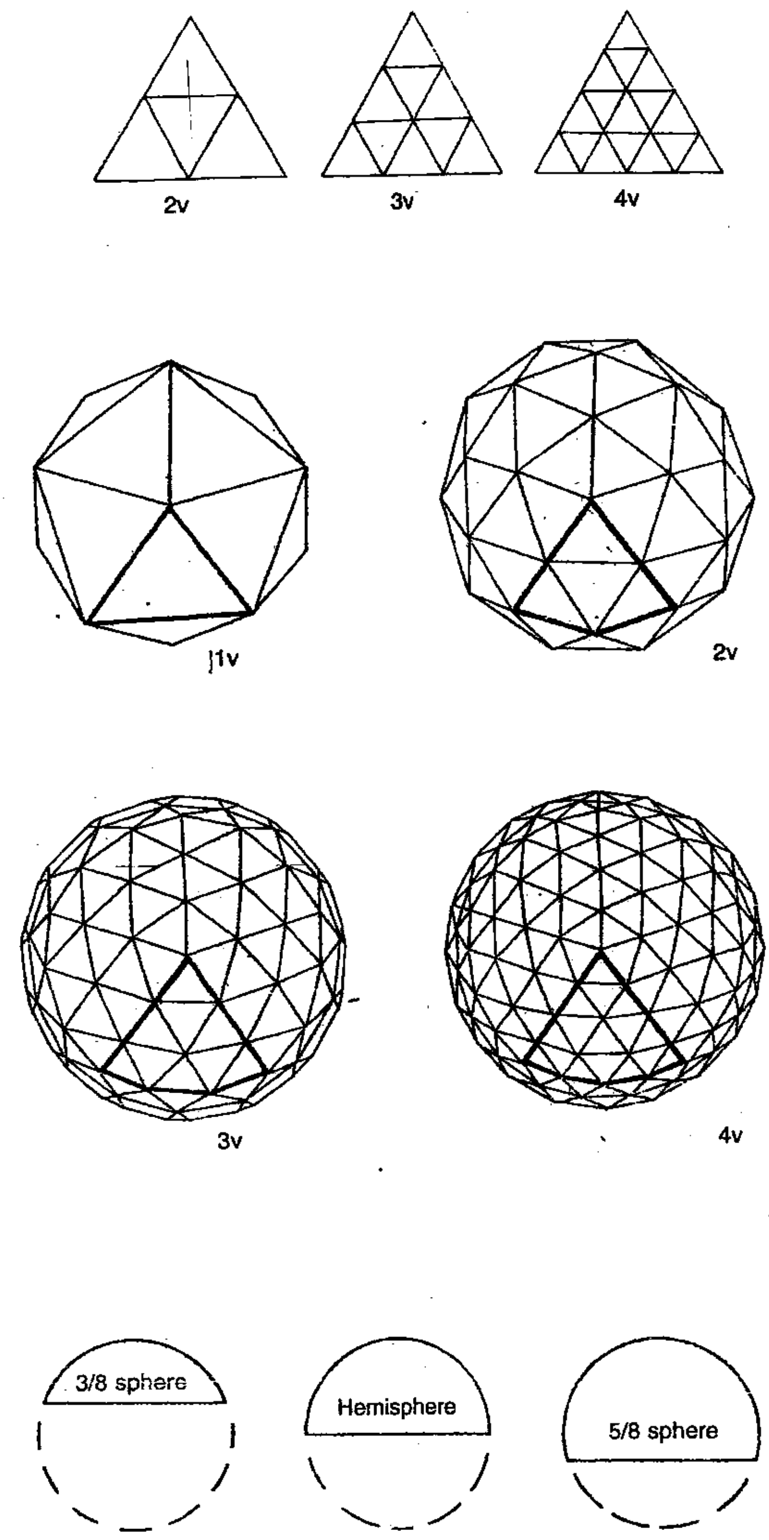
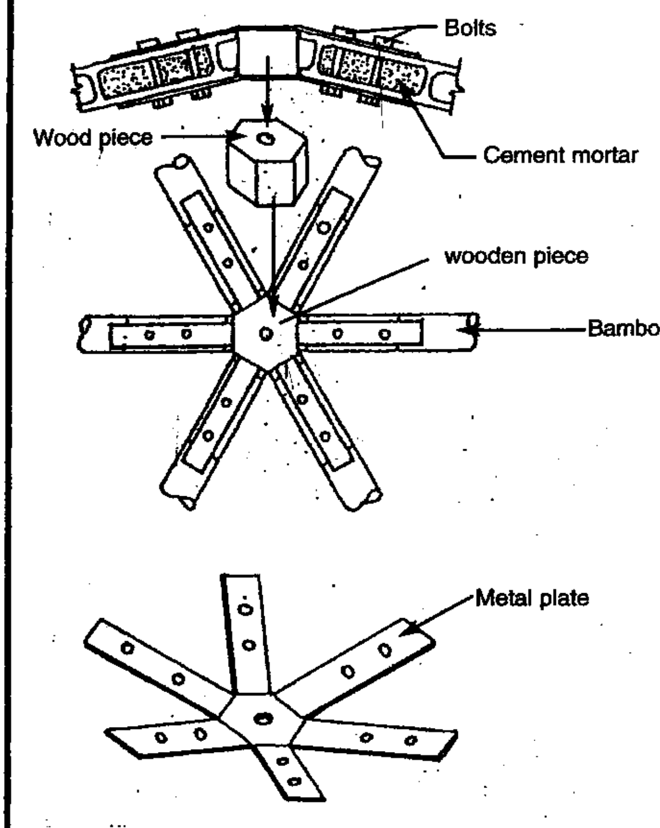
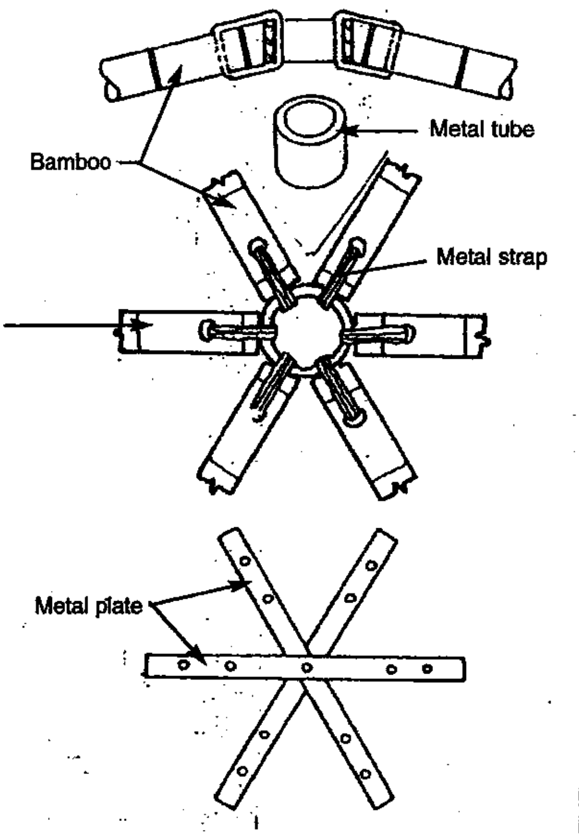


Fig. 20.34 **BAMBOO GEODESIC DOME - TYPES OF JOINTS**

A. With a doble bent plate and wood block



B. With aluminium pipe and galvanized strap



C. With a plybamboo plate and bamboo laminated struts.

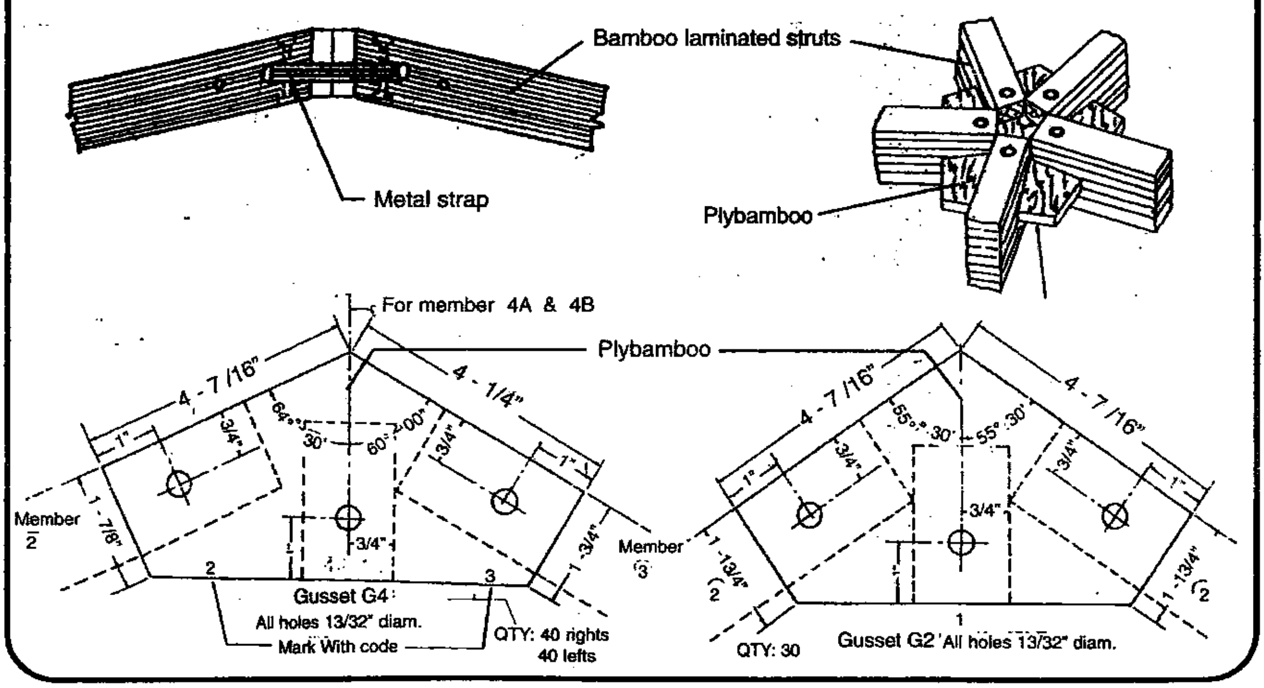


Fig.20.35 TYPES OF FRAMING USED IN THE GEODESIC DOME

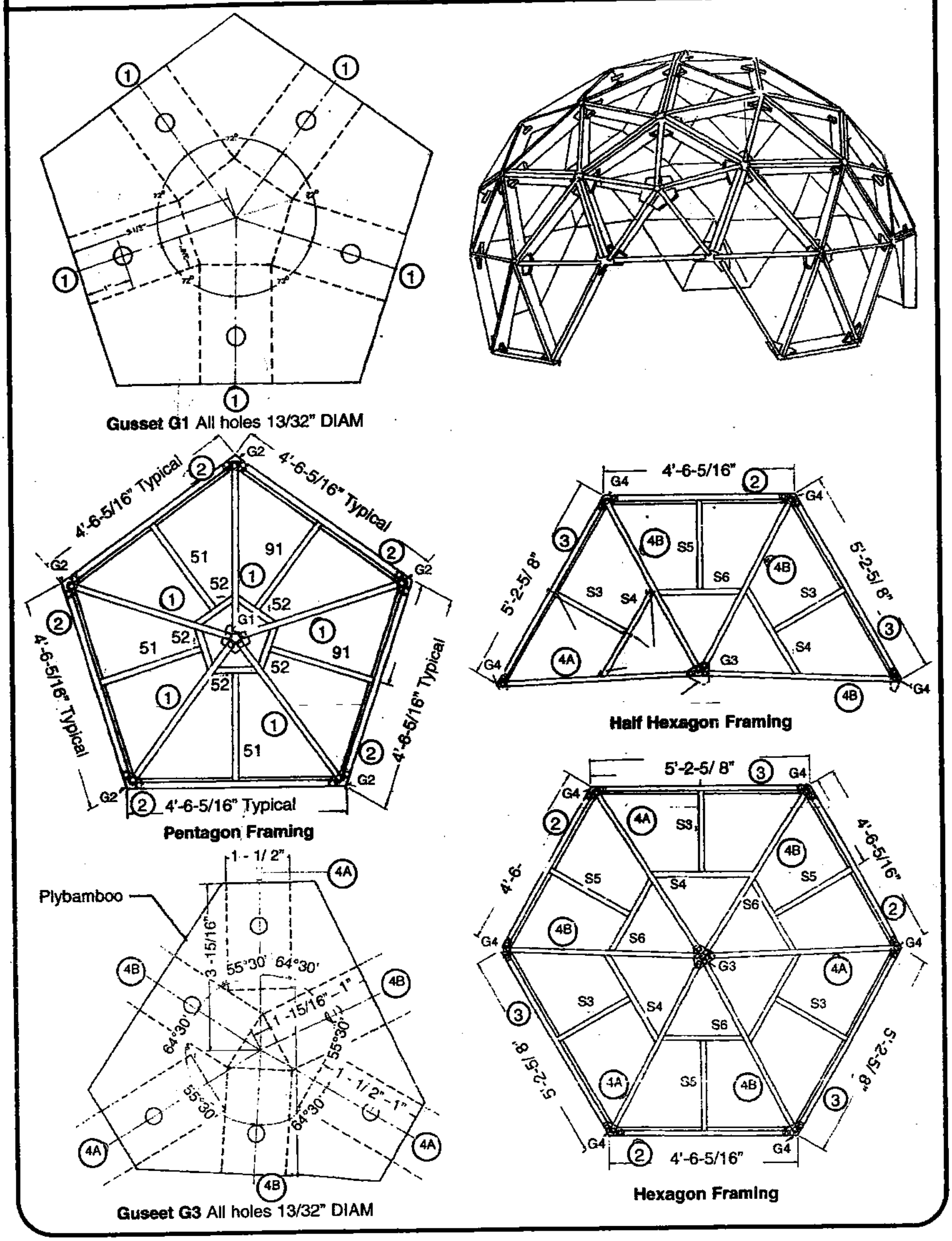
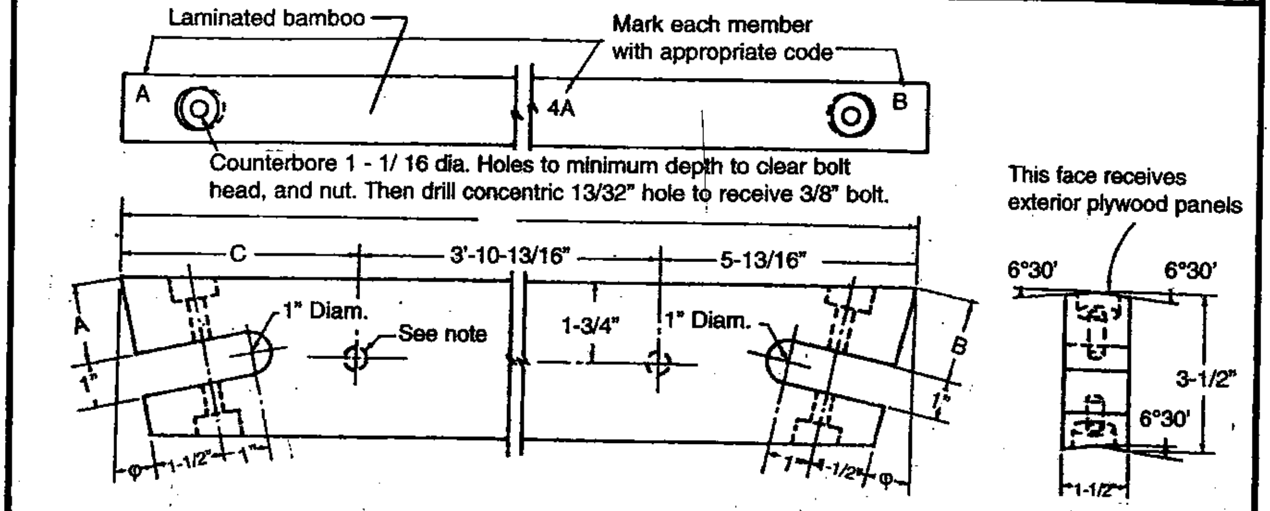


Fig.20.36

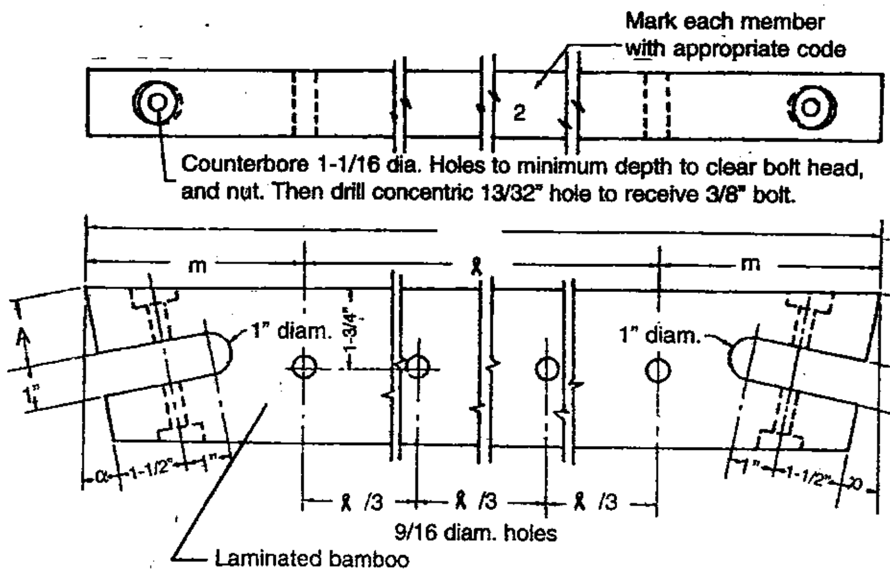
GEODESIC DOME STRUTS

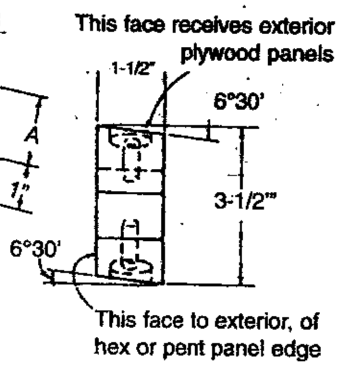


SCHEDULE STRUTS - 4A - 4B							
QTY	CODE	L	A	B	φ	REMARKS	C*
30	1	3'-8-15/16"	1-5/8"	1-3/4"	9°-30'	"A" at pent center, "B" at pent corner.	-
40*	4A	4'-10-1/8"	1-5/8"	1-3/4"	12°-00'	"A" at hex center, "B" at hex corner.	5-1/2"
40*	4B	4'-11-1/8"	1-13/16"	1-3/4"	12°-00'	"A" at hex center, "B" at hex corner.	6-1/2"

Note: 5-4A's and 5-4B's receive holes shown.
These are to be used in the 5 half hexagons at the base.
Holes are 9/16" diam.

Note:
Check thickness of gusset plywood before cutting slots each end of struts. Adjust 1" dim. As needed to provide slip fit. Do not force gussets into strut ends. Discard and replace any struts which split

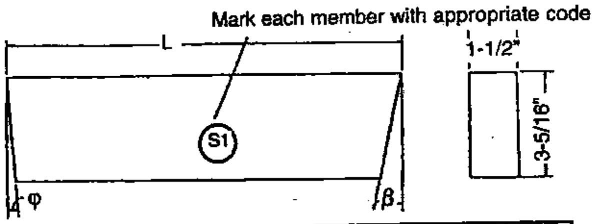




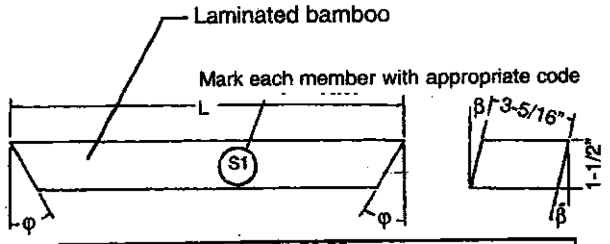
SCHEDULE FOR STRUTS 2 & 3							
QTY.	CODE	L	ℓ	m	A	α	REMARKS
65	2	4'-3-3/16"	3'-1-3/16"	7"	1-5/8"	11° - 30'	Dimensions & and m to be as accurate as possible
40	3	5'-0"	3'-10"	7"	1-5/8"	12° - 45'	For proper fit of hex and pent panels

Fig. 20.37

BAMBOO GEODESIC DOME - CONSTRUCTION



Schedule submember S1-S3 S5					
Code	QTY.	L	φ	β	Remarks
S1	25	2' 3-7/16"	4°00'	11°30'	End butts 2, β end butts S2
S3	25	2' 1-1/2"	6°30'	14°30'	" 3 " S2
S5	20	2' 3-7/8"	8°00'	14°oo'	" 2 " S2



Schedule submember S1-S3 S5					
Code	QTY	L	φ	β	
S2	25	1' - 0"	35°30	11°30	
S4	25	2' - 4-5/8"	31°30	14°30	
S6	20	1' -11-1/2"	27°00	14°od	

HOW TO CALCULATE THE LENGTHS OF THE STRUTS ACCORDING TO THE DOME DIAMETER.

The dimensions indicated in the drawings correspond to a dome 24 feet in diameter. If you want to build a bamboo dome larger or smaller, all you have to do is to change the lengths of the struts, the end angles and bevels remain the same no matter what size you build.

Once you decided the diameter of the bamboo dome, enter the desired dome radius (half diameter) in all boxes in column B of Table. 20-3 . Then for each strut follow this procedure:

Multiply column B by the chord factor in column C. Enter the product in the empty space in column D. Now subtract the figure in column E from the number you entered in column D. Enter your final figure - your strut length in inches, under column F.

Gussets: All gussets are made from plybamboo or plywood. Make full-sized templates of all the gusets ~~from stiff cardboard~~ or sheet aluminium. Remember to include marks for the position of the bolt holes. Drill 1/8" holes. Making the gusets is easiest on a table saw, but before you start check the miter gauge to be sure it's reading accurately.

G1- Center gusset for pents. Rip a strip of plywood 7 7/8" wide. Set meter gauge to 72 degrees, and cut off one end of the plywood strip. Now measure 5 inches from the obtuse angleyou just made an d mark. Align the mark with sawblade and adjust rip fence to bear against the 72 degree angle, with a block of wood clamped to the fence as a spacer. Now make a cut - you'll end up with a trapezoid. Repeat until have six. Mark with template all six trapezoids, then cut to shape on saw, with meter gauge still set at 72 .

G3 - center gusste for hexes. Rip a strip of plywood 7" side. Set miter gauge at 60 degrees, cut off one end of the street, flop and mark off 2 1/4" in from obtuse angle. Repeat fence trick described above. Cut 15 trapezoids. Mark with template. Set guage to 64 degrees 30 minutes and cut off tips. Note that the one flat edge needs slight trimin go to correct angle.

G2 - tip gusset for pents. Cut off a strip of plywood four inches wide. Set meter gauge at 34 degrees 30 minutes and cut off end. Saw may bind with this much angle on miter gauge. So after you make this cut, set gauge to 69 degrees. Position the angle end of this strip against -miter gauge, and align obtuse angle with blade kerf in miter - gauge face block. Clump a stop block to fence and cut. Flop and repeat until you have 30 triangles. Mark w/template, set miter gauge to 90 and-cut off tips.

G4 - tip gusset for exes. Cut 80 rectangles 7 5/8 by 3 5/8. Mark one w/temp. Set miter gauge to 64 degrees, 30 minutes. Align the line drawn at 64 degrees, 30 minutes with the saw blade, clamp a stock block to miter gauge and cut. Do the other 79 rectangles the same way - just one cut. Then reste gauge to 60 degrees. Position the block you marked with the template, lining up the 60 degree line with the saw blade.

Reposition stop block and cut all 80 blocks. Then mark all blocks with template, swing gauge to 90 degrees and cut off tips. When all gussets are cut, use a template and a punch to mark bolt hole location. Drill the holles and gussets are done. Mark each G4 gusset with code 2 or 3 so you will know later which ends fits which strut.

Once all gussets and struts are cut assemble the hex and pent panels. Bolt the frames together first, then nail in the supplementary struts S1 through S6. Avoid toe nailing whenever possible. So add the supplementary struts in the right order. On the hex panels put inthe S5 and S6 struts before you add the S3s and S4s. This allow you to the 4A and 4B struts into the ends of all S struts. On the pen panels you won't be able to avoid the nailing.

When assembling the hex and pent frames be sure to follow the notes on the plans.

Table.20-3 STRUT COMPUTATION

A Strut	B Radius of dome (inch)	C chord factor	D Reference dimension	E Gusset constant	F Strut length (inch)
1		.3297		2.438	
2		.3823		4.000	
3		.4411		3.500	
4A		.4215		2.625	
4B		.4215		1.563	

Source: Fuller and Sadao Inc. Popular Science (1972)

BAMBOO HYPERBOLIC PARABOLOID STRUCTURES

Fig.20.38 **TYPES OF HYPERBOLIC PARABOLOIDS**

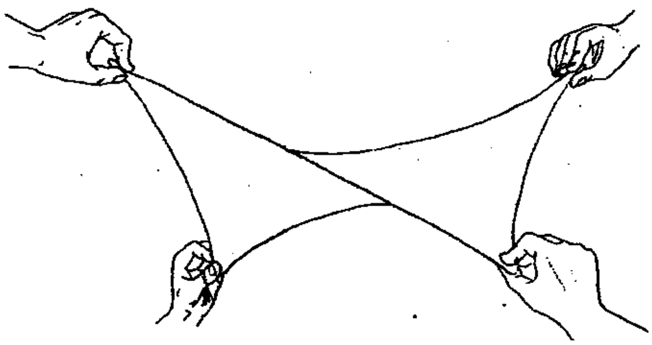
One of the many applications which can have bamboo in the field of structures is in the construction of hyperbolic paraboloids, known also as "saddle surface", which is one of the few structures which takes a curved shape in spite that is builted with streight structural elements.

Many builders have the idea that to build this type of structure is very difficult because the term "*hyperbolic paraboloid*" sounds very complicated, particularly for those that are not familiar with the geometrical figures. Really its construction is very simple once one can get a tridimensional idea of its shape.

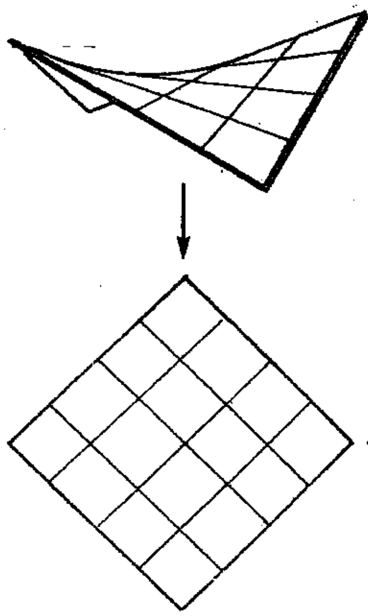
Two people can obtain the surface of a hyperbolic paraboloid, by pulling up on two opposite corners of a handkerchief and pulling down on the other two opposite corners (See Fig.A). In general the sides of the surface are straights.

There are two types of hyperbolic paraboloids: the regular (Fig B1) in which the frame has a square plan. and consequently the 4 sides have the same dimension.; and the irregular hyperbolic paraboloid which have two sides longer than the other two (Fig. B2).

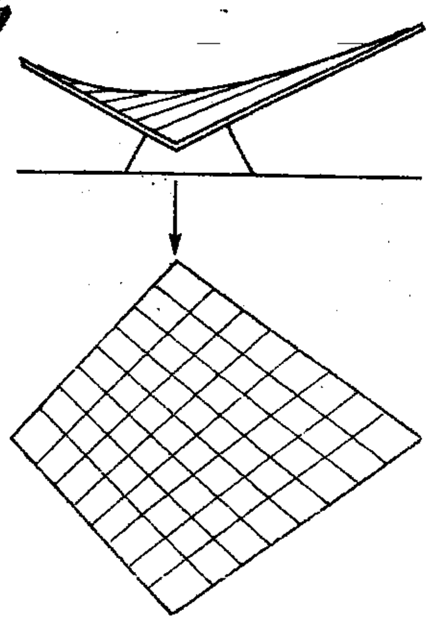
A. The surface of a hyperbolic paraboloid



Types of hyperbolic paraboloids

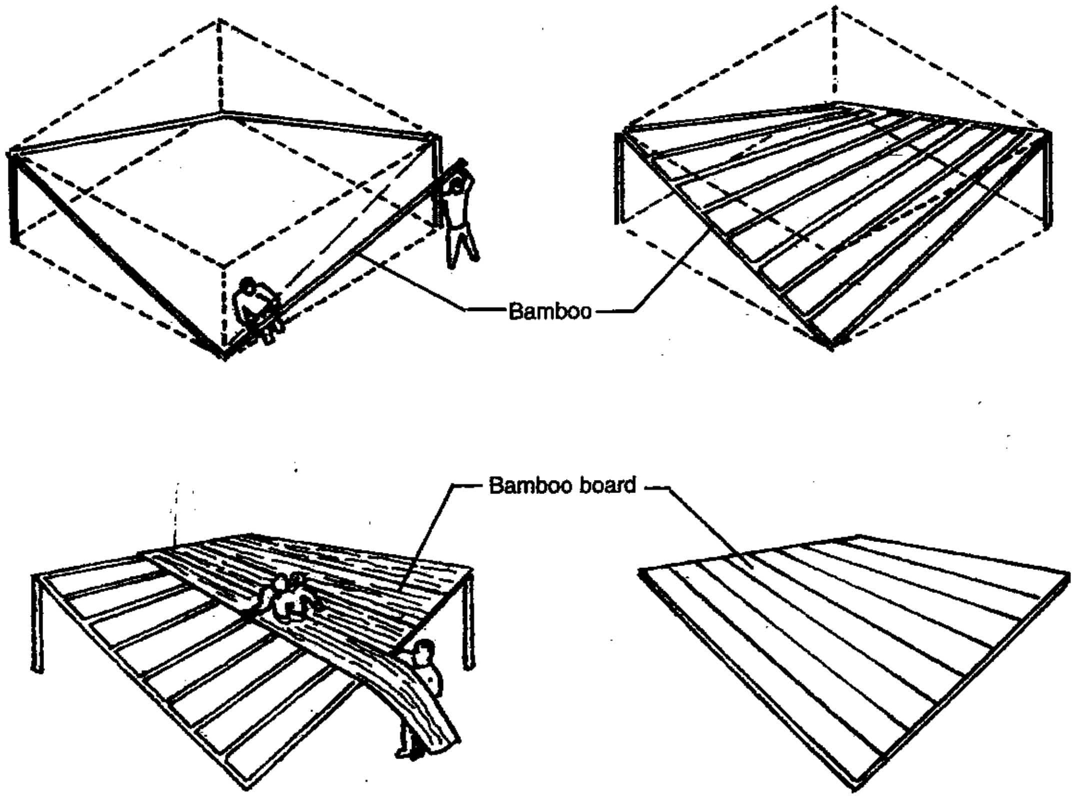


B. Regular hyperbolic paraboloid



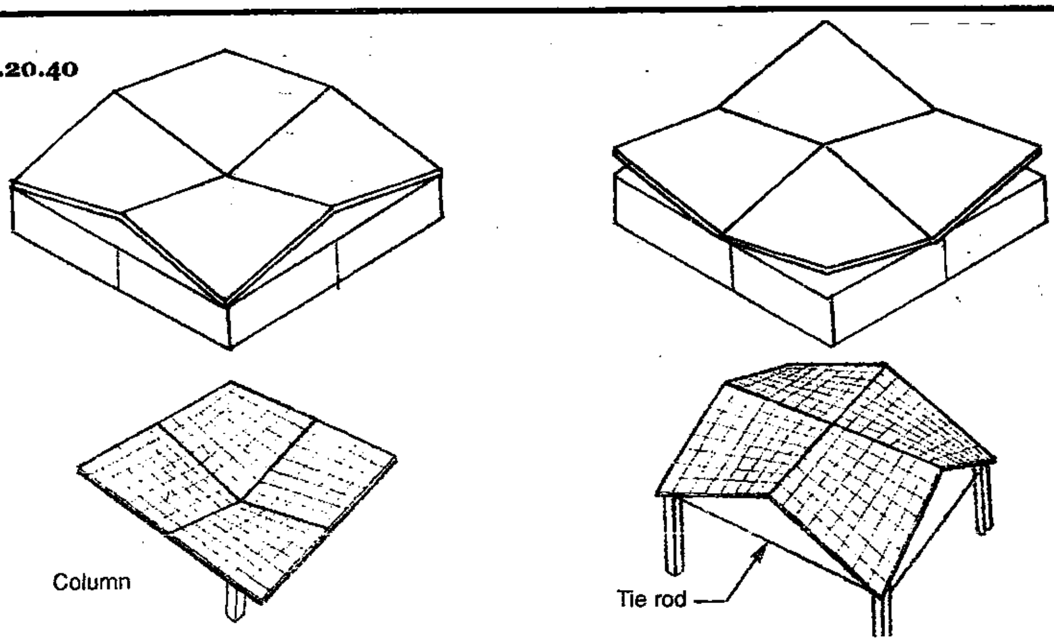
C. Irregular hyperbolic paraboloid

Fig. 20.39 **CONSTRUCTION OF REGULAR PARABOLOIDS**



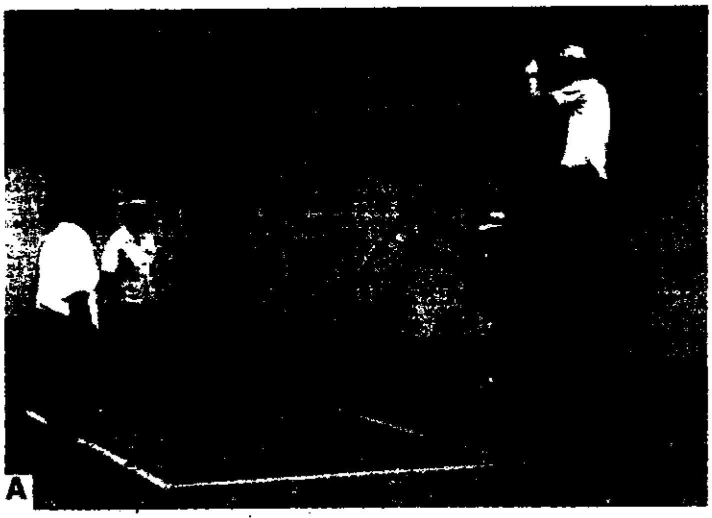
STRUCTURES BUILT WITH REGULAR HYPERBOLICS PARABOLOIDS

Fig.20.40



B. *Different types of roofs with 4 hyperbolic paraboloids The roof (1) is the same that in (2) but upside- down. The same occurs between 3 and 4, the difference is that the former has 1 column.*

Fig.20.41 **CONSTRUCTION OF A BAMBOO PARABOLOID IN HAWAII**



A

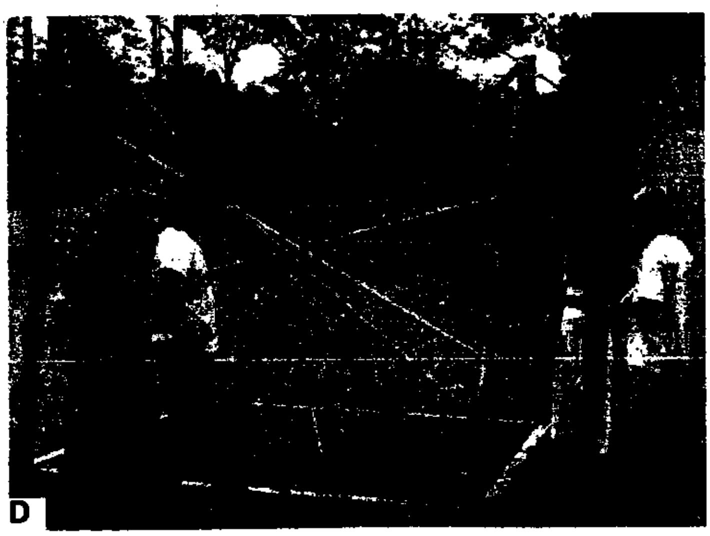
In 1996 I was invited by the University oi Hawaii at the Hilo Island to give a bamboo lecture and also a work shop for some people which atended the Seminar. There we built this regular bamboo hyperbolic paraboloid shown in the following photographs.

The first thing we did was to put in the ground a square frame and then we fixed in the top of a colum the first two struts as shown in Fig A. Then we made the same operation in the oposite side and also fixed a horizontal pin in each vertex. (Fig B).

Then we divided two oposite struts in eight parts and in the center of each division we fixed the end of the the struts as shown in Fig.C. Fig. D shows the structure once finished.

B

C



D

NOTE:
The structure shown in Fig.D could be used with decorative purposes If the hyperbolic paraboloid is going to be used as a roof, the height of the vertical pieces has to be about one quarter of that shown.

ROOF WITH SEVERAL BAMBOO HYPARS

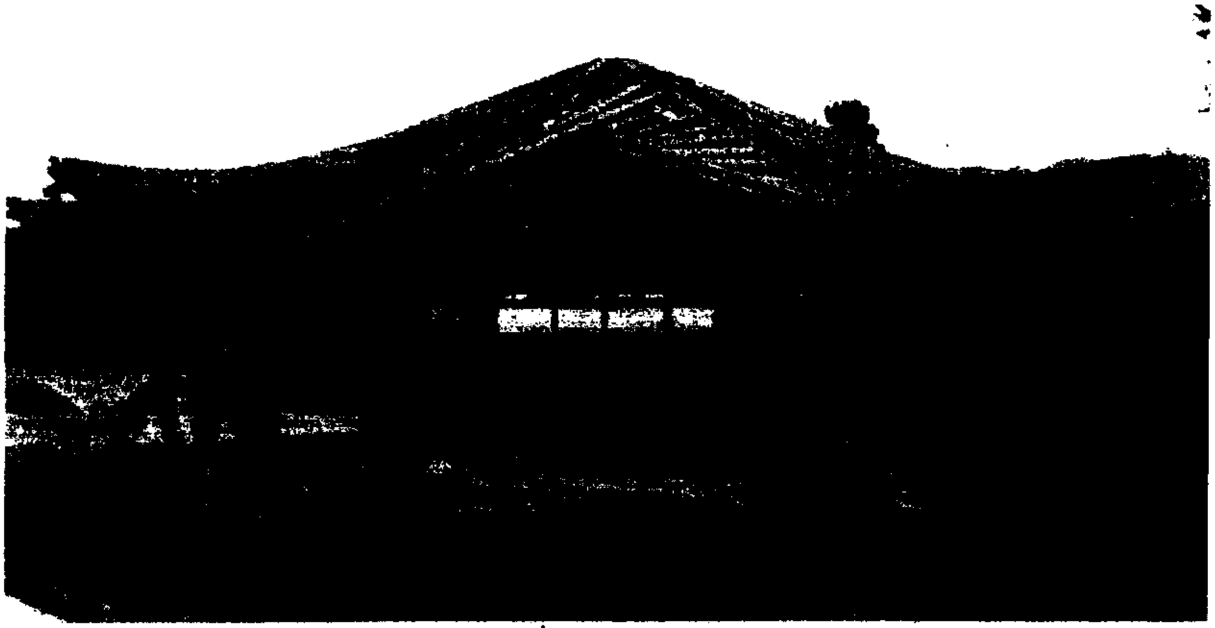
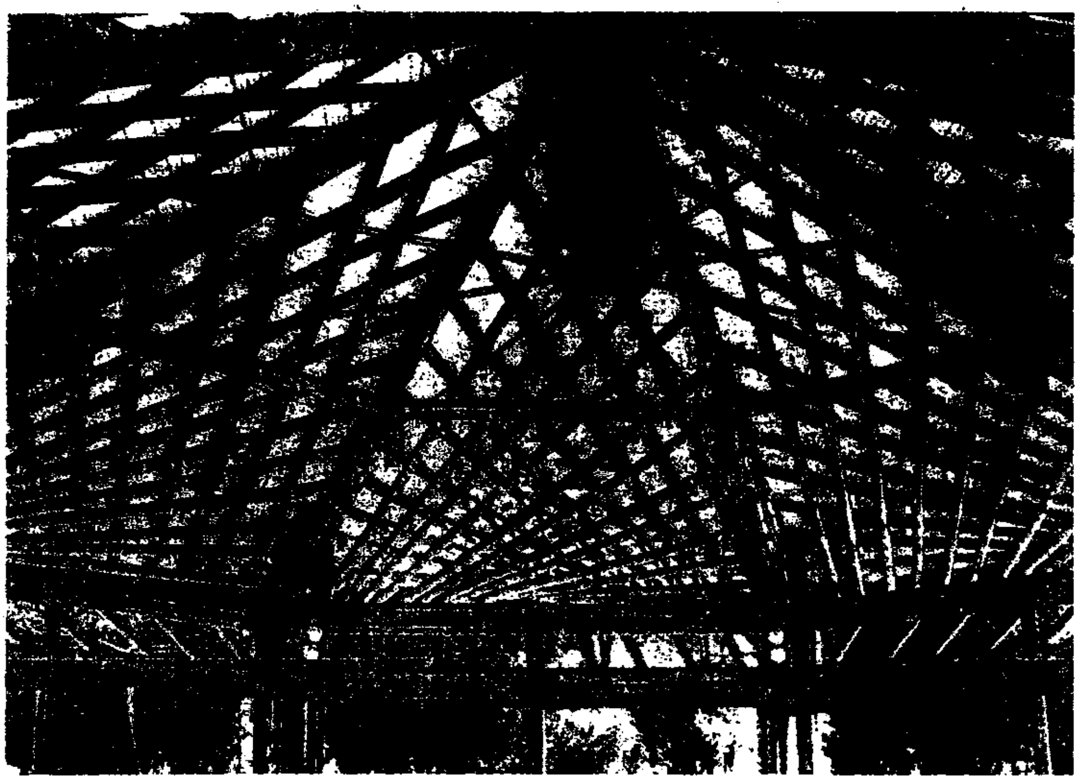


Fig. 20.42 A *This structure consisting of several Hyperbolic Paraboloids and was built in 1999 at the Botanical Garden of Bogota, Colombia. It was designed by the Arch. Guillermo Holguin and built by the Ing. Jairo Gil.*



B. *Interior view of the structure (Photo cortesy of Camilo Eduardo Cabezas -2002).*

BAMBOO CONOID STRUCTURES FOR ROORS AND WALLS

TYPES OF BAMBOO CONOID ROOFS - CONSTRUCTION

This technology has been used up to the present in the construction of conoid concrete shells roofs, but it could be used in the construction of bamboo roofs and in bamboo decorative walls.

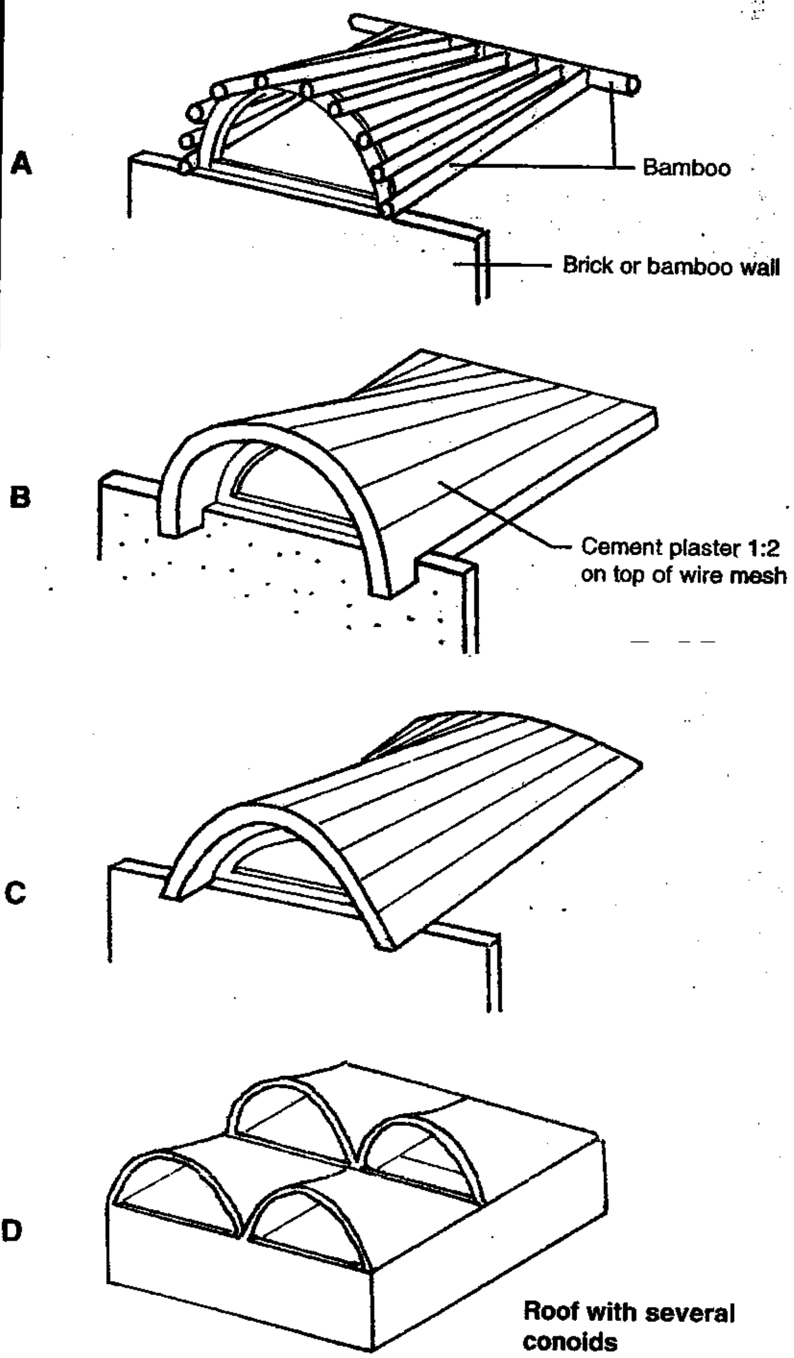
This type of structure and the hyperbolic paraboloid have in common that their curved shapes are ge-nerated by straight structural elements (in this case bamboo culms), joining the points of two arches with different height in the centers of the arch, or the points of a curve with equal number of points located in a straight horizontal bamboo beam or wall.

There are a variety of forms of conoid bamboo roofs such as the cylindrical and elliptical. Also it is possible to create other types of structures, i.e. using instead of two arches, a triangle and an arch, or two triangles of different height or dimensions.

The arches could be made with laminated bamboo, bamboo deformed longitudinally, wood, brick or concrete.

This type of structure could have many different applications in the construction of roofs for workshops and vertically in the construction of bamboo walls with beautiful shapes, etc.

Fig. 20.43



BAMBOO TENSILE STRUCTURES (TENSEGRITY)

Fig. 20.44

APPLICATIONS

According to Connelly and Allen, in the autumn of 1948, while experimenting with ways to build flexible modular towers, a young artist named Kenned Snelson, constructed a sort of sculture that had never been seen before, as ethereal in appearance as a movile.

Salvadori (1979) points out that the structural system invented and patented by Snelson with the name of *Tensegrity* have entered the field of art. Snelson has builted beautifully airy pieces of sculture, some of them very large. Fig.A. They are shown in museums and outside areas all over the world. Fig. A shows a large tensegrity sculpture.

This type of space trusses are built of thin steel cables and stainless steel compressive pipes, which could be replaced with bamboo culms of diferent diameters and lengths which have beauty, a low cost and an extraordinary compression strength.

Due to the lack of information about this tipe of structures are very few the artists architects and engineers which can design and built this kind of structures in which bamboo could play an important rolle in a near future.

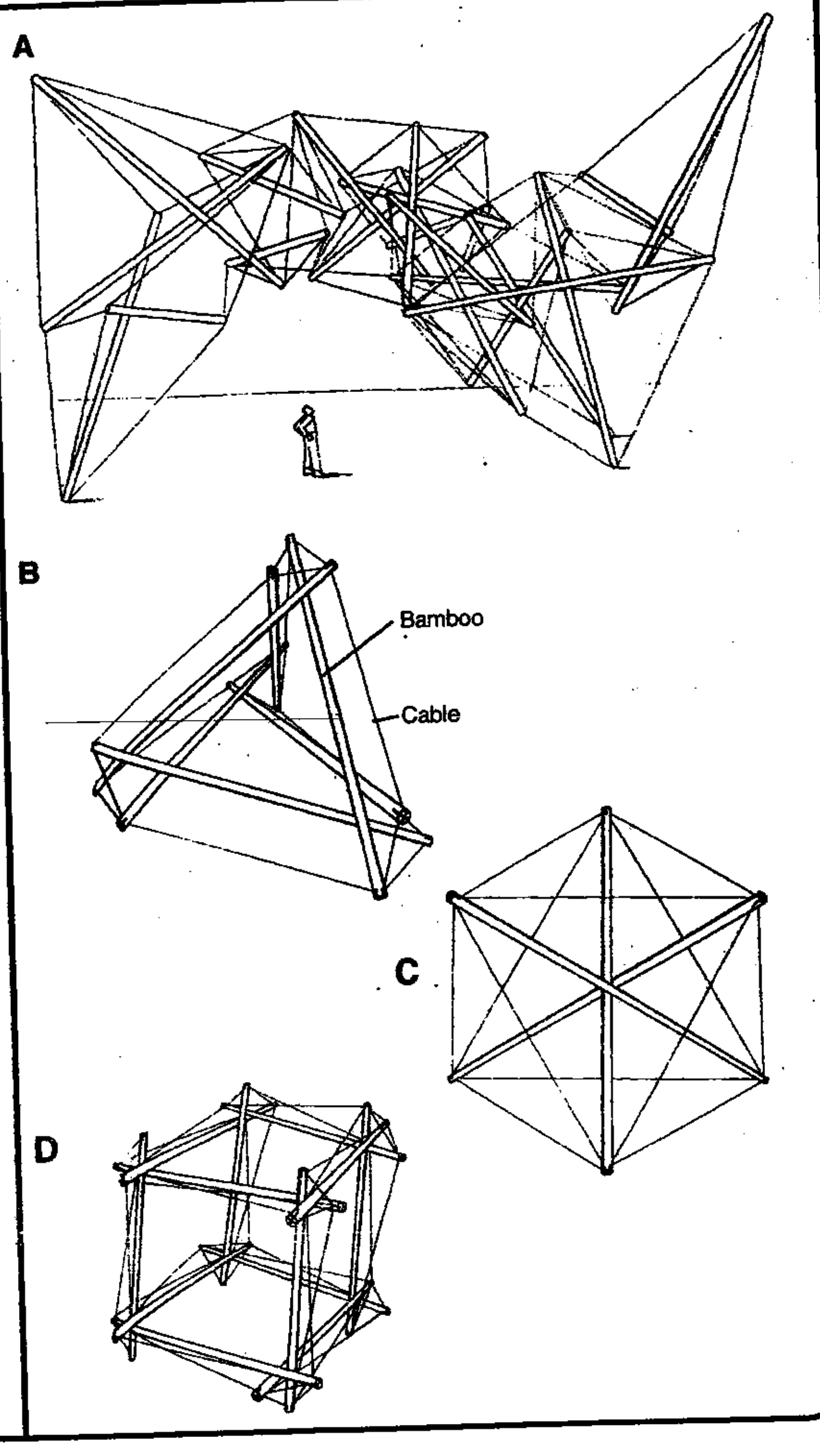


Fig. 20.45

BAMBOO TENSILE STRUCTURES

Simple tensegrities

The minimum structural system possible is a tetrahedron where each member must be able to be loaded in both tension and compression. Separating tension and compression results in the tensegrity tetrahedron-6 compression members and 18 segments of cable.

The octahedron tensegrity has 3 internal compression members running between opposite vertices. The normal edges of the octa are replaced with cables. The icosa tensegrity has 6 internal members and 30 segments of cable replacing the regular edges.

Models of any of these can be made by taping the compression members to the edges of the appropriate solids and then connecting the strings. When every thing is tight, collaps the solid and remove it. Use a tetrahedron for the tetrahedron and a cube for the icosa an octahedron. Fig A1 and A2.

Tensegrity domes

The simplest tensegrity dome is an extension of the octahedfron tensegrity space frame. Each triangle of the dome is one face of the octa tensegrity - the three members crossing are the three compression memebers of the octa. Six of the 12 cables of the octa become redundant and can be left off. Each compression members continues on to become a compression member of the adjecent octa face.

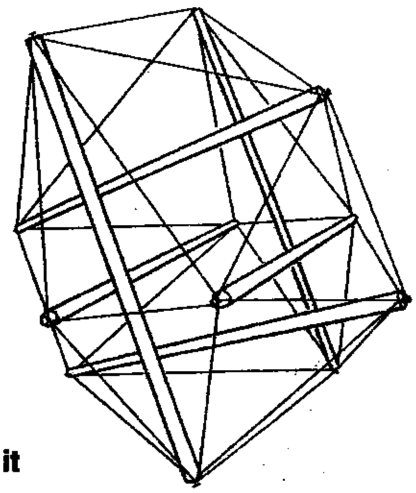
The upper part of the culm, with smaller but more vascular bundles and their fibre sheaths, has an increase fiber percentage and hence a higher specific gravity. In most of the species the upper part is the strongest part to compresion of the whole culm and consquently the top part of the culm is the most appropriated for TENSEGRITY.

A. *The pattern of wires makes an icosahedron.*

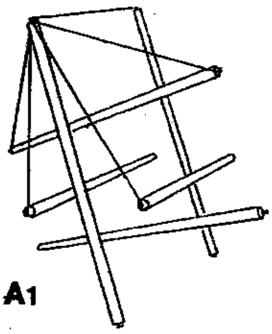
A1-A2. *In the models you can clamp the struts into place using bits of wood and scotch tape, or make a light cardboard cube and tape the pairs of struts to the opposite faces. (H. Kenner).*

B. *With some experience it is possible to make this "H" type of structure.*

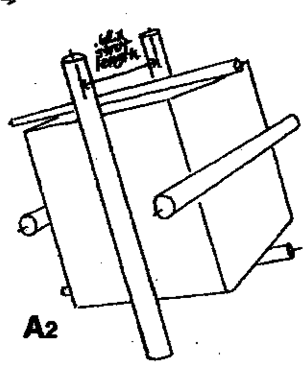
A.



How to build it

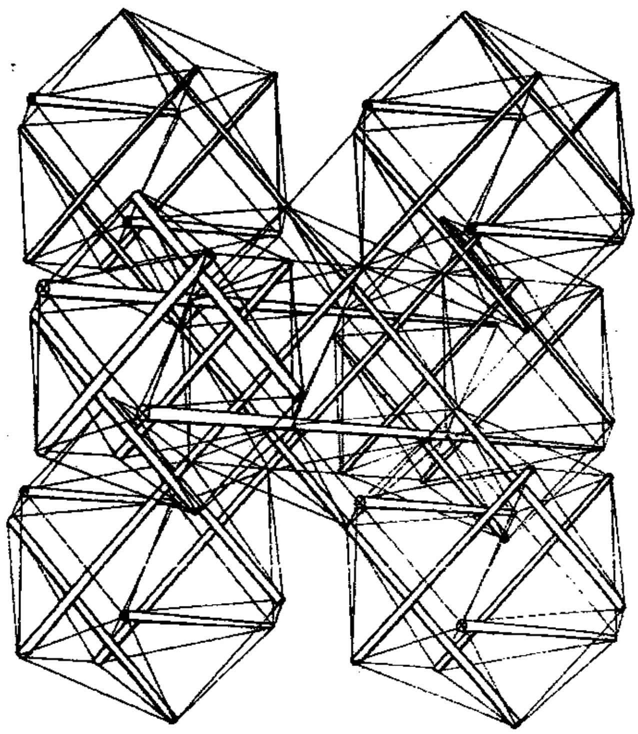


A1



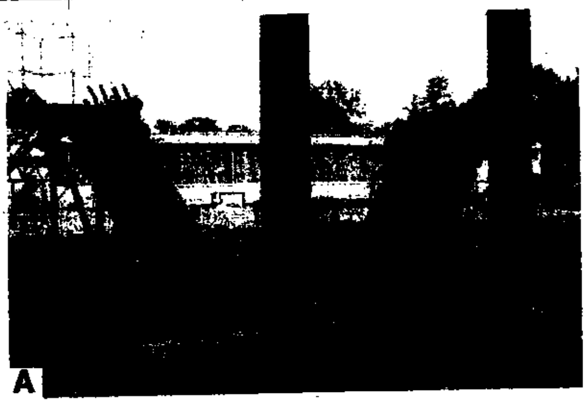
A2

B



CATENARY ARCHES MADE WITH BAMBOO SECTIONS (Gernot Minke)

Fig. 20.46 CONSTRUCTION OF CATENARY ARCHES



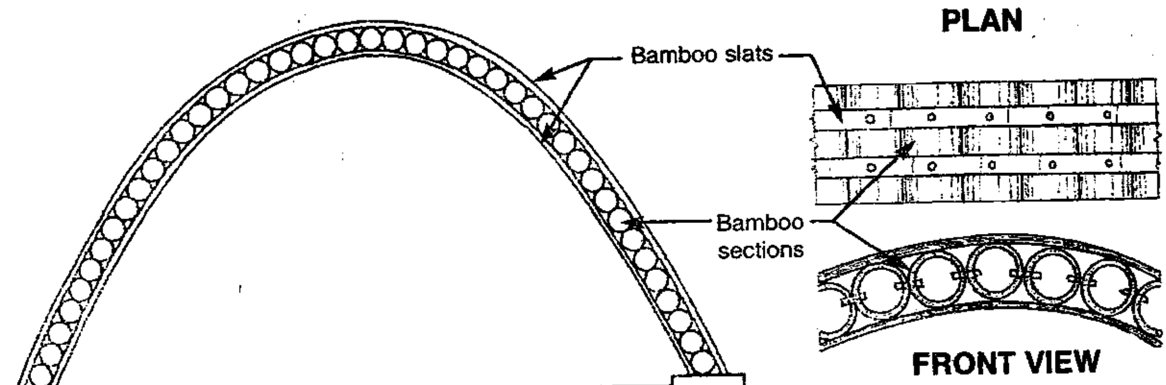
A

Gernot Minke carried out studies between 1981 and 1982 about building construction with bamboo at his Research Laboratory for Experimental Constructions of the University of Kassel in Germany.

One of the most interesting applications which he developed was the construction of a catenary arch made with bamboo sections fixed to 6 bamboo strips that were hanged suspended and which with an additional dead weight take the shape of a catenary. Once fixed the bamboo sections over the 6 strips, other 6 strips were fixed on the top of the sections as shown in "A", and then the whole structure was inverted as shown in "B".

B

Fig. B. *In this ~~type of structure is very important~~ to put some dead weight distributed on the exterior surface of the arch in order to make it more stable. In this case was stabilized by a layer of compact clay covered with turf.*



C. ELEVATION

D. *Plan and Elevation of the small bamboo sections show how they are fixed to the bamboo strips.*

STRUCTURES GENERATED BY NATURAL AND ARTIFICIAL DEFORMATION OF LIVING CULMS

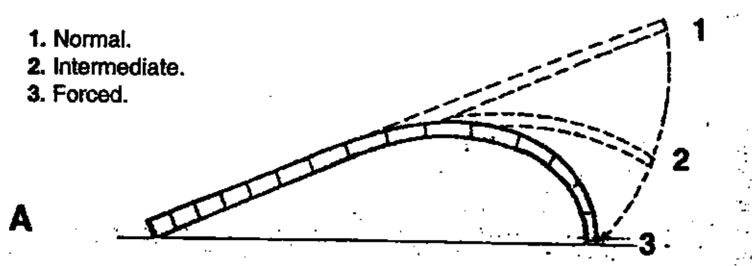
19

STRUCTURES GENERATED BY THE FLEXIBILITY OF THE CULM

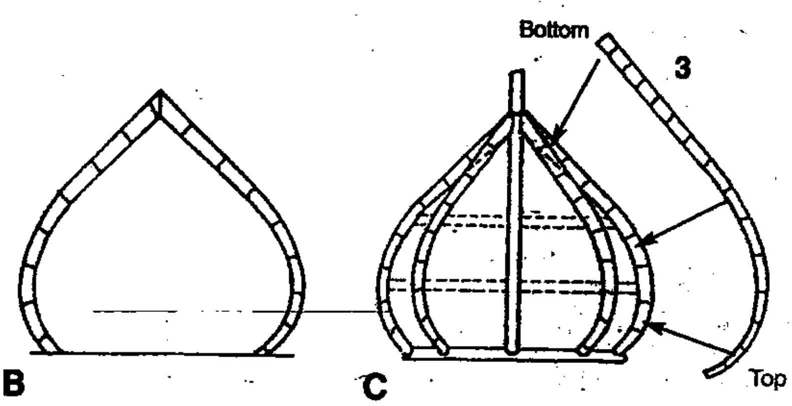
Most of the culms, particularly of giant species, such as *Guadua angustifolia* are erect and have a tapered shape due to its diameter and wall thickness reduces from bottom to top. Furthermore, the length of the internodes varies along the culm. Due to these reasons the only flexible part in this specie is the top part, and the different shapes that it takes when the top part is bended are shown in Fig. A. Nevertheless there are in the Americas other giant species such as *Guadua aculeata* from Mexico which are no erect and naturally form huge arches which can be used in the construction of some types of roofs.

The only country which has taken adventatage of the flexibility of their species in the construction of roofs and of diferent tipes of structures for temples and houses has been India, particularly during the Vedic Age which took place more than 4000 years ago. At that time Indian builders discovered that the top part of the culm was stronger in compression than the lower part or basal part of the culm (See Mechanical Properties of the culm) and in order to have a more atractive curve they use the culms upside down to form what was known as "the lotus arch" (Fig. B) which generate the "lotus dome" and other types of arches and domes which can be seen in the section of Indian Architecture.

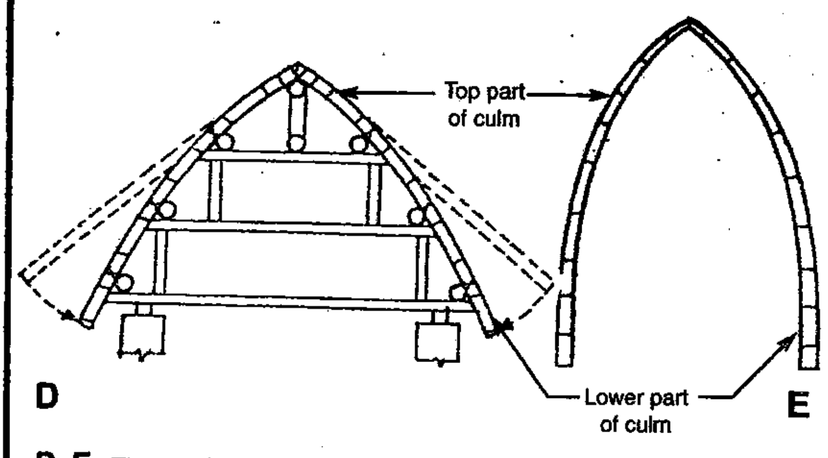
Fig. 21.1



Different positions which can take the culm



B.,C. *The position 3 was used in India upside down by the Vedas in the construction of Lotus or Bulvous domes. See page 418.*



D.,E. *The position number 2 has been used in India for the construction of ogival arches with different width in the base.*

Fig. 21.2 NATURAL LONGITUDINAL DEFORMATIONS OF CULMS

Particularly in congested bamboo plantations is common to see two types of longitudinal deformations of culms produced by culms which are in their growing process and find a barrier which obstruct their growing. In this case the culm can present three types of deformations: The deformation No. 1 occurs in those culms which grows with some inclination. The deformation No. 2 occurs when the culm grows vertically. In this case the culm turns down forming two curves with the shape of siphon in order to avoid the barrier and then it continues growing vertically. The deformation No. 3 (Fig. A) occurs when the deformation No. 2 takes place near the ground, and the curve has not enough space In this case the culm stops its growing an die. Fig A.

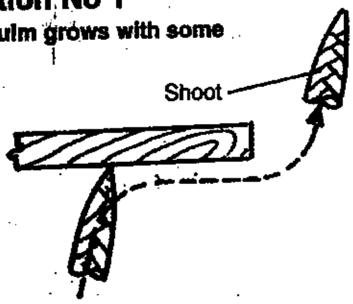
Fig.C shows 3 deformed culms interlaced that I used with decorative purposes.

A

Types of natural culm deformations

Deformation No 1

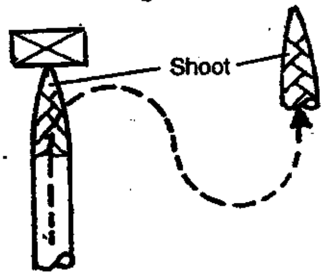
When the culm grows with some inclination



B

Deformation No 2

When the culm grows vertically



C

ARTIFICIAL LONGITUDINAL DEFORMATION AND ITS APPLICATION IN THE CONSTRUCTION OF THREE HINGED ARCH STRUCTURES

1. Application of Deformation No 1

The day that I saw for the first time the deformation No. 1 which is shown in the Fig. 21.2 B; I could imagine the extraordinary potential that this marvelous bamboo characteristics could have in the low cost manufacture of different types of three-hinged structural arches which are known with the names of radial, tudor, gothic, three-centered and parabolic arches (See Fig. 20.10, p. 309). Three-hinged arches, as the name implies, are hinged at each support at the crown or peak. This means that each arch is divided in two equal sections joined by a metal hinged at the crown. Detail of the metal hinge are shown in Fig. 21.4 detail No. 2.

The application of the deformation No 1 consist in to make a wooden square section form with the shape of half arch (See fig. 21.4) inside which will grow free the bamboo shoot. The form consist of 4 sides, three of which are fixed forming a channel and the forth lateral side has to be removable. The interior section of the form has to have a square form and the dimension of each side corresponds to the diameter of shoot (near the ground) plus 1 cm in order that the shoot grows free inside the form.

Once located the form in the top of the shoot is fixed with diagonals as shown in Fig. 21.4. The shoot in giant species takes about two or three months to grow about 10 meters. Once the tip of the shoot lieve the form at the top, the form can be removed very carefully but the deformed culm can no be cut inmediately and it is necessary to wate 3 years that is the time required by the culm to become mature. As I explained in other part of this book, all the bamboos used in construction has to be 3 or more years old.

The great advantage of this process is that the cost of each arch corresponds only to the cost of the wooden form which can be removed and reused about every 2 or 3 months, which is the time that the plant take for the development of each arch section.

In the Fig. 21.3 I show as a sample, a Tudor arch with the lefts section built in glue laminated bamboo or wood and in the wright side built with artificial deformed bamboo. Today (2002) in Colombia, the cost of a three-hinged tudor arch, 10 meters wide; made with glue laminated wood, has an aproximatelly cost of about US $5200 dollars. This cost include the cost of wood, airdry, transportation, machinery, clamps, etc and labor. The same arch made with glue laminated bamboo, has a cost about US $600 dollar; and made with artificial deformed bamboo, has a cost of about US$130 dollars.

This methodology will permit that a campesino can prepare in three years the number of arches that he is going to use for the construction of the warehouses he needs in his farm even for a two story house. On the other hand he can produce several types of structures for selling to other farms.

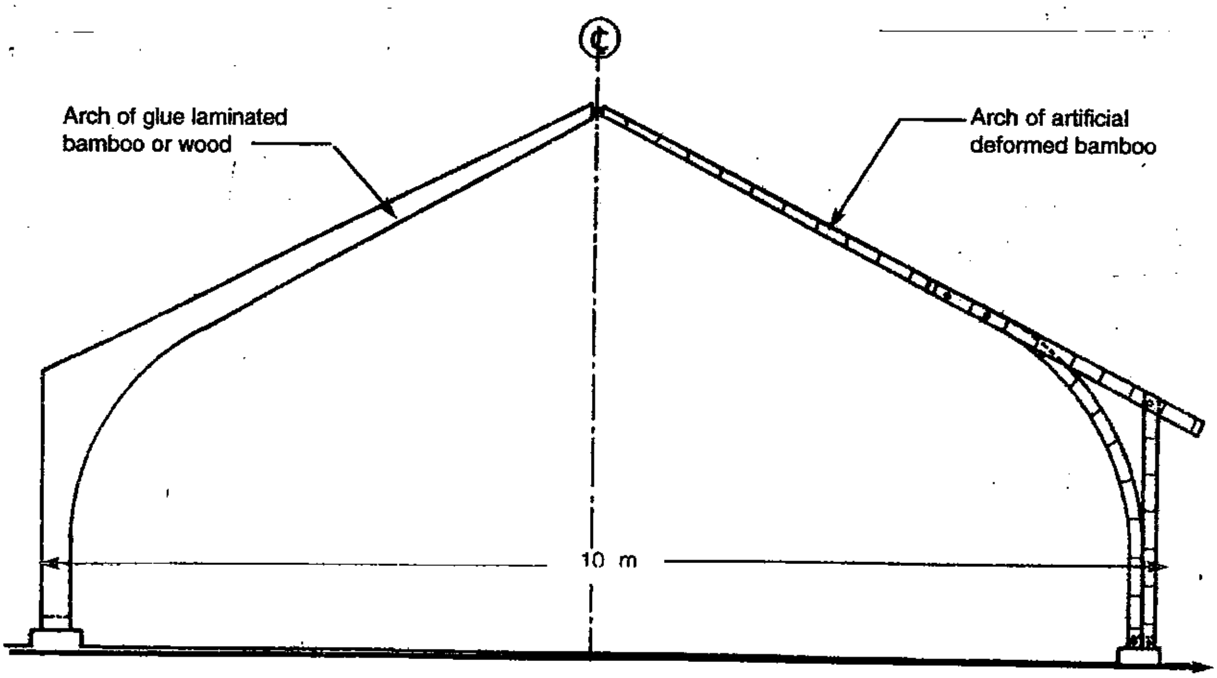
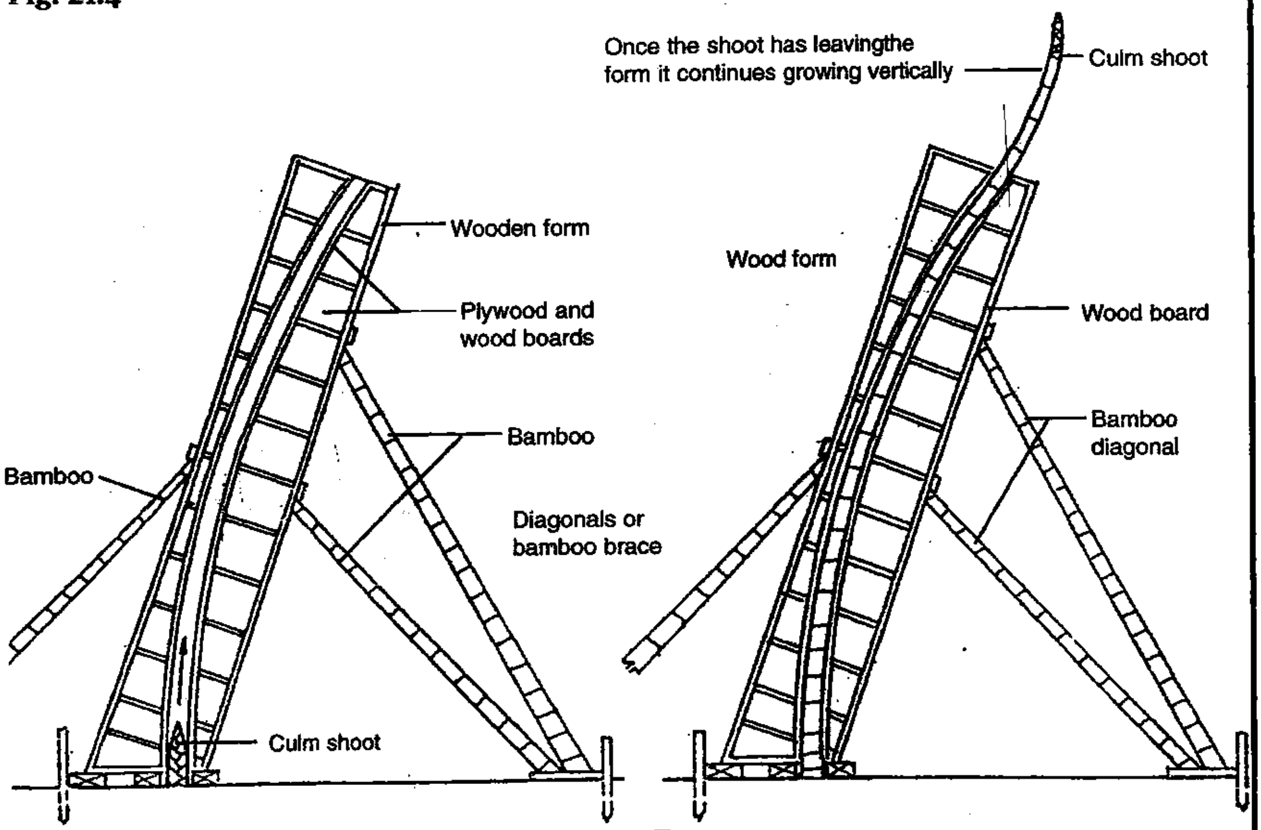


Fig.21.3 *A three-hinged Tudor arch could be built with glue laminated bamboo or with deformed culm.*

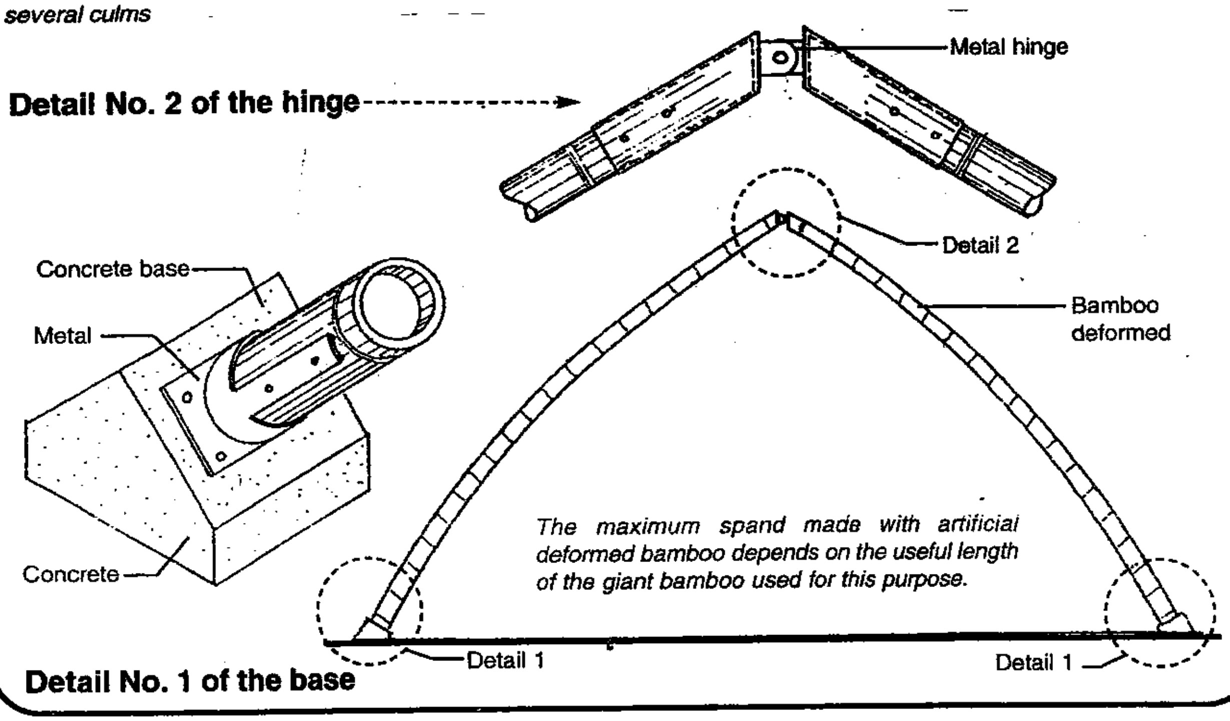
PROCESS OF DEFORMATION OF LONGITUDINAL ARCHES

Fig. 21.4



A. *Starting the deformation the culm shoot is introduced inside the wooden form, Then the form is supported by several culms*

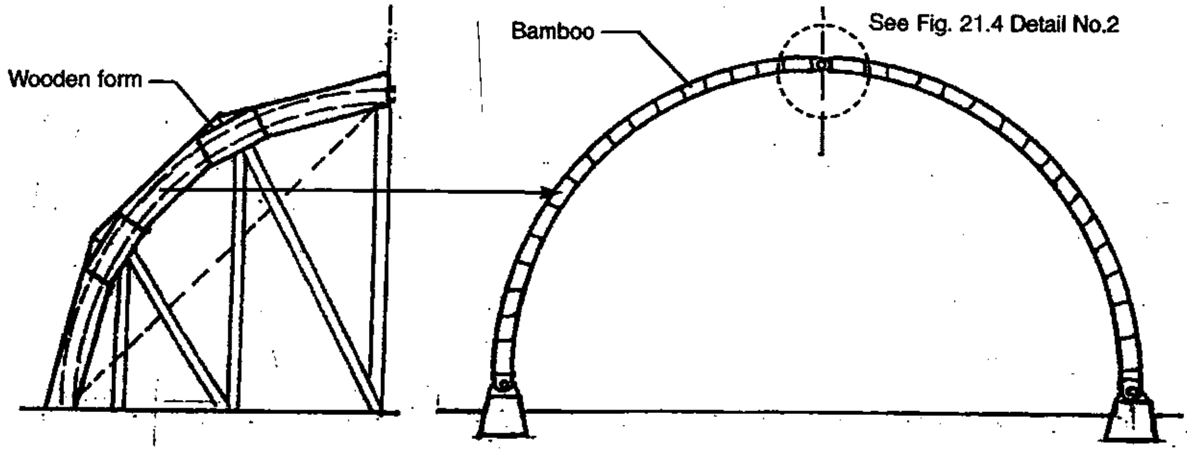
B. *Once the culm shoot has left the top the form, it can be removed.*



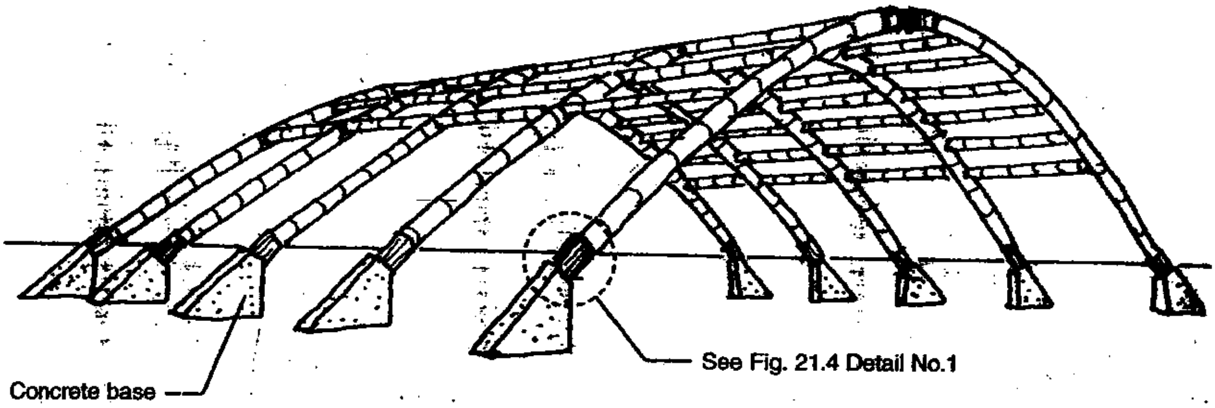
TYPES OF ARCHES WHICH CAN BE MADE BY DEFORMING CULMS

Fig.21.5

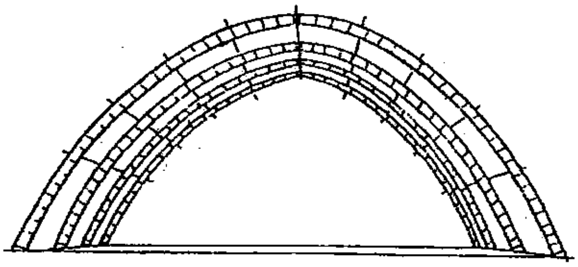
Application of Deformation No. 1



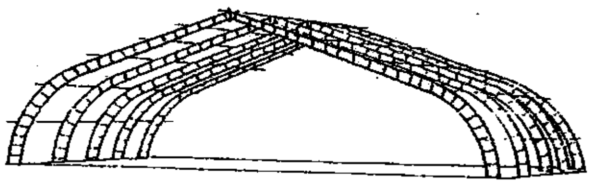
A. Three - hinged radial arch



B. Three - hinged parabolic arch (a)



C. Three - hinged parabolic arch (b)



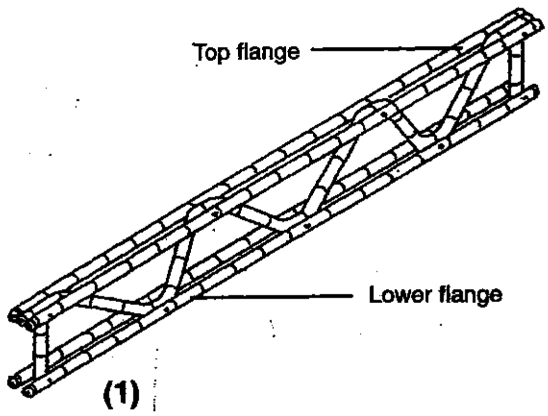
D. Three - hinged tudor arch

Fig. 21.6

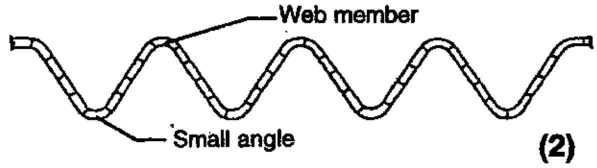
EXPERIMENT FOR MAKING A BAMBOO WARREN TRUSS BY DEFORMING THE WEB MEMBER

Application of Deformation No. 2

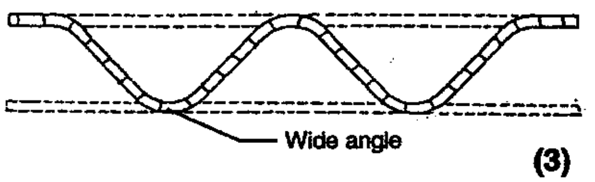
A. BAMBOO WARREN TRUSS



Detail of deformed bamboo with small angles



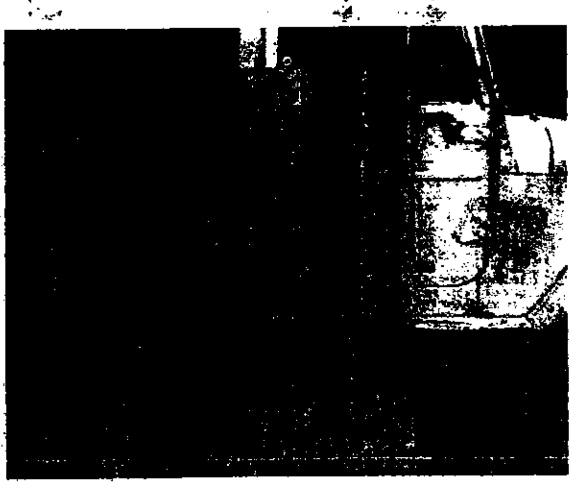
Deformed bamboo with wide angles



One of the useful applications which the deformation of culm No. 2 can have is in the construction of a Warren Truss (Fig. A) used as a beam in the construction of roofs, floors, bridges, etc. The most appropiate species which can be used for making the web member (the piece in zig-zag) by deformation of bamboo, are those species like *Bambusa Tulda* which are strong and has a diameter of 5 cms. Due to in the area where I used to make my experiments in Colombia, there are not this specie or other similar in diameter, I had to use the specie *Guadua angustifolia* which has 10 to 12 cm in diameter and required a larger wooden form.

In the first experiment which I carried out in 1993 in a farm of a friend of mine, I built a wooden form using wide angles as shown in Fig. A 3. About three month later I received in Bogota the information that the shoot was successfully growing out of the top of the form. Unfortunatelly that week the guerrilla destroyed the wooden box form thinking that there were weapons inside.

Since then I did not continue with this investigation until the year 2000 when I made my second experiment in the farm of my friends Olga and Gustavo Velez located near of Pereira city in Colombia. In this experiment I use a shorter form shown in the Fig. A 2 using in the curves sharper angles in order to determine the minimum angle that can be used with this type of bamboo. This experiment could not be continued because all the wooden boards of the forms were stolen a week later I took this picture.



B. *A short wooden form used in the experiment of deformation.*

C. *The bamboo shoot growing inside the short wooden form.*

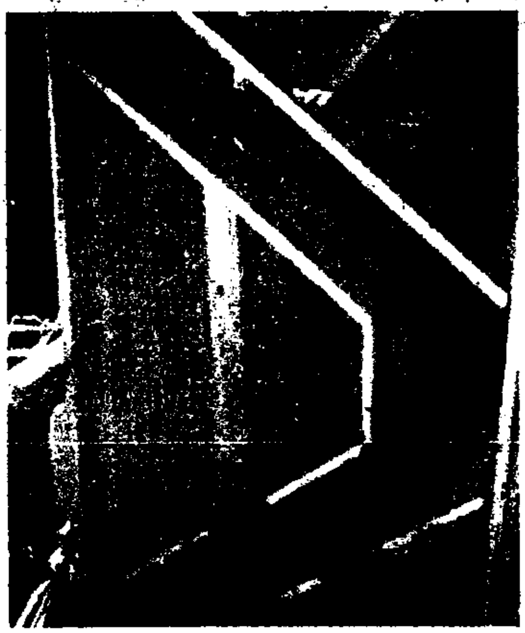
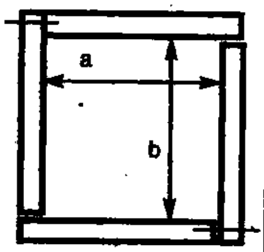


Fig. 21.7 HOW TO MAKE SQUARE AND RECTANGULAR BAMBOOS

A. *Culm'shoot.*

B. *Square Guadua angustifolia.*

C. *The form could be square or rectangular. Consist of two separate sections each one forming an "L". The drawing shows the position of each "L" and the location of the nails.*



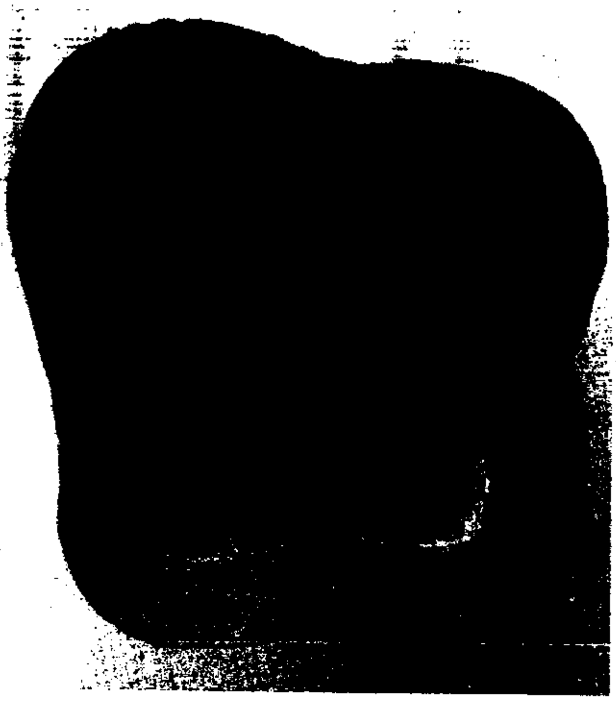
Culms with square or quadrangular cross section are made artificially in Japan particularly in the suburbs of Kioto where this technology has been industriaized.

This type of culms are produced by placing wooden frames over young shoots of *Phyllostachys pubescens* soon after they emerge from the ground and has in his base the maximum diameter (See Fig. 20.5 A).

The first step consist in taking the circumference measure in the lower part of the shoot (A) near to the surface of the ground. Assuming that the length of the circunference is 40 cm. If we want to make a square section, we divide this dimension by 4 and we get 10 cm that is the internal dimension of each side of the form. But if we want to have a rectangular section we can have 2 sides of 12 cm and two sides of 8 cms. In this case the internal dimension of the form is: "a"=12 an "b"=8 cm (See Fig. 21. 7 C). In the first case the wide of the wood boards has to be: 10 cm.+ the thickness of the wood board.

The forms are made with of 4 rought boards joined in two pairs by nails along the edges forming an "L" (See Fig. 21. 7 C). The two "L" sections are tied together with a rope made of a vegetal fiber such as jute or hemp (See Fig. 21. 8 A). The separation of the ties is about 30 to 40 cm. Once ready the form is placed over the shoot or sprout, and the lowest tie is fixed.

If the dimension of the circunference is taken with exactititude the results wil l be as shown in the figure B. But if you make a mistake and insted of 10 centimeters you put 9 cm as internal dimension of the sides the result will be as the figure D. Dont worry I failed 4 times and finally I got the result shown in figure B.



D. *If the dimensions of the form sides is, for example, 10 cm, and we erroneusly put 9 cm or less, the section of the culm grows deformed as shown in this figure.*

Fig. 21.8 **MANUFACTURE AND PLACEMENT OF THE FORMS**

A. Preparation of the forms in a factory of square bamboo in the suburbs of Kioto in Japan. Sections of square bamboo are used for the manufacture of lamps and in decoration. In many houses are used in the construction of walls surrounding the gardens of houses.

B. The two angles made with wood board are tied with ropes with a separation of 40 cm., except the lowest one which is tied at the base once introduced over the shoot as shown in Fig. C.

C. Fixing the lowest rope once introducing the form.

D. If the rope is not very well tied, slats of bamboo are introduced between the rope and the form.

E. This methodology is used in Japan for the manufacture of downspouts for houses.

REMOVING THE FORMS AND PAINTING THE CULM

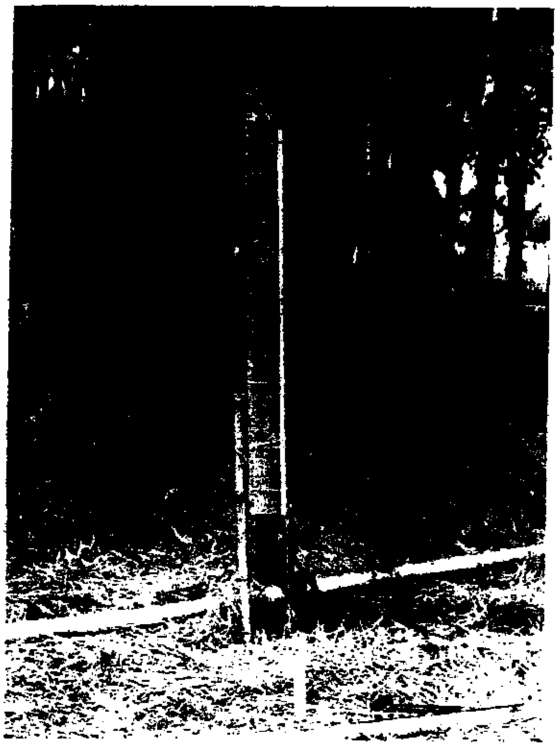


Fig. 21.9 A. *The forms once placed over the shoots are supported erectly by ropes extended from the top of the forms to the base of adjacent culms. When the culm have leave from the top of the form it takes the round form and the forms can be removed.*

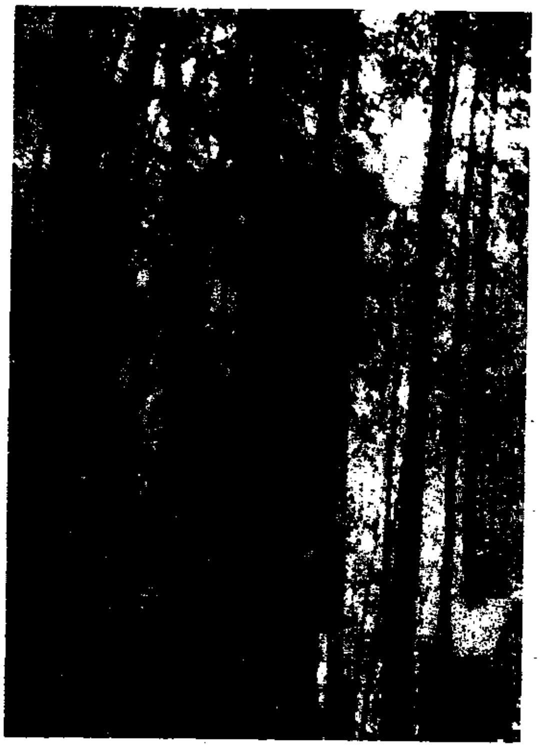


Fig. B,C,D *Once the forms and the sheaths leaves have been removed, the surface of the square culm is spotted with a rubber brush and wet clay containing hydroclodic acid or sulfuric acid of 60% (See Fig. C) which produces on the surface of the square bamboo the beautiful stains shown in Fig. D.*

C

D

20 THE EFFECT OF EARTHQUAKE FORCES ON BAMBOO BUILDINGS

Earthquakes are essentialy vibrations of the earth's crust caused by subterranean ground faults. Major earth quakes occur most frequently in particular areas of the earth's surface that are called *zones of high probability* such as the Andes in Colombia.

During an earthquake the ground surface moves in all directions producing shock waves which generate opposing irregular horizontal and vertical vibrational forces which push and pull upon a building's fundation, which causes the walls of the buildings to expand and compress (responding to the vertical shock waves) and to bend and sway from side to side (from the lateral waves)

Because buildings are generally designed for large vertical loads, the vertical forces of an earthquake are generally resisted. The horizontal earthquake movements, however, can easily exceed the lateral strength and flexibility of a conventional wood house structure, and it is ussually these lateral vibrations that result in cracked and broken the wood studs and columns (except when bamboo culms are used as studs and columns), separation of the superstructure and foundation, and the collapse of all or part of the building. This lateral earthquake waves can also literally burst the mortar seams of brick and concrete block that are underreinforced and /or improper connected to the framing of a building.

Normally, an earthquake code, requires a house to be designed for static forces called earthquake forces acting in the four directions shown in Fig. 22.1.

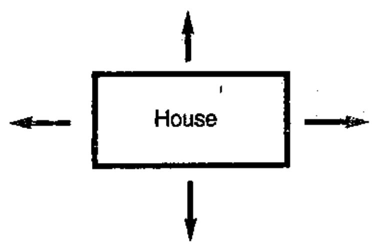


Fig. 22.1 *Direction of the horizontal earthquake forces.*

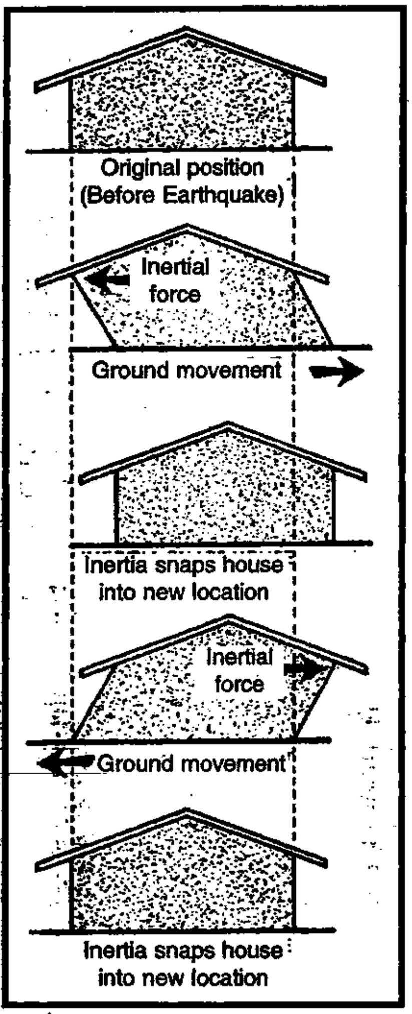


Fig. 22.2 *The most damaging effects on structures are generally the movements in a direction parallel to the ground surface (horizontally), similar to the effect of strong winds or hurricanes. These cause inertia forces in all parts of the building that are fixed to the foundation which causes a naturally stable structure to snap back into its original position when deflected by the earthquake.*

The inertia forces have both horizontal and vertical components, but in designing houses for earthquake zones, it ussually suffices to take on account only of the horizontal components.
After: Peter Yanev.

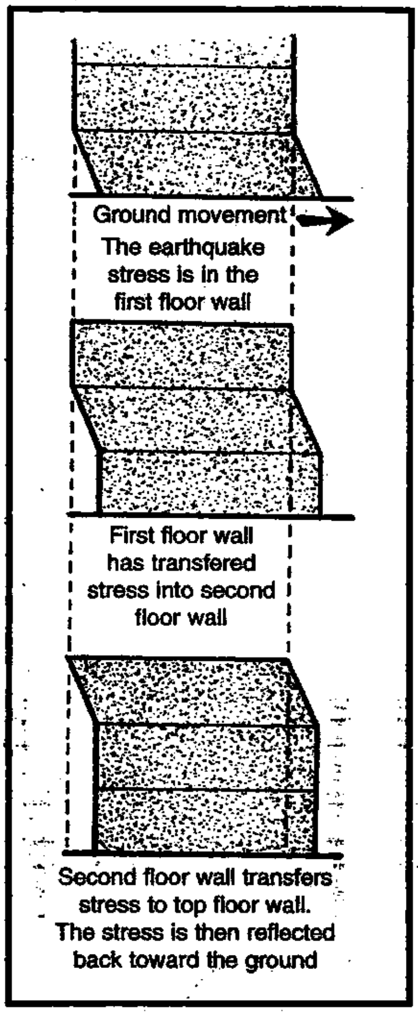


Fig. 22.3 *The effect of lateral earthquake movement on a building is clearly shown by P. Yanev in this drawing of a three story building. The movement emerges from the grownd and travels through the fundation to the walls- in efect one floor at a time. When the waves have reached the roof, they return to the foundation and grownd in the same way.*

The earthquake wave inevitably focus on any weak conections or materials, and once they begin to fail, the behavior of the building changes drastically. It is subjected to a chaotic mixture of new stresses and loads until the building fails.
After: Peter Yanev.

In each direction, the total horizontal force $F = a\ V$, where a occurs as a product of several factors given in the earthquake code in question, and V is the weight of the house (including service load). In seriously earthquake-threatened zones, engineers are typically required to design buildings for a horizontal force corresponding to 15 per cent of the dead weight of the the building, which in bamboo houses is very low.

The force effect caused by motions is generally directly proportional to the dead weight of the structure. This weight also partly determines the character of dynamic response of the structure. The other major influences on the structure's response are its fundamental period of vibration and its efficiency in energy absorption. The vibration period is basically determined by the mass, the stiffness, and the size of the structure. Energy efficiency is determined by the elasticity of the structure and by various factors such as the stiffness of supports, the number of infependendtly moving parts, the rigidity of connections and so on.

While the earthquake is going on, the house continues to be supplied with energy. During weak earthquakes, this energy can be absorbed partly by internal damping in the materials and partly as elastic energy. In heavy earthquakes these two means of absorbing energy do not suffice, and the house will not survive the earthquake unless its structural system can absorbe energy throught plastic deformation.

The basic structural components of any house are four:

1.- Those that lie in a horizontal plane such as the roof and floors and joists, beams and trusses, which are the distributing structural elements. They tie the walls together and disperse the static weight of furnishings, occupants and the elements themselves to the walls and foundation.

2.- The resisting structural elements are the vertical components of a building (walls, columns, studs and bracing). These elements support and transfer the load of the distributing elements to the foundation.

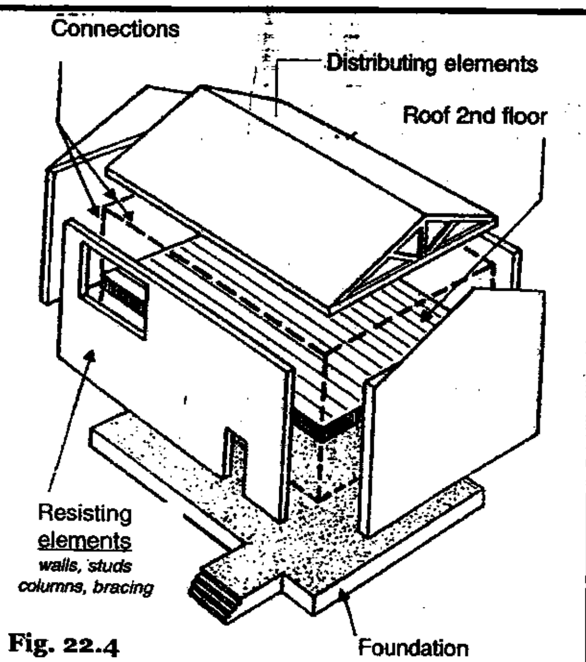


Fig. 22.4

3.- The foundation supports and ties together the walls and transfers the weight of the building to the ground.

4.- The connections tie all the components together such as nailing, blocking, joints and the bracing which strengthens the connections between the horizontal and vertical components of a structure and stiffens the vertical components (the walls, columns and studs) against damaging deformations.

DESIGN OF SMALL BAMBOO HOUSES IN EARTHQUAKE ZONES

Because of the severe lateral stresses to the walls columns and studs of a building during an earthquake, three basic types of lateral bracing are used in order to strenghten the walls and other vertical supports, which besides preventing the collapse of a building, also limits the damage to exterior veneers and plaster, plasterboard, window and door frames, and fixtures and furnishings, because it reduces the building's internal motions. They are *frame action, diagonal frame action* which are used in tall building's and *shear-wall bracing* which is the most recomended in the construction of wood and bamboo houses.

Shear -wall bracing entails the use of solid continuous walls of plywood with wood studs or a bamboo walls with bamboo studs separated 40-50 cms, covered in boths sides by bamboo boards as was explained in the chapter o walls. This type of walls adds great strength to the frame, allowing it to endure the lateral earthquake forces and to support the additional inertial weight of the roofs and floors.

The foundation. Because earthquake movemensts and shock waves are transmitted from the ground through the foundations of a building and then into the superstructure, a week or poorly foundation of a wood and bamboo house may fail even before the shock waves reach the rest of the building.

The outstanding characteristics of bamboo: The high earthquake resistance of bamboo buildings is the result of the strength, lightness and flexibility of the material which lessens the inertial weight that the walls must support. The lightness means that the inertial load results from the building's resistance to the ground movements will be relatively small.

Even giant bamboo used in building construction is flexible and enables the supporting components of the building, the walls, culms and studs to deflect with the lateral shock waves of the tremor without cracking or breaking.

On the other hand, cement plaster over bamboo board frames presents special requirements to prevent earthquake damage. Lime mortar (containing more than 10% lime) have no resistance when subjected to earthquake stress.

It is important to point out that bamboo frame buildings are not by any means quake-proof of course. Bamboo-frame buildings is most likely to suffer serious earthquake damage when one or more of the following conditions are present:

- A poor site of soft, unestable ground.
- A weak or poorly located or inadequately foundation.
- Structurally weak architectural features.
- A poorly constructed new building.

Fig. 22.4 *House structural components. After: Peter Yanev.*

- Insufficient lateral bracing, or an inadequate number of load-bearing walls and columns.
- Improper placement or inadequate connections of lateral bracing and other structural details.
- Small thin vertical support, such as the stilt used fo some hillside homes.
- Non-continuous corner columns and other critical supports in two-story building.
- Heavy roofs, such as clay tiles.
- In most of the earthquakes which had taken place in Colombia in Manizales in the eighties, and in Armenia in 1999, most of the bamboo houses survived except the bamboo houses wich fell down when were pushed by brick houses at the moment of collapsing by the earthquake. In the town of Pijao near Armenia all the bamboo houses survived. In the earthquake which took place in the nineties in the south of Colombia, in a town of the Paeces indians there were 21 houses, nine made of bamboo and twelve made of cement blocks. Only the bamboo houses survived.

Fig.22.5 *Part of the city of Armenia, Colombia, which was destroyed by an earthquake (Jan. 25, 1999). Most of the bamboo houses were destroyed when were pushed by the brick and concrete buildings when collapsed. See the lower bamboo houses on the slope which were not destroyed. (Courtesy of Javier Casallas).*

Hansen (1985) suggest the following norms for designing small wood-framed houses for earthquake zones which are also applicable to bamboo houses.

1. Aim for low weight of both structural and non-structural elements. This is due to the fact that the forces occurring in a house during an earthquake increase with the weight of the elements. In the design of small houses, the choice of roofing, in particular, can have important effect on the horizontal forces for which the walls and fundations have to be designed. The aim of the other points is to make the building as statically simple as possible since studies of damage caused by earthquakes have shown that simplest structures have the greatest chance of getting through an earthquake undamage. In the case of small houses, the best solution for the load carrying structure is a diaphragm made of wood-frame panels clad with plywood, chipboard, wood fiber boarding or plaster board, and in the case of bamboo, the use of wall with doble bamboo boards plastered.
2. Choose a simple, compact plan.
3. Aim for symetry. The ideal is symetry about two vertical planes at right-angles to each other.
4. In two story houses, structural walls in the upper story must always be supported directly by ground floor walls transmitting the load to the foundations.
5. Seek a clear separation in the form of flexible joints between the house's structural and non structural elements. Hansen (1985), Peter Yanev.

Fig. 22.6 and 22.7 In Manizales the poor people used to build their bamboo houses in the hillside areas, even on slopes extremely steep, and in the rainy season the water increase the weight of the soil producing some times landslides and consequently the colapse of one or several houses as shown in these pictures.

Fig. 22.8 CONSTRUCTION MISTAKES IN BAMBOO STRUCTURES

A.

D. *The use of young culms in structural members can produce crushing or dangerous cracks in beams and rafters.*

To build with bamboo is not easy because due to this material is hollow, it is not posible to make with bamboo the same types of joints used in wood construction. This rule was not bore in mind by the two new architects who design and built this two floor house and by the charpenters who were in charge of the construction of this house where I found the most incredible mistakes in bamboo construction that I have seen in my life, and that are shown in these photographs. Fortunatelly during the time which was built this house there was not an earthquake.

Fig. A - *Crushing of the rafter*

Fig. B - *The wrong use of wood joints in bamboo construction.*

Fig. C - *The wrong and dangerous splicing of the main beams. The wrong use of wood joints*

Fig. D - *The wrong splicing of beams.*

Fig. E - *The crushing of the main beam. The splicing of the beam, the cracks on the end and the mix-up of beams.*

B.

C.

E.

INAPPROPRIATE STRUCTURES FOR EATHQUAKE ZONES

Fig. 22.9 A-B. *This curious structure that I saw in Brazil could be greatly affected in an earthquake since the top part is going to move as an inverted pendulum.*

Courtesy of: Antonio Salgado.

C. ***This bamboo roof which looks like a cantilever was originally the roof of a garage for 5 cars,supported by 6 bamboo columns. One day a truck going backwards knocked down the first bamboo column, the structure did not fall down and nothing happened, so the owner removed the other 5 columns. I had to change my parking area. The roof lasted 5 years before it was removed.***

D-E. *Before the earquake which took place in Manizales, Colombia in the eighties I took this picture (D) in which the house is supported at the corner by a bamboo column, which fell down during the earthquake.*

SOME CONSTRUCTION DETAILS RECOMMENDED AS EARTHQUAKE-PROOF

Fig. 22.10 *The construction details indicated in this page are some of the recommended by the Colombian Association of Earthquake Engineering in their "Manual of Earthquake Resistant Construction in Plastered Cane Housing" (2000). These details include:*

***A.**-Lateral bracing with diagonal.*

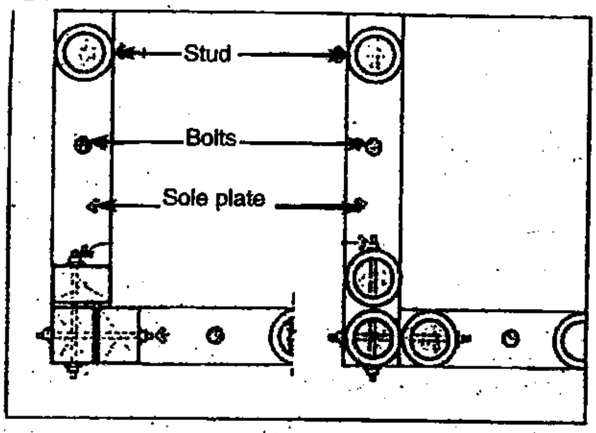
***B.**-Types of supports for master beams.*

***C.**-How to fix the wood or bamboo columns or studs in the exterior corners of bamboo walls.*

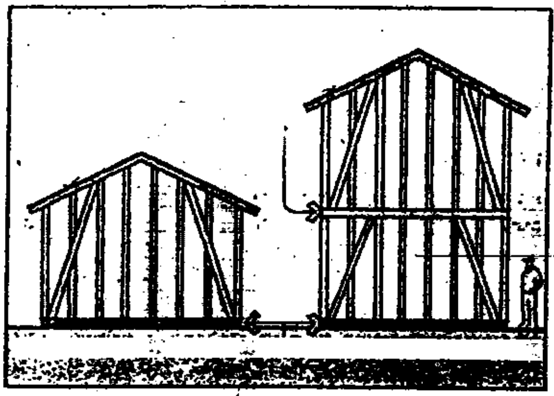
***D.**-Joint of an interior wall crossing.*

***E.**-Joint of an interior wall with an exterior wall.*

C.



A.



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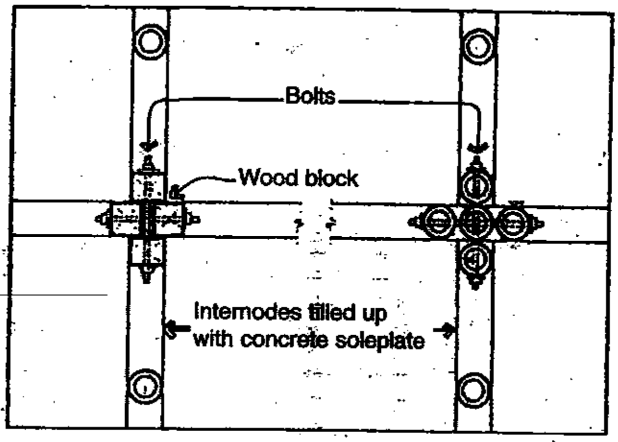

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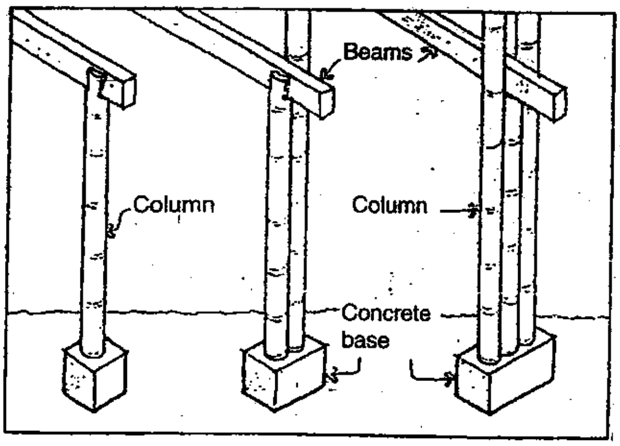
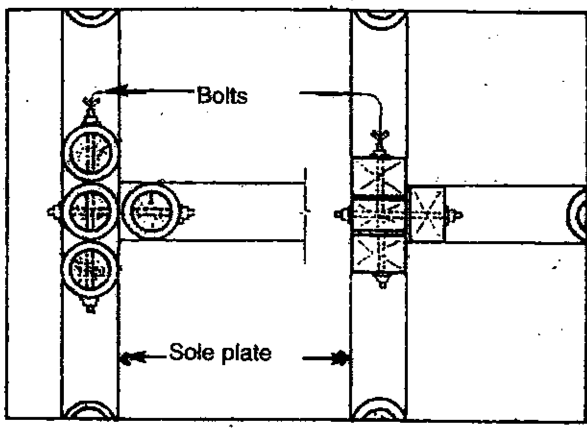


E.

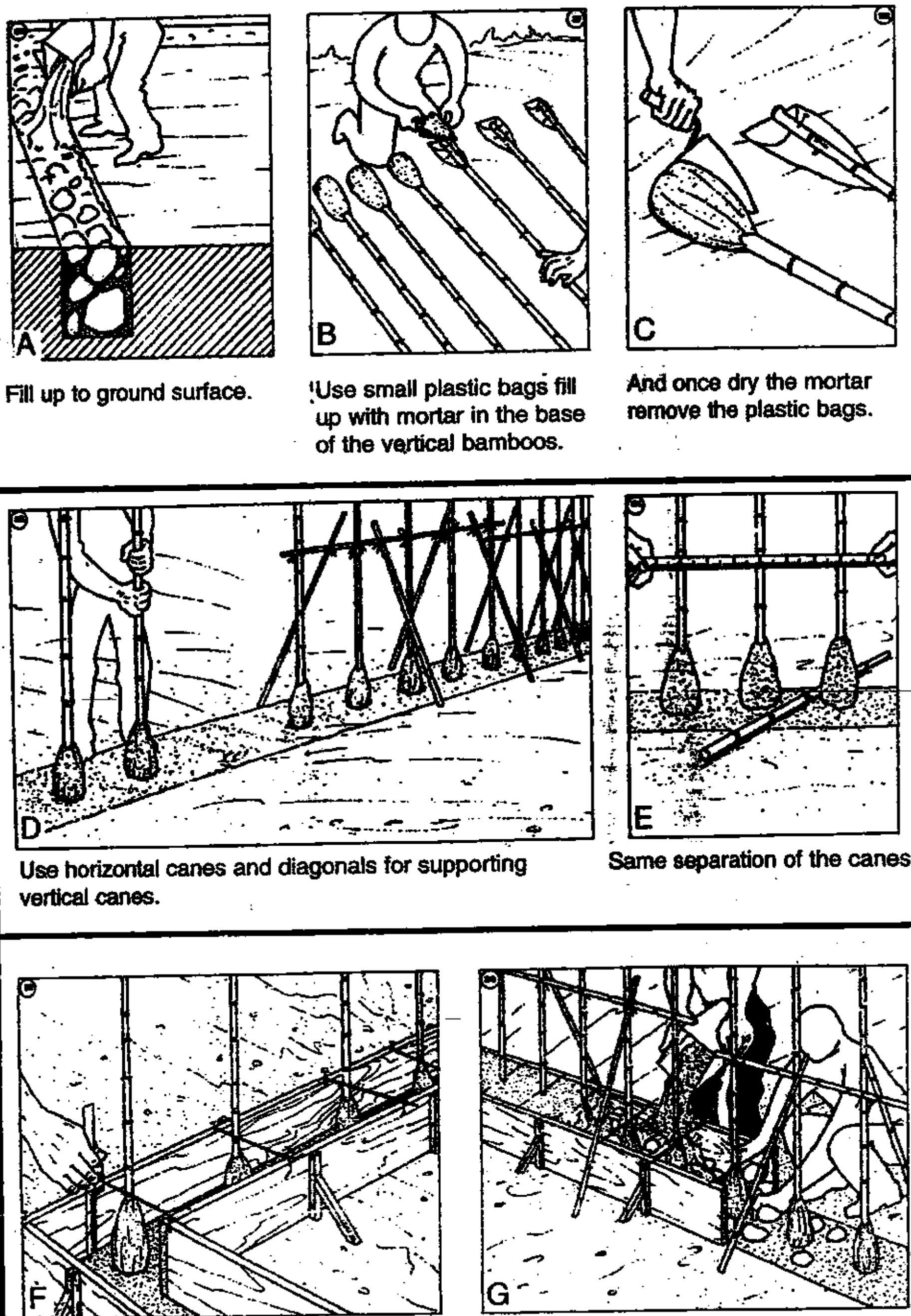


THE USE OF BAMBOO AS REINFORCEMENT OF ADOBE WALLS IN EARTHQUAKE ZONES

Fig.22.11 **PLACING OF VERTICAL REINFORCEMENT**

Chinese were the first in using small diameter bamboo culms (3 to 4 cm) as reinforcing of their adobe houses located in earthquake zones. Later on the builders of the Chimu Empire in Peru used giant bamboo species that were brought from Ecuador by sea in order to build the city of Chan Chan where bamboo was used particularly as reinforcement of the huge adobe walls 9 m high which surrounded the city and some internal areas, as I explained before.

The present study that I show in this chapter is related to the use of bamboo culms of small diameter as reinforcement of walls in adobe houses located in earth quake zones. This study was developed severa; year ago by the Research Center of the Pontificia Universidad Catolica in Lima Peru where the adobe is one of the most used materials in housing construction.



A. Fill up to ground surface.

B. Use small plastic bags fill up with mortar in the base of the vertical bamboos.

C. And once dry the mortar remove the plastic bags.

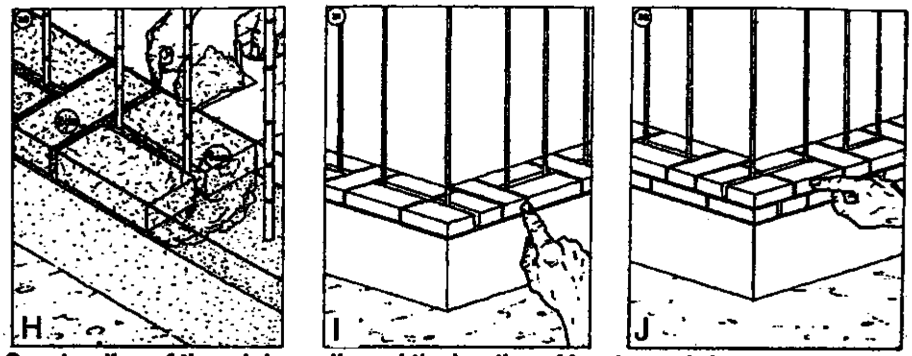
D. Use horizontal canes and diagonals for supporting vertical canes.

E. Same separation of the canes.

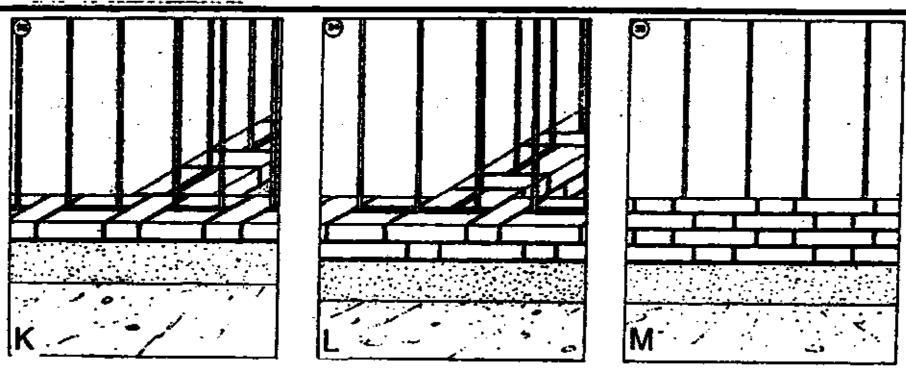
F. Locating the forms for pouring the base of the wall.

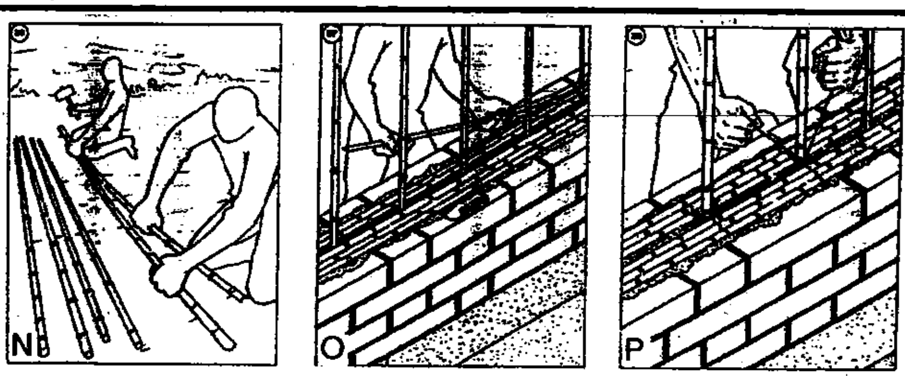
G. The base of the bamboos are tied to the wood forms.

Fig.22.12 **PLACING OF HORIZONTAL REINFORCEMENT**

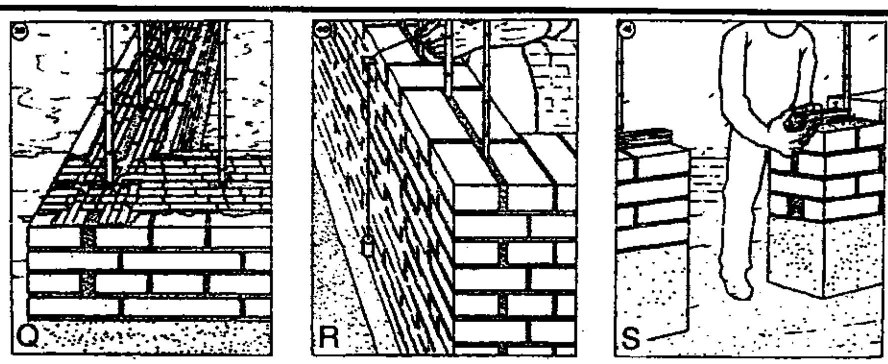


Construction of the adobe walls and the location of bamboo reinforcement.



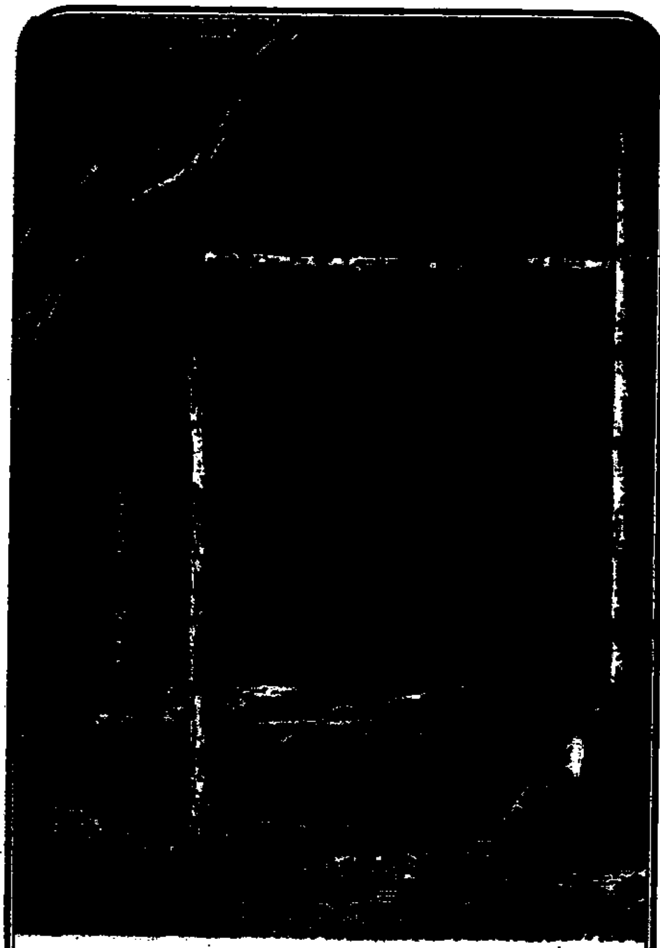


The horizontal reinforcement is located every four layers.



PART 8

The Bamboo Culture in the Americas and Asia



Thatched hut (Gautier's drawing)
Geografia Pintoresca de Colombia in 1869.

21 ANCIENT AND MODERN USES OF BAMBOO IN THE AMERICAS

THE FIRST BAMBOO CONSTRUCTIONS

Vestiges of the most ancient prehistoric construction known up to the present time in the Americas with an antiquity of 9.500 years, were found by the archeologist Karen E. Stothert (1988), in a preceramic place located in Santa Helena Peninsula, near Guayaquil in the coast of Ecuador, known as OG SE-80. In the excavation made in this place she found a trench with a circular form of 1.5- 2 meters in diameter (Discovery No. 63), interupted in the northeast side where the entrance was supposed to be. Inside the ditch or trench there were round holes where had been buried the structure. According to their dimensions, it is possible that this small construction was used as a funeral chamber instead of a dwelling.

The cultural residue found inside the chamber gave a reading of 7,550 (+-) 120 year B.C, which means that it belongs to the phase "las Vegas Temprana" (8,000 to 6,000 years B.C.) of the Preceramic Period. Stothert points out that it is possible that this structure was made in a similar way to that of the structure found by Donnan in 1964 in the Chilca river in the central coast of Peru. These structures had a diameter of 2.40 meters. According to the reconstruction made by Donnan, one end of the long and flexible sticks was fixed in a circular and shallow trench with the tips fixed together in order to make a structure similar to a beehive. He adds that in the construction of the roof they used a mixture of mud and grass. Similar construction methods were found later in Real Alto in the Peninsula of Santa Elena in Ecuador.

Generally it is very difficult to determine whether a prehistoric structure was built with bamboo or timber on account of the organic matter decomposing faster than any other material, but there are some reasons to prove that the material used in these construction were bamboo.

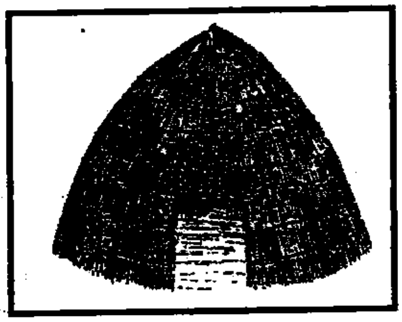


Fig. 23.1 *Reconstruction of the 9.500 years old bamboo dwelling or funeral chamber, considered to be one of the most ancient construction in the Americas.*

Fig.23.2 *Reconstruction of a 3.500 years old dwelling in Real Alto, in which walls of bamboo boards plastered with clay (as shown below) were found.*

According to Olaf Holm (1985) the most ancient bamboo dwelling of the Americas was found in Valdivia I, Real Alto in Ecuador builted 5,000 years ago, and had an oval shape, 4,50 by 3.50 meters. The walls were covered with clay mixed with straw. The use of bahareque made with bamboo boards (bamboos open out flat) plastered with clay, were found in houses builted 3,500 years ago. Their vestiges were discovered in Ecuador by Professor Segundo J. Merino and his wife Juana Gonzalez in the archeological site known as Milagro I, located in Canton Milagro, province of Guayas. In the conversation I had with Mrs. Gonzalez on June 15, 1992 in Guayaquil, Ecuador, she said that they found in this place pieces of clay with the impression on them of the bamboo boards. According to Olaf Holm, the fragments found by Prof. Merino and his wife belongs to the wall of a bamboo house builted 3,500 years ago (about 1,300 years B.C.).

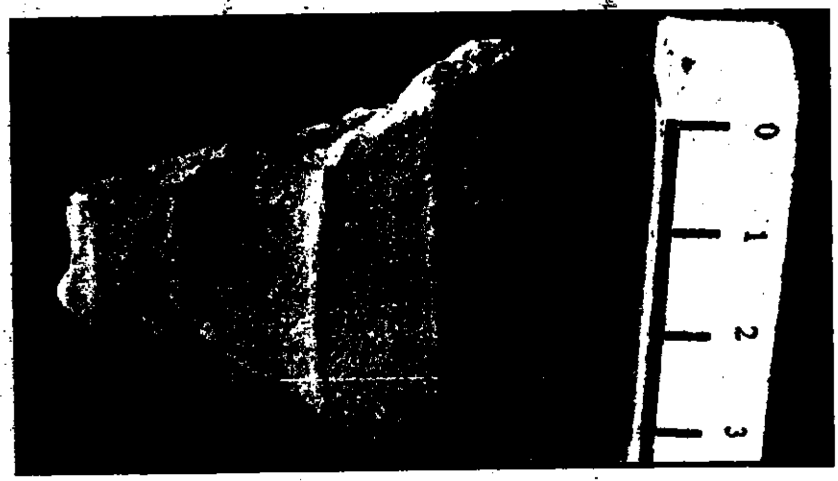


Fig.23.3 *Piece of clay with the impression on it of a bamboo slats. It belongs to the wall of a bamboo house builted 3.500 years ago. (Photo courtesy of Dr. Olaf Holm, Lalo F. Cruz, Banco Central del Ecuador and Jorge Moran).*

THE ANCIENT CITIES

According to the informations of spanish chroniclers and priests who came to the Americas in the 16th century with Columbus and later on with the spanish conquerors, at that time there were inmenses pure forests of giant bamboo canes which the spaniards called respectively as *cañaverales (canebrakes)*, and *cañas gordas (fat canes)*. Also there were in many areas tree forests mixed with giant bamboo species. Most of the bamboo forests were distributed along the basins of the great rivers since the south of Mexico, Central America and South America to the north of Argentina (except Chile where the giant species of genus *Guadua* do not grow).

Many of these areas were inhabited by natives who used to live in towns located inside the bamboo forests, surrounded by forts which they built using living bamboos as a way of protection against the tribes that were their enemies and later on against the spanish conquerors. In this way, bamboo became to be the most important material for these natives who were in contact with this material since the moment they come into the world, when their umbilical cord was cut with a bamboo knife, until the end of their lives when their body was buried wrapped with bamboo boards or bamboo mats. They spent their lives in bamboo houses surrounded by bamboo forts, cooking using internodes of bamboos, using musical instruments and arms made of bamboo.

From the above we can conclude that at the arrival of Columbus there was a bamboo culture in the Americas similar to that of Asia, and the two most outstanding bamboo culture centers were located in Guatemala, Central America and in the area of Colombia and Ecuador. According to Resinos (1952), in Guatemala, the city of *Guamarcaah*, was the largest and most important city of Central America; capital of the *quiche* culture, who were descendants of the mayas. This city was called by the aztecs of Mexico, *Utatlan*, that means "*city of cañaverales*" because it was surrounded by bamboo forests. This city was destroyed by the Spanish conquerors and their kings assassinated.

The second and most important bamboo culture was located in the north-west part of South America between the Atlantic coast of Colombia and the Gulf of Guayaquil in Ecuador in the Pacific coast. In this area were found the largest pure and densest bamboo forests and the best and large number of giant species particularly in the basins of the rivers Cauca and Magdalena in Colombia.

By the other hand, the natives of this area developed the best construction technologies in bamboo houses and bridges and became to be the best builders with bamboo of the Americas. This is the case of the Paeces tribe who still exists in the south of Colombia, who invented the stayed bridges, originally made of bamboo (see page 466), and today made with concrete and steel cables.

But the most interesting part of this story is that south of the Gulf of Guayaquil, along the dry area of the coast of Peru where bamboos do not grow, there were two Empires: the Chimu located along the desert coast of Peru, and the Inca located in the mountains. Both civilizations developed excelent bamboo construction technologies, in spite that they had to "import" this material from the Gulf of Guayaquil located in the north border of the Chimu Empire and transported by sea. Still Peru import from Ecuador thousand of tons yearly. This is the reason why in Peru the giant species of bamboo are known as "caña de Guayaquil".

The use of bamboo in the construction of the Chan Chan city in Peru.

In Peru, the Incas and the Chimus, were with the Mayas of Central America, the most advanced cultures of the Americas. In agriculture, they used fish and guano fertilizers. In the field of engineering and construction both cultures were the most outstanding in extensive artificial irrigation and excelent builders with stone, adobe and bamboo. The Incas de-veloped the "quincha walls" (see page 237, 238), and the suspention bridges using braid ropes, which according to Pálomino (1978) were made of *Pichu*, a shrub about 3 meters long.The structural technology used in the construction of these bridges was similar to that used in India and China in the construction of suspention bridges using cables made with bamboo strips. (See suspention bridges). But in the construction of huge and long adobe walls 9 meters hight the Chimus were the first, probably in the world, in using vertical expansion joints and giant bamboos as interior reinforcement of the adobe walls with antiseismic purposes, which erroneusly has been considered by some archeologists as "guides for construction of the walls"(see fig. 23.6).

Chanchan was founded by Tacaynamo and flourished between the years 850 and 1425 A.D. This city covered roughly 2,300 hectares and was the largest and most important and populated pre-Columbian city in South America. This metropolis, which Hewett called "the Babylon of America", was composed of 9 huge walled units or compounds, which served succesive Chimu monarchs as palaces, and treasuries in life, as shrines in dead.

Fig. 23.4 *Ruins of Chan chan 5 kilometers of Trujillo, located in the Moche Valley in the coastal desert of northern Peru. The Chimus Empire dominion stretched some 970 kms. along the Pacific coast northward to the Gulf of Guayaquil, and southward almost to Lima (Phot. David Brill).*

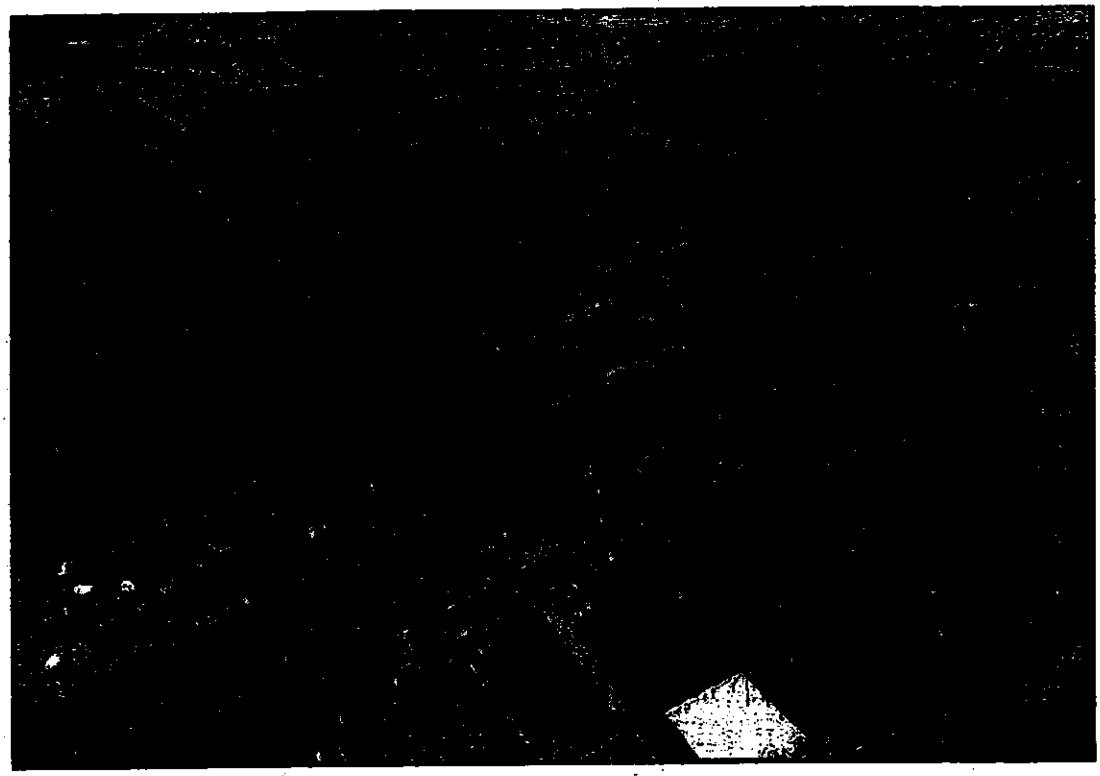


Fig. 23.5 *Part of the royal residence protected by hight adobe walls, reinforced with giant bamboos. Surrounded the city are the quarters with walk down wells and dwellings made of adobe, bamboo and totora, where 50,000 people used to live. (Artist, Robert W. Nicholson).*

According to Beals (1961) each unit was more or less auto-sufficient, with irrigated fields, stone reservoirs, fountains, pyramids and gabled houses, adorned with alto-relievos, clay arabesques, niches for figures etc. The main platform-elevated palace of slanting walls, with its broad central entrance terrace, numerous apartments, galeries and halls, had some door ways forty feet wide; quite a feat, since they were sustained only by strong bamboos and adobe. Each one of the units or citadels had a large number of warehouses surrounded by huge adobe walls 9 meters hight by 2.50 meters wide in the base, in which were utilized millions of adobes made with bamboo molds and millions of giant bamboo culms brought from the Gulf of Guayaquil by the sea.

The vertical expansion joints were made about every 5 meters. In these joints the adobes had not mortar. These vertically joints permit movement in the horizontal direction only, and also permit the separate segments of the wall, to expand and contract in response to temperature changes originated during the day and night without adversely affecting the wall structural integrity.

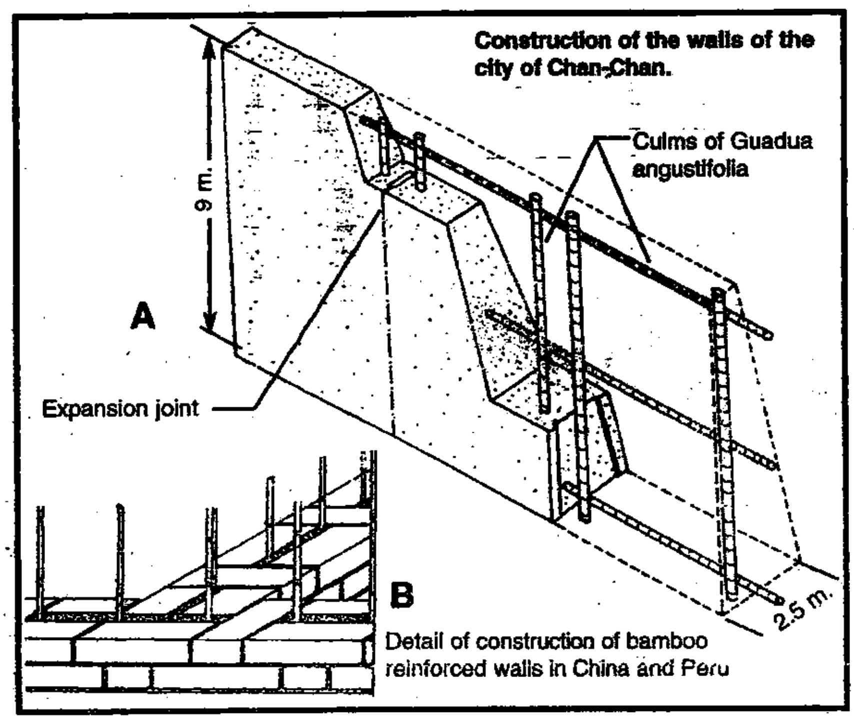


Fig.23.6 A. *Detail of construction of the adobe wall of Chan Chan showing the bamboo reinforcement and the expansion joints. The reinforcement with bamboo gives stability to the walls during earthquakes. Since ancient times, the Chinese have reinforced the adobe walls of their houses with small diameter vertical and horizontal bamboos for the same purpose.*

The interior reinforcement of the walls in Chanchan was made with giants bamboos with a diameter of about 12 to 15 centimeters. They were located vertically and horizontaly inside the wall, forming a grid 4 meters in both directions. The purpose of this reinforcement was to "tie" the separate walls sections in which were divided longitudinally the wall by the expansion joints and for given them stability in the earthquakes.

Day (1978) point out that, in 1970 there was an earthquake in the Moche Valley and he observed that the "modern" adobe walls collapapsed but nothing happened to the walls of Chanchan ruins.

It is very important to point out that the same methodology used in Chanchan for reinforcing the adobe walls with giant bamboos, was used at that time in China (and is still used), for the constructions of smaller adobe walls (50 centimeters wide by 3 meterhight), in which were used as reinforcement and with the same purposes, bamboo culms with small diameter (3 to 4 centimeters), (Fig. 23.6).

In the quarters that surrounded the city, most of the dwellings were builted with adobe walls, and bamboo was used in the structure of the roof. The thatch was made with *totora* reeds. (*scyrpus californicus*), a water plant which grows at the Titicaca lake, which were used in the construction of houses boats, rafts, islands, floating bridges, mats, roofs and even as human food. Due to the importance that this plant has for the Chimus, they developed in Chanchan dicked salt marshes for growing totora reeds.

In 1470 higland Incas conquered Chan chan and transfered much of his wealth (and many of its skilled craftsmen) to Cusco, their capital. In 1535 when Chan chan was partialy abandoned were discoverd by Pizarro's conquerors soon after founding the city of Trujillo.

With the arrival of the spanish conquerors to the Americas they started a sanguinary persecution of the natives in order to steal their treasures or for subduing them as slaves. At the end of the sixteenth century they had exterminated 90% of the indigenous population of the Americas, which, in its great majority perished incinerated by the spanish conquerors in the bamboo forests where they sought protection and where they had their towns and bamboo forts.

With them disappeared their traditions and the pre-Columbian bamboo culture that existed in all countries from Mexico to Peru and which was more developed in the area of Colombia and Ecuador where existed the best technologies in the construction of houses and bridges.

Since then bamboo only were used by the survived natives and their descendants and later on by the poor people and campesinos in the construction of their dwellings.

Fig.23.7 *Spanish conquerors attacking an indian fort built with two bamboo walls. Its interior was filled with stones and clay as can be seen in the right side of the drawing. The spanish soldiers were protected by a portable bamboo wall, which they used like a shield, and protect their arms and legs with bamboo sections.. The dash line divide de interior and the exterior part of the indian fort.*

BAMBOO ARCHITECTURE IN COLOMBIA

RESURGENCE OF THE BAMBOO CULTURE IN COLOMBIA IN THE 18TH CENTURY

After having been a symbol of the identity and culture of the natives, bamboo turned into a symbol of "their misery, slavery and death" and became to be at the time of the Colony (after the conquest of America), the most hatred plant for the spaniards and their descendants. At the midle of the eighteen century in Colombia, hundreds of "Antioqueños" or descendants of spaniards, who lived in the State of Antioquia, emigrated with their familes to the mountains of the Andes where they founded the state of Caldas and the city of Manizales as its capital. For their long trip throught the bamboo and tree forests in mountains, valleys, and by rivers, they used to hire indians as guides that also were in charge in getting them the food and in the construction of bamboo rafts, bridges, and temporary dwellings, in which the antioqueños usually spent weeks or months, and that were the beginning of the large number of towns that they founded.

Many Colombian historians erroneously consider that were the immigrants from Antioquia State who invented the bamboo technologies that were developed in Colombia. We have to recognize that were our ancestors, the indians who populated our country and Ecuador who developed these technologies more than five thousands years ago, that later were improved by the spanish builders.

With the arrival of spanish builders to Colombia in the eighteenth century, they introducced some Spanish construction technologiees which little by litle the new generation of builders of the Caldas state and particularly those of Manizales, most of them descendants of indians and spanish, applied these technologies in the constructions with bamboo improving in this way the original technologies developed by our ancestors. For example, the walls of the houses that originally were made only with bamboo boards fixed to the vertical studs with strips of leather or filled the interior with clay supported laterally by bamboo splints, at first were plastered with a clay mortar. Later on were plastered, following the Spanish technology using a mortar made of horse dung pulverized, mixed with buckshot sand in proportion 1 : 2 and water. After applied the first coat of plaster it is necessary to wate 30 days before to apply the second coat. At the end of this time the first coat present a lot of cracks. The second coat consist of a plaster of lime and sand in proportion 1 :4 which later were changed by cement and sand in proportion 1:8. After that the houses were painted with lime and changing their aspect.

By the other hand in the twenties' began in Manizales the production of spanish tile, which replaced little by little the thatching roofs of the houses of towns and rural areas, and due to its weight originated new types of roof structures made with bamboo, creating a new type of architecture typical of this area.

The combination of wood and bamboo in the construction of structures and houses improved the quality of the traditional construction, and also generated new type of structures (see Fig. 23.24). For example the combination of

Fig.23.8 *Typical temporary bamboo dwelling built by the indians for travelers during the "Antioquian colonization" in Colombia.*

bamboo columns and studs with wood joists and wooden beams, made easier the leveling of floors, and also the construction of bamboo houses with 4 to 6 floors. In this way they avoid the problems which exist for leveling the horizontal bamboo culms when they are used in floors as joists and beams. Due to the tapered shape of bamboos it is necesary to put fillings between the bamboo beam and the bamboo joist under the end that have the smallest diameter, in order to level it with the oposit largest diameter, as it will be see later.

At the end of the twentie's arrives to Manizales the Portland cement which replace the horse dung plaster and made possible that the first engineers-architects of Manizales which studied in France were able to imitate in the façade or front of government buildings, schools and houses builted with bamboo, beautiful details made in bamboo and mortar of the French architecture of that time (see fig. 23.15 & 23.16). It is incredible what the Manizales' artesans of that time could made with bamboo and cement plaster.

All these new technologies were apply in the construction of Manizales, which in 1932 not only was the most beautiful city of Colombia, and the coffe center most important of the country but the largest city of the world built entirely with the best bamboo construction technologies that could be developed by man. All the houses of rich and poor families and important buildings, such as churches, schools, hospitals, banks and government offices etc. were built with bamboo. Since then this city is considered as the "cradle of the bamboo architecture of the Americas".

Today, new buildings in concrete and brick have replaced most of the bamboo houses in Manizales and only survive about the 20% of the old bamboo constructions that probably very soon will disappear.

MANIZALES THE CRADLE OF THE BAMBOO ARCHITECTURE

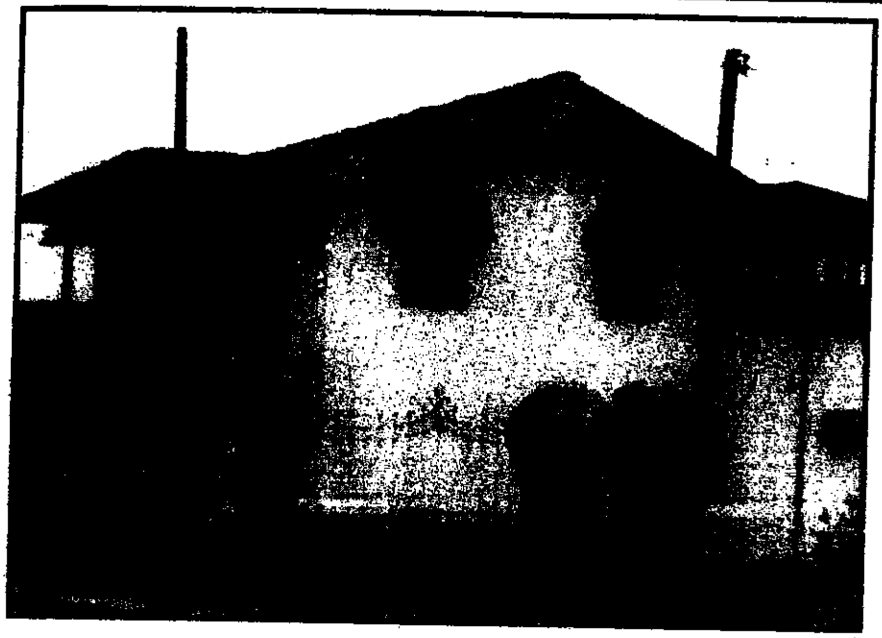


Fig. 23.9 *According to the information I got from the architect Robert Velez in 1980, this is one of the oldest houses of Manizales. It was built around 1890, which means that it is about 112 years old, and it is still in good condition due to good maintenance.*

Fig.23.10 *Typical architecture of a middle class family in Manizales. The most interesting fact about this city is that both the richest and the poorest people lived in bamboo houses.*

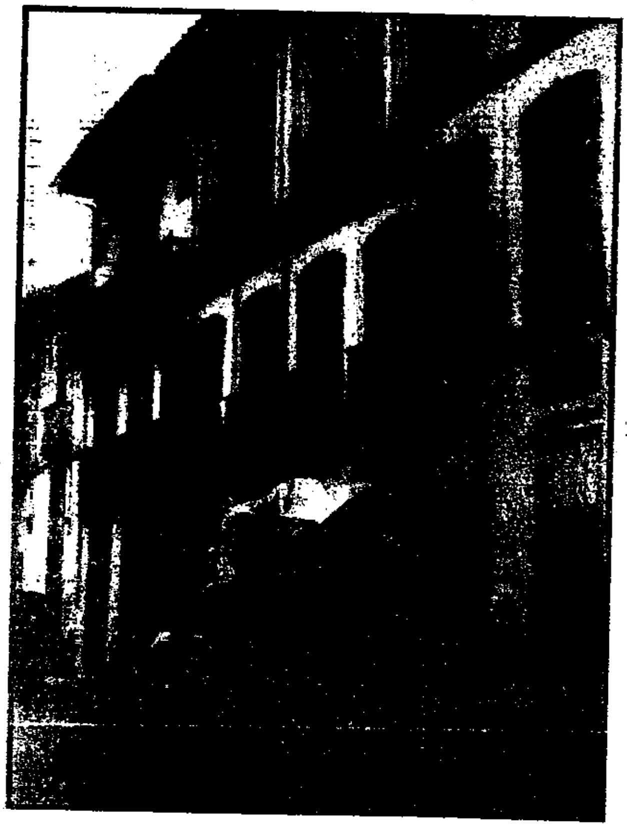


Fig.23.11 *Three story houses built with a bamboo structure by the rich people in Manizales. Generally they had beautiful balconies and windows with elaborate wood frames.*

Fig. 23.12 *This picture was taken in San Jose Park, a residential area of Manizales. In this park, as in many others in the town of Caldas state, the park is surrounded by bamboo houses which were built many years ago by the rich families. At the present time, many of these bamboo houses have been replaced by brick and concrete buildings.*

Fig. 23.13. *One of the central streets of Manizales. showing the typical architecture of the bamboo houses.*

Fig. 23.14. *The Spanish tile roof, the design and shape of the wooden windows, and the wooden balconies with balusters made from a palm known as chonta are also typical of this architecture.*

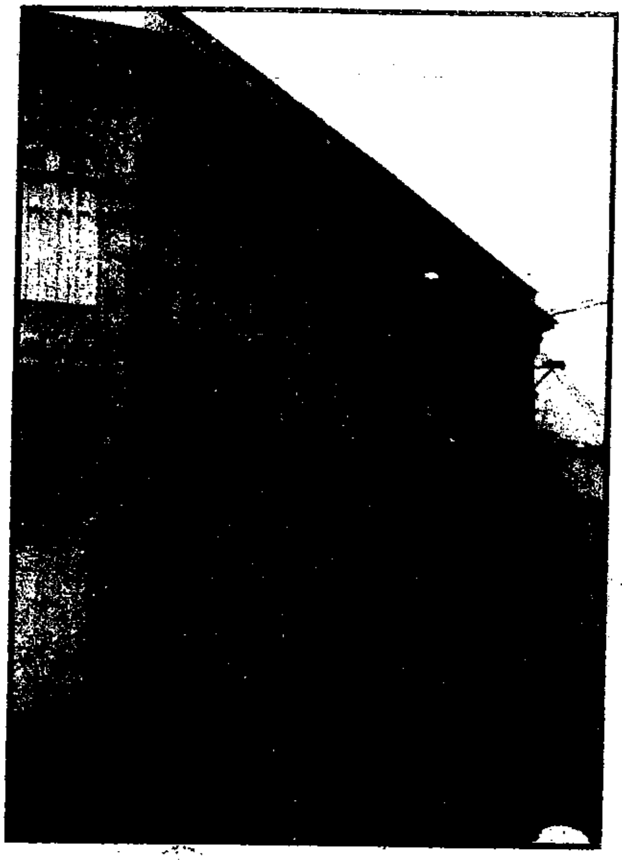


Fig. 23.15. *In the nineteen thirties, several engineers from Mani-zales, who had studied in France, brought construction details from French architecture, which were adapted to the bamboo structures. This can be seen in this beautiful building which looks as if it were made of concrete, but it has a bamboo structure.*

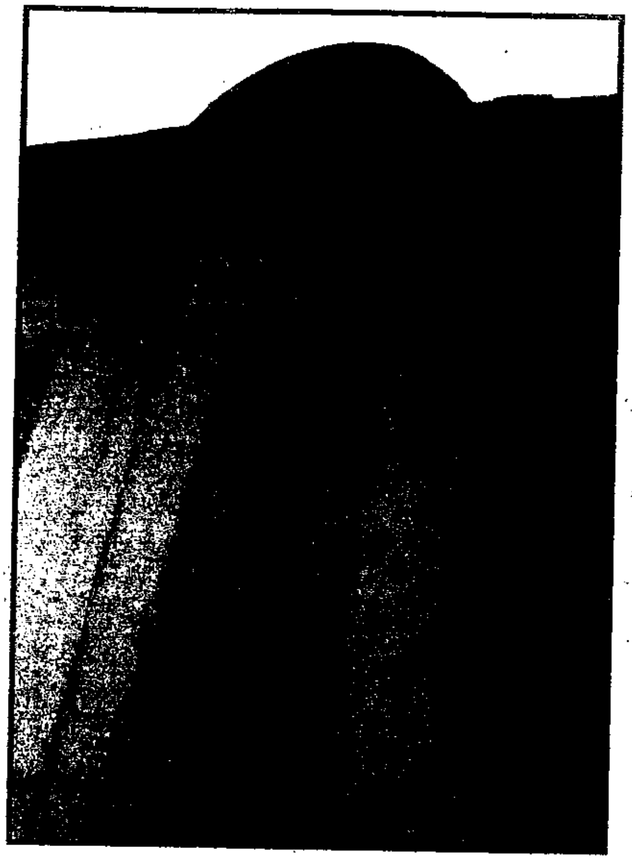


Fig. 23.16 *Other details of the French architecture used in bamboo houses. These two samples demonstrate the excellency of the bamboo artesans from Manizales.*

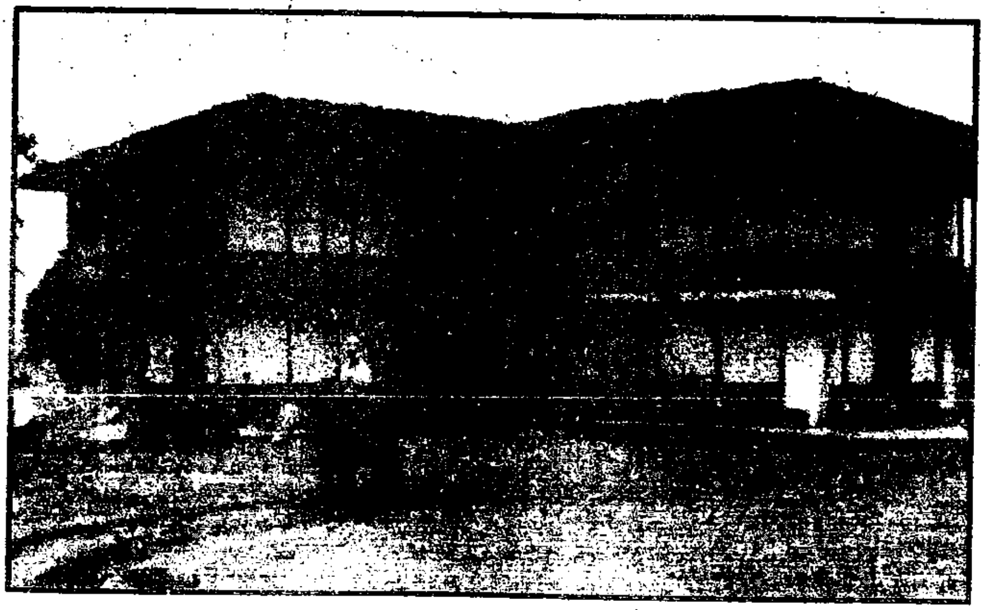


Fig.23.17 *In Caldas State of Colombia, coffee plantations had a great influence in the design of rural bamboo houses. They were surrounded by wide corridors on which were dried the coffee beams, depending to the position of the sun.*

Fig. 23.18

THE TRADITIONAL BAMBOO ARCHITECTURE

Fig. 23.18 *In poor areas, he most important part of the house is the front, but the back part of the house is horrible, as can be seen on the left.*

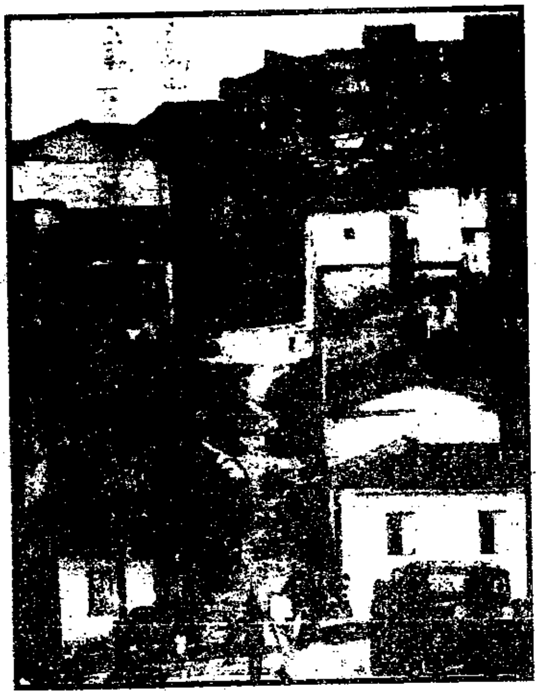


Fig. 23.19 *Most of the peasants who emigrate to the cities are experts in construction with bamboo and they build their own houses.*

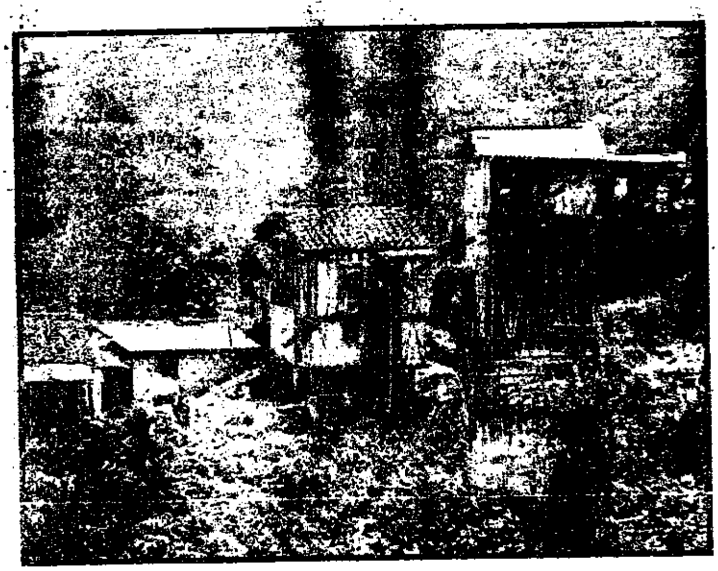


Fig.23.20 *This picture shows the back of the houses with 3 floors but in the front they only have one floor. The road is very steeply inclined as shown in the dash line.*

BAMBOO CONSTRUCTION TECHNOLOGY DEVELOPED IN MANIZALES

The bamboo species used in construction

Of the seven native species which grow in Colombia, only three species are commonly used in construction. They are *Guadua angustifolia* Kunth, which is known by the vernacular name of "macana" and which has an average diameter of 10-14 cms and a height of 17-22 m. This specie is the strongest and consequently it is used for structural purposes, like columns, beams and joists. The other two species have not yet been identified and are known by their vernacular names: "Guadua cebolla" (onion guadua) and "Guadua de castilla". The former has about the same diameter and height of Guadua angustifolia but the thickness of the wall is smaller and it is most commonly used for the construction of roofs, studs, for weaving and for making bamboo boards for walls and ceilings. "Guadua de castilla" is the largest of our native species with a maximum diameter of 20 cms and it was the most commonly used for the manufacture of bamboo boards and is now on the brink of extintion.

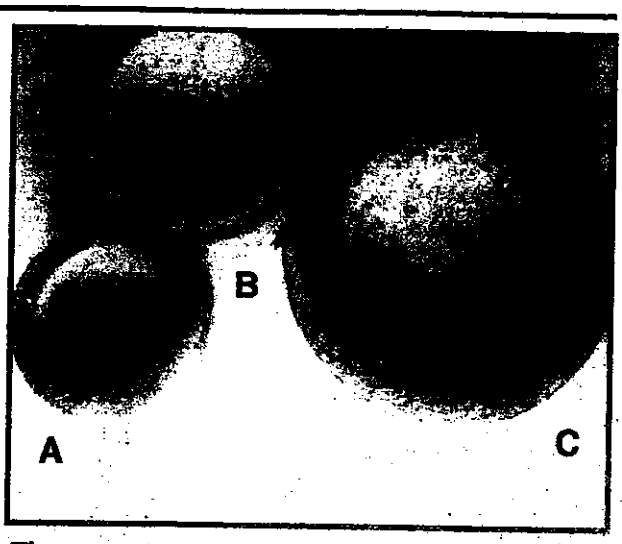


Fig. 23.21 *Cross section of the three most important bamboo species used in construction in Colombia. (A) Guadua angustifolia (B) "Guadua cebolla" (C) "Guadua de castilla".*

The structure

As I explained before, Colombia is probably the only country in the world where bamboo is used traditionally in the construction of all parts of the house, which include the main structure (columns, beams and joists), the floor structure (beams, joists and bamboo boards or bamboo slats for the floor), the roof structure, which includes the rafters, purlin joists and ceiling (bamboo boards) and the construction of walls (studs and bamboo boards). In general, the technology used in the construction of bamboo houses and other buildings, which was developed by bamboo builders in Manizales more than one hundred years ago, is very similar to that of the traditional framing used in wood construction in the United States, where is known by the names of "western" or "platform framing".

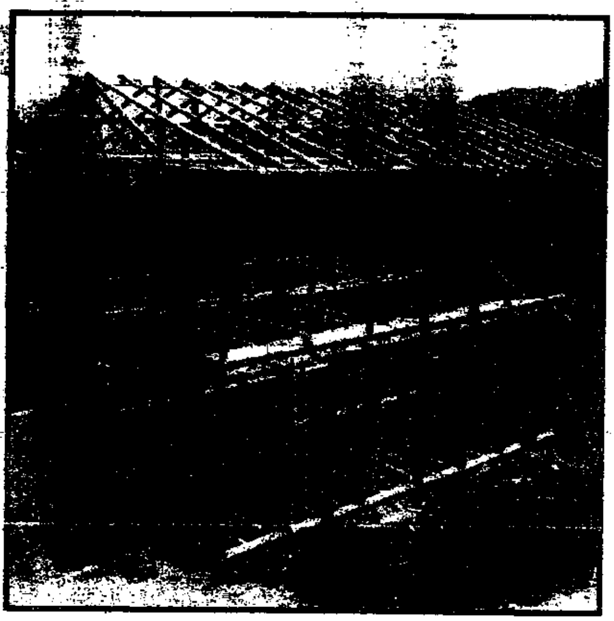


Fig. 23.22 *Traditional bamboo structure of a rural house in the state of Caldas in Colombia. Except for the wooden beams, all of the structure is made with bamboo.*

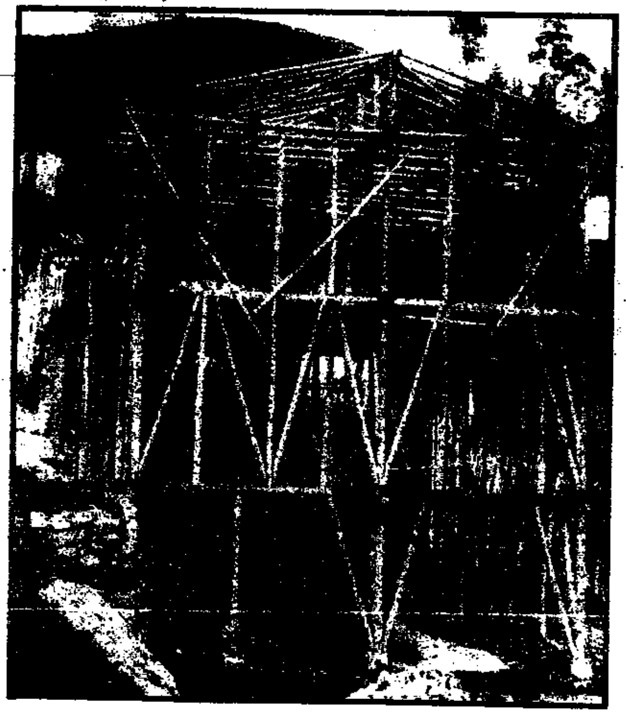
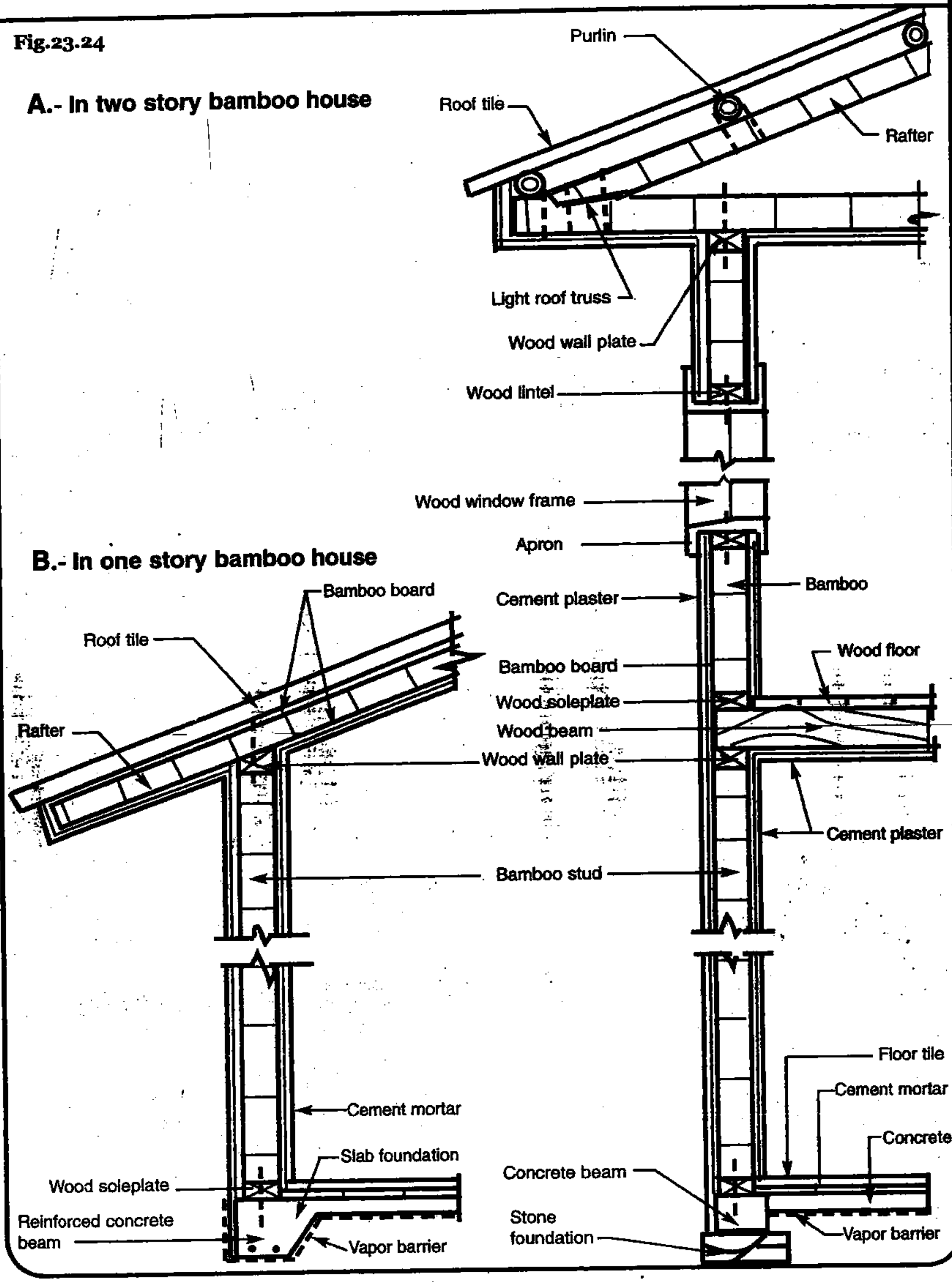


Fig.23.23 *View of the traditional bamboo structure which is similar to the western or platform framing used in wood construction in the United States.*

BAMBOO AND WOOD HOUSE CONSTRUCTION

Fig.23.24



Unlike Colombia, in Asia most of the strongest species native to different countries are not durable and, consequently, the main structure of the house is built with timber pieces and bamboo is only used as rafters in the construction of the roof and transformed into woven boards is used in walls. These bamboo boards are fixed to the outside surface of wood studs or columns to form the walls.

How the bamboo substructures and structures of the houses were built on the hillsides

Manizales, and most of the cities and towns of Caldas state in Colombia, are located in the Andes Mountains on beautiful and sloping locations where it was necessary "to build the plot before building the house", which means making the necessary excavations and backfilling in order to have a flat surface in the area where the house was going to be built. Fifty years ago, this operation was done by hand or using water under pressure to remove the earth from one place to fill the opposite side.

Due to the time and cost of this operation, plus the cost of the retaining wall, the peasants and poor people who could not afford the cost of this preliminary work, generally built their bamboo houses in sloping areas at the street level, supported in the back by bamboo columns resting on stones or brick bases, which were set in small excavations in the sloping ground. (See Fig. 23.25).

Depending on the angle of the slope and the area of the house, sometimes it was necessary to build a huge substructure to support a large house at street level, which in many cases could be from 12 to 15 meters lower in the back. In order to avoid the flexibility of the long culms, and to improve the stability of the house, the substructure was divided into 3 meter high sections as this was generally the length of the bamboo studs used in this type of construction. All the beams used in the substructure and structure of the house were made of wood which makes it easier to the level the floors and roofs, and allows all of the bamboo studs to be cut the same length. This is not possible if bamboo culms are used as beams. (See Figs. 23.25 A-B).

There are cases in which the house has to be built beside a road in the montains. In this case, the house is connected to the road by a bridge or a ramp.

It is important to point out that this type of houses were usually built by bamboo builders and even by the same peasants who were generally experts in bamboo construction technology. Probably many people will ask why a peasant could afford the cost of a huge substructure which generally costs more money than the house itself. This is because sixty years ago there were so many bamboo plantations in Colombia that the owners of the largest plantations used to donate all the bamboo needed to build the houses of the people who lived in the same area or worked on the same farm.

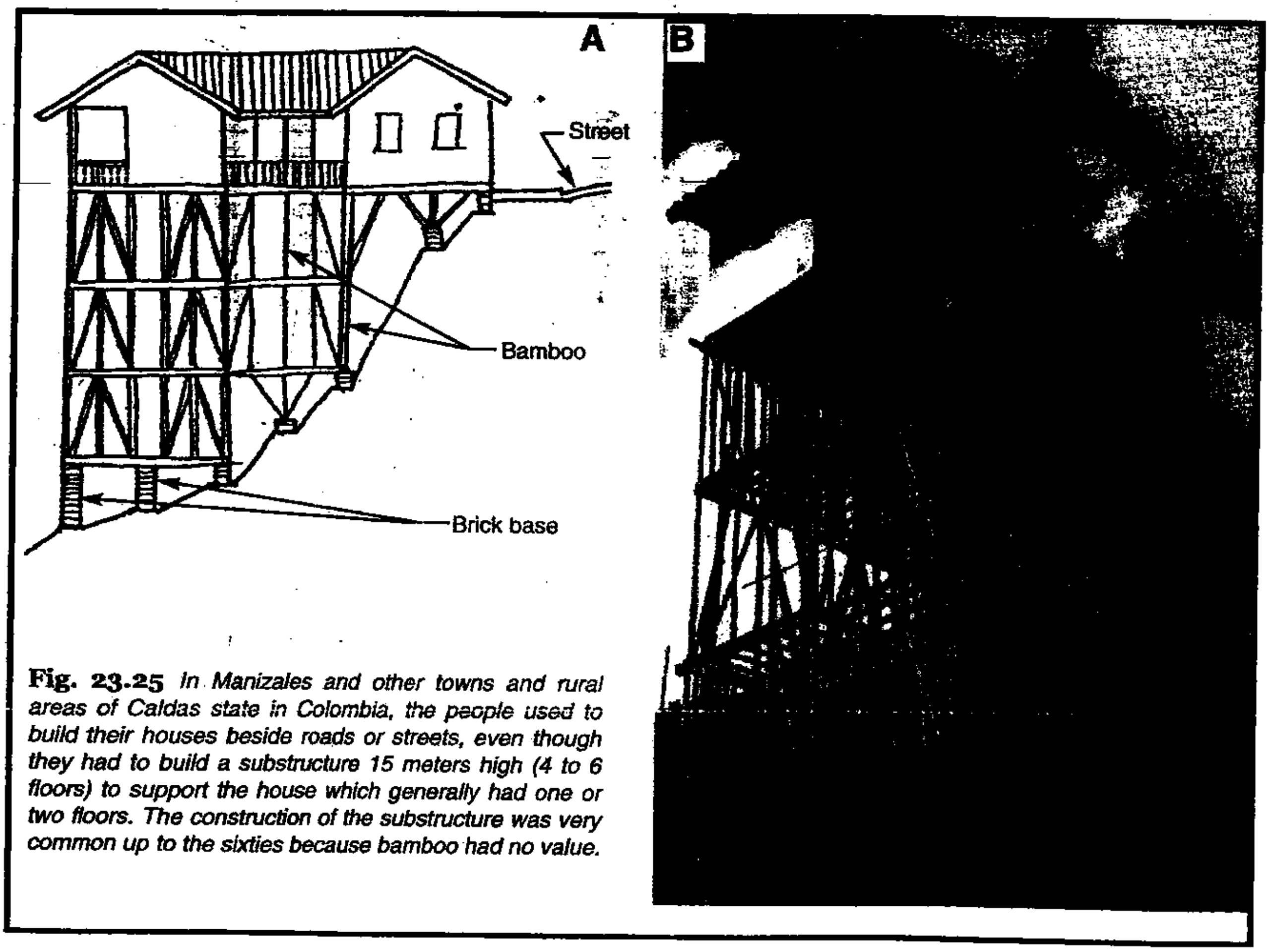


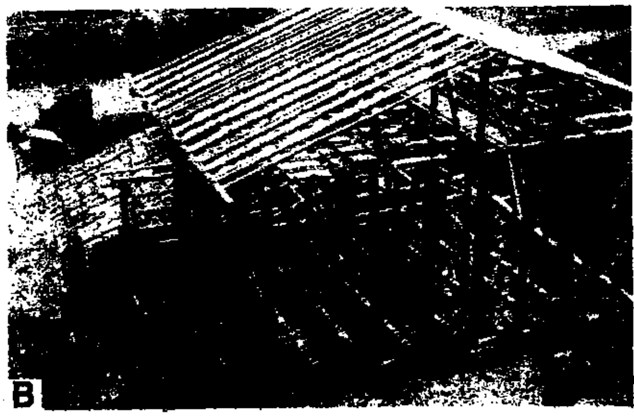
Fig. 23.25 *In Manizales and other towns and rural areas of Caldas state in Colombia, the people used to build their houses beside roads or streets, even though they had to build a substructure 15 meters high (4 to 6 floors) to support the house which generally had one or two floors. The construction of the substructure was very common up to the sixties because bamboo had no value.*

Fig 23.26 *Sometimes the house has to be separated from the street or road. In this case, the house is connected to the sidewalk or road with a bridge or ramp.*

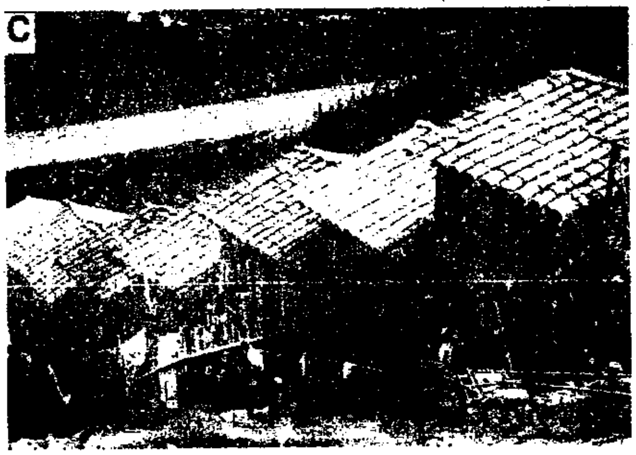
Construction of houses perpendicular to the contour lines

Fig 23.27 *Shows the structure and houses built on sloping streets in towns and cities located in the mountains of Caldas state. Most of these houses are built by peasants or by bamboo builders who build excellent structures, such as the one shown in C.*

A



B.- C. *Houses built in a poor area near the Cartago city inColombia. They had an excellent bamboo structure shown in figure B.*



PLASTERING OF THE BAMBOO WALLS WITH CEMENT-MORTAR

As I explained before, in most countries of South East Asia, the main structure of the house is made with wood or timber. Round bamboo is only used in the construction of the roof structure, and transformed into woven panels used in the construction of internal and external walls and ceilings without any finishing except paint. Bamboo is traditionally used in its natural form.

Colombia is the only country in the world where the bamboo walls and ceilings of the house are plastered with mud or with cement mortar because in our culture people don't like to see the bamboo exposed as in Asia. Only in the poor areas (see Figs. 23.27 B-C), most of the houses are not plastered due to its high cost.

In order to demonstrate how the appearance and quality of the houses improve when they are plastered and painted, Fig. 23.28 A shows five houses without plaster, and Fig. 23.28 B shows the same houses once they have been plastered and painted. It is important to point out that the five houses shown in this pictures were designed and built by Simon Velez in Manizales about 1970. This was, I think, his first work with bamboo.

Fig. 23.28 A. *This shows the back of five houses built about 1970 by Simon Velez in Manizales in the district of Galan, before they were plastered and painted.*

Fig. 23.28 B *The same houses shown in once plastered and painted.*

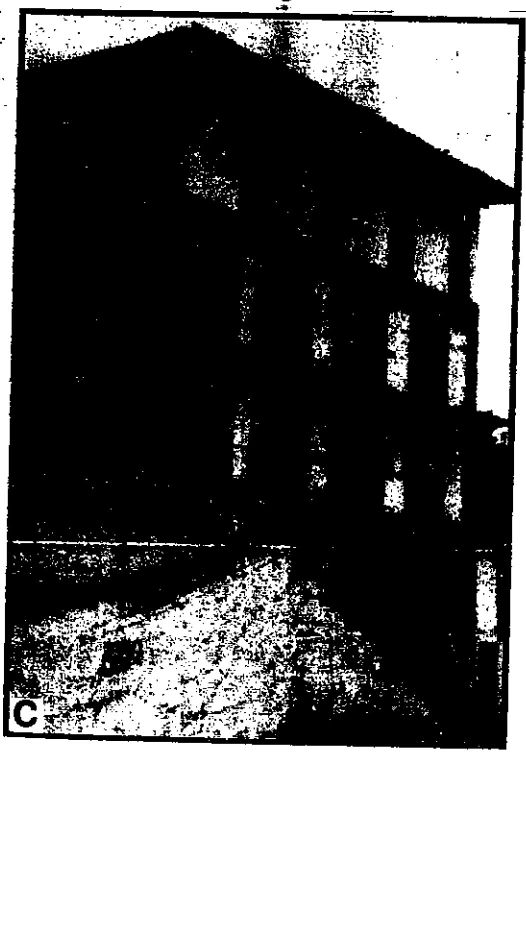


Fig. 23.28 C. *This shows a four story bamboo building built in 1920 in Salamina, Caldas state. At that time, the plaster used was a mixture of horse dung and sand in the proportion of 1:2. In the seventies the plaster and the bamboo boards were changed for new bamboo boards and cement plaster. The photograph shows all the process of changing the bamboo boards, the plastering and painting. Once finished, the building looks like new.*

Fig.23.29 THE FIRST BAMBOO HOUSING PROJECT IN MANIZALES

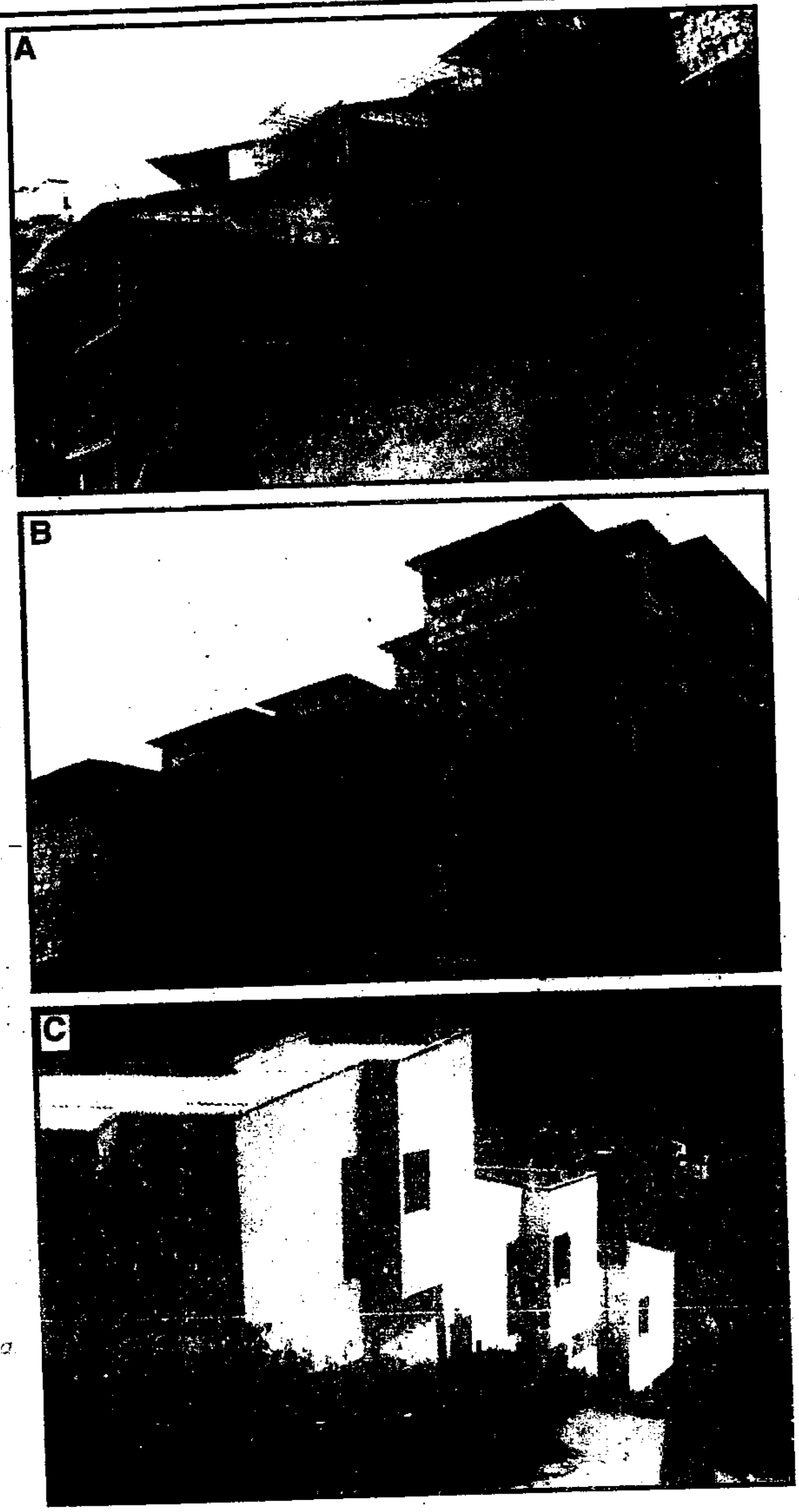
This is probably one of the most interesting experimental bamboo housing projects developed on the hillsides in Manizales which was carried out in the seventies by the Instituto de Credito Territorial (I.C.T.), a government office which is in charge of building low cost housing projects for poor people in Colombia. This project was designed by Jorge Arcila, who was also in charge of its construction.

This project was located on a very steeply sloping hillside (about 30°) and in its construction two types of foundations that can be seen in the longitudinal sections were used experimentally (Fig. 23-31).

1) One group of bamboo houses was built following the slope of the ground.

2) In the other group, the houses were terraced and separated by retaining walls.

A concrete slab 4 centimeters thick was successfully laid over the floor of bamboo boards supported by bamboo joists and reinforced with a 1/8" electro welded metal mesh.



A. The bamboo structure.

B. The bamboo structure covered with bamboo boards, before plastering.

C. The house once plastered and painted.

Fig. 23.30 **HOUSE PLAN AND DISTRIBUTION**

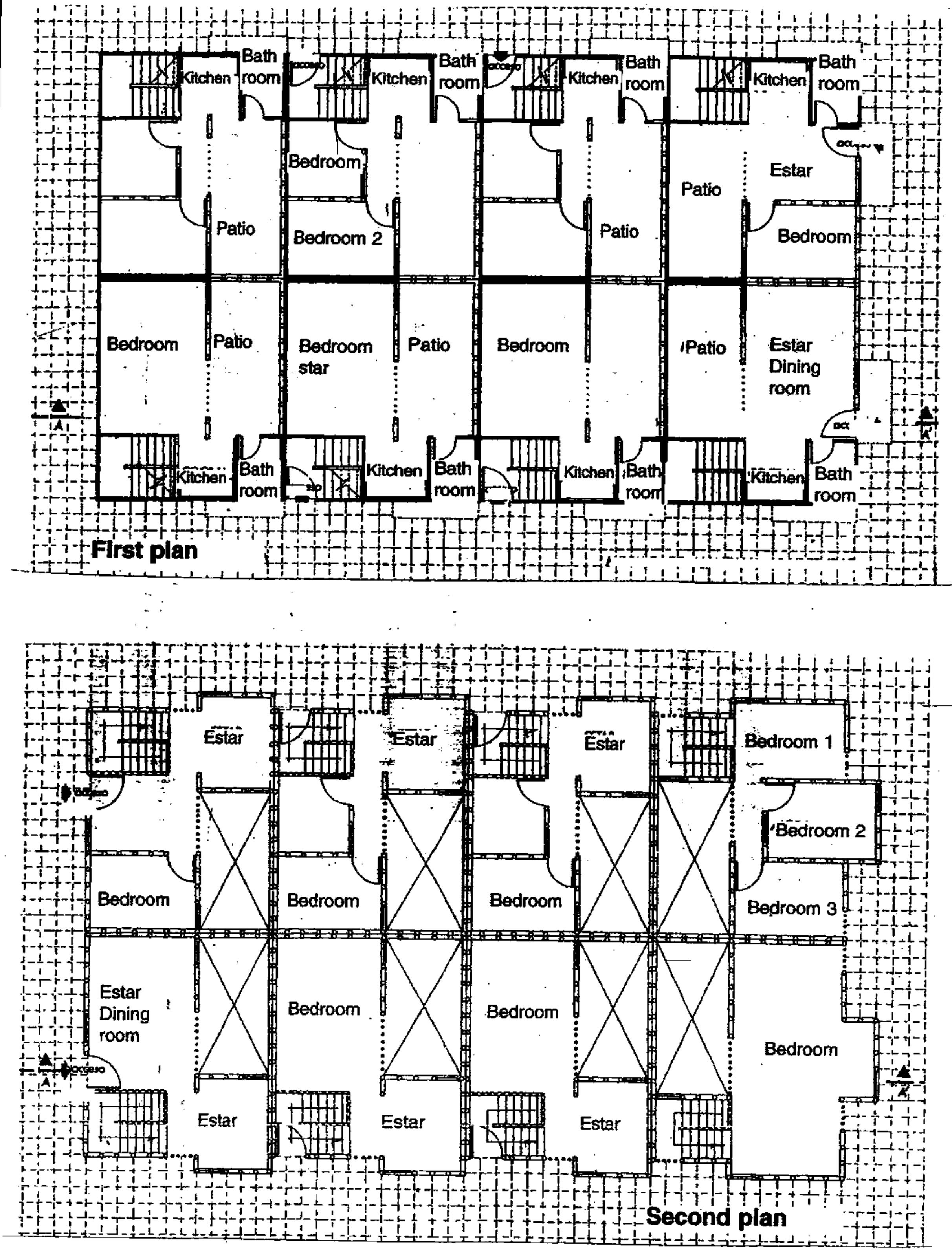
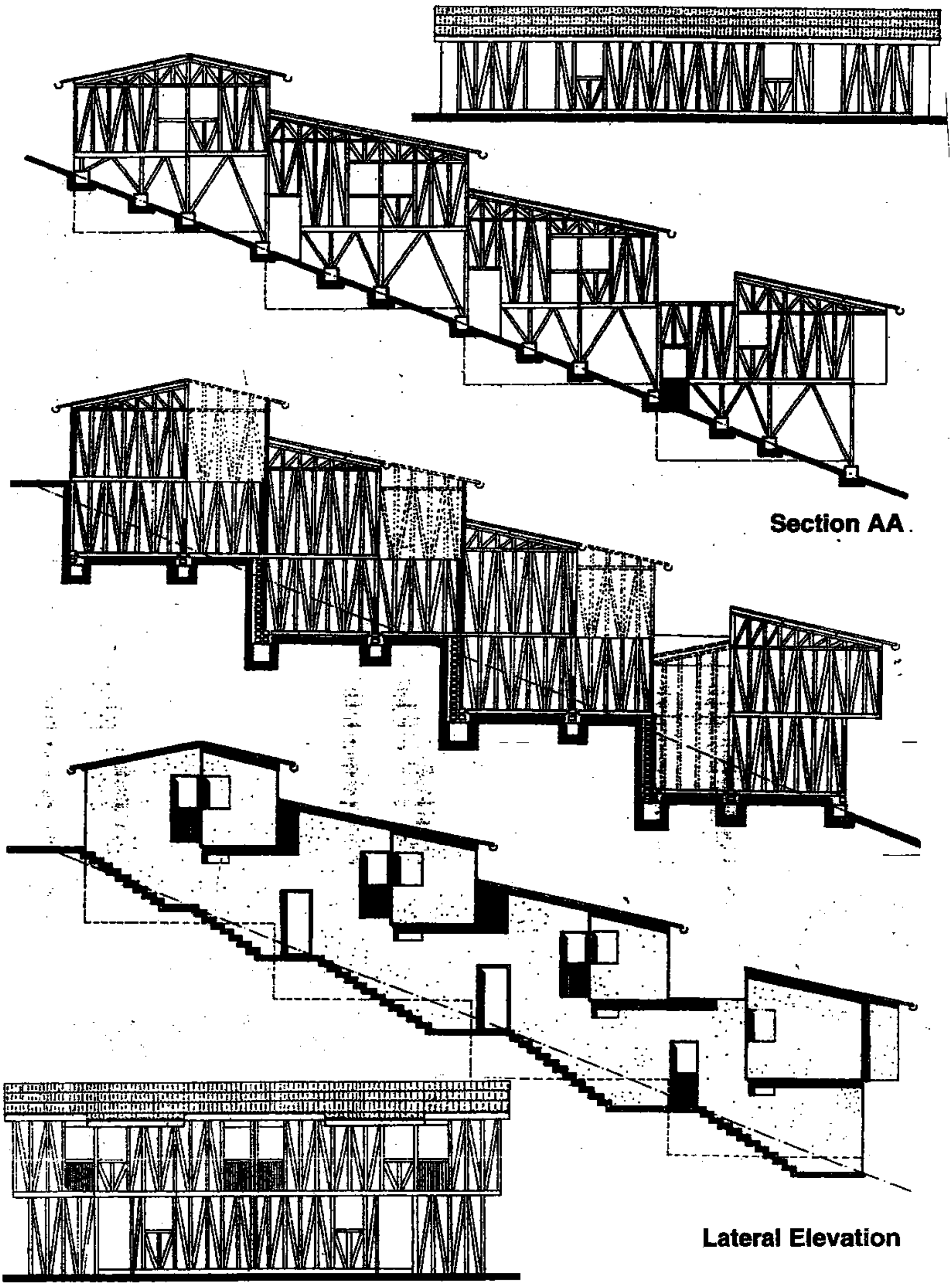


Fig. 23.31

LONGITUDINAL SECTIONS



Section AA.

Lateral Elevation

THE LARGEST BAMBOO STRUCTURES BUILT BY COLOMBIAN ARCHITECTS

Fig.23.32 THE BAMBOO ROOF OF CARLOS VERGARA

Carlos Vergara was a professor at the School of Architecture of the Valle University in Cali, Colombia, and was one of the best bamboo builders that I know.

One of the most interesting bamboo structures that he designed and built in 1987 with the collaboration of Carmen Elisa Cabal was the roof of the dining room of the Cañas Gordas Country Club in Cali, Colombia, which has an area of 25 x 25 meters. It is the largest bamboo structure built in Colombia up to the present time with a square plan.

A *The dining room of the Cañas Gordas club in Cali Colombia.*

B *Interior view of the huge structure built with Guadua angustifolia.*

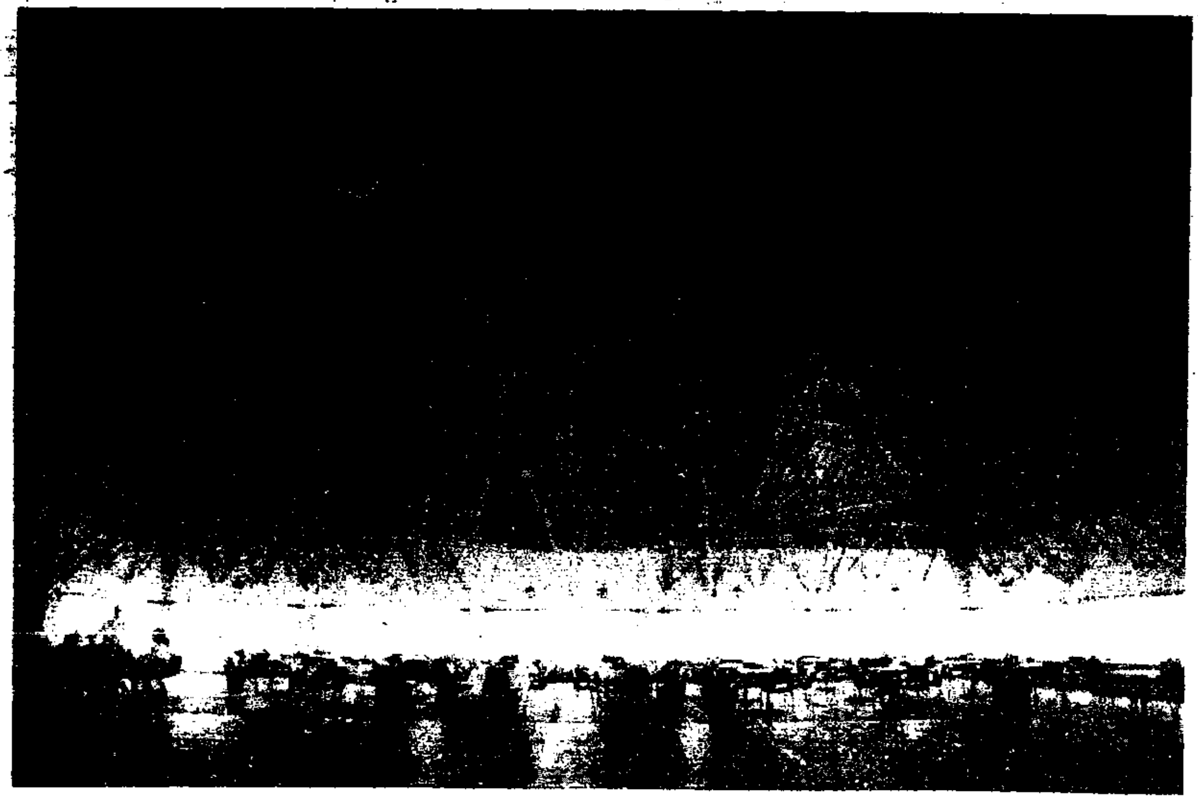
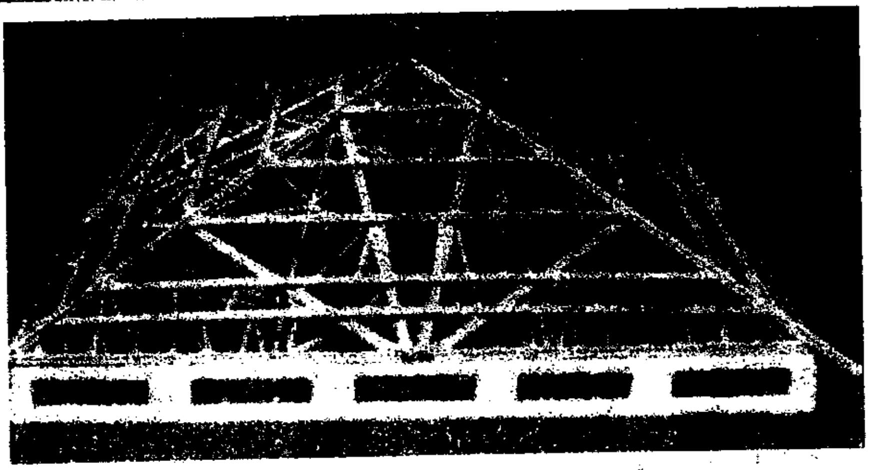
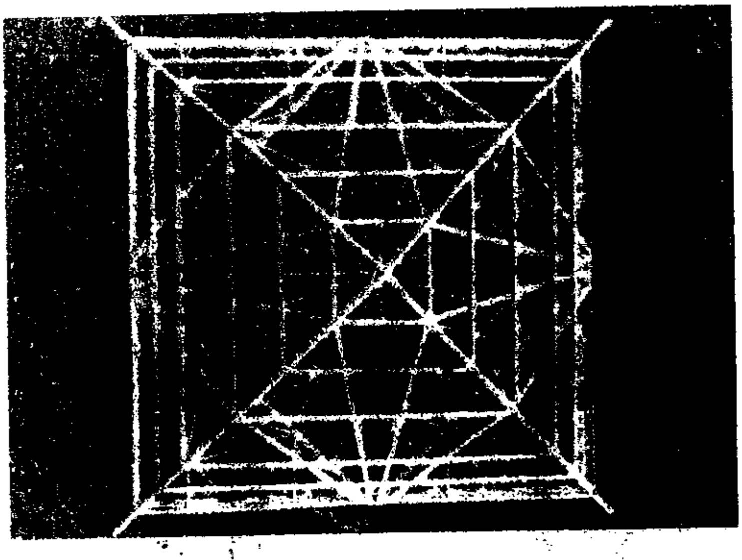


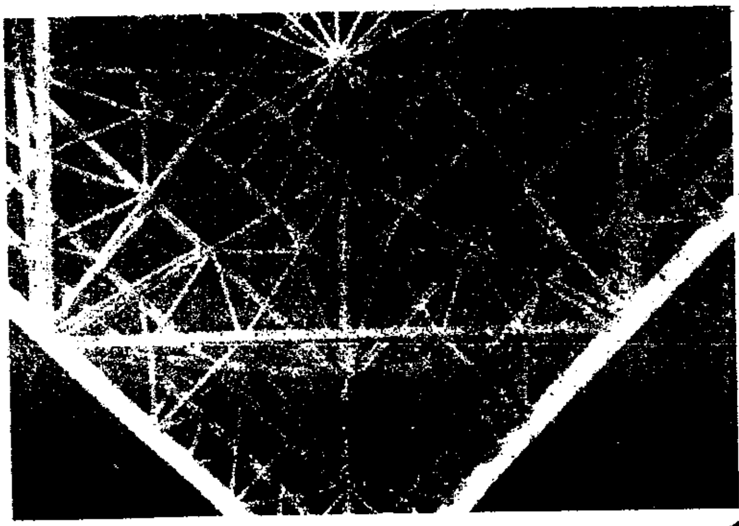
Fig. 23-33 **PERSPECTIVE AND PLAN OF THE STRUCTURE**



A. *It was necessary to make this model in order to explain the location of the differents members of the bamboo structure to the builders.*



B. *In order to use shorter structural members, four trusses were built in each corner to form an interior square.*



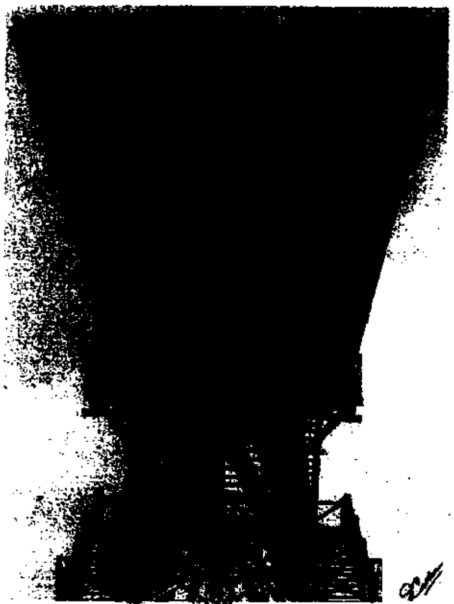
C. *This shows the detail of one of the trusses built in each corner and surrounded by structural members.*

Fig.23.36

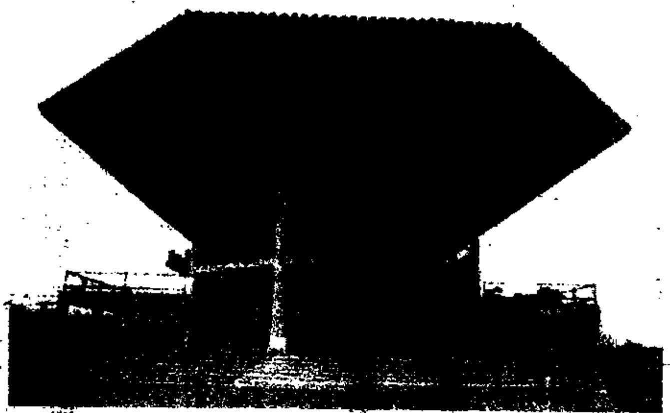
THE LATEST BAMBOO ROOF STRUCTURES OF SIMON VELEZ

In the eighties, Velez developed a new model of giant bamboo roofs like those shown on this page. They were generally supported by concrete structures and also by wood structures. The roof plan was rectangular and had from 6 to 12 sides. The technology used in the structure is similar to that used by the Spanish builders in the construction of churches, known as "par and nudillo" shown in Fig. A.

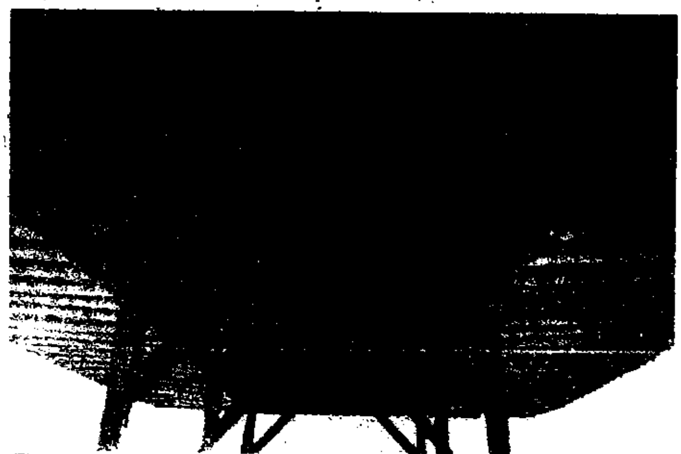
A



B. *Observation tower, in Parque de la Cultura Cafetera in Montenegro, Quindio Colombia. Only the roof is built with bamboo.*



C. *Country Club Peñalisa in Girardot, Colombia. 1992-1997.*



D

Fig.23.37

BAMBOO ROOF STRUCTURE IN ECUADOR

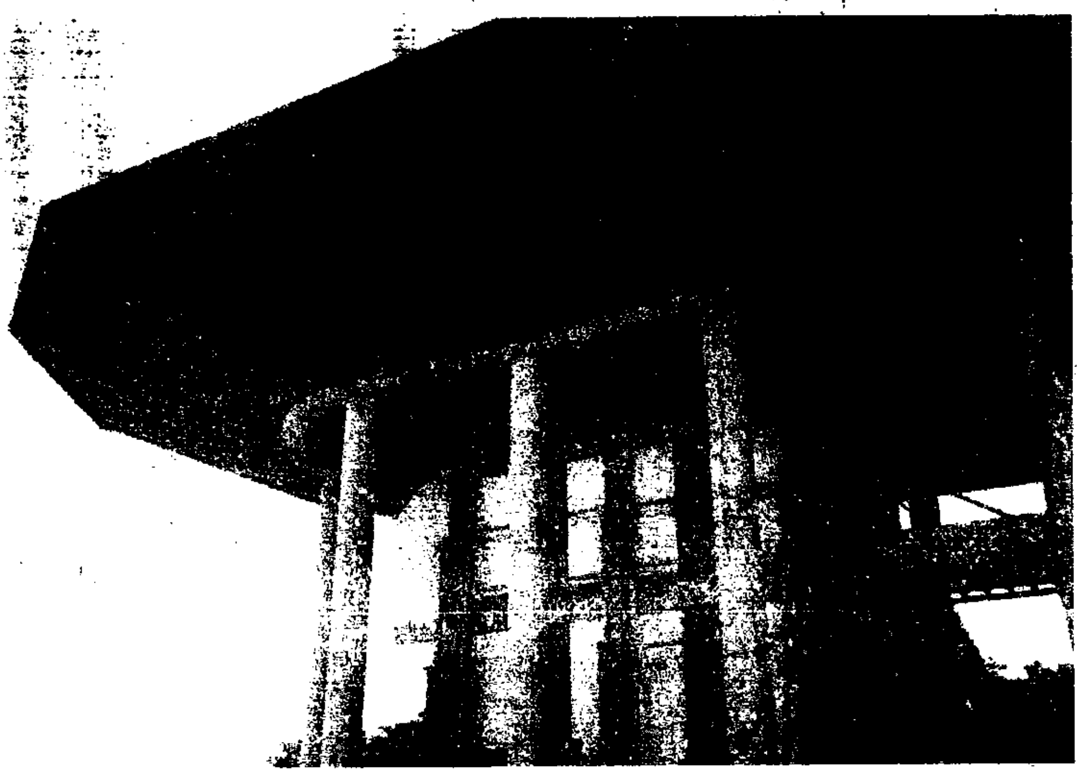
A

THE MANGLAR HOUSE

This house was built in Guayaquil, Ecuador by Simon Velez in the year of 1993. The excellent photographs was taken by the Arch. Jorge Moran.

Inside the concrete structure which supports the huge bamboo roof structure, a family house was built separately.

B



C

Fig. 23.38 CROSS SECTION AND PLAN OF THE ROOF STRUCTURE

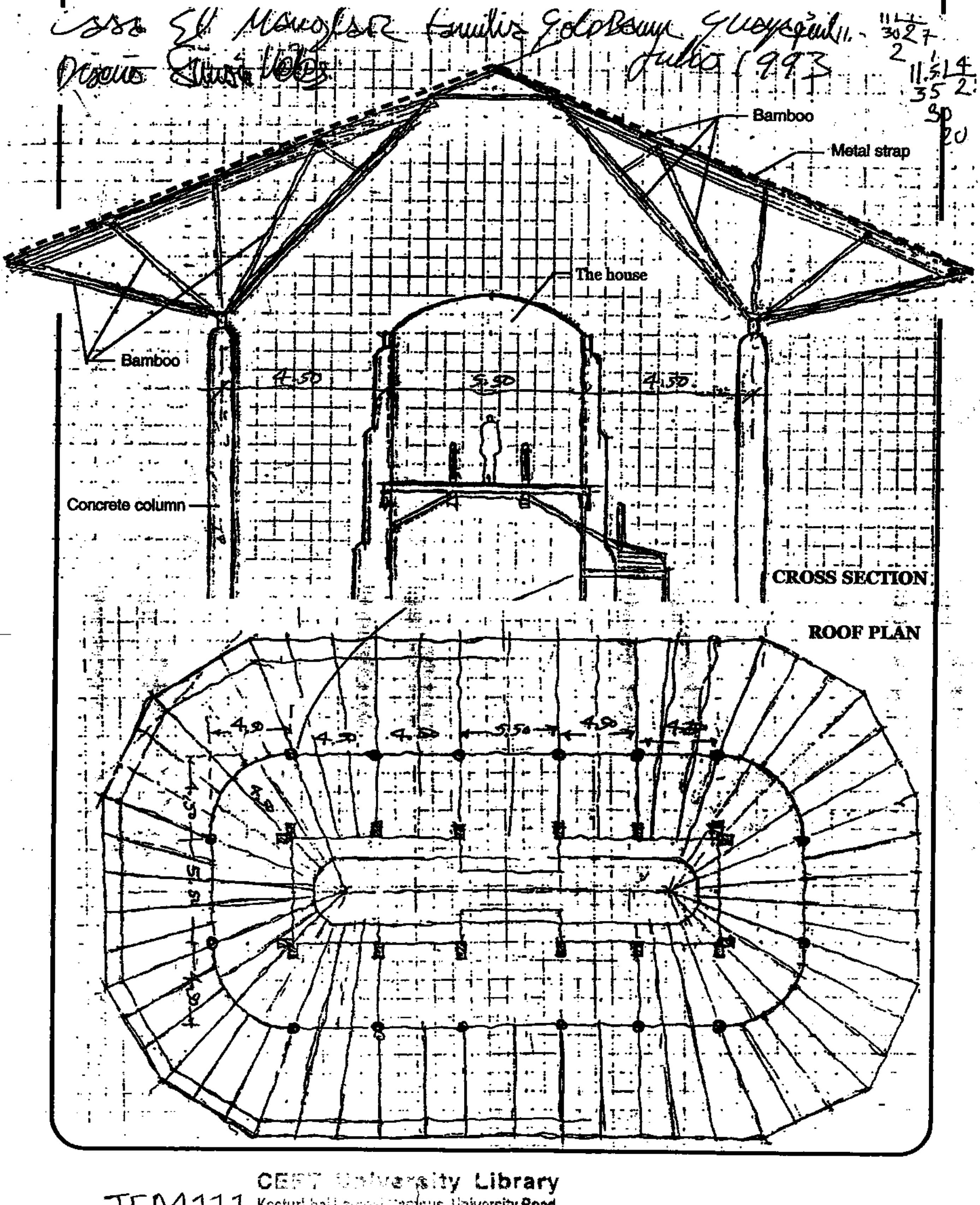
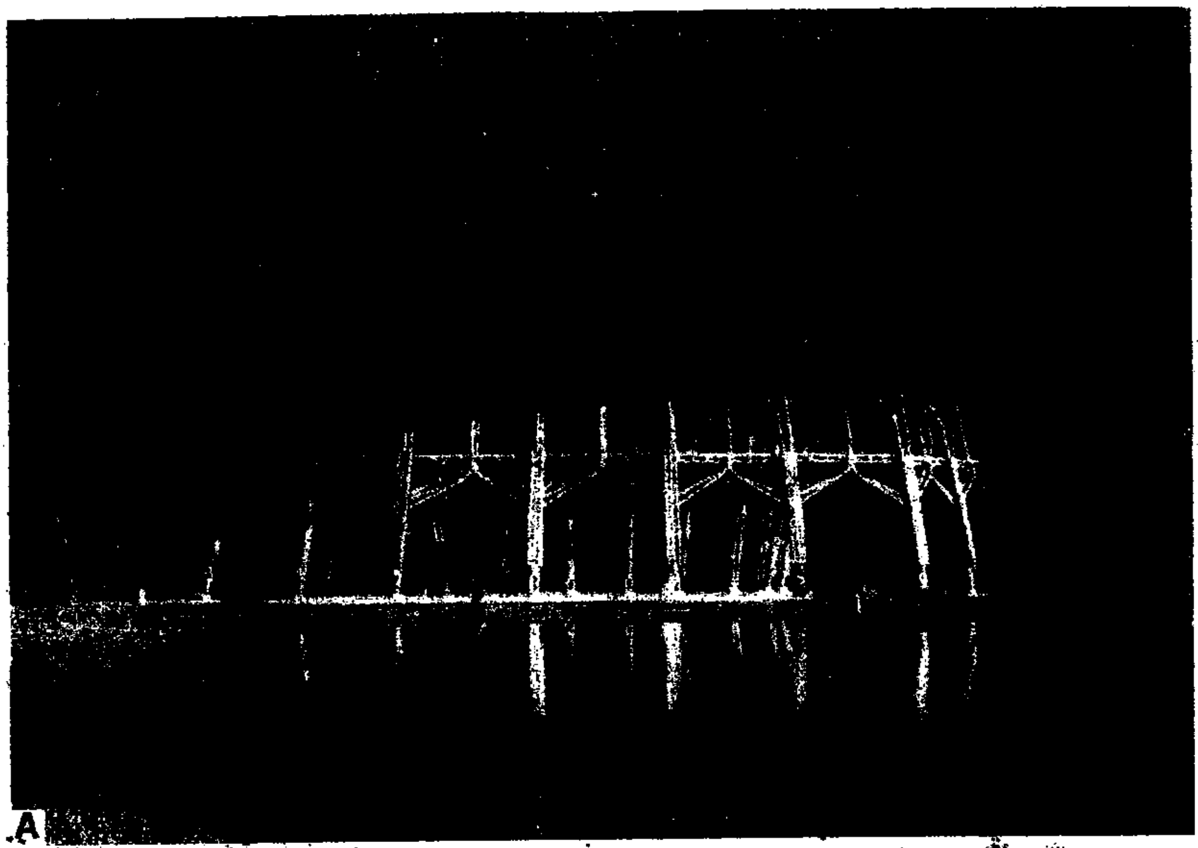
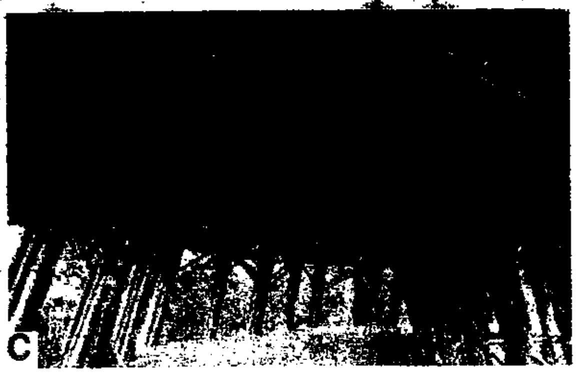


Fig.23.39 THE CIRCULAR BAMBOO ROOF OF ZERI PAVILION



A

B



C

THE ZERI PAVILION

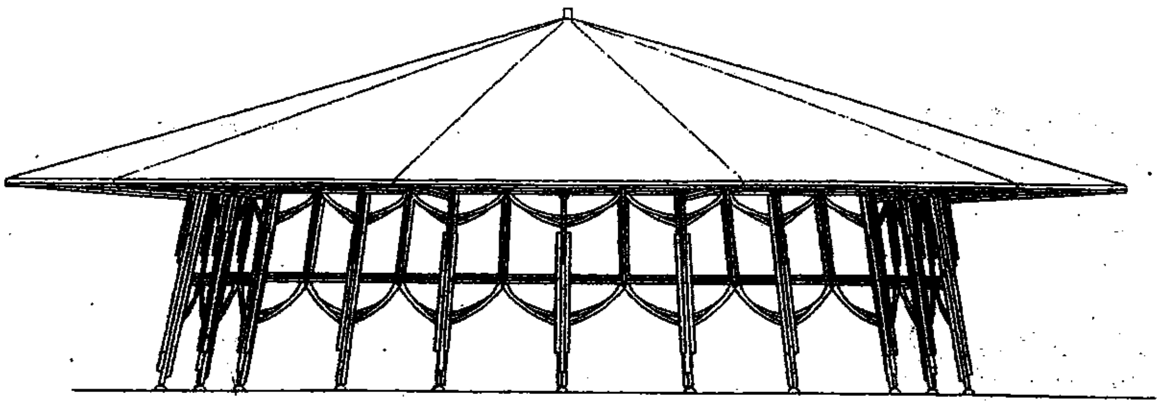
This beautiful bamboo and wood pavilion was designed by Simon Velez for Expo Hanover 2000. It was built first in Manizales in order to test its structure.The test results were considered very satisfactory and consequently its construction in Hannover was authorized by the Expo Hannover 2000.

Only the structure of the roof was built with bamboo. The supporting structure of the roof was builted up with a native timber specie.

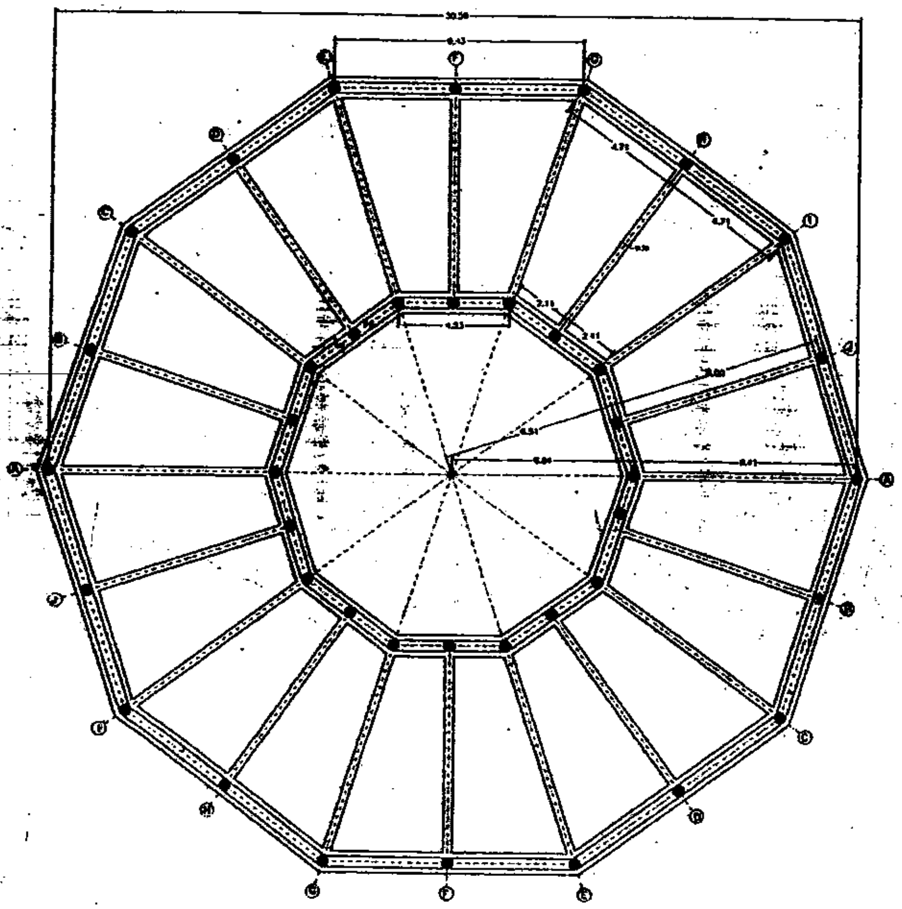
The excelent photographs were courtesy of the Comite de Cafeteros de Caldas.

Fig. 23.40

THE ZERI PAVILION ROOF

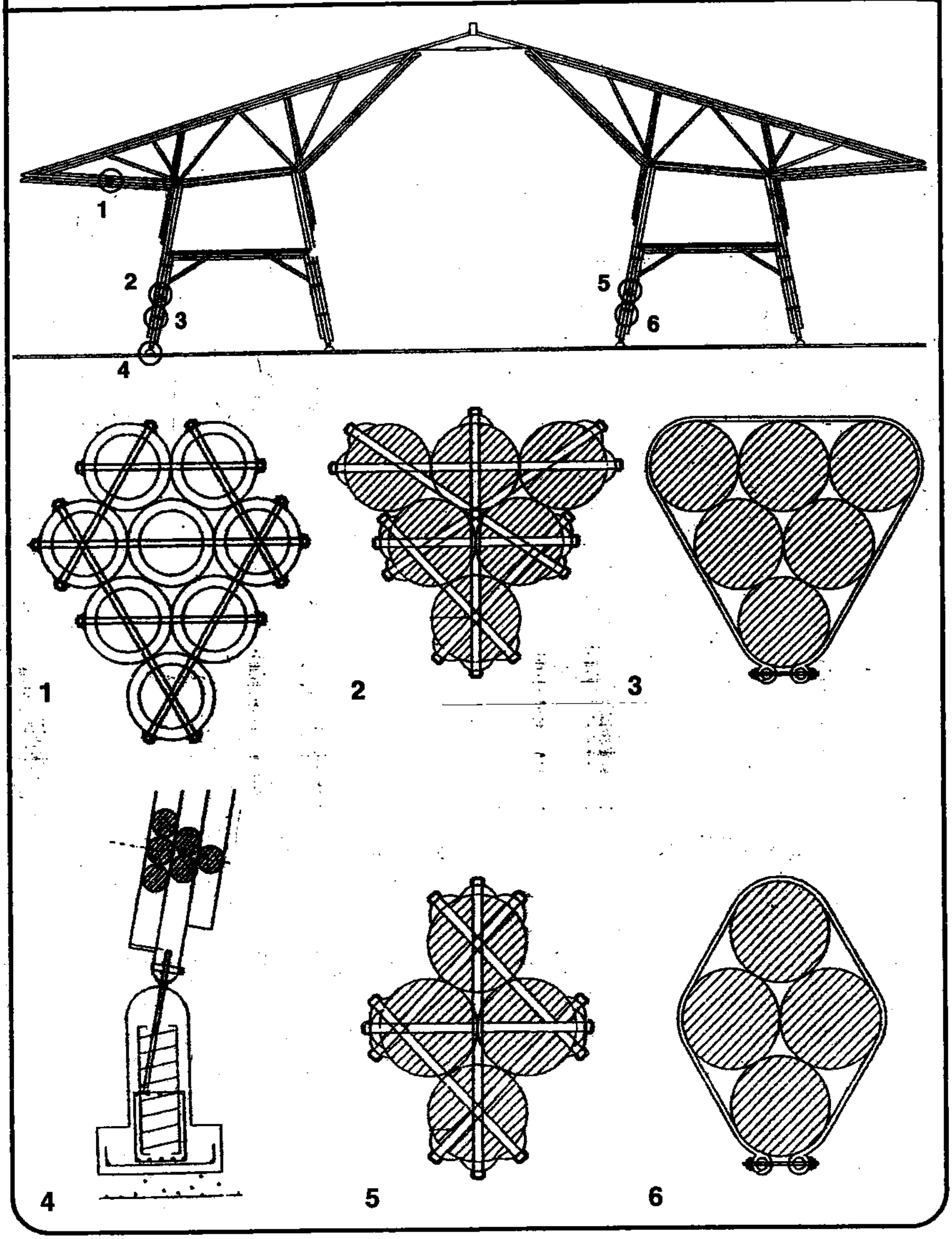


ELEVATION



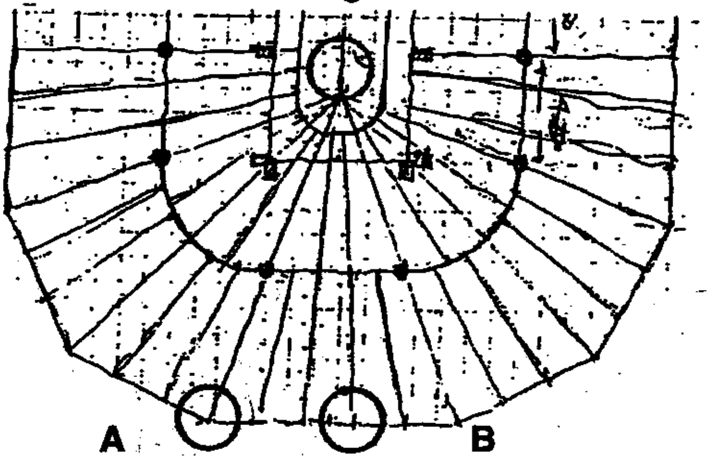
PLAN

Fig. 23.41 CROSS SECTION AND CONSTRUCTION DETAILS

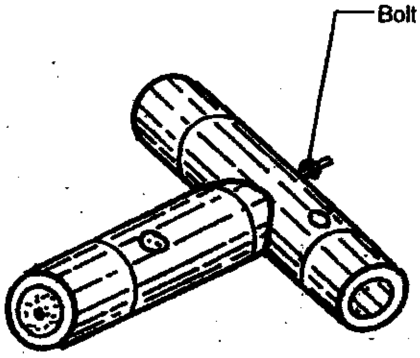


ROOF CONSTRUCTION DETAILS DEVELOPED BY S.VELEZ

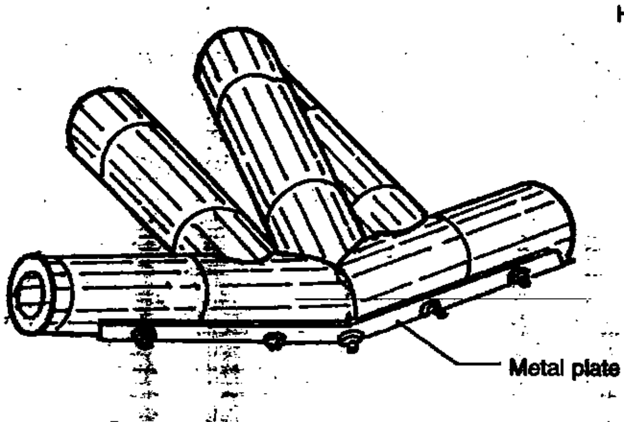
Fig. 23.42



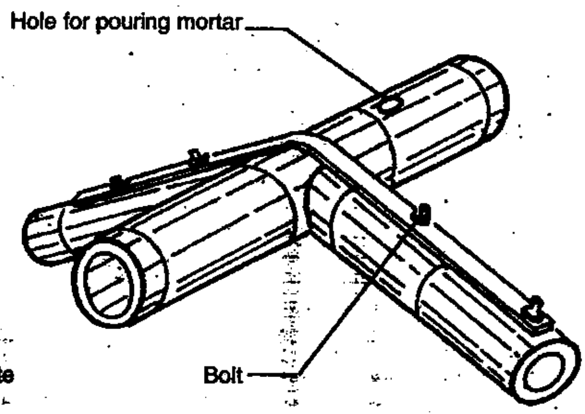
Roof Plan (See page)



B Eave Detail ("T")



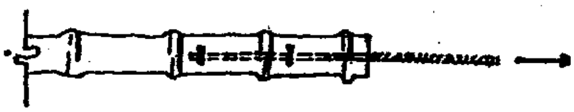
A Eave Detail (In angle)



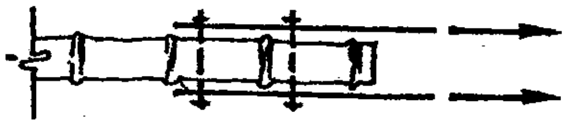
C Ridge Detail

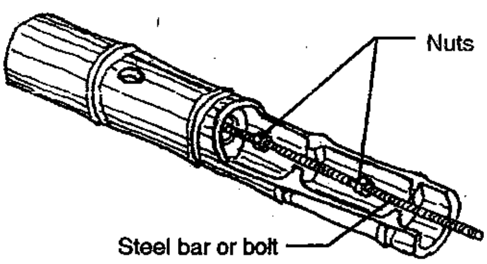
TENSILE AND COMPRESION JOINTS

Tensile and compression joint No 1



Tensile joint No 2

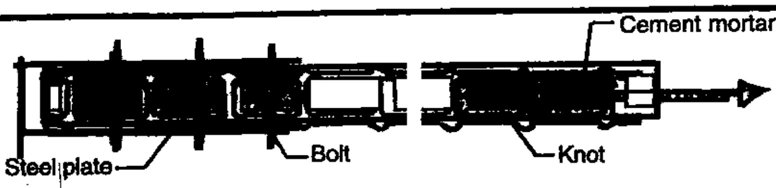




Tensile Joint No.1 Two internodes filled up with cement mortar are reinforced with a Ø 1/2" bolt with a nut in each internode.

Tensile Joint No.2. consists of two metal flanges (3/16" by 2") fixed to two empty internodes or filled up with mortar with two Ø 1/2" bolts.

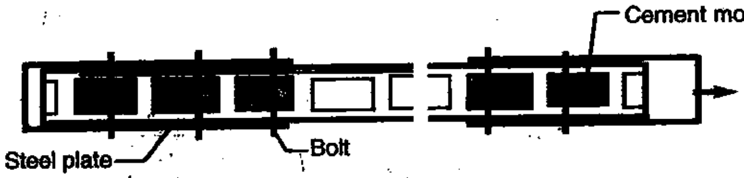
Fig. 23.43 TENSILE TESTS OF BAMBOO JOINTS (J. Garzon 1996)



A) - Test T.45 - A long bolt or bar 3/4" in diameter with nuts and 2 internodes with cement mortar.- Number of tests 5

Failure: *The cement mortar cylinders removed the internal nodes. There are cracks along 2 sides of the internodes.*

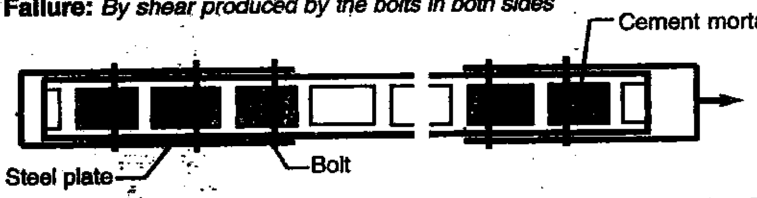
Rupture load (Kg)	Length section (m)	Exter. diamet. (cm)	Wall thickn. (cm)	Averag Interno (cm)
1) 4000	1.93	11	1.00	25
2) 4200	1.96	11.5	1.75	25
3) 4200	1.88	12.5	1.75	23
4) 4250	1.75	10.5	2.00	20
5) 4800	1.94	11.5	1.75	25



B) - Tests PP85 -Two internodes without cement mortar and two bolts Ø 3/4". Number of tests 3

Failure: *By shear produced by the bolts in both sides*

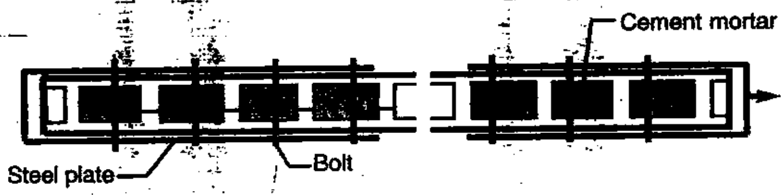
Rupture load (Kg)	Length section (m)	Exter. diamet. (cm)	Wall thickn. (cm)	Averag Interno (cm)
1) 4000	2.03	10	1.00	27
2) 3300	2.80	9.5	0.85	27
3) 3.500	2.50	10	1.00	36



C) - Tests PP80 - 2 internodes with cement mortar and bolts Ø 1/2". Number of tests 7

Failure: *By shear produced by the bolts in both sides. In some cases the cylinders were cut by the bolts longitudinally in 2 sections*

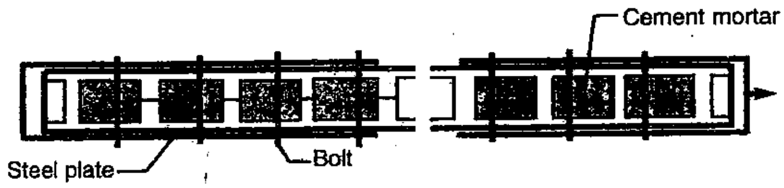
Rupture load (Kg)	Length section (m)	Exter. diamet. (cm)	Wall thickn. (cm)	Averag Interno (cm)
1) 7450	2.48	9.00	1.00	34
2) 5800	2.47	10	1.25	35
3) 6750	2.53	10	1.35	34
4) 7510	2.42	8.5	1.00	39
5) 7500	2.78	12.5	1.5	33
6) 8000	2.00	11	1.5	28.5
7)10000	1.97	10.5	1.75	26.5



D) - Tests PP95 -3 internodes with bolts Ø1/2", without mortar. Number of tests 3.

Failure: *by shear produced by the bolds in both sides*

Rupture load (Kg)	Length section (m)	Exter. diamet. (cm)	Wall thickn. (cm)	Averag Interno (cm)
1) 6750	3.02	9.5	1.25	26.8
2) 3600	3.06	11	1.60	30
3) 3100	2.99	10	1.00	33



E) - Tests PP90 - 3 internodes with mortar and bolts Ø1/2" Number of tests 6

Failure: *Same as (C).*

Rupture load (Kg)	Length section (m)	Exter. diamet. (cm)	Wall thickn. (cm)	Averag Interno (cm)
1)13500	2.52	11.5	1.75	29
2)11530	3.10	10	1.00	26
3)12800	2.54	12	2.00	28
4)11900	2.69	10	1.25	27
5) 9800	3.00	11	1.75	26
6)11730	2.94	10	1.25	28

Source: Jenny Garzon Caicedo (1996)

CONCLUSIONS OF THE TESTS CARRIED OUT BY GARZON & DIAZ

A) Conclusions of the tests carried out by J. Garzon & F.Diaz (1996):

1.- According to the above tests, both systems of joints are trustworthy if they are carefully made.

2.- The joints in which bolts and steel straps were used are stronger (about 50%) than those made with axial screws or long bolts.

3.- The strength increases proportionally with the number of internodes filled with mortar cement.

4.- In the joint with an axial screw, the allowable load recommended for the internode is 716 kg with F.S. = 3.

5.- In the joint with bolts, the allowable load recommended for the internode is 900 kg and for each additional internode it increases by 30%.

6*. *Guadua angustifolia* or "macana" with short internodes and diameters between 10 -14 cms is the strongest.

B) Some of the conclusions of Fernan Diaz are the following:

1.- Small diameter culms with thin walls had very low results.

2.- Culms with diameters between 10 and 12 cms and with longer internodes had the highest strength. It was observed that the cement mortar cylinders failed first and then the bolts.

3.- Bamboo was stronger than any one of the fasteners or connectors used.

4.- In the joint with an axial screw with one nut and only one internode filled with cement mortar, the breaking load could be 2,500 kg. and for two internodes it could be 5,000 kg.

5.- An internode with bolts filled with mortar can support a tension of about 4,000 kgs. but two internodes with bolts can support a tension of 9,000 kgs.

RECOMMENDATIONS IN THE USE OF INTERNODES WITH CEMENT MORTAR (by O. Hidalgo)

Fig.23.44

A.-Bamboo culms which are going to have internodes filled with cement mortar should be mature and previously air dried. If the internodes are young green culms, once they become dry, they will shrink and crack when the cement mortar cylinders are compressed.

B -The diaphragm (a) consists of a thick border (which supports the concrete cylinder) and a thin wall at the central part. Only the central part (b) should be perforated with a diameter a little bigger than that of the nut located in the steel bar or a long bolt.

If the border is partially destroyed (c), the type of failure shown in D (the lower drawing) occurs, produced by the pressure of the mortar cylinders.

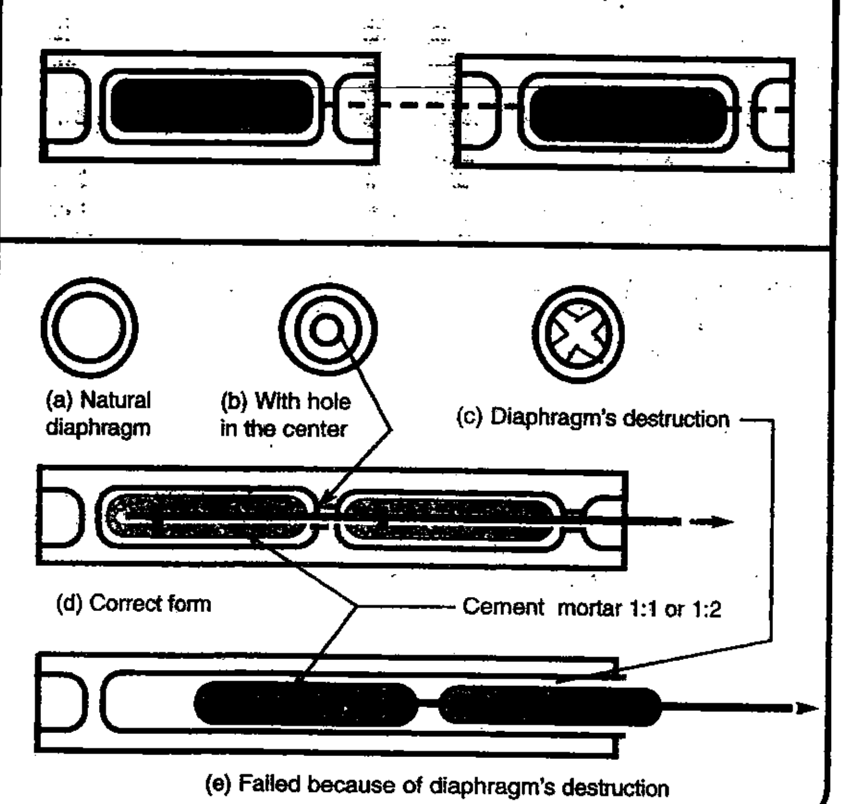


Fig.23-45

RECOMMENDATIONS (2)

First of all, for this type of construction it is recommended the use of culms sections of strong species like *Guadua angustifolia*, three years old or older, previously treated with appropriate chemicals.

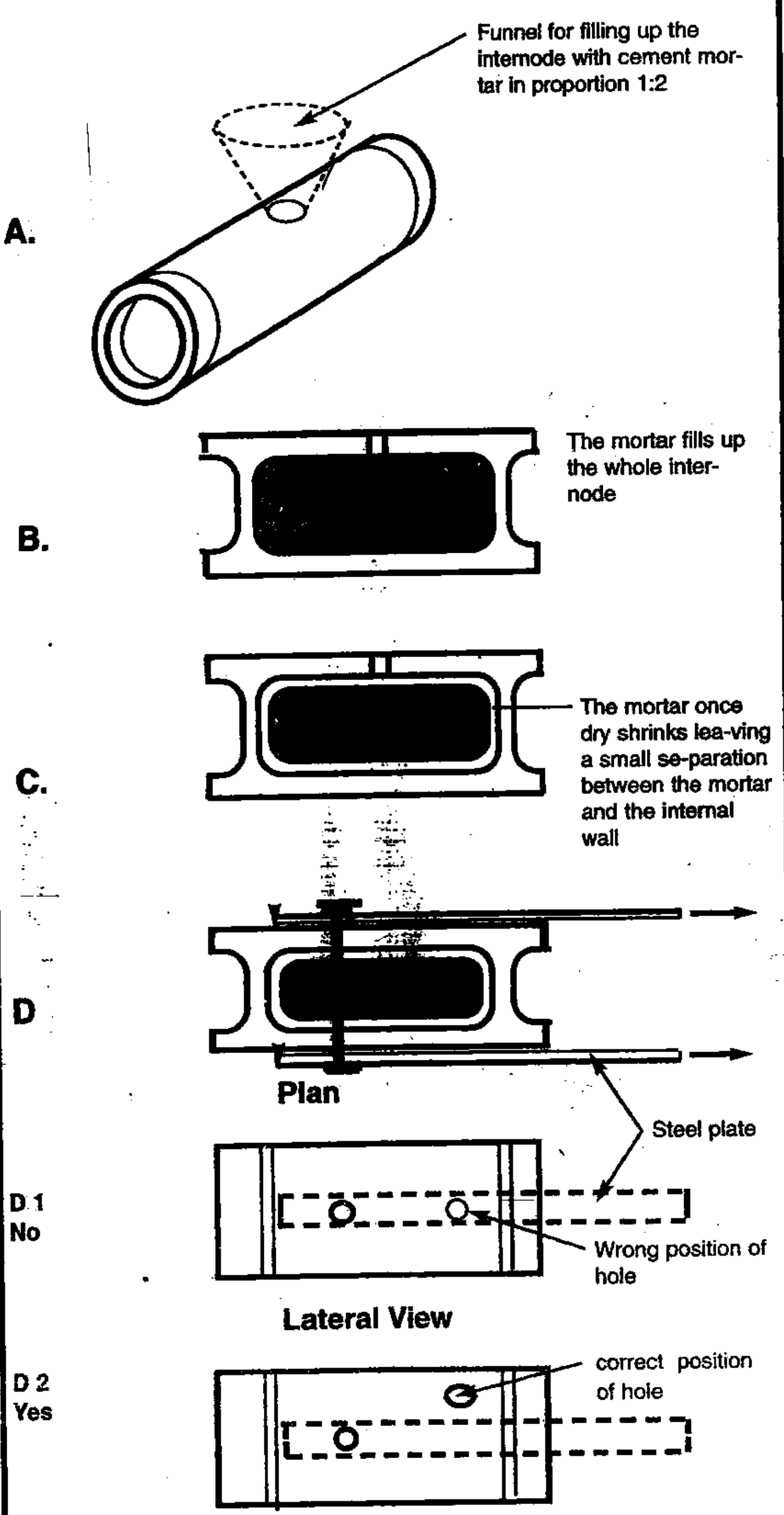
The cement mortar (with only the necesary water), in the proportion of 1:2 (cement-sand) by volume is recommended for filling up the internode once the steel bar or the bolts are located in place inside the internode.

The holes for pouring the cement mortar should be 2.5 cm (one inch maximum) in diameter. Never make square holes for this purpose.

Fig. A. The transversal section shows how the cement mortar is poured filling up the whole internode. (See **Fig. B**). Once the mortar mix dries, it shrinks, leaving a small separation between the culm wall and the mortar cylinder and also with the diaphragm, as shown in **Fig. C**. Due to this reason the cylinder loses its adherence with the culm wall and consequently it operates as a piston which is supported by the internal partitions.

For this reason, it is not recommended that the whole diaphragm located between two internodes that are going to be filled up with cement mortar be removed. In this case, only remove the necessary area of the central part to introduce the steel bar or bolt with the nut.

Fig. D. When bolts and metal straps are used as fasteners, they should not be located in the same axis of the hole used for pouring the cement mortar or the holes where the bolts are going to be located as shown in Fig. D 1. The correct position is to locate the holes in a separate axis as shown in D 2.



TRADITIONAL BAMBOO ARCHITECTURE IN ASIA

22

WAS HOMO ERECTUS THE FIRST ARCHITECT IN CHINA ?

Bamboo history goes back to the beginning of civilization in China where man and bamboo have been interwoven since prehistoric times. According to Pope (1989), there is evidence to suggest that bamboo was utilized by Homo erectus in Southeast Asia one million years ago. This means that Homo erectus was the first hominid who used bamboo for construction.

As the name implies, Homo erectus is definitely a human species and one of the earliest fossil precursors of modern man which was discovered by a young military doctor from Holland, Eugene Dubois, who sailed into Java in 1887 with the sole purpose of finding the hypothetical missing link between apes and humans. In 1891, he found a skullcap, a femur and a molar, that came to be known as Java man, along a bend in the Solo River near the village of Trinii. At first, he considered the specimen to be a manlike ape and labeled his discovery Pithecanthropus erectus, meaning "upright ape man". Homo erectus evolved from its more apelike predecessor, Australopithecus, around 2.5 million years ago and in turn gave rise to Homo sapiens.

The archeologist Hallam Movius of Harvard investigated many archeological sites in India, Southeast Asia and China in 1937 and 1938 and found that in this area there were two long-lasting paleolithic cultures that he separated with the "Movius line" (which his colleague Carleton Coon named in his honor). This was a geographical boundary, extending through northern India, that separates two long-lasting paleolithic cultures. West of the line are found collections of tools with a high percentage of symmetrical and consistently proportioned hand axes which are called Acheulean tools. But in eastern China or Southeast Asia, there were more crudely made tools known as choppers and chopping tools. Both types of tools are attributed to our hominid ancestor Homo erectus and are of a similar age (Acheulean tools are from 1.5 million to 200,000 years old; chopper-chopping tools from 1 million to 200,000 years old).

For years this explanation was accepted by anthropologists and taken as evidence of racial isolation and backwardness. But later on, Pope (1989), in the excavations he made in many sites of Southeast Asia, realized that something was very strange because there were no fossil horses of Pleistocene age (1.6 million to 12.000 years ago) in this area. The only exceptions were a few horse fossils from one place in Southern China. He found that in the past the zone that lacked open-dwelling mammals was a bamboo forested zone that coincided almost perfectly with the distribution of the chopper-chopping tools. This means that the chopper-chopping tools were made by Homo erectus for cutting bamboo culms, and also for transforming it into different materials, since he could not do this with the acheulian hand ax.

Beals & Hoijer (1971) point out that the chopper-chopping tools used in South and East Asia, by groups such as the Choukoutienien of China and the Soan from India, originated from pebble tools which are stream bed pebbles, usually ovoid in shape, with a few flakes knocked off on one or both sides to make a cutting edge. According to the above, the first hominid that cut and used bamboo for construction and other purposes in China was the homo erectus, probably more than one million years ago. According to Hsiung (1983), the most ancient information which exists about articles made of bamboo in China, such as mats, baskets and others, was unearthed from the ruins of Hemodu and Shishan in Zhejiang Province and can be traced back to the New Stone Age, or Neolithic, 5,000 years ago.

A similar tool derived from the chopper-chopping tool was also used by the American Indians, probably for cutting bamboo in the tropical area of this con-

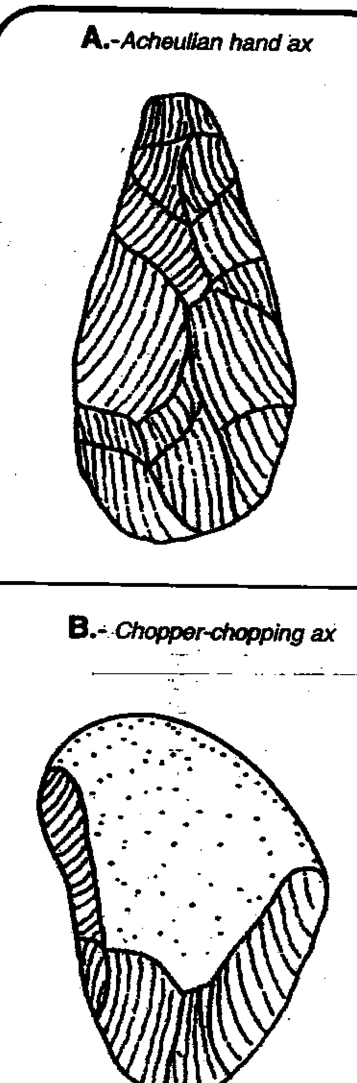


Fig.24.1 *Types of prehistoric stone axes developed by homo erectus in Asia more than one million years ago. The acheulian ax was an impact ax, the chopper-chopping ax was developed for cutting bamboo.*

tinent where the giant bamboo grew. According to Beats & Hoijer (1971), evidence generally accepted as incontrovertible places man in North America between around 15,000 and 20,000 years B.C. The earliest American Indians must have walked across from Asia at a time when lower sea levels created a land bridge in the Bering Strait area between Asia and Alaska. Man also had certainly reached the southern part of South America by about 9,000 BC. There is no clear relation between the tool complexes of early American Indians and those of Southeast Asia. Some crude chopper-scraper complexes suggest derivation from Asiatic chopper-chopping tool traditions; others show Mousteriod similarities, and there is some evidence of blade-tool techniques.

One of the most extraordinary properties that I have found in the giant bamboos, that makes me think that this plant was designed and programmed by "nature" with the purpose of supporting not only the development of the most primitive civilizations but also of very poor people, who generally do not have tools for building their houses, is the fact that bamboo is the only plant in the vegetal kingdom which has a density and tensile and compression strength superior to that of any tree; can be easily cut and transformed into different materials like slats and boards in a minimum of time, using only stone flakes resulting from the manufacture of choppers.

But the most interesting fact is that Homo erectus discovered that he could very easily cut a giant bamboo culm if the edge of his hand ax was inserted forcefully at an angle of about 45 degrees, in a zone about 2 centimeters above or below any node of the culm, where the shortest fibers of the internode are located. (See Fig. 1.24 page 23).

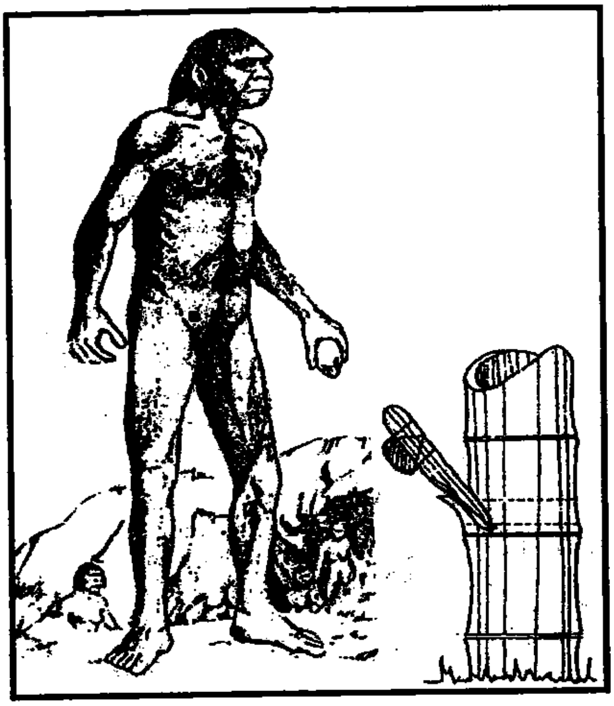


Fig. 24.2 *Homo erectus discovered that the bamboo culm could be cut with a chopper ax only in a zone (about 3 cm high) above or below the nodes, which is where the shortest fibers are located.*

Was the first man engendered by a bamboo culm ?

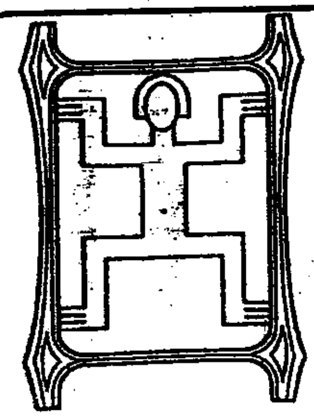


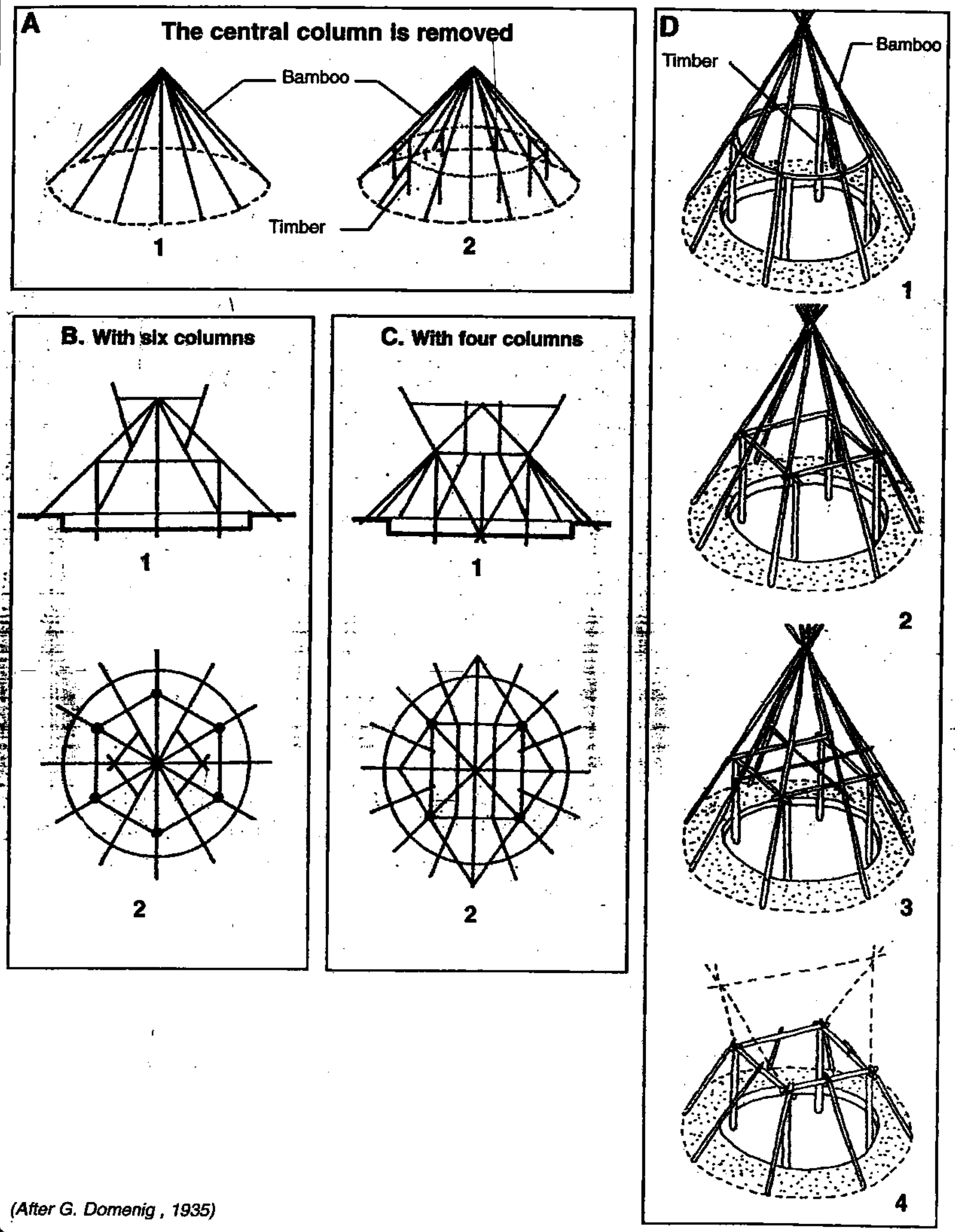
Fig. 24.3 *A legend says that the first man and the first woman came into the world in different internodes of the same bamboo culm. Since then bamboo has given them shelter and protection. The drawing shows man's birth from a bamboo internode. This is the logotype designed by the author for the First Latin American Bamboo Symposium which he organized in Manizales, Colombia, in August 1981. Since then it has been used by the author in his publications as his emblem.*

The great importance that bamboo has had for the people in tropical countries where this plant grows is reflected in the position it occupies in their mythology and folklore. For many primitive cultures of southeast Asia and South America, bamboo came to be an element so essential for their living that they believe that in the world of plants bamboo was the representation of the divinity and also the origin of their ancestors. It is said, for instance, that the Piyuma tribe in Formosa (Taiwan) believed that the first man and woman of their ancestors came from different internodes of the same culm of a bamboo plant that grows in Arapanai, a place near the coast. Since then, bamboo has given them shelter and protection.

A similar folktale exists among the Tagal, a Philippine tribe. Rumpf, who died in the year 1693, says in his "Herbarium Amboinense" that the Malays, in his time, believed that the first man sprang up from a hollow culm of bamboo. Arber (1934), said that the kings of Butong, a small Island near Celebes, in Indonesia, also claimed that they sprang up originally from a giant bamboo.

According to the mythology of the Patangoros, a Colombian Indian tribe which disappeared many years ago, after the great flood only one Indian survived. For many years he walked lonely and sad, but one day the Heaven Master felt pity towards him, and came down to earth bringing with him two pieces of bamboo. He transformed one piece into a woman and gave it to him as a companion and with the other piece, he built them a house (Patiño 1975).

Fig.24.4 **EVOLUTION OF PRIMITIVE CONICAL TIMBER AND BAMBOO JAPANESE ROOFS**

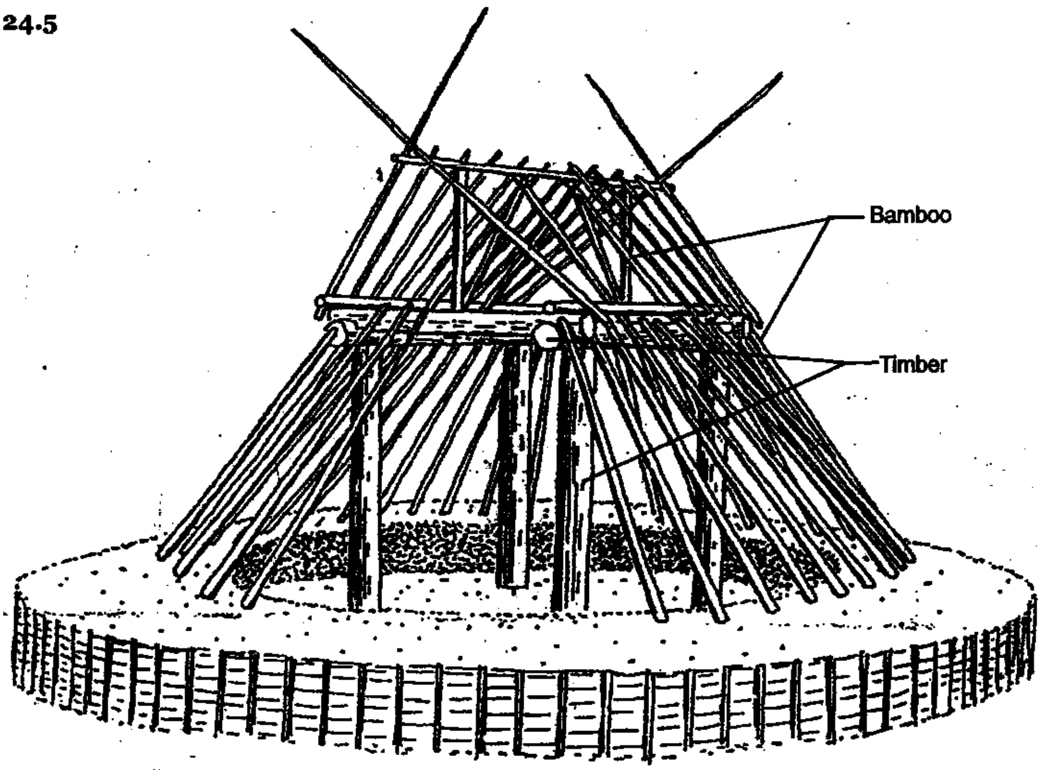


(After G. Domenig, 1935)

EVOLUTION OF PRIMITIVE CONICAL ROOFS IN JAPAN(2)

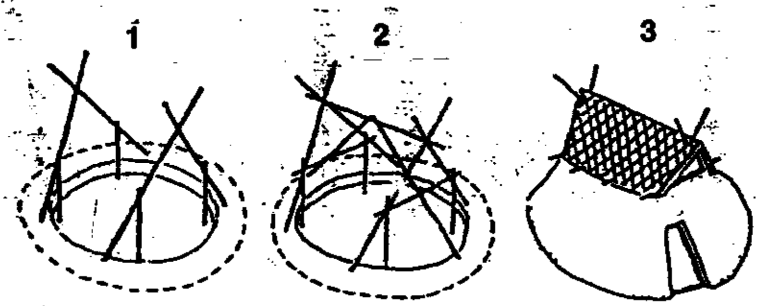
Fig. 24.5

A

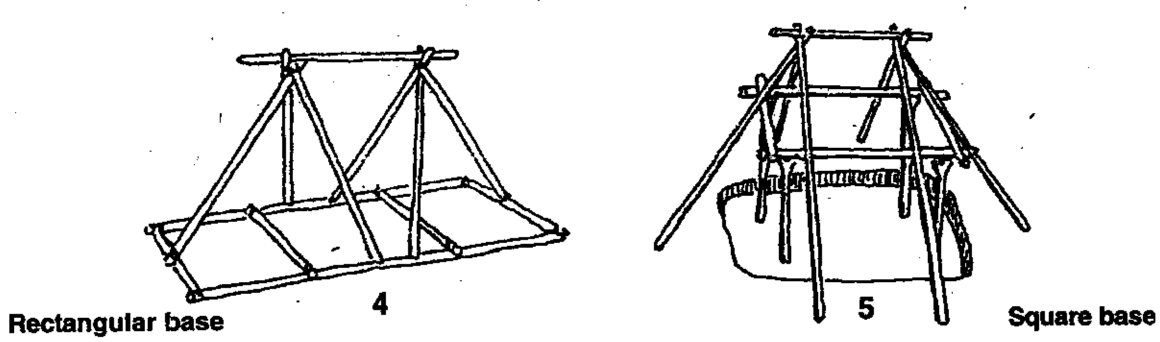


A. *The structure consist of four wooden columns and beams which support the bamboos which form the conical roof of the base.*

B



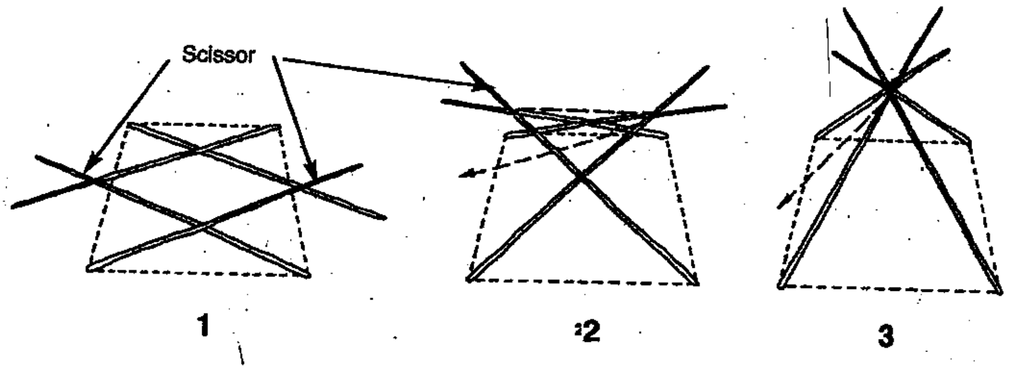
Evolution of the structure **(See page 404)**



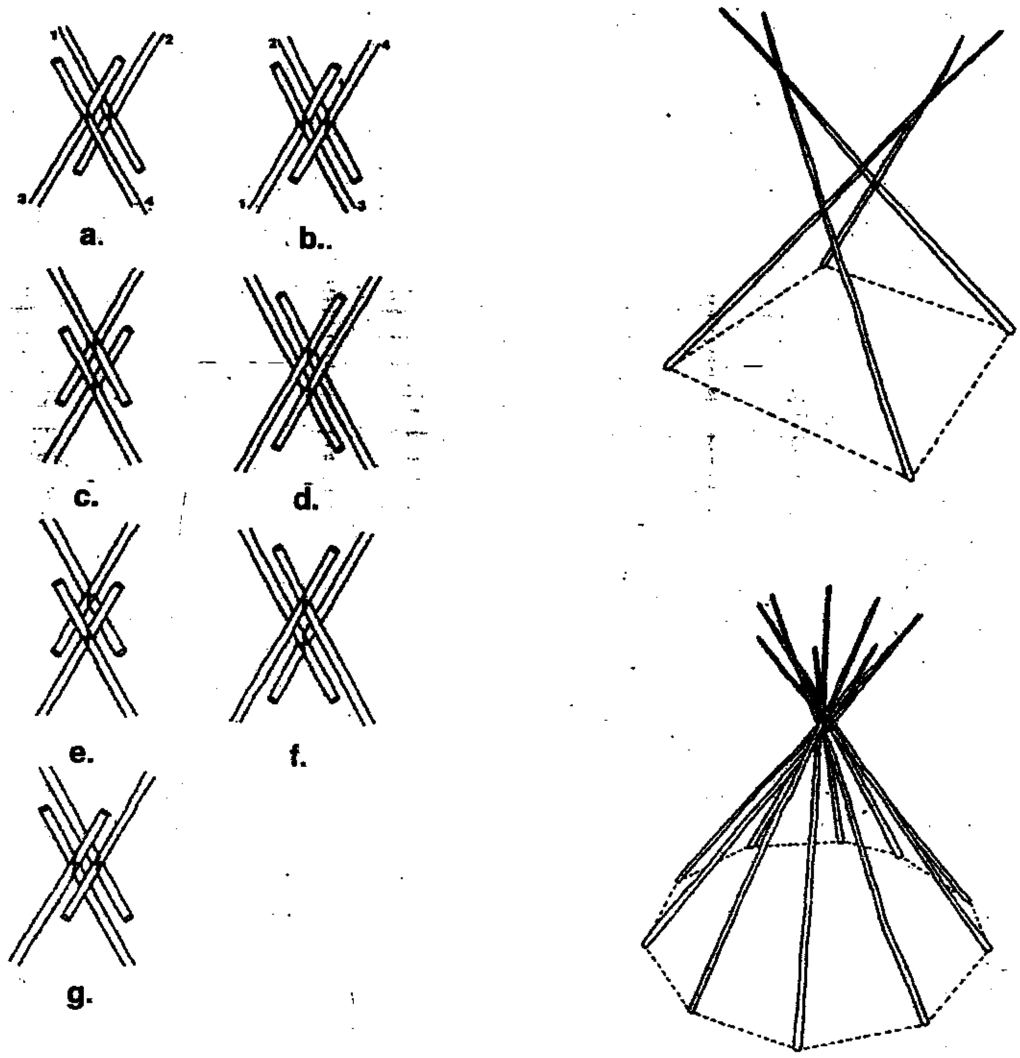
THE USE OF BAMBOO SCISSORS IN PRIMITIVE HOUSES

Fig.24.6

A. How to fix the bamboo scissors

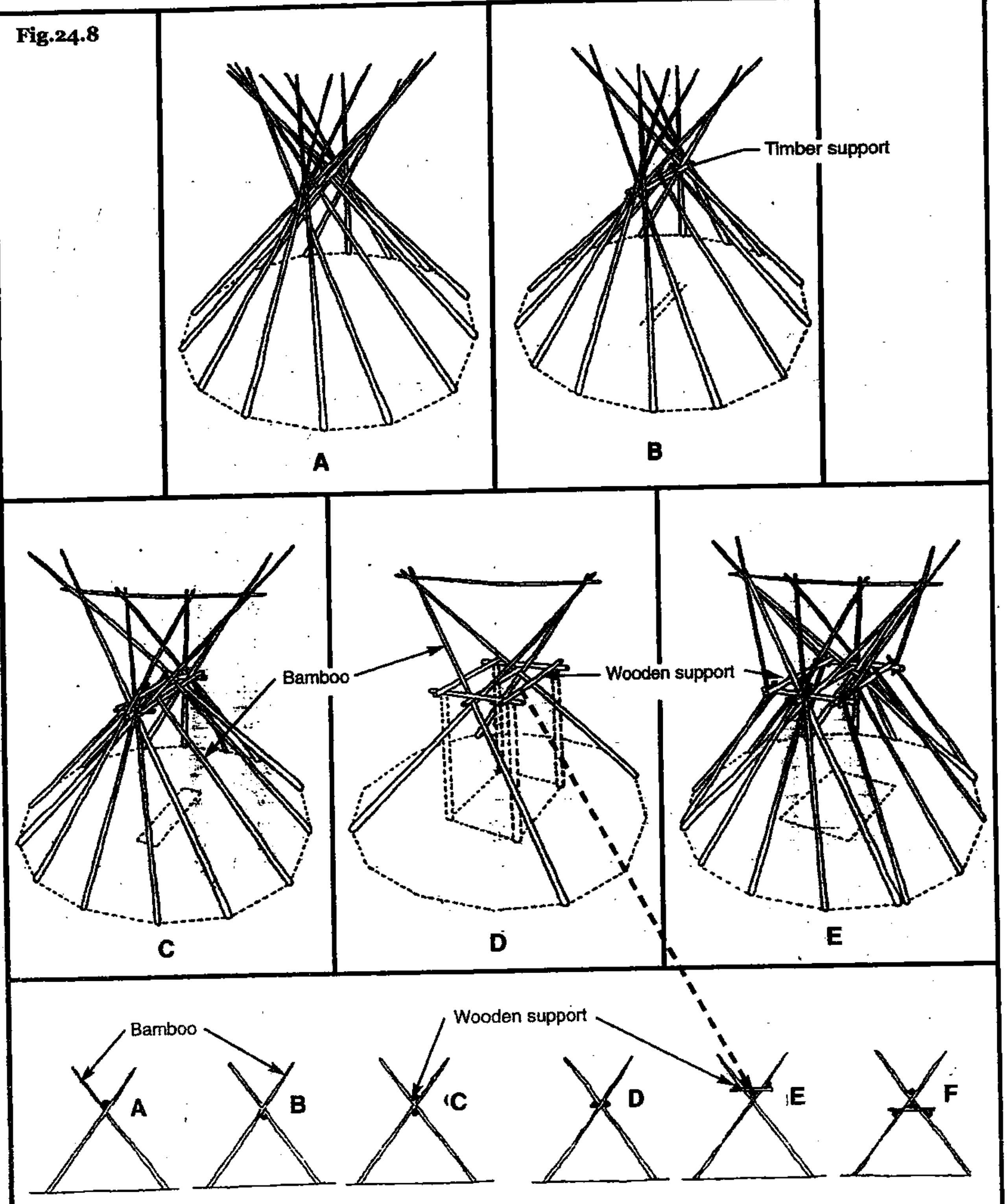


B. Different types of joints used with bamboo scissors



1.-EVOLUTION OF BAMBOO CONICAL ROOFS IN SOUTH EAST ASIA

Fig.24.8

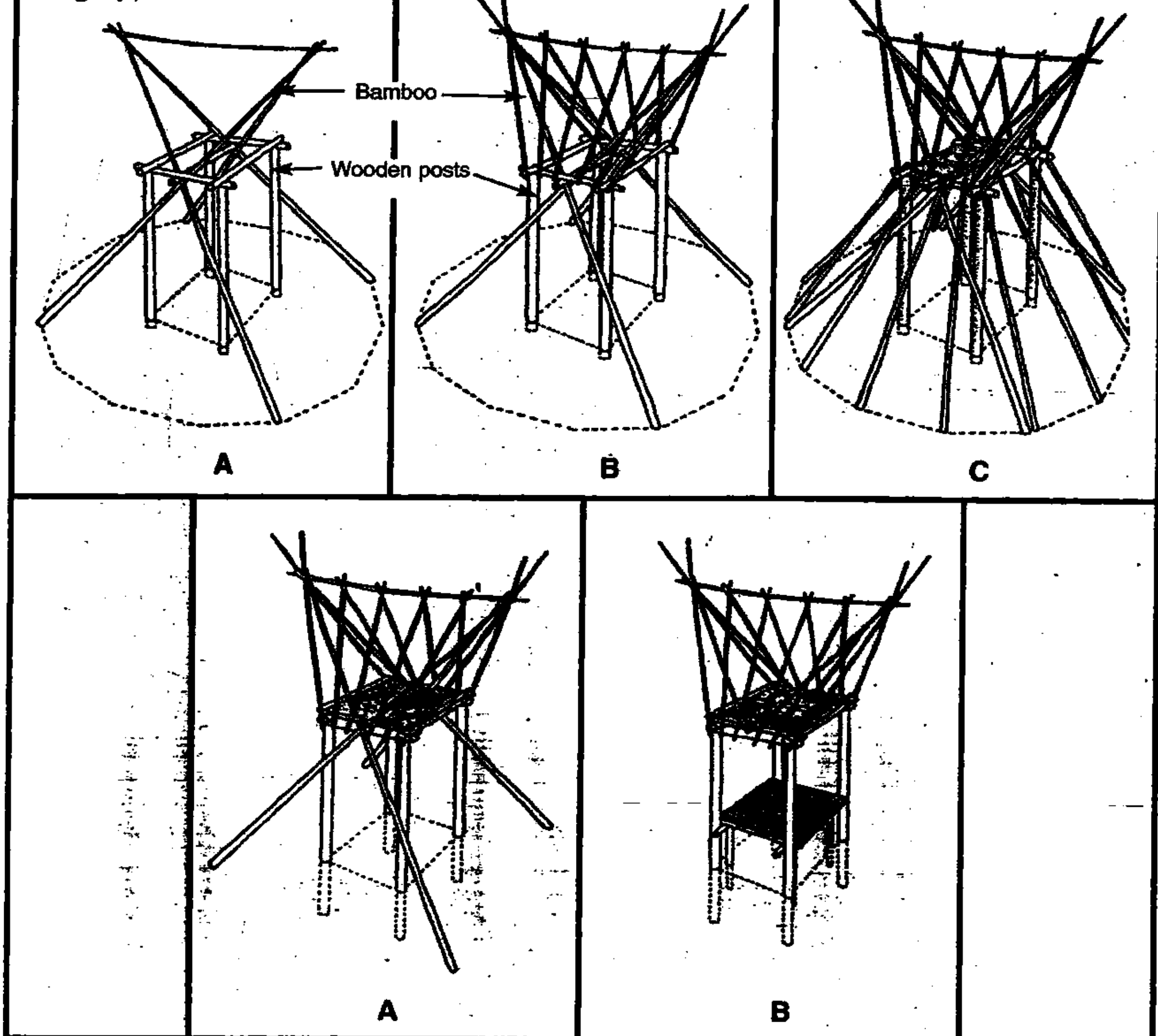


Different positions of wooden supports

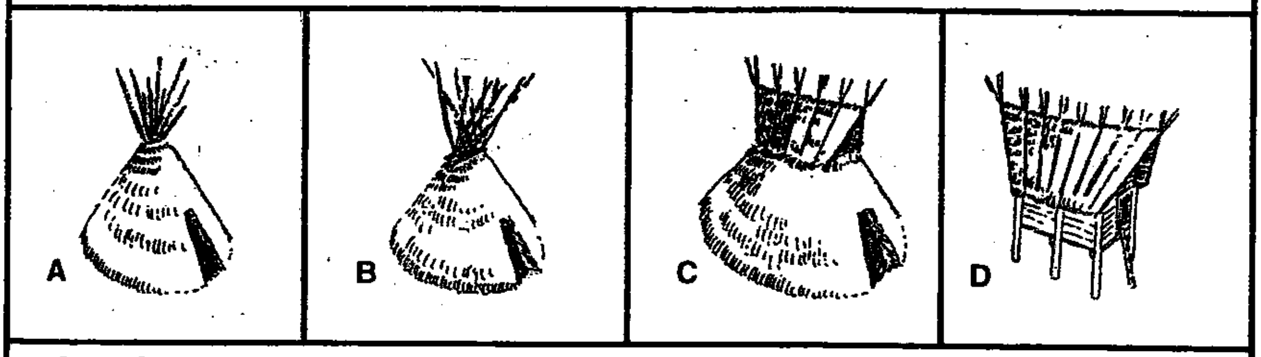
Source:G. Domenig, 1935

2 - EVOLUTION OF CONICAL ROOFS IN SOUTH EAST ASIA

Fig.24.7



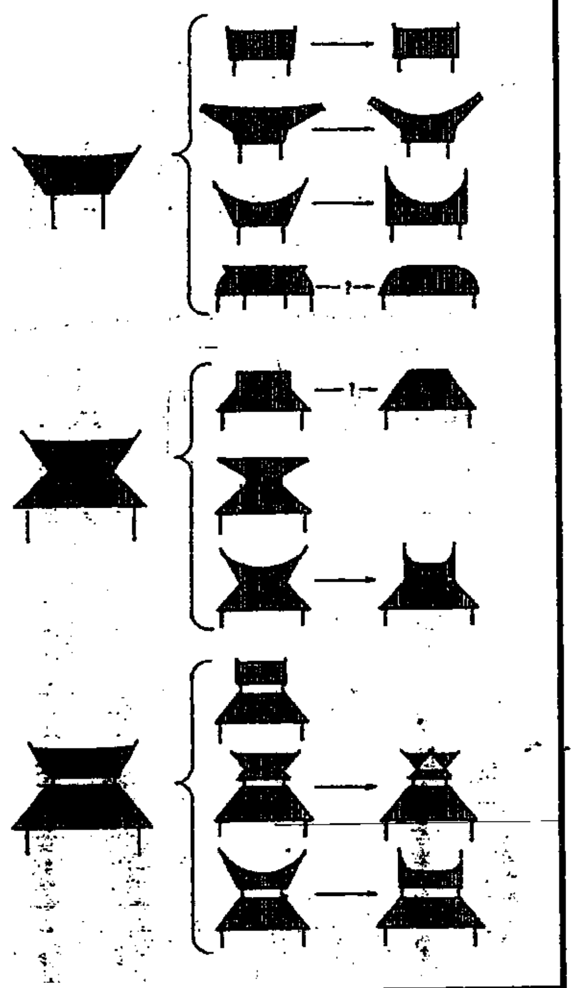
SOME FINAL RESULTS OF THE EVOLUTION (See page 401)

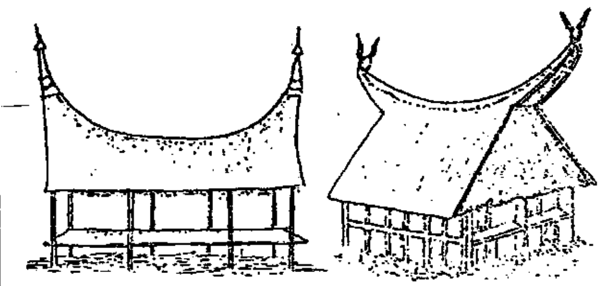


Source G. Domenig , 1935

Fig.24.9 BAMBOO ROOFS IN SOUTH EAST ASIA AND THE INFLUENCE OF BOATS ON THEIR ARCHITECTURE

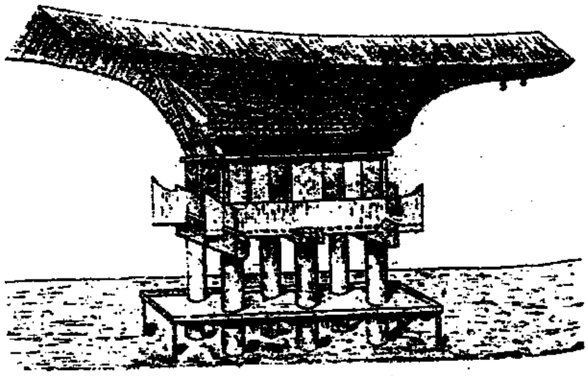
A. Traditional Types of Roofs





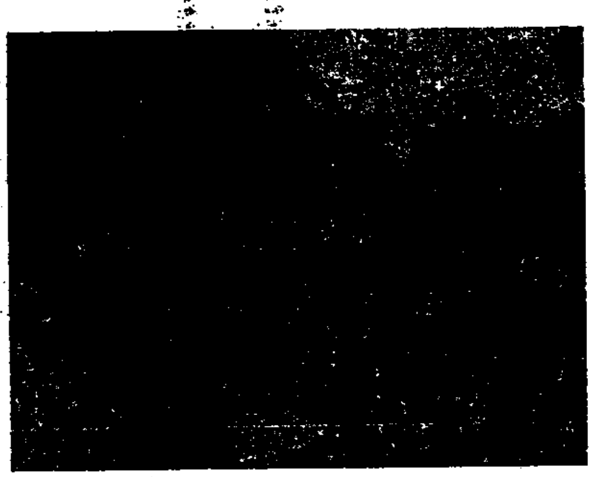
(1) (2)

B. *1)Pasemah house, Sumatra, Indonesia.*
2) Tamimbar house, Eastern Indonesia.



C. *Sa'dan-Toradja house, 1902.*

D. *Tana Toraja house, South Sulawesi.*

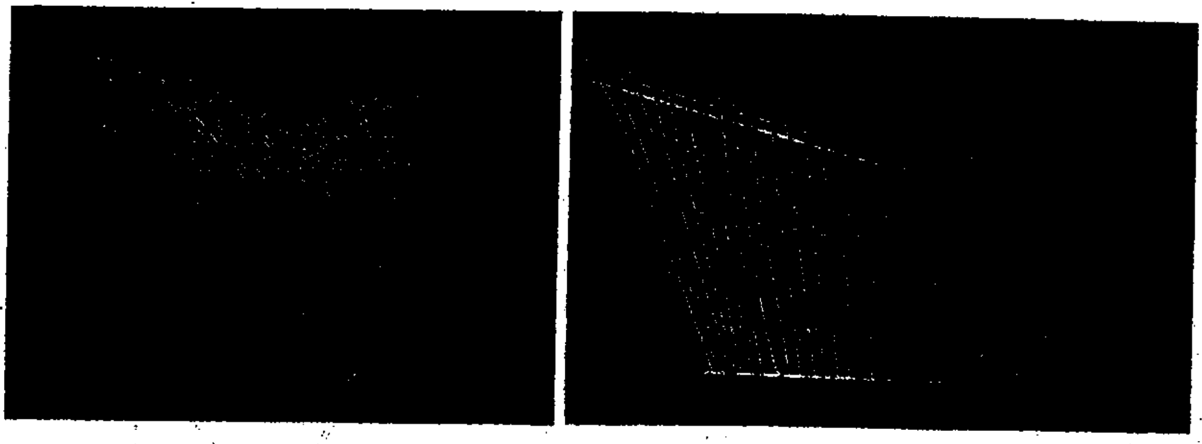


E. *Sa'dan Toraja house.*

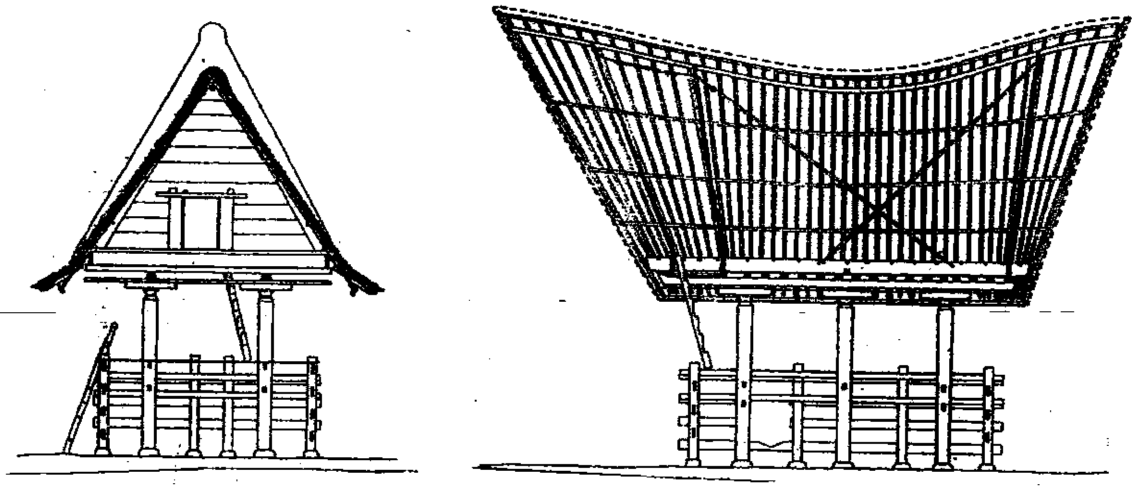
Source: G. Domenig, 1935

BAMBOO &TIMBER ROOF ARCHITECTURE (SOUTHEAST ASIA)

Fig.24.10 **A. Bamboo roofs with curved ridge**

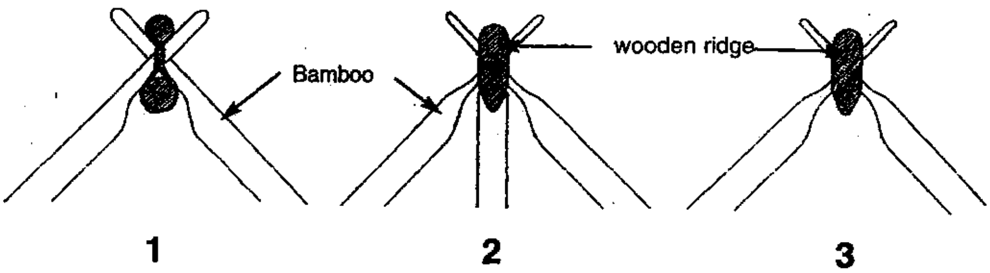


A *In this type of roof with a curved ridge, bamboo is used in the rafters.*



B *The whole roof is supported by wooden columns.*

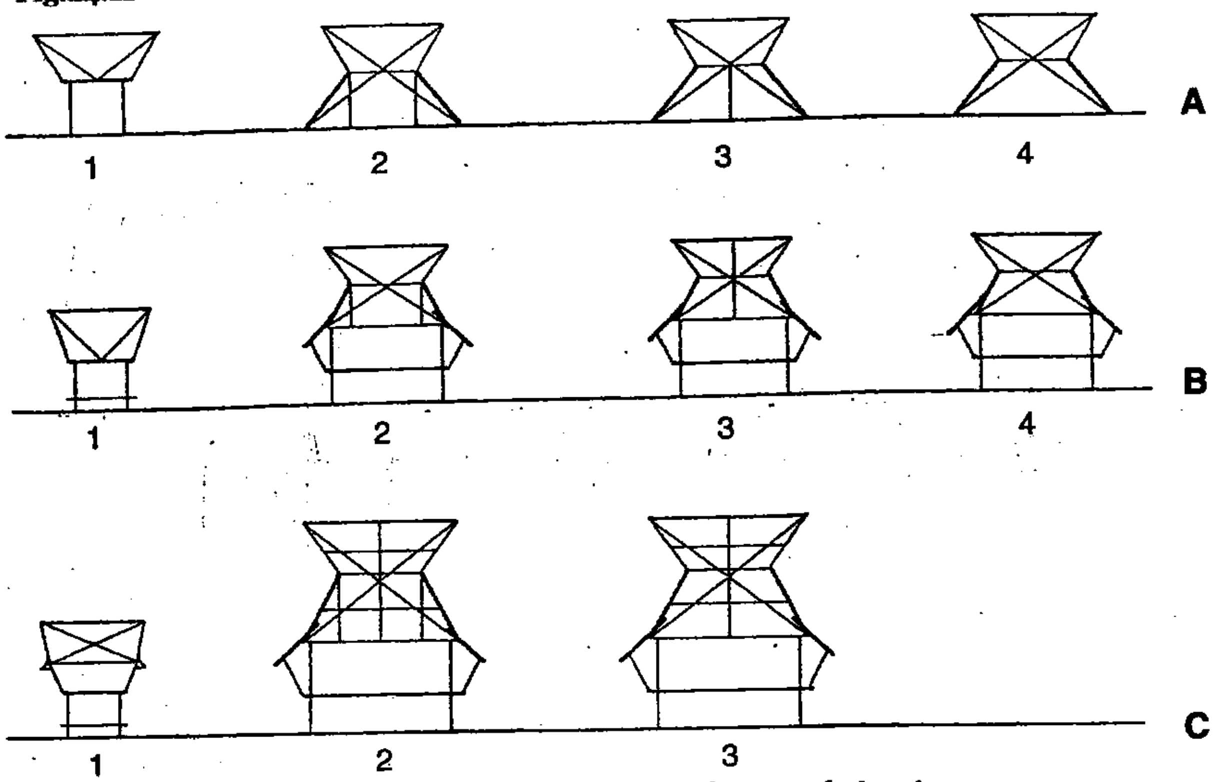
C JOINTS BETWEEN THE BAMBOO RAFTERS AND THE WOODEN RIDGE



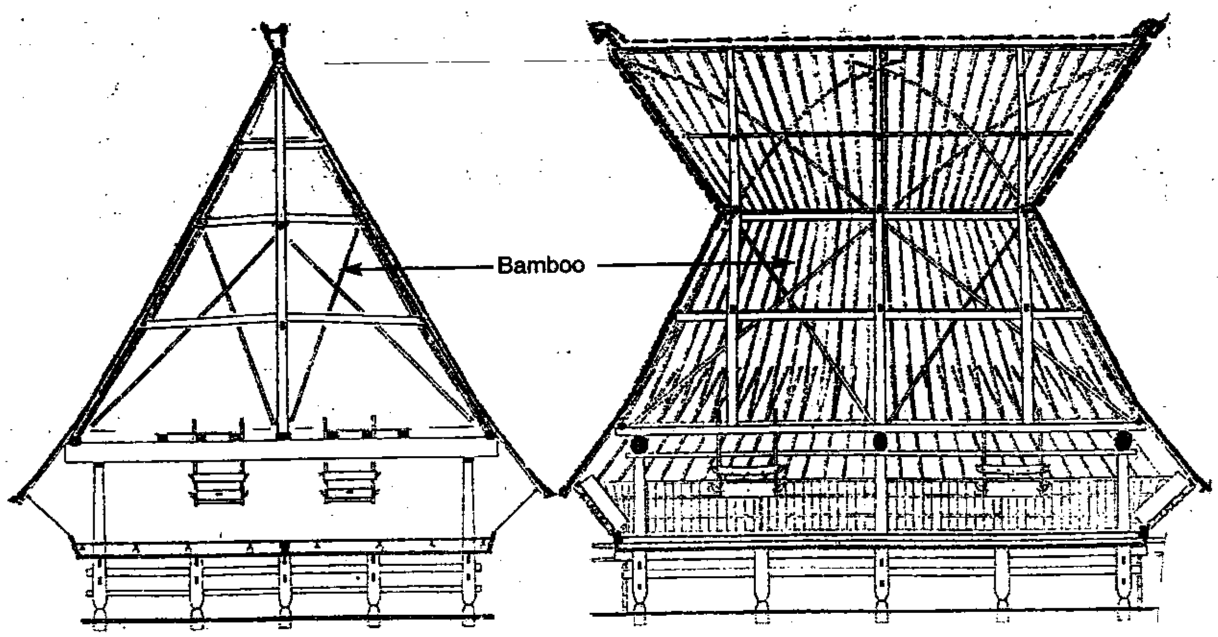
Source: G. Domenig, 1935.

BAMBOO ROOF ARCHITECTURE IN SOUTH EAST ASIA

Fig.24.11



Different types of timber and bamboo roof structures



Source: G. Domenig, 1935.

ROOF CONSTRUCTION IN INDONESIA -THE TORADJA HOUSE

Fig.24.12

Photo by Beckwith in F. A. McClure.

Fig.24.13

THE TORADJA HOUSE - CONSTRUCTION

In most of the countries and islands of South-East Asia, the main struture of the building and houses are built with timber, wood and palm stems, and bamboo is only used in the construction of roofs particularly as refters. Board of woven bamboo are used in the construction of interior and exterior walls.

According to Lewcock and Brans (1977), the influence of boats and boat building on houses and religious shrines can often be seen in the maritime societies of the world, In its most direct from this influence ranges from the re-use of old boat timber, producing unusual curves in the roofs of buildings, to the utilization of complete boats, or copies of them, as shelters on land.

In a technologically developed culture the influence of boats on building conflicts with the development of houses or communal buildings as integrated structures; in the latter the demands of use and construction at a more sophisticated level take precedence over the secondary use of old materials from boats, or reconstruction of them as roofs. In such circumstances, where a society's traditional links with the sea still extend to the urge to express them in buildings, conscious resort to symbolism is made.

An important feature of this type of building is that the huge overhanging gables at front and rear are not ussually supported by poles direct to the ground (even though the prow and stern of the stored boat frequently are) as though to emphaise that the superstructure is a complete form supported only in the platform at its base, the gables are often braced in a series of kingpost trusses, linked by one diagonal member in each gable.

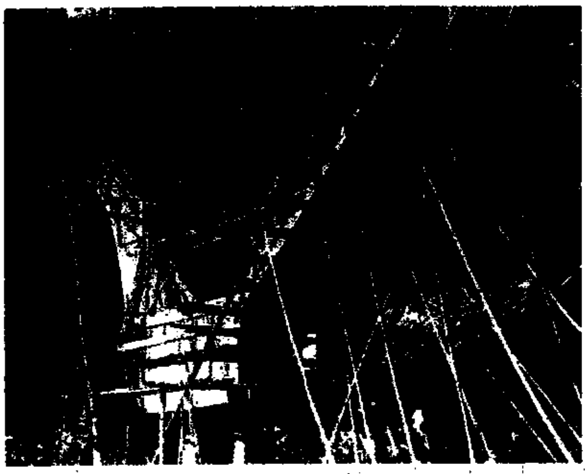


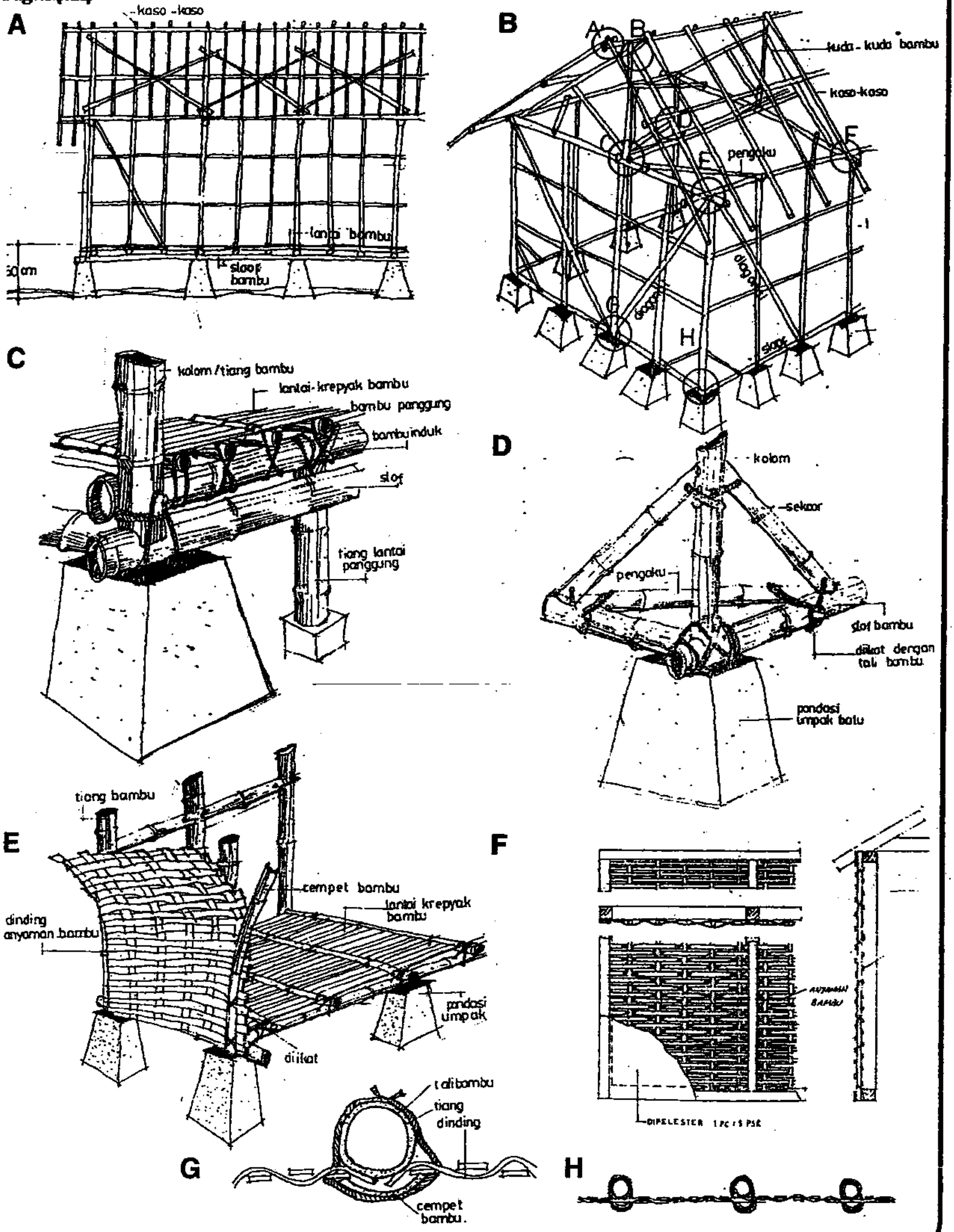
Fig.24.13 A *Construction of the Toradja house.*

Fig.24.13 B *In the Party for the Dead. Twenty to more than 100 kerbau are killed, along with many pigs. Hundreds of guests attend, staying in shelters constructed for the occasion. Tomokaka, the middle class, are accorded a three to six-day ceremony, with four to 10 kerbau and many pigs killed, depending on how much the family can afford. Tobuda, the lowest class, have a simple funeral ceremony lasting one or two days with one or two kerbau and a few pigs killed.*

Photo: Pamela Meyer

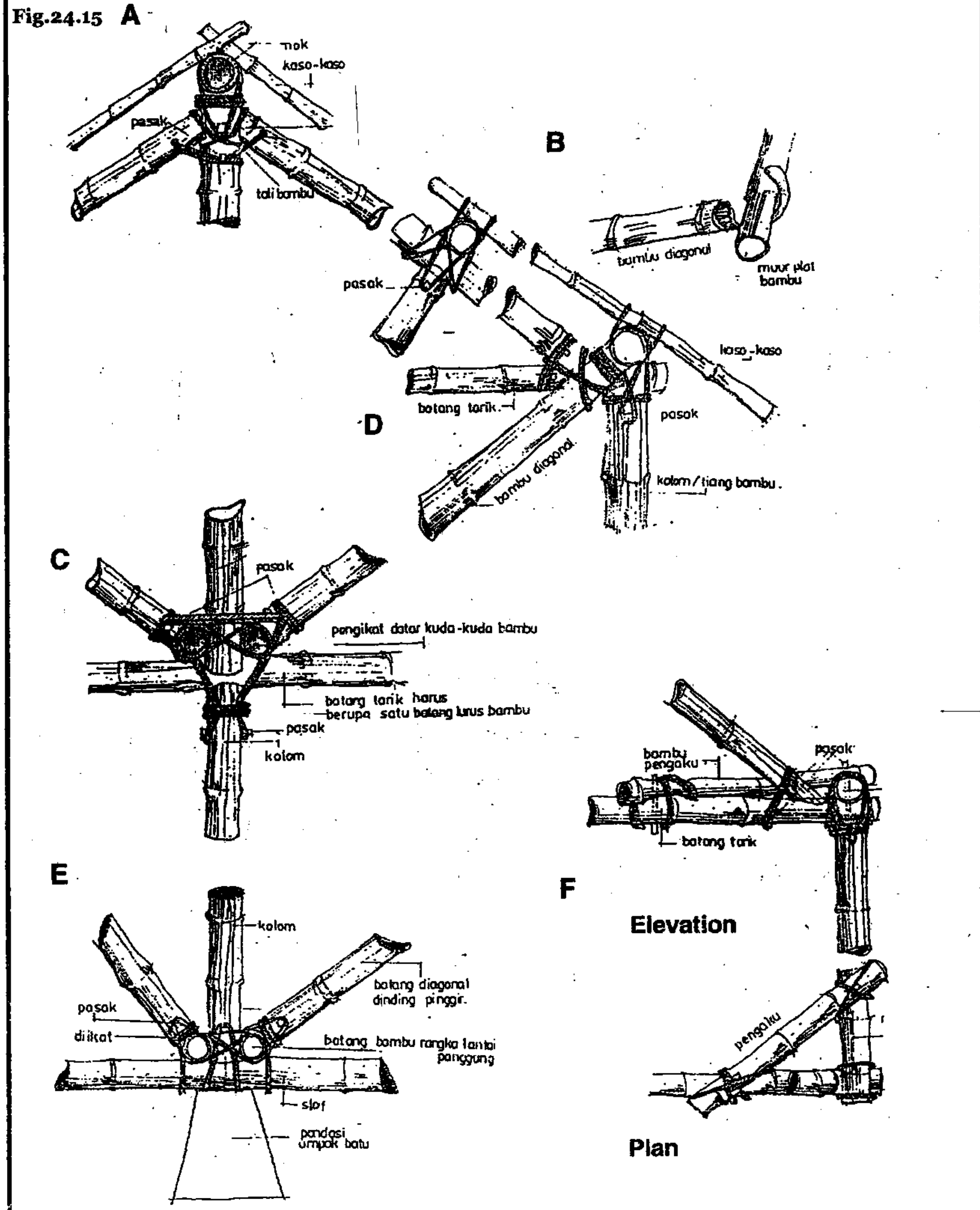
INDONESIA - TRADITIONAL BAMBOO HOUSE CONSTRUCTION

Fig.24.14



INDONESIA - TRADITIONAL BAMBOO HOUSE CONSTRUCTION

Fig.24.15



Source: Penyuluhan Pemugaran Perumahan Pedesaan. Pusam Penelitian Dan Pengembangam Pemukiman. Regional Centre for Research on Human Settlements.

ANCIENT BAMBOO ARCHITECTURE IN CHINA

Fig. 24.16 THE ANCIENT BAMBOO HOUSE

As I explained before, due to the low durability of most of the giant bamboo species of Southeast Asia, at present most countries in this area do not use bamboo for the construction of the main structure of their houses. It is used for the construction of the roof and it is transformed into weaving boards used in interior and exterior walls. In China, the whole structure, including the roof and walls are made of timber, although in many cases the walls are made of adobe reinforced with small diameter bamboo culms or with brick. However, in the past, the material most used in the whole construction of houses was bamboo, even in China, as shown in Fig. 24.16 A.

One of the best and most complete descriptions of the architecture of an ancient Chinese house, which probably belonged to a rich family and was built entirely of bamboo, was made by Violet-Le Duc (1876) in his book "Habitations of Man". In his description he includes the house plan and excellent perspectives where the beautiful construction details and the tastefully composed bamboo trellis work, which closed all the openings and allowed the air to circulate, can be seen.

Probably the most interesting construction details that can be seen in Fig. 24.17, are the bamboo Vierendeel truss in the porch of the house and the beautiful bamboo rigid frames of the main room (Fig. 24.18) which support its roof. These rigid frames were the beginning of the spatial structures.

Fig. 24.16 A *View of the ancient Chinese bamboo house.with huge roofs, made of thick bamboos, bent and covered with reeds ingeniously disposed, sheltered the interior from rain.(after Le Duc).*

Fig. 24.16 B **The House Plan**

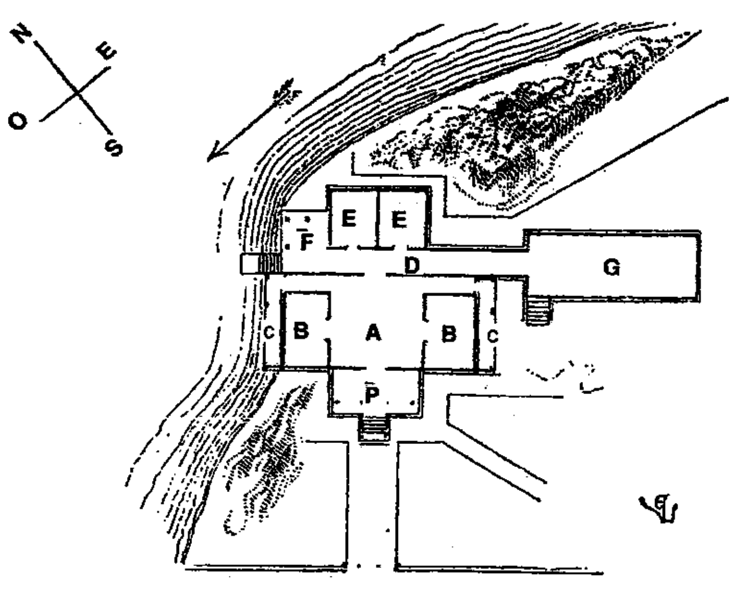
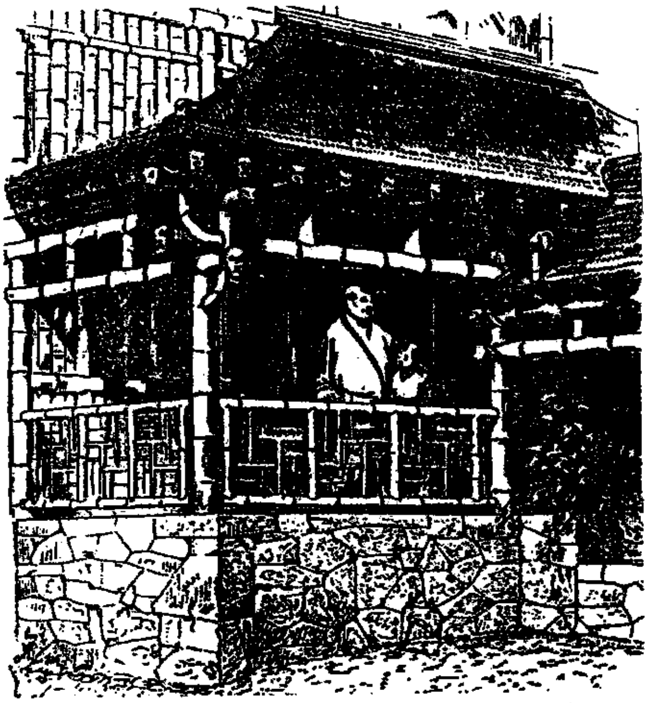


Fig. 24.16 B *The house consisted of a porch (P) raised a few steps above the ground (Fig.24.17). This very low and deep porch was the entrance into a main central room (A), which was lofty and lighted near the roof which covered it. This room opened onto two side rooms (B), which were very much lower in height, and narrow passages which led right and left to two covered balconies projecting on brackets (C). One of these overlooked the river. Behind this gallery, another wider one (D) led onto a terrace (F) to two small chambers (E) and to a long low building (G), allotted to the servants, kitchen and storage of provisions. A small landing stage descended from this terrace to the river to facilitate excursions on the water.*

THE PORCH (P) - DETAILS OF JOINTS AND VIERENDEEL TRUSSES



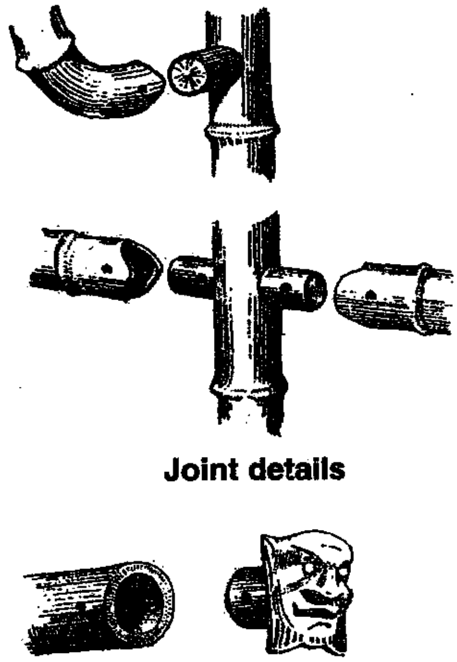
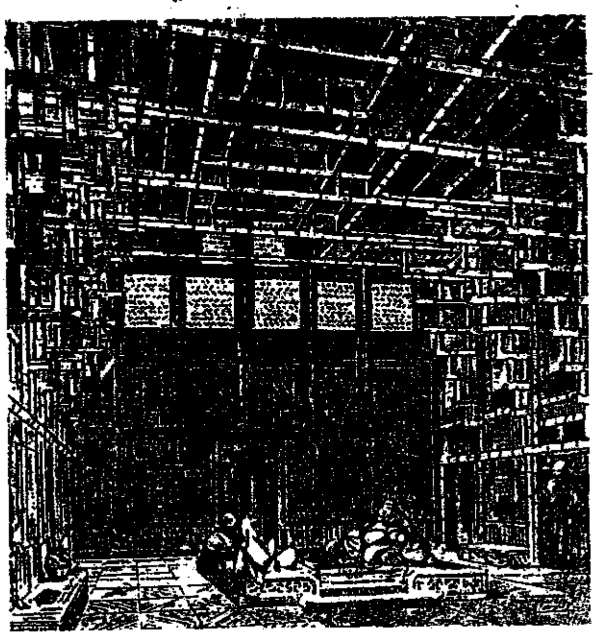
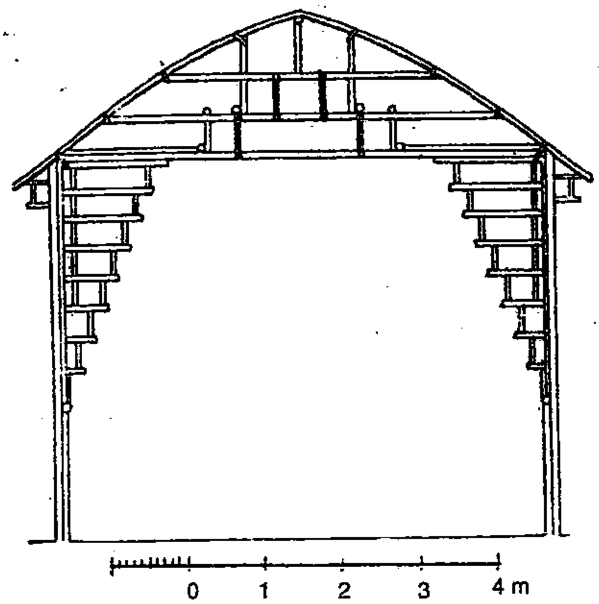


Fig. 24.17 *New structural forms such as the Vierendeel truss and different types of bamboo joints were developed in China in the construction of bamboo houses. Today bamboo is not used with this purpose.*

THE MAIN ROOM (A) -DETAILS OF THE BAMBOO RIGID FRAMES



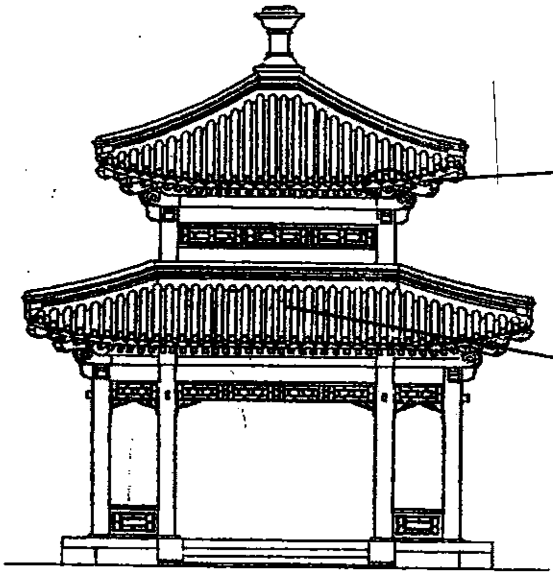


Chinese Bamboo rigid frame

Fig. 24.18 *With the invention of the rigid frames, larger main rooms were built in the Chinese homes.*

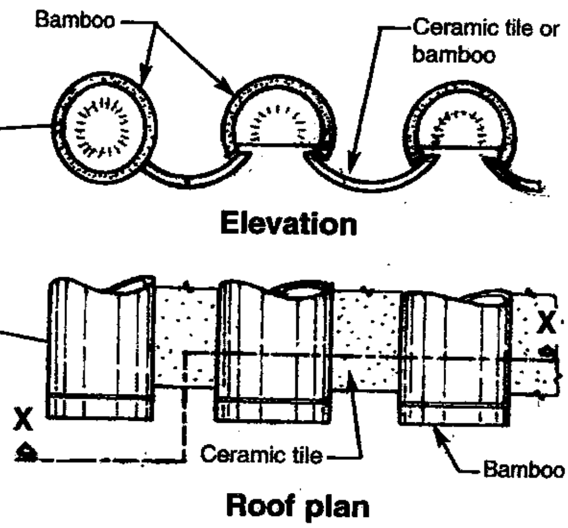
Fig.24.19

THE ORIGIN OF THE CHINESE ROOFS



A. *Elevation of the beautiful Chinese roof.*

Ancient bamboo roofs



B. *In the past, long giant bamboo sections were used for the cap and gutter. Later on, the bamboo gutter was replaced by a ceramic tile.*

C. *Today, the bamboo cap and gutter has been replaced by ceramic, an d the roof looks like a series of bent bamboo culms.*

ANCIENT BAMBOO ARCHITECTURE IN INDIA

The Hindu tradition is rooted in the Vedic Age, the period of Indian history that extends from about 1500 B.C. to 600 B.C. Chronologically, it is defined by the disappearance of the ancient "Indus Civilization" (which probably declined some time early in the second millennium B.C.) and the coming of the Aryan peoples.

Culturally, the designation "Vedic" indicates the dominant cultural and religious influence of India, and the creation of a body of literature, the Vedas, which has served to undergird every aspect of the civilization.

The Vedic Age was a time of fusion of different cultures and traditions. It started with the great Indo-Arian migration (toward the end of the second millennium B.C.) to north-west India, and which in the course of time laid the foundations of the Vedic Age. The Aryans were originally nomads who, on settling down in the plains of India, became partly pastoral and partly agricultural, having as their habitations rudimentary structures of bamboo thatched with leaves. It was not, therefore, from the fine houses forming the towns of the Indus Civilization, but from such rudimentary bamboo houses and the various simple expedients devised to meet the needs of the forest dwellers that Indian architecture had its beginnings. Its foundations were in the soil itself and from this aboriginal condition, it began its development (Brown 1912).

From a variety of sources it is possible to visualize the kind of building that the early settlers found suitable for their purpose. Considerable miscellaneous information is contained in the Vedas, those lyrical compositions which have been preserved through three milleniums, while ingenuous vignettes depicting the life of the times are carved in bas relief on the stupa railings of Barhut and Sanchi. In addition, there is the significant character of the subsequent architecture which reproduces in many aspects the type of structure from which it originated.

The building styles

According to Havell (1913), the principal Indian building styles may be roughly divided into three main periods, according to roof construction, which is the chief determining factor in the evolution of architectural style. The first period is that in which roofs were built with a bamboo framework; in the second period, the bamboo construction was reproduced more permanently in timber carpentry; and in the third period, the wooden construction was adapted to brick or stone. In all three periods, brick and stone were used to some extent in the substructure of the buildings. The introduction of stone building, in the third century B.C., has left an indelible mark on subsequent Indian architecture.

The same classification will serve to roughly indicate the buildings which belong to the three different strata of society. The first one represents the humble dwellings of the ryot and of the lower castes generally; the second, the houses of the well-to-do middle classes; and the third, the palaces of the rajah and of the nobility, military or civil state buildings, and temples or mosques.

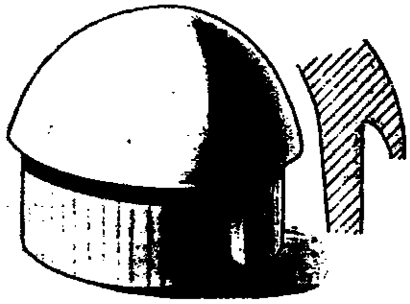
According to the same author, among the building laws laid down in Manasara, India, "Private houses or mansions may consist of from one to nine stories, but this is to be determined by the rank of the person for whom they are built. The lower castes must never construct their houses with more than a single story" (Havell 1913).

Most incredibly, in spite of all the limitations the lower castes in India had, they developed the best construction technology with bamboo that formed the roots of Indian architecture.

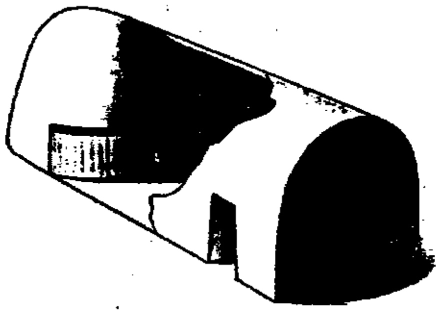
Fig. 24.20 *Vedic village showing the different types of roofs, the gateway and the fence which surrounded the village. All of them were originally built with bamboo. The roofs of the houses within the village enclosure were of various shapes, but at first, the circular ones predominated and they generated the bamboo domes. At a later date in the evolution of the Vedic hut, the circular plan was elongated and took on a rectangular form. This generated the bamboo barrel roof and several types of arches which in turn generated new types of vaults and cupolas. All of them were invented by the Vedas.*

EVOLUTION OF BAMBOO DOMES AND BARREL ROOFS

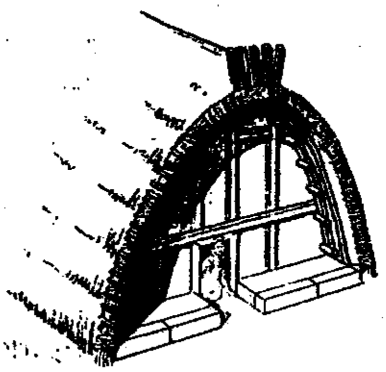
Fig 24.21 Evolution of domical roofs and barrel roofs



A. Domical roof (Sudama)

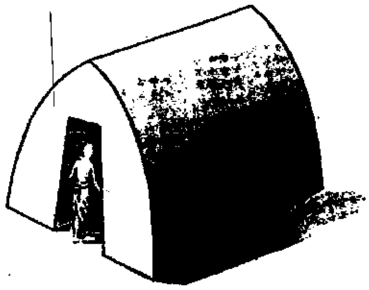


B. Barrel roof (Sudama)

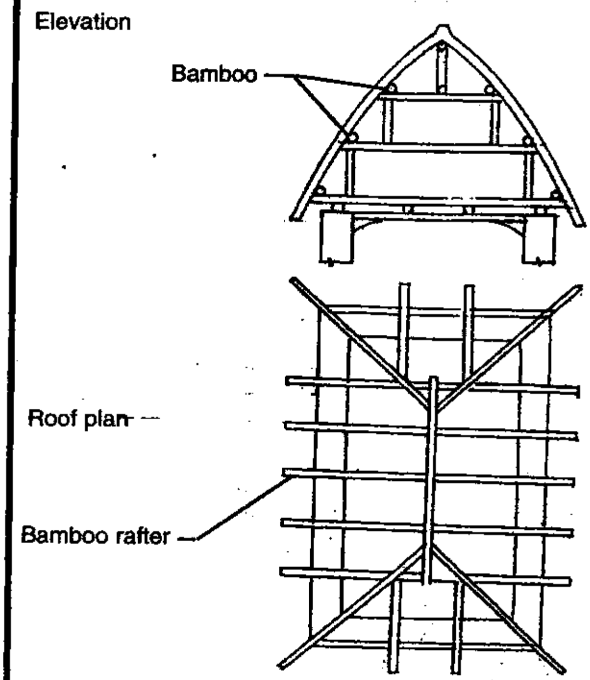


C. Bamboo barrel roof (Toda hut)

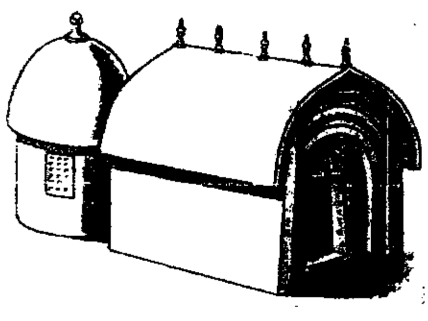
Fig.24.22 Evolution of bamboo roofs with semicircular pointed gables (ogival arch)



D. Ogival roof (Sita marhi)



E. Seven raftered bamboo roof (Bengal)



Lomas rishi

The shapes of the houses or cottages in the Bengal villages

According to Percy Brown (1912), the houses within a Bengal village were of various shapes, (Fig. 24.21 - 24.22) but it is fairly certain that at first those with a circular plan predominated. Those who have studied the origins of construction have remarked on primitive man's natural tendency towards rounded forms, giving as examples pots and baskets. In the case of the art of building, the foundations of the old city of Rajgriha in Bihar, which probably flourished about 800 B.C., indicate that circular buildings were then common.

Domical and barrel roofs

In the Vedic village, houses were built on the beehive pattern made with a circular wall of bamboos held together by bands of withes and covered either with a domical roof of leaves or thatched with grass (Fig. 24.21 A).

At a later date in the evolution of the Vedic house, the circular plan could not be increased in diameter (in the villages) so consequently it had to be elongated in one direction (Fig. 24.21 B). This developed into the rectangular plan with a barrel roof formed on a frame of bent bamboos covered with thatch; later on the thatch was replaced by planks of wood or tiles.

Vaulted roofs

One device to maintain the barrel shape of the roof was to stretch a thong or withe across the end of the bamboo arch like the cord of a bow, in a word an embryo of tie rod. This contrivance, tightened the chord of the arch and produced a shape resembling a lotus flower petal or a horseshoe, a type of archway commonly referred to as the chaitya or "sun window" (Fig. 24.25), which became characteristic of the subsequent architecture of the Buddhists. Such primitive shapes and expedients as the rounded hut with a heavy eave of thatch and the barrel roof with its framework of bent bamboos, all, in a greater or lesser degree, influenced the Indian architectural style.

The vaulted roofs of Asokan buildings, as sculpted in the Bharut and Sanchi reliefs, are all derived from bamboo prototypes. They are barrel shaped, with semicircular or pointed gables. This style, which may be called the Early Magadhan style, belongs to Bengal, a region in which bamboo, even in the present day, determines the structural character of village huts and also that of temple architecture.

It is necessary to explain that the peculiar double curvature given to these Bengali roofs and the drawing-out of the eaves at the four corners of the cottage are not mere freaks of the unpractical Oriental builder, but thoroughly scientific inventions designed for throwing off heavy rain. A thatched roof of the straight-lined European type could hardly be made water tight for a long time in the torrential monsoon rains of the lower Ganges valley. The same reason applies to the more permanent roof of brick and plaster, designed on similar lines (Fig. 24.26), used in the old temples and mosques of Bengal.

The lotus or horseshoe arch

The modern Bengali style of temple is the lineal descendant of the early Magadhan style. The form of the lotus-leaf or horse-shoe window or gable of the Asokan buildings is that which bent cane or bamboo naturally assumes. The elasticity of the latter is a valuable quality in roof construction which Bengali craftsmen were not slow to utilise, although there were ritualistic as well as technical reasons which commended this form to the Asokan builders.

The lotus-leaf arch symbolized the sun rising from the sea or from the banks of the holy Ganges River. The adoration of the rising sun has been from time immemorial, and still is, an essential part of all Indian religious ritual, and it agreed well with the joyous spirit of the early Buddhists to let the sun's first rays enter their houses and shine upon the images in their temples through these lotus-leaf windows and gables. Their vaulted roofs were first built with bamboo ribs of the same form; in the rock-hewn Buddhist chapter-houses of a later period we can see the bamboo ribs imitated in wood. When stone began to be used more extensively in building roofs, the difficulty of making such stone ribs for large size vaults probably lead to the trabeate building style, with terraced roofs taking the place of the early Magadhan method, except in the country of its origin, Bengal, where brick vaulting and arches came into use.

The lotus dome

The principle of ribbed dome construction continued, however, to be used for domes not built solidly of stone or brick. The lotus-leaf or bent bamboo arch became the structural basis of the lotus dome, known to Western writers as the "bulbous" or "Tartar dome". The earliest Indian domes; those of stupas or relic shrines, were approximately hemispherical in shape and built of solid brickwork; but when images of Buddha began to be placed under domed canopies supported by columns, such as we see sculpted on the facade of the great Ajanta chapter-house, the dome was necessarily a structural one and being so, would be constructed in the Magadhan country with bamboo ribs bent into a lotus-leaf or "bulbous" shape. The eight-ribbed Dravidian domes, such as are sculpted at Mamallapuran and Kalugumalai, are all reproductions of structural domes of this type built with bamboo or wooden ribs. The bell shaped dome is derived from the lotus or bulbous dome by adding eaves with an upward curve, which served the practical purpose of keeping the rain off the walls of the building.

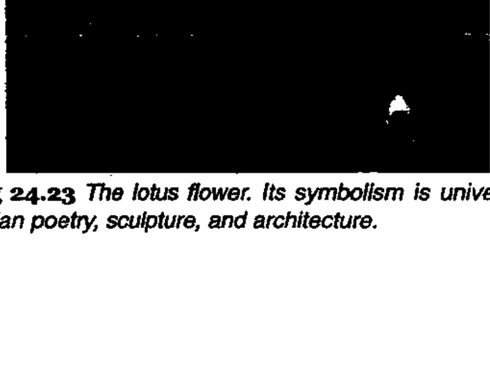
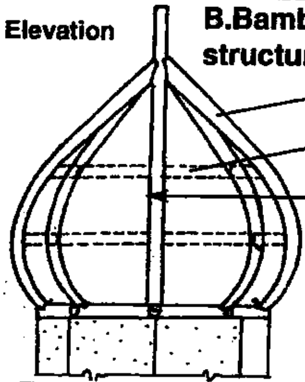


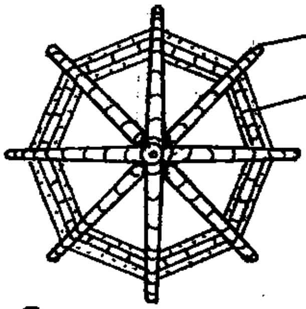
Fig 24.23 *The lotus flower. Its symbolism is universal in Indian poetry, sculpture, and architecture.*

Fig. 24.24 **THE LOTUS ARCH AND THE LOTUS DOMES**

B.Bamboo lotus or bulbous dome structure



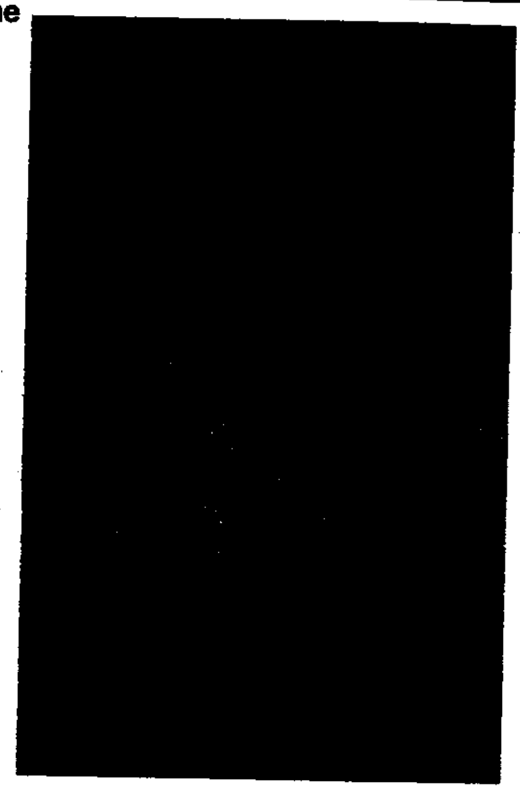
B. Elevation



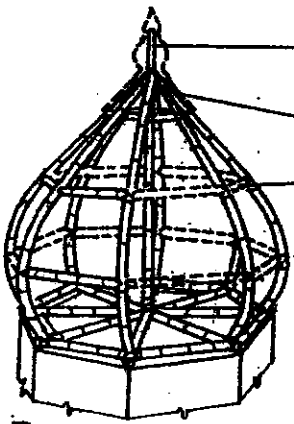
C. Plan

The bamboo lotus or bulbous dome is generated by the revolution of a Lotus arch around its central axis.

Regarding the shape which the bamboo culm takes when it is bent, see page 347.

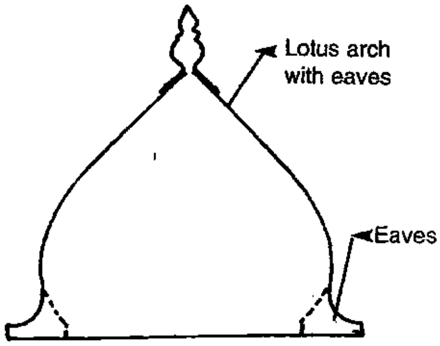


A. View of the Taj Mahal, one of the must beautiful buildings of India. Its stone cupola descends from the ancient bulvous bamboo cupolas or domes.

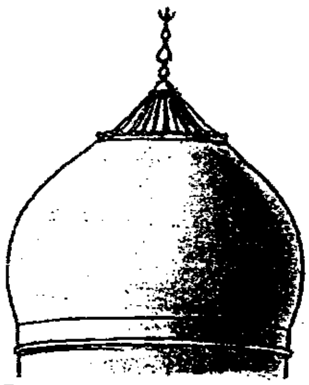


D. Perspective

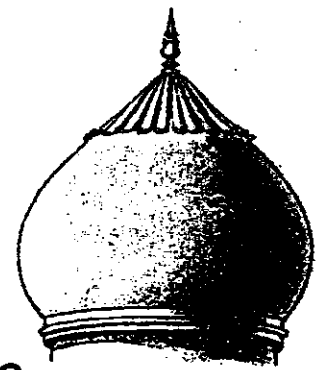
Types of "Mughal" domes derived from Bulvous bamboo domes



E. Bell shaped dome

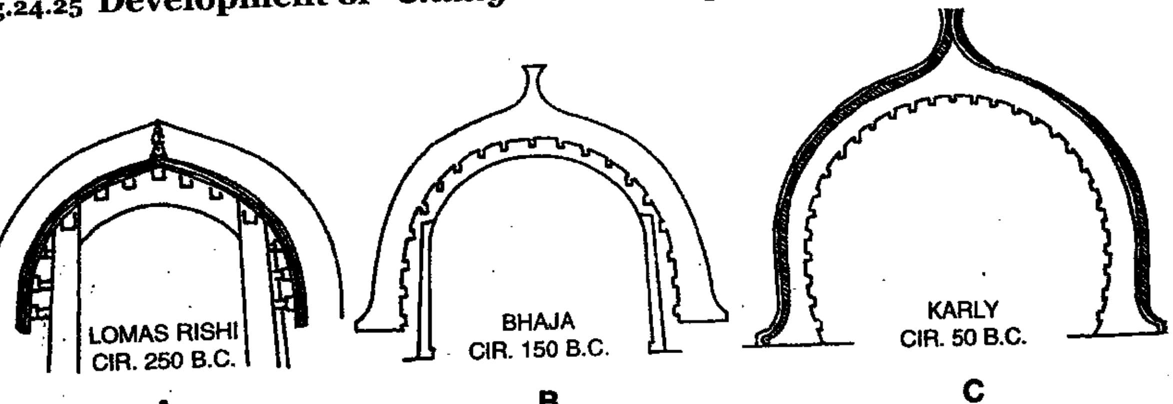


F. Taj Mahal- (Agra 1634)



G. Safdar Janos' Tomb Delhi, 1753 A.D.

Fig.24.25 **Development of "*Chaitya Arch*" originally built with bamboo**



The symbolism which the ancient Hindu craft canons, the Sipasastras, connects with the ornamentation of a dome is directly derived from the principles of bamboo construction. The ornament gave symbolic expression to the most vital parts of it.

In a primitive ribbed dome made with a bamboo framework, there are four essential parts which ensure the stability of the whole:

1) the pole or axis which must be firmly fixed either in the ground or upon a stable base such as an inner roof or dome; 2) the bamboo ribs; 3) the ties by which the ribs are secured to the pole at the springing of the dome; and 4) the cap which secures them firmly at the crown of the dome.

The lotus petals which invariably decorate the springing of an Indiam dome are placed just where the ties form a chakra, the wheel of Law to Buddhists and the symbol of the universe to all Hindus, and bind the ribs together at the base. The eight spokes of the wheel would be placed auspiciously by the master craftsman in the direction of the four quarters and four intermediate points. The cap at the crown of the dome, decorated by the Mahapadma the mystic petalled lotus or by the amalaka, resembled the nave of a wheel, the most sacred of symbols denoting the central force of the universe, the cause of all existence. Hence, the prominence which was given to this member by all Indian craftsmen, and the veneration with which the amalaka was regarded.

The water pot or kalasha containing a lotus bud, placed above the Mahapadma or the amalaka as a finial was the most appropriate symbol of the creative element and of life itself (Havell 1913).

The primitive lotus dome, translated into permanent materials, had many practical recommendations, for the form is one in which the outward thrust is reduced to a minimum. Hence, although in India, when stone began to be widely used in temple building, the system of building massive domes in horizontal courses largely superseded the Buddhist method, the earlier system used by Indian craftsmen continued in vogue in Persia and Central Asia where stone construction on a large scale never became general.

Havell (1920) points out that the symbolism of the lotus flower and leaf is universal in Indian poetry, sculpture, and painting. It is especially applied to the rising or setting sun, which is likened to a lotus flower floating in the cosmic waters. The similarity in the form of the dormer windows and gable-ends of Indian houses, when roofed with bent bamboo rafters, and the sun's disc as it touches the horizon was doubtless the reason why they were so extensively used as a decorative motive in early Indian art.

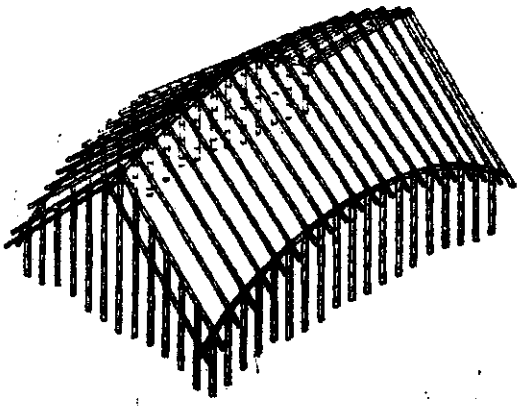
Arabian architecture, like most Arabian culture was derivative. The dome of the great mosque at Damascus, built early in the eighth century A.D., was certainly not an invention of Saracenic builders, or the first of its kind. The miniature stupa domes at Ajanta exhibit the same construction principle, though they themselves are only sculptors' representations of real structural domes, which had a bamboo framework and were probably built by the thousands in bamboo or wood by Buddhist temple craftsmen of the same and earlier periods, not only in India but wherever Buddhism was planted in Asia.

The original domes must have been hollow structural ones, first built on a bamboo or wooden framework. The only question is by what method such large size hollow domes could have been made structurally possible? Certainly bent bamboo ribs must have been used originally to produce the characteristic curve of the dome, just as they were used to form the lotus leaf arch, or window of early Buddhist buildings, and they are used in the roofing of bamboo and wooden Indian houses. The use of radiating bamboo ties, like the spokes of a wheel, is suggested in several of the earliest Indian stupas, e.g. the ancient Jain stupa found near Mathura; they would have been a necessary means of producing stability in bamboo structures of this kind, and the symbolism is peculiarly appropriate for a Buddhist shrine. An inner dome, such as is used in Persia (Iran), to serve as a support for the wheel and for the king-post to which the ribs of the dome were attached at the crown, is a natural development of the same structural principle. But that Persia (Iran) borrowed the lotus dome from India is certain, for bent bamboo in roof construction is a peculiarly Indian method. Its application to domes is clearly indicated in the domed canopy on the Sanchi gateway which is the prototype of the so-called Dravidian temple dome and also of the Ajanta stupa domes.

The name "lotus dome" was given by Indian craftsmen who worshipped the rising sun as the mystic world lotus and carved its petals at the neck (griva) and crown (mahapadma) of the dome. The Indian lotus dome is the technical modification of the primitive hemispherical dome of Mesopotamia, due to the use of bamboo and thatch. in India..

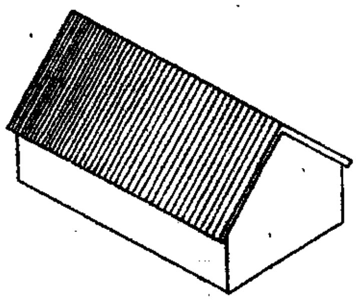
BAMBOO CURVED ROOF AND ITS EVOLUTION IN BAMBOO CUPOLAS

Fig.24.26 A. Type of roof known as "*dochala*" originally built with bamboo

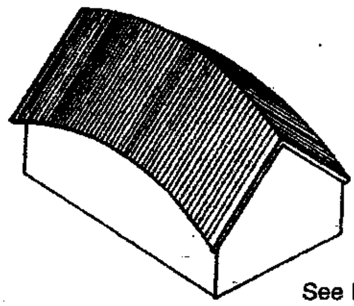


Bamboo structure

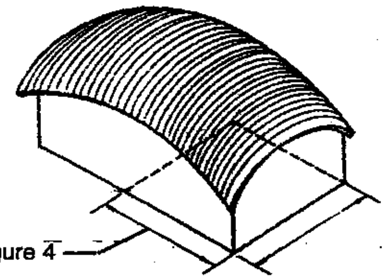
B. How I think that was the evolution from a bamboo peak roof to the vault rib



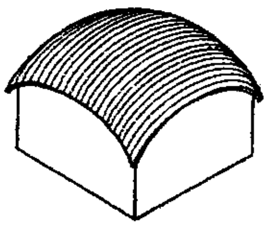
1.



2.-Dochala roof



3.-Chauchala roof



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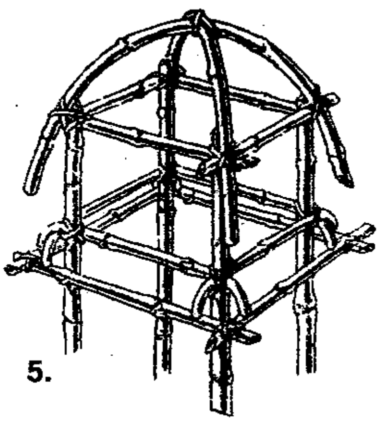

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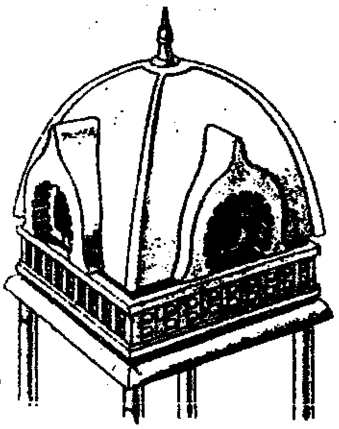


6.

1) Original bamboo peak roof with straight ridge.- 2) The stright ridge was curved and formed the "dochala roof"- 3) The straight gables of the dochala roof were curved and formed the "chauchala roof". 4) When the " chauchala roof " had a square plan" borned the "vault rib" was born. 5) and 6) construction of the bamboo vault.

In the same way, the curvilinear sikhara is the technical modification of the conical hut of Mesopotamian and Persian villages. In both cases, the forms were fully developed constructively in India many centuries before Indian craftsmen were pressed into the service of Islam and applied the same principle to the roofing of mosques in Arabia and Persia and eventually to mosques in India (Havell 1920).

According to Dani (1961), in India, Bengali architecture derives its basic form from bamboo, which has been rightly utilized by the people in erecting their dwelling houses thatched over with dry grass. It is on this bamboo style that wooden construction has been imposed by the higher classes; and both of these have in turn influenced the brick style in Bengal.

The Muslims came here with a set tradition, and they imposed their method of construction on the local people. It was only gradually that Muslim architecture felt the impact of local influence, which led to the evolution of a distinctive style in Bengal. However, the Muslims had to build using the available resources, and when these are fully analysed, we begin to understand the origins of Muslim architecture in Bengal. They can be understood under three headings: 1) architectural forms, 2) architectural designs, 3) constructional elements.

1) Roof types

In the Bengali villages, we can see bamboo huts with curved roofs and long drawn eaves. Bengalis, taking advantage of the elasticity of bamboo, employ a curvilinear form of roof in their dwellings (Fig. 24.26). The roofs take two shapes: a) *Chauchala* type, or that having four sides, and b) *Dochala* type, or that having two sides with gable ends and a central curved ridge (Fig. 24.26).

The curve of the roof is na-tural in the case of the bamboos, so much so that the Bengali eye became used to it, and this curvature appeals to their taste. This new form of bamboo roofs has had a most important influence on both the Muhammadan and Hindu styles when they were translated into brick or stone architecture during the Muslim period. This curvilinear form of roofs found its way in the 17th century to Delhi and in the 18th to Lahore.

The *chauchala* roof is seen as early as A.D. 1459 in the Sathgumbad Mosque at Bagerhat in Khulna district, and the dochala from the time of Shah Jahan. The curvature of the cornice and the parapet became common in A.D. 1415 -1432.

2) Architectural design

The peculiar Bengali design that developed in the course of time also takes its inspiration from the bamboo huts of Bengal. In these huts, there are two important features. a) The four corner posts of bamboo are tied together by long bamboo diagonals. It is on these posts that the main structure of the hut stands, the intervening space being screened by bamboo plates. In a like manner, the typical Bengali style that developed in the time of Jalaludding Muhammad (A.D. 1415-1432), translates these posts into corner towers, which are given prominence, and it appears that they are holding the building together. b) The second feature, which is derived from the same source is the variation given to the wall surface by alternate recesses and off-set projections just as we find in the wood and wattle-hut.

In order to emphasize the resemblance, the architect also provides a continuous molding in the middle of the wall, just as we find long bamboo poles in the middle of the hut at the level of the door lintel.

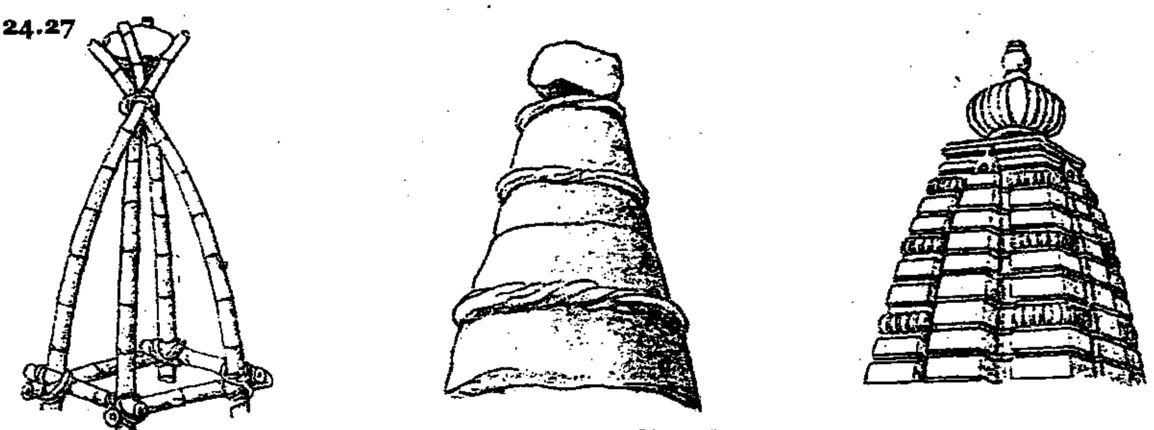
3) Constructional elements

It is very difficult to say what particular element is the special contribution of Bengal to Muslim architecture. Havell likes to attribute the pointed arch, the mihrab and the engrailing on the arches of Bengal, but these, except the last, are so common in the Muslim world that it is difficult to be dogmatic on this point.

However, the adherence to the two-centered pointed arch springing from the side pillars appears to have a natural counterpart in the bamboo original, where the tying together of two bamboos tightly produces this form. Similarly, the type of barrel vaulted roof seen in the Gunmant Mosque and Fami Masjid at old Malda, recalls the bamboo shed so well-known in the boats of Bengal. The engrailing, as seen in the mihrab of the Adina Mosque, is the earliest of its kind in Muslim architecture.

But the most important feature of Bengal's contribution is not the addition of new elements to Muslim architecture, but rather the adaptation of the existing Muslim elements to the taste and tradition of Bengal.

Fig. 24.27



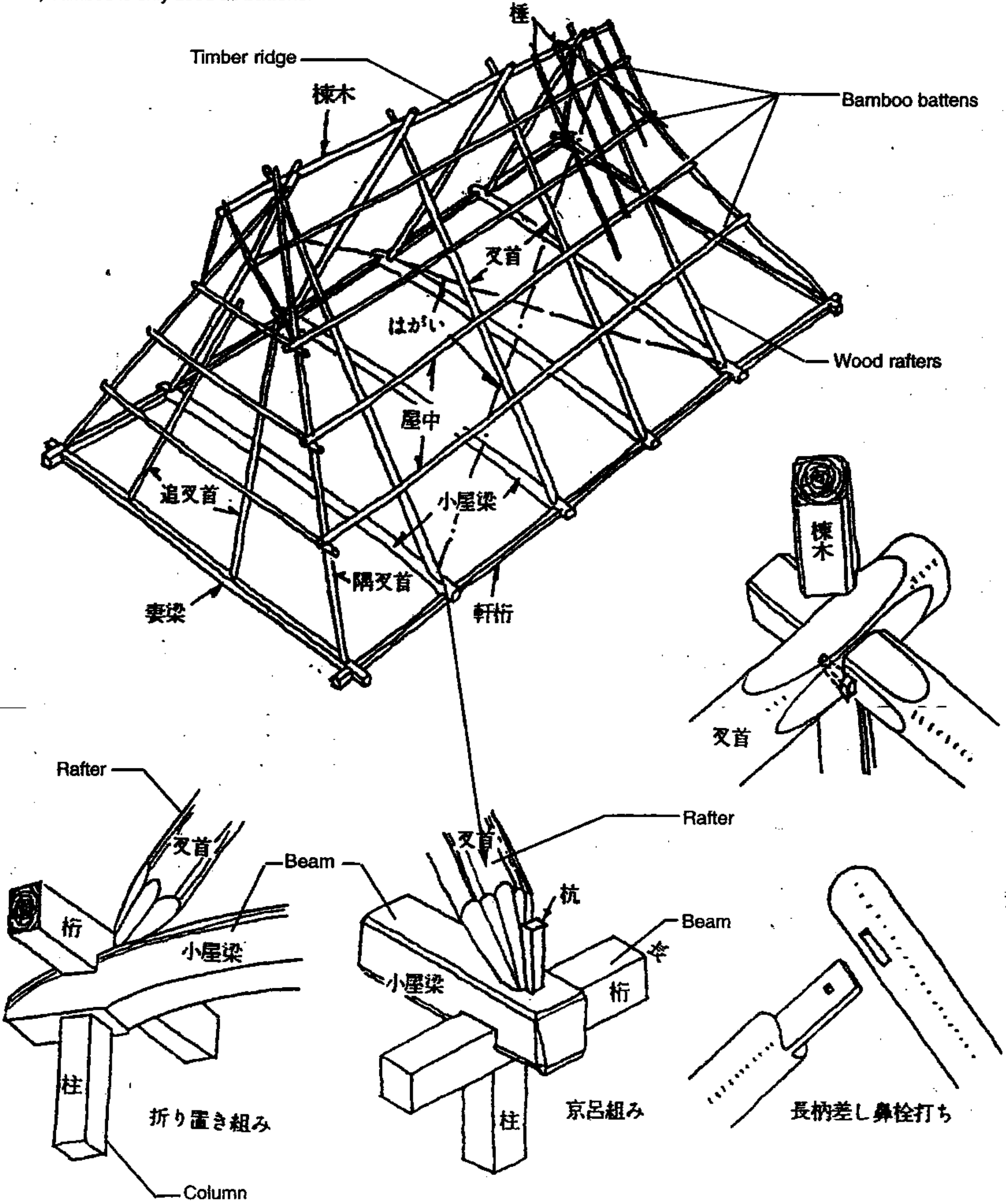
Suggested construction of early Sikhara

"Steeple" of a Toda "Church", Ootacamund, South India

Finished structure

Fig. 24.28 TRADITIONAL JAPANESE ROOF (TIMBER & BAMBOO)

In the traditional japanese roof structure, bamboo is only used as battens.



Details of wooden structure

PART 9

Application of Bamboo in Different Fields of Engineering

Bamboo bridge (Riou's drawing)
Geografia Pintoresca de Colombia in 1869.

23 BAMBOO IN THE FIELD OF AERONAUTICS

THE USE OF BAMBOO IN THE CONSTRUCTION OF AIRPLANES

In this section we shall shortly see some ancient and modern bamboo applications which, directly or indirectly, were precursors of the greater inventions in the field of aeronautical engineering. They are:Bamboo kites which were undoubtedly the beginning of aviation; bambooairplanes; bamboo rockets and the black powder which were the key to space travel, but also to destructive weapons.

Kites and gliders

The rise of aeronautical engineering in the 19th century depended fundamentally upon the study of an apparatus, which was Chinese in origin and unknown in Europe before the 16th century, namely the bamboo kite.

Kites of bamboo, fabric, or paper have been used in China, Indonesia, Melanesia and Polynesia since ancient times. In some of these countries, kite-flying was practiced as a religious funtion connected with the gods. In China, bamboo kites were used by the military forces for signalling. Large kites had the capacity to carry human aeronauts aloft to spy on the enemy. By 1906, it was possible for a man to remain for an hour at a height of 2600 feet, suspended by two trains of kites (Needham 1963).

There are differences between kites and airplanes. The lift of the kite is provided by an airstream of wind, while that of the airplane's wing is provided mechanically by its propeller. Nevertheless, in 1907, Cody fitted a 12 hp.engine to one of his modified man-lifting kites and flew it without a pilot. The kite played a very important role in aeronautical engineering, particularlyin the the development of gliders and airplane wings.

The most famous builder of gliders was Otto Lilienthal who, between 1891 and 1896, made close to two thousand brief flights in sixteen different glider designs, which were based on his aerodynamic investigations. Most were monoplanes with stabilizing tail surfaces mounted at the rear. Lilienthal also tried a few biplane and folding designs, but the original monoplane glider, or Normal-Segelapparat (standard sailing machine) as he called it, produced the best results.

The gliders had split willow frames covered with cotton-twill fabric sealed with collodion to make the surface as airtight as possible. Collodion is a viscous solution of nitrate cellulose in a mixture of alcohol and ether that dries to form a tough elastic film. The wings ranged in area from ten to twenty square meters and could be folded to the rear for easier transport and storage. Control was achieved by shifting body weight, since the pilot was cradled vertically in a harness suspended between the wings. Lilienthal's gliders were the ancestors of the first gliders built in modern times with bamboo. See Fig 25.2

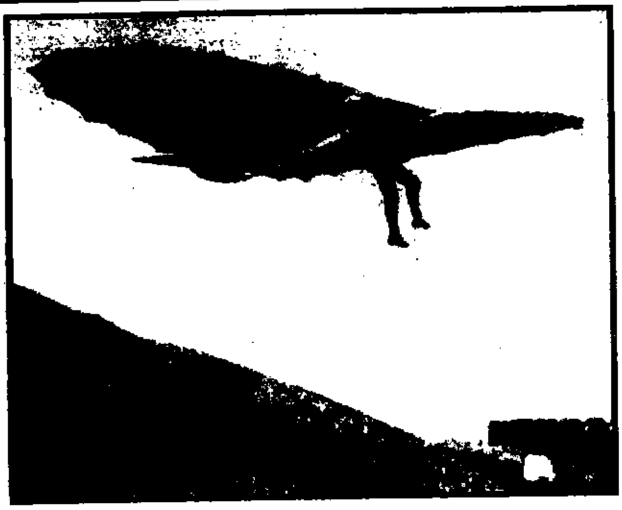


Fig.25.1 *The first glider. Lilienthal gliding in one of his standard monoplanes, and using weight shifting to balance the craft.*

Fig.25.2 *The construction of modern gliders in the decade of 1the 1960's was iniciated using bamboo for the construction of the main structure but there were problems for joinning tension members.*

According to Needham (1965), in 1893, the Australian Lawrence Hargrave invented the box-kite for greater stability and lift. Normally, two cells were connected by booms to form a tandem frame, and it was this which inspired mostof the biplane builders during the first decade of the twentieth century.

The use of bamboo in the first airplanes.

Because of its high strength-to-weight ratio, bamboo has long been associated with aeronautical engineering. In 1907, Santos-Dumont built the first airplane with a bamboo structure. In 1908, Cody and others built bamboo frame flying machines.

According to Opdycke (1987), initially, bamboo and wood were used for airframes, with steel or aluminum fittings at the connections. Bamboo was used as spars or struts only. The frame was braced internally and externally against stresses in all directions.

Bamboo worked fairly well for some spars if it was braced with struts and wire.The joints in the cane were weak and were often bound with tape and glue; sometimes the partitions were reamed out and wooden dowels inserted to stiffen the cane.

Metal fittings of cast aluminum had to be used for joining bamboo to woodstruts or to other bamboo and for anchoring the wire bracing. Struts, usually upright in the airstream, were soon made of wood, usually spruce, instead of bamboo. The reasons that bamboo struts were replaced by wood struts were:

1) The problem that bamboo has for making joints, especially tensile joints.

2) The problem that occurs when green (just cut) bamboo struts are tied to metal fittings with wire. Once the bamboo strut dries, it shrinks and the tie becomes free and can produce many accidents.

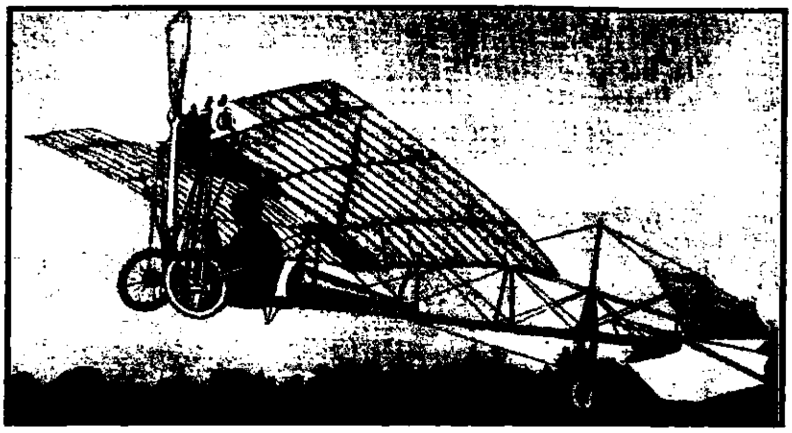


Fig. 25.3 *The first flying test of the Demoiselle in 1909 (Folia de Sao Paulo, maio 1996).*

***Demoiselle,(or Dragon-fly).* the first airplane with a bamboo structure built by Alberto Santos-Dumont.**

In 1907, in Paris, Santos-Dumont built the first Demoiselle model with the number 19. The structure was built with bamboo brought from China covered with silk and painted. It was powered by a 20 Hp motor weighing 22 kg. It was 8 meters long with 10 sq. meter wings and a wing-span of 5.10 meters. The totalweight was 56 kg. Due to the problems that he had with the small motor and with the dimension of the propeller, he decided to build a new airplane with a bigger motor and a longer propeller. In this plane, the pilot sat just behindthe engine. The new Demoiselle (No.19 bis) had the same type of bamboostructure, and the same wing-span but shorter by 6 meters. It was powered by a30 Hp Darracq 1.800 rpm water cooled engine, weighing 50 kg. In this model, theengine was located above the wings. This airplane flew 200 hundred meters at aheight of 6 meters.

The Demoiselle was considered to be the smallest, lightest, and most powerfulairplane yet built and was widely copied and flown by other aviators because Santos Dumont never patented any of his designs. The plans of the *Demoiselle* were published by *Popular Mechanics* in the United States in 1910. The plans of this airplane are included in this section.

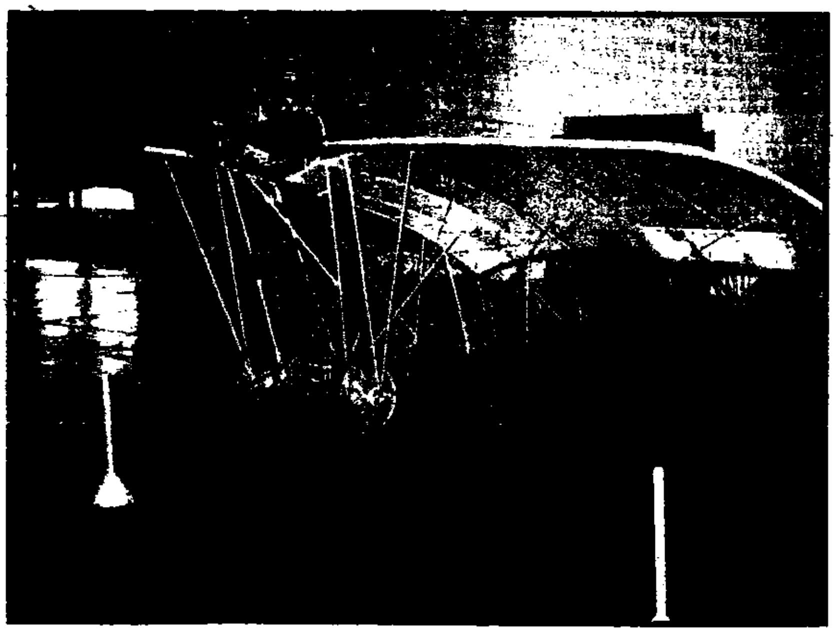


Fig. 25.4 *Reproduction of the Demoiselle or Dragon Fly ,the first airplain with bamboo structure built by Alberto Santos-Dumont in Paris in 1907. This reproduction is found in the Aeronautic Museum of Rio de Janeiro.*

The use of bamboo in the dirigible balloon of Santos Dumont

Alberto Santos Dumont achieved his first successful flight in his Number 1 dirigible in Paris on September 20, 1898, in a craft powered by a small motor-cycle engine. This little power plant drove his No 1 along quickly enough in relation to the day's light breeze that he could steer the craft in the chosen direction. This first dirigible, was designed around the engine, which was cylindrical with cones at the front and the rear, 82 feet in length and 11 feet in diameter, with a gas capacity of 6350 cubic feet.

A silken rudder was added at the stern and a system of shifting weights hanging at the end of ropes fore and aft was added to tilt the dirigible up or down. The engine swung a2-bladed propeller at a sprightly 1200 rpm. Suspended from the envelope was a lightweight girder kell supporting the small bamboo control basket which accommodated the pilot, engine, tanks, pusher propeller and triangular rudder.

However, it was his No 6 of 1901 that brought Santos-Dumont real fame. It had the shape of an ellongated ellipsoid and was 100 feet long by 20 feet thick with cone shaped ends. He installed a larger compensation balloon (2118 cubic feet) inside the gas bag with a connecting tube to draw air from the propeller blast. Three automatic valves were added to keep the gas bag from exploding. Suspended from the envelope was the bamboo bridge.

In it he won the 100,000 franc prize offered by M. Deutsch de la Meurthe, a weathy member of the Aeroclub, for a flight of about 11.3 km (7 miles) from the Parc d'Aerostation at St. Claud, around the Eiffel Tower and back.

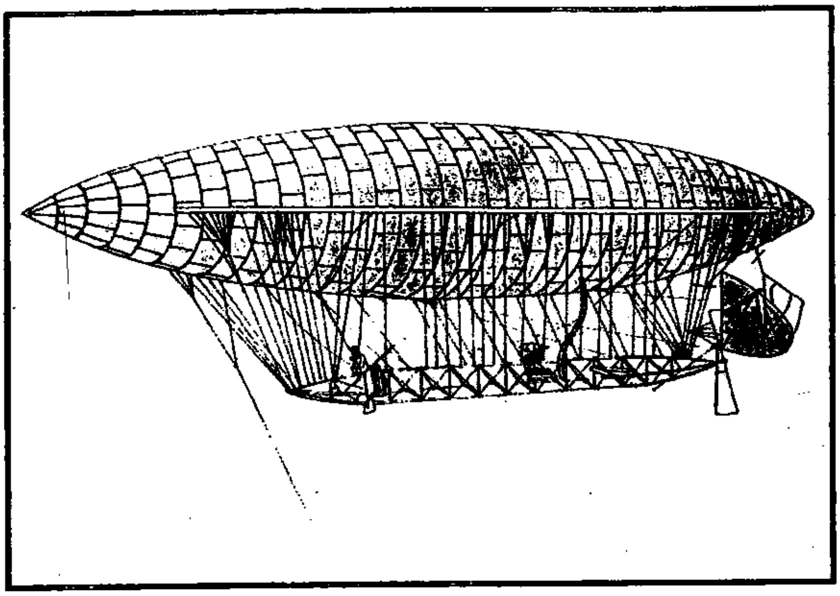


Fig. 25.5 *The completely practical airship was born when Alberto Santos-Dumont(1873-1932) fitted it with a gasoline engine for the first time in 1898. He built 14 airships, of which the one illustrated is typical and gained worldwide fame on October 19, 1901, when he flew the sixth one around the Eiffel Tower in Paris. The structure of the bridge was made of bamboo.*

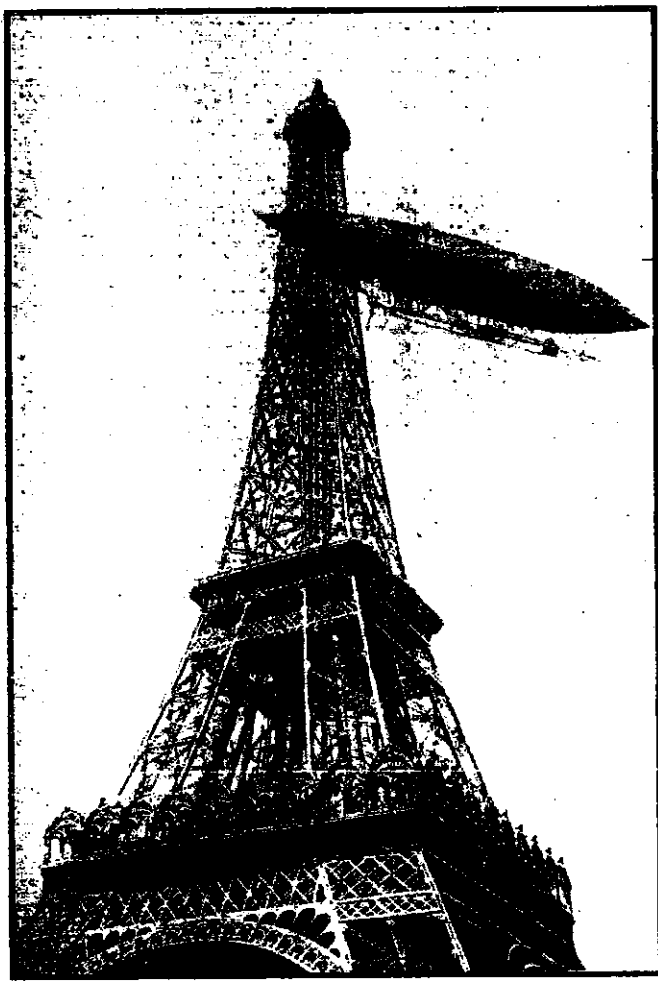
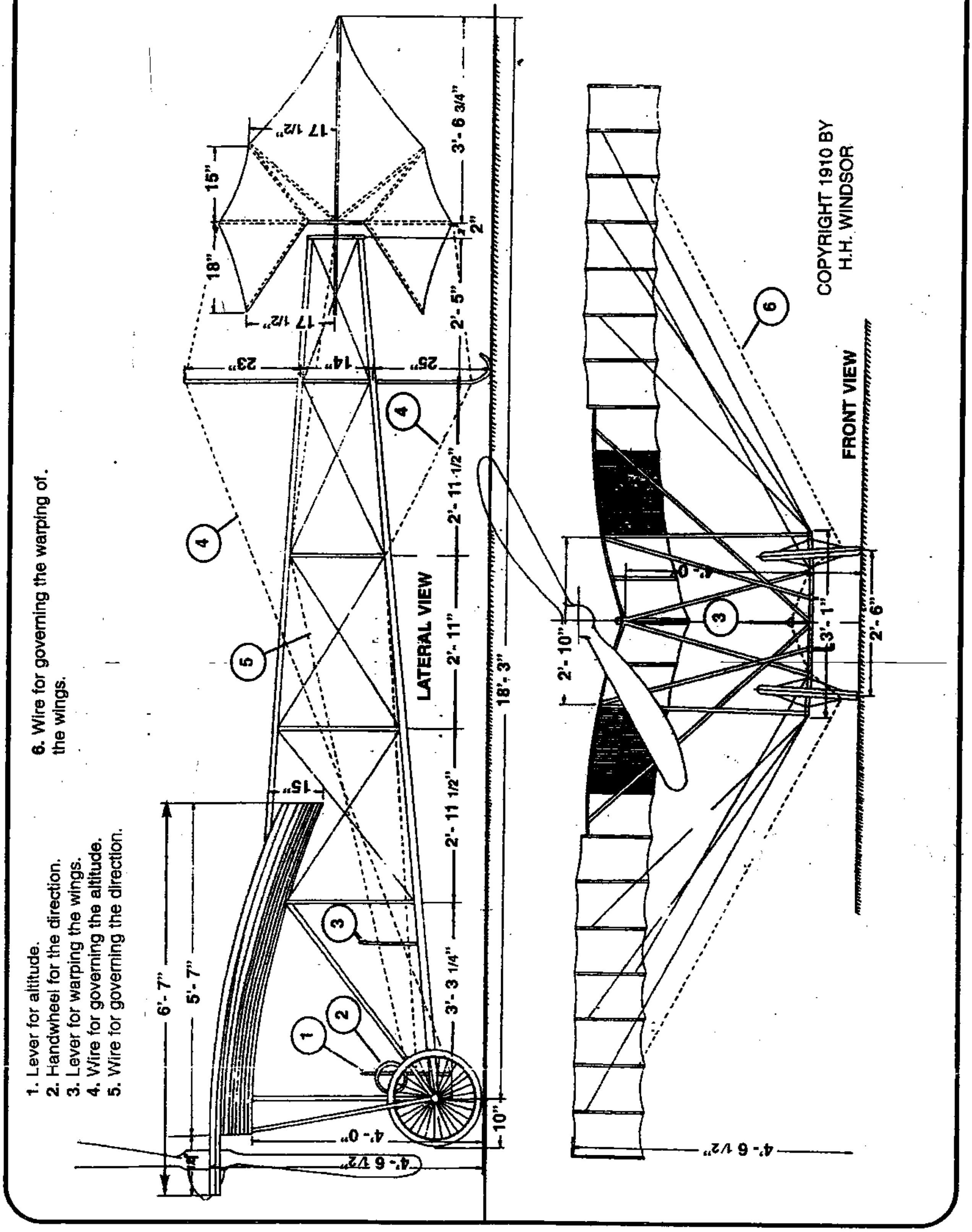


Fig. 25.6 *Santos-Dumont used bamboo not only in the construction of the Demoiselle airplane, but also in the twowinged airplane known as the 14 Bis, in the construction of a helicopter, which besides the structure had 2 propellers made of bamboo, and in the construction of most of the bridge structures of the 14 models of dirigibles that he built and tested, such as the No. 4 and 6 that can be seen in the photograph flying near the Eiffel Tower in Paris in 1906.*

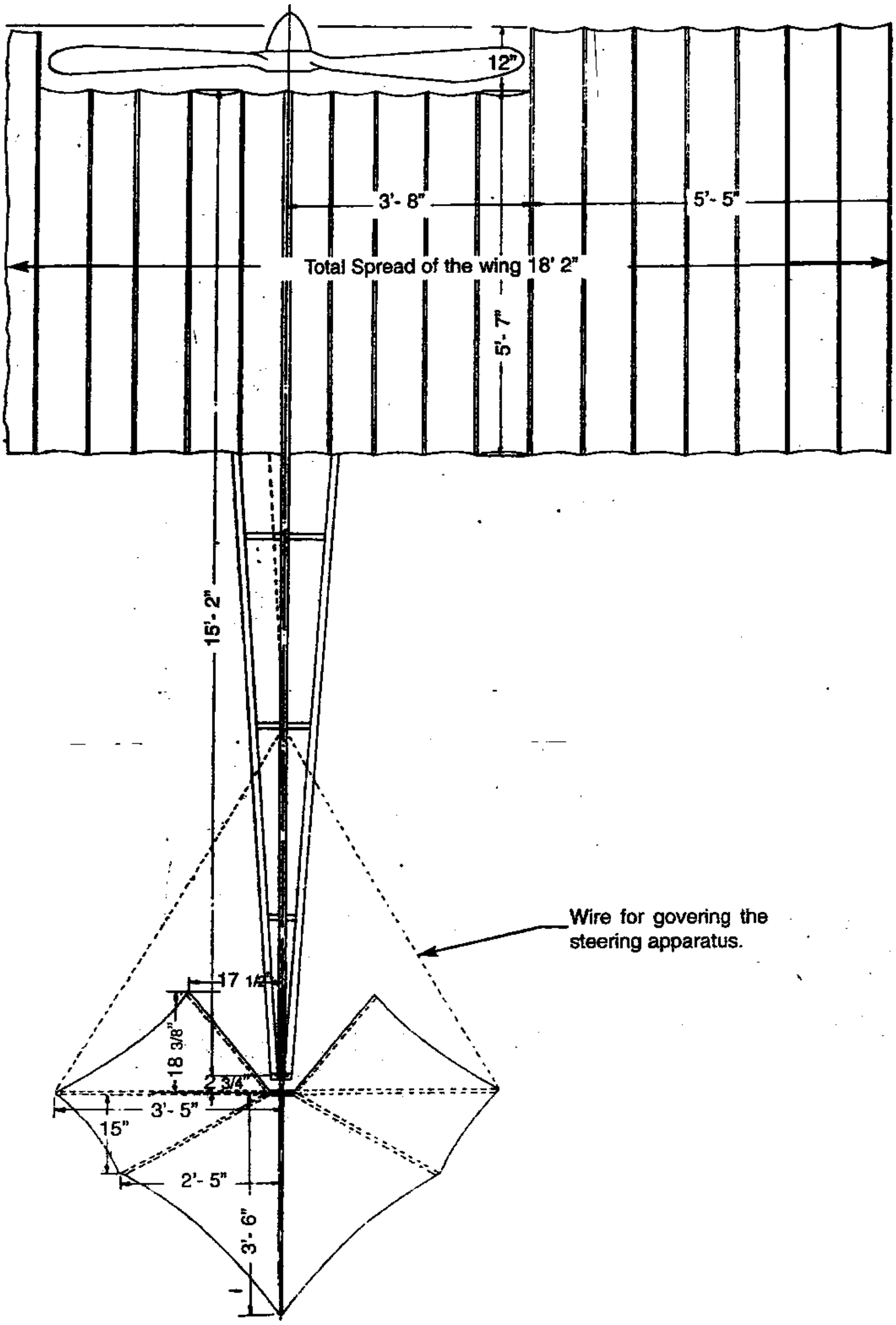
THE "*DEMOISELLE*" SANTOS-DUMONT'S MONOPLANE - (1)

Fig.25.7 LATERAL AND FRONT VIEW



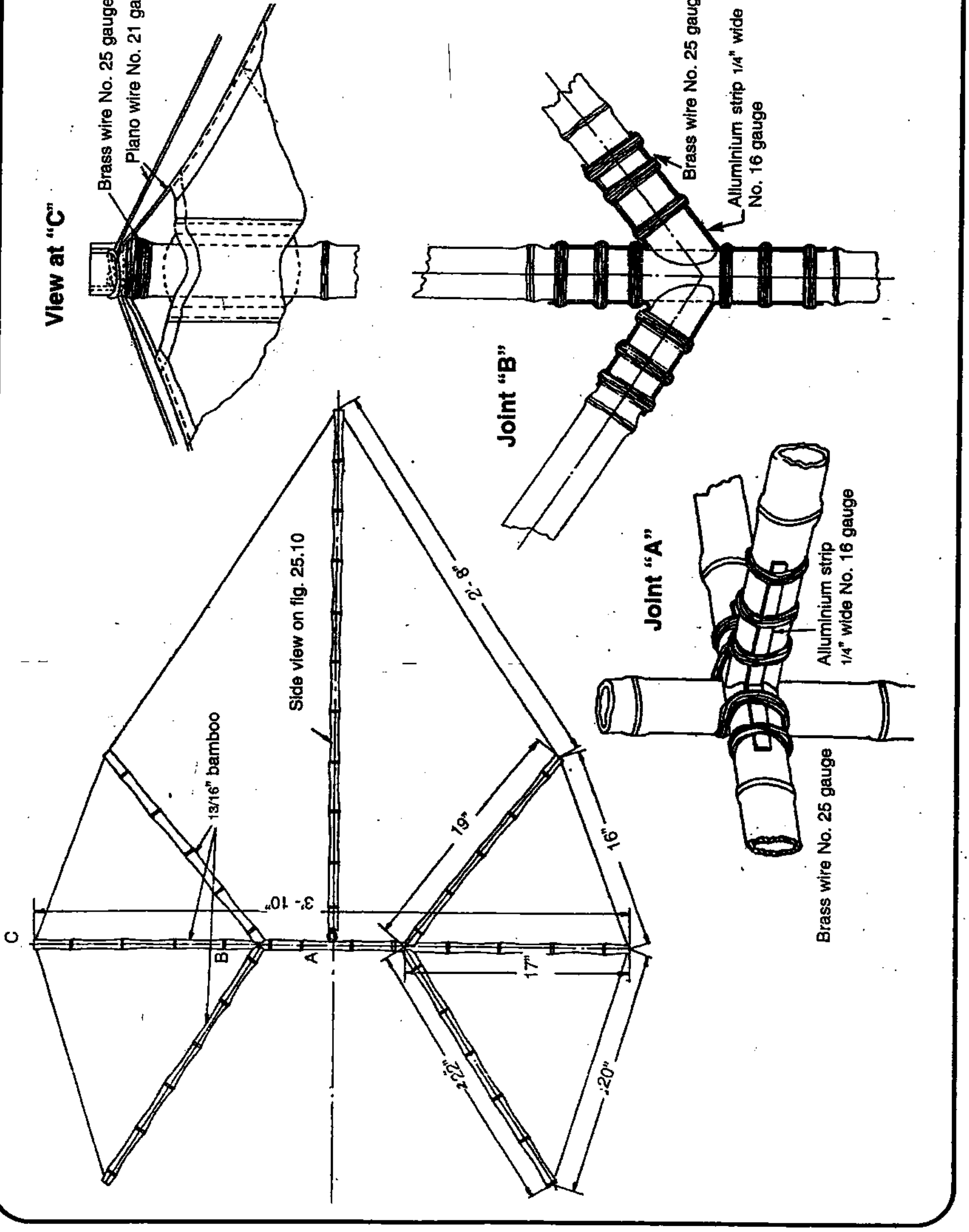
THE " *DEMOISELLE* " SANTOS-DUMONT'S MONOPLANE - (2)

Fig.25.8 - PLANT VIEW



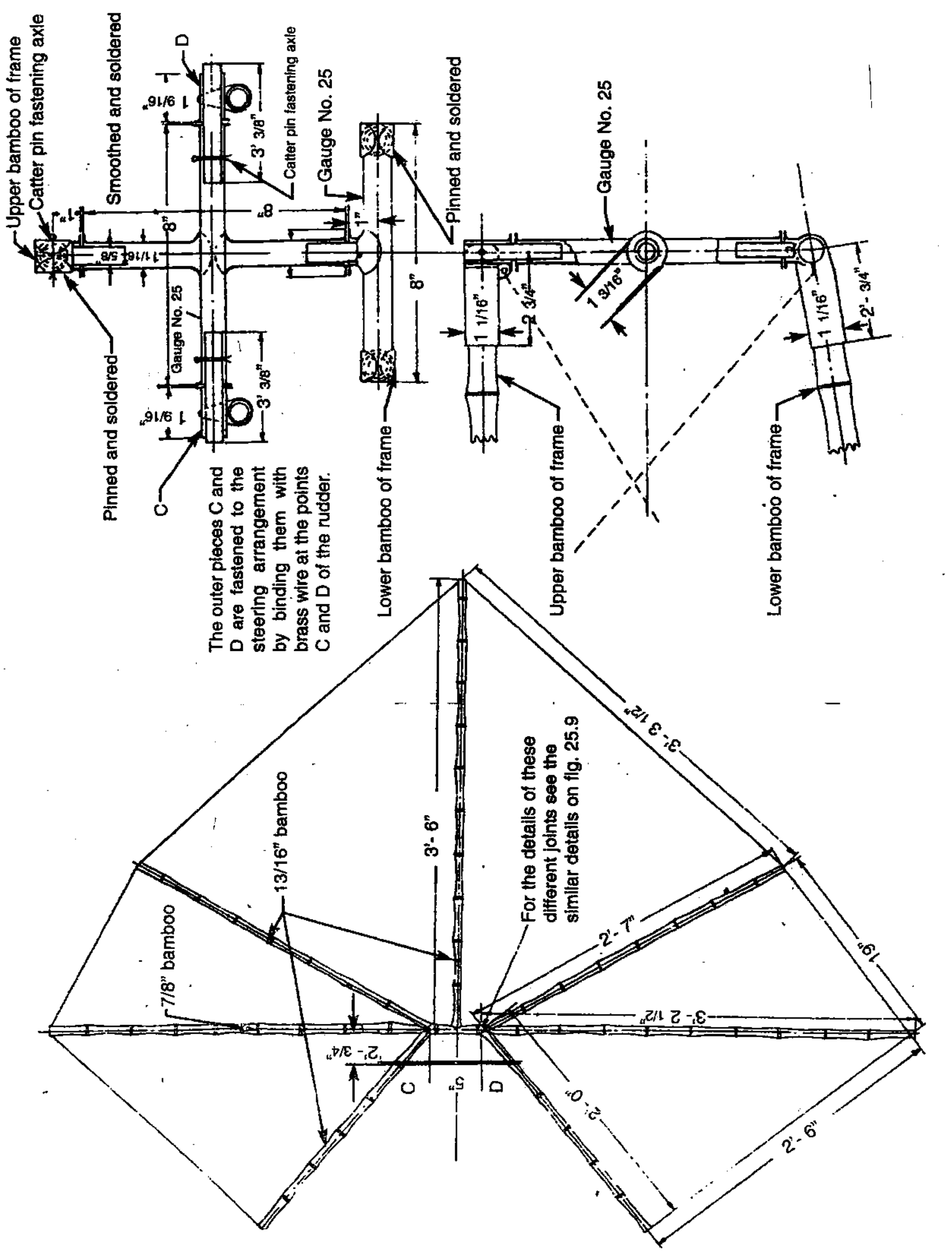
THE " *DEMOISELLE* " SANTOS-DUMONT'S MONOPLANE - (3)

Fig. 25.9 Details of Rudder



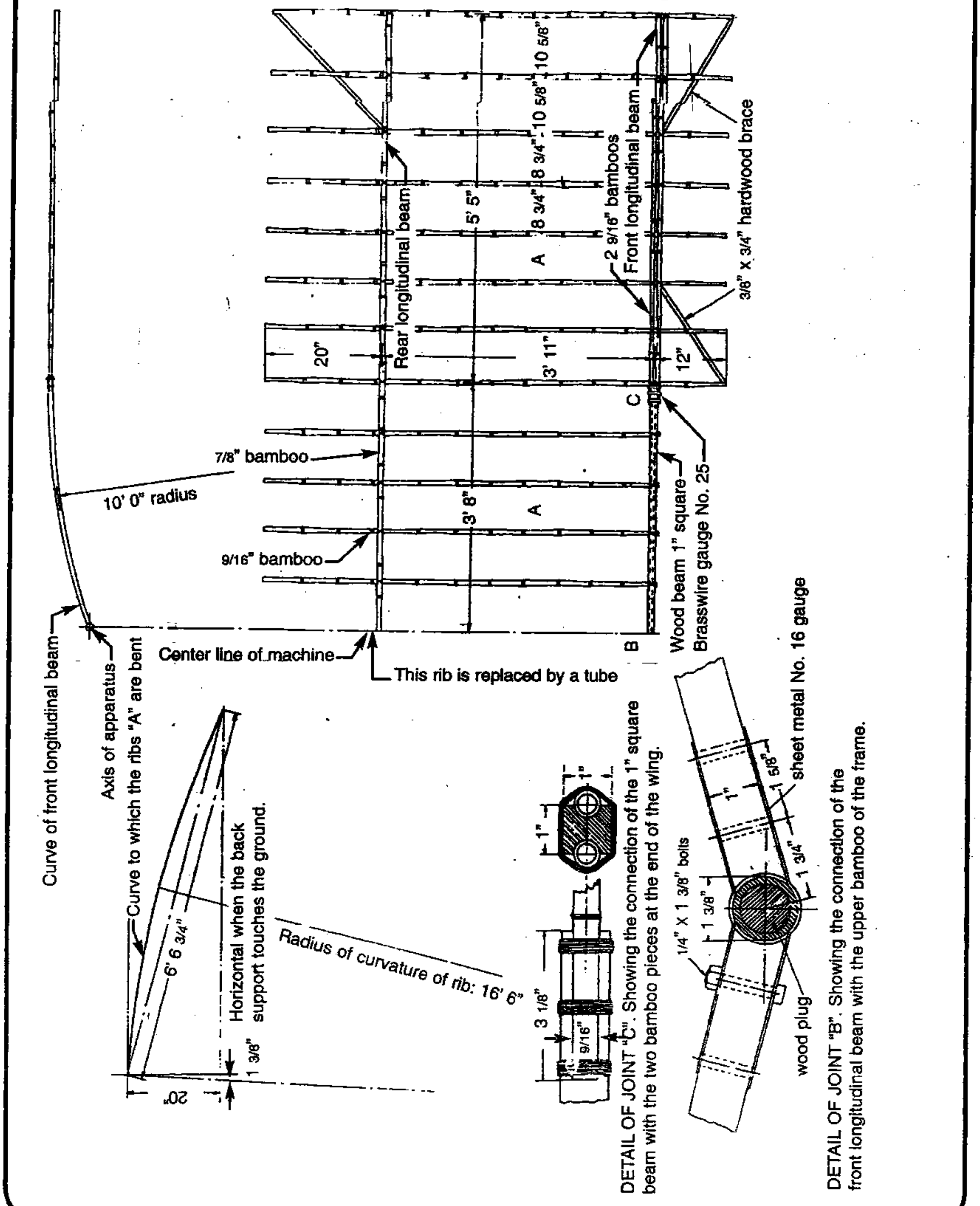
THE " *DEMOISELLE* " SANTOS-DUMONT'S MONOPLANE - (4)

Fig.25.10- Details of the Rudder and the Steering



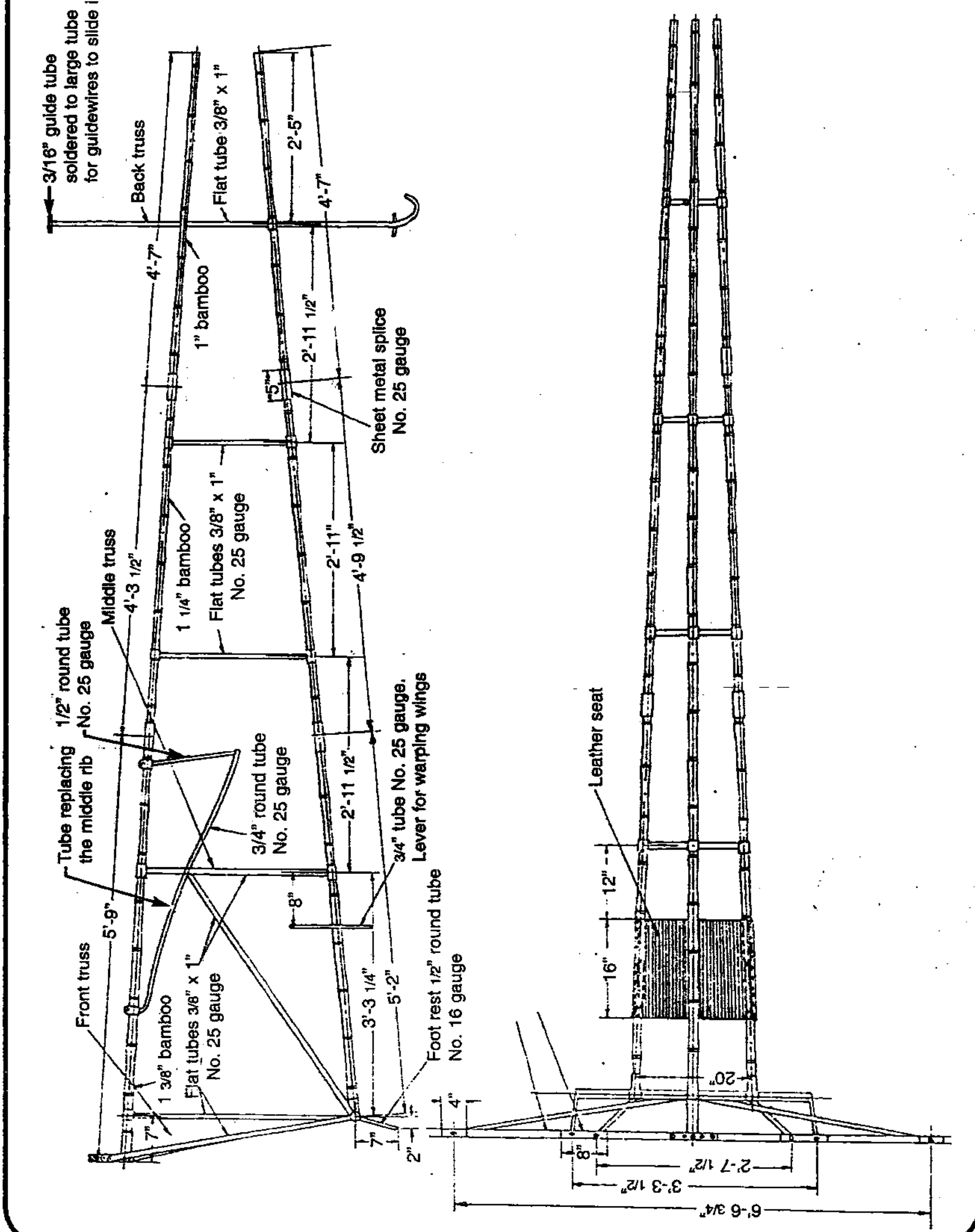
THE "*DEMOISELLE*" SANTOS-DUMONT'S MONOPLANE - (5)

Fig. 25.11 Detail of the left-hand wing



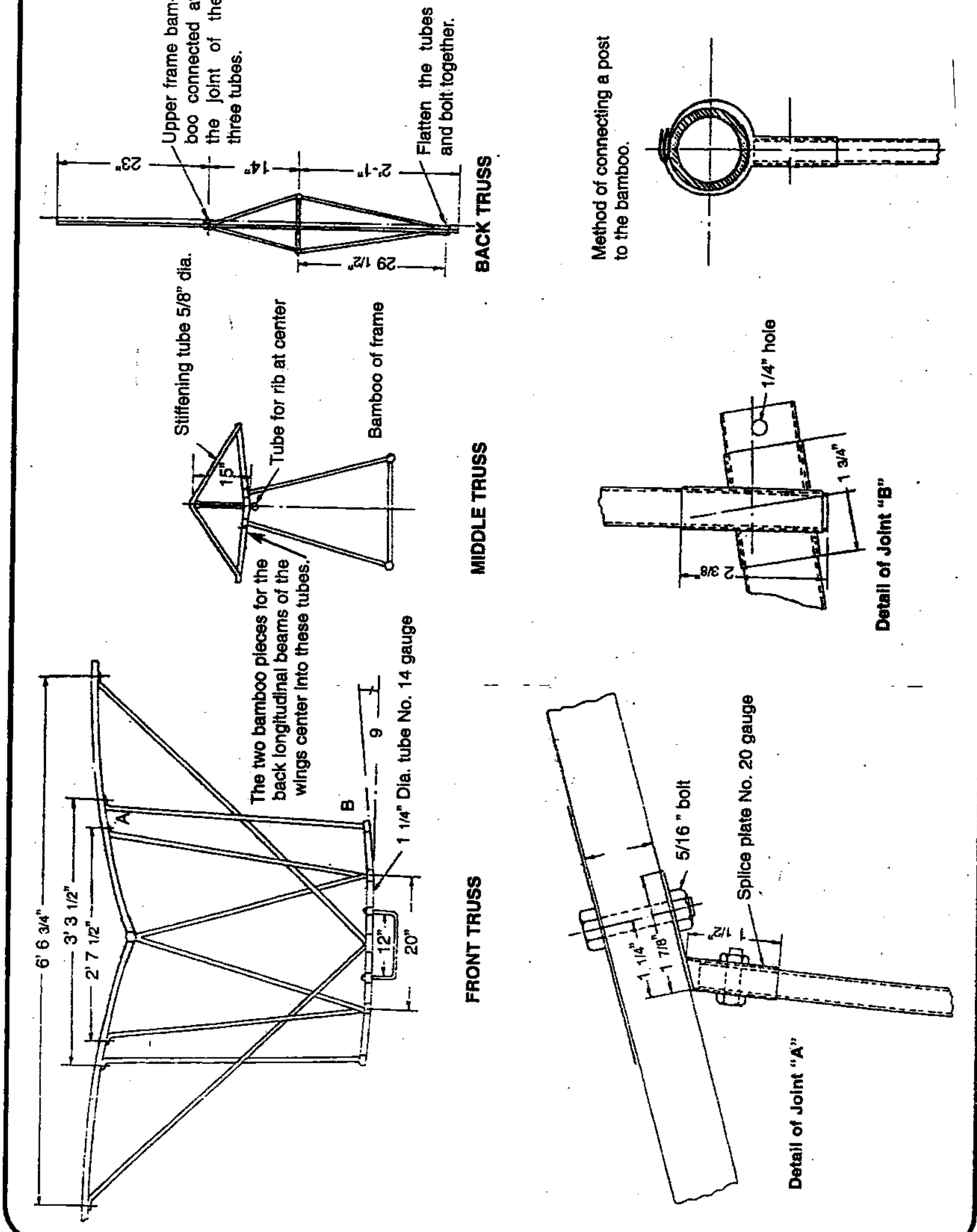
THE " *DEMOISELLE* " SANTOS-DUMONT'S MONOPLANE - (6)

Fig. 25.12 Details of the frame



THE “ *DEMOISELLE* ” SANTOS-DUMONT’S MONOPLANE - (7)

Fig. 25.13 Details of the frame



THE FIRST AIRPLANE MADE WITH A BAMBOO FUSELAGE

In 1951, the engineer, Antonio de Leon, at the Institute of Science and Technology in Manila, built a wooden frame plane and used bamboo mat panels for the fuselage covering .The bamboo mat could be woven, with any one of the local methods used in the Philippines in the manufacture of hats, baskets, chairs and other woven products. However, the best method for use in aircraft construction is the one locally known as "sawale" in which the strips are woven diagonally,i.e. at an angle of 45° with respect to the horizontal axis of the airplane and is the best adapted to take shear stresses on the skin covering. The strips for the mats were taken from two species, *Bambusa spinosa* and *B. vulgaris*. The strips used were 1 cm wide andt thickness ranging from 0.8 to 2 mm, depending on strength characteristics required. Before using the mats, they were given a protective treatment against borers and weevils by pickling them in a briny bath. The matswere immersed in the bath for a period of 48-60 hours, depending of the texture of the strips and the size of the mats. They were then rinsed in clear water and dried.

Application of the mat.

Whether in single or double ply form, the bamboo mat can readily be used for cantiliver and stressed skin construction for all types of light aircraft adapted to wood or plywood frame construction. As an aircraft material substituted for plywood, it could be extensively used for skin covering of wings, fuselages and control surfaces. In the first L-14 MAYA light research aircraft, the woven bamboo material was distributed as follows:

1.-As an overall covering for the whole fuselage with the panels applied on the wood framework by simply gluing and nailing. Single-ply mat was used throughout.

2.-On the nose portion of control surfaces to take torsional stress loads. Inthe subsequent research aircraft model, the L-15 TAGAK ambulance and utility aircraft, the mat was used in the following parts:

1).-As a covering of one half of the tail booms.

2).-As a covering of the nose portion of all control surfaces.

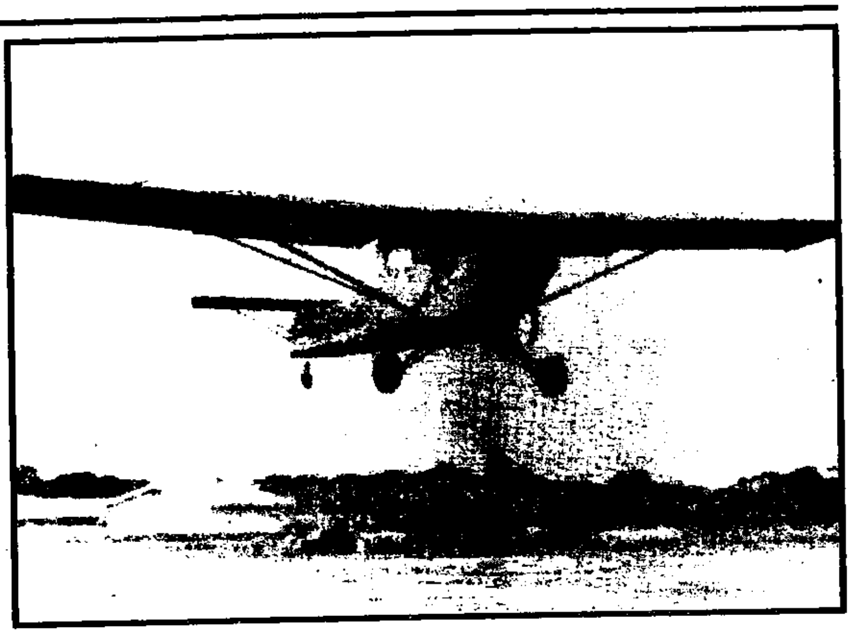


Fig.25.14 *The XL-14 Maya, the first airplain built in Phillipines with a bamboo fuselage by the engineer Antonio de Leon in the Institute of Science and technology of Manila .*

3).- As a partial covering of the fuselage.

4).-As stiffening for the wing-nose portion.The layout of the bamboo strip structure follows somewhat the principle of the so-called geodesic construction of aircraft bodies, which has been extensively used for dirigibles and for air-frame construction by Vickers-Wallis. The airframe is constructed with metal strips or stringers drawn spirally around the fuselage from one end to the other. One band goes right and the other left at 90 degrees, so that the whole system forms a stiff network

Fig. 25.15 *Interior view of the XL-14 Maya. where the bamboo weave of the fuselage, covered with several coats of paint, can be seen.*

that needs no further reinforcement, such as struts, tie-roads or bulkheads. On the same principle, the bamboo strips form a tight outside covering although it is not prestressed to take up bending, so it still requires the bulkheads and stringers framework. Normal shear and torsional stresses are taken by the woven-bamboo covering. These shear loads are transformed to act as tension and compression loads on the individual bamboo strips as shown in the figure.

Mat application on the fuselage

Mat application on the fuselage. The woven strip matting was first used on the L-14 MAYA research aircraft at the Institute of Science and Technology. The whole fuselage of this aircraft was covered with a single layer of the mat. In the preparation of the bamboo panels, the mat was laid flat on a smooth surface, and the weaving of the mat was tightened. Instead of using a press, a thick metal plate was set over the mat and the plate was filled with heavy ironweights. Although the pressing did not turn out as effective as desired, it gave the woven-strip matting an initial smoothness.

To prevent the mat edges from prying open, a coat of thin glue was brushed on the portion that was to be sheared or cut later. The mat was cut into appropriate panel sizes with the help of prepared patterns and set onto the wood structure of the airframe. Application was effected by gluing and nailing.

The panels were joined by simple overlapping joints. With the panels in position, the surface was given an overall coat of thin glued applied by brush on the outer surface which was thin enough to penetrate well into the weave. This was necessary to improve the stiffness of the material and prevent the strips from sliding past each other when acted upon by loads during flight.

To smooth the rough outer surface, a wet mixture of fine sawdust (preferably from soft wood) and glue, was applied as a putty to fill in the crevices and uneveness of the bamboo surface. This application has the advantage of making the surface leak-proof. After sanding and proper smoothing, the surface was ready for the usual aircraft specification finishing, which consists of the application of three coats of aircraft clear cellulose nitrate dope by brush and light sanding after the third coat. This was followed by three more coats of aluminum-pigmented dope for the final finish. The inside surface of the bamboo mat was finished with two coats of wood varnish.

The finish of the outer bamboo-mat surface may be improved by the applicationof a thin fabric covering. This was tried on the horizontal tail surface and the nose control of the control surfaces. This process eliminate the need for using putty, besides providing better protection of the outer surface from weather condition. The increase in weight, due to this application, is negligible. In general two or more layers of the woven bamboo mat can be pressed or laminated together with the application of a suitable glue. The glue used in the aircraft was a commercially available, water-resistant plastic resin glue known as "Weldwood". It gives the material a plywood character with excellent strength and finish characteristics. Regardless of the number of layers, the mat can always be worked to any size or shape, especially as an outerstress-skin covering for webbing and reinforcements in aircraft construction. It can be shaped and bent easily by steaming the material or by using the simple wet techniques.

Table 25-1 Strength characteristics of woven -bamboo strip matting used in the L-14 air craft construction

Average strip dimension	
Thickness	0.6 - 1.2 mm.
Width	12 - 18 mm
Length of internodes	35 - 45 cm.
Specific weight	0.6 - 0.8 g/cm³
Moisture content	12 - 15%
Panel weights	
Plain woven panel	1.2 - .3 kg/sq. m
Treated with filler and finishing	1.55 -1.75 kg/sq.m
With fabric cover and finishing	1.7 - 1.95 kg/sq. m
Tensile strength of strips	
Maximum (plain)	1,830 kg/cm²
Average wuth nodes (selected)	1,330 kg/ cm²
Minimum with nodes	635 kg/ cm²
Shear strength of mat panels	
Strips set at 90°	110 kg/ cm²
Strips set at 45	245 kg/cm²
Bending strength of strips	
Maximum	1,500 kg/ cm²
Average with nodes	850 kg/ cm²
Compression strength of strips	
Average	365 kg/cm²
Minimum	250 kg/cm²
Modulus of elasticity 2 x 10⁵ to 3 x 10⁵ kg/ cm²	
Glue shear strength of bamboo to wood	
Maximum (dry)	40 kg/cm
Average (dry)	33 kg/cm
Minimum (dry)	26 kg/cm
Average (wet)	20 - 22 kg/cm
Glue shear strength of bamboo to bamboo	
(Parallel grains):	
Maximum (dry)	48 kg/cm
Average (dry)	39.5 kg/cm
Wet	27 -30kg/cm
Workability	good

Tab. 25-2 Average bending strength to weight ratios of several commonly used materials for aircraft construction and bamboo strips.

Materials	Density gr/cm²	Bending kg/cm²	Cm⁻¹x10³
7 ST aluminum alloy	2.78	3,880	1,395
24 ST alluminum alloy	2.78	4,350	1,565
1025 carbon steel	7.87	3,880	493
X-4130 chrommoly steel	7.87	6,700	852
18-8 stainless steel	7.87	6,480	823
Spruce	0.40	670	1,680
Birch	0.60	820	1,370
Douglas fir	0.51	810	1,590
Bamboo strips	0.65	1,250	1,925

The maximum size of bamboo mat panels used in the L-14 research aircraft was about 25 x 50 cm. The average rectangular panel was 18 x 40 cm.

CONCLUSIONS

Tests on the XL-14, especially during the functional stage when the aircraft was purposely exposed to severe weather conditions for more than four weeks during the rainy season, did not show adverse effects on the material. Neither were traces of deterioration or *Dinoderus minutos* attack noticed during the three years after its construction. At one time during the taxiing and take off tests of the aircraft, it was accidentally dropped from a height of about ten feet from the ground. The aircraft did not experience any structural failure except on the landing-gear system, which was easily remedied. The pilot claimed that it had good damping characteristics for shock loads as well as good sound-absorption qualities.

The bamboo matting or sawale used in this experiment is relatively strong and its fatigue strength under bending stress is much higher than that of wood. Its non-magnetic qualities may make it useful for aircraft for special purposes. It is definitely non-corrosive, and therefore an ideal construction material for sea-plane floats and flying boat hulls.

The good bending characteristics of bamboo would enable it to serve as the spring to absorb landing shock loads. This would eliminate the necessity of using separate shock-absorbing accessories in the landing gear system. In the Cesna Aircraft there is no landing gear aside from the cantiliver spring-type landing leg.

One main contention of the common observer is that the aircraft is a fire hazard but even metal aircraft burns.

During the last war airplanes were made in China using a very strong ply-bamboo which was developed by the Chinese Air Force Research Bureau.

Fig.25.16 *Showing the Tagak. The whole fuselage of this aircraft was covered with a single layer of the bamboo mat known as sawale.*

Fig. 25.17 Design of the 'wobex' panel

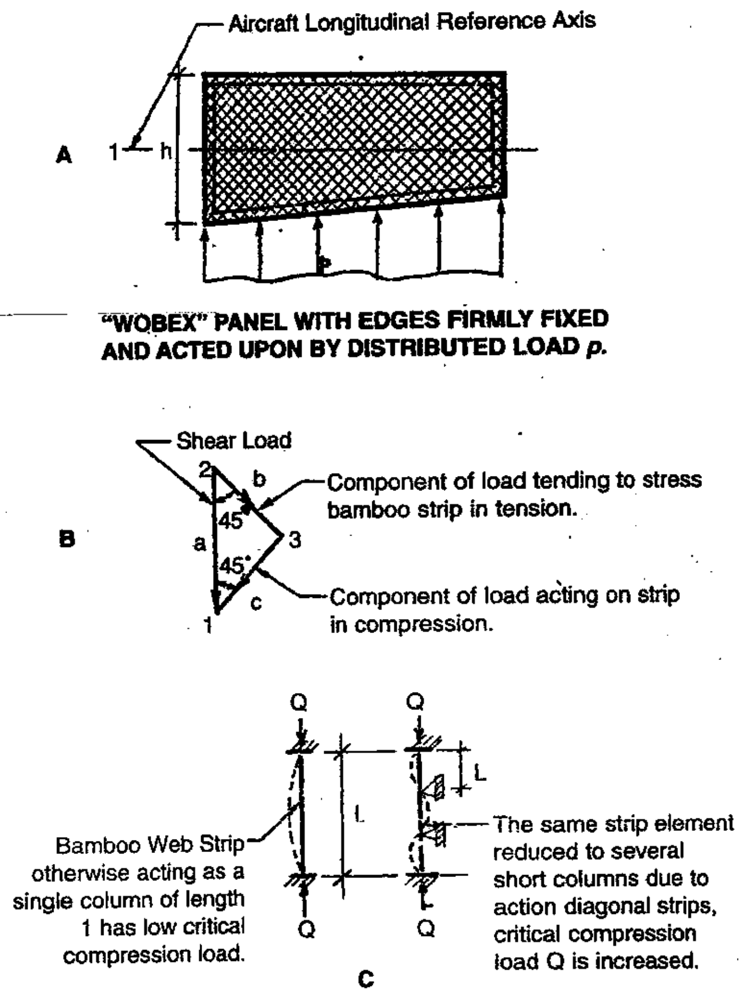
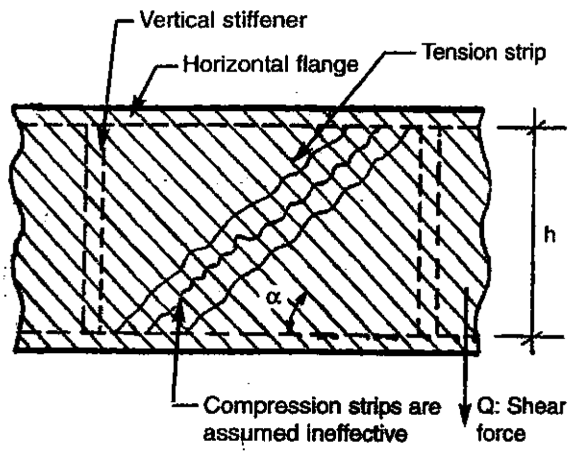


Fig. 25.17A -**Effect of interweaving bamboo strips in the diagonal compression length**



ANC-18 Forest Laboratory Product Equation (4) for short columns, which is:

$$\sigma_c = \sigma_{cu} [\ 1\text{-}1/3\ (L'/K\rho)^4]$$

Where: $\sigma_c =$ [1-1/3 $(L'/K\rho)^4$]= compression stress developed along the diagonal strips. σ_{cu}= ultimate compressive stress parallel to the grain for bamboo with nodes. $L' = L\ /\sqrt{C}$ where C is the fixity factor and can be equal to 1.5. $K = [L/\rho]$ cr an empirical constant with ρ as the radius of gyration.

"Wobex" panel treated as a Wagner beam.
Frames with parallel span flanges and vertical stiffeners, the following equation may be applied.

$$\sigma_T = 2Q\ /h\ t \cdot 1/\ \sin 2\alpha$$

Where: σ_T = diagonal tension stress in the strips.
Q = applied shear load. t = web thickness.
h = effective web height. α = angle between diagonal strip and reference axis.

BAMBOO AIRPLANE PROPELLERS

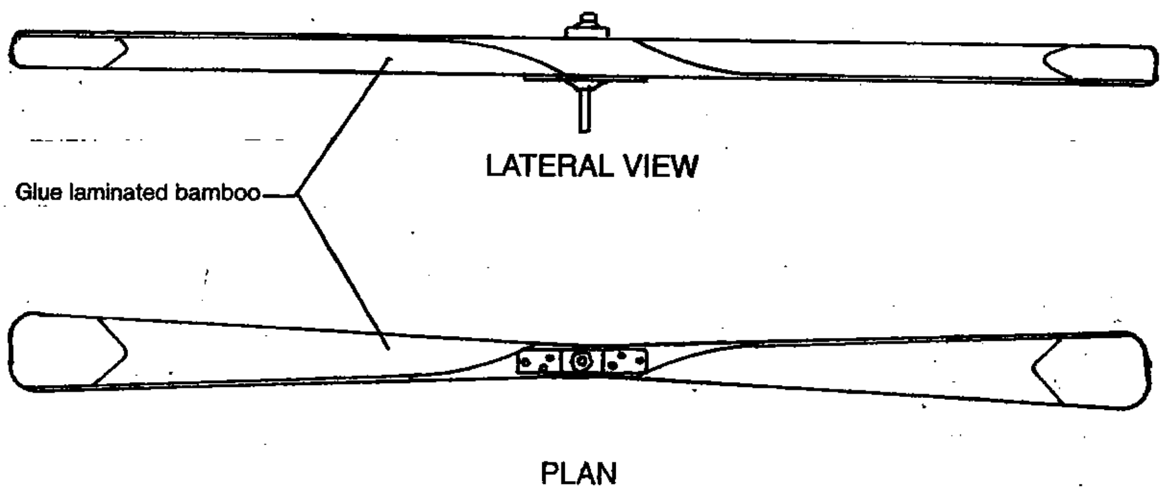


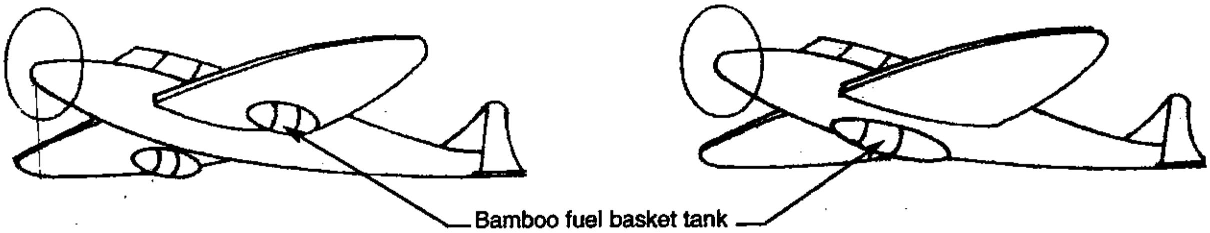
Fig. 25.18 *The first glued laminated bamboo propeller for airplanes was manufactured in Japan in 1933.*

According to the Indian Forester (1933), bamboo airplane propellers have been made by a Japanese aircraft engineer and have successfully undergone most exhaustive tests. Using the new process, after it had been treated with anti-corrosive vapor, the arc-shaped bamboo was flattened under an especially constructed roller. The pieces were then fastened together with casein glue.

According to a report by the Aviation Research Institute of the Tokio Imperial University, these propellers were more durable and elastic than those made of mahogany or circassian walnut used at that time. They were from 20 to 30% cheaper than the usual types and were practically unaffected by heat and moisture.

BAMBOO FUEL BASKET TANKS FOR COMBAT AIRCRAFTS

Fig. 25.19



During the Second World War, the Chinese had problems with the fuel tanks of their combat aircrafts, which had a very small capacity for a long flight. They solved this problem by making bamboo fuel baskets that were hung out below the wings or from the fuselage, as can be seen in the drawings. These bamboo tanks were dropped once they were empty or when they were attacked by an enemy aircraft.

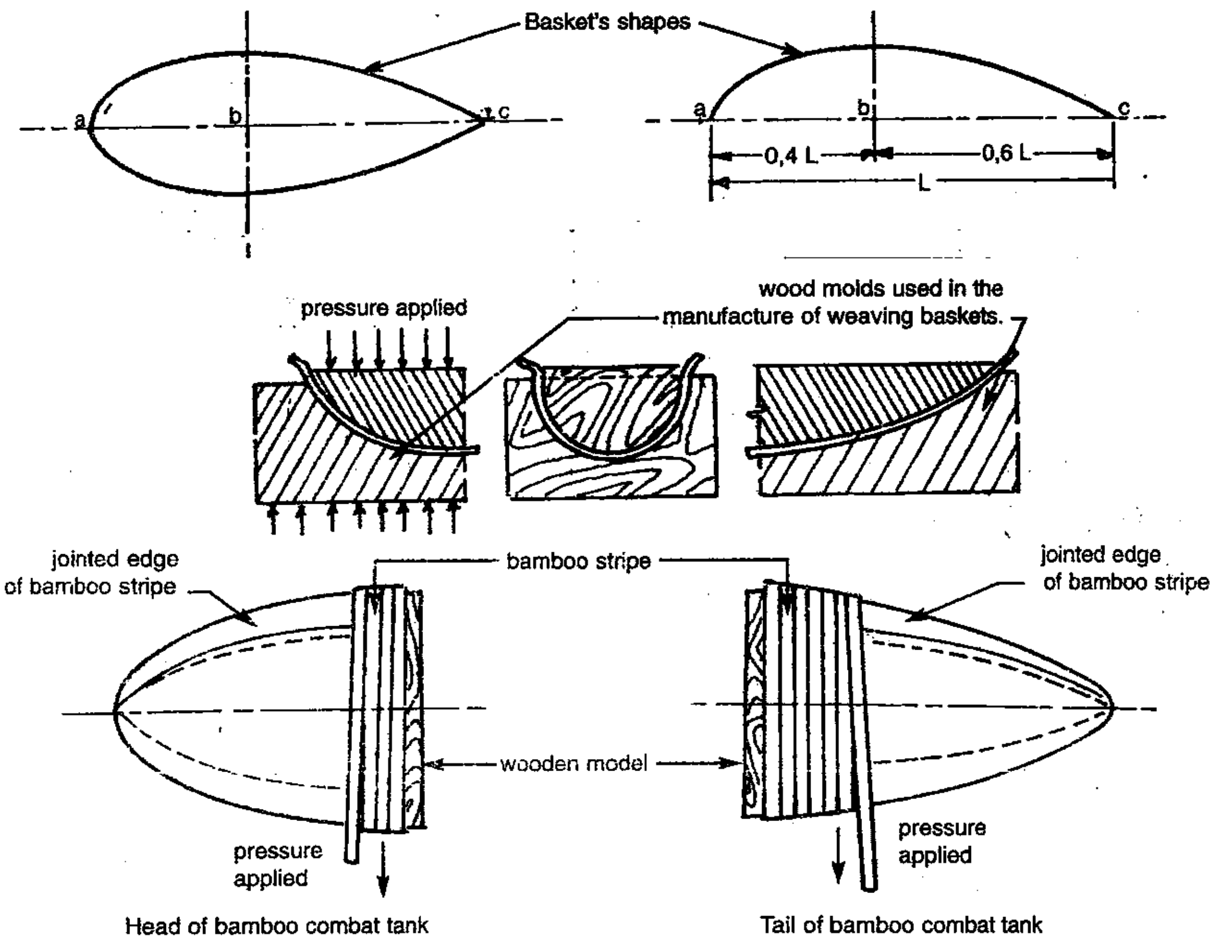
The preliminary experiments were conducted by Yu and Lo (1946) at The Chinese Aeronautic Research Institute. They found that the best material to make the bamboo fuel basket leak-proof and resistant to both fuel and water, was rawlacquer, and the process was the following. Two types of materials are used for the inside of the oil tank: a) kraft paper treated with casein glue, and b) kraft paper treated with urushi.

1.- The best urushi used should have a higher water content and less oil content.

2.-The thickness of applied urushi should be uniform and not too thick because it won't dry.

3.- The second layer urushi isn't applied until the first layer has dried for 24 hours.

Fig.25.20 Manufacture of bamboo fuel baskets



4.-The powder of calcium oxide should be uniform and fine.
5.- The ratio of urushi to calcium oxide is 1: 1 ; 1:0.25; and 1 : 0.50.
6.-The mixture of urushi and calcium oxide should be uniform.
7.-The inside of the tank should be clean and dried before you apply the mixture of urushi and calcium oxide.

Manufacture of tank shell

2.-Dry (baking) of a tank shell.
3.-Cleaning of tank shell.
4.-Inside padding of a tank.
5.-Opening the fill hole.
6.-Matching the tank shell.

Surface coating treatments on both the inside and the outside shell of tank

1.-Coating inside by using the mixture of urushi and calciun oxide.
2.- Surface coating of the first layer of paper.
3.-Surface coating of the second layer of paper.
4.-Surface coating of third layer of pa per.
5.- Surface coating of fourth layer of paper.
6.-Surface coating of the first layer of silk.
7.- Surface coating of the second layer of silk.
8.- Outside coating of tank shell by using a mixture of urushi and calcium oxide.

Assembly of accesory and joint together

1.-Joint the head and the tail together.
2-Sealing the inside adjoining slit.
3.-Leaking test by filling the gas line.
4-Seating the outside adjoining slit.

Surface coating treatment on outside shell of tank

1.-Coating the middle section with uruchi.
2.-Coating the middle section with a mixture of urushi and calcium oxide.
3.-Coating the whole shell.
4.-Polishing.
5.-Coating with aluminum powder.
6.-Stamping and inspection.

Fig. 25.21 Manufacture of bamboo fuel baskets (2)

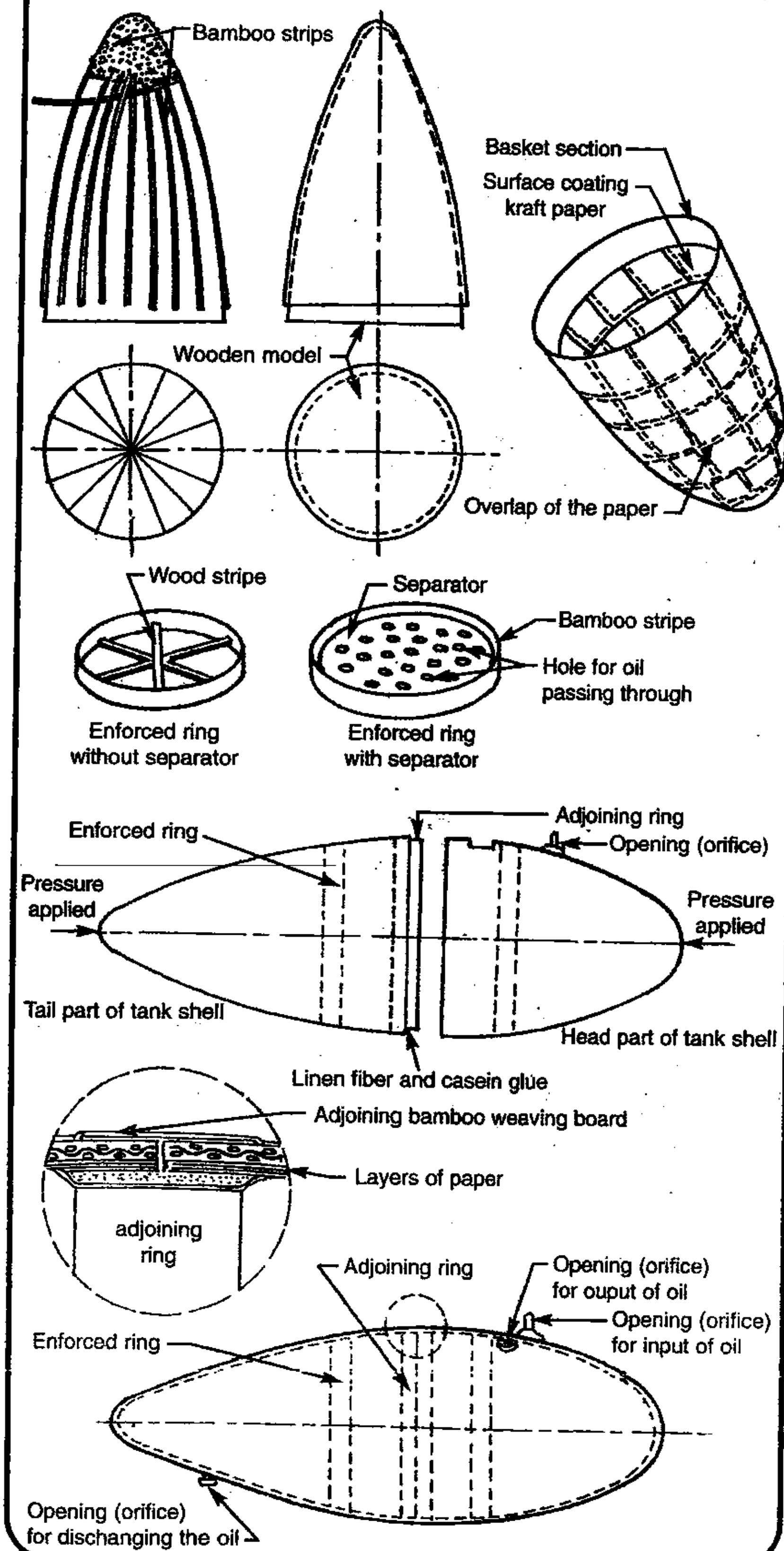
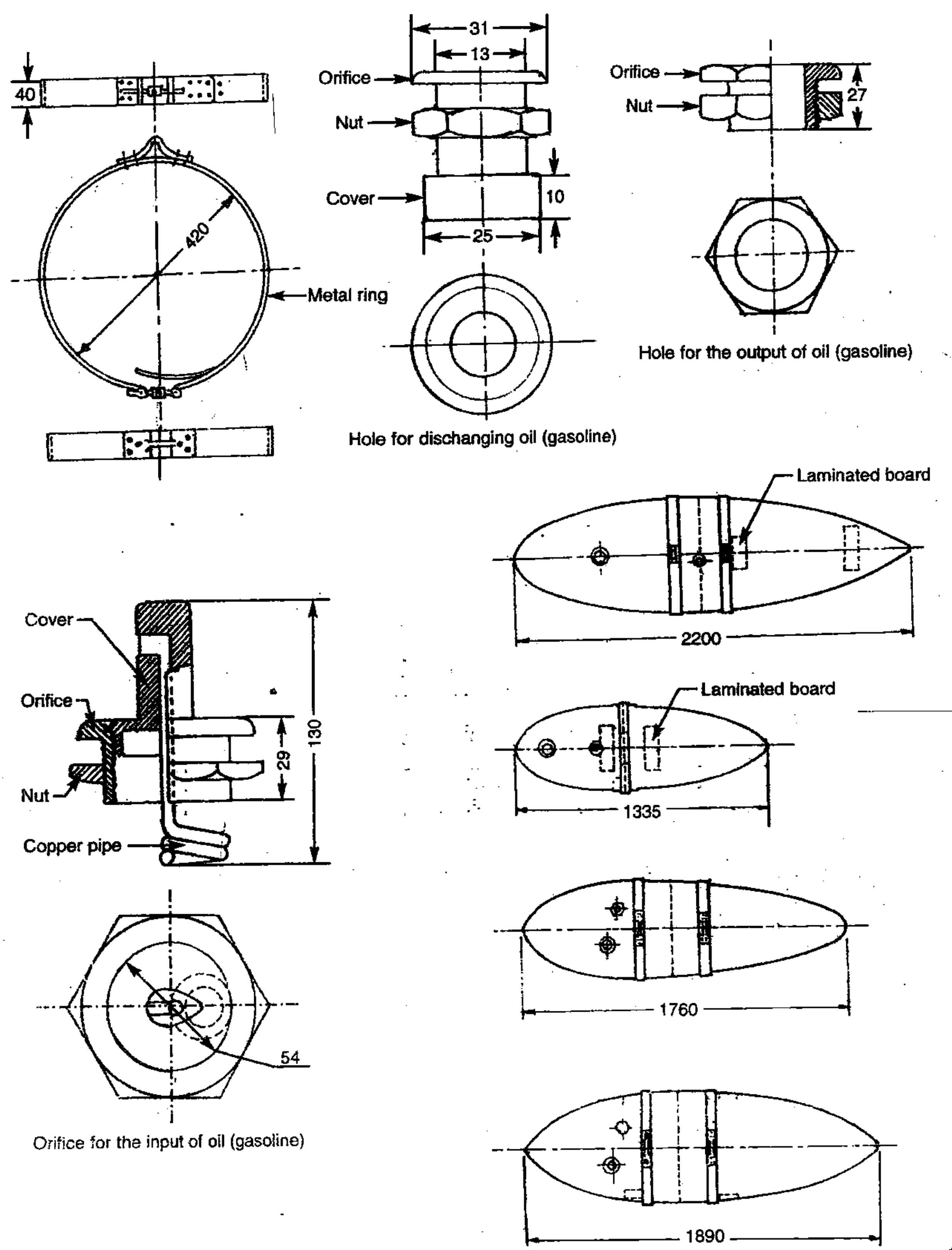
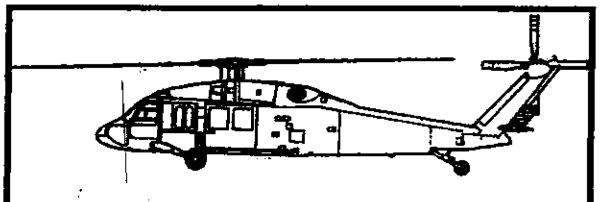


Fig. 25.22 MANUFACTURE OF BAMBOO FUEL BASKETS (3)



THE ORIGIN OF THE HELICOPTER



Sikorsky UH-60A Black Hawk (USA)

According to Needham (1965), the first plane which Ko Hung proposed for flight in the 4th century, was the helicopter top. The returning or revolving blades were based on the ordinary Chinese top which was simply an axis bearing radiating blades set at an angle, and given a powerful rotation by pulling a cord previously wound round the stem. One of its most common names in China was the "bamboo dragon fly" (chu chhing-thing).

In 1792, this toy attracted the attention of Sir George Cayley, who modified the original toy by using a bow-drill spring to work two feather air-screws which kept the top mounting into the air. (Fig. 25.23) While the original toy would rise no higher than 7-9 meters, his improved model would mount upward of 27 meters into the air. This, then, was the direct ancestor of the helicopter rotor and the godfather of the airplane propeller.

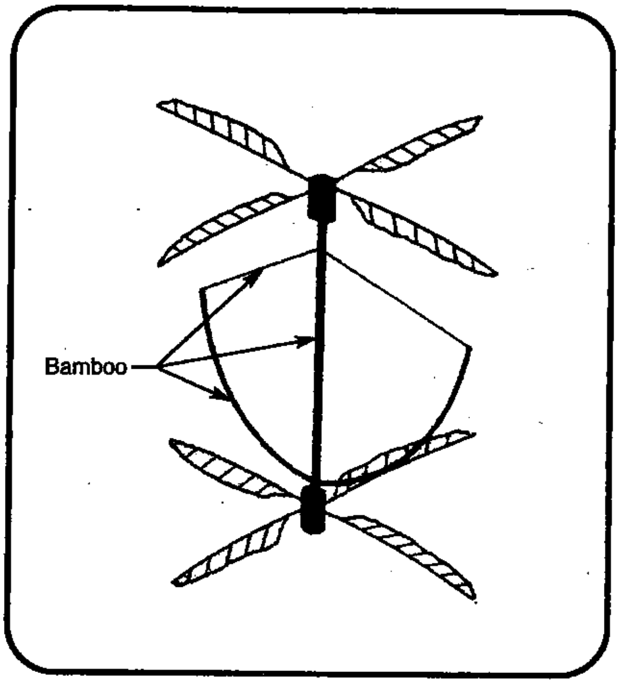


Fig. 25.23 *The bamboo "dragon fly", the toy that was the origin of the helicopter.*

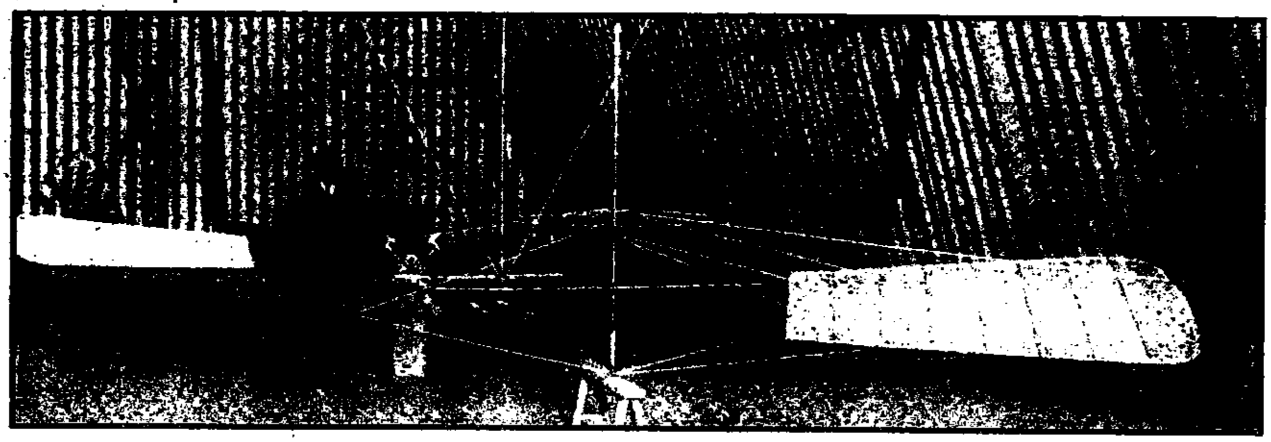


Fig. 25.24 *This bamboo model is considered as the basic idea of the modem helicopter. It was one of the several models developed by Santos Dumont.*

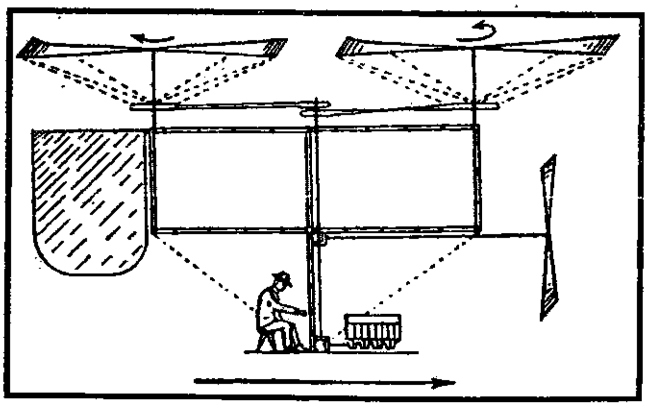


Fig. 25.25 *The Santos Dumont twin-rotor helicopter project of 1906. Overall lenght quoted as 41 ft. and height as 49 ft. 6 in. A 24 h.p. levavasseur engine- weighing 77 lb..-was specified.*

24 BAMBOO IN THE FIELD OF CHEMICAL ENGINEERING

BAMBOO PAPER - THE USE OF BAMBOO TABLETS FOR WRITING

The world pulp production capacity in 1990 was 184,200,000 ton. of which 1,685,000 were from bamboo. (Shen 1992). According to a survey made by FAO the bamboo pulping capacity in the world, between 1990 -1995 was as follows:

1.- India	1,300,000 tons
2.- China	200,000
3.- Vietnam	64,000
4.- Brazil	58,000
5.- Bangladesh	42,000
6.- Myan.	20,000
7.- Indonesia	11,000
8.- Cambodia	1,000

About 60% of the pulp used in making paper in India came from bamboo, and there were 35 factories that make paper from bamboo pulp, with an annual production estimated at about 600.000 tons in 1980. The Indian paper industry mainly used *Dendrocalamus strictus* and *Bambusa arundinacea*. In China there were 96 paper mills which use three to five years old bamboos as raw materials to produce relief printing, type writing or offset plate paper and more paper mills using bamboo were planed to be constructed in Sichuan, Fujian, Jianxi and other provinces.

The use of bamboo tablets as writing material

Up to the end of the Chou dynasty (256 B.C.) through China's classical period, writing was done with bamboo pens, using ink from soot or lamp black upon slips of bamboo and wood, which were the most popular materials for writing before paper was invented. Wooden tablets were primarily used for official documents, ordinances, short messages, and personal correspondence, where as literary writings and books of considerable length were generally done on bamboo.

Because of its light weight and smooth surface, in comparison with other hard materials, bamboo was sepecially chosen by the Chinese people as the principal medium for writing before paper was extensively adopted. Bamboo tablets, being stronger than wood, could be perforated at one end and strung together, with either silken cords or leather thongs, to form books.

According to Tsuen-Hsuin Tsien, preparing bamboo tablets for writing was probably more complicated than preparing wood. The philosopher Wang Chung, writing about A.D. 82, remarked that wood was cut into large pieces which were separated into various boards and, after smoothing the surface, they were used for documents. However, for bamboo, writings were not made on the outer cuticule of the culm but rather on the under surface after the green skin was scraped off, although sometimes the inner side of the stem was also used for writing. The stem was first cut into cylinders of certain lengths, which were then split into tablets of a certain width. The raw tablets, however, were not ready for writing until they had been treated and cured. This process was called "killing the green". After the external covering of green skin was scraped off, the tablets were dried over a fire to prevent quick decaying.

The famous bibliographer Liu Hsiang-ching (80-8 B.C.) noted that "sha-ching (killing the green) is a process of making bamboo into tablets for writing. There is juice in fresh bamboo that causes decay and injuries by insects, so those who prepare bamboo tablets dry them over the fire".

Fig. 26.1 *Long before the invention of paper Chinese scribes wrote upon strips of bamboo. These are from the ruins of the Niga and Lop-Nor sites, and from the Tung-huang Limes. Reproduced from Ruins of Desert Catay, Stein (1912).*

Old tablets could be used over again after the writing on the surface was removed. When mistakes were made, the error could also be erased by scraping with a knife from the surface. There seem to have been standard sizes for bamboo and wooden tablets used in ancient times. The standard varies according to the usage and the relative importance of the documents. The size of bamboo tablets for literary writings was fixed at 71 cm, 35 cm and 20 cm. Large tablets were used for classics and small ones for commentaries and historical records.

The invention of paper.

Long before the invention of paper Chinese scribes wrote upon strips of bamboo. These are from the ruins of the Niga and Lop-Nor sites, and from the Tung-huang Limes.

PAG 444 -Old tablets could be used over again after the writing on the surface was removed. When mistakes were made, the error could also be erased by scraping the surface with a knife.

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The invention of paper. The year A.D. 105 is usually set as the date of the invention of paper, because in that year the invention was officially reported to the emperor by the eunuch Tsai Lun. Whether Tsai Lun was the real inventor or only the person in official position who became the patron of the invention (as Feng Tao did laterwith printing) is uncertain. In any case, his name is indelibly connected with nvention in the minds of the Chinese people. This new paper was made using tree bark, hemp, rags and fish nets (Carter 1925).

The invention of the hair writing brush, attributed to General Meng Tien in the third century B.C., caused a transformation in writing materials. This transformation is indicated by two changes in the language. After this time, the word for chapter used means "roll" and the words for writing materials became "bamboo and silk" instead of "bamboo and wood". There is evidence that the silk used for writing during the early part of the Han dynasty consisted of actual silk fabric. But as dynastic records of the time state "silk was too expensive and bamboo too heavy". Consequently, these two materials were not convenient, and clearly a new writing material was needed.

The first step was probably a sort of paper or near paper made of raw silk. This is indicated by the character for paper which has the silk radical showing material, and by the definition of that character in the Shuo wen, a dictionary that was finished around the year 100 A.D. The paper found in Turkestan in 1931 shows a certain amount of progress, especially in the art of loading and sizing to make writing easier.

The earliest paper were simply a net of rag fibers with no sizing. The first attempt to improve the paper so that it would absorb ink more readily consisted of giving the paper a coat of gypsum. Then followed the use of a glue or gelatine made from lichen. Next came the impregnation of the paper with raw dry starch flour. Finally this starch flour was mixed with a thin starch paste, or else the paste was used alone. Better methods of maceration also came into use that proved less destructive to the fiber and produced a stronger paper.

Fig. 26.2 *A Chinese workman removing the partially desintegrated bamboo from the pit, after it had been in a lime and water solution for several months. It is next cleansed in clear water to remove the lime, then beaten for the papermakers. (Hunter, 1943).*

The use of bamboo in the manufacture of pulp and paper started in India as a result of long and careful pioneering experiments by William Raitt.

The ancient technology of bamboo hand made paper in China.

According to Sung (1966), in the seventeenth century, bamboo paper was an industry of South China, especially in Fukien province. At that time, bamboo shoots that had completed their full development were used for the manufacture of paper. However, the better grades of paper were made from young culms that were cut down in early summer aand had not yet put forth their branches and leaves. For cheap papers, the requirements were less exacting and a wider range of bamboo species was employed as asource of pulp.

For the preparation of paper, bamboos are cut into lengths measuring about five or six ch'ih (1 chi=0.33 mts.). A pit is dug right there in the mountain and filled with water in which the bamboos are immersed and kept under water by heavy stones. The water supply is constantly maintained by means of bamboo pipes so that the pit will not run dry. After soaking for one hundred days the bamboos are carefully pounded and washed to remove the coarse husk and green bark or node (this is "killing the green").

The mass of pounded bamboo, having a hemp-like appearance, is mixed with a high-grade milk of lime and water and put into a cooking cask to be boiled over a fire for eight days and nights. In the boiling of bamboo, (the wooden cask isheld in top of a metal) pot, which in turn is attached with the aid of mud and lime to a cone-shaped stove (Fig. 13.2). This pot measures fifteen ch'ih in circumference and over four ch'ih in diameter and has a capacity of more than ten tan of water. When the cooking cask has been placed on the pot, the boiling process begins. The bamboo pulp is cooked for eight days, and then the fire is stopped and the pulp allowed to cool for one day.

After cooling, the cask is removed and the bamboo fibers are taken out of the cask to be thoroughly washed in clear water. This is done in a washing pit of which the bottom and four sides are lined securely with wooden boards in order to keep out the dirt. This lining is not necessary for making coarse paper.

When the fibers are washed clean, they are soaked in a solution of wood ash and transferred to the cask of a pot. The fibrous mass is pressed to flatten the top, covered with about one inch of rice stalk ash, and finally cooked by heating the water in the pot until the water in the cask is boiling.

After this, it is tranferred to another cask and strained with the passage of a hot solution of ash from top to bottom. This is followed by washing it with a passage of hot water; if the water cools off, it is reboiled to repeat the washing. After some ten days of repeated cooking, straining and washing, the bamboo pulp will naturally become odorous and decayed. It is taken out to be pounded in a mortar (in hilly regions water powered pestles are usually employed) until it has the appearance of kneated dough.

This pulp is poured into a square-shaped tank (Fig 23.3). The exact dimension of a pulp tank, however, are governed by the size of the paper-making screen being used, which in turn is determined by the size of the paper sheets to be made. When the clear supernatant liquid in the pulp tank is three inches deep, as caused by the gradual settling of the fibrous mass, a chemical solution is added. The material used for the preparation of this chemical solution has the form of the leaves of the "peach bamboo" and is called locally by different names. This chemical solution is capable of bleaching the paper sheets to a white color after drying.

Fig. 26.3 Chinese paper making as illustrated in the 7th century book

a. *Steeping and washing cut bamboos*

b. *Cooking the inner mass of bamboo in a pot.*

c. *Dipping the bamboo mold and lifting pulp from a bat.*

d. *Pressing moist paper sheets to release water.*

e. *Drying paper sheets on a heated wall.*

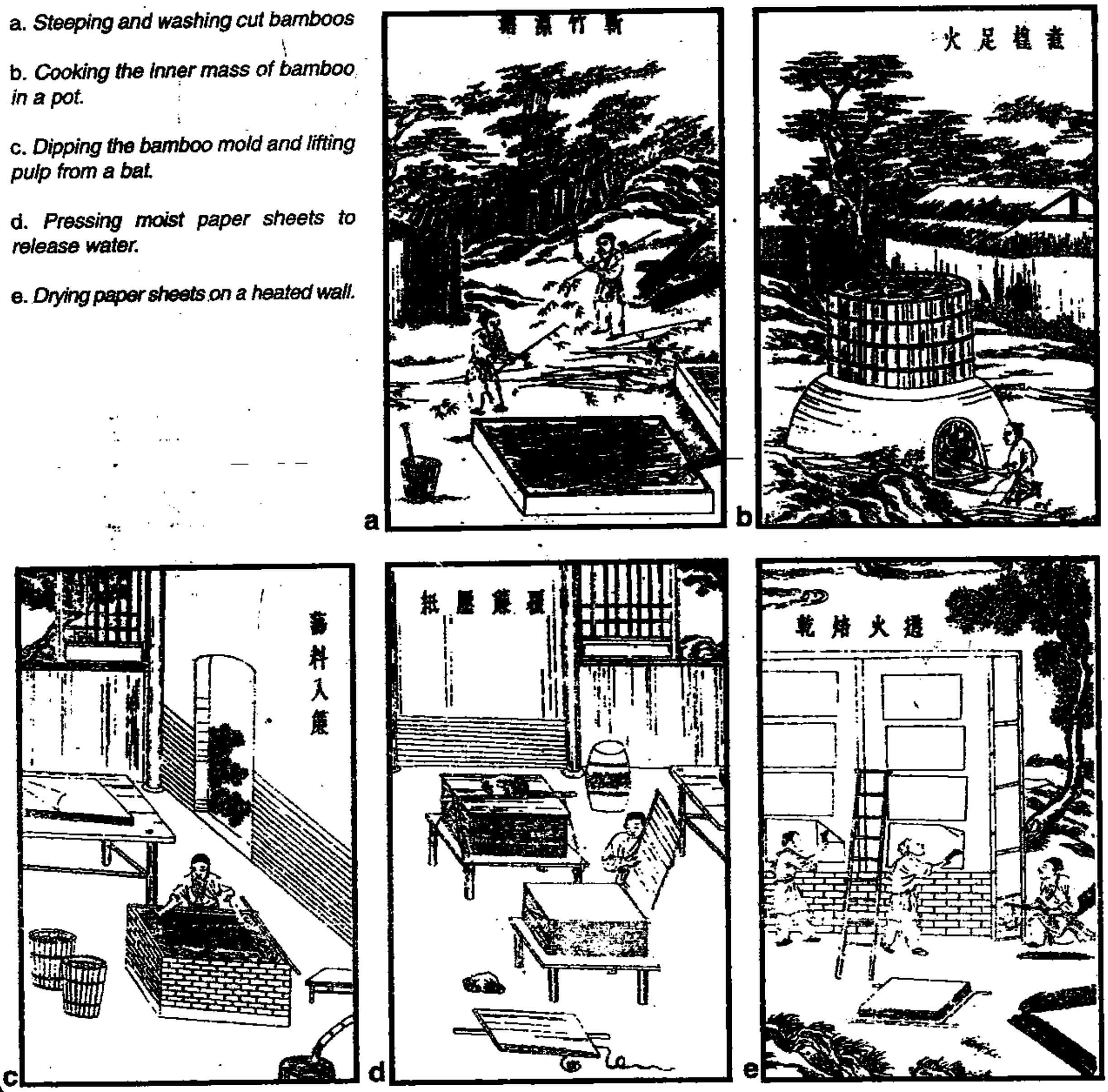
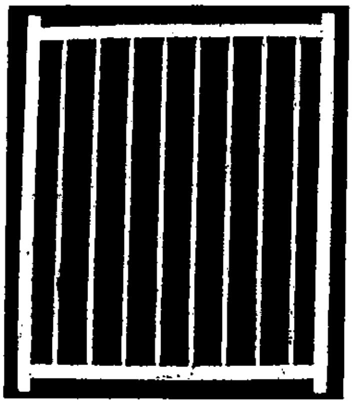
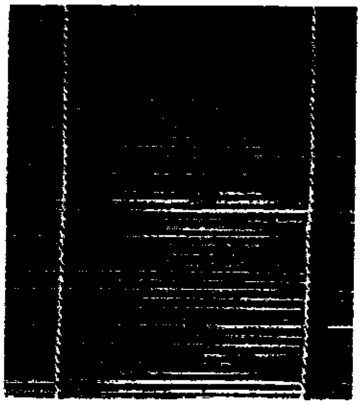


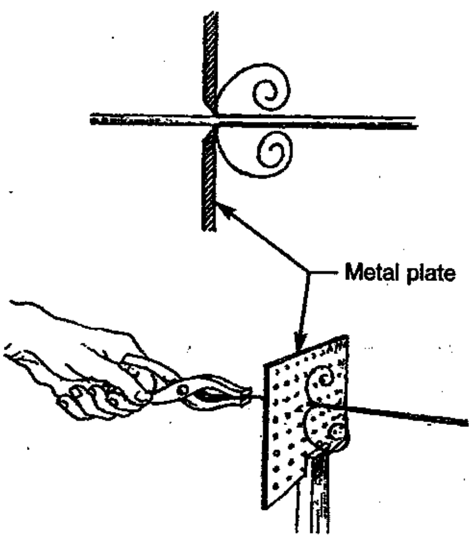
Fig. 26.4 *The screen ("laid") used for the manufacture of paper.*



A.-Mold-frame. *The "laid" a mold cover made of bamboo, lies on the mold frame during the dipping of the mold ; the mold-frame, with its ribs, supporting the mold-cover and keeping it flat.*



B.-The mold-cover or "laid" (enlarged) *made with bamboo splints tied with silk or horse-hair, rests upon the mold-frame during the formation of a sheet of paper .It causes slight identation in every sheet of paper formed there. This was the original "laid" paper.*



C.-Making bamboo round splints

The screen used for the manufacture of paper sheets is made of a rectangular frame covered with a mat woven of finely split and polished bamboo. In the construction of the common type of screen or mold, on which the finest paper is still made by hand in Orient, bamboo is always used. The essencial part of the mold is a flexible screen of slender wire-like fastened together in parallel array by means of hair, silk or ramie. The best screns are made from the peripheral wood of large culms of *Phyllostachys pubescens* or *Ph. bambusoides*. After preliminary splitting, the strips are reduced to the desired size and to a cylindrical form by being pulled throught a hole in a piece of steel. (See fig, "C" In this way wire-like strips of marvelous uniformity and fineness may be produce. Some screens have as many as 32 strips to the inch. The finished screens, after having been treated with lacquers are objects of great beauty and unbelievable durability. The binding fibers which corresponds to the warp in weaving, are the first part of the screen to wear out.

The worker holds the screen with both hands and sumerges it in the fibres suspention of the pulp tank so that some of the latter remains on top of the screen. The thickness of the paper will depend on the way in which the screen is manipulated: shallow sumerging results in thin paper, while a deeper dip produces a thick one. Water from the pulp will drain off around the screen's edges and back into the tank as the bamboo material is left on top.

The screen is then inverted and the paper is dropped onto a wooden board until many such sheets have been piled together. When the number is sufficient, the sheets are cover with another board and the upper and lower boards are rope tied with the aid of a pole placed over the top board, as in a wine press and all the water is squeezed from the sheets (Fig. 13.41). when this is done each sheet is lifted up by means of a small brass tweezer and dried with heat.

For drying paper, a doble wall of earthen bricks is erected with the ground between the two rows covered by bricks. A fire is lighted at the first hole and the heat travels through apertures and spreads to the wall surfaces where the bricks will become hot. The wet sheets of paper are spread onto the wall one by one, baked dry, and then taken off as finished sheet. In recent times the large-size sheets have become known as "Large fourfold" which is highly prized as a writing paper.

After the ink and colors of waste paper are washed off, the paper is reduced to pulp by soaking in water and transferred to the pulp tank to making new paper.This process of paper making not only eliminates the expensive operations of cooking and straining (the bamboo or wood) , but also loses very little of the waste paper so used .This procedure is not popular in south China where bamboo is abundant and cheap.

In the manufacture of burnt-offering paper and coarse paper, the procedures of cutting the bamboo, cooking and straining the fibres with ash solutions, and washing the fibres with water, are the same as described above. These kinds of paper, however, are not baked dry after the sheets have been taken off the screan, but are first pressed to remove the excess water and then dried by the sun.

The stationery paper was made entirely of fine bamboo fibres and screened from a thick pulp. This paper fetches a high price on the market. The highest grade known as "official stationery" is used as letter paper by high officials and wealthy persons. It is thick ans smooth and without any fibre ribs. When used for red ceremonial cards, it is first treated with alum water and then dyed red with safflower juice. (Sung Ying-Hsing 1966; Tsuen-Hsuin Tsien; Hunter D. 1943).

THE TRADITIONAL TECHNOLOGY OF HAND MADE PAPER

The production technology of hand made paper is basically a traditional technology that has been practiced for hundreds of years. It has a complete set of procedures. The specific procedures differ little despite materials used. The paper quality is dependent on the choice of materials, water quality, dosage of chemical egest, carefulness of operation and the experience ofthe master workers.

In hand made paper production, fresh bamboos were used as the raw material, particularly young culms, that had noy yet put forth their branches and leaves.The bamboo for pulping was divided into raw material and boiled material. A brief description of the key points of the manufacturing process is given as follows:

1). Soaking of the bamboo (removing the green skin of the bamboo). Fresh bamboos are cut into sections 2m long, and are put into ponds for soaking for 1-3 months depending on the specific local conditions. Now, the time of soaking is shortened by adding lime. Then a wooden hammer was used to remove the green skin by repeated pounding. Bamboo joints and diaphragms were removed with part of the soluble trash.

2). Boiling. Caldrons with a capacity of 5,000 kg were used for boiling. In the past, the boiling was done in two stages: boiling with lime and boiling with soda ash. Materials were boiled for about 5-10 days under normal air pressure. With the lignin removed, the fibers were dispersed in the stock. In recent years, the procedure has been improved. Bamboos are cut into short segments and are first put in the lime water or soda ash solution. After caustification, the boiled materials are put in the clear solution, covered and water sealed. Only one day is needed for boiling. Raw material is not boiled with soda ash.

3). Washing. Black liquor was dripped from the boiled materials, which were washed with warm water two or three times. Then they were put in ponds for soaking until they were macerated. The alternative was to pour bean drink or rice water in them to ferment for 5-7 days. Afterwards, they were soaked and washed.

4). Bleaching (sunning) In ancient times, for making white paper, the stock was spread on the southern slopes of hills to receive sun and be weathered for three to four months. During this period, they were turned two or three times. This was the natural oxide bleaching. In Sichuan, hand made paper was bleached with bleaching powder. The paper thus bleached was called "powdery white".

5). Pounding (beating). Coarse matter and trash were removed before the bamboos were washed and pounded. As to material pounding, in most sites in Sichuan, water-moved stone hammers or treadled stone hammer were used in pounding. Fibers were fibrillated and dispersed into the stock in high concentrations. As the fibers were well interwoven, the paper had better strength.

6). Preparing the stock. Stock was put in the tank containing clean water with a dispersing agent added so that the fibers were suspended evenly in the water, facilitating picking up the web. The area of the tank should be larger than the bamboo screen.

7). Picking up. The wet in which the fibers were evenly distributed and well interwoven was left on the bamboo screen. Then they were shifted to a woven press. This is the critical link in papermaking so the picking up was often done by the technical superintendent.

8) Pressing. When the number of webs was over one thousand, a flat board was put on them. Part of water was pressed out of them by a level. A soft brush was used to paste them on the walls of the drying oven.

9). Baking. There was cold baking and hot backing. The brick wall of drying oven was plastered with lime water to give it a smooth surface. Hot baking meant the inner layer of wall was heated. Cold baking meant drying by natural ventilation.

10). Packing. The oven-dried or air dried sheets were sorted and counted. In the usual case, each one hundred sheets were a dao, although sometimes two hundred sheets were a dao; 40 daos made a bale; and 200 daos were a bundle. Next, they were bound with bamboo strips and ready to be marketed.

The production process was simple or complex, depending on the quality and variety of paper to be produced, but all work was done manually. It was characterized by high intensity of labor, simple equipment and a long production cycle. Long ago, efforts were made by the workers to improve the equipment, tools and operating methods. Now, in some mills, chemical pulping has been adopted, but the picking up is still done manually. In workshops using traditional production technology and manual operation the stock is mainly churned tanks. The traditional technology of hand made paper has its own strong points, which modern mechanical paper making should learn from. For example, the choice of bamboo materials, joint and diaphragm removal, green skin removal, oxide bleaching, and pulp beating at high concentrations were its advantages. Some of these have been applied in the modern paper industry and are mechanized. In a word, the hand made paper industry should adopt the modern pulping and papermaking technology to give up the low efficient methods of production.

Bamboo fiber character

There are several hundred bamboo species in China, of which 30 are often used for mechanical papermaking. They are roughly divided into two types: the first type includes medium and small bamboos with thin-walls, 2-8 mm thick, and a diameter of 2-6 cm, such as *Sinocalaumus affinis, Dendrocalanus membranaceous, Phyllostachis heteroclada, Ph. nidularia, Ph. bissenti, Pleioblastus amarus, Bambusa textilis, B. portentosa and Monocladus amplexicaulis.* These are the most used for modern paper making. The second type are large bamboos with thick walls, 10 - 20 mm, and a diameter of 8-20 cm. The main species of this type is *Phyllostachys pubescens*, which occupies 70% of the area of bamboo forest in China, covering more than 2 million hectares in 4 provinces.

Bamboo fiber is long and thin with an average length of1.4-2 mm, slightly shorter than that of coniferous tree species; but longer than that of broad leaf trees and most species of Gramineae. It belongs to the category of medium or long fiber.

The average width is only 0.01-0.015 mm. The large ratio between length and width is suitable PAG 448 for crosswise connections in papermaking. The cellulose content of bamboo is as much as that of wood, while the ash content is higher than that of wood, but lower than that of grass. Consequently, bamboo is an excellent material for paper-making. However, its texture is tense, the density of the culm wall is high, the cell membrane is thick and the cell space is small, so proper measures are needed in production to solve the problem. The fiber form, chemical composition and culm structure of bamboos of different species and ages, growing in different areas, differ greatly.

Bamboo can be effectively used for pulping, therefore it is very important to study the behavior of bamboo material in the pulping and papermaking procees. The quality of chemical pulp depends on on the parameters in the structure of the fiber, especially the fiber form, and the characteristics of thin fiber structure.

Bamboo storage and material preparation

The quality of bamboo culms depends greatly on the time of cutting. One of the records says that bamboo wares made from culms cut in winter will not be damaged by moths. Generally speaking, bamboo cutting should be done from the beginning of winter to the beginning of spring (in tropical areas, from the beginning of the rainy season). During this period of time the physiological action is lowered by the cold temperatures, which reduces the nutrient and ash content of the culm, and, as a result, the strength of the culm is improved. Products made from summer-cut bamboo are seldom attached by fungus and borers. In Sechuan Province, bamboo culms are cut from the end of October to February for papermaking.

To ensure the continuous operation of a paper mill with an annual output of twenty thousand tons of bamboo pulp, it is necessary to keep 30-40 thousand tons of fresh bamboo for 5-6 months in storage. As bamboo culms contain moisture, starch and carbohydrate, they may easily be damaged by mold or borers if stored under improper conditions. This results in a reduced quantity of pulp obtained. Experiments demonstrated that the yield of coarse pulp from damaged bamboo culms decreased by 5-10%, and the strength by 20-35% in comparison with that from undamaged ones. It is essential to pay great attention to the purchase and storage of bamboo. Some paper mills regard bamboo storage as the first link in production process and have strengthened its management. The main measures are:

1). Strengthen the quality check when bamboo culms come into the mill. Culms damaged by molds or insect pests should not be accepted. The moisture content of healthy culms should be checked strictly.

2). Maintain good drainage at the storage site. The ground should be flat. The base of the bamboo stacks should be 300-500 mm higher than ground surface and underlaid with stones to prevent standing water.

3). Maintain good ventilation of the bamboo stacks, arranging ventilation channels and transport passages among them. The stack size should be properly arranged according to the production scale and the material storage area. It isdesirable that they be 30 m long, 10-12 m wide, and 5-6 m high, with a ridged top, and covered with waterproof material during the rainy season.

4). Carry out strict fire control measures. Prepare enough fire extinguishing facilities. Forbid smoking and using fire near the bamboo stacks. Appoint specialized fire control officers in accordance with site conditions.

5). Use bamboo culms in a reasonable order. The name of the bamboo species, weight, date of acceptance and the name of the person in charge of the storage should be mentioned on a brass plate on every stack. The rule of "first come, first used" should be observed.

6). Check bamboo stacks frequently at regular intervals. The checks should be increased during the rainy season. Insecticide and fungicide shouldbe applied when damage by insects or mold is found. Slightly damaged culms should be used immediately.

Fuzhou Paper Mill based in Jangxi Province in China has conducted a one year experiment on bamboo storage. They stated that newly cut Pyllostachys pubescens culms were stored in stacks underlaid with stones on the storage site. The culms were chipped when their moisture content decreased to 20%, and the chips were piled in a storage shed. Both the storage site and the shed had good ventilation and drainage. No insect damage was found after one year of storage.

Chipping and material preparation

Chipping is the beginning of pulping. The quality of the chips is closely connected to the economic benefit of pulp and paper production. Long-term production experience has indicated that the ideal chip size is 20± 2mm long.

When the actual size of chips in production was kept in the range of 15-30 mm, the rate of qualified chips exceeded 90%. Chips of improper size affected pulping.

Chips of a greater size will prop up against each other in the container and distributor causing insufficient utilization of container space and an increase in chemical consumption; normal production cannot be continuously cooked. Uneven chip size will cause uneven permeability of liquid chemicals and increase uncooked cellulose in coarse pulp. Chips of a smaller size will reduce the yield and strength of coarse pulp, particularly the tearing strength. The size of chips is very important as it affects the cookin quality and the amount of chemical consumption. In order to produce chips of a proper size, the following measures are suggested:

1). Select proper chipping and screen machines in accordance with the papermaking scale and chip demand so as to guarantee even feeding and continuous chipping.

2). Maintain the sharpness of the chipping knife blades. Appoint special grinders to grind them regularly. Equip all shift teams with their own knife blades. Observe the wear on the blades closely and change them regularly. The clearance between the rolling knife and the fixed knife should not be too large; it should be 0.5-1 mm for the disk chipper, and 0.05 mm for the roll chipper.

3). Pay close attentio to the removal of dust and screening of chips in the process of chipping. Metal scraps, sand and stones, bamboo waste and long pieces should be removed from bamboo bundles. Check the quality of chips on every shift. The material preparation process in existing paper mills is quite simple: bamboo culm- > chipper -> belt conveyer -> chip sieve -> belt conveyer -> digester.

FUELS DERIVED FROM BAMBOO

1.-ETHANOL (ETHYL ALCOHOL)

The high cost of petroleum and the future scarcity of this liquid fuel is is now so apparent that the question of its early replacement has become a vital problem for the future development of all of our countries, and it calls for the development of new ideas and new sources of energy.

Our great source of energy is undoubtedly the sun. How can this source best be utilized? Obviously in the growth of plant life from which, in turn, alcohol and other fuels may be produced. One of the most appropriate plants for this purpose is bamboo due to its fast growth. Most of the giant bamboo species of the Americas can grow about 20 meters in 4 months and about three years are required for the culms to harden and mature. The culms grow to their maximum diameter which varies between 12 and 20 centimeters depending on the species. After cutting, bamboo does not need to be replanted. Bamboo can be cultivated on the slopes of mountains which are not used for agriculture releasing fertile lands for food production.

But most important, information already exists showing that bamboo was successfully used not only in the distillation of a diesel type fuel oil by Von L. Piatti (1947) but also that in the Americas at the Instituto Agronomico de Campinas, in Brasil, Barreto & Azzini (1981) used bamboo as a raw material for the production of ethanol. They point out that assuming a carbohydrate content of 80% (starch, cellulose and pentosan), a saccharification efficiency of 80% and a fermentation efficiency of 80%, an ethanol yield of 340 liters per ton of raw material could be expected. Assuming a productivity of 20 t/ha/year of bamboo dry matter (which has been found in Trinidad using Bambusa vulgaris when harvested at intervals of 3 years), a yield of 6,800 liters per annum/ha.could be obtained.

The conventional technology for ethanol production by fermentation utilizes a single carbohydrate, such as sucrose from sugar cane and sugar beets, starch from cereal grains, tubers and roots, and cellulose from wood and agricultural residues as the substrate for the conversion. The utilization of bamboo, a carbohydrate-rich crop containing starch, cellulose, and pentosans, to obtain high ethanol yields would be feasible if an efficient carbohydrase system were available and a process for the complete conversion of these carbohydrates were developed.

In India, Ram and Seenayya (1991) of the Department of Microbiology of Osmania University carried out a research project related to the production of ethanol from straw and bamboo by primary isolates of Clostridium thermocellum. The ability of Clostridium thermocellum to hydrolize cellulose and hemicellulose directly to ethanol has a great potential and significant advances have been reported by several authors. Most of the research on C. thermocellum has used commercially available, purified cellulose. To make this fermentation commercial, more experiments need to be conducted with natural cellulosic materials. However, native biopolymers are poorly fermented by C. thermocellum and physical or chemical treatments are needed to improve substrate utilization and ethanol yields by using only 1% substrate (wheat straw). As ethanol tolerance appeared to limit the yield of the product, it was necessary to improve the existing isolates or isolate new strains of C. thermocellum which were more adaptable to practical fermentation conditions.

In the investigation carried out by Ram and G. Seenayya, two new strains of C. thermocellum have been isolated. Strain SS8 has a broad substrate spectrum (Sai Ram & Seenayya 1989), whereas strain GS1 ferments only cellulose and cellobiose. Both strains display higher ethanol tolerance than other wild-type strain of C. thermocellum and can grow and degrade cellulose in the presence of 1.5% (v.v.) ethanol. In an article the above authors reported on the abilities of these isolates to degrade native and pretreated agricultural materials such as rice straw (Oriza sp.), bamboo pulp (Bambusa sp.) and stems of Lantana and Parthenium weeds.

The materials and methods used in the fermentation experiments were the following. All tests were conducted in 120 ml serum vials containing 20 ml of pre-reduced CMS medium containing (g/l): KH_2PO_4, 1.5; K_2HPO_4, 2.0; urea 2.0; $MgSO_4$, 0.8; $CaCl_2$, 0.15; yeast extract, 0.5; cellulose 8.0; sodium citrate, 3.5; cysteine HCL, 0.15; resazurine, 0.2; in N_2 atmosphere. The media were sterilized by autoclaving at 121° C for 30 min. A 5% (v/v) inoculum grown on 4 gr. cellulose/l, was added and incubations were carried out at 60° C without shaking. The media were buffered with 0.4, 2, 3 and 4% $CaCO_3$ at 10, 50, 75 and 100 g cellulosicsubstrate/l, respectively. Triple strength CMS medium was used when the substrate concentration was above 10 g/l. Medium containing starch was maintained at p.H. 7.5 by periodic additions of 3 M NaOH every 15 h. To determine the effect of sugars, filter sterilized concentrated sugar solutions were added to the sterile CMS medium before innoculation.

Preparation of the Treated Biopolymers

The rice straw and stems of Lantana and Parthenium weeds were cut into approximately 1 cm pieces, ground in a mortar and pestle and extracted by boiling with distilled water for 30 min. Alkali extracted fractions were prepared by autoclaving the agricultural materials at 120° C for 15 minutes with 1% (w/v) NaOH, followed by neutralizing with H_2SO_4. These pieces were thoroughly washed with distilled water and dried at 60° C for 48 h.

Delignified bamboo pulp (DBP) was obtained from M/s Bhadrachalam Paper Board Ltd, A.P., India.

Estimation. The undegraded cellulose was estimated using the method of Weimer & Zeikus (1977). The reducing sugars were determined by dinitrosalicylate. Starch was determined using the method of Dubois et al (1956). The optical density of cellulose-grown culture was determined at 520 mm after filtering the broth through Whatman No. 1 filter paper. Ethanol and acetic acid were determined by gas chromatography of a sample of centrifuged fermentation broth acidified with H_3PO_4.

The results of the fermentation experiments with bio-polymers showed that Clostridium thermocellum strains SS8 and GS1 grew well on pure crystalline cellulose, producing 0.27 and 0.19 g ethanol/g substrate consumed, respectively. However, the untreated agricultural materiasl were poorly fermented. When these fractions were extracted with water, both of the strains fermented them appreciably, producing acetic acid as the major fermentation product. Alkali treatment further enhanced substrate utilization and ethanol yield.

At higher concentration of different substrates, the ethanol produced/substrate consumed ratios declined: the best ratios were with the substrates at 10 g/l.

In general, with increasing substrate concentrations the amount of reducing sugar remaining but the amount of ethanol produced increased with substrate concentrations up to 75 g substrate/l for strain SS8. A 2-fold increase in the ethanol yield by strain GS1 was noticed up to 50 g filter paper or DBP.

2.-LIQUID DIESEL FUEL

Piatti (1947) reported the successful preparation of liquid diesel fuel from an unstated species of bamboo culms by distillation.

Typical constants of this fuel are: d_{15}, 0.921;flame point, 55°; viscocity at 20° C, 1.1 Engler degrees, and at 55° C, 1.0 Engler degrees; water content, 0.35 per cent; total acidity, 0.45 mg. KOH/g; ASTM boiling point range, 140° - 250° C; nondrying oily residues, 1.5 per cent.

OTHER PRODUCTS DERIVED FROM BAMBOO

Activated charcoal absorbent is useful for water purification. The charcoal is manufactured by carbonizing bamboo stems (water content > 15%) within a clay kiln, and naturally cooling the carbonized product in the kiln. The age of the bamboo is preferably greater than 2 years old, and the final product charcoal has a hardness of more than 7 degrees and contains ~ 82% fixed C. (Isao Abe et al 1988).

Bactericides and fungicides for meat products containing bamboo extracts and acetates were studied by Atsuro (1993). The bactericides and fungicides for meat products contain 100 wt. parts bamboo extracts and 10-100 wt. parts acetic acid or its salts. The canes (1kg) of bamboos were refluxed with ether for 20 hours to isolate 40.2 g extracture. Hamburger meat was mixed with 1.1 wt. %. A mixture of 100 wt parts the extracture and 10 wt. parts AcOH, heated to 80°, and kept at 30° for 48 hours showed 8.9 x 102 viable cells/g vs 7.5 x 107 for the control mixed with 0.05 wt % AcONa instead.

Deodorants from bamboo This product is suitable as a deodorant for treating of odors from refrigerators or automobiles. Sheets or strips of Phyllostachys bambusoides (length 300mm, width 30mm, thickness 6mm) were. originally used for the preparation of deodorants from bamboo. They were pressurized with steam in a high-pressure chamber at 3 - 7 kg/cm2, heated at 130-1802 C for 30 -120 min. to remove water, and impregnated with a 6 - 8% alcohol solution for 6 hours to obtain a deodorant, which was placed in contact with an foul smelling air containing 0.500 col.% NH_3 for 20 min, resulting in the decrease of NH_3 concentration to < 0.005 vol. % (Kikuchi 1988).

25 BAMBOO IN THE FIELD OF CIVIL ENGINEERING

BAMBOO ROPES OR CABLES - USES IN ENGINEERING

Chinese tests from the 1st millennium provide ample evidence of characters referring to rope, cord and string. We can define what we mean by plaited or twisted rope (See Bamboo twisted cables used in reinforcing of concrete), that is, a cordage with a circumference of 2 cm or more. Twisted material with smaller dimensions may be termed cord and twine or, when very thin, referred to as thread and yarn.

In China, bamboo plaited or twisted ropes have had applications in many fields of engineering, e.g., in the construction of suspension bridges (See Suspension bridges), for tracking junks on the upper Yangtze River, in the construction of gabions and fascine bundles used in the construction of dikes, and in the hogging trusses that were used in the construction of boats (See hogging truss). Bamboo ropes, however, are not as easy to handle as hemp, and will not coil so quickly or in so small a space, nor will they stand a sudden cross-strain nearly so well. evertheless, they will endure a greater pullingstrain and are lighter in weight than any hempen houser of the same size, which could never hold out against the severe friction of the ragged rocks and would probably rot with the sudden changes of temperature and constant immersion.

Hemp ropes when wet lose about 25 per cent of their strength, whereas, in the results of a test carried out by the Whanpoo Conservancy Board, it would appear that the strength of bamboo rope is actually increased by about 20 per cent when saturated with water.

Although bamboo rope makers are to be found all up and down the Yangtze River,the best bamboo rope is said to come from a village about 20 miles above Ichang, known as Hwanglingmiao, which is famous for the excellence of its-bamboos. An upward-bound junk usually stops there to embark new supplies of tracking-rope for the voyage up stream. An average junk requires the astonishing figure of about one mile of bamboo rope of varying lengths and sizes. These ropes only last one trip despite the utmost care. Economy in tracking-lines is a dangerous policy and has been responsible for many accidents on the Upper Yangtze.

Not infrequently a bamboo rope is carried away, or has to be cut to avoid an accident; when this is the case, the rope is very rarely joined by splicing, as this is a technical matter, but by laying the two ends side by side and securely binding the rope at the overlaps for an interval of about one foot. A large rope may have three, or even as many as four, bindings at one foot intervals.

Discarded bamboo rope is used as fuel, and is also cut into lengths of a few feet and sold as torches, which last about 20 minutes.

The method of making the rope, which varies very little in different sites, is surprisingly simple and quick. The most tedious process, and that demanding the most skill, is the preliminary splitting of the bamboo into narrow strips about 1/4 to 1/2 inch (6 to 12 mm) wide, depending on the diameter of the rope required. The thickness of the strip is about 3 mm which corresponds to the exterior and densest part of the culm wall.

The canes are first soaked in water to make them soft and pliable. The splitting is done with a large sharp knife by a man who wears a protective finger sheath made of bamboo and who sits on a low bamboo stool. The plaiting of the rope is carried out by another man who stands facing a long, steep,downward slope or, where the country is too flat to permit this, is perched on a flimsily-built bamboo tower.

He wears a protective apron and between his knees he grips an 18-inch long half-cylinder of bamboo, which hangs from a string tied round his hips, into which he presses the coil as it leaves his fingers. The finished rope thuspasses through a sort of crude "fair-lead" and slips easily away from where he stands, either falling down the height of the tower or else sliding down the beaten earth slope before him. The twist consists of a varying number of bamboo strips, always in multiples of four, in which the joints are irregularly placed for extra strength.

The method used on the Upper Yangtze is then to coil the rope which is usually in lengths of 1,000 to 1,800 Chinese feet (333 to 600 meters), into a large, high, wooden tube permanently fixed over a cement stove. A solution of lime and water is poured through to a funnel into the base of the cement framework above which rests the rope, supported by a small, circular, projecting shelf which keeps it clear of the water by some inches. The whole is covered with another tub turned upside down over that containing the rope, and the rope is steamed for four hours over a coal fire, the lime in the water serving to harden the bamboos. The water is replenished through the outer funnel as it becomes exhausted. Draught and outlet for smoke is provided by an immensely tall, four-sided chimney, reinforced at each orner with the ubiquitous bamboo. A variation is the larger calibre bamboo rope made near Ichang, in which the strands are laid as in hemp rope instead of being plaited. This rope is used for moorings but never for tracking.

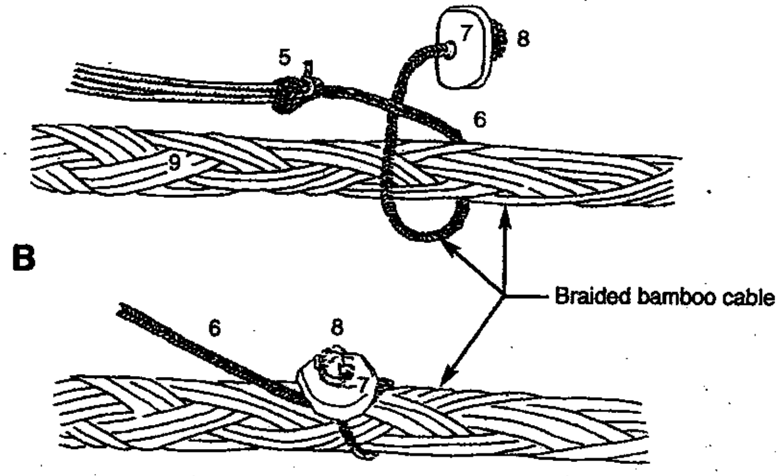
Tension tests of the plaited bamboo rope used for tracking junks in China

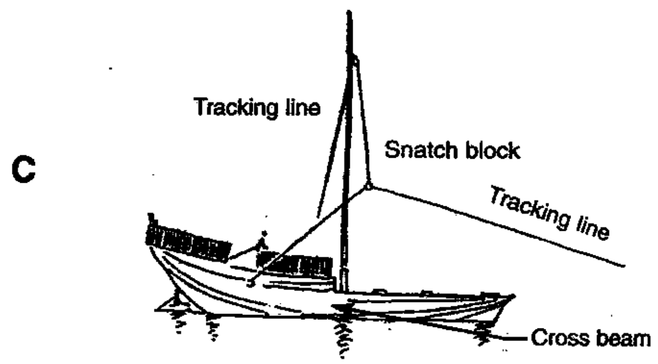
The following is a report regarding tension tests carried out by H.F. Meyer at the Whangpoo Conservancy Board in 1924:

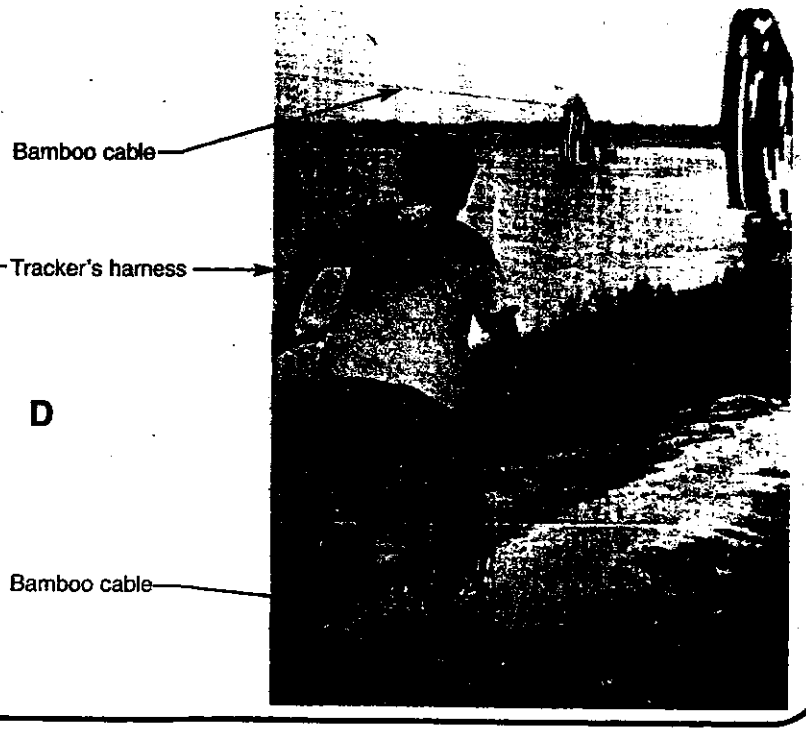
"The plaited ropes from the Yangtze Gorges consist of a middle cord of straight bamboo material split off from the interior part of the bamboo, serving only as a support for the fibers plaited around it, which form an outer load

Fig.27.1 PLAITED BAMBOO ROPES USED FOR TRACKING JUNKS

A. Tracker's harness made with braided bamboo







carrying layer. This outer layer consists of the outer fibers, each of which is about 1/8 of an inch of the culm wall (3 mm) of big strong bamboo stems. In the joints of the fibers forming the rope, the outer ones overlap each other by one foot (30 cm) while the inner ones have no overlap at all.

The one and a half inch (38 mm) diameter rope tested by me in November 1923 had a square section area of about 0.7 square inches of solid bamboo material, the central cord being 0.3 and the effective outer fibers being 0.4 square inches.

Some difficulties arose in finding a reliable device for fixing the specimen being tested in the machine. The best results were obtained when both ends were stuffed full of tar-filled rope and the ends then carefully wound with the same sort of rope in the way indicated in the sketch. The tested specimens were 2 feet 6 inches long (about 76 m).

The rope was capable of carrying about 11.000 pounds or more than 5 tons when absolutely dry. The middle cord broke at 8,000 pound (about 3,628 kg). The stress in the outer fibers was 26,500 pounds (about 1,863 kg per square centimeter), this being the average of three tests. The result compares favorably with my statements in "Tests of Mechanical Properties of Bamboo", page 16, where the same is given as 25,000 pounds per square inch (1,757 kg per square centimeter).

I did not succeed in obtaining any reliable results as to the strength of the rope when saturated with water, as the specimen slipped out of the grips before the final breakdown, but the tests indicated a 20 per cent increase instrength, corresponding to a total carrying capacity of about 6 tons.

Signed by H.F. Meyer, Engineering Assistant, 28th January 1924".

Tracking has been developed almost to a science on the Upper Yangtze River on the passage between Ichang and Chunking, where there is always a large group of long distance trackers to haul the junks along in the comparatively calm reaches between rapids where they cannot operate under sail alone. On rival at one of the bad rapids, the junks bank in and wait their turn to be hauled over the rapids. Sometimes as many as 200 or more additional men have to be engaged for this work. On the banks below one of the larger rapids there are a number of mat houses forming a temporary village (temporary, for the ground on which they stand is under water during the summer floods). Here lives a vast concourse of men, women and children, who earn a scanty living by assisting in the hauling of junks over the head of the rapids.

The trackers are either temporary or professional. The former are men who leave their normal work of farming or fishing. The latter are, as it were, a class apart, low caste indiduals, formerly opium smokers, and men of no great intelligence. (Worcester 1966).

Once harnessed to the junk, the men display perfect discipline and teamwork and are controled by the hythmic beat of a drum from the junk, the note being varied; the signal "stop" being denoted by a short sharp beat; "slow" indicated by a slow and even rhythm; and "full speed" denoted by rapid, constant drumming.

The complete tracker's harness consists of a cloth band joined by double ropes into a loop to which is connected a short sennit stopper, or tail (Fig. 27.1 D).

The trackers hitch themselves to the bamboo houser (Fig. A) with the sennit tail of their harness, which ears against the button when the strain is on (Fig. B), but loosens directly when the tension relaxes, forming a safetydevice whereby the tracker can easily release himself in an emergency, such as when the junk "takes charge" and sheers out into the current. Once a junk is cast off, her safety depends on the skill and cool head of the laodah, who must get some steerage way on to prevent her getting broadside into the current and colliding with a rock. (Worcester 1966).

Fig. 27.2 *Hauling a junk over the Yeh Tan. Most upward-bound junks are accompanied by a sampan, to land the trackers and the bamboo hawsers. Failing this, they have to bank in to do so . In the ordinary way, about a dozen men track a large junk, and two or more follow behind them to clear the line, which may extent for 800 yards in a difficult rapid. (After Worcester, 1966)*

FASCINE BUNDLES MADE WITH BAMBOO ROPES

The definition of fascine bundles or facina bundles is: a long cylindrical bundle of wooden sticks bound together at intervals and used for filling ditches, strengthening ramparts or making parapets, revetments or mats for river banks, dams or jetties.

Besides gabions, huge fascine bundles of kaoliang stalks fastened with bamboo rope were also developed. These were very convenient when the water was heavily silt-laden, for solid material would quickly be deposited in the interstices of the mass as the water filtered through, and in time it would become very compact. Such brushwood fillers (a Sung invention) were termed *sao*.

Figs 27.3-27.4 taken from the book Hsiu Fang So Chih (Brief Memoir on Dike Repairs) by Li Shih-Lu, shows the method of handling them. In closing a gap in the Yellow River dikes in 1904, the dike was about 30 ft. wide at the bottom and 11 ft. at the top; its height was 33 feet. The gap to be filled was 36 ft. wide at the bottom and 54 ft. at the top, with water pouring through it.

Gabions and fascines were used, handled by 20,000 men hauling on 100 ft. long cables eotechnic but on the heroic scale. In other works giant bales of kaoliang stalks with a cross section of 20 x 50 ft. were used for stopping a breach (Needham 1970).

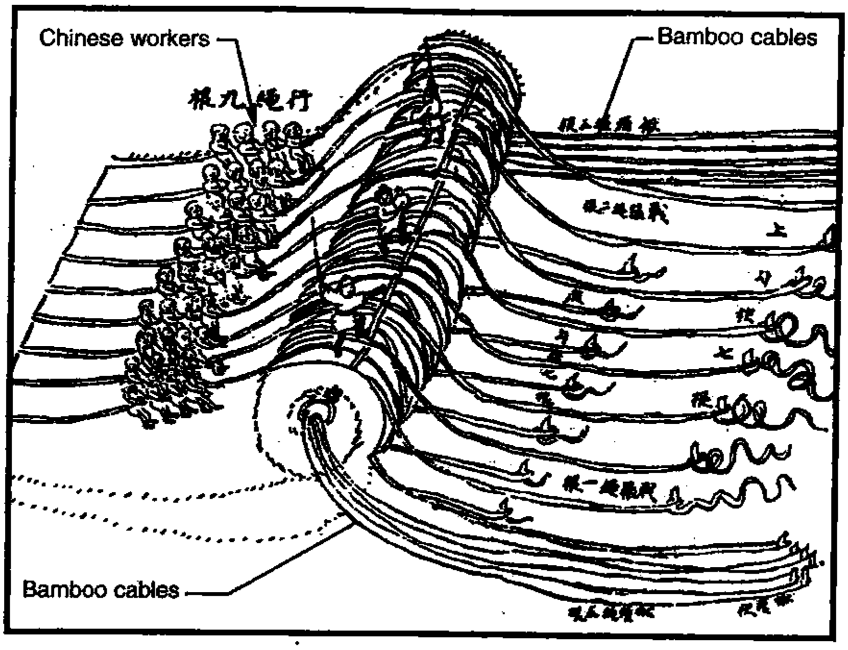


Fig . 27.3 *Sketch from the year 1775. Manhandling a giant fascine bundle into position. The nine houling ropes, with the haullers , are seen in the left, the side toward the water. The five 'end -head bundle cables' pass throu the centre of the fascine and being slowly paid out, act as brake. The seven 'overhook cables' continuous with the seven 'underhook cables' form a safety cage in which the fascine bundle (sao) can roll; they would have to be re-pegged from time to time. (Needhan,1970)*

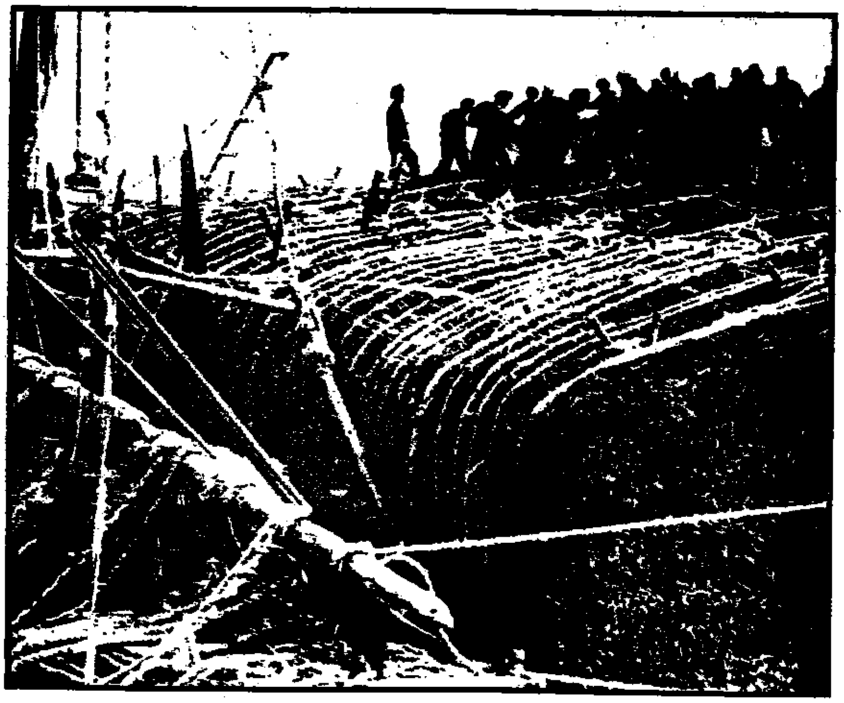


Fig. 27.4 *A huge baile (sao) of kaoliang staks are tied with bamboo ropes being lowered into a dike breach on the Yellow river near Liao-chheng and Tunga (Photo Todd, 1935). The cordage and pegging of these veritably mobile haystaks gives life to the sketch in Fig. 27.3. When such a bale is in place a foot or so of earth is deposited on top of it so that it settles down more firmly into the mud and silt of the bottom.(Needham, 1970).*

GABIONS MADE WITH BAMBOO ROPES - THEIR USES IN BRIDGES

The remarkable tension strength of plaited strips of bamboo culm has already been referred to in connection with tow ropes, driven belts, suspension bridges, and so on. Since it was available in such unlimited quantities, the earliest technique was probably to leave the baskets or skips in which stones or earth had been carried to the spot in position, instead ot taking them away to fetch more. As time went on, the elongated gabion, or sausage shaped open workcrate of bamboo packed with stones, was developed.

The dimensions of the gabions used by Wang Yen-Shih seem to have been 40 feet in length and 17 feet in diameter. Today 60 feet lengths are commonly used; and this stage musthave been reached by the time of Yang Yeng and Wang Yeng Shih in the year 28 B.C. The great advantages of this invention has already been emphasized in many works; the relative lightness of the gabions permitted their use on alluvial subsoils without deep foundations, and their porosity gave them a most valuable shock-absorbing function, so that surges and sudden pressures did not damage the defenses.

It is interesting to find that the same device was employed in Europe, no doubt independently, at least from the 14 th century onwards, especially in the sea-dikes of the Netherlands. There bales of compressed sea weed, or a screen of compressed sea weed within piling, or bundles of reeds fixed down with their roots pointing seaward, were usedoutside the Dutch clay polder dikes. Such shock-absorbers, less resistant to decay than bamboo basket-work, had to be renewed every five years (Needham 1970).

Fig. 27.5 BAMBOO BRIDGES SUPPORTED ON BAMBOO GABIONS

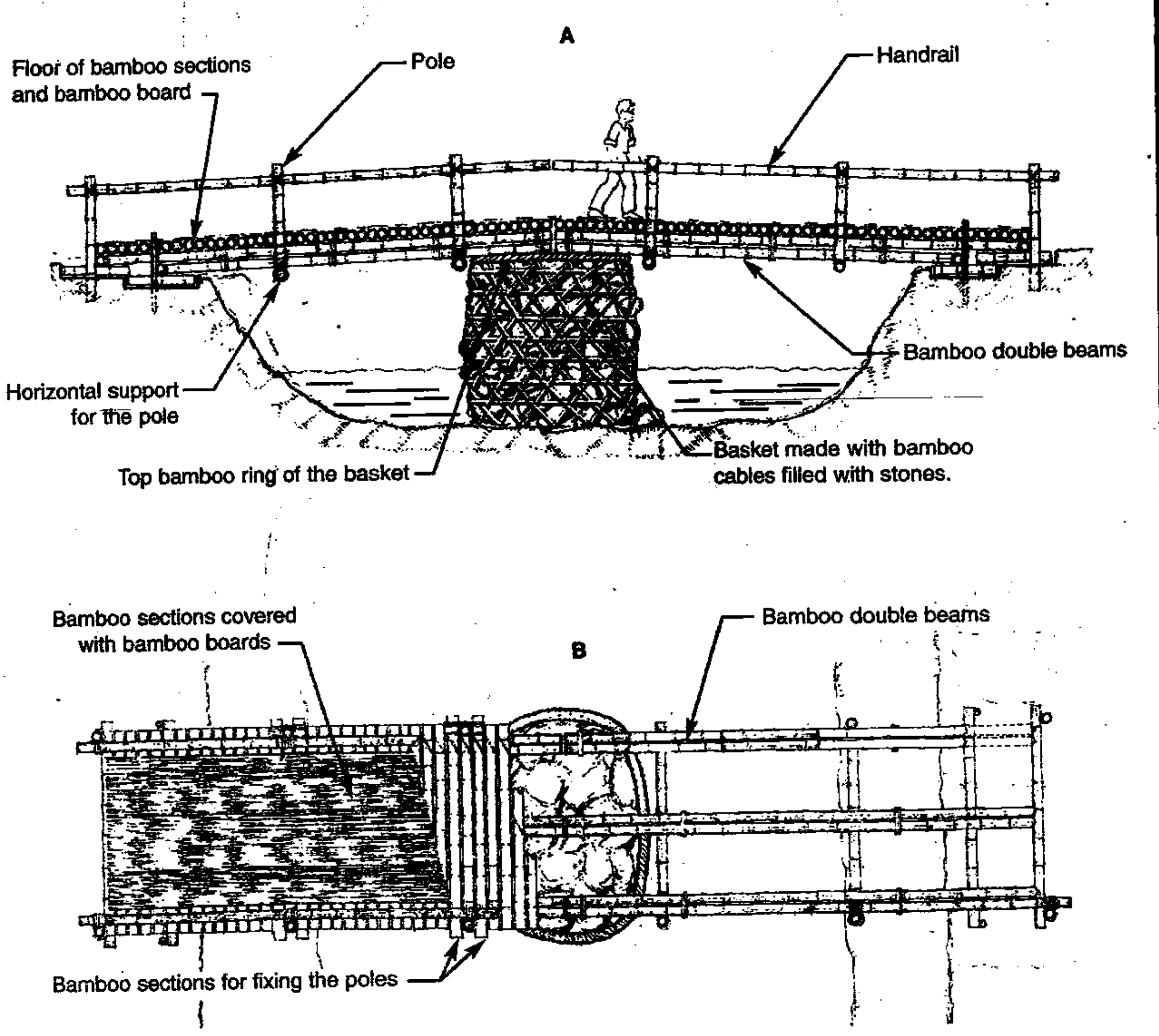
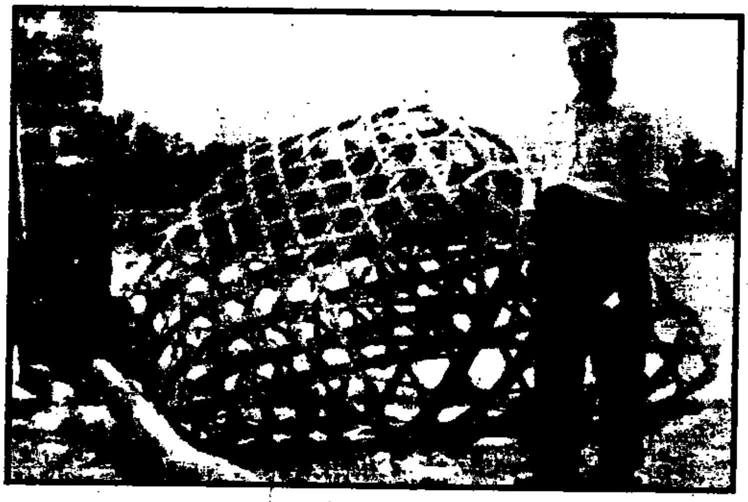


Fig. 27.6 BAMBOO GABIONS USED IN BRIDGES AND RIVERBANKS

A. *Ancient bamboo bridge supported on several giant bamboo gabions.*



B. *Giant bamboo baskets weaven with bamboo ropes that were used filled with stones as gabions in river banks and also as supports of wood and bamboo bridges.*

C. *In Japan the small bamboo gabions used in river banks were known as "snakes".*

BAMBOO BRIDGES

PRIMITIVE CHINESE SUSPENSION BRIDGES (1)

PRIMITIVE BAMBOO SUSPENSION BRIDGES

Fig. 27.7

A. *A single cable used as "bridge deck".*

B. *A single cableway forming a catenary curve.*

Marco Polo, the 13th century Venetian traveler who visited China, recorded in his travelogue that China was a country of numerous bridges, with 12,000 in Hangchow alone, most of them made with stone and wood.

In China most of the bamboo suspension bridges are in the western and southwestern regions, Szechuan and Yunnan, and in the Tibetan borderlands, where the deep river-gorges produced the need for them. They have played an important roll from an early date in the comunication of the people of China and the peoples of Thailand, Burma, Nepal, India, and Kashmir.

According to Goodrich, there is a pesistent legend that the first suspension bridge in China was builted by the Han Emperor Ming (A.D. 58-75). This is the *Lan chin* bridge one hundred *li* (or about 33 miles) southwest of the town of Ching-tunting (lat. 24° 31', long 101° 04') in the province of Yunnan.

The bamboo ropes or cables used in the construction of bridges are fabricated into a circular unit of the desired dimensions either by twisting (See manufacture of bamboo cables by twisting for reinforcing concrete) or by plaiting, made in the same way as the cords of small diameter that were used for towing ships against the current of navigable rivers, or when the wind was unfavourable for hoisting sails; while the heavier cables, with larger dimensions up to 90 meters long (300 feet) and up to 30 cms in diameter are used for bridges.

In the plaited cables, bamboo strips taken from the inner part of the culm wall, form a kernel or core in the centre of the rope. Round them is woven a thick plaiting of bamboo strips taken from the outer silica-containing layers. The plaiting is made to grip around the kernel when the cable is summited to tension, the more tightly the higher the tension. These cables generaly have a diameter of two inches. The big bridge cables consist of three or more of these cables plaited or twisted together.

When the bridges are built, the cables are towed or floated across the river, hauled up and anchored to posts set in the ground, or are tied round large trees.

The technic used in China for shooting birds with arrows to which long strings and weights are atached so that the arrows can afterwards be recovered, may have been important in solving the problem of getting suspension bridge cables in position across almost impassable gorges.

When placed in a testing machine, the straight inner strands brakes first, while the plaited material shows very great strength, breaking at a load of 1,828 kg/cm² (26,000 lb per sq.in). An ordinary 5 cm (2 in.) hemp rope can carry a stress of only about 562 kg/cm² (8,000 lb. per sq.in). Moreover, while hempen ropes lose some 25% of their strength when wet, the tensil strength of plaited bamboo cables increases about 20 % when they are fully saturated with water. By the other hand the silica containing outer surface is very resistant to wear, e.g. against rock surfaces, which is naturally important both in towing and bridge cables.

Needhan (1970), point out that on a journey up the Yangze in 1908 Esterer made some measurements on the bamboo cables used by the trackers on junk-hauliers. He reckoned a tension of 518 kg/cm² (7362 lb. per sq. inch) (av.) which was of the same order as that normaly taken (at that time) by steel wires, yet the breakages were very few.

TYPES OF PRIMITIVE BAMBOO SUSPENSION BRIDGES

According to Needhan (1970),the eastern part of the Tibetam massif must surely be the focus of origing of primitive suspension bridges, not only on account of their total frequency, but because so many forms, from the simplest to the most advanced pre-modern types of bridges are found there.

The simplest and most ingenious device that was often erected in ancient times for transporting persons, goods, and animals across deep swift streams, particularly in the mountains borderlands between China and Tibet where no stone structure is possible; consists of a strong single bamboo cable and having a diameter commensurate with its length and the weight of the load it is likely to bear. This single cable was used in the following kinds of bridges and also to carry the runner of a ferry-boats back and forth. (Fig. 27.9). It is posible that the single rope bridges are the origin of the ordinary suspension bridges that we will see in this chapter, but they may have developed as a simplification of the latter.

1) A single bamboo cableway suspended horizontally. Perhaps this is the simplest of all the primitive types of bamboo bridges. It consists of a single cable suspended horizontally between shear legs which are placed on either side of the river or gorge to be spaned. A person or bamboo basket is attached to a wooden slides which slides on the cable. This bamboo basket can acommodate two persons and can be pulled across from the oposit bank by means of a lighter cable. (Fig. 27.8). According to Smith (1964), in a bridge of this kind over the Brahmaputra, the cable was made of three strands of bamboo cables, each one inch thick, twisted together and spanning 180 meters (600 feet).

Fig. 27.8 *A suspension bridge using a horizontal single bamboo cable way. The two ends of this bamboo cable are at aproximatelly equal heights on each side of the river. The wooden slide carries a rope cradle to support the passengers, as well as cords on each side to pull it.*

2) A single cableway forming a catenary curve. A quicker crossing can be obtained by two cables each one for traveling in opposite direction. Each cable is lifted up by shear legs on oposite sides of the gorge, and declining in catenary curves so that their arrival points are much lower than their points of departure, so that the traveler slides along under his own weight. Men and animals pass across hanging in various kinds of cradles suspended from a wooden slides which have a groove and well greased with yak butter to reduce friction, but even so the cables have to be frequently renewed. By the other hand in order to reduce the heat generated and to prevent it catching fire on account of the friction, the cable is lubricated and cooled by trickling water on it from a bamboo tube.

In some places were used "strap-hangers so that the rider could pull himself forward towards the end of the span. In this case the straps are crossed over the chest, carried under the thighs and fastened to the wooden slides from behind the neck. Passengers are always warned against touching the cable as the sharp edges of the bamboo strands are apt to cut the fingers badly. The other cable, suspended over the abyss, conveys travelers in the opposite direction.

McClure (1957) quotes the following description made by E.H.Wilson, in his book "A Naturalist in Western China", 1913: ..."*This simple but extremely useful structures consist of a bamboo hawser stretched across the stream ussually from a higher to a lower point. The howser may be anything from 8 inches to a foot thick, and being heavy sags considerably in the middle. To cross one of these cable bridges a person is supplied with a length of strong hempen rope hanging free from a saddle-shaped runner of oak or some other tough wood. The rooner clips the cable, and the hempen rope is fastened under and around the legs and waist to form a cradle. When all is properly secured the person throws one arm over the top of the runer, gives a slight spring, and glides down the inclined cable at an encreasing speed. The impetus obtained in the downward rush carries the passenger over the central dip and more or less up the lesser incline on the opposite side. If the momentum is insuficient to land the person, the remaining distance has to be traversed by taking hold of the houser and hauling hand over hand. Crossing by these bridges is fearsome work until one is accostomed to it. It is speedily accomplished, and there is practically no danger so long as one keeps a cool head and the ropes do not brake. It is a common sight to see men with loads and women with children on their backs cross these bridges. But heavy loads are usually fixed to the runners and hauled across by a rope attached to them*".

Mules and luggage are passed over in the same manner. For the animals a special cable with heavy straps is used.

3) A single cable used as "bridge deck".

The next step in the development of the suspension bridge consisted of fixing two parallel cables hung across the river horizontally, to two points at more or less equal height in each side, one five feet or so above the other. The traveled had to walk on the lower cable and hold the upper one to keep their balance. The better bridges of this kind are those which have a doble cable to walk on and the balancing cable is connected with the "bridge deck"by vertical ropes 3 to 5

Fig. 27.9 *The ferryboat cable is attached to the wooden "runner" which carries the boat quickly from one bank to the other.*

meters appart. In good weather it requires less preparation and trouble to cross these gang bridges, as no helpers are necessary. When a gale blows and the cables sway in the wind, the curved switch back cable is preferable. Fig. 27.7 A.

4) The "V" bridge. This is a derivation of the "deck cable" bridge. in which are added arrangements which would permit travelers to cross without hanging in a cradle or acquiring the skill of a tightrope walker. One of the simplest ways in which this was done was to suspend aditional ropes as hand-rails for better balance of the pedestrians so that the set of three formed a "V" section, the rails being attached to the tread- cable at short intervals rails. It is very important to point out that was this kind of bridge generated the suspension bridge proper.

5) Ferryboat cable.(Fig. 27.9) A single bamboo cable has been used in another very interesting manner to expedite and make safer the crossing of some of the streams which are too swift for ordinary navigation. Here the cable is suspended at a high of a few meters above the surface of the water, and instead of the "saddle", a boat is attached to the wooden "runner". Then the force of the current, which would otherwise carry the boat downstream in spite of all human efforts, is transformed by means of an oar or rudder set at the proper angle into lateral trust which carries the boat quickly from one bank to the other (McClure, 1957).

The most advanced premodern bamboo bridges

The most advanced premodern bamboo suspension bridges, also known as "flyng bridges", were considered to be a major engineering achivement. These were developed by the Chinese of western China and Tibet and by the tribes living on the southern slopes of the Himalaya range. According to Fugl-Meyer (1937), the history of suspension bridges in China is very uncertain; some believe that they were copied from the suspension bridges built in the Himalayas, but Chinese suspension bridges are quite different from the three cable suspension bridges found in the Himalayas. The suspension bridges of the Chinese-Tibetan borderlands are built according to an entirely different principle. If one type influenced the other, it must have been indirectly through the passing of information from tribe to tribe. Similar topographical conditions seem to have caused both the people of the Himalayas and the Chinese to independently become suspension bridge builders.

In the Chinese suspension bridge, the usual principles known in connection with wooden bridges are applied. A number of heavy cables of plaited bamboo fiber are suspended side by side over the distance to be spanned. There are eight to twelve cables, tightened as much as posssible by a very ingenious system of capstans at each end. Hand railings of frailer cables frame the bridges on both sides 5 to 6 feet above the main cables. The deck cables are interconnected and covered with wooden boards. In this kind of suspension bridge, cables simply substitute the wooden stems found in an ordinary single-span truss bridge. The characteristic of this bridge is that the main cables take the shape of a catenary curve, as does the deck. Due to this, these bridges are known as catenary bridges.

The Himalayan suspension bridge appears to be the product of a primitive civilization. It does not have the same finished appearance as the Chinese bridge, but the principle underlying its construction is much better from an engineering point of view, and it may be well be considered the prototype of the true modern suspension bridge.

In the Himalayan bridge, the two main ropes lifted high above the deck at both ends, are suspended parallel to each other a few feet apart in a gentle curve. A narrow bridge deck hangs under the main ropes and leads from bank to bank in either a nearly horizontal line or in a flatter curve than that of the main cables. The deck is fastened to the two main cables by vertical strands or slings of thinner cables running under the deck from one main rope to the other.

It seems probable that the Himalayan supension bridge arouse out of the three cable bridge ("V" bridge) when the hand-rails replaced the main cables and their ends were fixed higher up on the banks and the cable for walking on was hung from the two main cables, which had been originally used as hand-rails.

Most remarkable is the fact that bridges identical to those of the Himalayas were developed in ancient times in Peru, South America (Fig. 27.10 B) by the Incas. The most important was the Huancayo Valley bridge, which spanned 46 mt (150 ft). The cables used in the construction of these suspension bridges in Peru were made, according to Needham(1965), of maguey fiber and hide. But according to Palomino (in Ravines 1978), the plaited cables of the Sarhua suspension bridge were made of Pichus (a 3 meter high shrub).

According to the above, we have to make the distinction between the "suspention bridge" proper from the Himalayas and the "catenary bridge" from China. Both are suspension bridges, but a suspension bridge proper has a flat deck suspended (by smaller secundary cables) from the main cables thrown across the river, and the passengers move horizontally. In the catenary bridge, the main cables directly support the deck and, consequently, the deck actually follows the curve of the cables. In this case, the passengers travel along the curve.

Differences between the Himalayan and Chinese suspension bridges

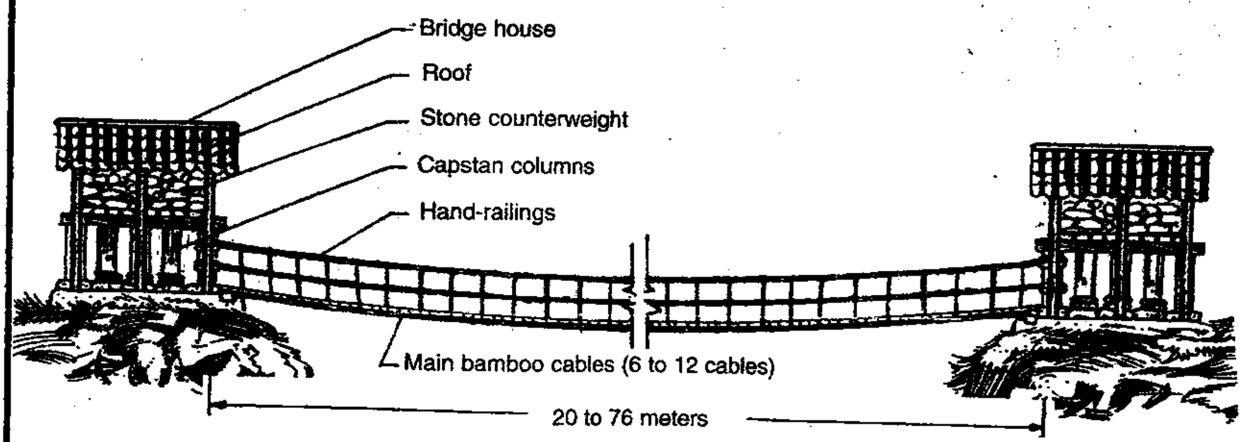
The Himalayan suspension bridge

Fig. 27.10A *The Himalayan suspension bridge was derived from the 'V' bridge and was the origin of modern suspension bridges.*

Fig. 27.10 B *This shows a drawing of the suspension bridge built on the Carabaya river in Peru, which is similar to the Himalayan bridges. The thick cables or ropes are braided out of wines and pliable twigs, and are supported by the piers rised on stone embackments.*

Fig. 27.11

Chinese Catenary bridge



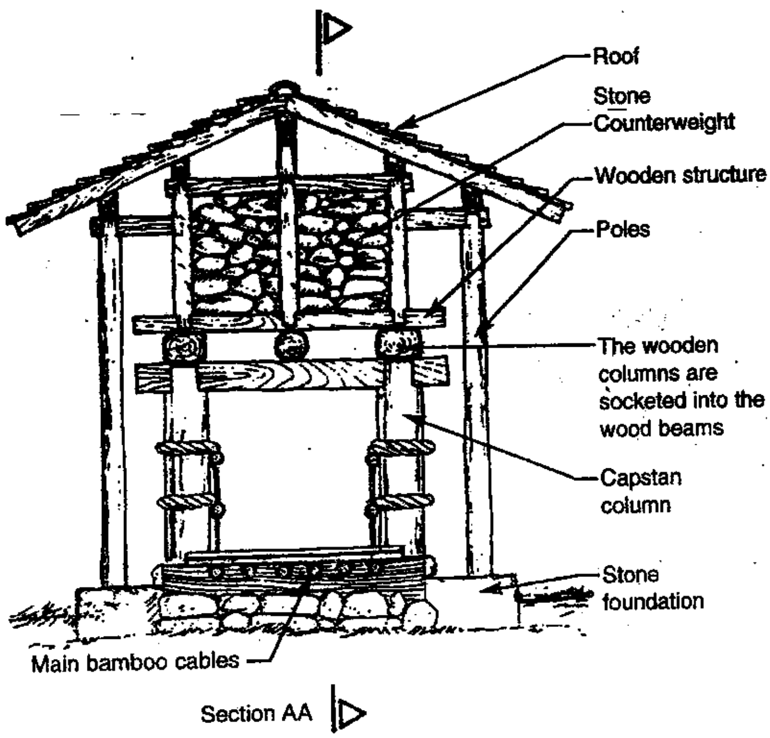
THE CATENARY SUSPENSION BRIDGE

Most ordinary Chinese suspension bridges consist of a single span. On each side of the abyss, at each end of the bridge a substantial bridge house is built on a stone foundation, its roof being supported either by wooden poles or stone walls. Inside this house or porch there are two rows of stout vertical wooden columns, one for each of the side-cables of the bridge, and these columns act as rotation capstans for tightening the bridge cables. The columns are socketed into the foundation below and into the wood beams above. The big stone counterweight under the roof of the bridge house prevents the capstan-columns from lifting themselves out of their sockets. The columns have holes in which bars can be placed so that the columns can be rotated or turned round as vertical axis. When a rope is fixed to a column, it can be tightened by turning the column, in much the same way a violin string is tightened by turning the key. The main cables under the deck are fastened to the capstan-columns nearest the span, or to horizontal winch-columns under the floor boards, and in front of the bridge house they pass through hardwood leads which give them their proper position under the deck. The hand-railing cables are fixed to the other columns or even to the stone roof supports. Very often the number of cables in the two hand-railings corresponds to those under the deck. When the deck cables begin to deteriorate, they are replaced by new cables, and the old ones are used to replace the old hand railings, which are then discarded.

The hand railings are connected by smaller vertical cables as a protection. The deck cables are connected by hardwood pegs driven through all of them. The entrance through the bridge house is inconvenient on account of the cables which cross over the floor from the front leads to the columns. The deck is supported by from six to twelve cables and the spans vary from 40 - 60 meters (130 - 200 feet).

Fig. 27.12 The bridge house - Construction details

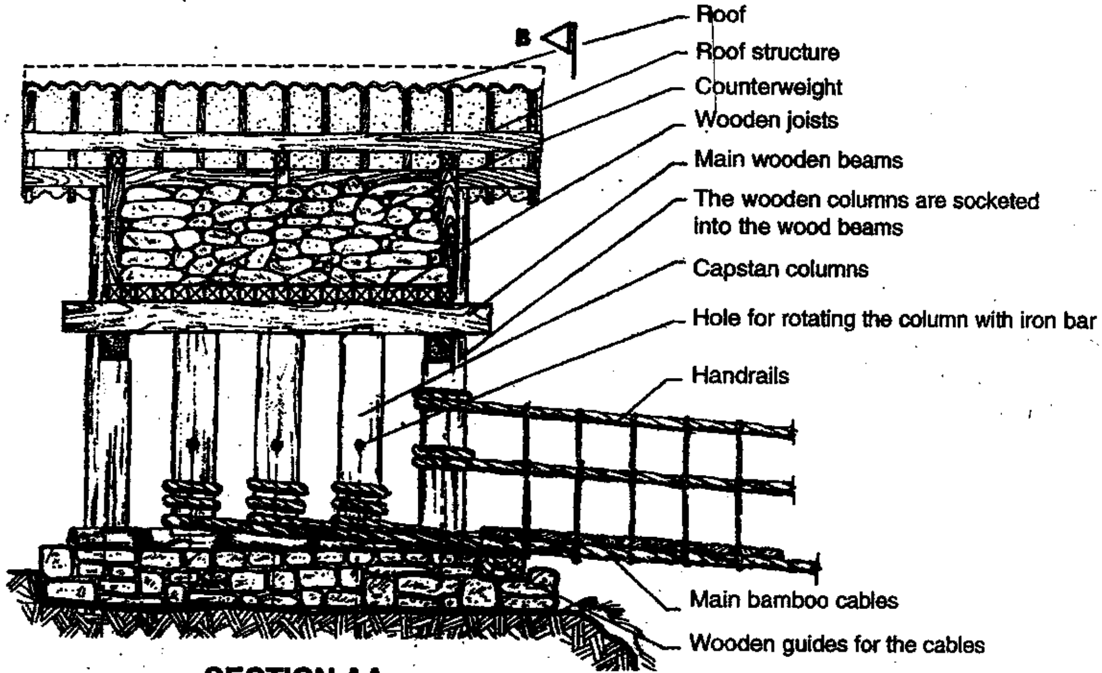
An ancient bridge house in which the stone counterweight over the columns, the fixed and rotary columns and the bamboo cables can be seen.



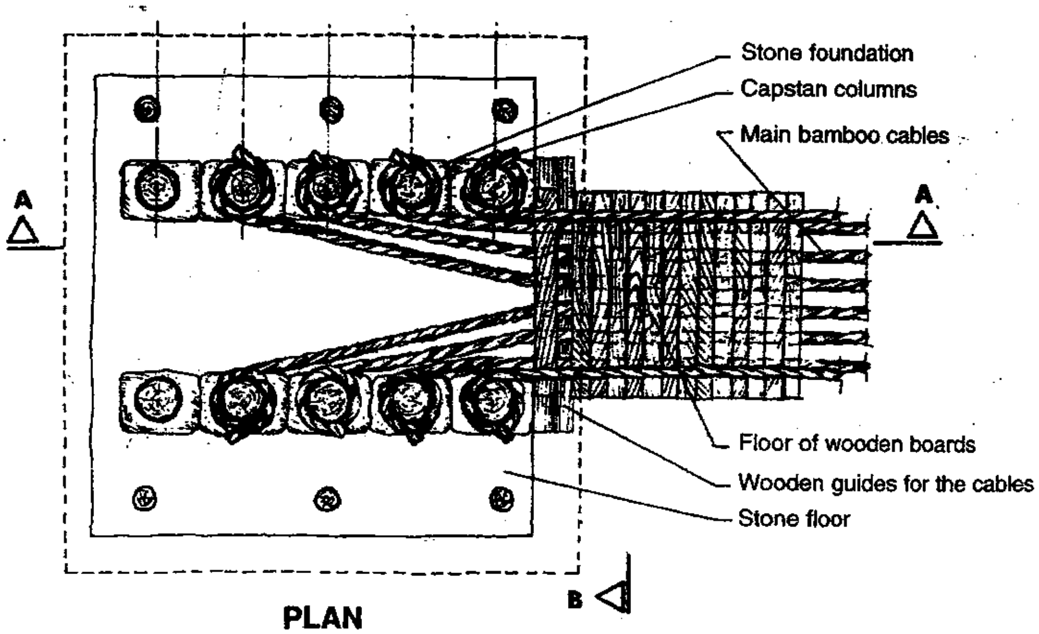
Detail of the bridge house

Fig. 27.13 **CONSTRUCTION DETAILS - THE BRIDGE HOUSE**

Longitudinal section and Plan



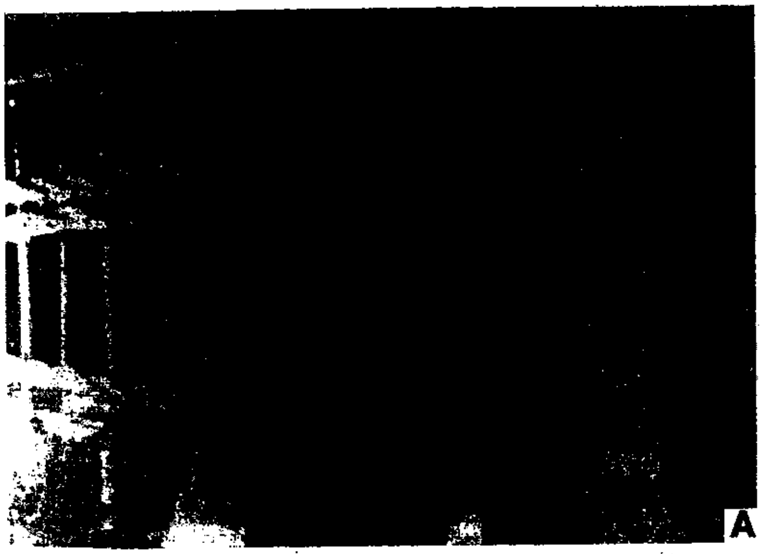
SECTION AA



PLAN

THE POSITION OF THE BAMBOO CABLES IN THE BRIDGE

Fig. 27.14 A. *Inside this house or porch there are two rows of stout vertical wooden columns, one for each of the side-cables of the bridge, and these columns act as rotation capstans for tightening the bridge cables. The diameter of the cables was usually 0.30 m. and it could be compared to the head of the Chinese man located under the central cables.*



B. *Generally the number of the cables under the bridge were about ten and were changed every year for new ones.*

C. *As explained before every year the cables which are located under the bridge are replace every year for new ones and the removed cables are used as hand-rails.*

D. *The An-Lan suspension bridge. Bamboos are fastening the hand-rail cables.*

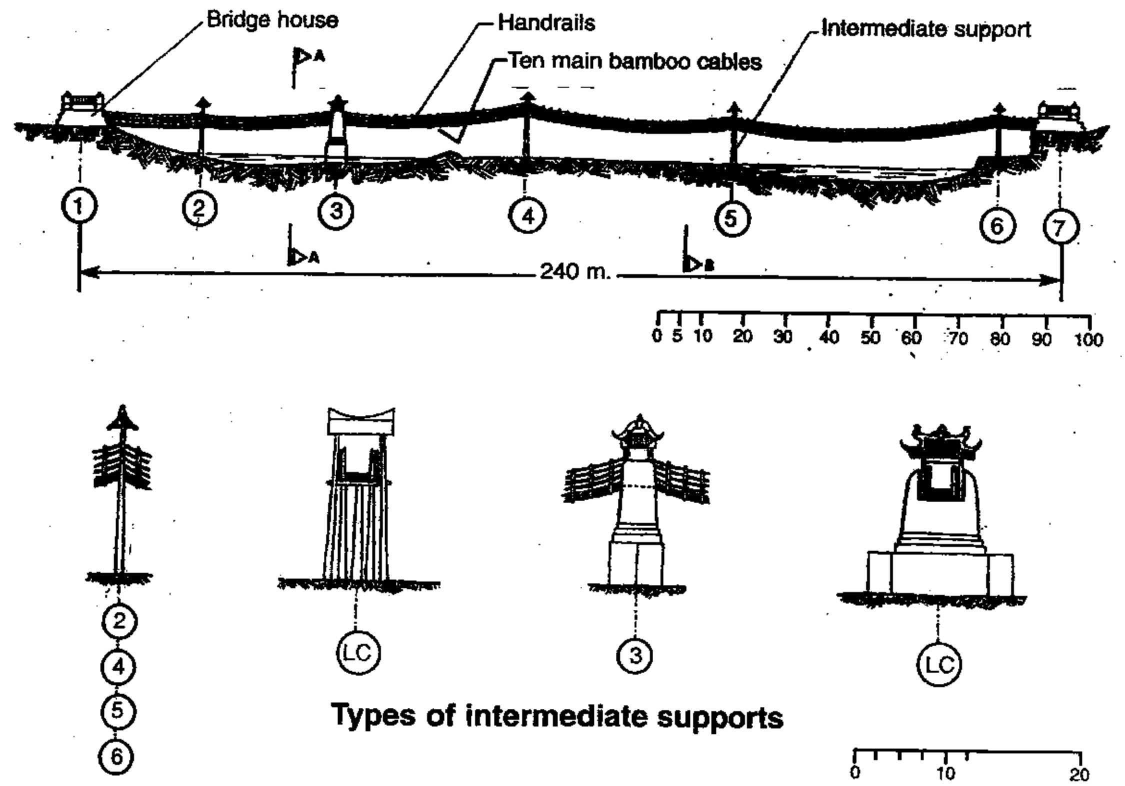
THE LARGEST CATENARY SUSPENSION BRIDGE IN CHINA

Fig.27.15A Chinese stamp of the Pearl Bridge

Fig.27.15 B. *The largest suspension bridge (240 m) built with bamboo ropes over the Min-chiang River at Kwan Hsien County, China.*

Only in a few places are found bamboo suspension bridges made in more than one span. The most famous and impressive bridge of this kind was the Chupu (Pearl Bank) Bridge which was erected over the Min-chiang River in Kwan Hsien County, the site of the remarkable 3rd century irrigation works which render fertile the plain of Chengtu in Szechuan. The Chupu Bidge is about 240 meters long and has six-spans, the largest of which measures 61 meters (200 feet), the bridge is 2.75 meters (9 feet) wide and is carried by ten bamboo cables, each of which is 16.5 centimeters (6 and a half inches) in diameter. First constructed about 1,000 years ago, it was later damaged and ferry boats were used instead. It was reconstructed in 1803; then, in 1974, when plans were drawn up to build a sluice-gate on the bridge-site, a steel cable suspension bridge, similar in size to the original one, was built 100 meters downstream from it. For unimportant bridges with short spans, the bridge houses and their capstan systems are missing. The main ropes of the deck are tied to posts planted in the ground, and the hand railings are lifted to their proper height by wooden stays. In the Sui Dynasty (A.D. 569-618) most of the bamboo cables were replaced by iron chains.

Fig, 27.15 C Details of the bridge and the type of supports

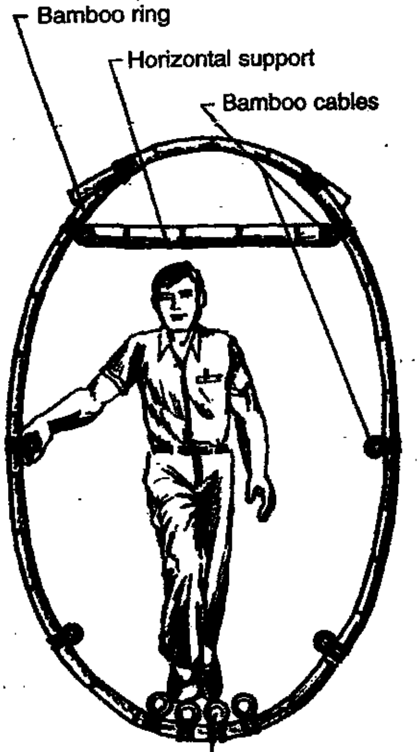


TUBULAR BAMBOO SUSPENSION BRIDGE IN INDIA

Tubular bridges are the result of an improvement consisting in adding an overhead cable to the hand rails and plaiting the whole together so as to form a continuous tubular structure. Such bridges are made by the Abor tribes people on the Assam-Tibet border some one hundred miles up from Dibrugarh, and reliable descriptions speak of spans of as much as 245 meters (800 feet) with a swing of 15 meters (50 feet) from side to side. The Nagas also construct impressive bridges with various combinations of cables. According to Parry (1932), the Lakhers built bamboo bridges called "hleiri", with which the larger rivers are spanned during the rains. A spot is selected, preferably with suitable trees on each bank, as otherwise tall wooden posts have to be erected, and bamboo cables are strung across the river from bank to bank and attached to the trees. These cables are tied together and used for the sides of the bridge. From these bamboo cables, hoops 1.52 meters (5 feet) high and 1.21 meters (4 feet) wide are hung at intervals of 1.20 meters (47 inches), and tied onto the cables suspended above.

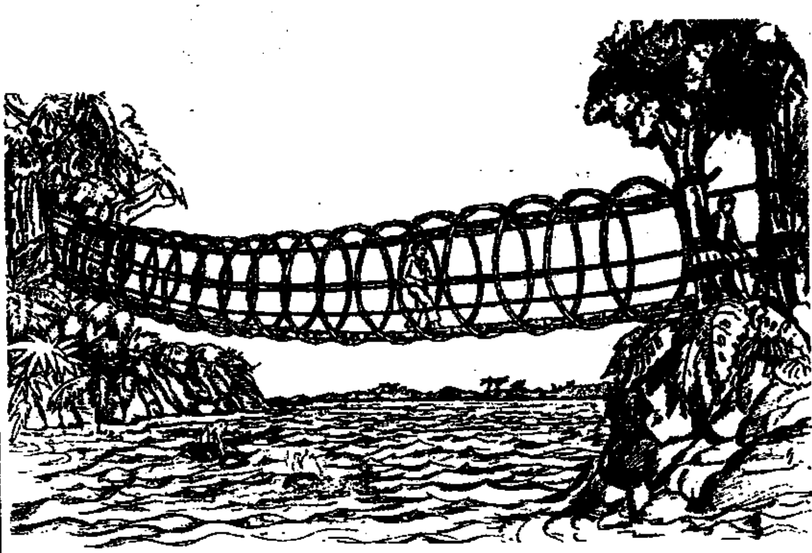
The deck, which consists of six long bamboo cables, rests on the bottom of the hoops, and is tied onto them with bamboo. Each end of the canes forms ~~the floor and~~ is attached to a wooden log fixed between the trees or posts. To prevent the bridge from swaying excessively bamboo ropes are taken from the suspending canes and tied to the trees. These bamboo bridges are used for crossing unfordable rivers like the Kolodine and the Tisi. For small rivers, they build rough bridges called "hleideu", consisting of two crossed posts at each end, over which four bamboos are run to make a pathway. Instead of bamboo, sometimes canes called ari (*Calamus erectus* Roxb.) are used.

Fig.27.16 A



CROSS SECTION

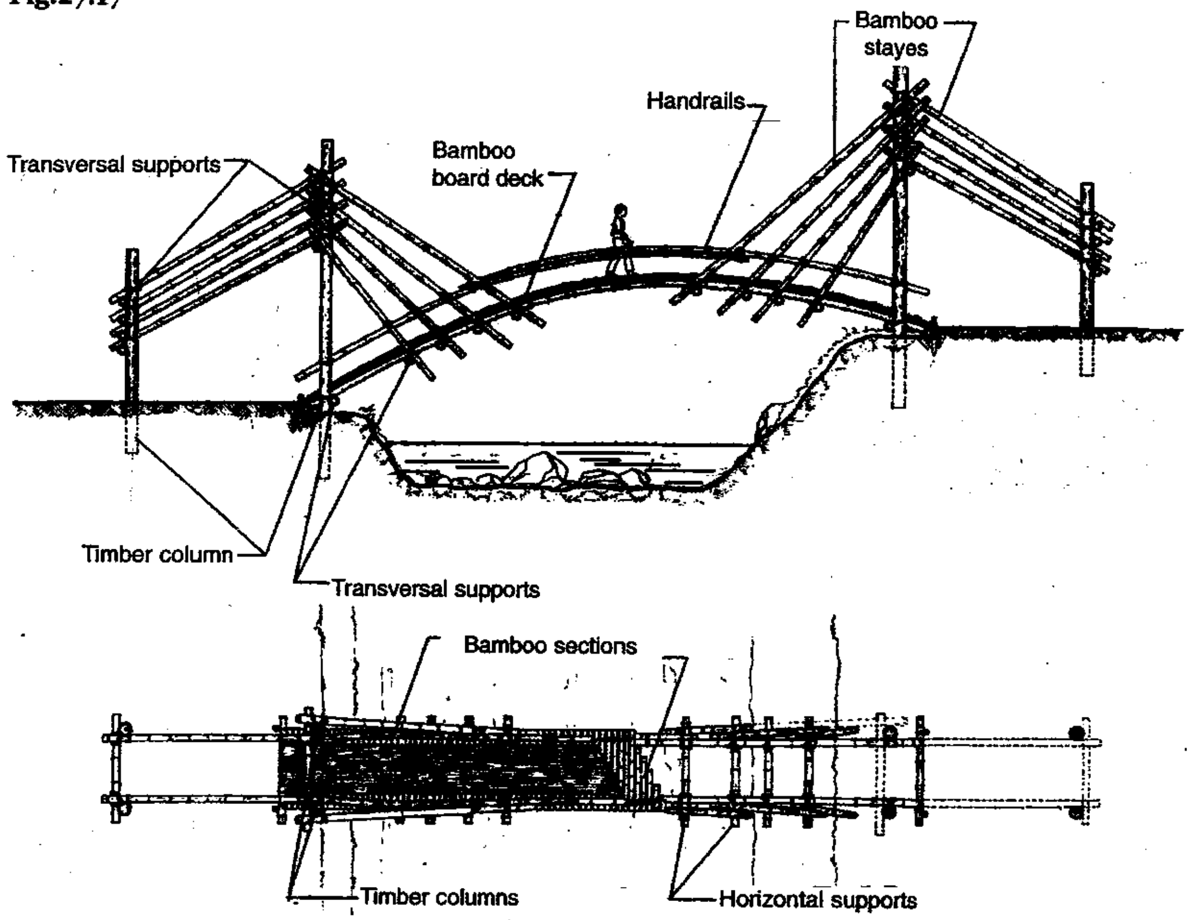
Fig.27.16 B



B. *Tubular bamboo suspension bridge in India.*

THE PAECES' BAMBOO STAYED BRIDGE IN COLOMBIA

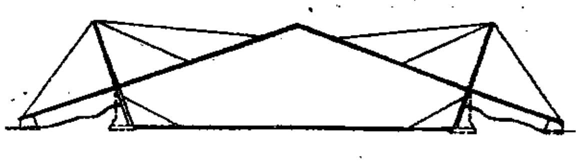
Fig.27.17



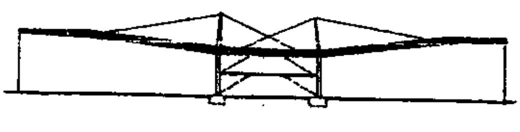
In Colombia the Paeces Indians located in Cauca State, in the south of the country, were the best builders in the construction of bridges. They invented the bamboo stayed bridges shown in the Fig. 27.17.

This technology is still used in the Tierradentro region in the southern part of the country. The bamboo stays are fixed at the top to timber columns and at the bottom to the main bamboo girders of the bridge. The concept of cable-stayed bridges is not a new one. Engineers have indeed designed such structures back in the 18th and 19th centuries when chains and high strength bars were used for stays. The techniques of modern cable-stayed bridges were initiated in Germany in early fifties. After the Second World War, Germany found itself in need of many bridges as part of a plan to rebuild the destroyed transportation system. Materials were in short supply, and the German engineers had to use elaborate mathematical analysis and models to save on material costs. This was the time when the concepts of the orthotropic bridge deck systems came about.

Roof structures derived from the Paeces stayed bridge

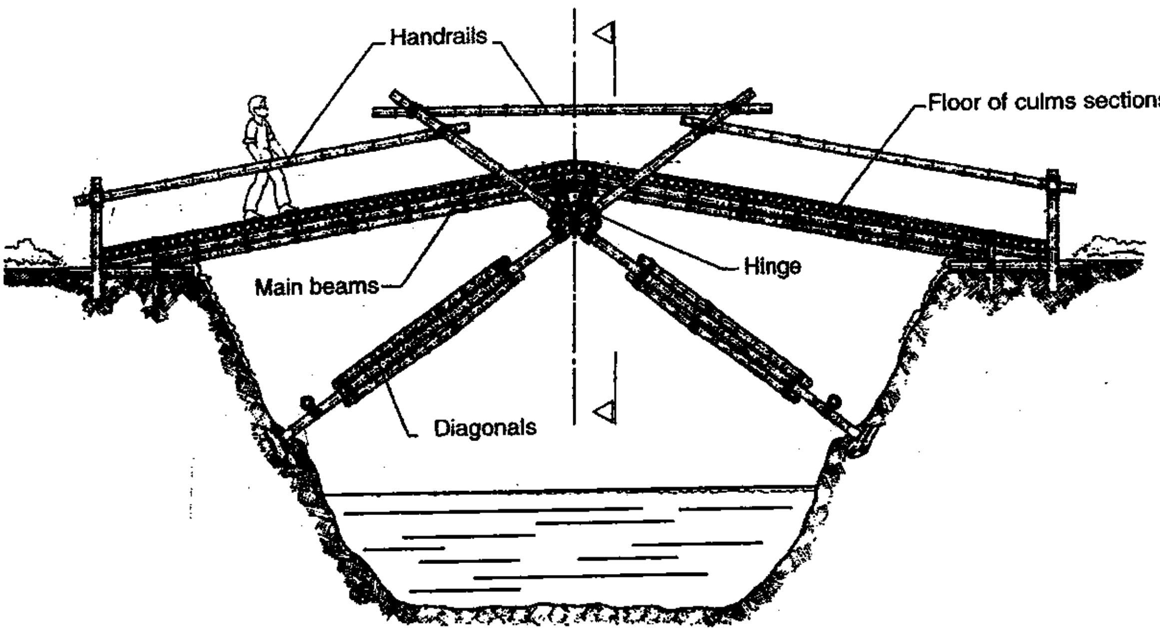


B. *Section of the Arena of Blyth with a stayed roof*

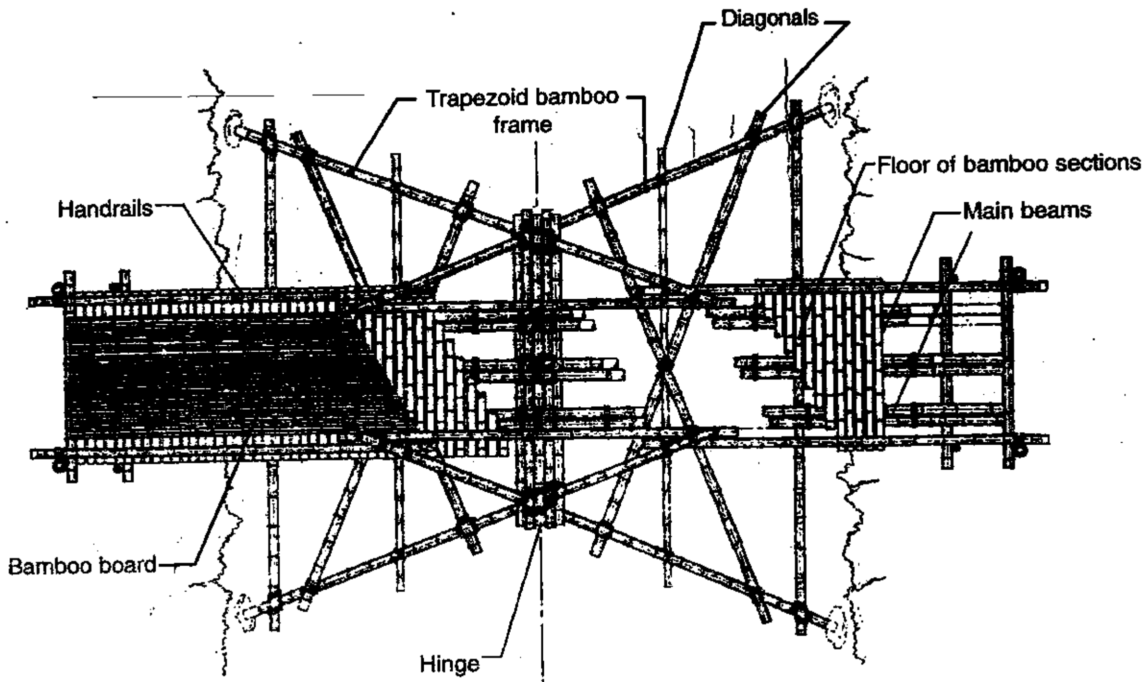


C. *Section of the Hangar # 17, Kennedy International Airport, N. York*

Fig. 27.18 **BAMBOO SCISSOR BRIDGE**

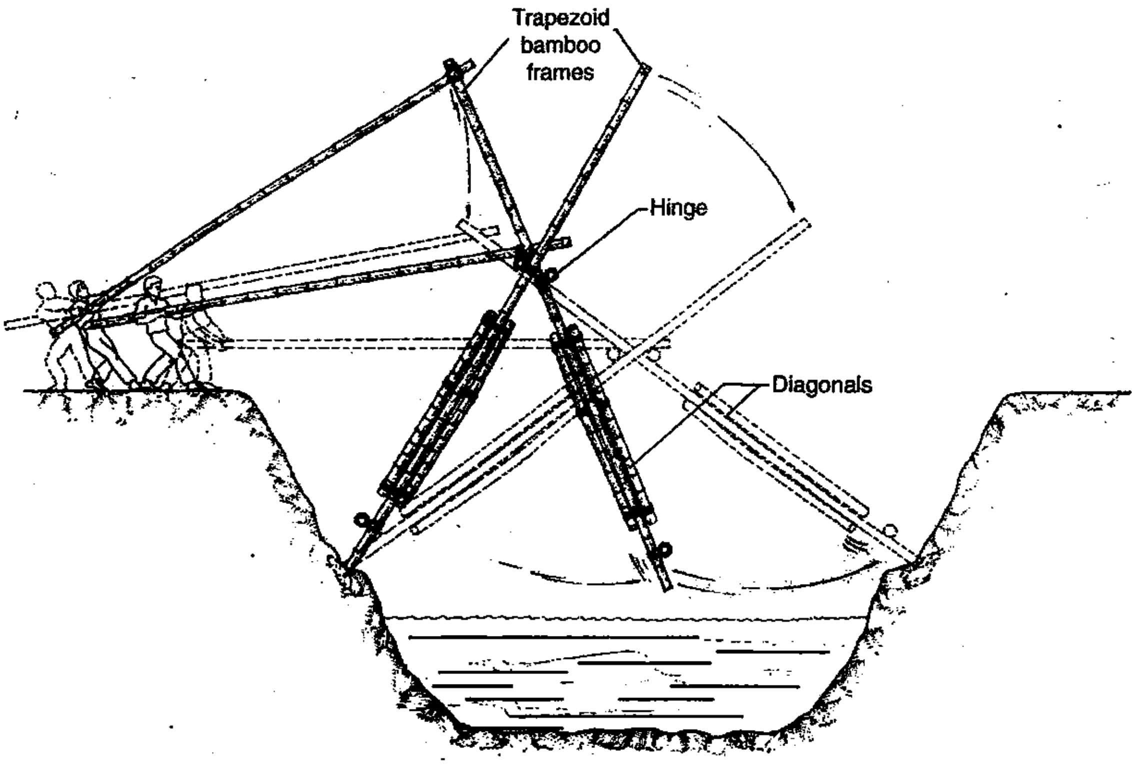


LATERAL VIEW

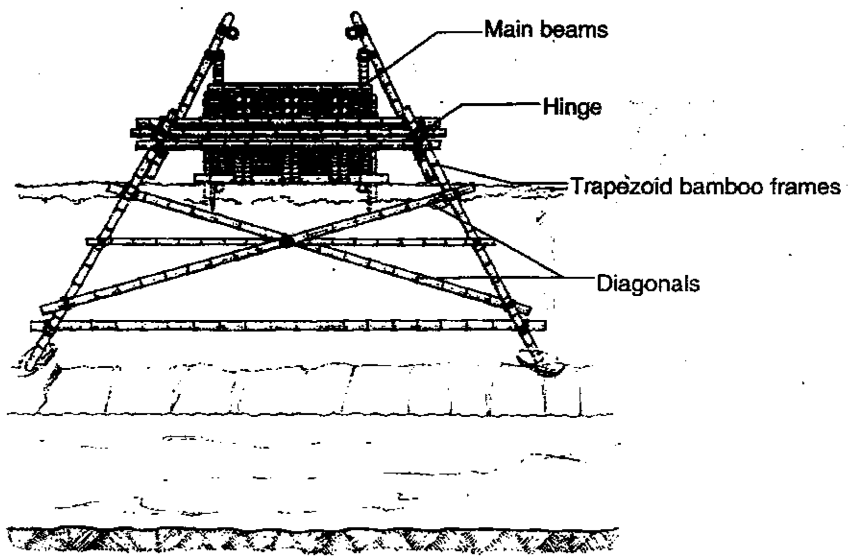


PLAN

Fig. 27.19 **BAMBOO SCISSOR BRIDGE - CONSTRUCTION**



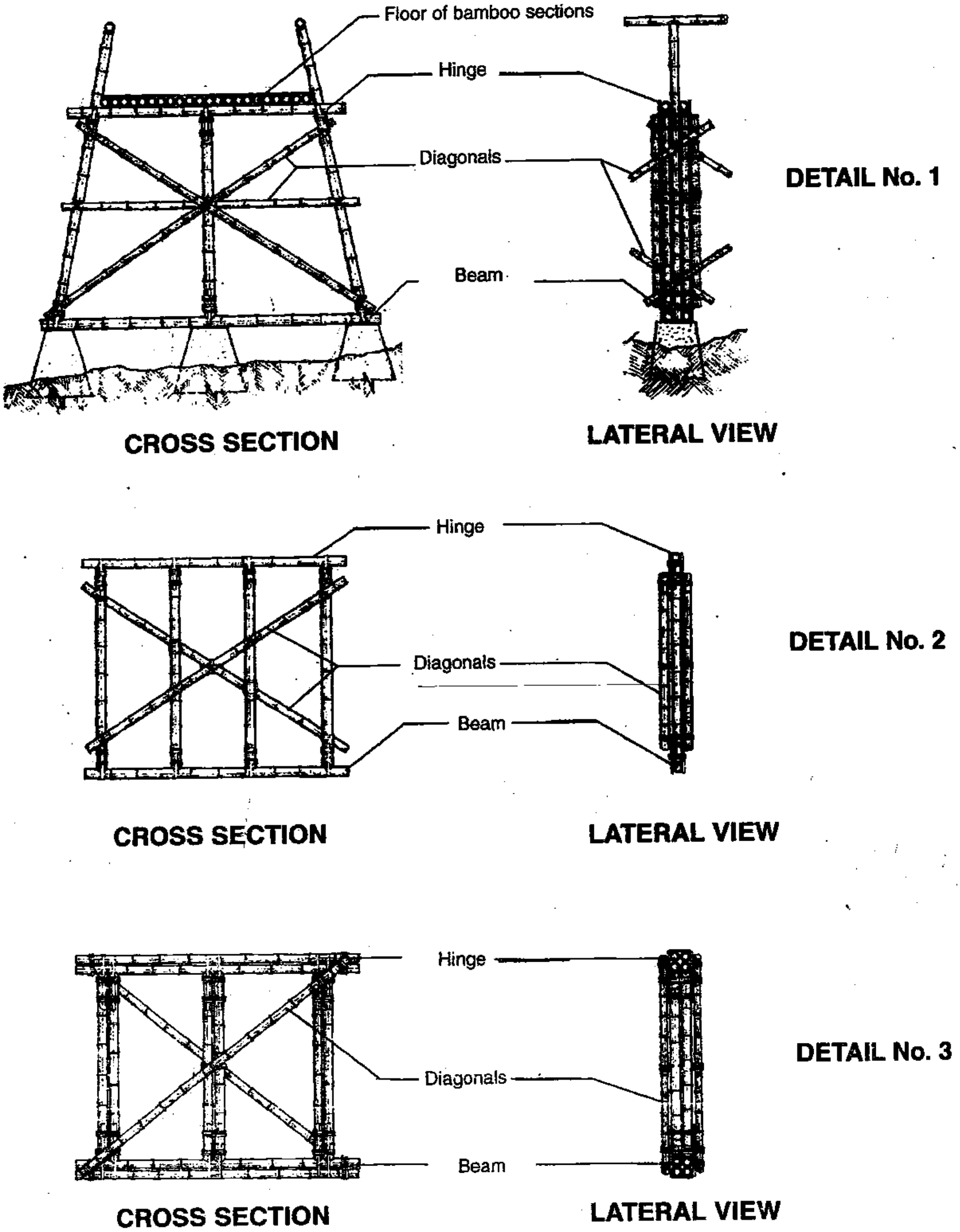
BUILT-UP



CROSS SECTION

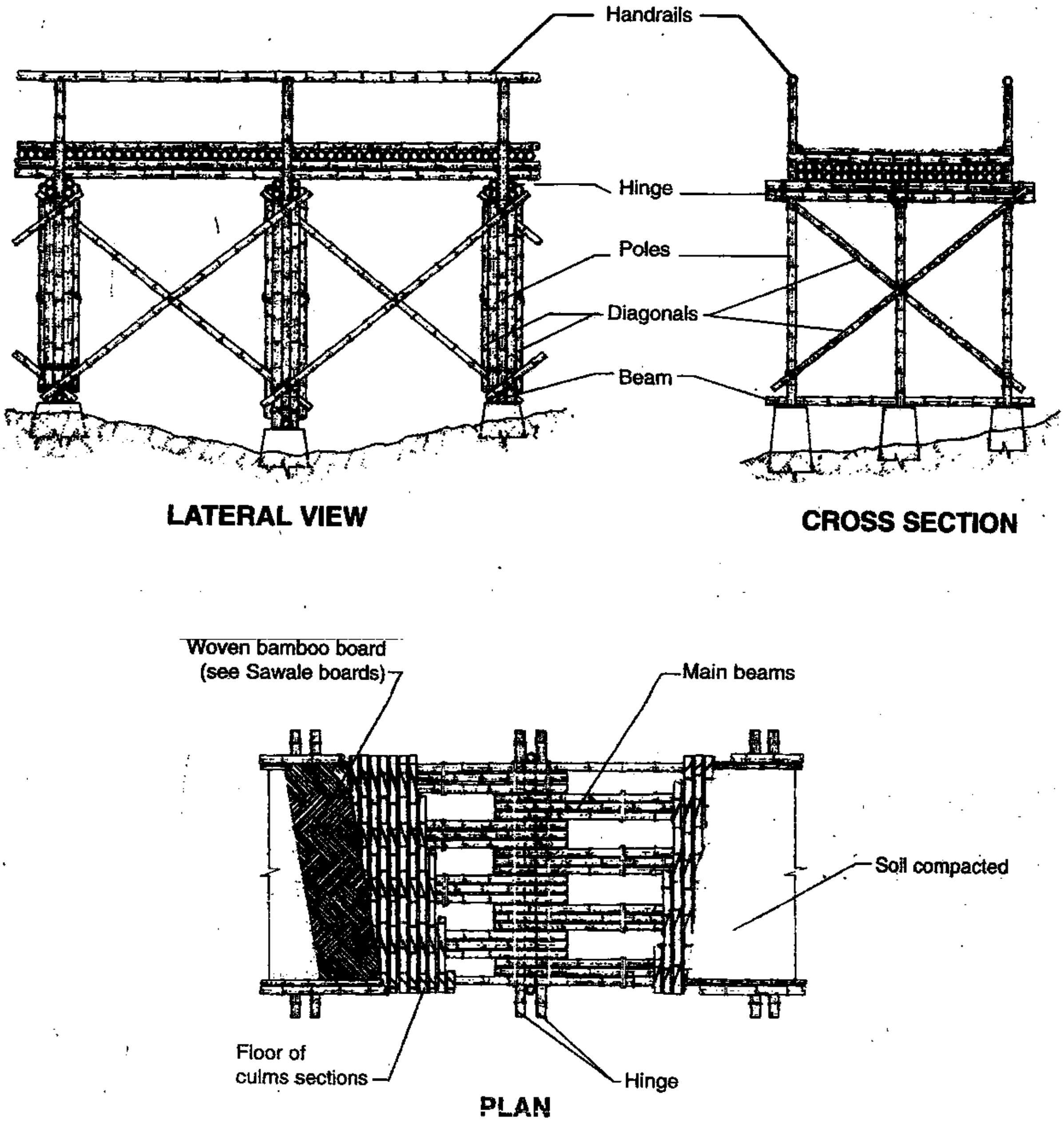
TEMPORARY BAMBOO BRIDGE WITH DIFFERENT SUPPORTS

Fig. 27.20



TEMPORARY BAMBOO BRIDGE WITH DIFFERENT SUPPORTS

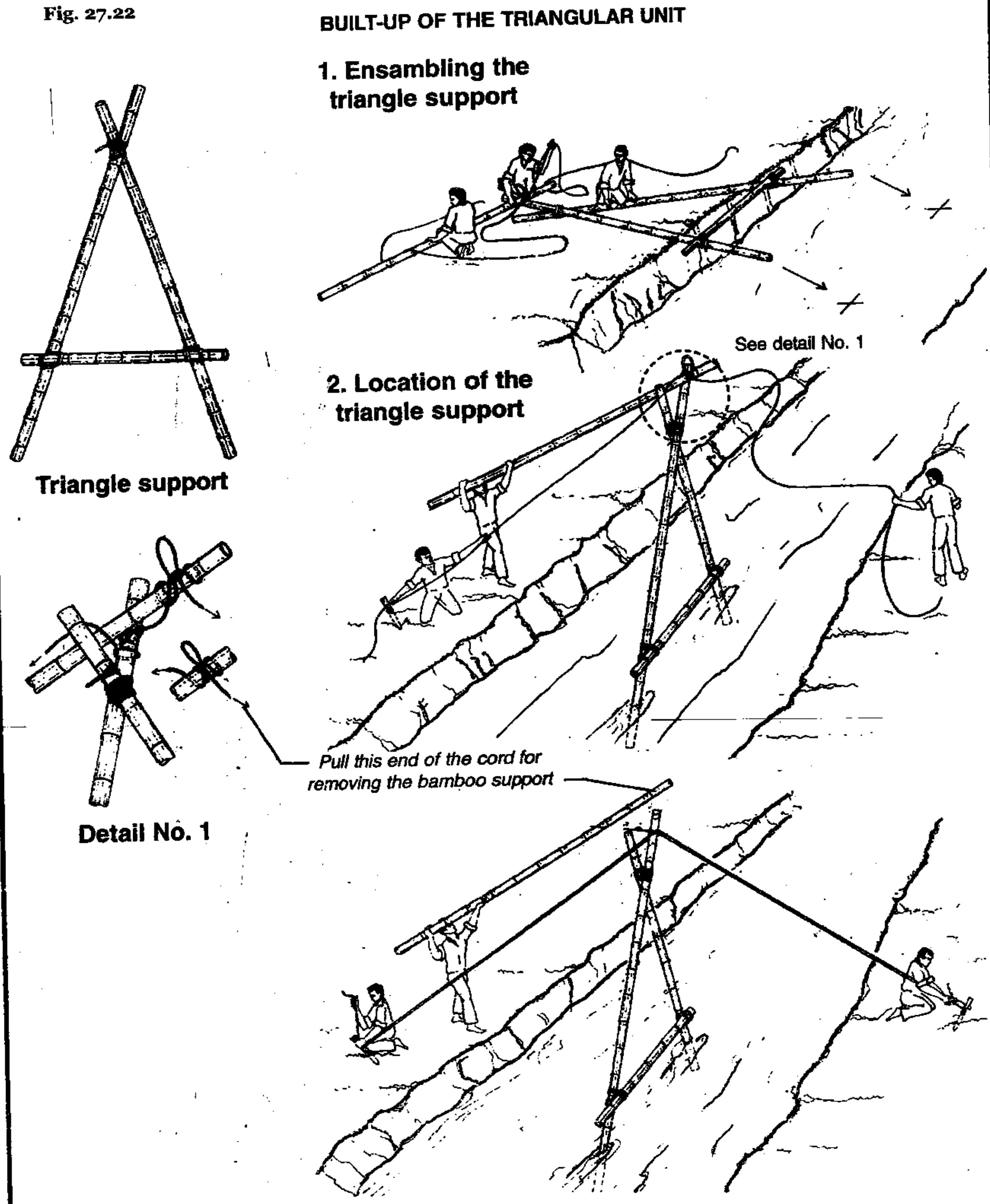
Fig. 27.21



CONSTRUCTION OF AN EMERGENCY BAMBOO BRIDGE TYPE "A" (1)

BRIDGE TYPE 1

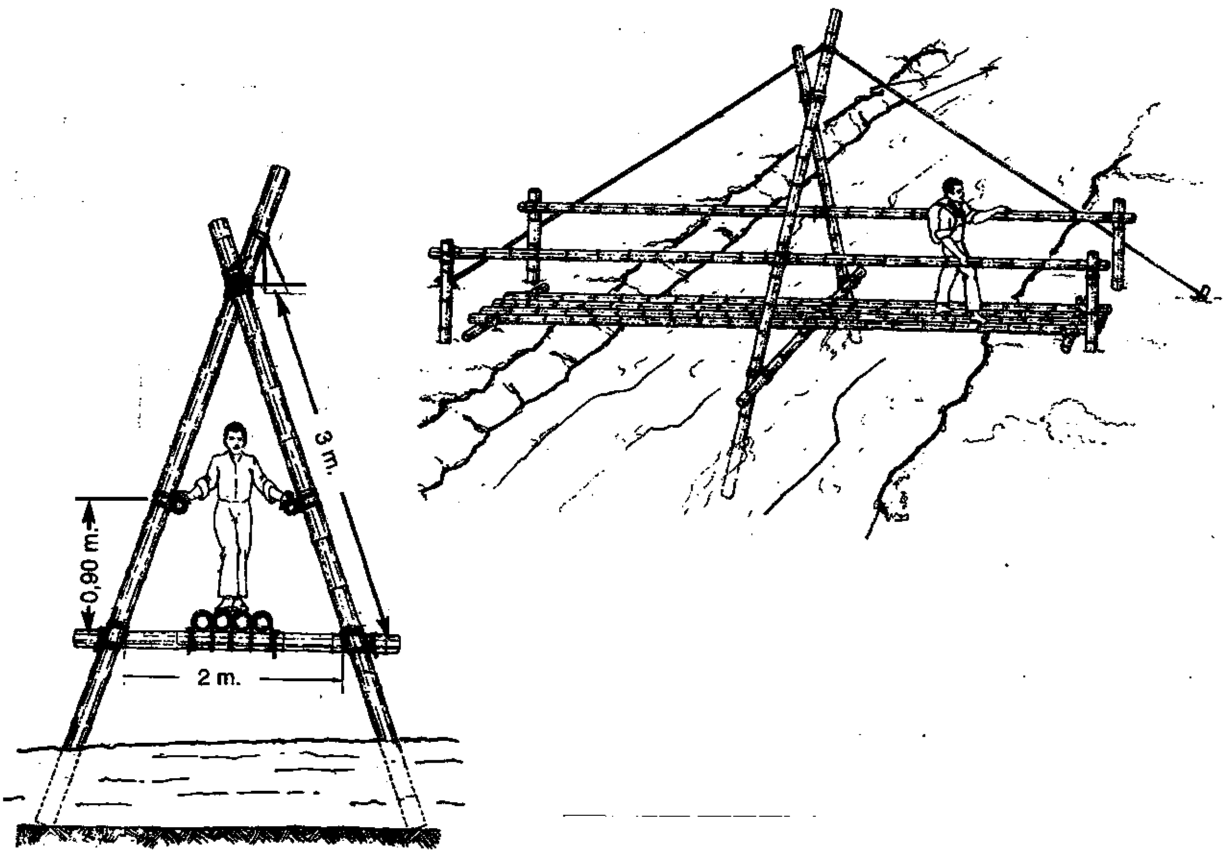
Fig. 27.22



CONSTRUCTION OF AN EMERGENCY BAMBOO BRIDGE TYPE "A" (2)

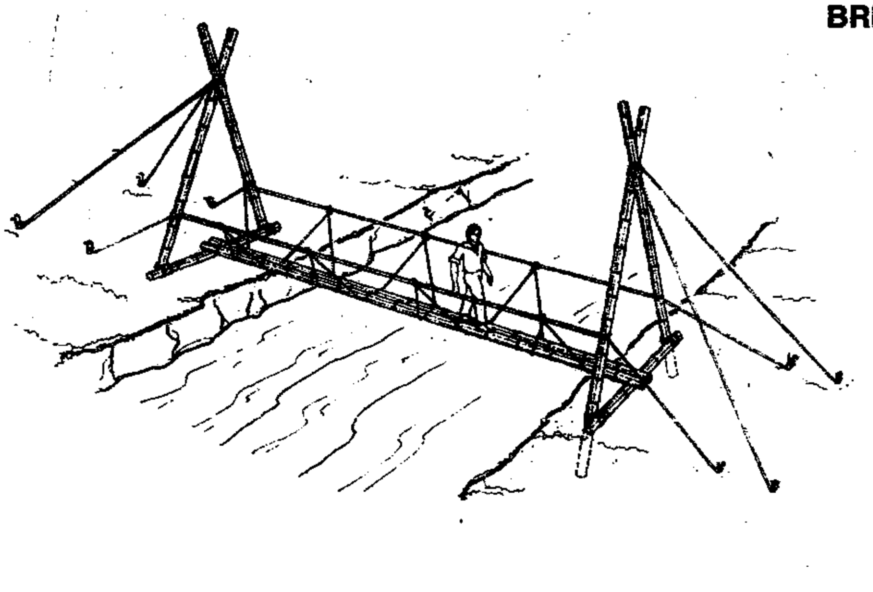
Fig. 27.23

BRIDGE TYPE 1



CROSS SECTION

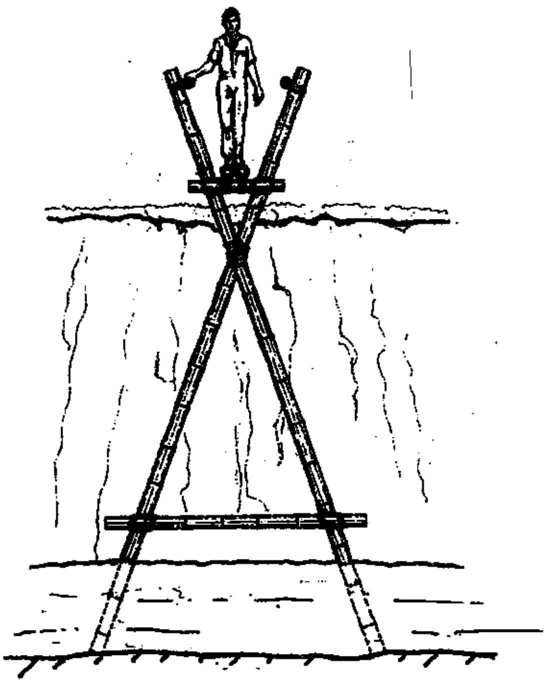
BRIDGE TYPE 2



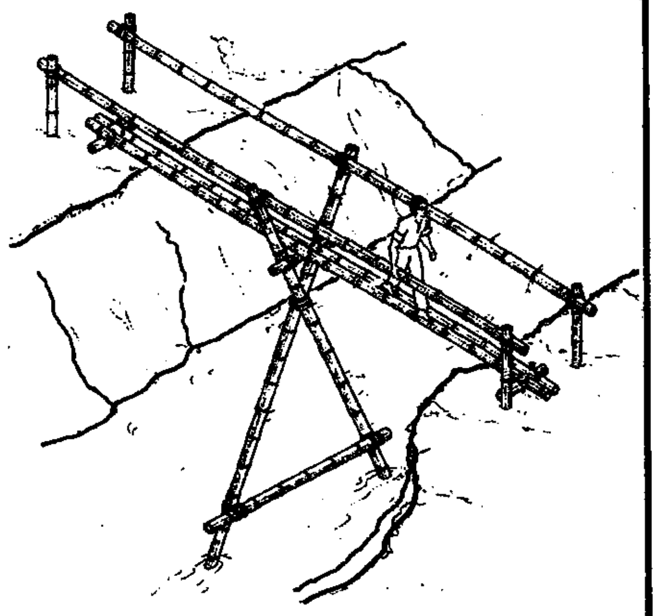
CONSTRUCTION OF AN EMERGENCY BAMBOO BRIDGE TYPE "Y"

Fig. 27.24

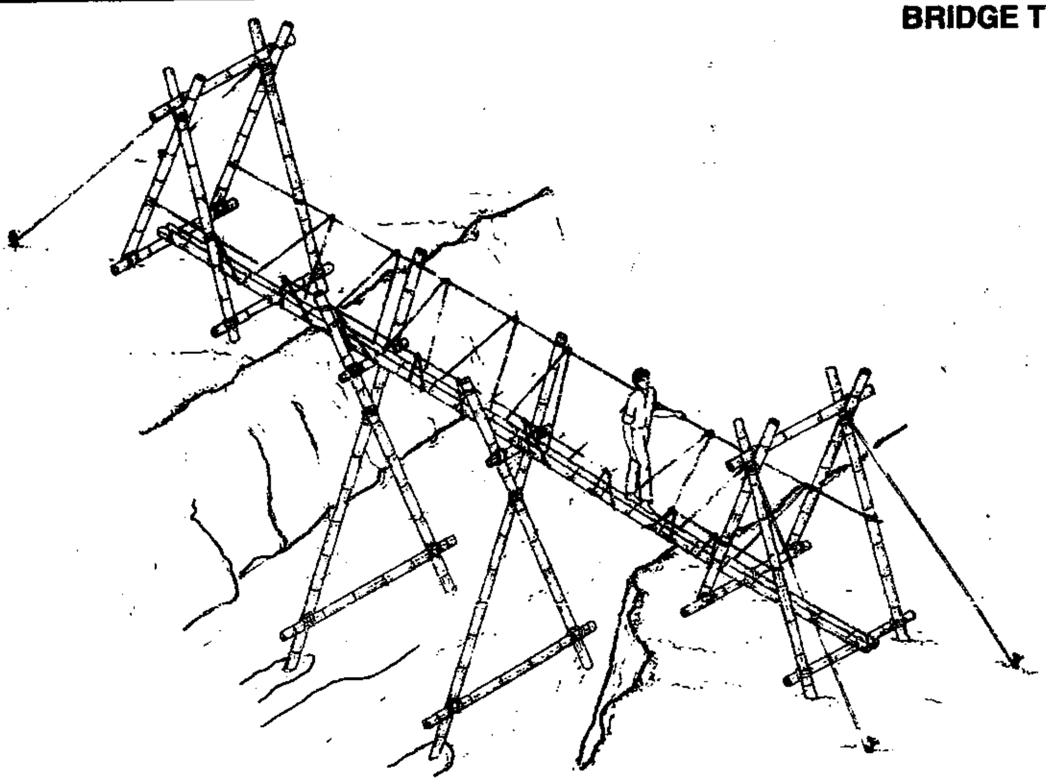
BRIDGE TYPE 1



CROSS SECTION



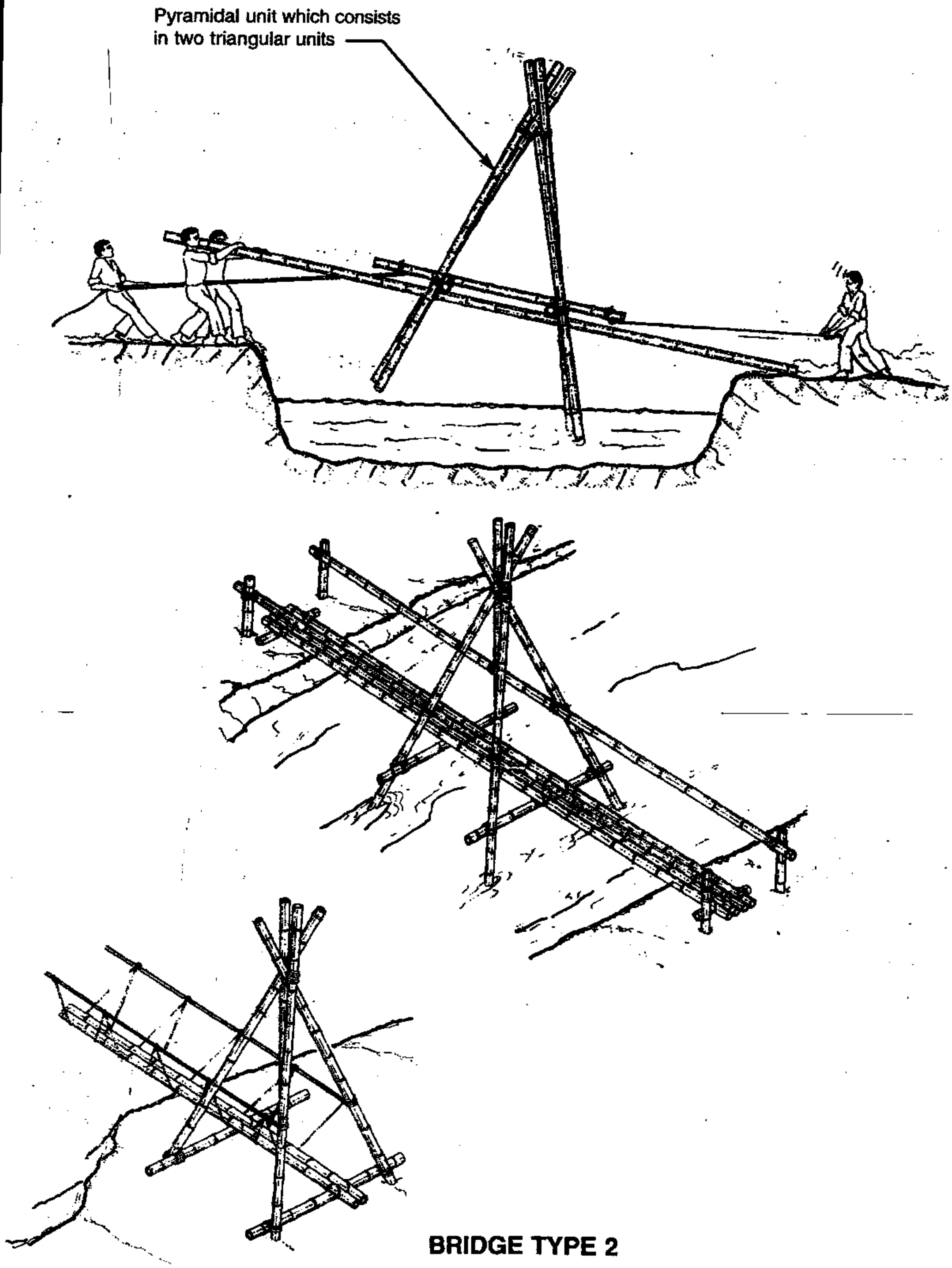
BRIDGE TYPE 2



CONSTRUCTION OF TEMPORARY BRIDGES WITH PYRAMIDAL SUPPORTS

Fig.27.25

BRIDGE TYPE 1



BRIDGE TYPE 2

BAMBOO TRIPOD SUPPORTS USED IN THE CONSTRUCTION OF DIKES

Many of the big bridges of Fukien and of western China are built and repaired behind coffer-dams, under conditions which even a European contractor would find it difficult to combat. In western China, scouring and other damaging effects make the repairs very frequent and the cofferdam question is of great importance.

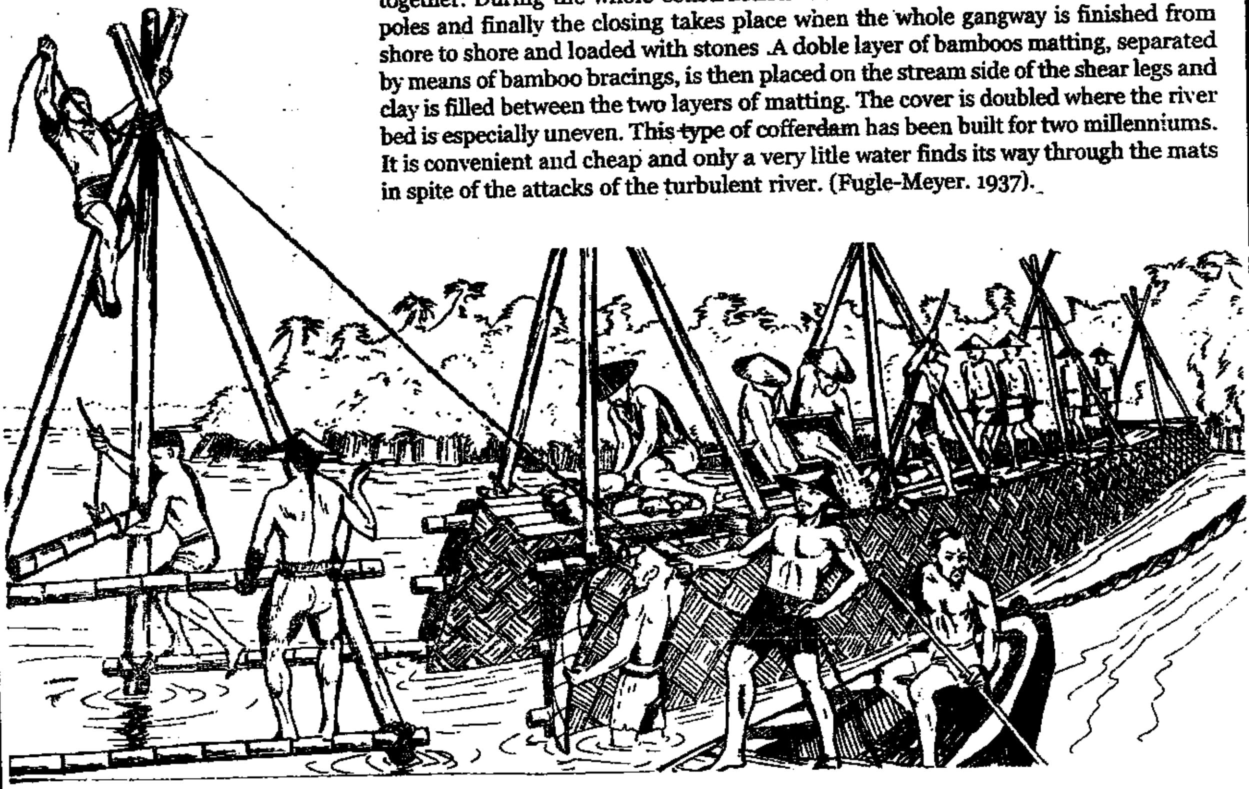
A very interesting type of dike or cofferdam is used in the Kwan Hsien irrigation works. At that point, the wild Min River is divided into two branches. In order to effect the yearly repairs to the irrigation system and the bridges, first one branch and then the other is cut off by cofferdams.

Shear legs, each consisting of three long pine poles, are placed across the river in a long curved line against the current, each with two legs in the upstream and one leg in the down-stream direction.

Fig. 27.26 (A) *This shows the type of dike or cofferdam used in the Kwan Hsien irrigation works. At that point, the wild Min River is divided into two branches.*

Men working from boats fastened to both banks by long bamboo cables, and others working from a gangway rigged on the shear legs which are already in position, place the shear legs, one set at a time. As soon as a set of shear legs has been placed in position, the gangway is continued so as to include them, and, for stability, a weight of stones is placed on the planks.

The gangway is built about 1.20 meters (4 feet) above the water surface, and 1.80 to 2.40 meters (6 to 8 feet) under the point where the three poles are fixed together. During the whole construction the water flows undisturbed between the poles and finally the closing takes place when the whole gangway is finished from shore to shore and loaded with stones .A doble layer of bamboos matting, separated by means of bamboo bracings, is then placed on the stream side of the shear legs and clay is filled between the two layers of matting. The cover is doubled where the river bed is especially uneven. This type of cofferdam has been built for two millenniums. It is convenient and cheap and only a very litle water finds its way through the mats in spite of the attacks of the turbulent river. (Fugle-Meyer. 1937).



CONSTRUCTION OF BAMBOO BRIDGES FOLLOWING OLD MODELS OF WOODEN BRIDGES DEVELOPED IN EUROPE

TYPES OF WOODEN BRIDGES WHICH CAN BE BUILT WITH BAMBOO

Due to the extraordinary compression and tensile strength of our giant bamboo species, and their natural curve and lightweight, this material can be used with many advantages in the construction of several types of bridges as those developed in the 18th century in Switzerland and Germany, Some of these bridges are included in this section, that I reproduced from the excellent study carried out by J.G James (1999), (*The evolution of wooden bridge trusses to 1850*) as part of the "Studies in the History of Civil Engineering" edited by Joice Brown.

The transformation of some of these wooden bridges to bamboo, were carried out in Colombia by Jörg Stamm, an expert German carpenter who lives in this country.

According to James (1999), until the end of the 18th century development of the long-span wooden throught-truss bridge took place primarily in Switzerland and parts of Germany where the basic raw material for such structures long lengths of stout pine was plentiful and cheap and in everyday use. Such development came almost entirely from technologists (i.e. practising carpenters) rather than from academically trained architects or engineers. To such craftsmen the framing of large structures was an inherited language in which the capabilities and limitations of the medium were intuitively grasped without need of strength calculations or framework analysis. New ideas were tested in model form and, in the second half of the 18th century, span length of covered (i.e. waterproofed) through -trusses were extended to 200 feet (60 m) using simple rectangular frames in conjunction with struts, polygons and arches.

It is important to point out that natural bamboo culms could be used in the construction of arches with small rise using its natural curves as can be seen in the photographs. But in the cases where it is necessary to make large perfect archs, bamboo can be deformed longitudinally and artificially as shown in other section. (See artificial longitudinal deformation of bamboo for building arches).

Fig. 27.27 **BASIC WOODEN BRIDGE TYPES WHICH CAN BE BUILT WITH BAMBOO (After: J.G James 1999)**

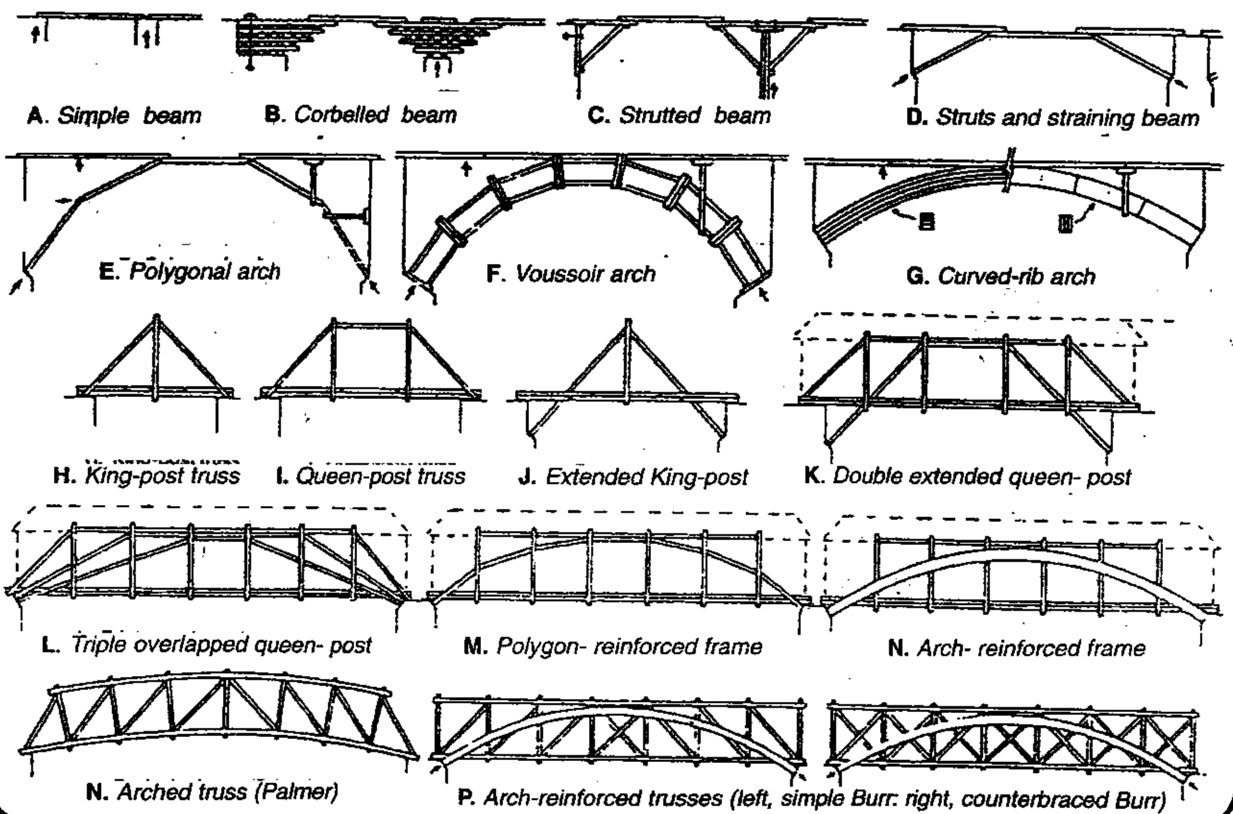
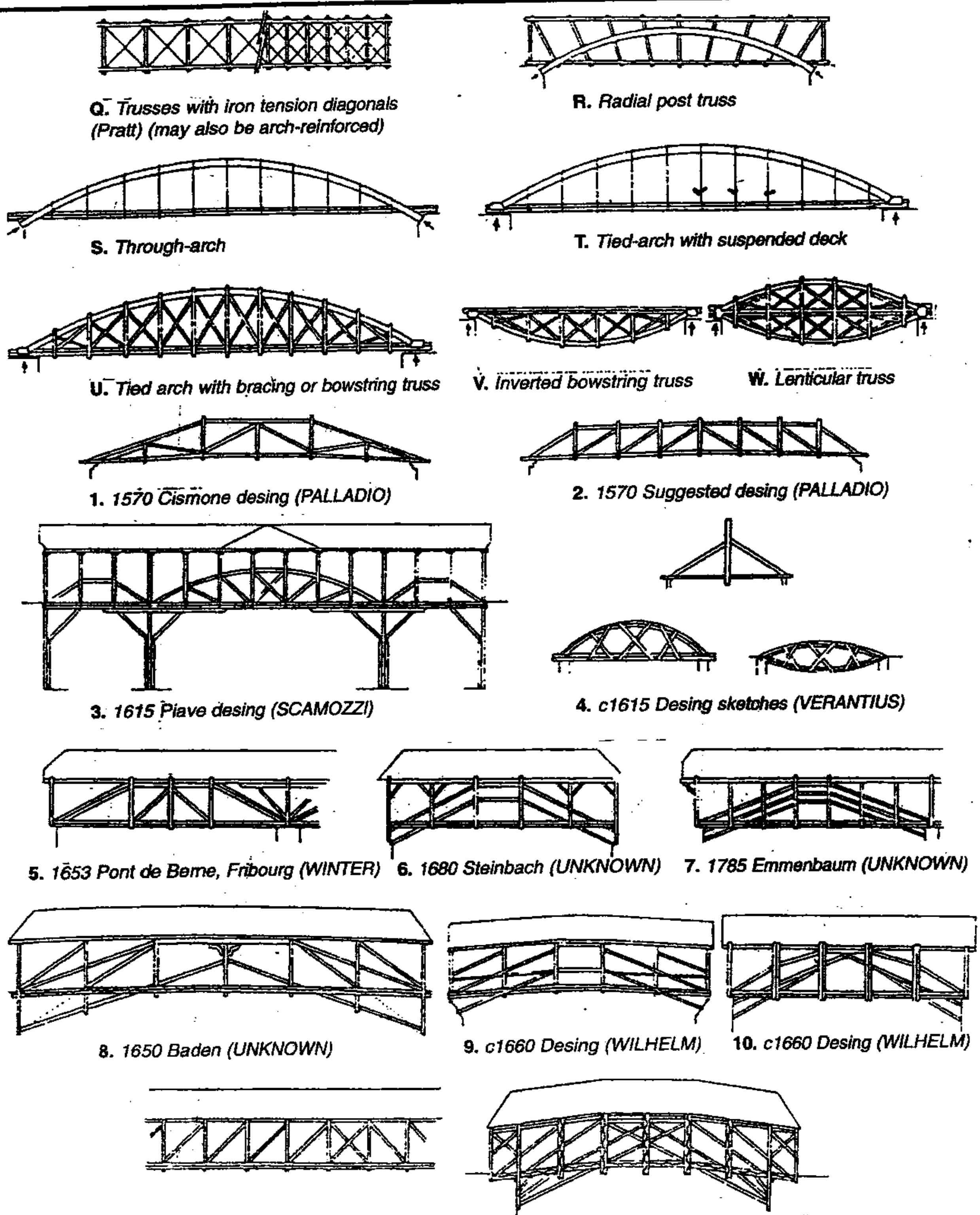


Fig. 27.28 WOODEN BRIDGES WHICH CAN BE BUILT WITH BAMBOO (2)



Q. Trusses with iron tension diagonals (Pratt) (may also be arch-reinforced)

R. Radial post truss

S. Through-arch

T. Tied-arch with suspended deck

U. Tied arch with bracing or bowstring truss

V. Inverted bowstring truss

W. Lenticular truss

1. 1570 Cismone desing (PALLADIO)

2. 1570 Suggested desing (PALLADIO)

3. 1615 Piave desing (SCAMOZZI)

4. c1615 Desing sketches (VERANTIUS)

5. 1653 Pont de Berne, Fribourg (WINTER)

6. 1680 Steinbach (UNKNOWN)

7. 1785 Emmenbaum (UNKNOWN)

8. 1650 Baden (UNKNOWN)

9. c1660 Desing (WILHELM)

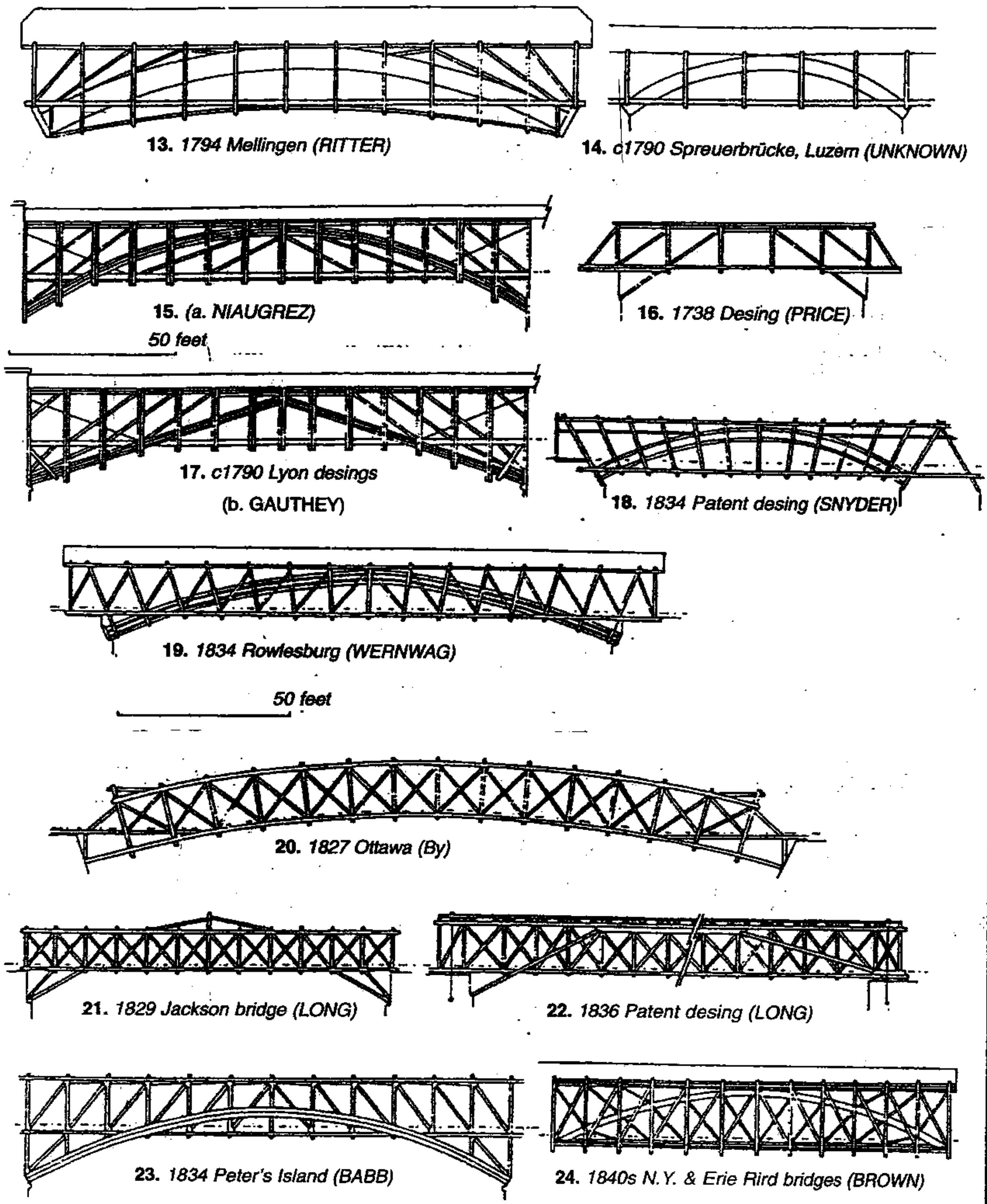
10. c1660 Desing (WILHELM)

11. 1735 Schramm

12. pre1726 Grimma (UNKNOWN)

Source: J.G James 1999 (The Evolution of wooden bridge trusses to 1850) - Studies in the History of Civil Engineering Vol. 8

Fig. 27.29 WOODEN BRIDGES WHICH CAN BE BUILT WITH BAMBOO (3)



13. 1794 Mellingen (RITTER)

14. c1790 Spreuerbrücke, Luzern (UNKNOWN)

15. (a. NIAUGREZ)

16. 1738 Desing (PRICE)

17. c1790 Lyon desings (b. GAUTHEY)

18. 1834 Patent desing (SNYDER)

19. 1834 Rowlesburg (WERNWAG)

20. 1827 Ottawa (By)

21. 1829 Jackson bridge (LONG)

22. 1836 Patent desing (LONG)

23. 1834 Peter's Island (BABB)

24. 1840s N.Y. & Erie Rird bridges (BROWN)

Source: J.G James 1999 (The Evolution of wooden bridge trusses to 1850) - Studies in the History of Civil Engineering Vol. 8.

BAMBOO BRIDGE WITH ROOF COVER -COLOMBIA(Jörg Stamm)

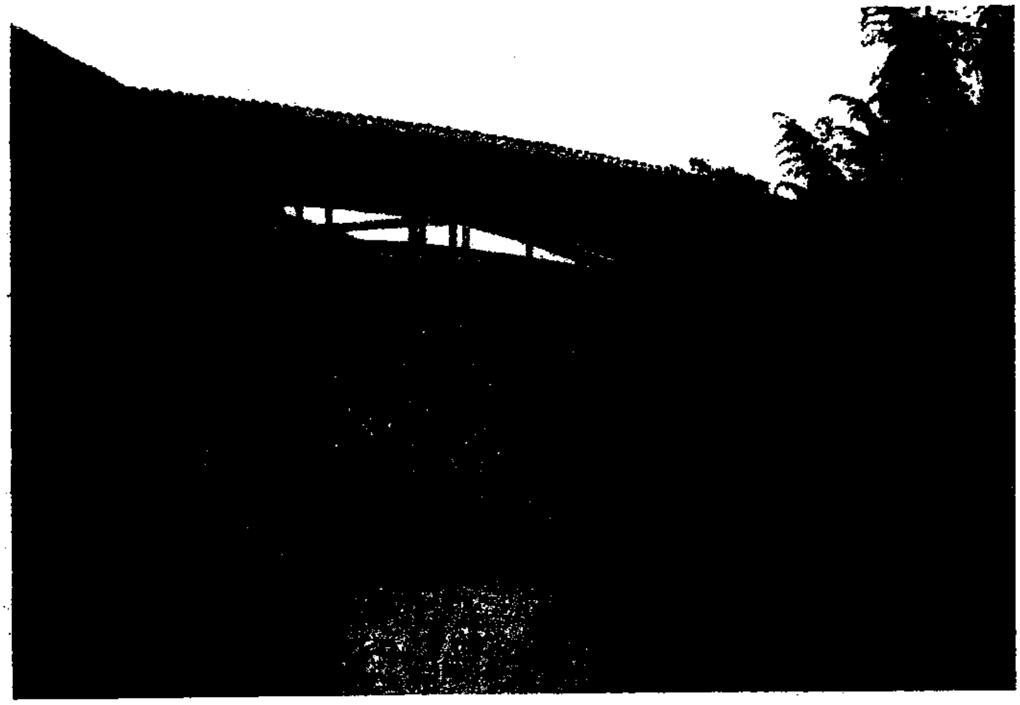


Fig. 27.30 A and B

This 30 m long bridge of is an excellent reproduction, built in bamboo by Jørg Stamm, of a wooden bridge built in Europe in the 18th century as shown by James (1999) in Figs. 26.28 and 26.29.

It was built by Stamm over the Ullucos River in Insa, Tierradentro, Cauca State in southern Colombia. This bridge and the 40 meter long bamboo bridge (Fig. 26,32 and 26.33) built in the city of Pereira by Stamm, are the best demonstration that it is possible to use bamboo to build most types of wooden bridges that were developed in Europe and in the United States.

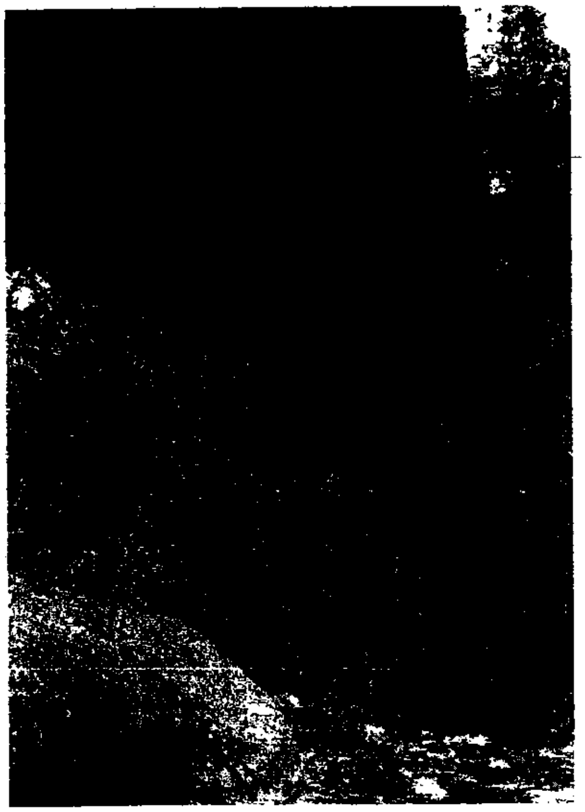


Fig. 27.30 B. *View of the underside of the bridge.*

ULLUCO'S BRIDGE WITH ROOF COVER -COLOMBIA (J. Stamm)

Fig. 27.31 A. *Inside view of the bridge showing the concrete floor and the excellent bamboo structure. (Jörg Stamm).*

Fig. 27.31 B. *Here we can see the strength of the bamboo structure.*

Fig. 27.32 PEREIRA'S BAMBOO BRIDGE - (COLOMBIA) 40 m. span

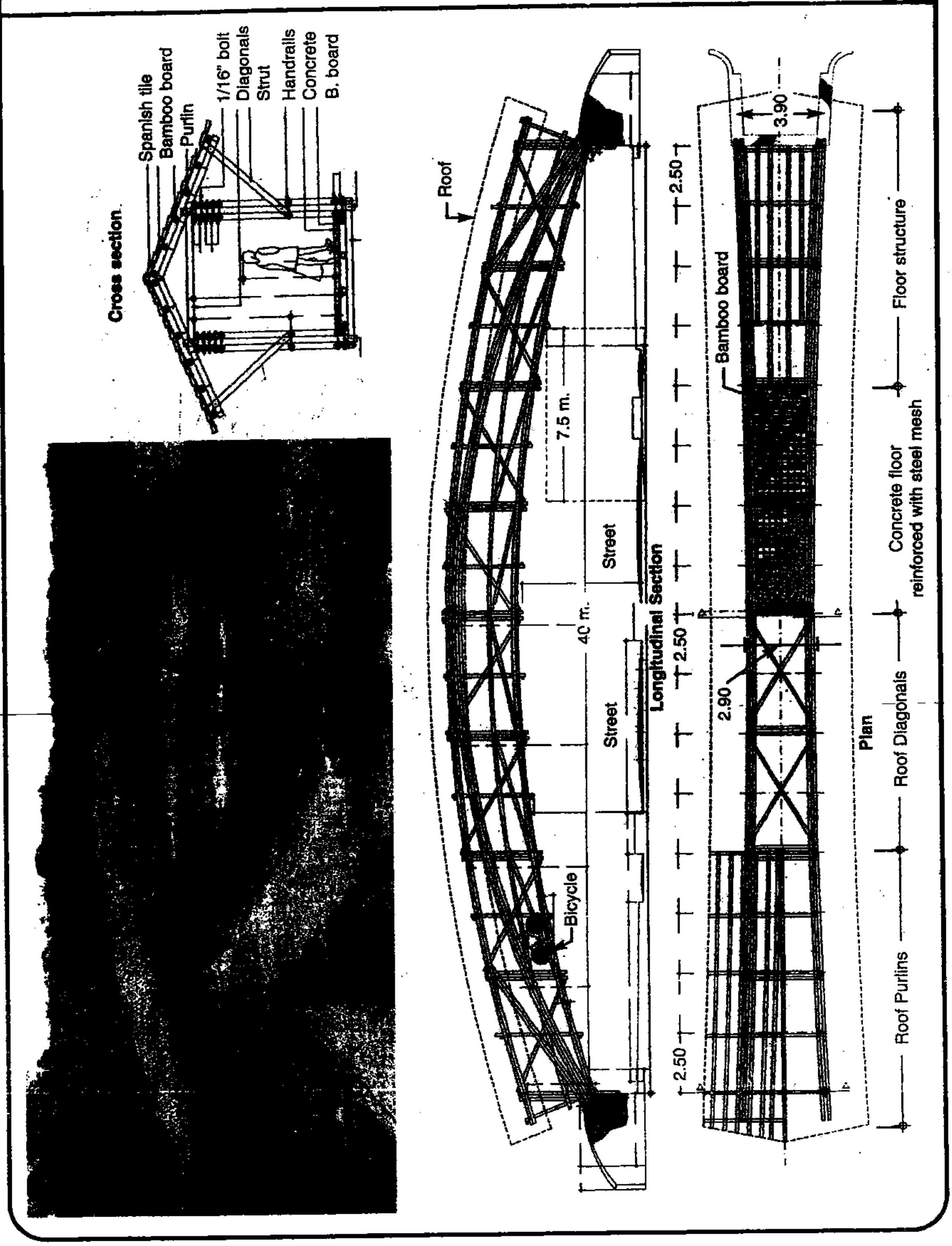
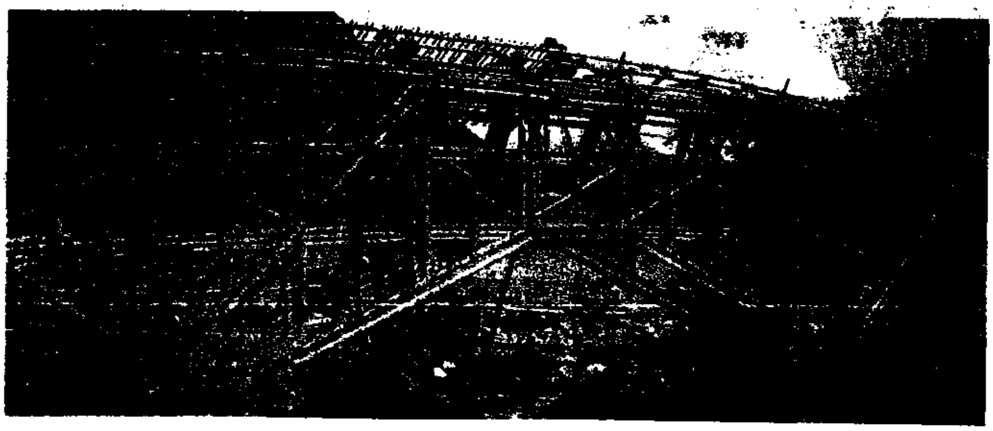


Fig. 27.33 **COQUIYO'S BAMBOO BRIDGE (J. Stamm)**

A. *The construction of the lateral structure of the brigde is assembled on the ground.*

B. *The brigde, once the lateral structures and the roof have been assembled.*



C. *Covering the roof with ceramic tiles.*

BAMBOO MATS USED AS GEOMEMBRANES IN EARTHWORKS

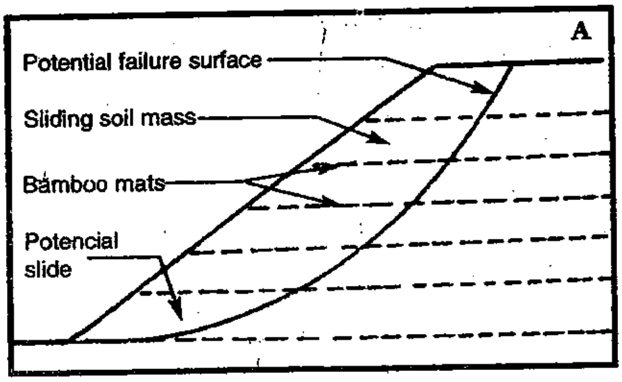
Geosynthetics

The use in of geomembranes in the reinforcement of soil structures such as embankments and retaining walls started in the United States in the seventies. For this purpose were developed the geosynthetics which include various types of fabrics manufactured in woven, non-woven and grid form from polymers including polyamide, polyester and polypropilene. These materials were known with the names of geotextiles, geomembranes, geocomposites, geogrids and filter cloths. They are included in soil structures to enhance the soil's performance, by providing some properties that the soil itself does not possess. An example of the use of geomembranes as reinforcement of slopes can be seen in Fig. 27.34 A.

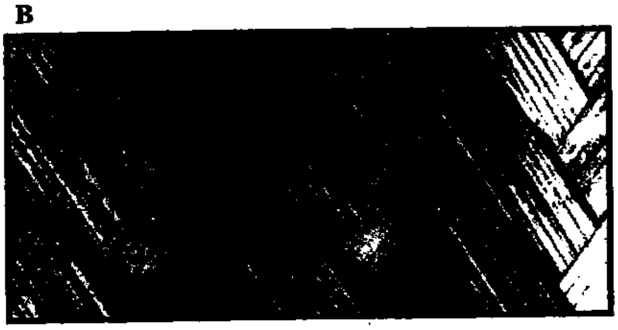
Bamboo mats

Woven mats of split bamboo have been used for many years in India and particularly in China in roadway embankments, retaining walls and as wearing surface of bridges and roads as shown in the Figs. 27.34 E, F. The bamboo mat prevents the mixing of the embankment fill with the soft subgrade soils, and resists the tensile stresses which would otherwise be generated across the bottom of the embankment.

Bamboo mats used as geomembrane have many adventages in relation to geosynthetic membranes such as its extraordinary tensile strength which in many species surpass that of structural steel. On the other hand it is possible to make use of bamboo's bending resistance, a property geosynthetics do not posses. According to Douglas (1988) Bamboo mats could be used to separate road embakment fill and soft, weak subgrades Also whole culms could be used with mats to increase roadbed strength. Grids of small diameter bamboos culms can be lashed together, at centreline spacings on the order of 0.3 metres. These grids have already been used to reinforce the shoulders of steep slopes (Fang 1979).

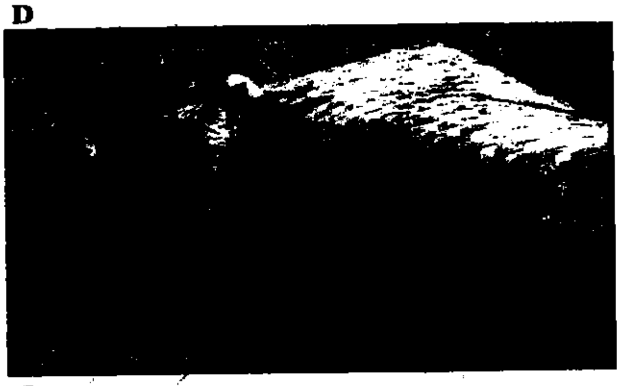


B



C

D



E

F

Fig. 27.34 A. *Shows the use of geomembranes made with bamboo mats known as "sawale" (shown in* **B**) *used in the stabilization of roads. -***C** *and* **D** *Manufacture and transportation of the sawale mats. -***E** *Used on surface of pontons and on roads as shows in figure* **F**.

BAMBOO IN THE FIELD OF ELECTRICAL ENGINEERING

26

BAMBOO FLYWHEELS FOR ENERGY STORAGE

The use of bamboo in the construction of flywheels

The flywheel -Its use in fire making

How did man learn the art of fire making?. One hypothesis is that some primitive gatherer of bamboo shoots for food, observed fire that been caused by friction between wind blown bamboo culms, as the result of sparks produced by some culms with more silica content. This led him to experiment. Finally his experiments led to several types of bamboo implements for making fire by mechanical means. Among these are the thong-drill, the bow drill and the pump-drill. Later came the bellows, a double cylinder forge, to keep the fire alive.

Of the bamboo fire-making instruments, the bamboo pump-drill (Fig. 28.1) was the most outstanding, for it was the first tool made by man with a stone fly-wheel that could store and release mechanical energy. The flywheel concept, useful for so many centuries and for so many purposes from driving potter's wheels to uninterruptible power for large computer installations, helicopters, hoists and buses, (Fig. 28.2) may soon join forces with bamboo.

In 1975, I had the opportunity of meeting Dr. David Rabenhorst, an aeronautical engineer at John Hopkins University in the United States. At that time, he had developed a new super flywheel which was capable of powering a car for 170 kilometers with no need of "recharging" and without using gasoline or batteries. During his development program, Dr. Rabenhorst studied many materials for building the superflywheel, and came to the conclusion that bamboo has many qualities that make it a cheap suitable material for kinetic energy storage. Unfortunately, despite centuries of bamboo use by man, at that time Dr. Rabenhorst was having difficulties obtaining accurate data on the strength behavior of laminated bamboo due to the lack of technical information. Since then, I have started doing research on laminated bamboo in Colombia using *Guadua angustifolia*. (See laminated bamboo.) From the experiments I carried out in this field, I came to the conclusion that someday bamboo flywheels will contribute to solving the energy crises that we will have in the future.

The flywheel is a heavy wheel attached to the shaft of a machine for the purpose of storing and releasing rotational energy in relation to the requirements of the machine. The outer rim of the flywheel, which is very heavy, serves as the major storehouse of energy. As the wheel's speed increases, the wheel stores energy; as its speed decreases, it gives up energy.

The flywheel is probably the oldest energy-storage device invented by man. A stone flywheel was used first in the pump-drill (Fig. 28.1) for making fire and particularly as boring-drill. Later on larger stone flywheels were used as potters' wheels in ancient Ur of Chaldea, more than 5500 years ago. But modern engineering has put the old idea to

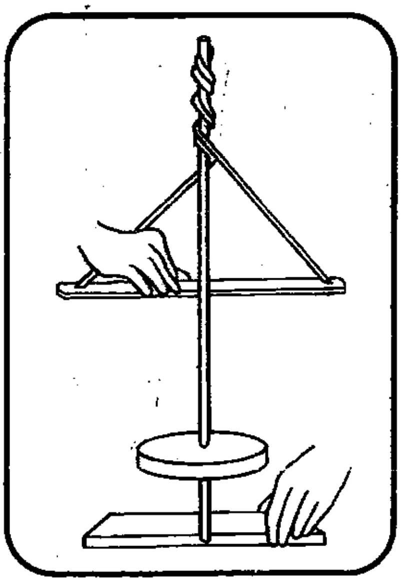


Fig. 28.1 *Original pump drill with stone fly wheel.*

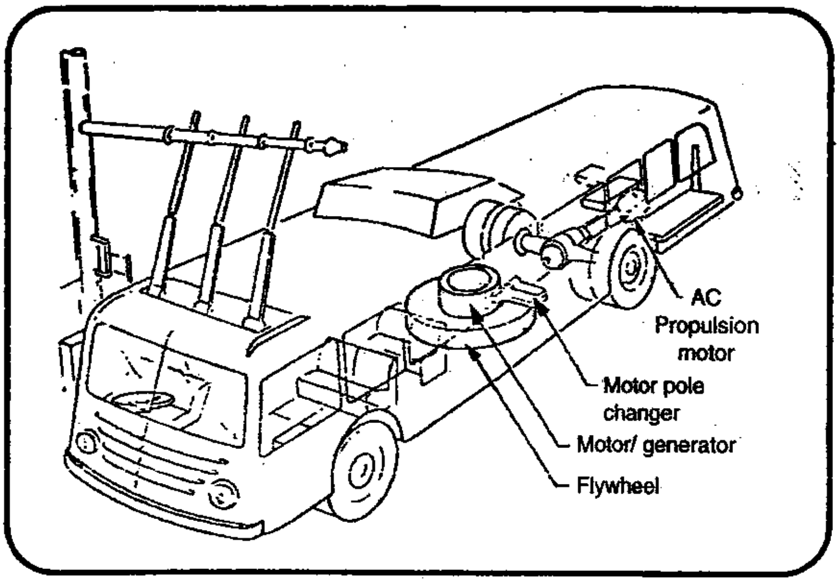


Fig. 28.2 *The Oerlikon inercial energy storage bus in which the flywheel was charged by an electrical motor. The motor was driven by electricity supplied via utility poles at each bus stop.*

work in such areas as uninterruptible power for the first large computer installations, helicopter hoists, buses large power shovels in aircraft catapults, emergency power generators, naval torpedos and will revolutionate the transportation of the future.

The Howell torpedo using flywheel energy storage was patented in 1884. In a more recent study a flywheel powered torpedo was proposed having a capability of producing 300 horspower for 7.5 minutes. Although the first proposal to power a vehicle was patented in 1904. the first practical application in production apparently was the Swiss Oerlikon bus or Gyrobus (Fig. 28.2) that was used both in Switzerland and the Belgian Congo in Africa. The bus was operated for about sixteen years of succesful service beginning in 1953. The 70 passenger bus (35 seated and 35 standing), 35 feet long, weighed 24,000 pounds, was driven by a conventional 3,300 pound flywhell, 64 inch-diameter that could propel it for upward of half a mile. The flywheell was designed to operate at about 3 watt-hours per pound and to fail at about 6.

The flywheel was the sole energy storage device in this vehicle instead of available lead-acid batteries, which would have weighed only one-third as much. In this case the flywheel was charged by an electric motor. The motor was driven from electricity supplied via utility poles at each bus stop as can be seen in Fig. 27.2.

The special contact arms on the bus engaged the utility pole when the bus was stationary at the bus stop, and the flywheel was charged (spun up) with an electric motor while the bus was loading passengers, then after a charge time of two minutes or less, the bus proceeded quitly and with no pollution to the next bus stop where the procedure was repeated. In this application, when the bus left the charging station, the flywheel was driving the electric motor instead of vice versa, so the motor was then the generator, which drove others motors at the wheels. The control system was arranged so that a large part of the braking energy was recovered by the system to recharge the flywheel whenever the brakes were applied. This provided a considerable saving in consumed power. The fly wheel in this application provided about 3 watt hours per pound, which at 3300 pounds was sufficient to propel the bus for 0.5 mile with adequate reserve range.

A system having a considerably better performance was latter proposed in 1964, and the characteristics of this system are also shown in Fig. 28.2. The higher performance flywheel in the proposed configuration would have increased the nominal range of the bus to about four miles (instead of half mile), plus a three-mile reserve.

The modern flywheel

A flywheel, like a battery, is an energy-storing device. But flywheel stores energy in much the same way that a bicycler, by pedding extra fast can coast for a time on the excess energy he expends. The modern flywheel, after being placed in a spining motion releases "store" energy as it slows down. How much energy you can pack into a flywheel? The amount of energy that can be store depends on

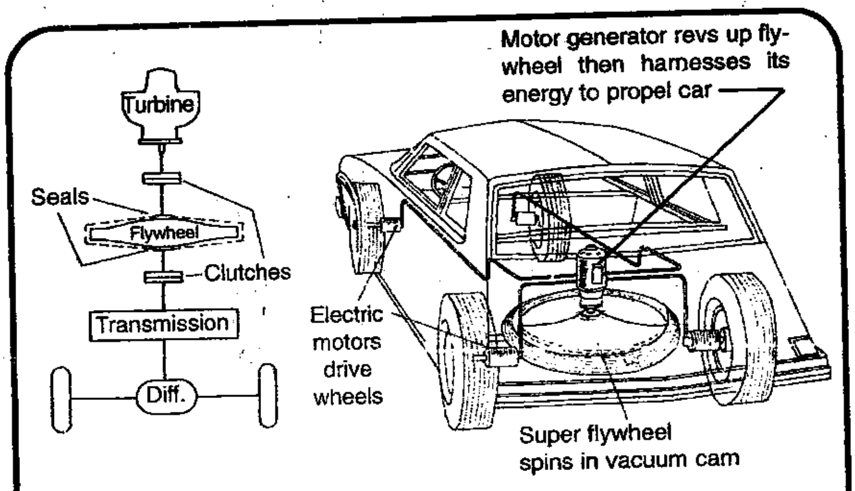
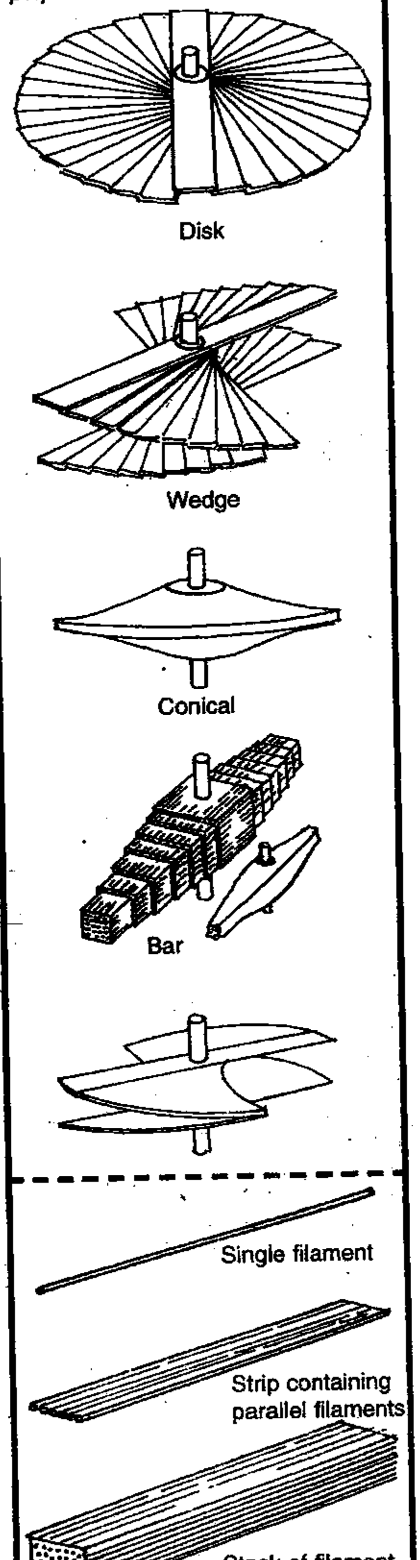


Fig. 28.3 *The future automobile powered by a flywheel.*

Fig. 28.4 *Some of the shapes of bamboo superwheels for different purposes.*



how fast the flywheel is turned, the faster it is turned the longer it takes to slow down. The flywheel's greatest enemy is friction. For this reason the flywheel has to rotate in near-vacuum enclosed space. According to Dan (1973), the University of Virginia tested a 100-lb flywheel that lost only one rpm per day. A magnetic suspension system was used and a 10-5 torr vacuum.

A wheel that spins at very high speeds (many times the speed of sound) will coast for several days, slowing down gradually. However, it is very important to bear in mind its maximum speed or how fast it can spin before centrifugal force tears it to pieces and makes deadly missiles of its hurtling fragments. What sets its maximum speed limit for safety is the strength of its material and its density.

Until the sixties, flywheels were made of materials that were equally strong in all directions, like solid steel which flew apart when turned too fast. But from about 1970 up to the present time, modern supermaterials, such as anisotropic boron, carbon, fiberglass and kevlar, have been studied. Some of this fibers are lighter than steel but have many times higher strength to density than the best steel.

One of the must important scientists who was a pioneer in the use of these new materials and in the study of organic materials like wood and bamboo for the construction of flywheels was David Rabenhorst (1971). He has developed a high energy flywheel or superflywheel as the heart of a variety of stationary and portable energy storage systems, including a new type of automobile (Fig. 28.3) which has no engine, radiator, transmission, gas tank, muffler, or tail pipe; the battery will be replaced with a 30 inch diameter flywheel, located in the rear compartment in a vacuum can. This car can cruise at 75 mph. and accelerate from 0 to 60 mph in much less than 15 seconds. The flywheel spinning at up to 23,700 rpm. stores enough energy to propel the minicar for two hours at a cruising speed of 110 miles. Then in a 24 minute "charging" period at home or in a wayside garage, electric current revs up the flywheel for another run of equal duration.

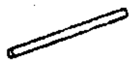
Rabenhorst's theory about the superflywheel is that by using materials of uniaxial tensile strength in special rotor configurations, flywheels can store more than 30 watt-hours per pound of rotor material. This value may be compared to 8 to 10 watt -hours per pound for current lead acid batteries and 3 watt-hours per pound for the flywheel-powered Swiss Oerlicon bus of the 1950's.

According to Rabenhorst (1971), at 30 watt-hours per pound the superflywheel will rotate at a top speed of about 3800 feet per second regardless of the material used in its construction. This is equivalent to about 30,000 rpm for a rotor having a 30-inch spinning diameter. In order to accomodate these conditions, the rotor is operated inside a vacuum can at a pressure on the order of 10-2 torr. Energy is transmitted trough the sealed can by any one of several methods, depending on the application. Typical of these would be the magnetic coupling, the harmonic drive, the fluid wave generator, the magnetic fluid seal, and in the case of an all-electric system, the static hermetic seal. In the last case, either the entire motor/generator could be located inside the vacuum can, or the could be placed between a solid rotor and its stator.

The potential use of bamboo in the construction of flywheels

In 1974, while I was collaborating with Dr. Thomas Soderstrom at the Smithsonian Insttitution in Washington D.C., gathering information about industrial uses of bamboo for the bamboo library, I had the opportunity of talking to Dr. David Rabenhorst at the Applied Physics Laboratory at the John Hopkins University in Silver Spring, Maryland. I was interested in knowing the results he had obtained in the experiments he had done using wood, and the potential useof bamboo in this field.

Table 28-1 SHAPE FACTORS (K) FOR COMMON FLYWHEEL DESIGN

	Hyperbolic disc (OD aproaches infinit)	1.00 Factor K
	Modified hyperbolic disc	0.93
	Truncated conical disc	0.81
	Flat unpierced disc	0.61
	Rim with web	0.40
	Single filament bar	0.33
	Brush	0.33

Source: Dan (1973).

In the conversation I had with Dr. Rabenhorst, he said that to study the application of wood in this field was very easy due to the lot of information which exists about the physical and mechanical properties of the wood species. Although technically bamboo is a grass, it has many wood qualities that make it especially suitable for kinetic energy storage. Unfortunatelly, it was extremely difficult to obtain much accurate test data on tensile strength of bamboo.

So far the useful information that he has found seems to indicate that bamboo will have energy-density and cost factors more than twice those of wood, and this adventage is expected to improve as better data become available. Due to this reason he recomended to make more accurate studies on the physical and mechanical characteristic of our best species of the Americas that are more resistant than the Asiatic species. According to Rabenhorst (1972), the studies made about the potential flywheel applications have concluded that, nex to safety, the most important requirement for mustfuture flywheel systems will be the low cost, rather than high performance, as expected.

Surprising as it may seem, wood and particularly bamboo are excelent superflywheel materials, and at the present time these are at the top of the list in watt-hours per unit cost. The technology required to make the wood product competitive with the other superfly materials has been in use for thirty years. The principal drawback of the wood products is their low density; however, as will be seen below, there are ways that this deficiency can be improved.

Wood and bamboo have the following characteristics: (a) an energy storage capability comparable to the best steel flywheel; (b) a flywheel safety comparable to other flywheels made of filamentary composites: and (c) a flywheel cost that will be an order of magnitude much lower than the best high performance flywheels.

The same autor points out that if the energy per unit weight is a funtion of strength /density, then it follows that energy / $ is a funtion of the strength / density / $ for the material in question. It is emphasize that the criterion is strength / density / $; not merely strength / $. For example, kevlar has ten times the strength of bamboo, but a bamboo superflywheel can store ten times as much energy per dollar as a kevlar superflywheel (but at ten times the size).

The energy per unit volume of either of the two basic configurations considered above is a funtion of the strength of the material only. For example, if two materials had the same weight, but one have half the density of the other, then the lighter one have twice the energy storage capability per pound. However it would ocupy twice the volume for the same weight, so the energy per unit volume would be the same.

Superflywheel characteristics

There are a number of flywheel configurations based on the optimum use of many new supercomposit materials that have a much greater strength-to-density ratio than the best isotropic matcrials. These superfly wheels, as they are known, use essentially straight-filament anisotropic composite materials much like bamboo.

Two basic superflywheels configurations that are particularly applicable to the wood and bamboo fly wheel are shown in Fig. 28.5. The one thing that these configurations have in common is that in suported sections of the rods are radially oriented and hence, are in pure tension during the

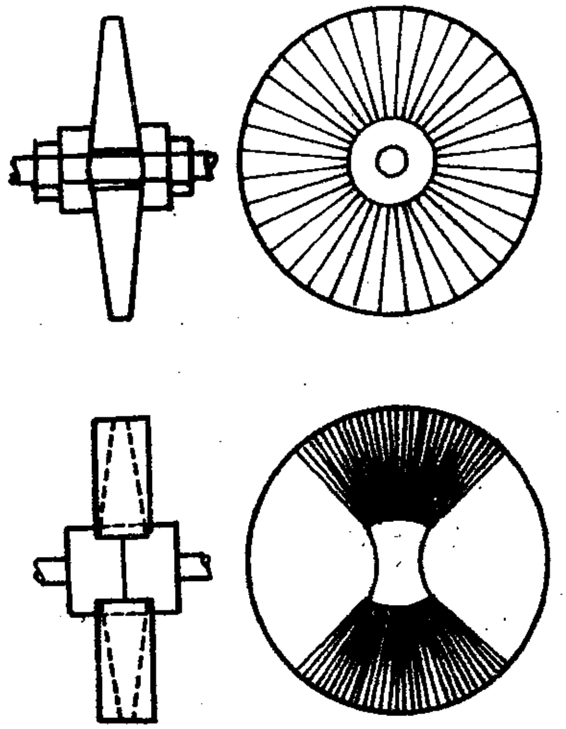


Fig. 28.5 *(a) Spoked disk configuration with laminated bamboo or wood segments with radial grain. (b) Fanned strip configuration.*

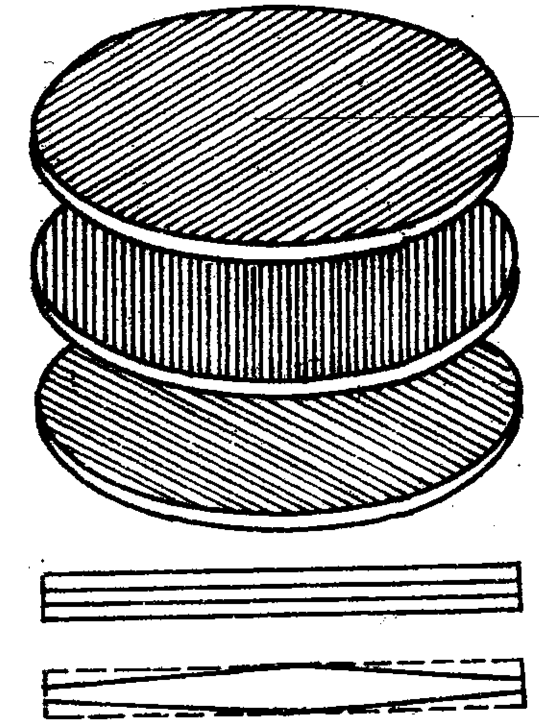


Fig.28.6 *Construction of the Pseudo-isotropic flywheel (laminated anisotropic layers of bamboo).*

Table 28-2 PERFORMANCE OF TYPICAL WOODS IN A SUPERFLYWHEEL (Rabenhorst 1972)

Species	Ultimate tensile strength at zero moisture psi	kg./sq cm	Weight at zero moisture lb/m³	Ultimate energy density* (watt-hr/lb.)	Usable energy density* (at 50% UTS
Bamboo *(Bambusa tulda)*	**52.000**	**3,656**	**0.0202**	**38.6**	**0.0202**
Birch	31,500	2,214	0.0252	18.7	0.0252
Hickory	32,300	2,271	0.0277	17.5	0.0277
Mahogany, Phillippine	24,200	1,701	0.0191	19.0	0.0191
Pines (various, average)	22,000	1,546	0.0195	16.9	0.0195
Redwood	16,000	1,124	0.0144	16.7	0.0144
Spruce, sitka	19,500	1,371	0.0151	19.4	0.0151

* E/W =1.5 x 10^{-5} x strength/density; this represent the average K factor of the three applicable Superflywheel config.

operation of the flywheel this is why they are so applicable to the anisotropic composit materials, which have strong unidirectional strength characteristics.

A third configuration, called the pseudo-isotropic flywheel is shown in fig. 28.6. It is comprised of many layers of thin sheets of anisotropic composit material glued together (See laminated bamboo), oriented to result in an averaging effect of the unidirectional properties of the sheets.

The following material requirements of the superflywheel are just about ideal for wood and bamboo or for any high strength material.

* Operation will be nominally at room temperature.
* The loading will be in essencially pure tension.
* Operation will be in a vacuum, with no significant oxygen or water vapor. The vacuum operating environment will prevent the development of future defects from insects and fungy (rotting), since these living organism require oxigen, moisture, and certain temperature ranges in order to survive. Without any one of these they can not survive, and, of course, in the vacuum environment they will be deprive of oxygen and moisture.
* There will be no corrosive or contaminating environment.
* The stress in the elements will be virtually unidirectional, although some of the configurations discussed for the wood and bamboo applications will also have a magnitude transverse requirement. Unlike most structural aplications, there is no requirement for high modulus of elasticity.
* Unlike must structural requirements, there is no requirement for a ligh weight, per se. In fact, for a given-strength-to density ratio, it is ussually better to have the material as heavy as possible in order to minimize the volume requirements.

Table 28-3 Characteristics of typical superflywheel materials

U	Usable strength at % of UTS	Density lb/in³	Energy/ weight watt-hr/ lb	Est. cost- $ / lb	Energy Cost watt-hr/ $
Solid bullk material					
Glass - now	160.000 at 80%	.09	18	unknown	unknown
Predicted	400.000 at 80%	.09	44	<1.00	>44
Composite material					
Fiobergias/ Epoxy - Now	100.000 at 33%	.073	14	1.00	14
-Predicted	469.000 at 70%	.08	59	2.00	30
Carbon / Epoxy best K/W	154,000 at 70%	.054	29	high	low
best K/$	75,000 at 70%	.07	11	1.00	
Kevlar(80%)/Epoxy -Now	236,000 at 80%	.05	47	8.00	6
-Predicted	236,000 at 80%	.05	47	2.00	24
Bamboo	**26.000 at 50%**	**.02**	**13**	**0.20**	**65**
Bare filaments m.					
Steel wire-best K/w	480,000 at 80%	0.283	17	10.00	2
best K/$	300,000 at 80%	0.283	11	0.45	24
Kevlar - Now	458,000 at 80%	.05	92	8.00	12
-Predicted	458,000 at 80%	.05	92	2.00	48
Boron best K/W	560,000 at 80%	.093	60	high	low

Source: Rabenhorst (1974)

1. - Performance is base on multi-rim configuration (K / W + 1.57 x 10^{-5} x Strength / Density)

2. - All cost values E / $ can be improved considerably by the use of low cost balast.

THE ELECTRIC LAMP OF THOMAS A. EDISON MADE WITH A BAMBOO CARBON FILAMENT

THE ELECTRIC LAMPS PATENTED BY THOMAS A. EDISON

Thomas A Edison patented several of his inventions related to the Electric Lamp. with the following numbers : Patent 227; 228Electric light, February 3, 1879-Patent 227,227, Electric Light , February 10, 1879.-Patent 227,229, April 21 1979.-Patent 223,898, Electric Lamp in November 4 A.D.1879. - Patent 224,329, Electric-lighting apparatus , February 3, 1879 - Patent 227,226, Safety-Conductor for Electric Light, March 25, 1880.

Patent 223,898. ELECTRIC LAMP
Thomas A. Edison, Menlo Park, N.J.
Filed Nov. 4, 1879

"To all whom it may concern:

Be it known that I, THOMAS ALVA EDISON, of Menlo Park, in the State of New Jersey, United States of America, have invented an Improvement in Electric Lamps , and in the method of manufacturing the same, (Case No. 186) of which the following is a specification.

The object of this invention is to produce electric lamps giving light by incandescense, which lamps shall have high resistance, so as to allow of the practical subdivision of the electric light.

The invention consists in a light given-body of carbon wire or sheets coiled or arranged in such a manner as to offer great resistance to the passage of the electric current, and at the same time present but a slight surface from which radiation can take place.

The invention further consists in placing such burner of great resistance in a nearly perfect vacuum, to prevent oxidation and injury to the conductor by the atmosphere. The current is conducted into the vacuum-bulb through platina wires sealed into the glass.

The invention further consists in the method of manufacturing carbon conductors of high resistance, so as to be suitable for giving light by incandescence, and in the manner of securing perfect contact between the metallic conductors or leading -wires and the carbon conductor.

Heretofore lightby incandescence has been obtained from rods of carbon of one to four ohms resistance, placed in closed vessels, in which the atmosferic air has been replaced by gases that do not combined chemically with the carbon. The vessel holding the burner has been composed of glass cemented to a metallic base. The connection between the leading wires and the carbon has been obtained by clamping the carbon to the metal. The leading wires have always been large, so that their resistance shall be many times less than the burner, and, in general the attempts of previous persons have been to reduce the resistance of the carbon rod. The disadventages of following this practice are, that a lamp having but one to four ohms resistance cannot be worked in great numbers in multiple are without the emploiment of main conductors of enormous dimensions; that, owing to the low resistance of the lamp, the leading-wires most be of large dimensions and good conductors, and a glass globe can not be kept tight at the place where the wires pass in and are cemented; hence the carbon is consumed, because there must be almost a perfect vacuum to render the carbon stable, especially when such carbon is small in mass and high in electrical resistance.

The use of a gas in the receiver at the atmospheric pressure, although not attacking the carbon, serves to destroy it in time by "air washing" or the attrition produced by the rapid passage of the air over the slightly-coherent hightly-heated surface of the carbon, I have reversed this practice. I have discovered that even a cotton thread properly carbonized and placed in a sealed glass bulb exhausted to one millionth of an atmosphere offers from one hundred to five hundred ohms resistance to the passage of the current, and that it is absolutely stable at very high temperatures; that if the thread be coiled as a spiral and carbonized, or if any fibrus vegetable substance which will leave a carbon residue after heating in a closed chamber be so coiled, as much as two thousand ohms resistance may be obtained without presenting a radiating-surface greater than three-sixteenths of an inch; that if such fibrous material be rubbed with a plastic composed of lamp-black and tar, its resistance may be made higt or low, according to the amount of lamp-black placed upon it ; that carbon filament may be made by a combination of a tar and a lamp-black, the latter being previously ignited in a closed crucible for several hours and afterward moistened and kneaded until it assumes the consistency of thick putty. Small pieces of this material may be rolled out in the form of a wire as small as seven-one -thousandths of an inch in diameter and over a foot in length, and the same may be coated with a non-conducting non-carbonizing susbtance and wound in a bobbing, or as a spiral, and the tar carbonized in a closed chamber by subjecting it to high heat, the spiral after carbonization retaining its form.

All these forms are fragile and cannot be clamped to the leading -wires with sufficient force to ensuring good contact and prevent heating. I have discovered that if platinum wires are used and the plastic lamp-black and tar material be molded around it in the act of carbonization there is an intimate union by combination and by pressure between the carbon and platina and nearly perfect contac is obtained without the necessity of clamps; hence the burner and the leading-wires are connected to the carbon ready to be plaxed in the vacuum-bulb. When fibrous material is used the plastic lamp-black and tar are used to secure it to the platina before carbonizing.

By using the carbon wire of such high resistance I am enalble to use the fine platinum wires for leading-wires, as they will have a small resistance compared to the burner, and hence will not heat and crack the sealed vacuum-bulb. Platina can only be used, as its expansion is nearly the same as that of glass.

By usinfg a considerably length of carbon wire and coiling it the exterior, which is only a small portion of its entire surface, will form the principal radiating-surface; hence I am able to to raise the specific heat of the whole of the carbon, and thus prevent the rapid reception and disappearance of the light, which on a plain wire is prejudicial, as it shows the least unsteadiness of the current by the flickering of the light; but the current is steady the defect does not show.

I have carbonized an used cotton and linen thread, wood splints (Bamboo splints)*, paper coiled in various ways, also lamp-black, plumbago and carbon in various forms, mixed with tar and kneaded so that the same may be rolled out into wires of various lengths and diameters. Each wire however, is to be unifor in size throughout.*

If the carbon thread is liable to be distorted during carbonization it is to be coiled between a helix of copper wire. The ends of the carbon or filaments are secured to the platina leading-wires by plastic carbonizable material, and the whole placed in the carbonizing-chamber. The copper which have served to prevent distortion of the carbon thread, is afterward eaten away by nitric acid, and the spiral soaked in water, and then dried and placed on the glass holder, and a glass bulb blown over the whole, with a leading-tube for exhaustion by a mercury pump. This tube, when a high vacuum has been reached in hermetically sealed.

With substances which are not greatly distorted in carbonizing, they may be coated with a non-conducting non-carbonizable substance which allows one coil or turn of the carbon to rest upon and be supported by the other.

The drawing (fig. 28.7) shows the lamp sectionally a is the carbon spiral or thread. cc' are the thickened end of the spiral, formed of the plastic compound of lamp-black and tar. dd' are the platina wires. hh are the clamps, which serve to connect the platina wires, cemented in the carbon, with the leading wires xx, sealed in the glass vacuum-bulb. ee are copper wires connected just outside the bulb to the wires xx. m is the tube (shown by dotted lines) leading to the vacuum pump which, after exhaustion, is hermetically sealed and the surplus removed. Fig.2 represents the plastic material before been wound into a spiral. Fig. 3 shows the spiral after carbonization, ready to have a bulb blown over it.

I claim as my invention -

1. An electric lamp for giving light by incandescence, consisting of a filament of carbon of high resistance, made as described, and secured to metallic wires, as set forth.

2. The combination of carbon filaments with a reciver made entirely of glass and conductors passing throught the glass, and fron which receiver the air is exhauted, for the purposed set forth.

3.- A carbon filament or strip coiled and connected to electric conductors so that only a portion of the surface of such carbon conductors shall be exposed for radiating ligh, as set forth.

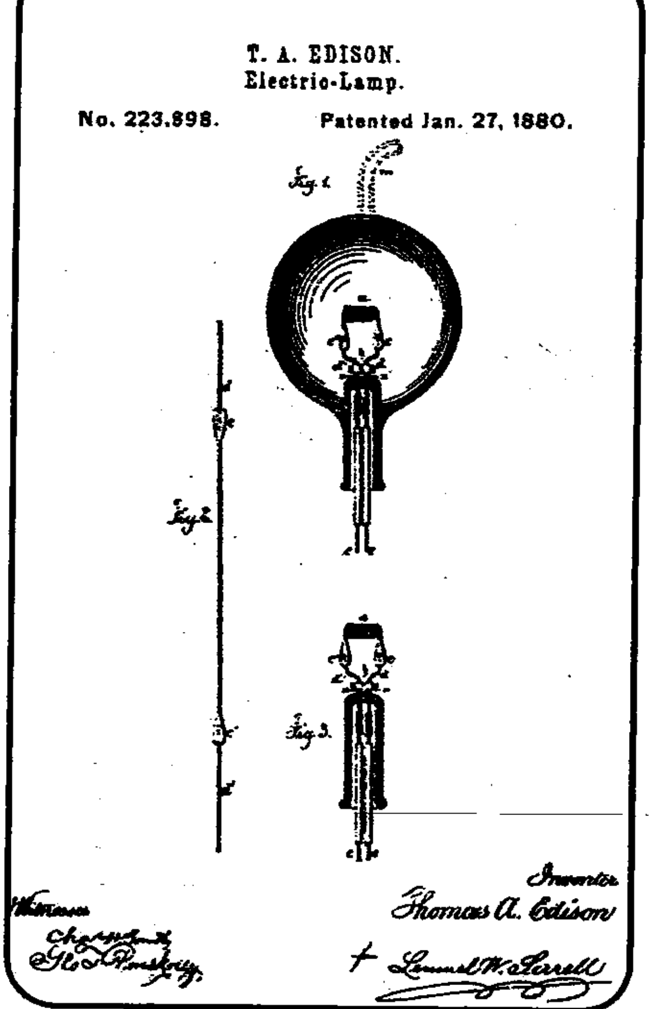
4.- The method here in described of securing the platina contac-wires to the carbon filament and carbonizing of the whole in a closed chamber, substancially as set forth.

Signed by me this 1st day of November, A. D. 1879"

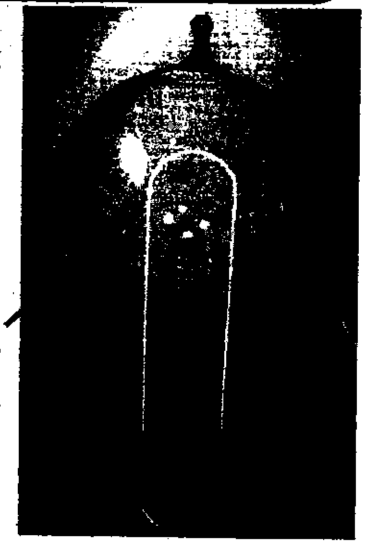
THOMAS A. EDISON

Witnesses:
S.L. GRIFFING

Fig. 28.7 - The electric lamp



JHON F. RANDOLPH



Filament of carbon of high resistance, made of bamboo as described, and secured to metallic wires.

At that time (1880) bamboo was considered as a timber or wood

27 BAMBOO IN THE FIELD OF HYDRAULIC ENGINEERING

BAMBOO RURAL AQUEDUCTS - TYPES OF BAMBOO JOINTS

Bamboo pipes

Hollow bamboo pipes have found numerous uses. Bamboo with the internal partition removed from a natural pipe, and this fact had a great influence on East Asian invention. In the earliest times, it offered itself as a material for flutes and pipe-like musical instruments, which deeply molded the development of Chinese acoustics through the ages. From the Han dynasty onwards, bamboo was used in the conveyance of brine from the deep borings to the places where evaporation was to take placefor the production of salt. It found use in piped water installation. Cut longitudinally, it served as light tiles on roofs and every sort of simple channels. Bamboo tubing was further used in alchemy and the beginnings of chemical technology in the form of containers for such purposes as the descensory distillation of mercury and the solubilisation of minerals. It generated the sighting-tube so characteristic of medieval Chinese astronomical instruments and fulfilled its most fateful destiny by becoming the ancestor of all barrel-guns early in the 12th century. Bamboo pipes have been extensively used as a substitute for metal and PVC pipes in rural aqueducts and irrigation works, particularly in Africa (in Tanzania and Ethiopia) and in Indonesia.

Rural bamboo aqueducts

Bamboo pipe consists of mature culm sections (3 to 4 meters long) taken from the bottom, middle, and top part of the culms so they have different diameters. At the joints, the nodes or partitions are bored out with a round chisel. For this purpose one end of a short length of steel pipe is belled out to increase the diameter and the edge is sharpened. A length of bamboo pipe having a sufficiently small diameter to slide into the pipe is used as a boring bar and is secured to the pipe by drilling a small hole through the assembly and driving a nail through the hole. Three or more chisels, ranging from smallest to the maximum desired diameter are required. At each joint the partition is removed by first boring a hole with the smallest diameter chisel, and then progressively enlarging the hole with the larger diameter chisels.

Bamboo pipe sections are joined in a number of ways as shown in the lower figure. Joints are made watertight by caulking with cotton wool mixed with tar, then tightly binding them with rope soaked in hot tar. Bamboo pipe is preserved by laying the pipe below ground level and ensuring a continuous flow in the pipe. Where the pipe is laid above ground level, it is protected by wrapping it with layers of palm fiber with soil between the layers. This treatment will give a life expectancy of about 3 to 5 years tothe pipe. Deterioration and failure usually occur at the natural joints which are the weakest part of the culm.

Fig. 29.1 The use of bamboo as water pipes

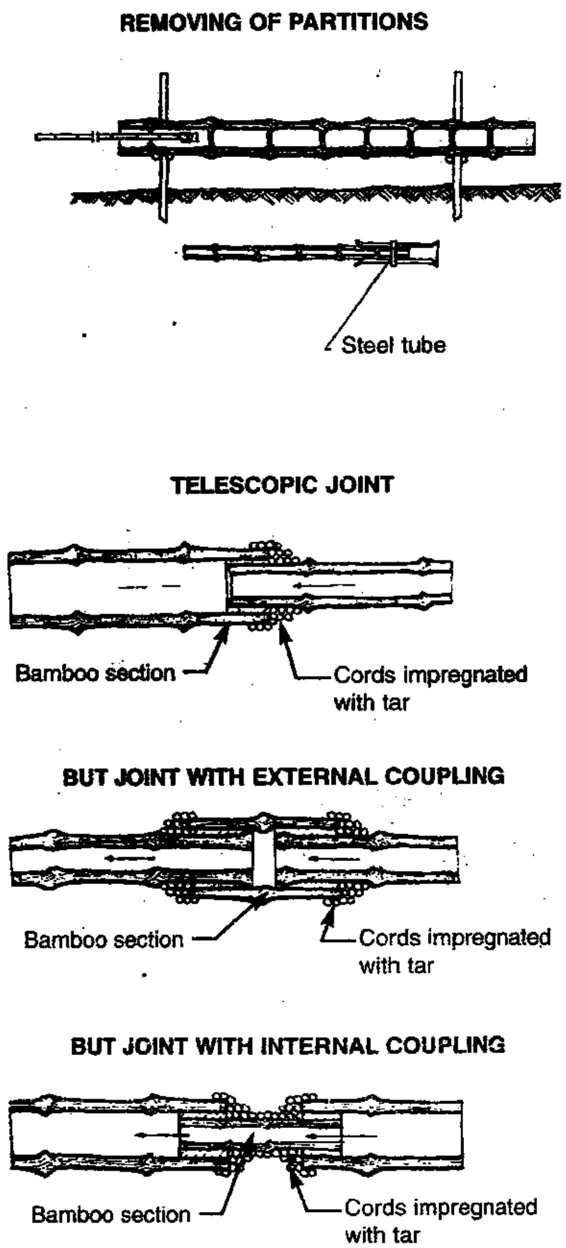
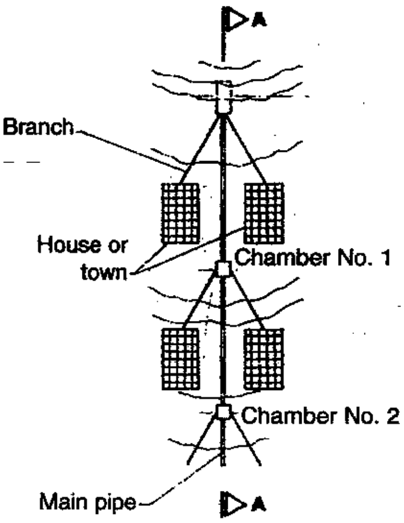


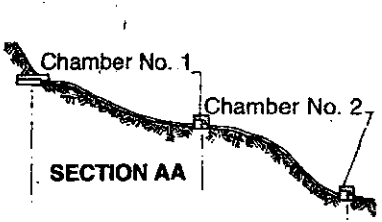
Fig. 29.2

RURAL BAMBOO AQUEDUCTS

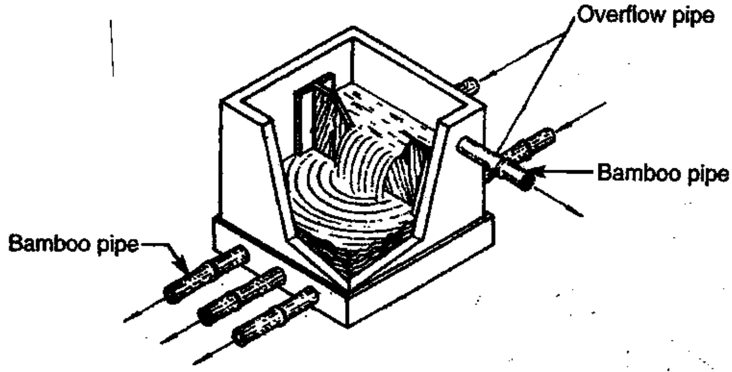
After a bamboo pipe is put into operation, it gives an undesirable odor to the water. This, however, disappears after about three weeks. If clorination is carried out before discharging to the pipe, a reservoir giving sufficient contact time for effective desinfection is required since bamboo pipes remove chlorine compounds and no residual chlorine will be maintained in the pipe.

To avoid possible contamination by ground water, an ever present danger, it is desirable to maintain the internal pressure in the pipe at a higher level than any external water pressure the pipe. Any leakage will then be from the pipe; thus, contaminated water cannot enter it. Bamboo piping can only hold pressure up to two atmospheres (2.1 kg/cm2 or +30 psi); hence, it cannot be used as pressure piping.

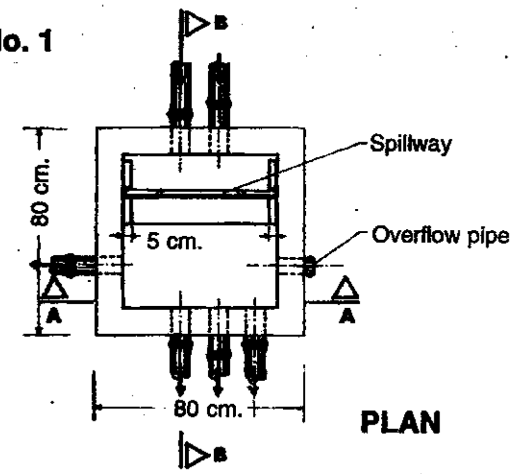




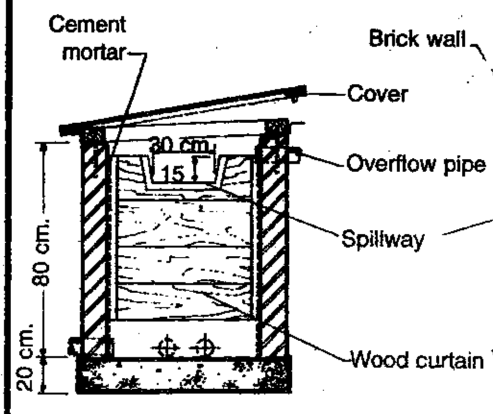
DISTRIBUTION CHAMBERS



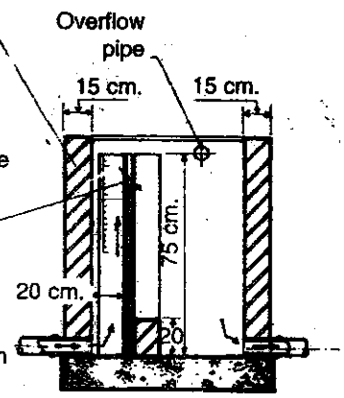
DETAIL No. 1



PLAN



CROSS SECTION AA

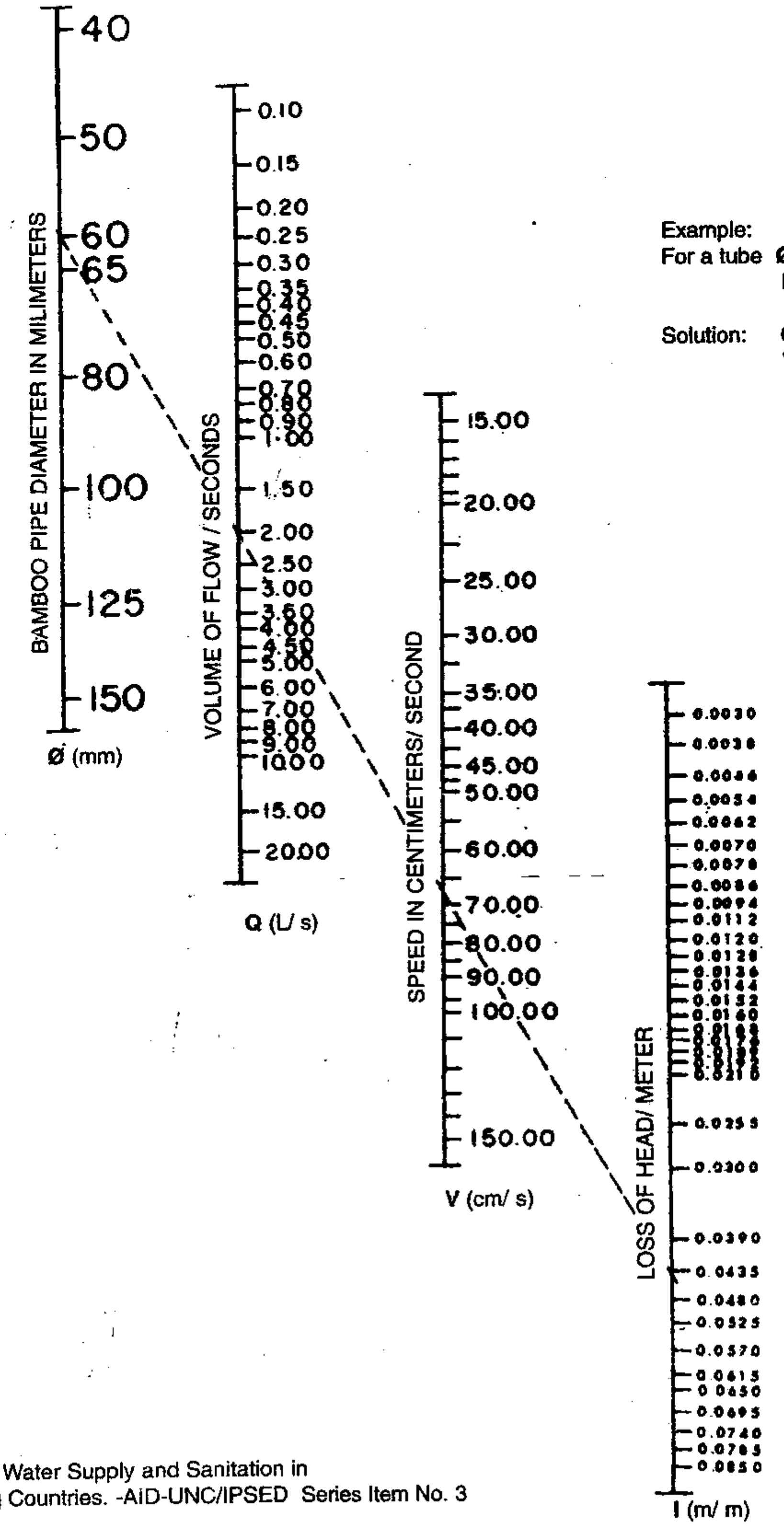


CROSS SECTION BB

DETAIL No. 2

BAMBOO AQUEDUCTS- NOMOGRAPH FOR FLOW IN BAMBOO

Fig. 29.3



Example:
For a tube Ø = 60 mm.
I = 0.0445 mm.

Solution: Q = 2.05 l/s.
V = 67.5 cm/s.

Note: After Water Supply and Sanitation in Developing Countries. -AID-UNC/IPSED Series Item No. 3

Fig. 29.4 BAMBOO FOUNTAIN - BAMBOO SUPPORTS

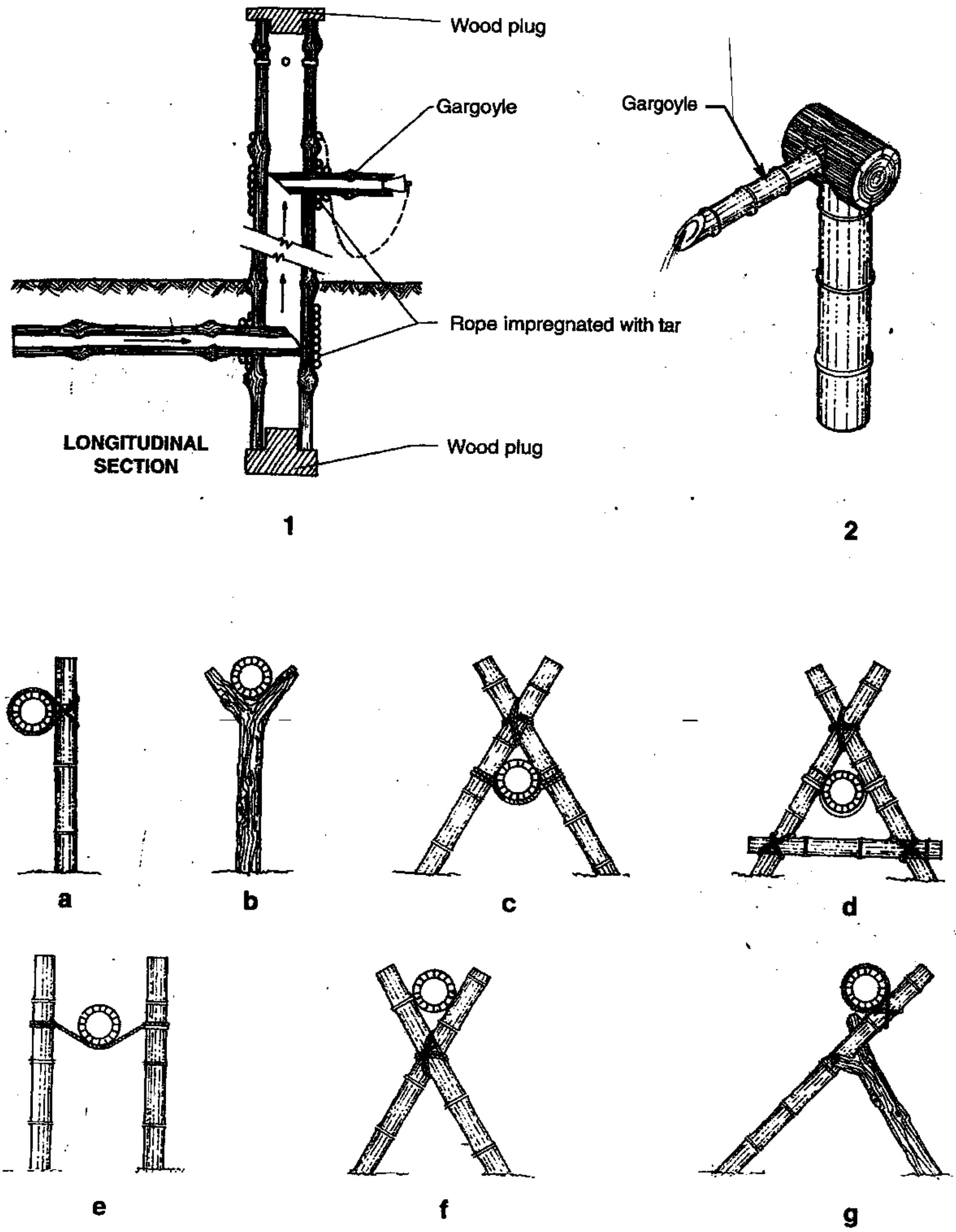


Fig. 29.5 **DIFFERENT TYPES OF BAMBOO AND WOOD JOINTS**

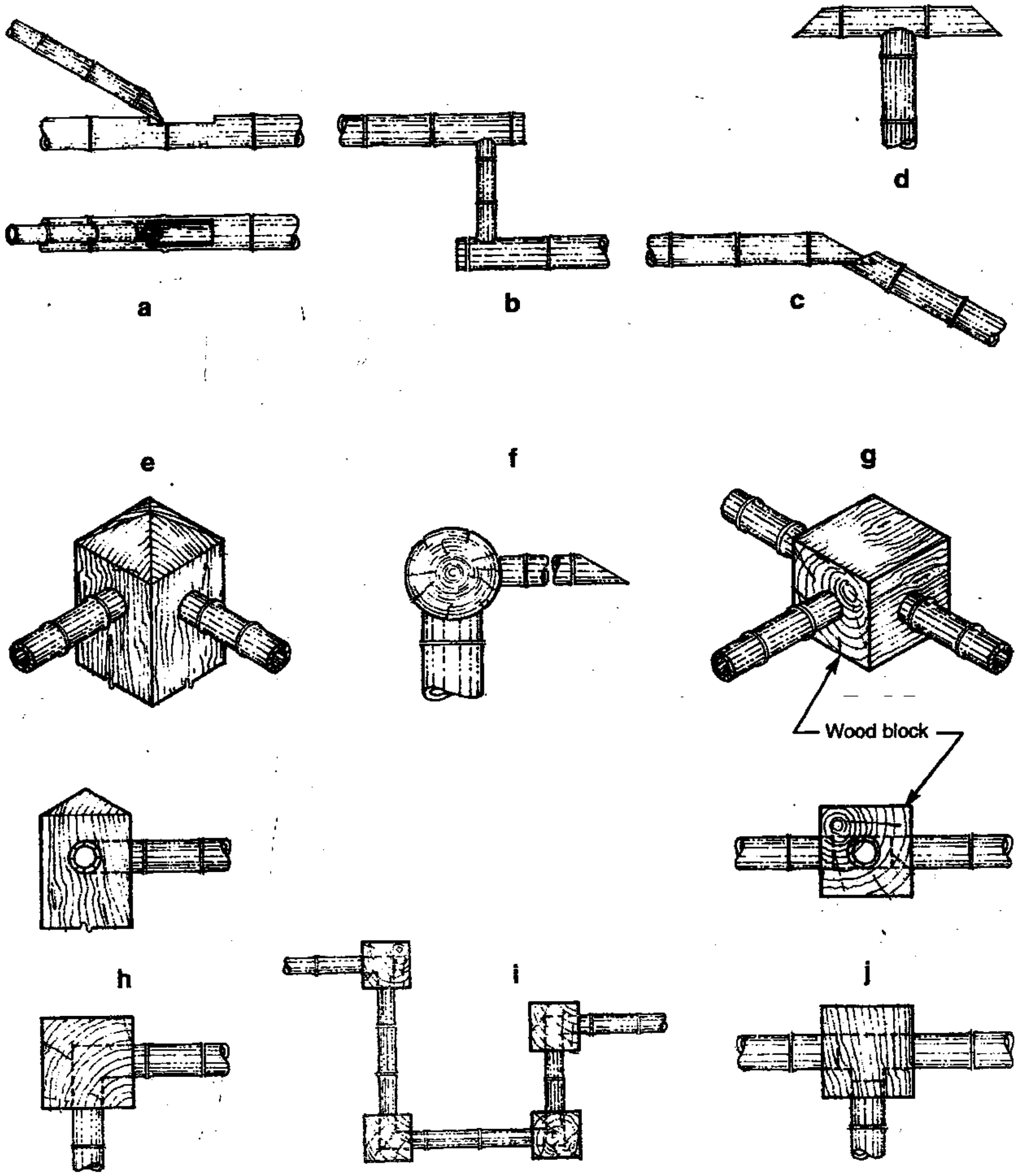
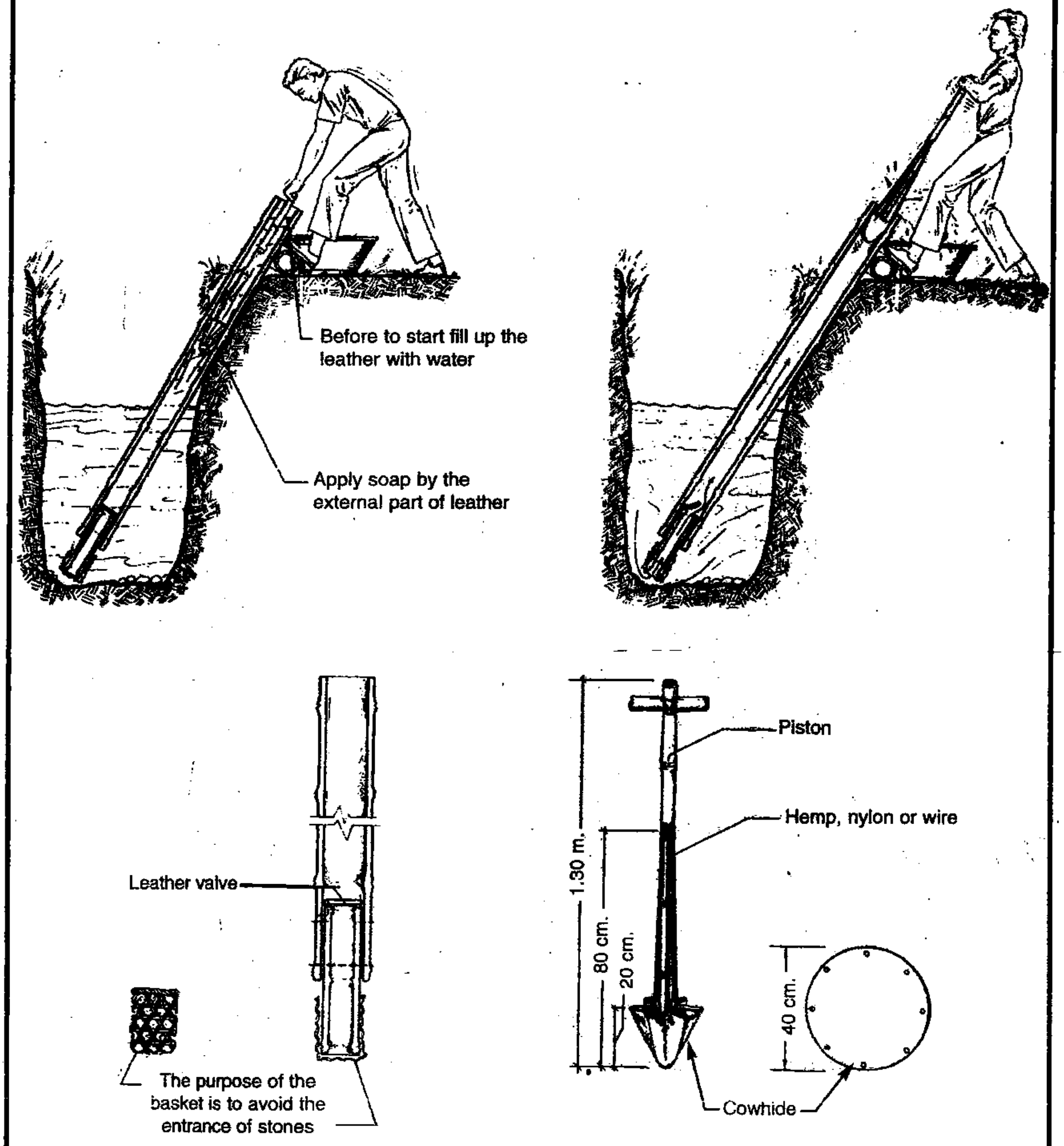


Fig. 29.6 **BAMBOO WATER PUMPS - PARACHUTE PUMP**



BAMBOO PIPES USED IN THE WELL SALT INDUSTRY IN CHINA

Uses of Bamboo pipes

According the story of the Salt Industry in China, in times of the Han Dynasty, there were actually "brine springs" in the provinces of Yunnan and Szechuan in China, situated far from the sea coast and at high elevations. Then came an earthquake and covered the springs, changing the contour of the country thereabouts. The natives then proceeded to dig for the brine and later they developed the business of boiling it (Crawford 1926).

According to Sung (1966), in the rocky mountains of Szechuan, salt wells can usually be drilled not far from rivers. The diameter of the well shaft is only a few centimeters and the well must be more than thirty meters deep, however, before the the salt water vein can be reached, hence the drilling of a salt well is a difficult and costly undertaking. The tool used is an iron drill with a very hard sharp tip shaped like the blade of a chisel, which bores holes in the mountain rocks.

The drill is suspended and held in place by a bundle of split bamboo strips, fastened together with bamboo ropes. Each time the rock has been penetrated about a meter, the bamboo suspender is lengthened by attaching to it another section of bamboo. Up to the first meter or so of the well, the drilling equipment can be operated by stepping on it with ones' feet, like the motion of pounding rice in a mortar. When the well becomes deeper, the drilling equipment is operated by hand. The rock fragments that result from the drilling are scooped up with an iron vessel attached to a long bamboo pole. The time required for completing a salt well ranges from over a month for a shallow one to some 6 months for a deep one.

The reason for the small diameter of the shaft is that a wide shaft allows the brine to degrade, through dissipation of its vapor, and become unsuitable for making salt.

Fig. 29.7

A

B

C

Fig. 29.8 BAMBOO USE IN THE SALT INDUSTRY IN CHINA (2)

When the brine level in the well is reached, good bamboo stalks or culms about three meters in length are brought in, and from them all the inner section partitions except the one in the bottom end, are removed and a valve which permits the brine to enter is set in the partition.

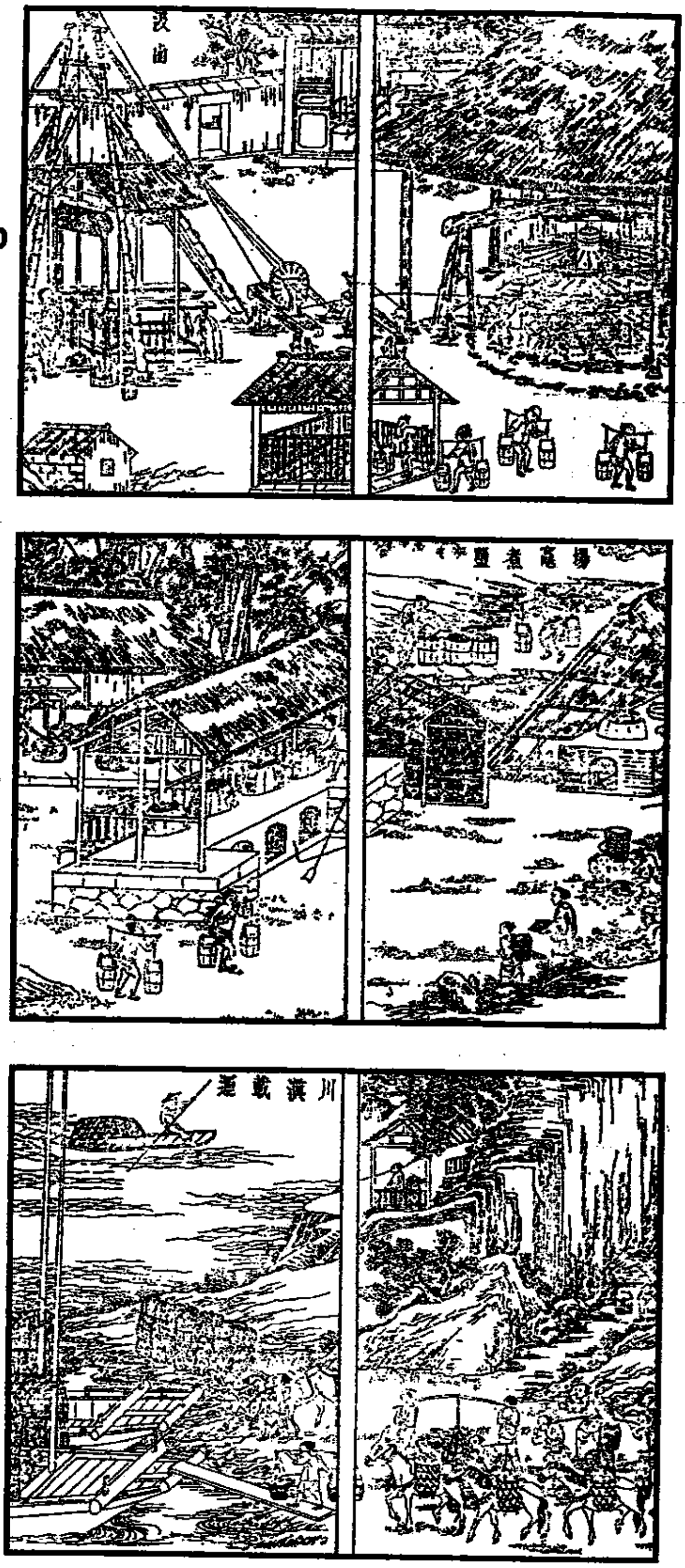
This bamboo is lowered into the well with a long bamboo rope (Fig. 29.8 D). After it fills with brine, it is raised to the surface by means of a pulley fixed over the well and a windlass turned by an ox-powered wheel (Fig.29.8 F). The brine so obtained is then poured into a pan for evaporation and crystallization (only a medium-size pan is used, not the "strong pan"). Very white salt will quickly crystallize from it. The transportation of salt in Szechuan and Yunnan pro-vinces is illustrated in Fig. 29.8 F.

The same author points out a highly amazing phenomenon in the fire wells of western Szechuan. These wells actually contain cold water, without the least appearance of fire. But split open a long bamboo culm and take out its inner section partitions, then put the culm together again and securely wrap it with varnished cloth. Next, place one end of this bamboo into the well, while the exposed end is connected to a curved section of bamboo to reach the bottom of a salt pan filled with brine. It will be seen that heat radiates from the mouth of the bamboo, to boil the brine in the pan. Yet if the bamboo culm is opened and examined, not a bit of charring or evidence of burning can be seen. To use the essence of fire without seeing the fire, is indeed one of the strangest things in the world (Crawford 1926).

D

E

F



28 BAMBOO IN THE FIELD OF NAUTICAL TECHNOLOGY

BAMBOO SHIP BUILDING IN CHINA

As I explained in the page 15, there is an information in very old Chinese books that in ancient China there were huge bamboos, up to 3.80 meters in diameter, which were used in the construction of boats or junks using one or several of their large internodes. For example, in the Sheng iching (Records Related to Marvelous Things) written by Tung Fang, who lived in the 2nd century B.C., in the southern wilderness in China there was a bamboo known as Ti chu (weeping bamboo) which grew to a height of several hundred chang (one chang = 10 feet = 3.33 m - one Chinese foot or chih = 0.333 m). The circumference of this bamboo was 3 chan and 6 chi; and the culm thickness was eight or nine "tsun" (tsun = one inch). Its shoots were delicious and if they were eaten, they would cure ulcers.

If the dimensions have not changed since ancient times and if there is no mistake in the dimensions that Hagerty (1919) gave in his translation of this book, this bamboo had a circumference of three chang and six chih = 36 Chinese feet = 12 mts which corresponds to a diameter of 3.81 meters.

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

The Treatise on Agriculture (Nung Cheng Chuan Shu) compiled by Hsu Kuang-chi originally published in 1640 states that the P'ei chu (Giant bamboo) is found in the southwestern part of the Han-shan district in Anhui province. According to the Tz'u - yuang, this variety measures one-hundred chang (333 m) in height, has a circumference of three chang and five or six chih (about 35 chih = 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 Treatise on Agriculture (1640) says that the Lung kung chu (Dragon duke bamboo) is a large variety that has a diameter of seven chih (1 chih = 0.333 m x 7 = 2.33 m in diameter) and between each joint (internode) there is a space of one chang (ten Chinese feet) and two chih (12 chih =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 mountain range in the Kuangtung province.

The opinion of Needham and other authors is that probably the use in ancient times of half longitudinal sections of bamboo internodes for the construction of boats generated the Chinese junks, due the similarity which exists between them and the bamboo culm.

According to Needham (1970), Chinese shipbuilding has a pattern entirely of its own. What shipwrights did all over the rest of the Old World quite failed to exhaust the ways in which it is possible to build ships. In Europe and Southern Asia, the fundamental beam, the keel, was scarfed at each end to another scarfed beam which turned upwards to form the stem-post and the stern-post respectively. The strakes of the hull which connected them were then held apart in the desired profile by an internal skeleton of bent timbers. However, the design of junks exemplified in the oldest and least modified types has a carvel-built hull lacking all three components which elsewhere were regarded as essential: keel, stem post and stern-post. The bottom may be flat or slightly rounded, and the planking does not close in towards the stern, but ends abruptly, giving a space that would remain open if it were not filled by a solid transom of straight planks. In the most classical types, there is no stem either, but a rectangular transom bow. The hull may be compared to half of a hollow cylinder or parallelepiped bent upwards towards each end and terminated by final partitions. Moreover there are no true frames or ribs whatever; they are replaced by solid transverse bulkheads of which the stem and stern transoms may be regarded as the terminal units. This is clearly a much more solid method of construction than that found in other civilizations. Fewer bulkheads were required than frames or ribs to ~~give the same degree of strength~~ and rigidity. It is obviously also possible for these bulkheads to be made watertight, and so to give compartments which would preserve most of the buoyancy of the vessel if a leak should occur, or damage below the water-line. In other ways also the bulkhead structure involved corollaries of great importance, for example in providing the essential vertical component necessary for the appearance of the hinged axial rudder. This, together with similar inventions in the sail propulsion (of surprisingly early date), we will speak of presently.

I need only stop to remark on the striking similarity between the bulkhead structure of the Chinese ship and the prominence of the transverse partitions or framework so fundamental in Chinese architecture. If the latter prevented longitudinal vista and permitted the classical curve of the roof, the former provided distinct holds, rendered the vessel extremely strong, and gave it the typical bluff bow and stern of large Chinese craft.

One is irresistibly reminded of the fact that the bamboo, the plant so familiar to every Chinese for its thousand uses, has transverse septa. Indeed an important clue may lie herein. The sampan (shan) is reminiscent of the bamboo stem just as strongly as the junk. It is an open skiff, bluntly wedge-shaped in plan, shallow, keelless and very broad in the beam aft where the gunwale rail is often continued beyond the stern as an upwardly curved projection endowing the craft with "cheeks" or horns facing astern. It was the roofing of the space between these projections that led to the overhanging counter of the junk.

There is every reason to believe that this particularly characteristic method of ship costruction goes back to the earliest times of Chinese civilization, for in the pictographs of the written language as used during the Shang period of the 2nd millennium, one finds that the word for ship (chou) is represented by a little drawing of what looks like a curved ladder. I know hardly any other Shang pictograph which enshrines so completely such a fundamentally distintive characteristic of a great branch of Chinese technology. So, perhaps the longitudinally sliced bamboo was its paradigm or model.

As for the physical evolution of the junk, the most probable view is that it derives from the bamboo raft. The remarkable sea-going sailing-raft, still used today in Chinese and Indo-Chinese areas southwards from the latitude of Taiwan, would have required only the conversion of the wooden thwart-beams into bulkheads, the substitution of wood planks for bamboo in the bottom and sides, and the addition of decking. Chinese and Annamese sailing rafts are of great interest, being equipped with five center-boards and tall lug-sails, permitting them to sail into the wind.

There is a possible Egyptian influence in shipbuilding in China; for example, some of the Egyptian Horian boats are quite square-ended like all true Chinese ships. Another common feature is the bipod mast, widely diffused in Southern Chinese shipbuilding. This mast type, from the engineering point of view was excellent and it came back in the days of metal tubing.

The bamboo hogging truss used in the Chinese and Egyptian boats

According ~~to Needham, if there had~~ really been West Asian influence on Chinese naval architecture, one might expect to find some exceptions in the Chinese culture-area to the basic principle of boats without keels, stem-or stern-post.

There is one, and it is of great interest. The dragon-boat (lung chhuan) is used for the races which form an important feature of the Fifth Month Festival, carrying thirty-six or more paddlers, and it is built with a true keel or kelson. Although bulkheads slotted to the kelson are built in, we clearly have here an archaic element of one of the constituent cultures which fused to create Chinese civilization. Even more interesting, however, it is found that in order to prevent "back breaking", a strong bamboo cable was passed over the tops of a series of vertical struts. Its two ends were looped under and round the ends of the ship so as to prevent them from drooping (Fig. 30.1). This rope could be tightened by some form of Spanish windlass, a skein of cords which can be twisted and so shortened by means of a long stick or lever thrust through its middle, exactly as was the common practice in ancient Egyptian ships. This is nothing other than the 'anti-hogging truss' (or hogging truss).

Probably this technology was taken from the Ancient Egyptians boats (somewhere between 4,000 and 3,000 B.C.) which were constructed by tying together several parallel bundles of reeds. Similar boats are in use today on the White Nile and also on Lake Titicaca, in South America. Since the bundles of reeds naturally tapered toward the ends, a roughly boat-shaped form was achived more or less automatically. Often the long, wispy ends on the reed bundles were tied in such a way that they turned upwards so as to provide a vertical decoration at the bow and stern.

Although most of the buoyancy of a ship is provided by the middle part of the hull and comparatively little by the tapering ends, nothing will ever prevent people from putting heavy weights into the ends of the ship. One result of this is that many vessels tend to "hog" (the two ends tend to droop and the middle of the hull tends to rise). This state of affairs is the opposite of that which exists in roofs and bridges, where the middle of the truss usually tries to sag below the level of the end-supports. This condition is called 'sagging' by engineers.

The Egyptians solved the problem by providing their ships with what is now called a "hogging truss". Thus, the big reed hull could be strained to any degree of straightness. As the art of shipbuilding progressed, the Egyptians came to construct their hulls from timber, rather than from bundles of reeds. However, since most of the planks were very short and nearly all of the fastenings might be described as wobbly, the need for the hogging-truss remained.

According to Gordon (1981), Greek shipwrights were more advanced than the Egyptian ones; however, their ships were also built from short lengths of timber, and their light hulls were very flexible and much inclined to leak. For these reasons, the Greeks retained the hogging-truss which was called the hupozoma.

This was a substantial rope which ran right round the outside of the hull, high up and just beneath the gunwale, which the helmsman could adjust by means of Spanish windlass. Since warships fought mainly by ramming each other, they had to be able to withstand a great deal of structural abuse. The hupozoma was therefore an essential part of the hulls of these ships; they were unable to fight, or even to go to sea at all, without it.

It is quite clear that the Athenian shipbuilders, down in the Piraeus, were familiar with the principles of trussing, and one might well ask why the Athenian architects, such as Mnesicles and Ictinus, did not latch on to the idea for the roofs of their temples. Perhaps the analogy between hogging and sagging never struck them, or perhaps they just never hobnobbed with shipwrights.

When the fragile oared fighting galley went out of use, hogging-trusses disappeared. However, the American river steamboats of the nineteenth century were every bit as flexible as the Greek trirème or the Egyptian vessels on the Nile. Their shallow wooden hulls presented exactly the same problems, and the Americans solved these problems in precisely the same way as the ancient Chinese and Egyptian did. All the river steamers in the United States were provided with hogging-trusses of the Chinese and Egyptian pattern. The only difference was that the tension members were made with iron rods, rather than bamboo or papyrus rope, and they were tightened by means of metal screws instead of a Spanish windlass.

The hogging trusses also occur, of course, in many different forms depending on the kind of sailing ship and in the United States this generated the invention of different types of trusses that were used in the construction of bridges.

One of the earliest of these and the most extensively used in the United States was the Bollman truss. Fig. 30.1 C.

shows a simplified Bollman truss with only three panels. The Fink truss (Fig. 30.1 D) does the same job as the Bollman truss, but does it rather better by using shorter members.

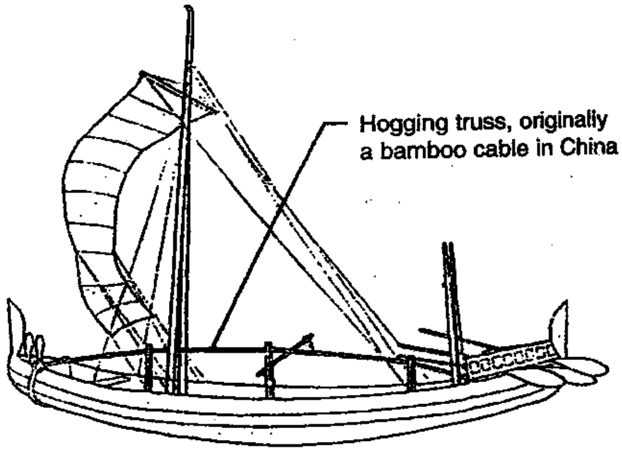
We can put a continuous member along the bottom of the Fink truss and turn it into what is more or less a Pratt or Howe truss (Fig. 30.1 E). This is pretty well what is generally used in the traditional biplane. It will be seen that the Pratt or the Howe truss will work equally well upside down, that is to say, in either hogging or sagging, provided that we take certain common-sense precautions.

Furthermore, if we arrange that all the members can take both tension and compression, we can simplify the structure by turning it into a Warren girder (Fig. 30.1 F). It is this form, or somthing like it, which is most commonly used for trusses made of ordinary steelwork (Gordon 1981).

STRUCTURES DERIVED FROM BAMBOO HOGGING TRUSSES

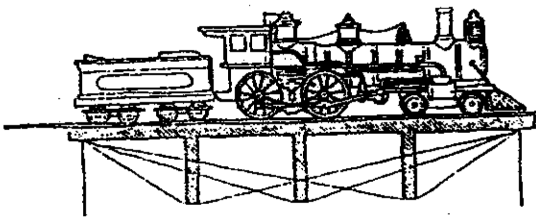
Fig. 30.1

Chinese were the first in providing their ships with what is now called a "hogging-truss". This consisted of a stout bamboo rope which was passed over the tops of a series of vertical struts, its two ends being looped under and round the ends of the ship, so as to prevent them from drooping. Later this technology was used by Egyptians. According to Gordon (1983) This technology was the origin of the several types of trusses shown below.

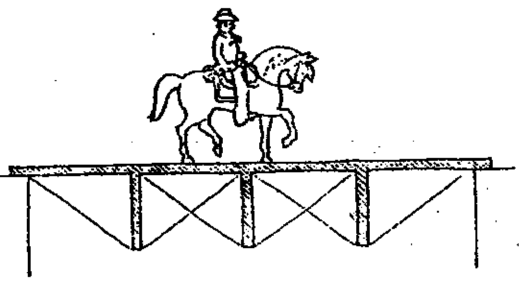


A. *Lateral view of the hogging- truss*

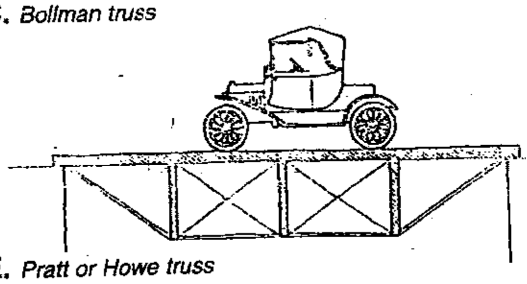
B. *Top view of the hogging-truss*



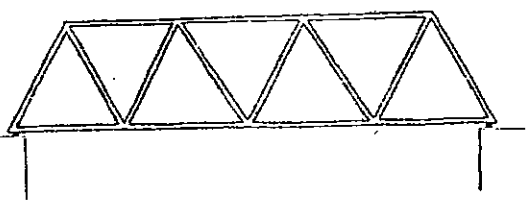
C. *Bollman truss*



D. *Fink truss*



E. *Pratt or Howe truss*



F. *Warren girder*

Source: Gordon, J.E., Structures or why things don't fall down. 1978

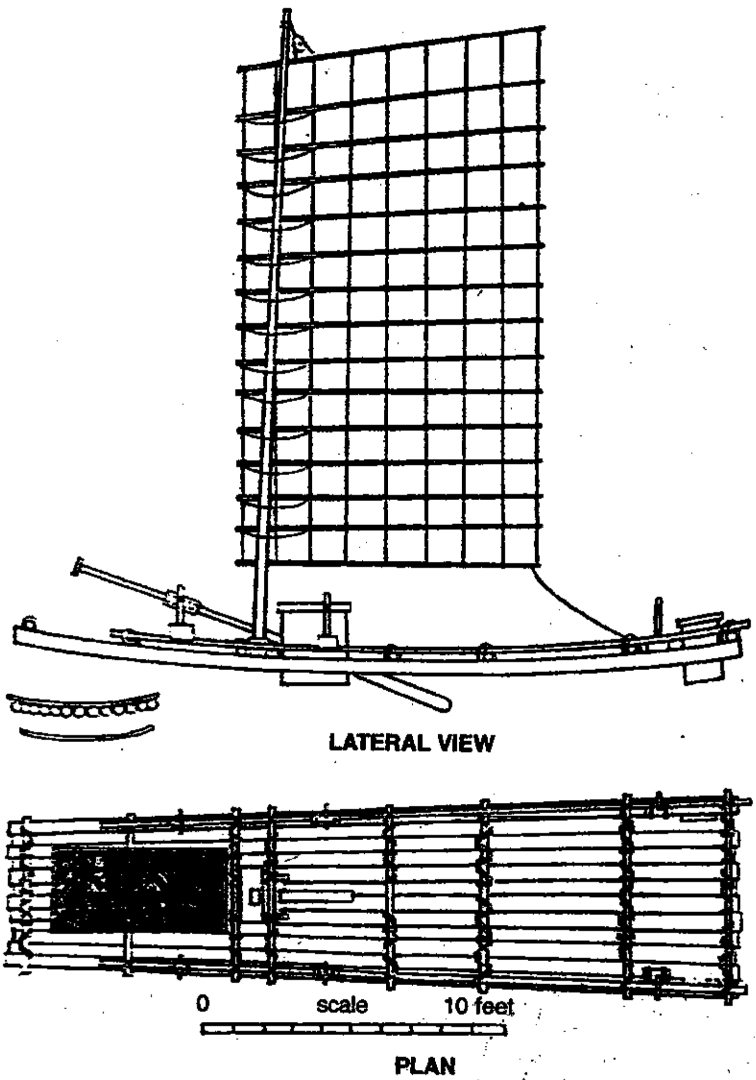
BAMBOO BOATS AND RAFTS

According to Worcester (1966), the Chu-p'ai or Tray Boat of T'ai Wan is certainly the most scientific and interesting of the many varieties of rafts to be found in the Far East. These boats are simple small rafts, measuring 12 to 40 feet long, with a draught of a few inches, built of about a dozen large bamboos lashed together with the tapering ends forward. The foremost end of the raft is narrower and more up-turned than the aft end.

The culms that are used grow to a height of about 60 to 80 feet with a maximum circumference of 17 inches. These species have a large core and are an extremely light wood. The bamboos are very carefully selected, for they must be of uniform size to prevent cracking and to reduce weight. The siliceous skin is removed, and the nodes are hardened over a slow fire. The raftsmen say that this treatment method also increases their "arresting power" when afloat.

Across the fore and aft poles, eight slightly smaller curved poles are lashed at the warships at intervals to suit the construction. The aft ends of the main bamboos, which are usually, though not always, broader than those in the bow, are painted red, black and green.

Fig. 30.2 **The Chu-p'ai or Tray-boat of T' ai Wan**



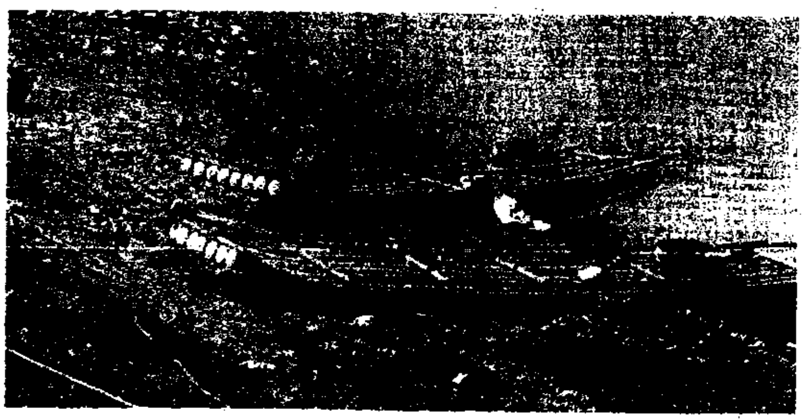


Fig. 30.3 *The bamboo raft. In the bamboo growing areas, the poles are cut down by local growers and collected into piles. The rafts are made from bundles of culms tied together and often take the form of long serpentine rafts sometimes extending for 100 feet. They are an interesting feature of the Soochow Creek as they snake their way in and out of the water traffic (Worcester 1966).*

29 BAMBOO IN THE FIELD OF MECHANICAL ENGINEERING

BAMBOO WATER WHEEL DRIVE

Machinery

Wood and bamboo appear in great prominence as the construction materials for machines in ancient and medieval China; only certain essential parts were made of bronze or iron.

Water wheel drive

From earliest times, the Chinese have used bamboo for power development and transmission, such as the water wheel drive, which is the most economical source of power. Water and the water wheel continued to be man's single greatest source of power until the coming of steam. As water wheels were improved, they powered machinery that sawed wood, and processed cloth, etc.

Probably the first water wheel developed was the undershot; that is, driven by a stream flowing beneath it. Eventually three types of water wheels were in operation: the undershot variety, the breast wheel which consists of a wheel placed to catch falling water at a midpoint and equipped with buckets on its paddles. The weight of the water caught by the buckets speeds the rotation of the wheel. The most efficient of all was the great overshot wheel in which water falling on a wheel from above also allowed the use of buckets on the paddles. Both the overshot and breast wheels gain added power from the force of the falling water.

The bamboo water wheel drive, particularly the undershot wheel type, is still the most used in several countries in Asia. In Burma it is used for providing power to grooved timber rollers which crush freshly cut sugar cane.

This wheel may be driven by the force of the current which pushes the paddles fixed radially around the wheel, resulting in a continuous rotation of the wheel. The structure of the wheel is made of bamboo, and the paddles can be made of bamboo or wood. The central axis is a timber trunk in which is fixed at one end of the radial structure. The central axis is supported by a wooden or bamboo structure.

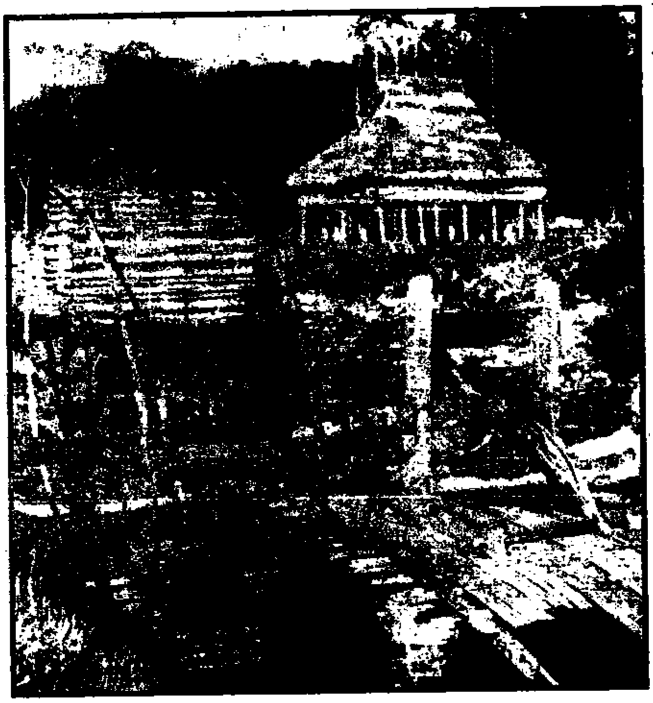
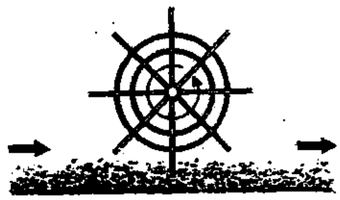
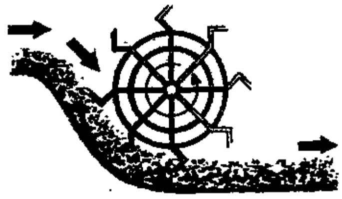


Fig. 31.1 *Bamboo water wheel drive with an undershot type wheel (see Fig. 31.2 A) is still used in Burma for providing the power to crush freshly cut sugar cane.*

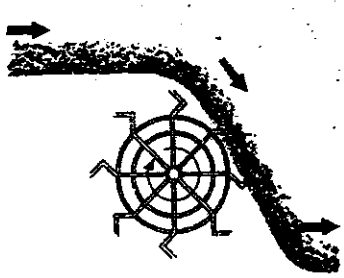
Fig. 31.2 Three ways of using the water wheel



A. The undershot wheel
Water coursing beneath this wheel, hitting its lower paddles, is what causes it to rotate.



B. The breast wheel
A wheel placed to catch falling water at midway point can be equipped with buckets on its paddles. The weight of the water caught by the buckets speeds the rotation of the wheel.



C. The overshot wheel
Water falling on a wheel from above also allows the use of buckets on the paddles. Both overshot and breast wheels gain added power from the force of the falling water.

Fig. 31.3 THE BAMBOO NORIA (CYLINDER WHEEL)

A derivation of the water wheel drive is the "bamboo noria", also known as the peripheral pot wheel, or cylinder wheel, used in China, Cambodia and other countries of Southeast Asia for irrigation and rural or village aqueducts. Its origin is unknown, but it was first illustrated in 1313 A.D.

The noria is used along river banks for lifting water from the river level to several meters high, depending on the diameter of the wheel. The river is dammed and channeled so that the water flows onto the lower part of the wheel, resulting in a continuous rotation. The cylinders attached to the wheel are filled with water as they become submerged, when the wheel turns around. They are subsequently emptied or discharged at the top of the wheel into a wooden or bamboo channel, and thence into the fields or an aqueduct system. This apparatus continues its operation day and night. When water is not needed, a piece of wood is tied to clog the wheel and stop its turning.

This wheel may be driven by the force of the current if it is furnished with paddles, but in lakes and ponds where there is no flowing water, it must be powered by men, using a multiple-pedal treadle wheel or animals like an ox-drawn wheel or donkey whim.

According to Needham (1965), the norias can attain a diameter up to 23 m (75 feet); this is possible because the norias built of bamboo are very light. The most common diameters in China are 14 m (45 ft) and 16 m (50 ft) as can be seen in the Yellow River. In China and Indochina, norias are often arranged in batteries with a common shaft, up to as many as ten in row (Ying Hsin 1966).

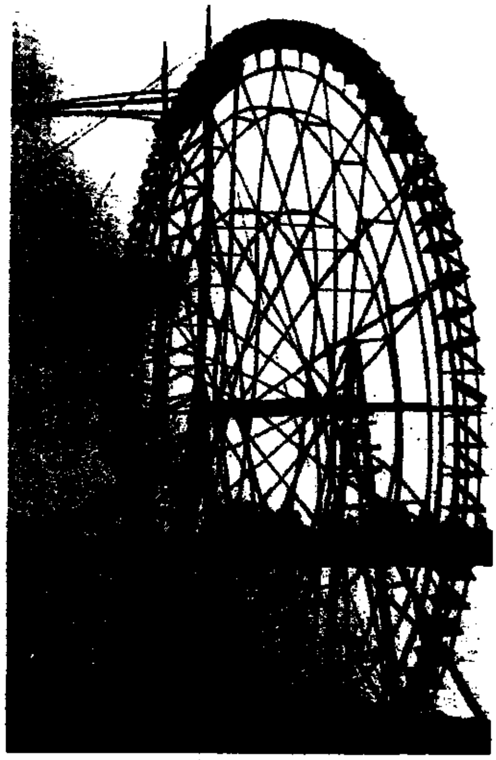


Fig. 31.3 A. Chinese noria 22 m in diameter

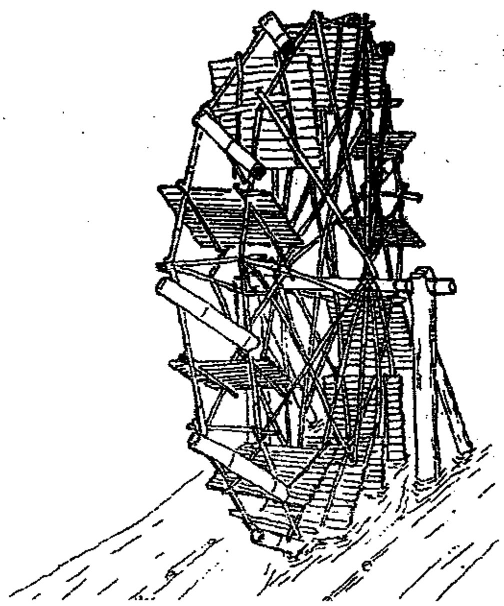


Fig. 31.3 B. A bamboo noria designed in CENTA (El Salvador)

Fig. 31.3 B. *The bamboo noria for irrigation in figure B, has a diameter of about 4 meters, was designed in the Centro Nacional de Tecnologia Agropecuaria C.E.N.T.A in Santa Ana, El Salvador by Chen Pao Chuan, Francisco Garcia and Nelson Flores.*

Fig. 31.4 BAMBOO NORIA (CYLINDER WHEEL)

Fig. 31.4
Chinese bamboo noria

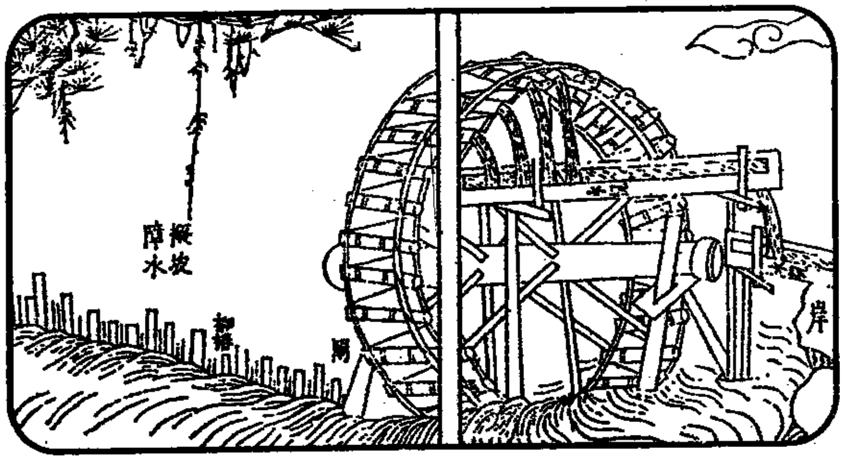


Fig. 31.5
Noria for high lifts

Nobody knows when this type of noria was introduced in China where it was known as kao chuan thung chhe or "noria for high lifts". The difference between this and the traditional noria is that this type of noria uses 2 wheels; one at the lower end, which is the reception end, and the other above.

Although this looks like a current-operated paddle-wheel, the drive came from above, using a multiple pedal treadmill or an ox whim. In this case, bamboo pipes are not attached to the periphery of the wheels. They are fixed to a chain that goes around the two wheels. Between the wheels there is a wooden or bamboo guide for the chain of bamboo buckets.

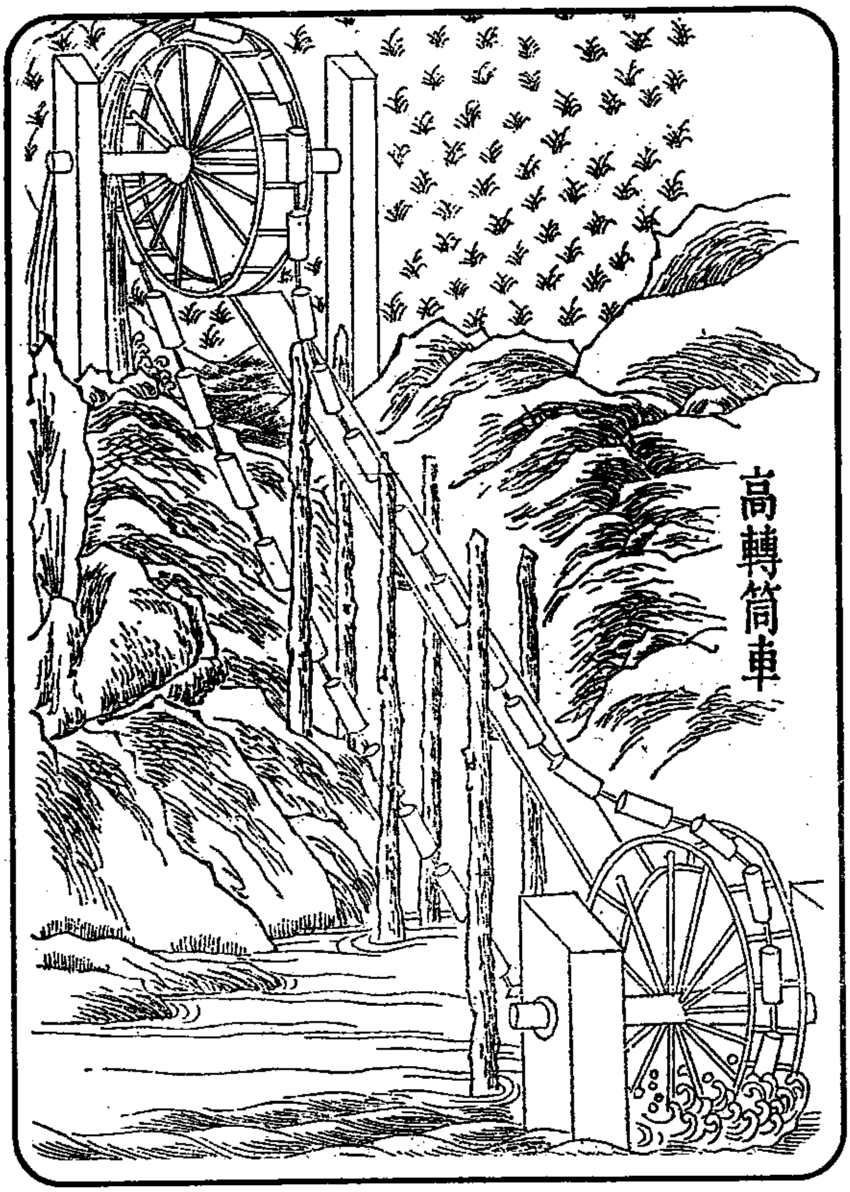


Fig. 31.6 THE OX-DRAWN WHEEL -THE WATER TURNED WHEEL

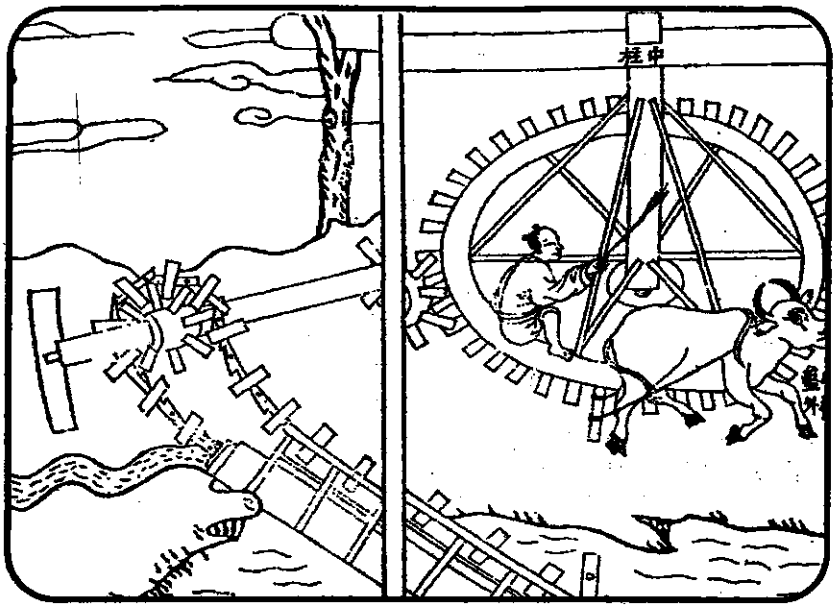


Fig. 31.6
The ox-drawn wheel
Near lakes and ponds where there is no flowing water, oxen are employed to turn the water wheel, or a few men can work a treadle wheel made of wood and bamboo.

In Yangchou prefecture, the people use another type of wheels that are turned by the wind.

Fig. 31.7
The water-turned wheel for irrigation
The cylinder wheel can be replaced by a water-turned wheel which is made of wood and bamboo.

BAMBOO WINDMILLS

CHINESE HORIZONTAL AND OBLIQUE BAMBOO WINDMILLS

The history of mills driven by wind power begins in Islamic culture and in Iran. The first mention of windmills is made in the works of the Banu Musa Brothers about the years 850 to 870 A.D. A century later, several authors wrote of the remarkable wind mills of Seistan (a sandy arid region located in the area where Persia meets Afghanistan and Baluchistan). A very detailed description of these windmills occurs in the Nukhbat al-Dahr (Cosmography) published in the year 1300 A.D. From this information, it is clear that the Iranian windmills were horizontal in type and enclosed in a shield wall so that the wind entered only in one side, as shown in the Fig. 30.7.

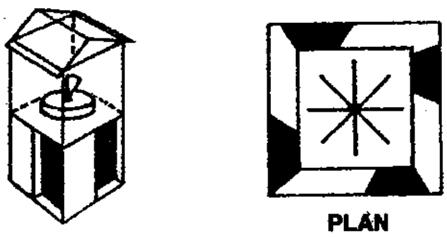


Fig.31.8 *Perspective view and plan of Iranian windmills Needhan (1970)*

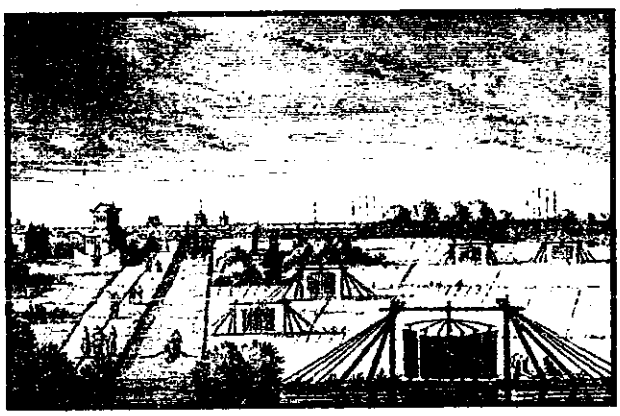


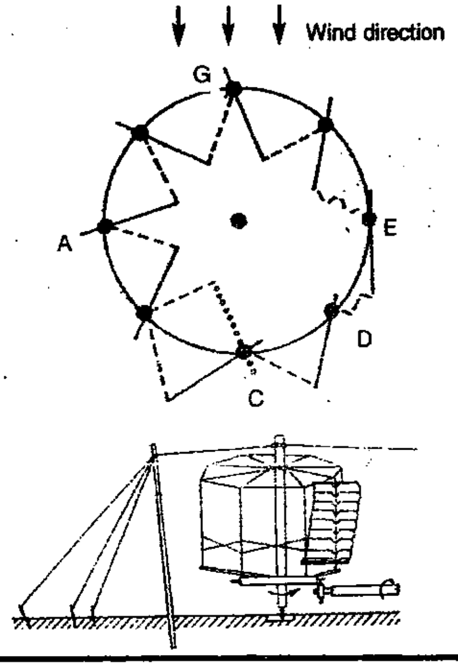
Fig.31.9 *The first European picture of a Chinese horizontal windmill, from Nieuholf's account (+1566).*

Horizontal bamboo windmills in China

According to Needham (1970), the first European to see the windmills in China was Jan Nieuhoff, who saw them in 1656 at Paoying in Chiansu while journeying north along the Grand Canal with one of the Dutch Embassies to Peking. Details of the description which Nieuhoff gave are illustrated in (Fig. 31.10).

These windmills are still extensively used all along the eastern coast of China north of the Yangtze, and particularly in the regions of Thangku and Taku near Tientsing, mainly as prime movers for operating square pallet chain-pumps by right-angle gearing in the numerous salterns where salt is made from sea-water. Chen Li made a study of this type of windmills. Their construction is of considerable interest, for the vanes or surfaces receiving the wind-pressure do not radiate from the central axis, but are in fact true junk slat-sails mounted in eight masts forming the periphery of a skeleton drum. Looking at Chen's diagram we see that the hat in the upper bearing of the central axle, and the needle is the pin or gudgeon on which it revolves below. The ingenuity of the whole contrivance is seen in the fact that it dispenses entirely with the shield-walls used in Persia (Iran).

Fig.31.10 Chen's diagram of the Chinese horizontal windmill (Needhan 1970)



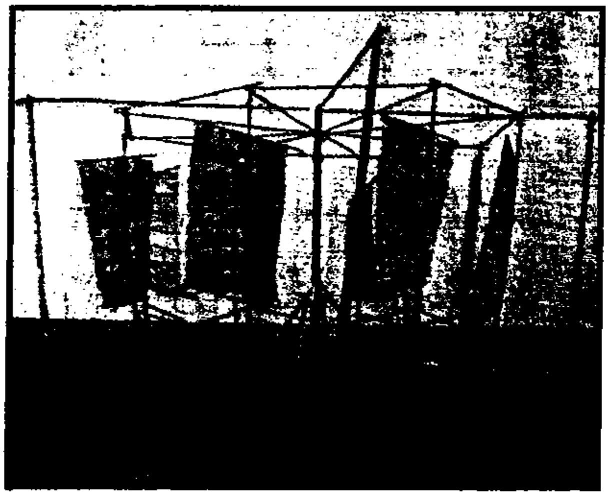


Fig. 31.11 *Typical Chinese horizontal windmill working a square-palet chain pump in the salterns at Taku, Hopei. The fore and aft mat and batten type sails luff at a certain point in the cycle and oppose no resistance as they come back into the eye of the wind.*

It was able to do this by adopting the fore-and-aft rig of Chinese Junks for the wind mill sails, as may be understood by the diagram in Fig. 31.10. In position A, the sail is held taut against the wind by its sheet rope, but when it reaches position C, the sail blows right outwards (luffs), coming back into the eye of the wind in position E, freely hanging and opposing no wind-resistance. By position G, the sheet has tightened again, preparing the sail to receive the full force of the wind. Chen Li found that effective wind- pressure was exerted for considerably more than 180° of the cycle, since in position D the sail does a certain amount of work while it is 'sailing into the wind'. The whole system constitutes an invention of great interest and practical importance since thousands of these simple machines are at work at the present day.

These windmills were also used in China on the Grand Canal for hauling vessels from one level to another by means of rollers on inclined planes.

Unfortunately, there are very few literary references in China to this or any other type of windmill, though perhaps some might be found in the local topographies of the provinces where they occur, but this search has not been made.

Chinese oblique-axis bamboo windmill

Chinese oblique-axis bamboo windmill In certain of the eastern Chinese provinces, wind power is harnessed for raising water by means of a curiously constructed windmill, the axis of which is set neither vertically nor horizontally, but obliquely (Fig. 31.12 A-B). These are particularly common between Shanghai and Hangchow. From the 16th century onwards very similar small windmills have been in use in Holland; their axles being continuous with the inclined shafts of Archimedean screws. Most probably, therefore, the oblique windmill was introduced in China in the 17th century as part of a compact piece of equipment which included the Archimedean screw. When the latter then failed to supersede the traditional types of water rising machines the oblique windmills continued in certain districts, being harnesse by appropriate gearing to square pallet chain-pumps.

Chinese oblique-axis bamboo windmill

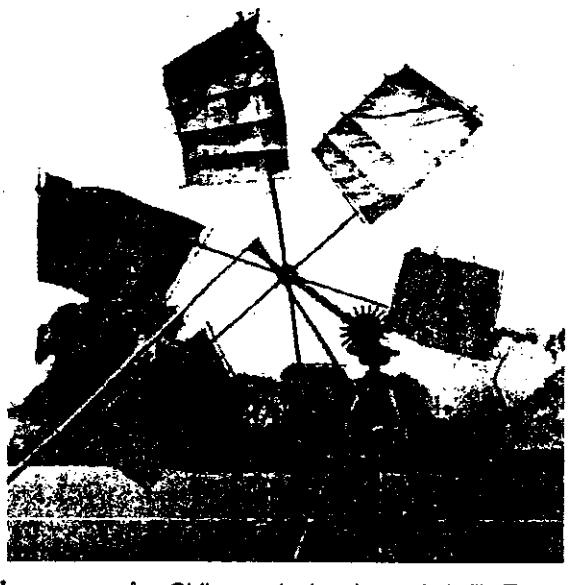
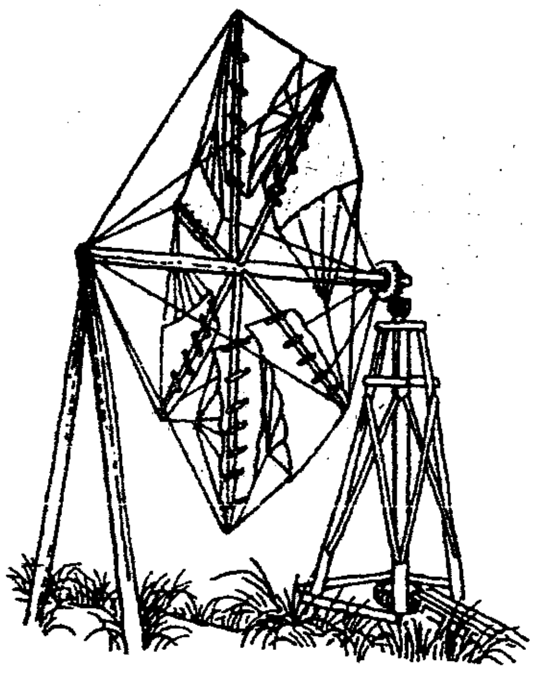


Fig. 31.12 A. *Oblique-axis bamboo windmill. These windmills are fitted with typically Chinese bamboo square pallet chain pumps mat and batten type sails, and work, as here, square pallet chain pumps for irrigation.*

B



VERTICAL BAMBOO WINDMILLS (Hidalgo & Laporte)

In 1982 I was working as a consultant for the United Nations in Ecuador building a windmill for a rural community where the people had to walk about 5 kilometers to get water from a river. We opened a hole on the ground in order to find the level of the subterranean water. It was about 1.80 meters deep, so we decided to build a bamboo windmill for water-raising.

While I was manufacturing the bamboo pump with a marble (see Fig. 31. 17 F), I was visited by a group of people and a French engineer, Roland Laporte who was also a consultant for the United Nations. He was so impressed with the bamboo pump and all the things that we could make with bamboo that he decided to work together with me on the construction of the windmill. Later on he built several bamboo windmills in France.

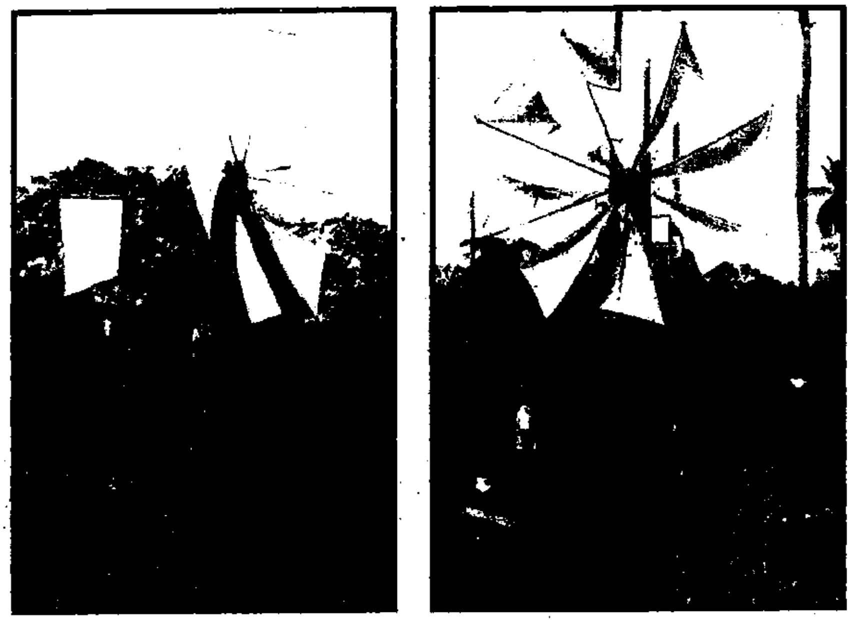
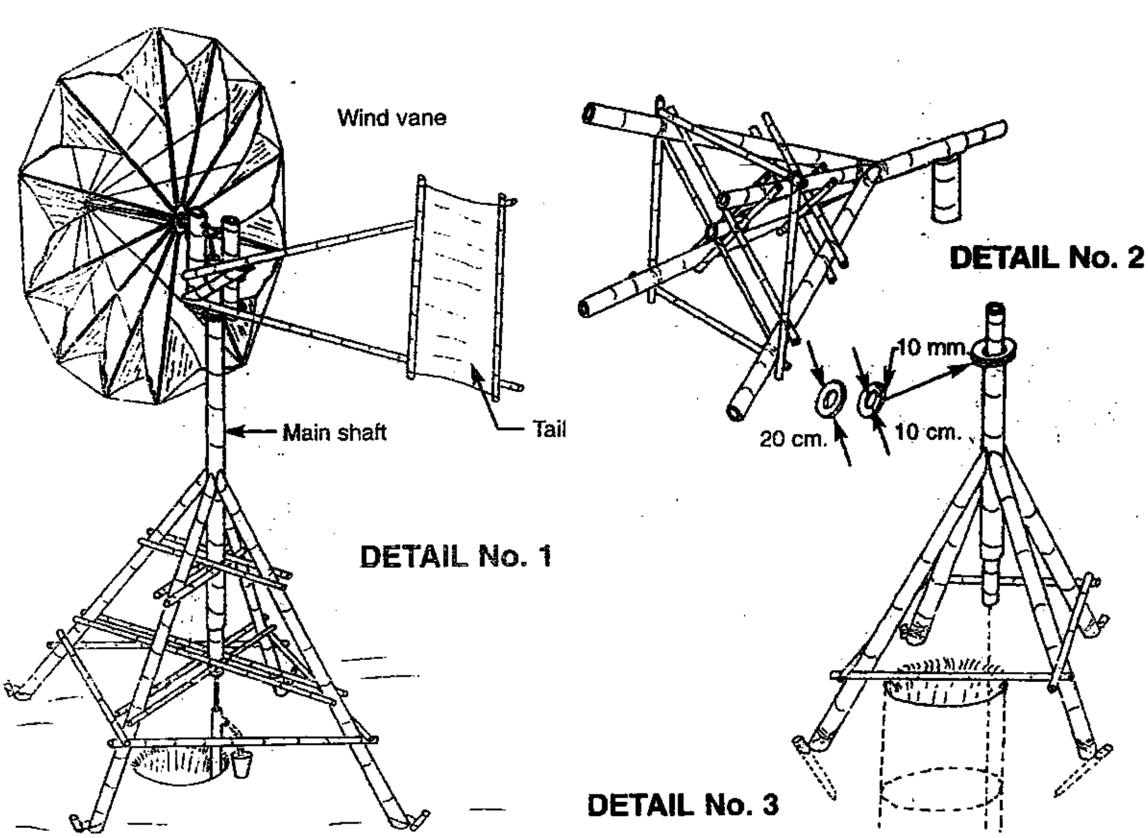


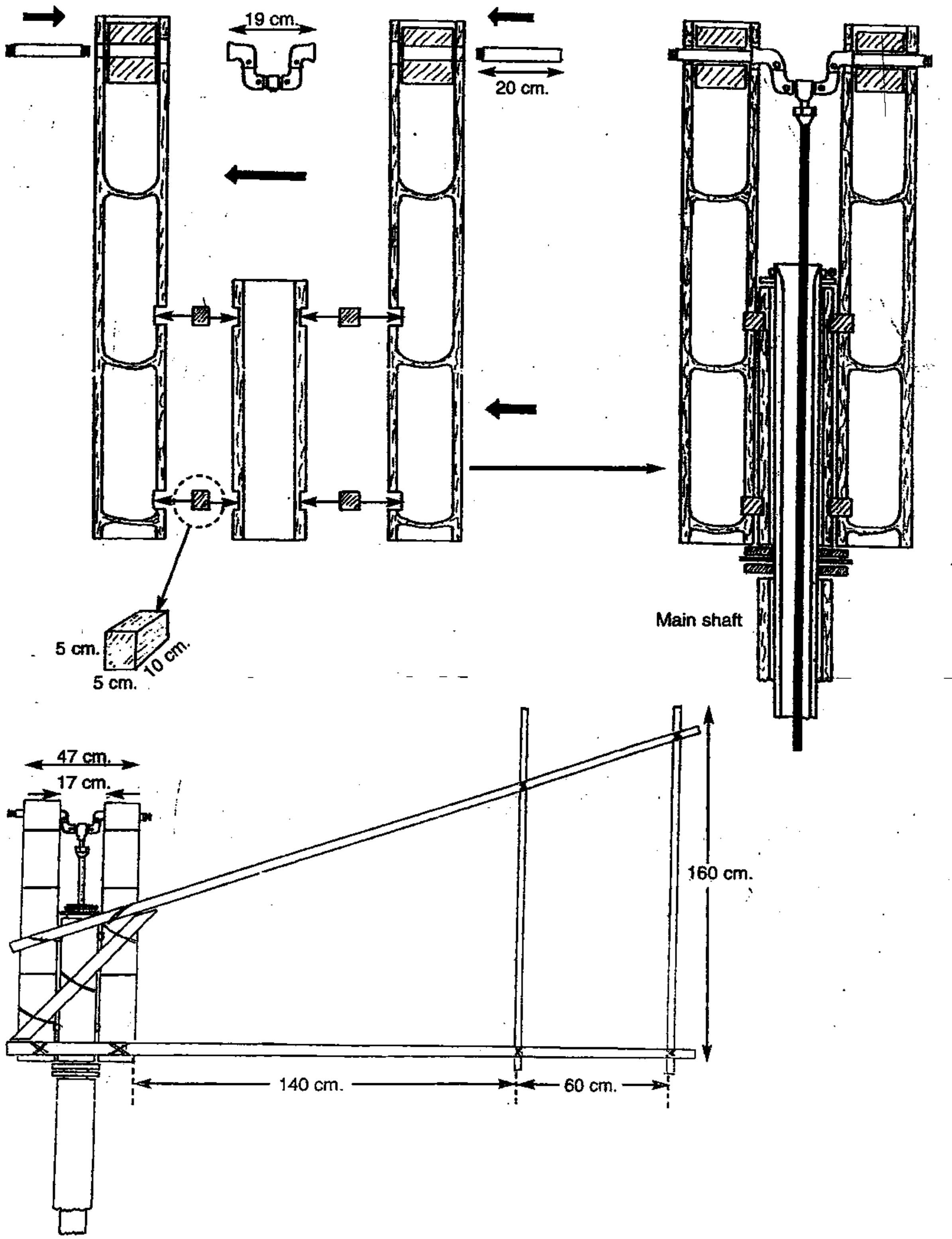
Fig. 31.13 *The vertical bamboo windmills with 6 and 8 sails.*

Fig. 31.14 Construction of the tripod



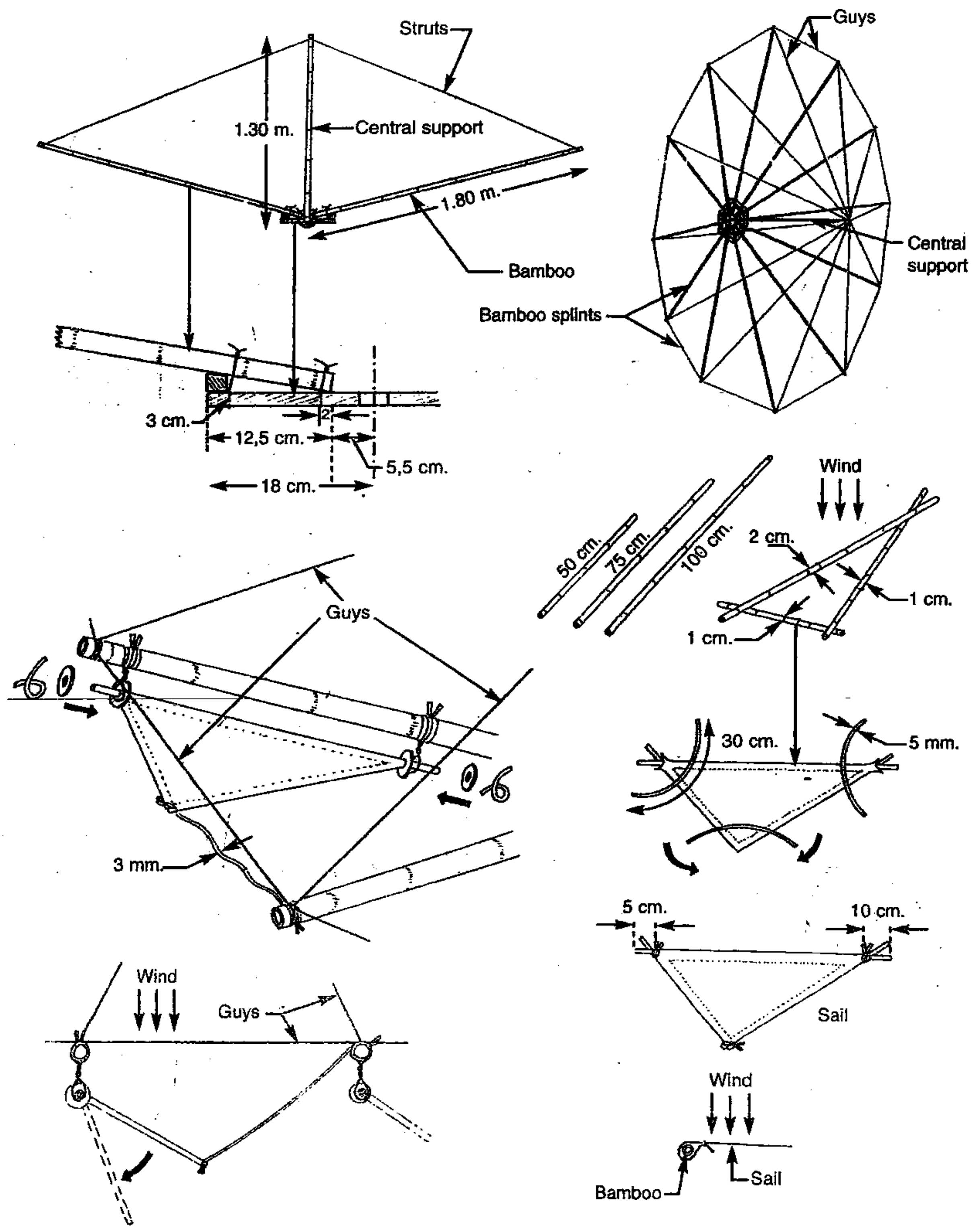
VERTICAL WINDMILLS - Construction of the crank drive

Fig.31.15



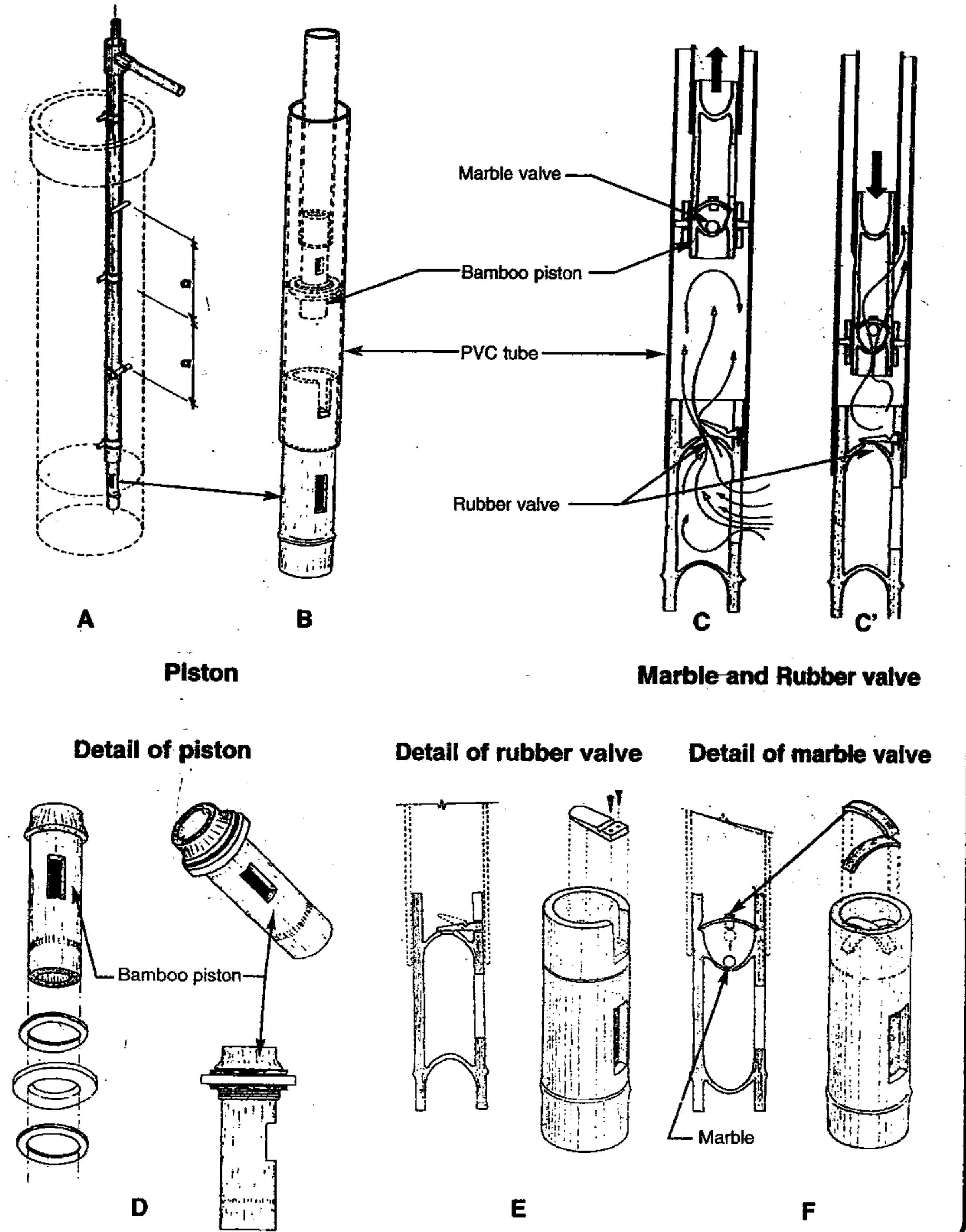
VERTICAL WINDMILLS - Construction of the sail windwheel

Fig.31.16



VERTICAL WINDMILLS - TYPES OF VALVES

Fig.31.17 **Construction of bamboo valves**



THE USE OF BAMBOO IN THE CONSTRUCTION OF MACHINERY

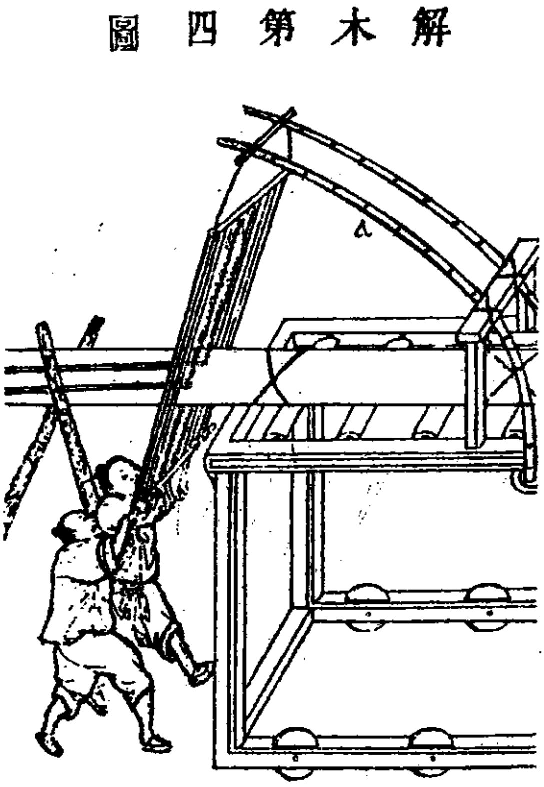


Fig. 31.18

1. TRUNK SAWING MACHINE

The flexibility of the top part of the bamboo culms was fully exploited by the Chinese in the construction of the lumber-man's saw as shown in this Chinese drawing.

2. BAMBOO ROLLING BEARINGS.

Home made ball bearings were made in all types of materials such as steel, iron, glass, and porcelain. In Szechwan the people even made ball bearings using bamboo for the casings and round acorns for the balls, and these were said to hold a weight of half to three-quarters of a ton. Very round acorns are a peculiarity of Szechwan oaks.

According to Jon Sigurdson (1967), bamboo ball bearings were manufactured in great quantities in rural areas of China to be fitted to farm tools, vehicles, and irrigation machinery. In August 1958, it was clearly stated that the movement for mass production of ball bearings had come into being very quickly in order to enable the manufacture of machinery to make up for the shortage of manpower experienced in agriculture. A People's Daily editorial stated that the government was giving every encouragement to local plants to make ball bearings. Shantung province alone was reported to have established some 60,000 small ball bearing plants by the beginning of September.

BAMBOO IN THE FIELD OF TEXTILES

30

UNDERSHIRTS AND ARMORS MADE WITH BAMBOO SECTIONS

One of the first applications which natural bamboo had in the field of textiles, was in the manufacture of undershirts, armor and curtains.

In China, short pieces of slender bamboo stem were threaded onto netting, each square of mesh being formed by four pieces of bamboo with knots visible in the corners, and the whole was made up into an undergarment worn by labourers. It provided insulation against the cold in winter and let cool air circulate next to the skin in summer.

In earlier times, such garments were also worn by the rich to prevent perspiration soiling their expensive robes in hot weather.

Curtains made with this material are still used in many countries as interior partitions in their houses.

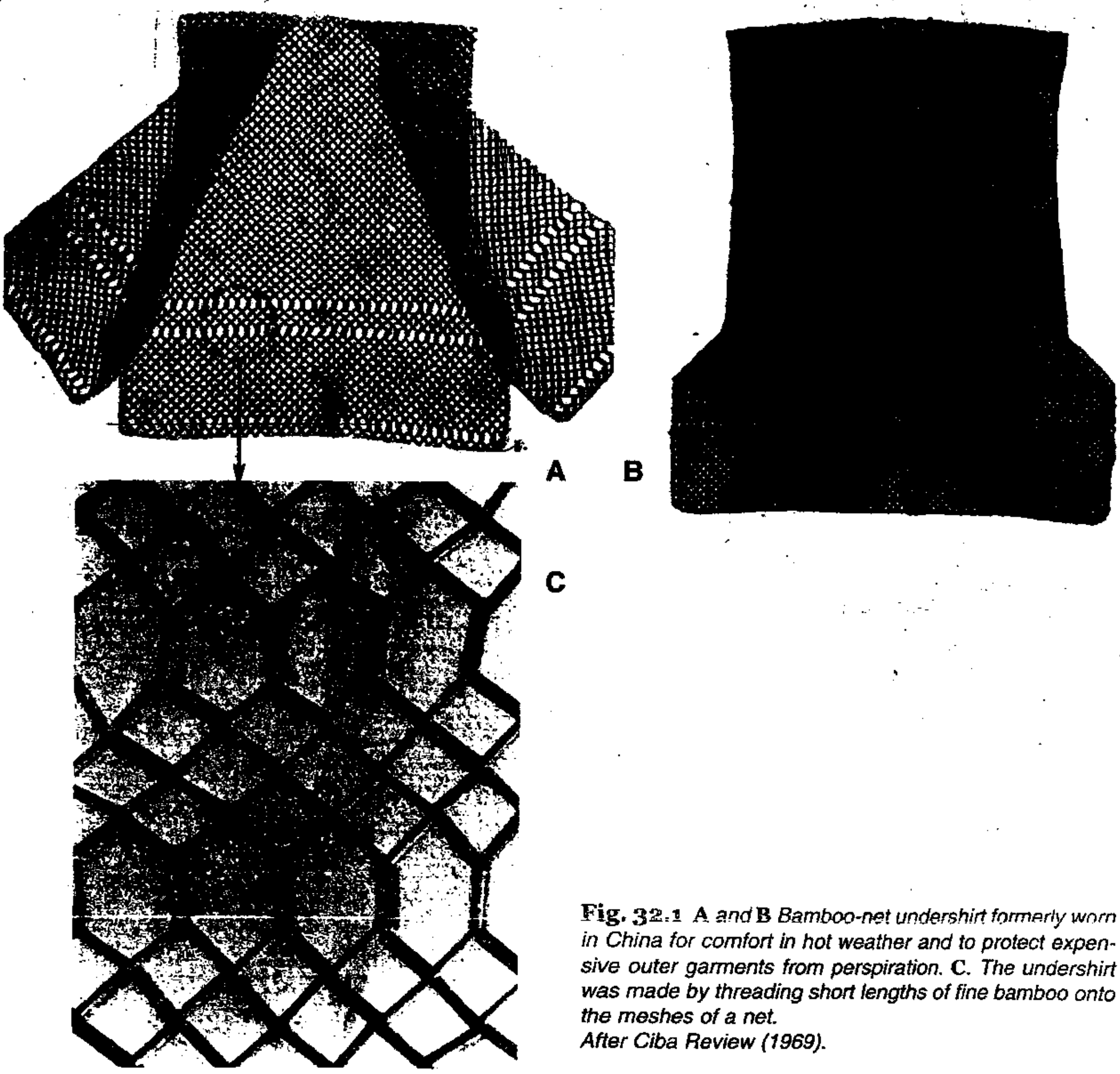


Fig. 32.1 A and B *Bamboo-net undershirt formerly worn in China for comfort in hot weather and to protect expensive outer garments from perspiration.* **C.** *The undershirt was made by threading short lengths of fine bamboo onto the meshes of a net.*
After Ciba Review (1969).

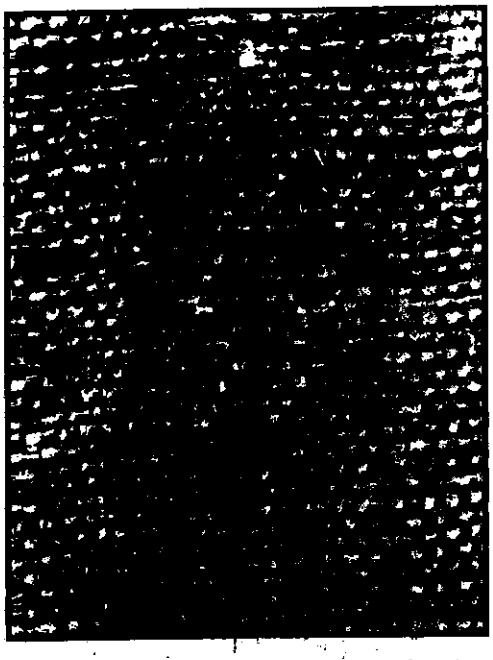


Fig. 32.2 *Close-up of the shirt fabric. Bamboo fibers were knotted together to make the yarn. Photo: Koninklijk Instituut voor de Tropen, Amsterdam. After Ciba Review (1969).*

Fig. 32.3 *Bamboo-fiber shirt with printed cotton and wool trimmings and black cotton embroidery on front. Such garments were worn by women working in the fields. 19th. century; Minahassa, North Celebes. After Ciba Review (1969).*

According to the *Chu pu*, the "I" people of Lingnan in the south of China used to take the shoots of *Tan chu* before they became bamboo and boil them in a lime solution, in order to extract a fiber which they use for weaving into cloth. (Fig.31.12). The best quality of this cloth is like *Hu* (Fine silk gauze).

Bamboo Cloth.

In Borneo, Java and Celebes, the indigenous peoples used primitive tools to make bamboo into cloth for garments, sacks and sails. They extracted the fibers from young stems with not more than four branches, cutting them apart at the joints, splitting the lengths into thin slats, and soaking them in water. The thick outer and thin inner "skins" were peeled off, leaving only the matrix with its embedded bundles of bamboo fiber and bast fiber groups.

Men and women chewed this material (a method also employed in preparing banana bast fibers), dried it, and cleaned the loosened, separated fibers with scrapers.

In Manado, North Celebes, great pains were taken with the opening-up operation. The matrix was either chewed and hackled or, alternatively, it was retted in water. The opened-up fibers were beaten and again soaked in water.

The fibers obtained by these methods were comparatively short and were knotted together to make a serviceable yarn.

The story of the bamboo and silk

Strange to say, bamboo played an important role in the history of the European silk industry. In the sixth century, silk was the chief export article from China, and the Chinese were keeping the process of silk production a strict secret. According to Carter (1925), the first Roman writers thought of silk as a vegetable product, which Virgil stated was combed from trees. Only in the second century of our era did they become better informed; Pausanias (ft 117-180) described the silkworm with fair correctness. Silk came into the Roman Empire in ever-increasing quantities during the classic period, and continued to come into Constantinople after Rome had fallen.

The re-opening of the silk routes was one of the central features of the foreign policy of Justinian (A.D. 527-65) and his immediate successors. These routes had been closed by the Sassanian power in Persia out of fear of the fast growing Turkish kingdom in the northeast, first heard of in Western history at this time. Justinian tried to interest the king of Abyssinia and certain Christian princes in India in a project to open a new trade road to the East that would avoid the Persian dominion altogether. When this plan fell through owing to the lethargy of the king of Abyssinia, advantage was taken of an embassy from the Khan of the Turks, and a return embassy was sent in 568 by a route north of the Caspian Sea to the Turkish court (in Turkestan) and an alliance was formed, the purpose of which was to compel Persia to allow a resumption of the silk trade.

Meanwhile some Nestorian priests returning from the east had brought to Justinian the news that silk was produced by caterpillars, whose eggs they believed they could obtain. With the emperor's encouragement, they proceeded either to China, or more likely, to the kingdon of Khotan in Chinese Turkestan, whither silk culture had been brought in the year 419 by a Chinese princess. The two monks returned to China and, by smuggling the eggs in a hollow bamboo culm contrived to elude the vigilance of the Chinese, made their way safely to Constantinople with their precious treasure. Thus began the decline of the great Silk Road that had spanned Asia for centuries.

From the eggs carried in this bamboo culm, if the story told by the Greek chroniclers is to be credited, are descended the silkworms that have been reared in Europe, being first introduced into Italy in the tenth century. Silk was thus, so far as is known, the first of China's great gifts to the West, reaching Europe some time before the Christian Era; however, the art of producing silk, unlike most Eastern arts, reached Western Europe just before the Crusades.

BAMBOO IN THE FIELD OF WEAPONS

31

BOWS AND ARROWS

Ancient bows

According to the Chu pu, (written by Tai kai-chi during the Tsin Dynasty, 265-306 A.D., the "I" tribes from Ling-nan split the culms of Chi chu (Thorny bamboo) for making cross bows. The diameter of this bamboo was about 20 cm and was solid. Later on, the technology for making bows was modified and different materials were used.

According to Sung (1966), the central body of a bow is made of bamboo and oxhorn. (The northeastern tribes, having no bamboo, use pliable wood as a substitute). The two ends of a bow are made of mulberry wood. When unstrung, a bow curves in such a manner that the bamboo lies on the inside and the horn on the outside surface. When the bow is drawn, the positions of bamboo and horn are reversed. The bamboo part is a whole piece, while the horn part is made of two pieces joined together. The end of the mulberry wood is carved (into a nock) for receiving the string, while the body of the wood is mortised securely into the bifurcated bamboo. One side of the bamboo is made into a smooth surface for fastening the horn.

The first thing to be done when making a bow is to prepare a flat strip of bamboo. (The bamboo should be felled in autumm or winter, because it tends to decay and be spoiled by insects in the spring and summer). The prepared bamboo strip, having a slightly ~~narrow center and two relatively wide~~ ends, is about two chih long. One side is first coated with glue on which the horn is fastened, while the other side is covered with a layer of glue, and the whole thing is reinforced by winding a sinew around it. The horn used here is made by joining the toothed ends of two pieces of oxhorn together. (This type of long oxhorn is not available to the northern tribes, who have to use four pieces of sheephorn joined together to form a horn plate. In Kwangtung province, the horn of both water buffalo and yellow cattle is used by the bow maker.) The horn plate of a bow is strengthened by covering it with ox sinew and glue, and the coating of glue is in turn covered by birch bark, which is soft and resilient, and gives the name "warm grasp" to the bow.

The birch (*Betula japonica*) tree, known as hua in China, is found chiefly in Liao-yang in Manchuria, but it is also found in abundance in northern and western China. Birch bark, being as soft as cotton, is used to cover the hand-grips of bows. Birch bark is also used for covering the hilts of knives and the poles of spears. The extremely thin variety of bark is employed as the inside lining of knife scabbards and sword sheaths.

The sinew taken from the spine of an ox is rectangular in shape and weighs about thirty ounces. After an ox is killed, this sinew is first dried in the sun, then soaked and softened in water, and finally separated into flax-like fibers. The resulting sinew fibers are twisted into bow strings by the northern tribes, because of their lack of silk fibers. In China proper, however, the sinew fibers are used for protecting and reinforcing the body of bows. The fiber is also made into cords for bowing cotton.

Glue is made from the bladders and intestines of fish. The boiling of bladders and intestines in water for the manufacture of glue, is largely carried out at Ning-kuo commandery. In Chekiang, where the Seiaena schlegeli fish is obtained from the East sea, the bladder that remains from the making of dried salted fish is converted into glue, which is stronger than any kind of metal or iron. The northern tribes also manufacture a glue by boiling sea-fish bladders (in water). This glue is as strong as the Chinese products, though it differs from the latter in chemical and physical properties.

The newly made crude-bow is placed on the rafters or a shelf in a room and is dried slowly from underneath by a constant fire on the floor. The drying period varies from a minimum of ten days to a maximum of two months. The completely dried bow, after being taken out of the room, is first polished, and then reinforced with ox sinew, glue and Chinese wood lacquer to result in the best product. If the bow manufacturer cannot wait for such a long period of drying, the residual moisture will cause the finished product to deteriorat at a later date.

Bow strings

Silk filaments from worms fed on the leaves of thorny treees (che trees) are used for making bow strings, because they are stronger and tougher than mulberry silk. To make a bow string, a silk thread is tightly wound around a core of more than twenty silk threads in three sections of more than seven tsun each in length, leaving two gaps, each about 0.1 to 0.2 tsun long. Such a cord can be folded into thirds when the bow is not strung. In the past the northern tribes used ox sinews for making all if their bow strings, but these could be easily spoiled by rain and fog. Therefore, they generally avoided war with China during the summer season. Nowadays, however, silk bow strings are also used by the northern tribes. Bow strings may be coated with yellow wax, although it is not absolutely necessary.

According to the Chu pu book (265-306 A.D), the Chin chu bamboo species which grows twenty or more feet high and has a circumference of several Chinese inches, is also suitable for making bow strings before the shoots have become a culm.

The nock at each end of a bow for receiving the string is covered with a piece of extremely thick ox leather or soft wood. This covering material or cushion, serves the same purpose as the pegs of a lute. When the string is drawn and snapped back to its original position, a tremendous force is developed toward the inside surface of the bow. This cushion protects the bow from such destructive force; otherwise it would be damaged.

Bows of various weights or pulls are made to suit the strength of individual archers. A bow of 120-catty pull is for the strong bowman, while the still heavier bows are for the very few people who have "tiger strength". The bow for the average bowman is 10 to 20 percent less in pull than the 120 catty one, and that for the weak bowman is 50 per cent less. In spite of differences in pull, all of these bows, when fully drawn, can propel arrows to hit a target. On the battle front, however, strong archers are needed for piercing of human chests and thin wooden shields. Weak archers are esteemed for the good markmanship of hitting a bull's eye or a willow leaf, thus conquering kill instead of force.

To determine the pull of a bow, the maker steps on the bowstring and presses it down toward the ground. The centural part of a bow is hung on the hook of a steelyard, and the force applied for a maximum bending of the bowstring, known as weight or pull, is measured by balancing the weight suspended on the marked beam of the steelyard.

In its crude form, a bow for a strong archer consists of roughly 7 ounces of horn and bamboo as well as 0.8 ounces of sinew, glue, and silk thread. The weight of these materials is 10 to 20 per cent less in a bow for an average archer, and 20 to 30 per cent less in one for a weak archer.

To preserve a finished bow, mildew and moisture must be avoided by all means.

To protect bows from mildew, drying ovens or boxes, each heated underneath with a charcoal fire, are usually set up in the homes of military officers.

Arrows. In ancient China there were many bamboos for making arrows, but, according to the Chu pu book, the best one is the Chien chu (arrow bamboo), it is hard and strong, and the internodes have a length of 1 m (3 chih). This coarse black bamboo is found in the mountains of Kiang-nan. The Kun chu and the Lu chu are two varieties that are also used with this purpose. Both grow in the marshes of Yung-meng in Hupeh.

According to Sung (1966), the raw material used for making arrow shafts varies with geographical location. Bamboo is employed in south China, willow in north China, and birch in the land of the northern tribes.

The arrow shaft is about two feet in length, while the arrowhead is roughly one inch long. A bamboo arrow is manufactured by gluing three of four bamboo strips together. These are subsequently trimmed and polished, with the aid of a knife, into a perfectly smooth shaft. After its two ends are wound with silk threads and painted with lacquer, the shaft is known as san-pu-chi or "three unevenness". The so-called "arrow bamboo" grown in Chekiang and Kwangtung provinces, can be trimmed directly into a shaft without the trouble of preparing and gluing bamboo strips.

A minimum amout of peeling and cutting is needed for making shafts from the straight twigs of willow and birch trees, and a bamboo shaft, being naturally straight, does not need to be straightened. In contrast, a wooden shaft, which tends to curve when dry, must be straightened during the manufacturing process by drawing the shaft through a straight groove. This groove is carved in a section of wood several inches long, which is known as an "arrow straightener".

During this treatment, both ends of the shaft are shaped to their proper size. The butt of a shaft is grooved to fit securely on the bow string, while an arrowhead is mounted on the upper end.

Arrowheads are made of iron. The northern tribes make their arrowheads in the shape of a peach-leaf spearpoint; the Li tribesmen of Kwangtung make theirs like flat blades; and in China proper the arrowheads resemble three-edged awl.

A whistling arrow is equipped with a hollow-centered wooden whistle approximatelly one inch long. When the arrow is in propulsion, air is forced into the whistle and produces a shrill sound. Such an arrow, referred to by the famous Taoist philosopher Chuang-tzu (300 B.C.) as Hao-shih or "whirring dart", was used by ancient Chinese armies and bandits as a signal to begin the attack.

The trajectory and speed of a traveling arrow are controlled by its tail fin of three feathers, which are glued around the butt end of the arrow shaft. The best arrow feaders are taken from eagle´s wings. Horned falcon or hawk feathers are next best, while owl and sparrow hawk feathers are still lower in grade feathers.

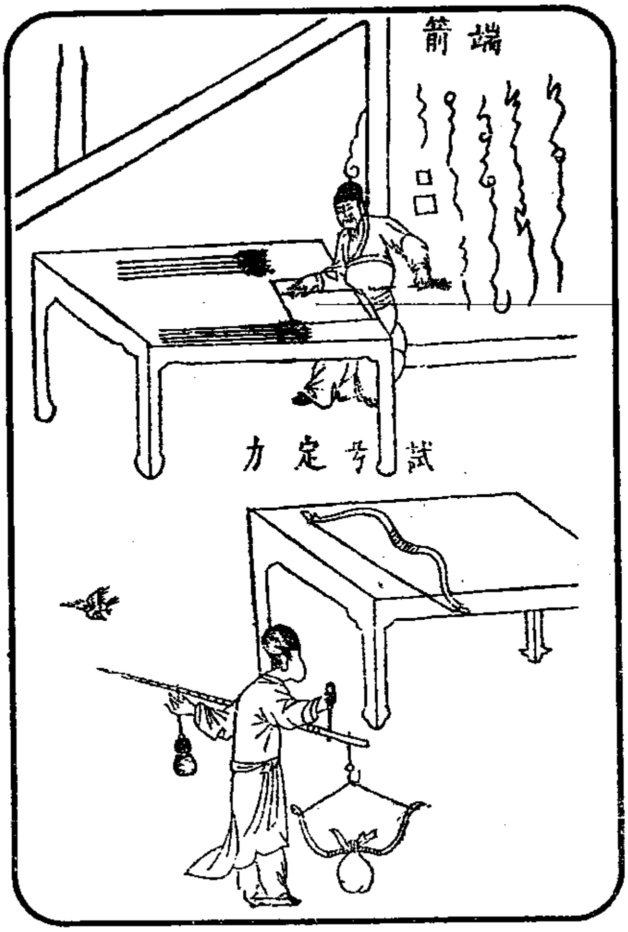


Fig.33.1 *Chinese drawing showing straightening the shaft of an arrow (top) and determining the weight or pull of a bow.*

BAMBOO AND GUNPOWDER

According to H. Nanbo (1970) in the 2-3rd century A.D. or probably in the 2nd century B.C. black powder was invented by alchemist accidentally. When the gold was separated from the silver at low -temperature reaction, by adding the nitre and sulfur to the gold ore in the alchemy furnace for making into gold, explosion occurred, by adding the charcoal at the first stage by mistake (which most be added at the final stage). Consequently it was the alchemists that gave the world the formula of black powder which served as the first rocket propellant used in the pao chu or cracking bamboo (firecracker), which has been in use for hundreds of years in war and for amusement in fireworks.

Black powder is a mixed explosive, consisting of three elements: potassium nitrate (salpetre) sulfur and charcoal. Other mixture used for this purpose were saltpeter, sulfur and linseed oil. After being mixed, placed in a hollow bamboo, and then lit, it will rise into the air. The first firecrackers may have appeared in the Chin Dynasty (221-7 B.C.). Fireworks became popular during the Tang dynasty (A.D. 960-1116) (Von Braun & Ordway III 1985). The development of gunpowder weapons was certainly one of the greatest achievements of the medieval Chinese world. The beginning of it can be found towards the end of the Thang, in the ninth century A.D., when the first reference to the mixing of charcoal, saltpeter (i.e. potassium nitrate), and sulphur is found. According to Needham (1970), this occurs in a Taoist book which strongly recommends alchemists not to mix these substances, especially with the addition of arsenic, because some of those who had done so had had the mixture deflagrate, singe their beards, and burn down the building in which they were working.

Development of gunpowder composition after the Sung Dynasty

According to Nambo (1970), in volumes 11 and 12 of *Wu Ching Tsung-Yao of Sung*, the table 33-1 is shown.

Powder making process. 1) For "Huo Chiu", the fire balls: Sulfur nest and "Yen Siao" the nitre are mixed, and pounded into powder. In the meantime, arsenic sulfur, "Ting feng" powder and lead oxide are sieved, mixed and ground into powder. In addition, dry lacquer is powdered, while "Chu ju" the silicious skin of bamboo and "Ma ju" skin of hemp are toasted a little and powdered. Beeswax, rosin, tallow, paulownia seed oil and heavy oil are mixed with one another, prepared, kneaded into ointment and then mixed with the above-mentioned powder.

Table. 33-1 Composition of gunpowder of Pe Sung Dynasty China 1045 A.D.

	Composition	For fire ball	For thorny Fire ball	For poisonous Fire b.
Coarse	Nitrate of potash	48.5 %	50%	38.5 %
	Sulfur	17.08.5	25.0	19.25 %
	Sulfur nest	8.5	0	0
	Rough charcoal powder	0	6.25	0
	Charcoal powder	0	0	6.4 %
	Other organics	26.0	18.75	35.85 %
	Total	100 %	100 %	100 %
	Lot	30.94 kg	30.0 kg.	29.2 kg
Detail of other organics	Asphalt		3.1 %	3.2 %
	Siao Yu oil		3.1	3.2
	Wax		3.1	
	Bees wax	0.6%		1.25
	Pawlownia Seed oil	0.3		3.2
	Heavy oil	0.6	3.1	
	Rosin	17.8		
	Arsenic yellow	1.2		
	Dry lacquer	1.2	3.15	
	Normal powder	1.2		
	Silicious skin of hemp	1.2	1.6	1.6
	Silicious skin of bamboo	**1.2**	**1.6**	**1.6**
	Monkshood			6.4
	Platain bean			6.4
	Wolf poison			6.4
	Arsenic frost			2.6
	Yellow pil	1.2		

Source: H.Nambo (1970).

When this mixture is wrapped in five sheets of paper, and tied up with hemp, "Huo Chiu", the fire ball, is made. In addition, melted rosin is put on the powder to make the igniter, which is shot by a ballista (an ancient military engine for firing missles). It is also used for discharging the poisonous smoke ball.

2) For "Jili-Houchiu", the thorny fire ball: Sulfur, yen siao (nitre), charcoal powder, asphalt and dry lacquer are pounded into powder. Meanwhile, siliceous skins of bamboo and hemp are finely cut, and mixed with oil, in which the paulownia seed oil, siao yu oil and wax have been melted to make the powder. As for the igniter, the material totalling 24.25 liang (0.91 kg) includes paper, 12.5 liang (0.47 kg); hemp 10; lead oxide, 1.25; charcoal powder, 8; asphalt, 2.5 and beeswax, 2.5 is applied to the fire wall.

3) For Tu yo yen ch'iu', the poisonous smoke ball weighing 30 kg. Its process is the same as that of the fire ball. It uses hemp rope, 3.6 m long and weighing 0.8 kg. As for the igniter, materials totalling 35.75 liang (1.34 kg.), which include the paper scrap 11.5; hemp akin to 10; asphalt, 2.5; beewax, 2.5; yellow pill, 1.25; and charcoal powder, 8, are pounded to make the outer coating of igniter.

ROCKETS - FIRE ARROWS

The rockets

The rocket was the key to space travel, the only known propulsion system that can operate in a vacuum. In its invention bamboo played an important role.

The invention of the rocket is tied to the discovery of black powder which served as the first rocket propellant used by the chinese in the pao chu or cracking bamboo (firecracker), which has been in use for hundreds of years for amusement in fireworks and in war was used for the first time by the Chinese in the thirteenth century when they shot off the first recorded "fire arrows" and terrified invading Mongols.

These fire arrows were all propelled by solid black powder, which consisted of 3 ingredients: charcoal (2 pounds), sulphur (1 pound) and saltpeter (6 pounds).

Kind of fire arrows

There were 3 types of fire arrows:

1) Bamboo arrows were fitted with an inflammable material- pitch, betumen, or resin. Launched by muscle power, they made flaming rocketlike arcs to their targets.

2) Bamboo arrows which transported a fire-pot containing naphta and other ingredients. Shot by hurling devices, the fire-pot spread its burning contents over a fairly wide area.

3) Rocket powered arrows consisted of an straight bamboo tube, 10 centimeters long, where the black powder was placed (See Fig. 33.2). Its end should be 5 cm from the fire. The tube is tied to the bamboo arrow shaft 70 cm long, and charged with a combustible agent to shoot the arrow.

After the invention of gunpowder, the tube was charged with gunpowder (940 A.D.) or other material that burned. Their range were more than 200 meters. In the case of of the powder whip arrow, ball shaped powder was made, and fastened to the head of the arrow. After the firing the fuse, arrows were shot into the enemy line with a blast and setting fire the enemy.

According to Lin (1942) in later years explosives were placed in bamboo tubes. According to some descriptions, originally the rocket, "When it was lit it made a noise that resembled thunder. Other writers described this wapon as "thunder that shake the heavens".

Later on the rockets were also fixed to bamboo spears that were described as flying spears. Firearms were known in China from the beginning of the Christian era.

Enemy armies, greatly impressed by the black powder and rockets of the Chinesse, adopted them for their own use. Knowledge of these weapons was transmited to Europe, probably reaching the West by way of the Mongols and the arabs.

Explosive bombs used with fire arrows

1) Fire Ball: was made of paper where piece of stones weighting 2-3 kg was put therein. Beewax, asphalt and charcoal powder were boiled in the muddy matter, and applied to the periphery of ball. Hemp rope was penetrated through, and in accordance with the distance, the ball was thrown by holding the head.

2) Thorny fire ball: Blade with its three branches and six heads was wraped in powder, penetrating hemp rope of 3.6 m long. The ball was fired by means of paper and miscellaneous agents. When the ball was shot, smoke broke out through the hot iron drill

3) Thunder fire ball: Dry bamboo with a joint diameter of 4.5 cm with no crack was selected. The joints remained un-pierced. In this bamboo 30 hard ceramic pieces were mixed with powder of 2-3 kg, and the ball was made of inner skin of bamboo. Both heads were sealed with bamboo pin, and the igniter was added on the outside of ball. When it was fired, thunderous noise was made and its smoke and flame ball scorch the enemy.

4) Poisonous smoke ball. In place of explosive ball, poisonous smoke ball was used.

17 th- Century Chinese rocket launcher

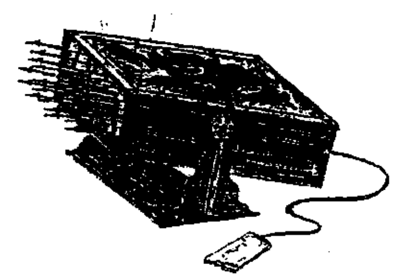
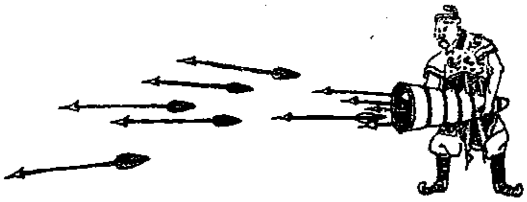


Fig. 33.3 *17TH-CENTURY CHINESE ROCKET LAUNCHER Chinese armies in the 13th and 14th Centuries employed a variety of rockets against the Mongol invaders. Carrying such descriptions as "long snake crush enemy" and "leopard herd rush transversally", these fire arrows were fired over ranges of hundreds of feet. But their accuracy was not great, and consequently they were not very effective. When fired in barrages however, even these primitive devices could be effective in spreading fear and panic through enemy troops and horses.*



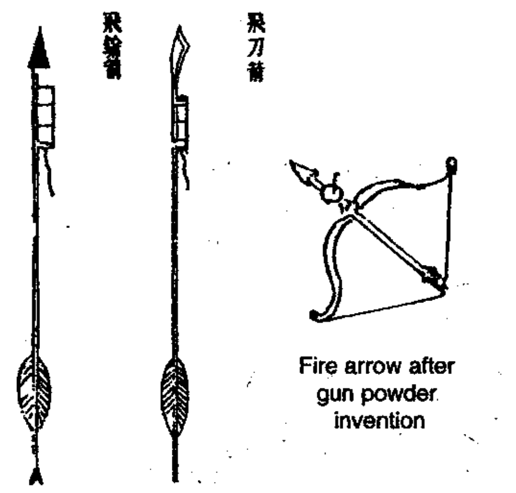
Fire lances

Later on the rockets were fixed also to bamboo spears that were described as "flying spears". According to Wu Ching Tsung Yao (1045 A.D.), similar to the lance bamboo, 5 cm outer diameter and 1.80 m.long, was charged with 200 g of explosives.After the ignition, it was shot, while revolving.

The firing lance, which was invented in Shou Chun of Nan Sung in 1159 A. D., was reported as follows: "the upper section of the large bamboo tube was charged with powder and projectiles. When ignited, flame came out. After the flame diminished, the projectil was discharged and the noise was heard 270 m off". It seems that this was a fire gun at the initial stage. There were some descriptions in the literature of Ming Dynasty that the T'ung chung, a copper cannon was a changed form of the bamboo joint. (Nambo. 1970).

There were several devices from which many arrows could be launched. This include "rocket -basket- arrows" which were fired from a cilinder of bamboo splints 4 feet long. Each cylinder contained from seventeen to twenty arrows on whose tips poison was smeared. Another contraption contained arrows "which will rush out on a solid front like 100 tigers"; they were fired from a frame, all 100 at a time, at targets up to 300 paces distance. There also was the "leopard-herd -rush-transversally" launcher, which could release forty arrows upon command, and the "long snake crush -enemy arrows", thirty of which were stored in a wooden box. These arrows were made of bamboo and were about three feet long. Each box of thirty weighed between 5 and 6 pounds, making this a hily mobile weapon.

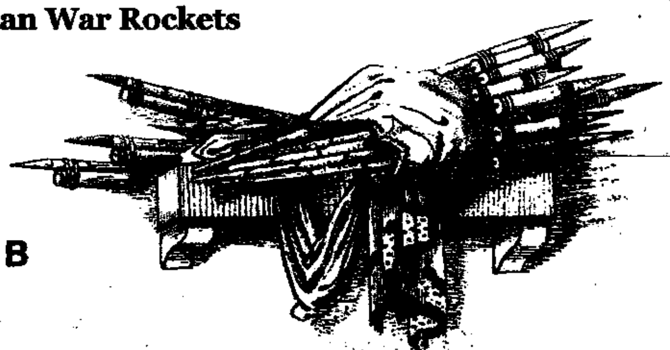
Fig. 33.2 A Fire arrows and fire lances



Left, Chinese fire -arrows of the type described inThe Complete Compendium of Military Classics. The two on top have explosives mounted on thir sides. Right, actual illustrations from the Wu Pei Chi (Von Braun & Ordway III 1985).

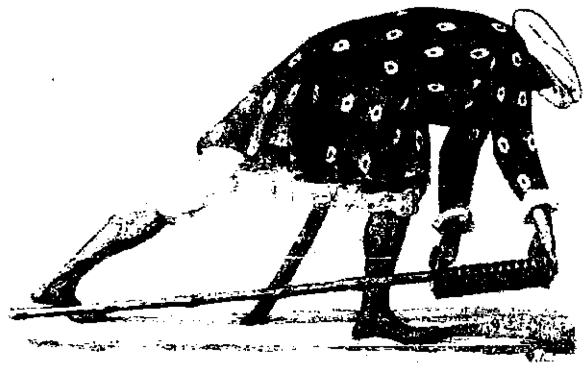
The Indian War Rockets

B



Symbol of Indian war rockets (1790). Taken from History, Religion, Learning and manners of the Hindoos.

D



C

Fig. 33.2 C-D *Indian rocketeers, late 13th century. From: Robert Home, Album of Sketches Including Classical and Renaissance, collection in the Victoria and Albert Museum, London.*

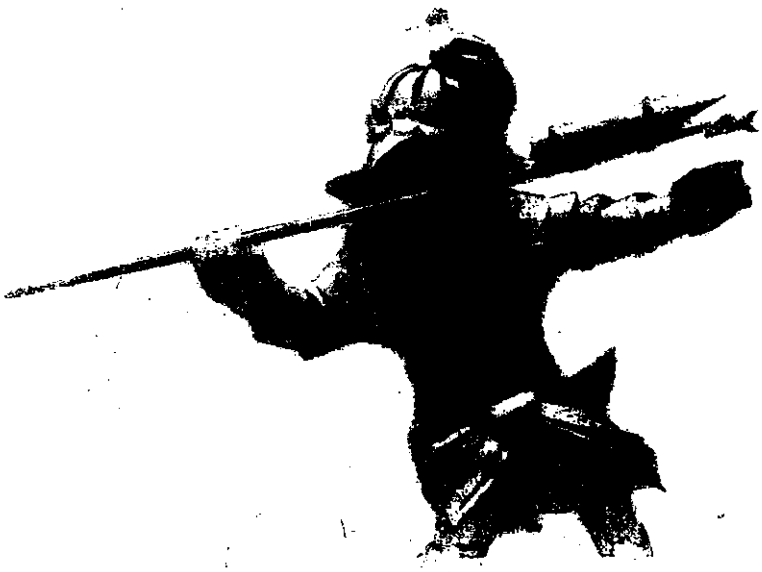


Fig. 33.4 Chinese rocketer. *Leo Monahan conception of a 13th- century Chinese warrior with a rocket propelled incendiary bamboo lance. (Smithsonian Institution).*

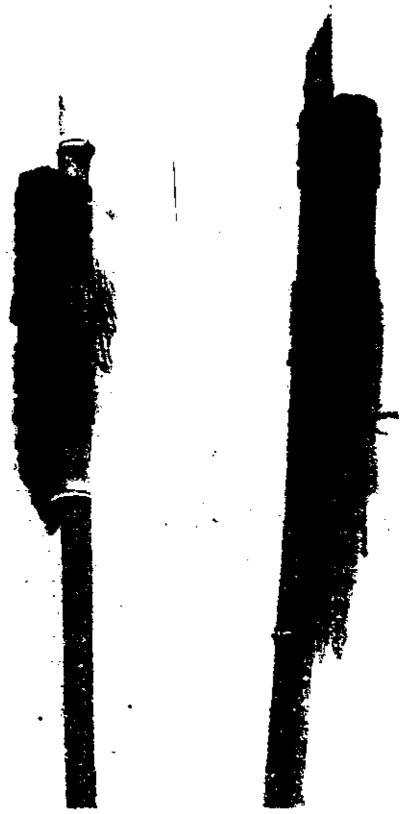


Fig. 33.5 Self propelled "bamboo flying spears". *A chonicler describing the Mongol siege of Pien-king in 1232 reported the use of a fire lance: "It suddenly flew forward and scattered its flame over an area ten steps".*

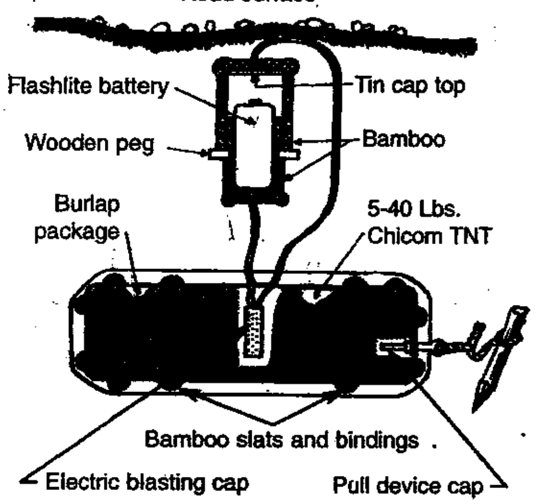
Fig. 33.6 *According to Nicolai A. Rynin (Mezhplanetyne Soobshcheniya) quoted by Von Braun & Ordway III (1985), the first "manned rocket", was made by a Chinese mandarin named Wan-Hoo, in about A.D. 1500. He took two large parallel horizontal stakes which were tied together by a seat place between them. Under this apparatus he placed forty-seven bamboo rockets which were fired simultaneously by the same number of servants. However the rockets under the mandarin seat exploted irregularly and from the resulting fire unfortunatelly the inventor was consumed.*

Fig. 33.7
The origin of the enormously powerful liquid propellant rocket engines that boost 20th century astronauts and cosmonauts into space may be traced to the simple black powder rockets first developed in the 13th century China. While the thrust of the F-1 engines that propel the first stage of the Saturn 5 is many thousands time greater than that of the primitive Chinese projectils, the reaction principle is the same for both.

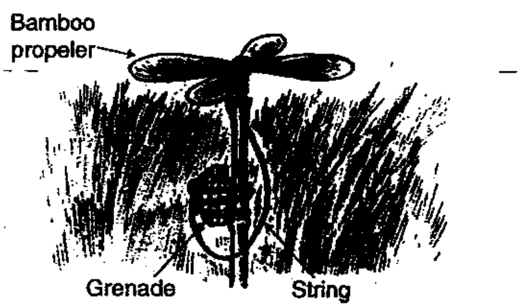
Fig. 33.8 SOME OF THE BAMBOO WEAPONS USED IN THE VIETNAM WAR

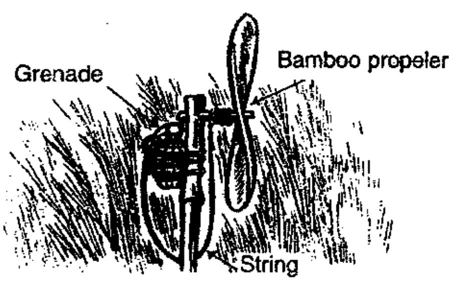
In 1968 the Military Assistance Comand of the United States published a Handbook for the US forces in Vietnam which explained different weapons and methods used by the Vienamese guerrillas against their enemies. This section includes only some of them in which bamboo parts are used.

VC MINE



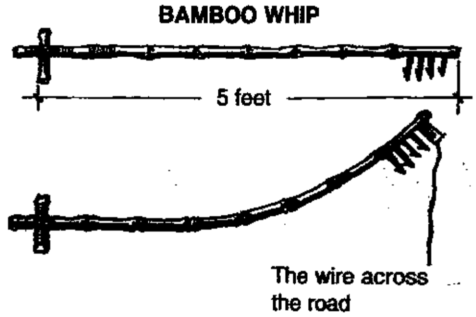
Four wooden pegs hold the top bamboo sleeve from foot and bicycle traffic. A vehicle will break the pegs and push the top bamboo sleeve down on the flashlite battery completing the circuit and detonating the mine.



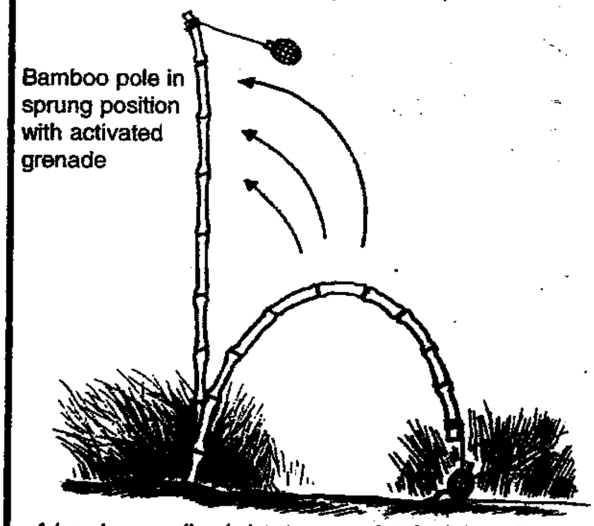


The stake, with a bamboo propeller attached has a string connected to the propeller and secured to the safety pin of a grenade. As a helicopter (s) approches the turbulance spins the propeller tightening the string and pulling the pin. Detonation normally occurs while the chopper is hovering and causes material damage and produces casualties.

BAMBOO WHIP

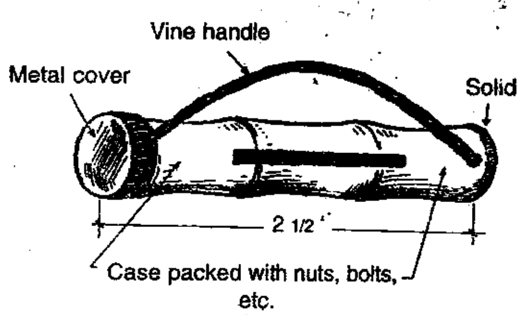


"JACK IN THE BOX"



A bamboo sapling is bent over and staked down in such a manner that very slight pressure on the bamboo pole or attached wires will release the pole and activate the grenade seven to ten feet overhead.

HOLLOW BAMBOO MINE



This mine is made from a large joint of bamboo. It is cleaned out and filled with plastic explosive or black powder. In addition to the explosive the section is also filled with nuts and bolts, rocks, nails and scrap metal or whatever material is available.
Although usually detonated by a pull friction type fuze, other means can be readily substituted.

PART 10

Uses of Bamboo in the field of Medicine

Carrier (Maillart's drawing)
Geografia Pintoresca de Colombia in 1869.

32 ANCIENT AND MODERN USES OF BAMBOO IN MEDICINE

BAMBOO KNIVES FOR SURGERY - CUPPING USES

SURGICAL KNIVES

Bamboo is the only organic material that can be used for making knives and surgical knives with a sharp edge. For this purpose a splint of the culm wall is used. The hard siliceous cortex takes a sharp edge which can be renewed by removing a strip. Where ordinary surgical appliances are not at hand, splints of any required length or size can be obtained from bamboo culms. At each sharpening, a notch is made below the handle, which is covered with plaited string, and a narrow strip is removed from the length of the blade. This is repeated until the blade is too narrow for use. For this purpose, older drier culms are preferred, as the younger ones yield somewhat under pressure. A fire hardened bamboo blade will cut ordinary bamboo itself and keep its edge for a considerable time.

Bamboo knives have been employed by primitive people of South America, South Asia, and Madagascar for domestic purposes, for removing the heads of enemies and for ritual acts. The following are the most outstanding uses:

1) Cutting of the umbilical cord. The Naga and other tribes from India use bamboo knives for cutting the umbilical cord. According to Mills (1926), this is held by the mother with her toe and cut by the father with a bamboo knife between the toe and the child. Six such knives are prepared by the father before the birth, one being thrown away if the child proves to be a daughter.

The tradition of cutting the umbilical cord of a newly born baby with a bamboo knife is still mantained in some parts of the Chinsese and Japanese countrysides. It is believed that the knife for a girl should be made from male bamboo, while female bamboo should be used for a boy.

2) Circumcision.- In Madagascar, circumcision is considered to be "an order of ancestors". It is practiced among the Tanala, Betsimisaraka, Antanosy and Sakalava, with a sharp sliver of bamboo (silaboloando). In these tribes, it is forbidden to use an iron instrument for this purpose. They have many taboos concerning the time before the circumcision; for example, the circumcised child must be watched so that he does not look at himself in a mirror because this will kill him.

3) Blood Letting.- In Melanesia, blood-letting is common when people are in pain. It may be employed for a severe headache, the forehead or temple being incised with a piece of bamboo. It is also resorted to in case of swelling in the limbs (Ivens 1927).

4) Head hunting.- This was practiced in Western Papua, in New Guinea south of the main range, in the Septik river basin and in the central Solomon Islands.

In these areas the taking of heads was done with bamboo knives. Scott (1915) commented that in New Guinea, a band of Tugeri head-hunters, using bamboo knives, decapitated three convicts who had left the gang in five minutes, with a neatness of execution that, according to the ship's surgeon, could not have been surpassed in a modern operating-room.

5) Castration of animals. The Renga Nagas from India and other tribes used to castrate boars with a bamboo knife. After the operation, the edges are pinned together with lemon thorns, and ashes are rubbed in the wound.

Bamboo internodes used as cupping

The airtight chamber formed by the outer layers and the internodes allows a section of an internode to be used instead of a glass as a cupping for medical purposes. This is a technique formerly employed for drawing blood to the surface of the body to produce counterirritation or for bloodletting by application of a glass vessel from which air had been evacuated by heat, forming a partial vacuum. In the Americas, this technique is used by rural people when they have a pain in their back. The partial vacuum is made by burning a match on top of a coin below an inverted glass or bamboo sections. See Fig. 34.1.

Fig. 34.1 *Bamboo sections used as cupping for medical purposes. The cuticule of the outermost surface and the internal suberized membrane both make the chamber formed by the internodes impervious and airtight.*

PHARMACOLOGY

THERAPEUTIC USES OF THE BAMBOO PLANT

Since ancient times, bamboo has been used in the native pharmacopea of many Indian tribes of the Americas and in many Asian countries, even for surgical purposes. Its use in this field could be considered insignificant when compared to the many technical uses to which the bamboo is applied. But once its therapeutic applications are known in several cultures, its new uses in modern medicine, and its orthopedic applications for handicapped have been considered, it is possible to measure the importance of bamboo in the fields of human and animal medicine, particularly in China, India and Indonesia where it is considered as medicinal material.

Numerous medical virtues are ascribed to all the parts of the plant, the rhizome, the shoots, the internodes and nodes of the culm, the leaves, flower, fruit, fruit sheath The same is true for the water that accumulates in the interior of the culm's internodes; the surface exudation of the bamboo culms when they are heated; the concretion, known as Tabashir, formed in the interior of the internodes; and the secretions, known as manna, formed on the outer surface of the nodes of joints. Unfortunately, one part of the plant could be considered poisonous.

1.THERAPEUTIC USES OF ROOTS

According to Keys, the roots of *Phyllostachys bambusoides* are considered astringent, styptic, and antipyretic.

2.THERAPEUTIC USES OF RHIZOMES

According to Smith (1871), a drug called Yu-chu prepared from the rhizome of *Bambusa arundinacea* was sold in China. This drug was considered to be cooling, demulcent, sedative, tonic, antiperiodic, and was recommended for artritis and as an eyewash.

3.-THERAPEUTIC USES OF CULM SHOOTS

Chemical and pharmacological components of the culm shoots.

The chemical components of the different sections in bamboos shoots were investigated by Kozukue (1988) in some bamboos from Hyogo Prefecture in Japan, with the following results: Oxalic acid, the major organic acid in bamboo shoots, was found to be most abundant in the apical portion (426 mg/100 g.f.w.). Fructose (600 mg.), glucose (500 mg.) and total sugar content (1300 mg.) were most abundant at the base.

It was found that bamboo shoots possess a lot of tyrosine and its content was remarkably different among four sections (635-1100 mg.). The content of proline and serine were small in all parts of bamboo shoots. Total lipid content was most abundant in the apical (800) and the ratio of neutrallipid, glycolipid, and phospholipid was 17-27-56. Bamboo shoots harvested at the best time and those that were large (about 900 g.) possessed a lot of organic acids, sugars, free aminoacids and a small amount of homogentisic acid.

According to Quantai (1994), bamboo shoots contain about 90% moisture and 3% protein. Bamboo shoot protein contains 17 kinds of amino acids, especially saccharopine, speramic acid and glutamic acid. The total carbohydrates which can be absorbed by the human body are above 2.5% and lipids are about 0.5%. In addition, there are magnesium (Mg) and germanium (Ge) elements which have anticancer and aging-resistant functions, and zinc (Zn), manganese (Mn), chromium (Cr) and other trace elements in bamboo shoots. They can be used for the production of.medical products and as health food.

According to Murphy (Indian Medical Gaz (1932), the sap of bamboo shoots has been found to contain hydrocianic acid and to possess anticeptic and larvicidal properties. Gosh et al (1938) said that young bamboo shoots or sprouts contain about 0.03% hydrocyanid acid (HCN) and 0.23% free benzoic acid (B2OH) in addition to fatty and wax-like substances, resins and about 2.5% reducing sugar. Sprout juice contains about 0.027% hydrocyanic acid and 0.16% free benzoic acid. It is known that 0.4:1000 hydrocyanic acid and 1:1000 of benzoic acid inhibit the growth of microorganisms while 1 : 4000 hydrocyanic acid can retard their growth.

According to the Ceylon Tropical Agriculturist (1944), 0.8% hydrocyanic acid was obtained from one shoot of *Bambusa arundinacea.* About two ounces of such a shoot would be enough to kill a healthy man. The maximum level of hydrocyanic acid is always found in the tip of the shoot. The elimination of hydrocyanic acid during cooking explains the complete absence of danger from poisonning.

Several key enzymes, such as nuclease and deaminase, involved in the synthesis of shikimic acid were isolated from bamboo shoots. An unnamed enzyme that dissolves fibrin, and another of the emulsion type, capable of hydrolyzing salicin, were extracted from bamboo shoots by Kato in Japan in 1911 (McClure 1974).

Therapeutic uses: The young shoots or sprouts of some bamboos that are used as food by men and cattle, have the following therapeutic uses:

Anticancer effects. According to Xiao et al (1988), fermented dry *Dendrocalamus latiflorus* shoot noodles, also called lactic dry *D. latiflorus*, have early anti-cancer properties. The processing procedures requires the use of the middle part of the shoot, after removing the hard nodes before boiling and fermentation (the usual fermentation time is from half to one month).

Internal ulcers. In the book Kuang ch'un fang p'u (anonymous) published in China in 1707 A.D., it is said that the shoots of the T'i chu (weeping bamboo), the biggest bamboo that has ever existed in the world, are delicious and if they are eaten, they will cure ulcers.

Worms in ulcers. In India, the most efficaceous application for dislodgement of worns in ulcers is a poultice made by pounding the young bamboo shoots. The juice is first poured on the vermin, and then the ligneous mass is applied and secured by a bandage (Kinsley in Watt 1889).

Internal worms. In Indonesia, the young sprouts of *Bambusa scandens*, popped in the ashes and then cooled, are eaten as a remedy for worms (Heyne 1950).

Nausea. In China, one species of bamboo sprouts is said to be effective in cases of nausea (Wallnofer 1965).

Stomach troubles. The Ao Nagas from India used to eat young boiled "longmi" bamboo shoots for stomach troubles (Mills 1937).

Ghonorrhoea. In the Book of Malayan Medicine (1930), the young shoots of *Bambusa* (?) are used for its treatment.

Hypertension. According to Wang (1989), the shoots of *Dendrocalamus Latiflorus* not only are full of nutrition, but can also prevent such diseases as hypertension.

Poultices. For this purpose young shoots are used (Perry).

Opacity of the cornea is treated with shoots of the variety *Schizostachyum acutiflorum*, Munro (*Bambusa diffusa*, Blanco) (?). For this purpose they are cut when about a palm in height, the outer leaves are removed and the center is soaked overnight with a little sugar candy. The following day the water in the bottom of the jar is collected and spread on the cornea (Pardo de Tavera 1901).

According to Smith (1871), bamboo sprouts or shoots are eaten by suckling mothers to increase the flow of milk, and they were sometimes given to children suffering from smallpox to bring out the eruption. The same author affirms the emmenagogue properties of bamboo.

~~Haemorroids, haemostasis~~ are cured with bamboo juice, obtained from cutting tender bamboo into pieces and juice can be extracted by methanol, alcohol, chloroform etc. It can also be extracted by distillation method. Bamboo juice contains Ge, Si, and other organic matters, which activate the cells of human body.

When concentrated bamboo juice was analyced by chromatogram column, three efficacious ingredients -A. B. C. were isolated. A. could clear the "hot" of intestines, and cure habit-forming constipation. When 10 to 20 mg was taken before going to bed for half month, B could stop anal fissure and blind pile bleeding When it was taken once a day 10 mg for five days, haemorrhoids andhaemostasis can be cured. When 50 ml of C was taken as a drink, hypertension came down in one hour and the symptom of dizzines, headache disappeared. Bamboo juice can be processed into bamboo wine and other health drinks

4. THERAPEUTIC USES OF BAMBOO CULMS

Gases found in the culm internodes of bamboo: In experiments, Gerland (1926) found that as the culm of the bamboo advanced in age there was a gradual decrease in the amount of CO_2 and an increase in O_2 in the air cavities. The ratio CO_2/O_2 invariably decreased as the age of the plant increased. The percentage of CO_2 was greater and that of O_2 less at noon than in the morning and evening. The average values of CO_2, O_2 and N_2 contained in the internodes of one variety of bamboo were: CO_2, 5.42%; O_2, 13.07% and N_2, 81.51 %. The proportions of CO_2 and N_2 were invariably greater than those of the atmosphere.

Several parts of the culm or stem, such as the peel, the nodes, and the internodes have the following therapeutic applications:

Astringent. The peel or exterior part of the culm of *Bambusa vulgaris* is used in India as an astringent in hemorrhaging, excesive menstruation, nausea and vomiting (Chopra et al 1956).

Epilepsy. According to Lopez (1972), in Colombia a decoction of joints or nodes of a young guadua culm are used to cure epilepsy.

Fever. A decoction of the woody part scraped from the culm is ingested to relieve a feverish condition (Perry).

The finely chopped bark (exterior part of the culm) gives an astringent medication for: hemorrhage, menorrhea, nausea, and vomiting. The bark of *Bambusa vulgaris* is emmenagogue, and antihemorrhagic; it relieves hiccups and vomiting and is sedative to thee fetus (Perry). The silicious matter found near the joints of *Dendrocalamus strictus* is used as a cooling, tonic and astringent medicine (Basu 1918). The epidermis of young stems of *Phyllostchys bambusoides* is regarded as sedative and antiemetic (Keys).

5. THERAPEUTIC USES OF SAP

The sap of *Arundinaria densiflora* is used for treating an ulcerated mouth, toothhache, and ophtalmia.

Fever. - The sap of the *Bambusa arundinacea* culm or a decoction of the unfolding leaves is administered as a treatment for fever (Perry).

Sap from the young shoots of *Bambusa vulgaris* is recommended for treating dropsy, fever, anorexia, disturbances of the embrion, hematuria and coughing with fetid sputum (Perry).

Loss of voice and laryngitis. - Two ko (214 ml) each of human milk and bamboo sap, (collected from heated short lengths of bamboo) are taken warm (Nakayama &Sivin).

The extracted juice of the stem of *Phyllostachys bambusoides*, is used as a sedative and antipyretic in catarrhal, bronchial and cerebral infections (Keys).

Bamboo juice prepared by heating short pieces of green bamboo, so as to drive out the sap at the cut ends, is prescribed in catarrh, fever, acute cerebral, spinal and bronchial affections, supposed to depend on wind and phlegm, and for healing wounds.

6. THERAPEUTIC USES OF CULM WATER

The bamboo water that accumulates in the interior of the culm internodes, which is used by the Malays both for rituals and ablutions and for cooking rice, has the following applications in the native pharmacopea of many countries:

Diuretic. In Colombia, the Indians considered it to be diuretic (Lopez 1975).

Bowel complaints. In India (Kurs 1876).

Eye disease. The water contained in the culms of *Dinochloa scandens* is used in Indonesia for treating eye disease and to sharpen vision, as well as internally and externally for scabby eruptions. Van der Burg says that the water iis used for an eye wash in case of inflamation.

Palliative in diarrhea. The water of some species is used for this purpose.

Jaundice. The water contained in the culms of yellow bamboo (*Bambusa vulgaris*) is taken for jaundice (Heyne 1950).

7.THERAPEUTIC USES OF BAMBOO LEAVES

In India, bamboo leaves are much valued as fodder, particularly when there is a scarcity of pasture. In Japan, the leaves of Sasa apoiensis have been used as feed for pastured horses since ancient times. Cattle and horses relish it and bamboo foliage forms the favorite food of elephants. In China, it constitutes the most important food for panda bears which inhabit some regions, including Sichuan, Shanxi and Gansu, located in high mountains, where according to Zhao (1993) the pandas eat 29 bamboo species. In human and animal medicine bamboo leaves have the following applications:

Anticancer effect. Sakai et al (1964) carried out research in Japan on the anticancer activity of a polysaccharide fraction prepared from leaves of the bamboo grass *Sasa albomarginata* and tested on several transplantable mouse tumors, comparing it with Mitomycin-C. The most significant results were obtained with 100-200 mg/kg doses of the polysaccharide fraction on subcutaneous tumors without toxic symtoms.

In sarcoma-180, the inhibition ratio was 98 % and in *Ehrlich carcinoma*, it was 94%. The injection had no effect on takes or growth of the tumor for the first 9 days after implantation. Between the 17th and 29th days after implantation there were many complete regressions when treatment was started one or five days after the implantation. Ascites tumors and Friend virus disease were not affected. The mechanism of action of this substance does not appear to be the same as that involved in tumor destruction by bacterial polysaccharides reported previously, because tumor resorption and necrosis ocurred without hemorrhage and the ascites tumor was not affected.

According to Kawase (1987), a medicinal effect of the extract from *Sasa* leaf called *Bamfolin* has been noticed in the medical and pharmaceutical fields. A lot of useful results have been reported as the result of testing animals with transplanted cancer cells. The same author said that Oshima treated 69 patients with serious cancerous diseases with *Bamfolin* for over 6 months and reported that some curing effects were recognized by 10% of them, as well as the promotion of appetite and alleviation of pain.

The leaves of *Phyllostachys bambusoides* are antipyretic and diuretic, decoctions being prescribed in stomatitis, pharingitis, and head and chest colds (Keys). Fever, painful throat, and cough are treated with the refreshing and emollient leaves (Perry).

Haemopty and Leprosy. The leaves of *Bambusa arundinacea* are used in India to treat leprosy, fever and hemoptysis (Kirticar 1918).

Emmenagogue. The leaves of *Bambusa arundinacea* have emmenagogue properties. The leaf-bud is used as a decoction to encourage the free discharge of the menses or lochis when this is scanty. This belief is common in both India andChina (Copra et al 1956).

Lotion for the eyes. In Chinese Medicine the bamboo leaf is used to prepare a lotion for the eyes (Satow 1989).

Hematemesis. The juice of leaves with aromatics is given in hematemesis (Dimock et al 1893).

Coagulated blood. According to Lopez (1975), in Colombia the infusion of leaves is given to dissolve the blood clots formed by coagulation.

Fevers. The Chinese make cough syrup from bamboo leaves and use "bamboo hearts" to treat fevers. (Ciba Review 1969).

Coughs and colds in Horses. The leaves of *Bambusa arundinacea* are very commonly given to horses as a remedy for coughs and colds (Dymock et al 1893).

Healing wounds. Leaves of *Bambusa vulgaris* are used for this purpose. In La Reunion, Colombia, they are used as stimulants and antiscorbutic.

Expulsion of the placenta in animals. The leaves of *Dendrocalamus strictus* of India are given to animals during parturition because of the belief that they cause a more rapid expulsion of the placenta (Kirtikar 1918).

Diarrhea in cattle. In India, the tender leaves of *Bambusa arundinacea* are used with black pepper and common salt for curing diarrhea.

8.THERAPEUTIC USES OF BAMBOO CONCRETIONS AND SECRETIONS.

TABASHIR

Tabashir or *tabasheer*, derived from the Sanskrit "tavak-shira" is a siliceous concretion found in the interior of the culm internodes of small number of culms of tropical bamboos, especially in *Bambusa arundinacea* and *Meloccana bambusoides*. In America, they are found in *Guadua angustifolia*. According to Dimok et al (1893), "Humbolt and Bonpland discovered this concretion in the bamboos known as "guadua", located near the volcano Pichincha in Ecuador not far from Quito".

This is confirmed by the fact that in Colombia some Indian tribes used the concretions found in the interior of the internodes of these species as a medicine. Its bluish opalescent beauty is regarded by the faithful as only equaled by its medicinal virtues. It plays a great role in Chinese medical literature, where it is called "Tien-chu, huang-mei or Huang".

In Materia Medica of the Hindus (1900), it is known under the name of *tabashir, bansa rochana, tavak-shira*, and the vernacular names of *banslochan, banskapur* and others. It is called apus and tahi bamboo in Java and singkara in the Sudanese language. It has been erroneouly called "bamboo mana" by some writers.

Tabashir consists of angular pieces, like fragments of shells or round disks, the larger ones about 2.5 centimeters thick, which take the form concave-convex to the inside shape of the node or joint of the culm internode in which the concretion has been deposited. It is said to be formed by extravasation of the juices of the plant. It is also considered to be the residue of the liquid ocasionally found in hollow internodes.

Chemical composition of tabashir. - The specimen of South American tabashir found by Humbolt in Ecuador was sent by him to Paris where it was examined by Fourcroy and Vauquelin. they found 70% silicic acid and 30% potash and lime. (Ann du Mus.vi 1806). According to Walt (1889) the most complete analyzis was made by Prof. T. Thomson of Glasgow (Records of Gen. Science 1836). He found: Silica 90.5%; potash 1.10%; iron peroxide 0.90%; alumina 0.40%; moisture 4.87%.

Therapeutic uses of tabashir. According to Sanskrit works on medicine, such as *Bhava Prakas* and *Raja Nighant*, tabashir is astringent, and sweetish to the taste. It possesses cooling and demulcent properties, allays thirst and fever and relieves cough and difficult breathing. It sweetens the humor and is serviceable in jaundice and leprosy. Its chief virtues, however, and those for which it is mostly esteemed, are supposed to be of a restorative nature, and it is highly prized as an aprodisiac.

According to Brewster (1928), it is supposed to be efficaceous in paralytic complaints, flatulency, and poisoning cases. Mixed with honey, it is used locally in apthae. Some Muslim physicians say that if this drug is used for any length of time it is apt to induce impotence (Watt 18).

MANNA (SECRETION)

The secretion or white powder which appears on the outer surface of the nodes or joints of some species of bamboo is known in Indonesia as manna. It is a sweet, white, brittle gum which is edible. According to Hooper (1900), it consists mostly of saccharine matter. This substance is sometimes exuded by flowering culms in dry sites.

The gummy manna found on bamboos in Java was reported by Von Lippmann (1927) to be largely melitose or melozitose. According to Chang (1938), a crystaline compound has been isolated from the white powder that is found in South China in *Bambusa chungii* McClure. The properties of the compound indicate that it is a triterpenoid ketone, either identical to or similar to freidelin.

In Tibetan pharmacology, bamboo manna is considered to be a sweet-flavored ingredient in the preparation of some medicines. Medicines containing manna cure inflamation of the lungs and sores (Ripoche, 1973). According to Chopra et al (1956), bamboo manna is used as tonic, as a remedy for fever, cough, and in snakebite.

POISONING FROM BAMBOO

There are ancient quotations about poisoning from bamboo culms. According to Kai-Chih's Chu-pu (317-419 A.D.), on Yung-shang, the Kuei-chu or "Casia bamboo" is very poisonous that if a person is wounded by one, he will certainly die. Probably this is a reference to wounds made by arrows which were made from the culm of this bamboo.

According to an extract from a review of the Bengal government Chemical Examiner's Report of December 2nd, 1944. "The shoots of ordinary bamboo, *Bambusa arundinacea* are used as food by man and cattle; and cases of fatal poisoning in men and cattle from eating bamboo shoots are on record.

The determination of the exact nature of the poison contained therein has so far baffled the toxicologists. This investigation was taken up at the beggining of 1941 and it was found that the shoots (when 6 to 18 inches in height) contain varying amounts of a cyanogenetic glucoside which on hydrolysis yields hydrocyanic acid, glucose and parahydroxymandelic acid. In one shoot as much as 0.8 per cent of HCN was obtained. About 2 ounces of such a shoot are enough to kill a healthy man. The maximum amount of HCN is always found in the tip of the shoot (height not exceeding 18 inches).

It is curious how many natural products which contain hydrocyanic acid (Prussic acid) have been used as food. It is true that the adequate cooking is usually sufficient to make them perfectly safe. It is interesting to speculate on how primitive man discovered the secret of using these products.

Poisoning from culm sheaths Bamboo could belong to the family of poisonous plants. According to the Union Medicale, 1873 (ser. 3, vol. 15 p. 96), the stiff hairs or bristles on the sheath that covers the bamboo culm shoot while it grows are used as a poison.

These filaments are mixed with food or drinks, but they do not descend into the stomach, they stop at the throat and slip into the respiratory organs where they soon produce a stubborn cough and an inflammation of the lungs. Poisoning using these filaments, tried in dogs, produced the following symtoms: lose of appetite, ardent thirst, stubborn cough, gradual emaciation, and swelling of the eyelids. Under the influence of this poison, the animals foam at the mouth, look distressed and shortly die of asphyxiation by gas.

On the other hand, in the studies carried out by Wang W. M and Zhao G.M.(1992) at the Hangzhou Science and Technology about the utilization of fresh bamboo shoot sheaths, they found that the culm sheaths proper can be dried and crushed after antiseptic treatment, or made into feed after anti-microbial fermentation .From it juice can be extracted to be substituted for fresh bamboo leach as traditiona medicine, perfume can be extracted from its fresh and tender part to make heath drink . In adition , it is also material for edible fungus cultivation after being crushed

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THE MOST CURIOUS THERAPEUTIC USE OF BAMBOO FOR A PERSON POSSESSED BY AN EVIL SPIRIT.(?)

In the Traite de Medecine Chinoise (Tome IV Formules Magistrales) written in France by Dr. Chamfrault and Dr. Ung Kan Sam (1961), I found on the page 60 the following curious formula for treating a person possessed by evil spirits:

Chevrotain, musc.	1,87 Grammes
Corne de rhinocéros	3,75
Bezoard de boeuf	1,87
Ambre	3,75
Fossile de mammouth (dents)	3,75
Polygala tenuifolia (feuilles et racine)	3,75
Cinabre	3,75
Acorus calamus (rhizome)	3,75
Petites perles naturelles	3,75
Pachyma cocos (Champignon, partie centrale)	7,50
Bambusa (concrétion, tabashir)	**3,75**

BAMBOO IN BIOMEDICAL ENGINEERING

THE FUTURE USE OF BAMBOO IN ORTHOPEDIC IMPLANTS

Biomedical engineering is the use and application of engineering methods, instrumentation, and technology, to solve medical problems in clinical medicine and the life sciences, including the manufacture of artificial limbs and organs. For example, electrical engineers design cardiac pacemakers to stimulate the heart when the natural pacemaker fails. Computer engineers design programs that monitor and analyze the heart rate, blood pressure, and temperature of patients in the intensive care ward. Chemical engineers design dialysis systems that cleanse the blood of waste products when kidney function fails. To replace blocked blood vessels, they design replacement vessels of special plastics that inhibit clotting.

For the life sciences, engineers develop instruments to improve our understanding of the working of the body. Improved electrodes probe into the brain and improved computer techniques analyze the brain signals to unravel the intricacies of how the brain works, etc.

Biomaterial is any non drug substance that can be used as a system or part of a system to treat, enhance, or replace any tissue, organ or body function. It is well known that biomaterials in nature possess composite structures.

Biomaterials are now made of all kinds of man-made materials, including polymeric, bioceramic and metallic materials which include stainless steels, cobalt-base alloys and titanium-base alloys. However, none of them can serve as perfectly as the living tissues to be replaced. If used as a bone repairing or replacing material, standard metallic orthopedic materials will cause stress-shielding of the bone surrounding the prosthesis due to the elasticity mismatch, or the structural behavior can lead to bone resorption. This phenomenon, termed "stress shielding", has been related to the difference in flexibility or stiffness, dependent in part on the elastic moduli, between natural bone and the implant material.

Relative movement of the prosthesis leads to the development of a soft tissue interface. The presence of wear particles triggers cell processes that cause osteolysis. Even for the less rigid titanium, its modulus of elasticity is still five times higher than that of human bone. The poor shear strength and wear resistance of titanium alloys have nevertheless limited their biomedical use. There has been, and there still is, concern about the high elastic modulus of the titanium alloys as compared to bone, and the variable fatigue resistance of the metallic implant. Both properties, if not optimized, may eventually lead to prosthesis failure through loosening or fracture.

The low modulus of polymeric materials limits their extensive application in bone reconstruction. For ceramic materials, the poor resistance against fatigue failure and low fracture toughness are not favorable for bone-repairing material; thus the necessity of searching for new biomaterials and for further improvement of orthopedic implants.

The problems related to implant-stiffness related stress shielding of bone haven resulted in a number of proposed solutions for more flexible designs and low modulus materials. For example, carbon-carbon and carbon polymer composites, because of their ability to tailor their elastic modulus closer to bone than metals, have been investigated as candidates for a new generation of implants. However they are far from being totally effective due to potential environmental degradation and poor tribological behavior (Long and Rack 1998).

According to the same authors, the "ideal" material or composite material for "total joint replacement" (TJR) prostheses should therefore exhibit the following properties: a "biocompatible" chemical composition to avoid adverse tissue reactions, an excellent resistance to degradation (corrosion) in the human body environment, acceptable strength to sustain the cyclic loading endured by the joint, a low modulus to minimize bone resorption, and a high wear resistance to minimize debris generation.

According to Sloten et al (1998), although more than 90% of the joint replacements currently performed are successful during more than 10 years, there is still a need for improvement. Besides the social aspect for the pacient himself, who wants to benefit as long as possible from his new, restored joint, there are also the financial aspects for both the patient and the social security or health care. Due to the large number of joint replacements (e.g. 300,000 hips are replaced world wide each year) and the high cost involved, there is a continuous strong demand for further improvement of orthopedic implants, which will last over 20 years in the human body.

Failure is generally due to aseptic loosening of the implant. Three main causes, which were explained before, have been identified: Stress shielding of the bone surrounding the prothesis, relative movement of the prosthesis and the presence of wear particles which trigger cell processes.

Some studies using wood as an implant material have been done, revealing that adverse cell reactions occurred due to leachable constituents, despite functional restoration and painless utilization of the limb.

BAMBOO AS A BIOMEDICAL MATERIAL

Bamboo, as a natural self-reinforced composite material, was studied for the first time as a biomedical material by Li, Liu, Wijn, Zhou, and Groot (1997), at the Sinica Academy in Shenyang, China, and published with the title of "In Vitro Calcium Phosphate Formation on a Natural Composite Material, Bamboo". The bamboo evaluated as a biomaterial in this study was the species *Phyllostachys bambusoides*. Its anatomical structure was investigated and its mechanical properties were measured and compared with those of some common bone-bonding or bone repairing biomaterials.

It was found that, among all kinds of biomaterials, bamboo has the closest modulus of elasticity to human long bone. On the other hand, Nogata and Takahashy (1995), found that the ability of a bamboo cell to generate electrical signals when stressed was a function apparently similar to that of the piezoelectric effect in bone which is stressed. They also suggest that the electrical properties play an important role in the modelling/remodelling of the skeletal system in biological hard tissues. It was concluded that a bamboo structure is designed to have uniform strength at all positions in both the radial direction on the transverse section and the lengthwise direction, and bamboo is a self-optimizing graded structure constructed with a cell-based sensing system for external mechanical stimuli.

According to Li, et al (1997), compared to wood, bamboo has the following advantages if used as a biomaterial:

(1) It was found that bamboo possesses longitudinal mechanical properties similar to human bone, and a gradient structure along the radial direction. The structure of bone shows the same features from the outer cortical to the inner cancellous bone regions.

(2) The average modulus of elasticity across the thickness of the bamboo culm can be 18 Gpa, which is equal to that of human cortical bone. Besides this, the wide span of distribution of its mechanical properties provides more choices, even from one bamboo culm.

(3) The longitudinal tensile, bending and compressive strengths of bamboo are higher than those of wood, and greater than necessary for load-bearing bone repairing or replacing biomaterial.

(4) In the case of poplar and birch wood, bone ingrowth was found in the larger pores, so the porous structure is beneficial to the ingrowth and anchorage of bone. The structure of bamboo has a wider variety of pores (sieve tubes, vessels and thin walled cells) than wood, possibly providing more chances for the ingrowth of bone.

(5) Another advantage of bamboo over wood is that bamboo contains some silica in both the inner surface (pith-ring) and the outer surface (rind) of the bamboo culm, and it is known that silica plays an important role in bioglass and glass-ceramic in the process of bonding to bone.

Li, et al (1997) in his recent work proved that the silica in bamboo has the ability to induce precipitation of calcium phosphate after removing fatty surface substances using chemical methods.

The cytotoxicity of bamboo was tested using the agar overlay method before and after heat treatments or extraction with some organic solvents (ethanol, methanol and toluene). The results reveal that these solvents can remove the cytotoxic components from bamboo. The generation of a reactive surface apatite layer is a feature shared by all bioactive bone-bonding biomaterials, so for the formation of a bone-bonding bamboo in vivo, the formation an apatite layer on it is a necessary prerequisite. In this study, bamboo was first grafted with x,w-di(aminopropyl) poly (ethylene glycol) 800 (NH2-PEG-NH2) and then soaked in two kinds of calcification solutions, accelerated calcification solution (ACS) and simulated body fluid (SBF) at 37° C, the final result being that a continuous layer of calcium phosphate was formed on the surface of the bamboo.

In this study, the bamboo culm was separated into several layers and the mechanical properties of each layer were measured separately. The plate samples for tensile modulus and tensile strength measured 160 x 12 h mm3, "h" being the thickness, and the ~~working span was 80 mm; the two ends~~ of the tensile sample were sandwiched with thin bamboo plates to avoid stress concentration. Tests were performed in a Hounsfield testing machine at room temperature. The crosshead speed was 2mm min-1. The samples for compressive strength were prisms measuring 10x10x20 mm. The crosshead speed in comparison was set at 1 mm min^{-1}. The longest dimension was along longitudinal direction.

Table 34-1 **Comparison of the mechanical properties of human bones, some common biomaterials and bamboo**

		Direction of test	Modulus of elasticity (GPa)	Tensile strength (MPa)	Compressive strength (MPa)
Leg bones	Femur	Longitudinal	17.2	121	167
	Tibia	Longitudinal	18.1	140	159
	Fibula	Longitudinal	18.6	146	123
Arm bones	Humerus	Longitudinal	17.2	130	132
	Radius	Longitudinal	18.6	149	114
	Ulna	Longitudinal	18.0	148	117
	Bamboo	Longitudinal	**18.4**	**237**	**105** (?)
	Calcium phosfate	Longitudinal	40-117	----	294
	Titanium	Longitudinal	115	340	-----
	Hydroxyapatite	Longitudinal	90	120	40-500

Source: Li, Liu, Wijn, Zhou and Groot (1997)

Table 34-2 Cytotoxicity test for bamboo before and after heat treatment or chemical extraction					
Material	As-received bamboo	Ethanol treated	Methanol treated	Toluene treated	Heated at 180^0
Result	Fail	Pass	Retest	Retest	Fail

Cytotoxicity test

The agar diffusion test (48 hours incubation) was performed as a cytotoxicity test. Three kinds of bamboo samples were prepared for cytotoxicity.

(1) As-received bamboo without any treatment. First, the bamboo internode was sliced into layers 1 mm in thickness; then these layers were cut into 1 x 1 cm squares.

(2) Sliced thin layer samples were extracted with several organic solvents at room temperature for two days and then in a Sohlet extractor for 2 days. The organic solvents were 100% ethanol, methanol and toluene. After extraction, the samples were rinsed thoroughly with culture working solution to remove the extraction solvents from the bamboo.

(3) As-received bamboo was heated at 180° C for 2 hours; its color turned dark after heat treatment. It was then sliced into 1 mm layers and cut into 1 x 1 cm squares.

All samples were sterilized by gamma ray radiation. Human skin fibroblasts were used as test cells. Latex rubber sheets (Hilversume Rubberhandel BV) and ultra-high-molecular-weight polyethylene (Goodfellow, Cambridge, UK) were used as positive and negative controls, respectively.

The cytotoxicity test was performed according to ASTM F813-83 and ISO/TR 7405. The agar medium (0.5 ml) was pipetted on the monolayer and slightly gelled. The test samples were placed on the gel, pressed down lightly and the remaining 1.5 ml was added. Test samples and negative controls were incubated in triplicate, positive controls at least once. The plates were placed in a CO_2 incubator at 37° C and 5% CO_2.

After 48 hours, the cell cultures were evaluated for morphology, zone of affected cells around the sample, intracellular granulation or fatty degeneration related to negative control.

Calcification behavior of as-received bamboo in ACS and SBF

Two kinds of calcification solution were used: SBF and ACS. The composition of SBF was (mM): Na^+ 142, K^- 5.0, Ca^{2-} 2.5, Mg^{2+} 1.5, Cl^- 147.8, HCO_3^- 4.2, HPO_4^{2-} 1.0 and SO_4^{2-} 0.5. ACS was developed on this laboratory; its composition was (mM): Na^+ 136.8. CL^- 144.5, Ca^{2+} 3.87 and PO_4^{3-} 2.32. The solution was buffered in 50 mM. Tris buffer (pH 7.4) at room temperature.

The bamboo internode was sliced into 1 mm thick plates, across the axial direction of the bamboo culm; then these plates were cut about 10 mm wide. Two groups of samples were soaked in 30 ml ACS or SBF, respectively; there were three samples in each group. The samples soaked in ACS were taken out at day 3, and those of SBF were taken out after 2 weeks. All samples were then rinsed thoroughly with distilled water, dried and coated with carbon for scanning electron microscopy (SEM) and energy dispersive X-ray analysis (EDX).

Grafting with x,w-di (aminopropyl polyethylene glycol) 800

Bamboo internodes were cut into 1 mm thick plates, and then extracted with 100% etanol at room temperature for 5 days and with toluene for 20 hours before grafting. Bamboo samples were dried at 40° C for 2 hours and then at 120° C for 2 days. To graft NH_2 -PEG-NH_2, bamboo samples (0.23 g.) were first treated with a solution of toluene and g -glycidoxypropil trimethoxysilane for 8 hours, then rinsed with toluene followed by treatment with a 10% solution of NH_2 -PEG-NH_2 in dimethyl sulphoxide (DMSO) at 80° C overnight. Finally, the samples were rinsed thoroughly with ethanol and acetone to remove the unreacted NH_2 -PEG-NH_2 and dried at 60° C for 1 hour.

Untreated bamboo samples were used as a control. They were soaked in 20% PEG 1000 solution for 2 hours; after thoroughly rinsing with 100% ethanol and distilled water, samples were subjected to the same calcification procedure as the as-received bamboo samples and, after 3 days in ACS and 2 weeks in SBF, samples were taken out and dried. Carbon was coated for SEM analysis.

Formation of a continuous layer of calcium phosphate

Grafted bamboo samples were cut into 1 x 3 x h mm (h is the bamboo thickness) pieces and put into 30 ml of ACS or SBF in a sealed polystyrene disposable beaker, and shaken in a water bath at 37° C. Samples in ACS were taken out at 1 and 2 days; samples in SBF were taken out at 2 weeks. After carefully rinsing in distilled water and drying, the samples were carbon coated for SEM observation. Some precipitate on the surface of the samples was scratched off for infrared analysis.

Results and discussion

In table 34-1, the most notable observation is that the modulus of elasticity of bamboo is the same as that of human bone. The compressive buckling strength of bamboo is somewhat lower than that of bone, the tensile strength being considerably higher. From the viewpoint of bone replacement materials, the longitudinal mechanical properties probably make bamboo the most suitable biomaterial to be found in nature.

The results of the cytotoxicity tests are summarized in Table 34-2, revealing that the as-received bamboo sample (untreated) and the samples after heat treatment at 180° C were cytotoxic. Heat treatment cannot remove the cytotoxic leachable components effectively, even though some polimerization processes may occur and the chemical components may change to some extent. Extraction with organic solvents has significant effects. After extraction in ethanol and rinsing in culture medium, bamboo is not cytotoxic in the agar overlay test. However, for the samples extracted with methanol and toluene, the results were 'retest', which

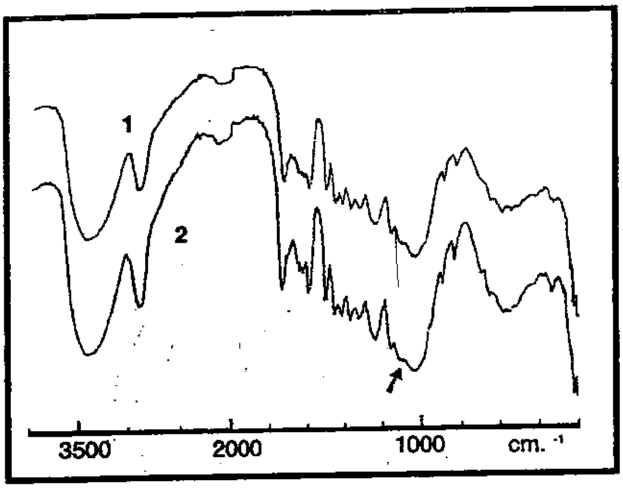


Fig.34.2 *IR spectra of bamboo. (1) Before grafting (as-received). (2) After grafting with NH_2 -PEG-NH_2*

means that samples had mild reactivity with cells. Therefore, ethanol is the recommended extracting solvent.

After soaking in ACS for 3 days or in SBF for 2 weeks, there was no calcium phosphate formed on bamboo that was detectable by SEM-EDX, which means that as-received bamboo is inert in calcification media. Furthermore, for the bamboo samples directly soaked in 20% PEG 1000 solution, only a few separate particles of Ca/P mineral could be observed after 3 days in ACS, which means that the bamboo is still inert.

After grafting, the dry weight of the samples increased by about 20%. The IR spectra also shows the difference before and after grafting polymer. Fig. 34.2 shows the IR spectra of bamboo as-received and after grafting with NH2 - PEG-NH2. The peaks at 955 and 710 cm-1 in Fig. 34.2 are due to the grafting; the peak at 1100 cm-1 is from CH2-O-CH2, which can only come from PEG.

After being soaked in ACS for one day, some mineral deposit could be observed on both the cross-section and the longitudinal section of the bamboo samples. However,

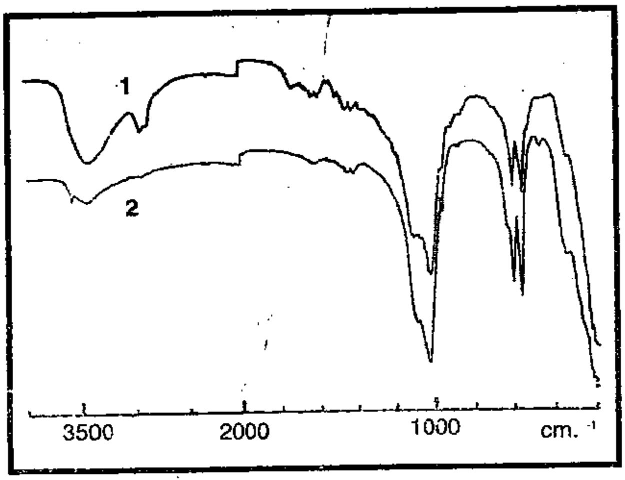


Fig.34.4 *IR spectra of: (1) the ceramic formed on bamboo cross-section after inmersion in ACS for 3 days; (2) Commercial HA (non-sintered).*

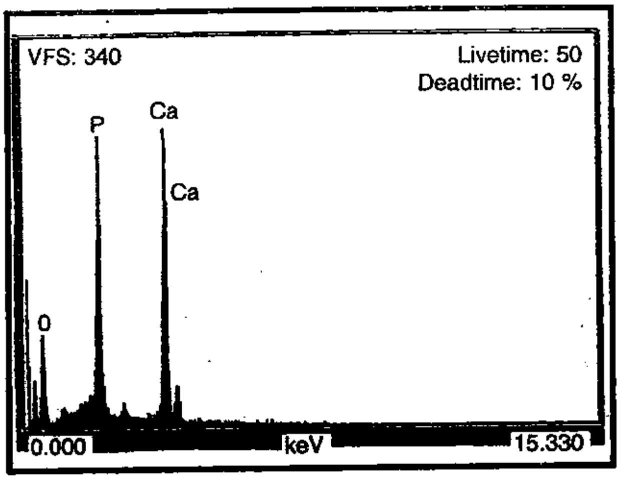


Fig.34.3 *SEM-EDX spectrum of the ceramic layer formed on a bamboo sample ater grafting with NH_2 -PEG-NH_2 and soaking in ACS for 1 day.*

the situation was obviously different between fiber strands and ground parenchyma tissue (as shown in Fig. 34.4). The ceramic grew on parenchyma tissue (thin-walled cells) much more than on fiber strands. The SEM-EDX spectrum showed that the ceramic consisted mainly of calcium, phosphorus and oxygen, as shown in fig. 34.4. Fig. 34.4 shows the IR spectrum of the mineral formed on a bamboo cross-section in ACS after 3 days. Peaks attributable to HPO42- (868 cm-1), PO43- (1030, 1080 cm-1) and CO32- (1400 - 1500 cm-1) could be observed. For comparison, the IR spectrum of commercial hydroxyapatite (HA) is also given in Fig. 34.6. The mineral is apparently carbonate-containing calcium phosphate.

On the grafted bamboo samples, a continuous layer of ceramic was formed in SBF. Fig. 34.5 A shows the longitudinal section of bamboo indicating that the mineral was formed on both fiber strands and thin walled cells. Fig. 34.5 B shows that the ceramic densely covered the entire cross-section of the bamboo; even its surface has a very complicated morphology. Fig. 34.5 C shows the ceramic morphology on bamboo fibers in the vascular bundle, where apparently it was more difficult for the mineral to precipitate from ACS. Fig. 34.5 D shows the thin walled cells covered with ceramic, from which it can be concluded that the mineral crystal grew even inside the cell chambers. This is important since the bamboo's porous structure may induce the ingrowth of bone. SEM-EDX analysis revealed that the ceramic includes calcium, phosphorus and oxygen (Fig. 34.6), identifying it as calcium phosphate.

As mentioned before, without any chemical modification or functionalization, bamboo is inert in calcification solutions (ACS and SBF). Only after the grafting of PEG does bamboo have the ability to form a calcium phosphate layer in vitro. This can be explained as follows: the major chemical components of bamboo are cellulose and lignin; both of which have OH in their molecules. In the grafting process, the reaction shown in Scheme 34.2 occurs.

After grafting, PEG was covalently bound to bamboo. It is well known that PEG has the ability to facilitate calcification, because the polyesther soft segment polymer in PEG will cause metal-ion chelation. Hamon et al concluded that a

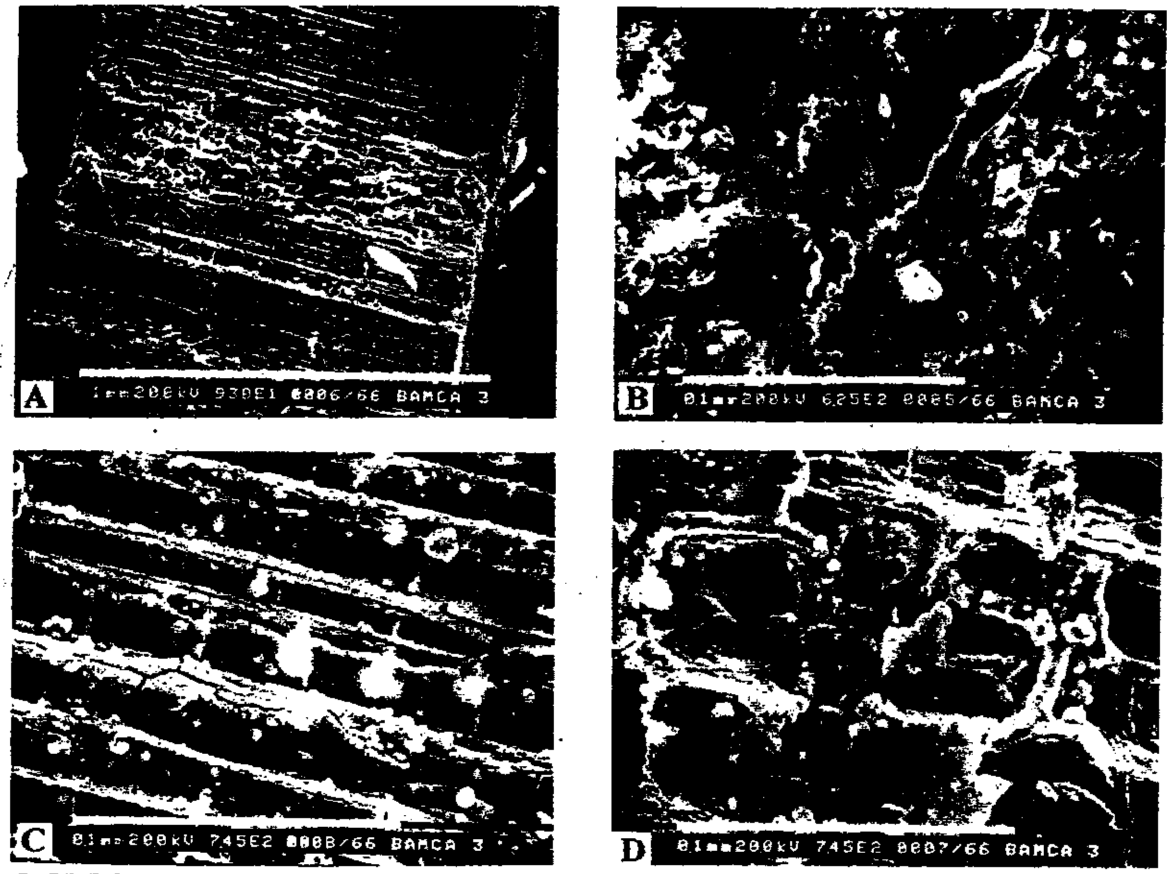


Fig. 34.5 *Scanning electron photographs of the ceramic formded on bamboo in SBF for 2 weeks after grafting with NH_2 - PEG-NH_2 A. The longitudinal section of bamboo. B. Cross section of bamboo. C. Longitudinal photo of fiber. D. Longitudinal photo of the parenchyma tissue.*

helical arrangement of the PEG backbone resulted in inwardly-directed oxygen atoms, allowing complexation between cations and the polymer. Because of the Ca2+ complexing ability of the PEG segment, the Ca2= concentration within the grafted PEG layer on the bamboo surface would

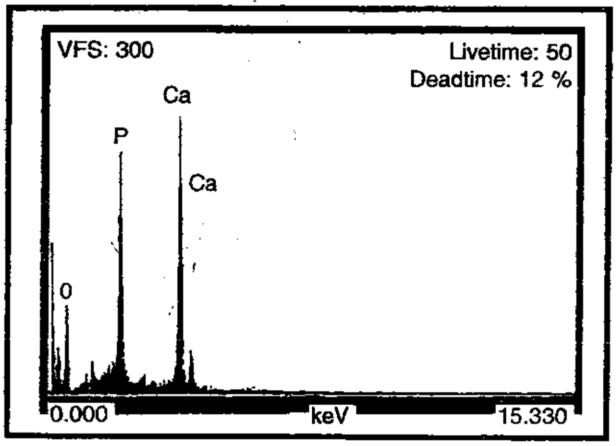


Fig. 34.6 *SEM-EDX spectrum of the ceramic layer formed on a bamboo sample after grafting with NH_2 -PEG-NH_2 and soaking in SBF for 2 weeks.*

be higher than that in solution. It is well known that if the ion activity product [Ca2+][HPO42-] is higher than a certain constant, non-homogeneous nucleation will occur. Thus nucleation most probably occurred on the bamboo surface, where a higher Ca2+ concentration was available. After bamboo was soaked in the calcification solution, Ca2+ ions from the solution were chelated onto the surfaces by the PEG molecules, and this increased the Ca2+ concentration and thus the ion activity product [Ca2+][HPO42-].

Consequently, calcium phosphate will precipitate onto the surface of bamboo. Due to the chemical bond between PEG and bamboo, and chelation between PEG and Ca2+, it is expected that the bonding strength between calcium phosphate and bamboo will be strong enough for practical application. Further experiments are planned to verify this.

CONCLUSIONS

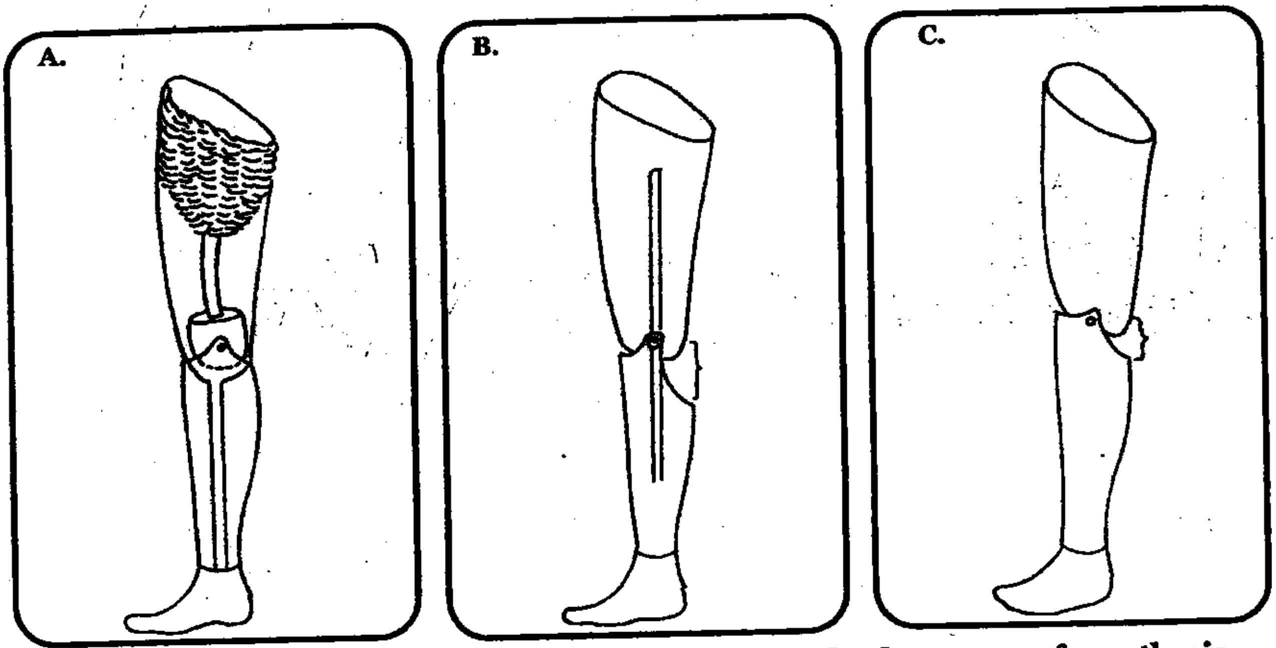
Ethanol, methanol and toluene can remove cytotoxic leachable componenets from bamboo to some extent, as verified in an agar overlay cytotoxicity test. When PEG, in the form of xw-di(aminopropyl) poly(ethylene glicol) 800 (NH2 -PEG-NH2), was grafted onto bamboo, it enabled the bamboo to form a continuous layer of calcium phosphate in vitro, in calcification solutions (Li, Liu, Wijn, Zhou and Groot 1997).

Fig 34·7

ORTHOPEDIA -BAMBOO PROSTHESIS

The extraordinary tensile and compression strength of bamboo, and its lightness have been fully exploited by Viklang Kendra, a rehabilitation center for the handicapped at Bharadwaj Ashram, Allahabad, Pakistan. There they manufacture several types of prostheses, artificial substitutes for a missing part of a body, like a leg or a hand, and they have rehabilitated thousands of poor rural handicapped people.

Some of these bamboo appliances and prosteses manufactured by Kendra are: bamboo splints, bamboo/cane walkers, cane crutches, cock-up/Volkman's splints, cervival collars, bamboo calipers, spinal jackets (lumbo sacral belts), splints for the hand, wheel chairs and lower extremity prosthesis. All of them required simple and unsophisticated techniques using bamboo and cane (Banerji B. & Banerji J.B. 1984).



Differences between cane-bamboo prosthesis and other types of prosthesis

	A. Kendra's Prostesis - Endo Skeletal	**B. Jaipur prostesis Exo-Squeletal**	**C. Conventional prostesis Exo-Skeletal**
Consistency	-Soft, like a normal limb. It has a lurch due to elasticity of cane /bamboo.	-Hard. - No elasticity and lurch.	Hard. No elasticity and lurch .
Socket	-Rectangular socket made of basket (cane), lined by sponge. -Permit aeration of amputated stump. -No sweating. It is specially advantageous for tropics.	-Socket beaten from aluminium sheet. -Does not permit aeration of amputated stump.-Sweating.	-Soaked shaped from wood or molded epoxi-resin . -Partial aeration ± through a valve (A).-Swating present
Body of thigh	-Soft. Covered by rubberised stockinette. -Skeleton is made of bamboo or cane.	-Hard. Covered by stockinette, colored by fevicol.-Aluminium, shape is welded.	Hard. Covered by stockinette. Epoxy compound or poly-propilene.
Knee joint	-Made of bamboo. Single axis join . Control on motion due to a spring unit which gives resistance to motion; enables the leg to move harmonically and normally. -Flexion angle 170°.	Made with steel with drop lock to keep it in place.- Double axis joint. No control in motion.-Flexion angle about 140° only. The leg unit has to have a gap to accomodate the thigh.	Made of steel, double axis.Double axis. No control on motion. Flexion angle 100° to 120°
Use of irregular path-ways	-Stress and strain on rough roads much less due to eleasticity of cane.	Stress and strain due to rigidity of aluminium.	Stress effects more due to heacy weight.

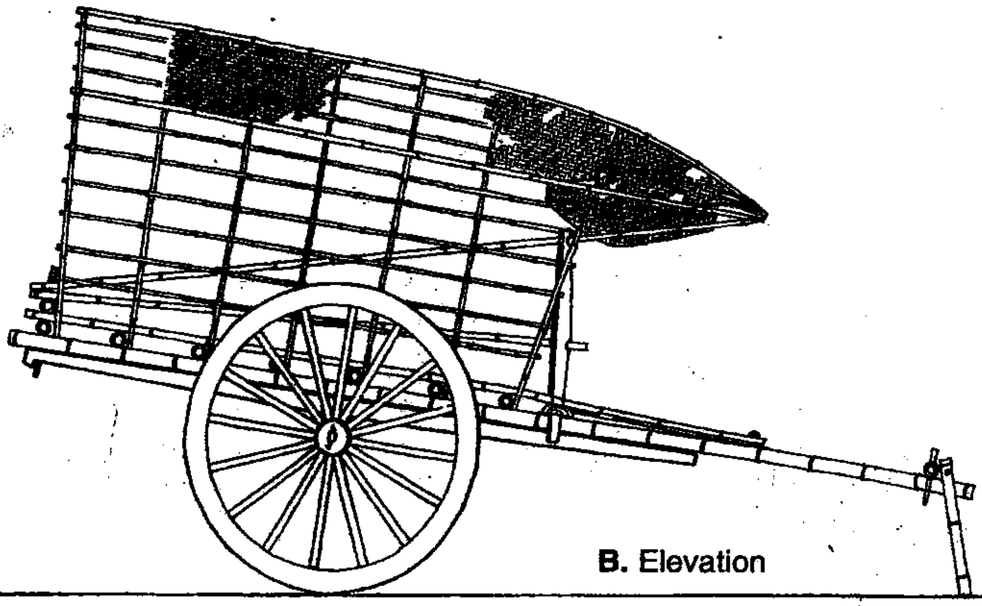
BABOO USES OF BANBOO IN DIFFERENT FIELDS

33

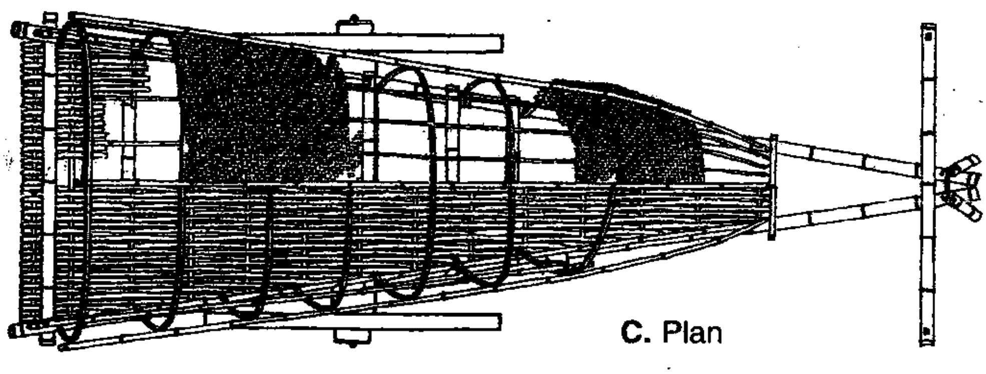
TRANSPORTATION - 1. BAMBOO BULLOCK CARTS IN INDIA

Fig. 35.1

(According to Ranjan, Iyer, Pandya, 1986) Bullock carts made of bamboo and wood are used in the plains of Assam and Manipur. The type of cart described here is found in the Kamrup District. Bamboo is used structurally in the bed, yoke, yokeshaft and super-structure of the cart while the wheel, axis block and main chassis are made of wood. These carts are seen in two variations, with or without a hood made of bamboo splits and matting.
SOURCE: Ranjan, Iyer, Pandya, 1986)



B. Elevation



C. Plan

Fig. 35.2 TRANSPORTATION -2. BICYCLE WITH BAMBOO FRAME

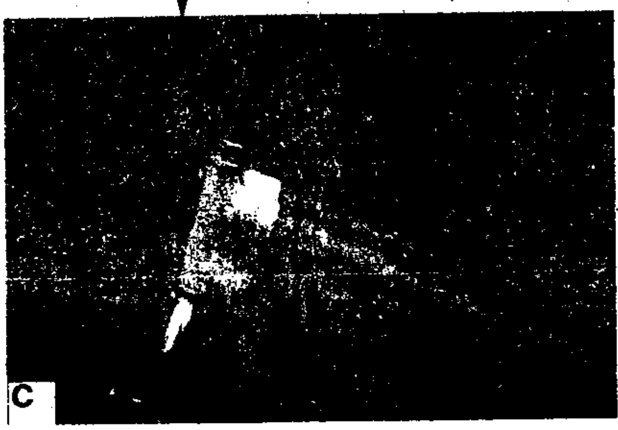

A

The Research Laboratory in Living Design – LILD, of the Arts & Design Department of the Pontifical Catholic University of Rio de Janeiro, PUC-Rio, Brasil, is the only laboratory which exists in the Americas dedicated to the study of bamboo technologies under the succesful direction of Professor José Luiz Mendes Ripper.

Designers, architects and engineers have been applying the findings of the laboratory in housing projects, furniture, auxiliary equipments for handicapped people, as well as other objects such as the bicycle with bamboo frame shown in the Fig. 35.2. This bicicle was designed by Flávio Deslandes, a former student of the laboratory. The bamboo frame consist of bamboo sections which are glued to metal joints. Furthermore a tension steel cable located inside each bamboo section conect the oposite metal joints.

The LILD activities also reach the countryside, including environmental reserves, by offering workshops on bamboo structures. Research professors, undergraduate and graduate students and former students, coordinated by research professor José Luiz Mendes Ripper, compose the design team of the LILD.


B


C


D

3. BAMBOO STYLUS (NEEDLE) USED IN PHONOGRAPHS

Thomas A. Edison was the inventor of the first practical recording machine, which was also a playback machine called the phonograph, using a cylinder which later on Berliner in Germany, turned to disc recording, which was known as gramaphone. Today the record player is still called a phonograph in America and a gramaphone in Europe.

Records were played by means of a stylus (called needle) and diaphragm assembly called a sound box, and the sound was amplified by means of a horn. The styluses were made of steel, sometimes chrome plated, and various kinds of thorns. Cactus needles and bamboo were also used; these gave a softer tone and reduced record wear, but would barely last one play without being resharpened.

As early as 1906 there were nine types of needles available: three to play quietly, three to play at medium volume, and three types for loud playback. These were sold by Universal Talking Machine Co. of New York. Loud needles had rounded tips, and softer-sound needles had sharper tips. The problem with all metal and jewel needles was that they chewed up the record grooves. Bamboo, thorn, and cactus needles were popular with collectors in the 1930's and 1940's because they produced minimum record wear, but, of course, the needles themselves wore out instead. They could be shaved for replaying, and shaving devices something like pencil sharpeners were sold for that purpose. Victor sold a fiber "needle cutter" in 1909 that used a plunger action, "enabling you to use each fiber needle at least ten times". The phonograph stylus or needles were manufactured from bamboo slivers. The slivers were heated in oil at 340° F and tumbled in barrels containing sawdust, which removed excess oil and polished the slivers. Then they were ready to be sharpened and used.

Fig. 35.3 *Bamboo stylus or needles were used in this type of phonograph, known in 1902 -1906 as "Victor III".*

4. BAMBOO SPRING LOCK

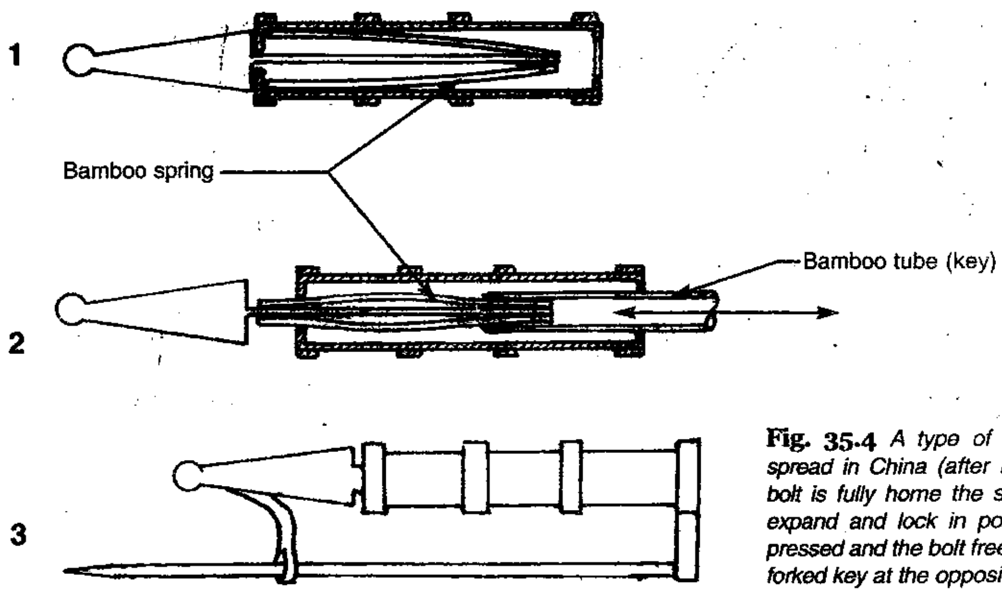


Fig. 35.4 *A type of spring padlock widespread in China (after Hommel,r). When the bolt is fully home the springs which it bears expand and lock in position; they are compressed and the bolt freed by the insertion of a forked key at the opposite end of the padlock.*

5. USE OF BAMBOO IN CARTOGRAPHY

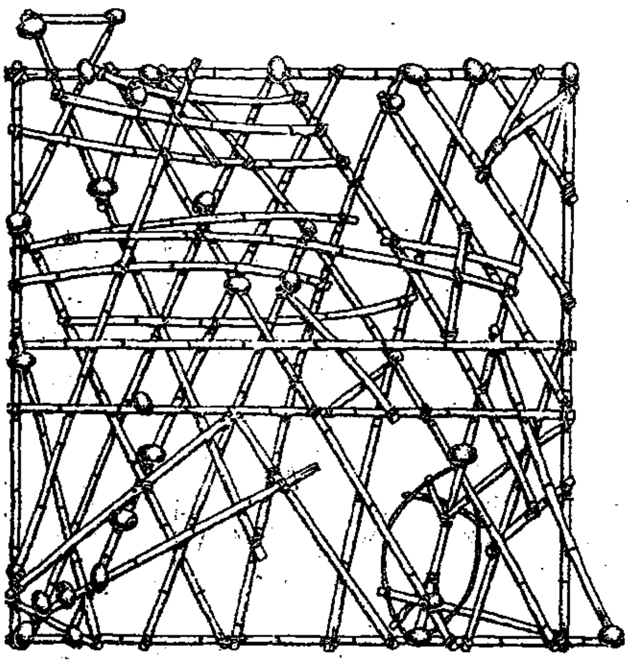


Fig. 35.5 *Bamboo Map showing the location of some of the islands of Micronesia which are indicated with small shells.*

Cartography (the study of map-making), map reading and map interpretation are therefore among the most important aspects of geography. Many other scientists, such a geologists, archaeologists, botanists, agronomists, and economists, also use maps in their work, and it is necessary for them to have a working knowledge of map reading and map interpretation.

According to Blair and Simpson, maps are the oldest written language in the world; long before any spoken language was developed into a written form, primitive man made maps and used them on his voyages. The early Asians, Africans, North and South Americans made sketch maps out of materials such a sand, stone, bark, wood, skins of animals, clay tablets and even pieces of bamboo.

One of the most treasured possessions of the early Micronesians was the stick chart shown in Fig. 35.5, the interpretation of which was a carefully guarded secret passed from father to son.

The position of islands (indicated by shells) was fixed by the wave patterns (indicated by sticks), as shown in the figure

In South America the ancient Peruvians made relief models of the landscape using stone, clay and straw. Primitive man used maps to show hunting and fishing grounds, travel routes and territorial boundaries. Many of these maps were very accurate and well orientated, as the North Polar Star and the sun were used to fix positions.

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