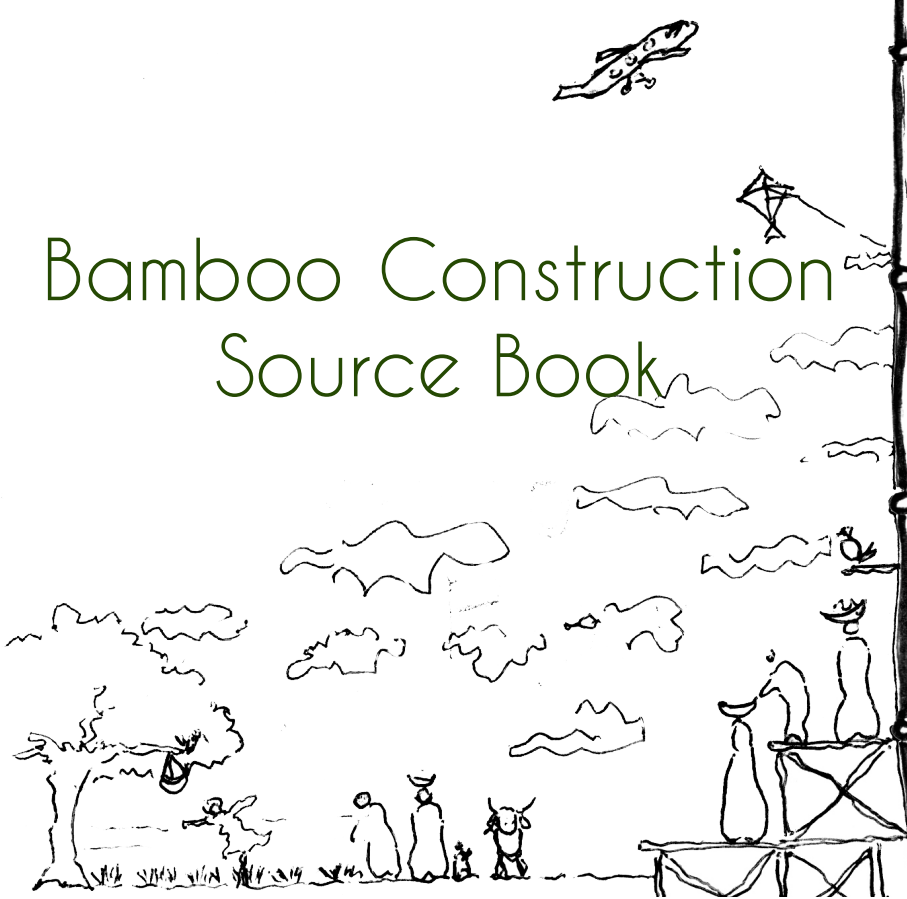
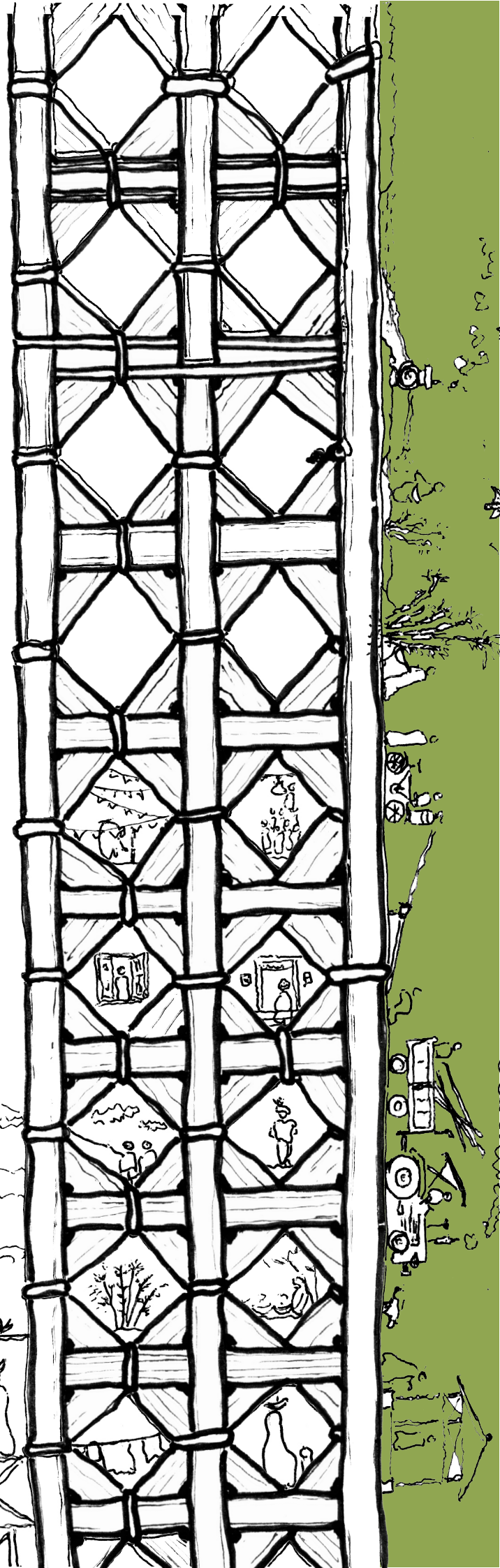


Bamboo Construction Source Book



Things came before people.
People came before words.

Tall, green, and nameless,
bamboo walked down centuries
and crossed continents
in time to stand there, waiting,
naked of language,
when the first people came,
to make the first village.

Bamboo Construction Source Book



Foreword

In the past, many people built their own houses, either by themselves or with help from their neighbors and from local artisans and builders. They knew how to select the best building materials from what was available locally and knew how to use those materials most efficiently to make houses which responded to the local seasons and met their various needs: economic needs, functional needs, cultural needs and environmental needs. A lot of this understanding about how to build was implicit - nobody spoke about it or wrote it down or thought of it as anything special. But all the same it represented an enormous heritage of local building wisdom and it was passed down from generation to generation through the process of building itself.

By contrast, most houses today are not designed and built by their owners but by contractors or masons or carpenters, and a lot of that particular local wisdom about building that used to belong to people has been lost. At the same time, greater and greater numbers of people in Asia are finding themselves without decent shelter, living in squalor and insecurity in urban slums and rural settlements, and yet aspiring to the kind of generic brick-and-concrete house they will never be able to afford. In light of this, it is important for us to re-think our strategies for housing the poor, and to re-visit some of that traditional building wisdom, in which people and communities were the key agents in building and upgrading their housing, and local materials and local building techniques were their inexpensive and environmentally-sustainable tools to do that.

In this handbook, we look in detail at one of those local building materials - bamboo - which for millions of Asian families has always been one of the cheapest, most-used and most essential local building materials. In the following pages, we will look at traditional techniques for treating and building with bamboo, and also examine some new techniques which can enhance that traditional building wisdom and make bamboo houses that are stronger, longer-lasting, more resistant to various kinds of disasters and more adaptable to changing climate conditions. We hope that this book will inspire local artisans, community builders and professionals in the Asia region, and will provide ideas that can be added to the knowledge they already possess about building with bamboo.

We would like to thank the Hunnarshala Foundation for compiling the material about bamboo construction which has been used in this handbook. We would also like to thank the Rockefeller Foundation, whose support to the Asian Coalition for Housing Rights (ACHR) has helped us to form and strengthen the Community Architects Network (CAN) in Asia, which has become an important regional platform for building our collective knowledge about housing by people and applying it in practice.

Community Architects Network (CAN)
May 2013

Preface

Working in flood affected area of Mithilanchal -Bihar, was a great learning. People of this region have built one of the most enduring lifestyle on their fertile planes and center of their life is bamboo .They say from birth to death every step of their life is supported by Bamboo . They usually held notion of trying to build in such a way that nature cannot degrade the material easily does not exist in this region. However they build in such a way that degrading material can be changed without bringing down the structure. Sustainability was not something that these people needed to learn .In fact, that was something that they could teach, to any one who listened.

Learning from the community encouraged us to bring it forward, to prepare guidelines for reconstruction of their houses and different manual for construction, based on learning and wisdoms of traditional building. Artisans locally called 'Dabiya Mistry', taught how an entire house can be build with just one multipurpose tool called Dabiya. (Big knife to cut and split bamboo)

Bamboo is ancient resident of earth among the most primitive of grasses, available for people since past million years. It still remains an integral part of human life . It is a renewable resource. During the growth period, it has a good influence on the climate of the region and helps to control erosion and floods .

Traditional knowledge is an open source for community to use and allows it to evolve for the future. In contemporary time information technology is becoming more and more popular and widely used by professionals and community. This book is an attempt to put together basic knowledge of bamboo, sourced from the wide pool of knowledge across the world and practicing community. The book also contains information to know more about different topics to be explored through web-world, that makes this book **The Source Book Of Bamboo Construction.**

The book gives basic idea about building with bamboo. It is advisable for beginners to involve practicing with local artisan to know more and explore it further.

We have tried to compile this book so that sharing of knowledge begins. For further improvement your critical views and suggestions are welcome. We hope this document will be useful to people with concerns towards communities. Last but not least, this sharing spirit guide us towards building a better world.

This book is an attempt to encourage young professionals , community builders , artisans and house owners in the region for supporting sustainable ,affordable and maintainable housing where bamboo is available .





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1. About bamboo

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

Bamboo is grass, typically woody, and fast growing.

The bamboo plant has an extensive underground network, of which the singular feature is the rhizome.

Over the ground, a stem (or culm) arises from the rhizome. The culm is normally a hollow cylinder, tapering towards its top.

An emerging culm is called a shoot. It is protected by sheaths that stay with the culm till it develops fully.

The growing rhizome is similarly protected by a sheath, which is however not normally visible since it is below the ground.

Roots extend from the nodes of the rhizome and from that part of the culm which is closer to the soil surface.

Most bamboos are monocarpic plants; they flower (and fruit) once in their lifetime and then die.

Bamboo is widely adopted by different culture for its versatility across the world. Use of bamboo evolve with the different culture and community and its still evolving.

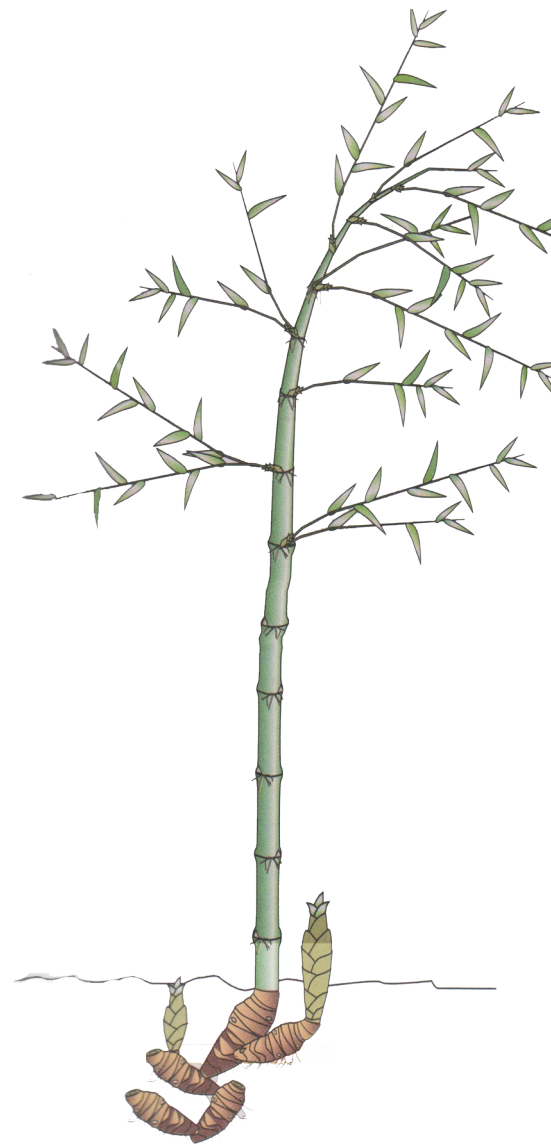


Fig.1. The Bamboo Plant

“Plants are people, just like us.
You see them, they see you.
The earth isn't blind
and the mountains aren't foolish.”

-Jose Valdez,

Mexican Farmhand

For More Information:

Book: Field Guide The Bamboo Book
Web: www.bambootech.org

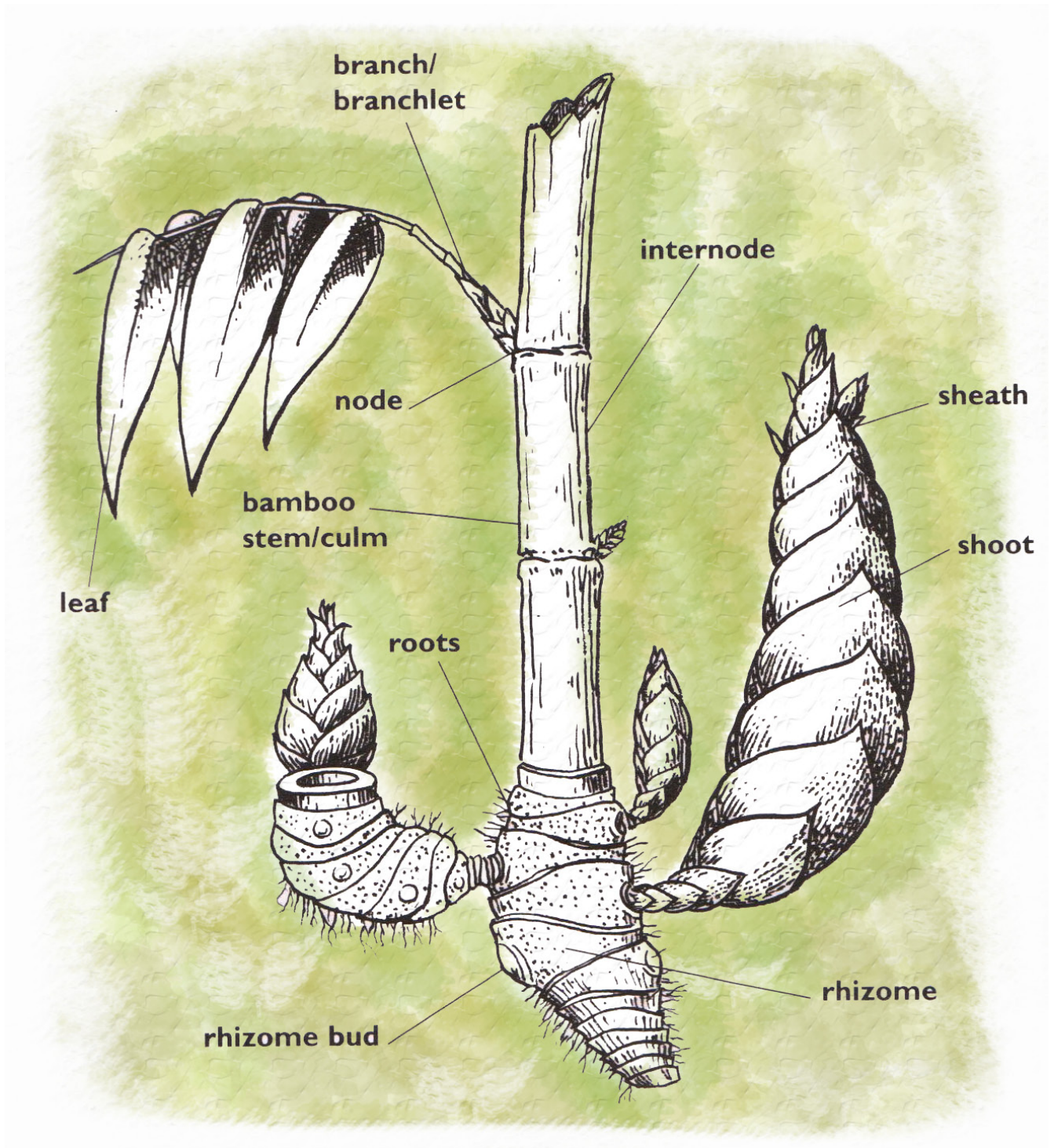


Fig.2. Diagram Bamboo Root

Bamboo Growth & Forms

TREE FORMS

These are bamboos up to 35 metres in height, and with large or medium-sized, usually thick-walled, culms.

Examples: *Bambusa balcooa*, *Dendrocalamus hamiltonii*, *Dendrocalamus strictus*.

The same botanical name may have different local name in different areas and its community knows it by that name and its also equally valid.



Fig.3.

STRAGGLER FORMS

These are medium-sized bamboos up to 15 metres tall, with the tip of the culm arching or drooping down or climbing on adjacent trees.

Example: *Melocalamus compactiflorus* (climbing bamboo).

“Bamboo growth more rapidly than any other plant on the planet. It has been recorded growing at amazing 47.6 inches in a 24 hours period.”

Reference

Book : Field Guide The Bamboo Book
Published By:
NMBA, TIFAC, DST, Government of India.

Web: www.bambootech.org

<http://www.lewisbamboo.com/growth-chart.html>



Fig.4.

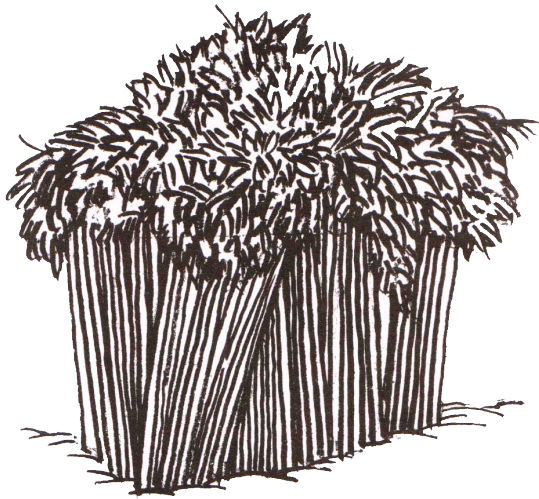


Fig.5.

REED FORMS

These are medium-sized bamboos, which commonly grow as reed brakes. They have thin-walled culms up to 9 metres in height with long internodes.

Example: *Ochlandra travancorica*.



Fig.6.

SHRUB FORMS

These are erect short forms of bamboo found in temperate species. They mainly occur at high altitudes, and have very thin culms that rise to a height of up to 5 metres.

Examples: *Arundinaria racemosa*, *Sinarundinaria falcata*. Shrub forms are widespread in India's Himalayan Regions, near the snow line in Arunachal Pradesh, Uttaranchal, Himachal Pradesh and Sikkim. They also occur in the Ghat areas of Kerala and Karnataka.

2. Various use of Bamboo

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

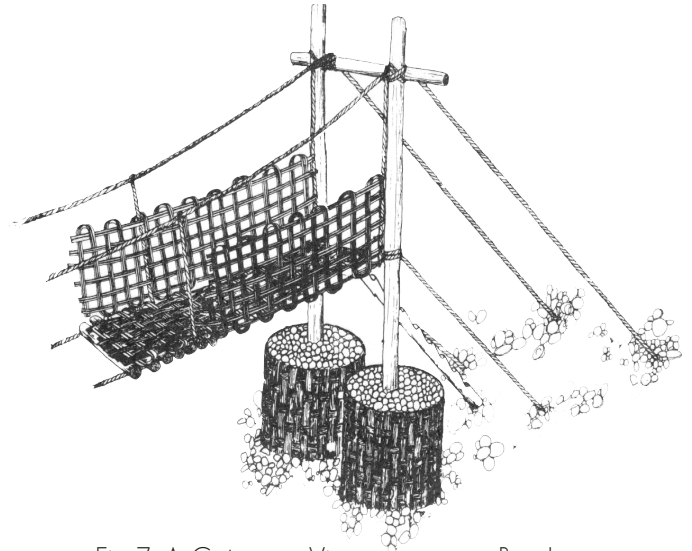


Fig.7. A Cutaway View of monpa Bamboo Suspension Bridge

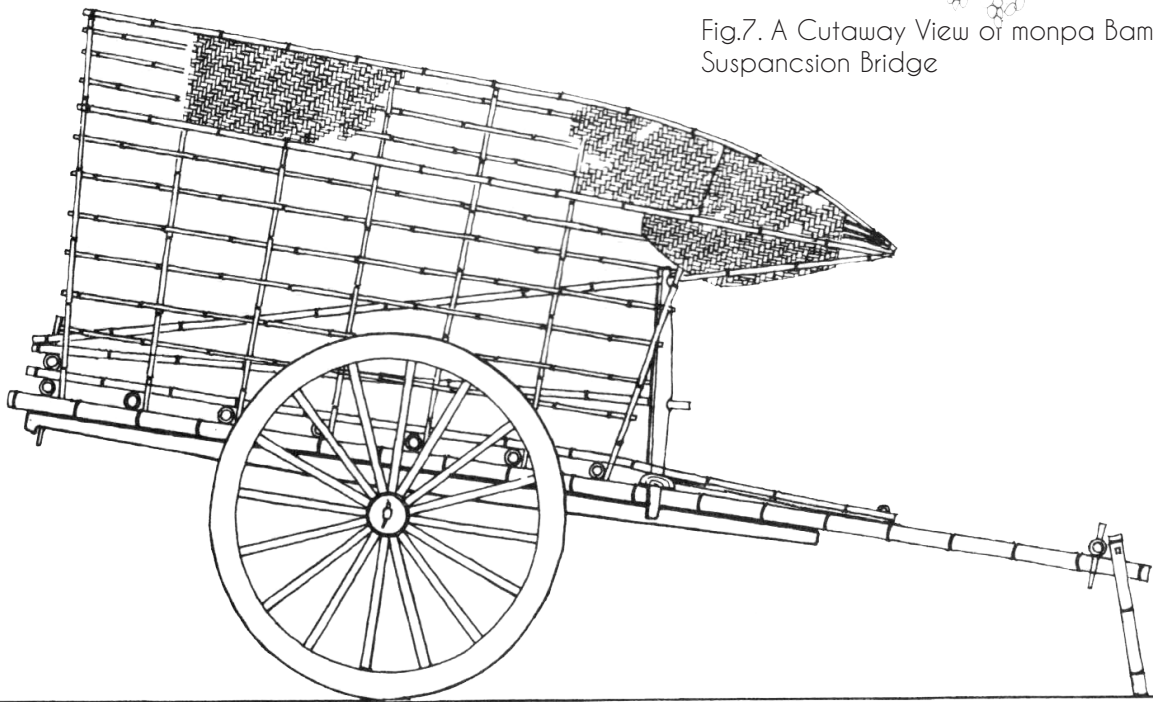


Fig.8. Bullock Cart in Manipur, India.

"In northern China, baskets are part and parcel of the rural population. Plain, practical, strong, durable, they are used chiefly for agriculture; collecting and carrying earth and manure, winnowing, storing grain, transportation...."

Reference

Book : Bamboo And Cane Crafts of Northeast India, NID, India.

Web:

<http://www.nid.edu/activities/research-publications/publications>

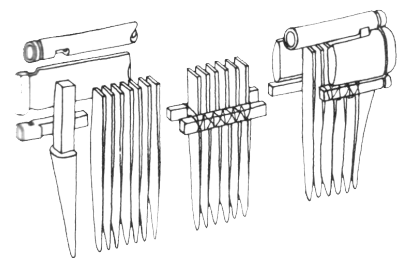


Fig.9. A Cutaway View Showing the Construction of khasi Comb

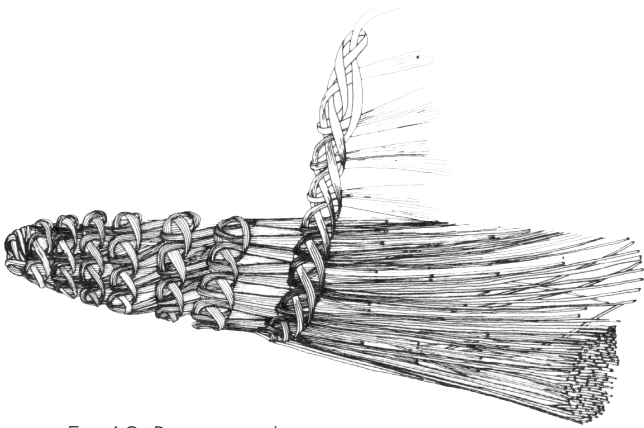


Fig.10. Diagram showing construction of Broom

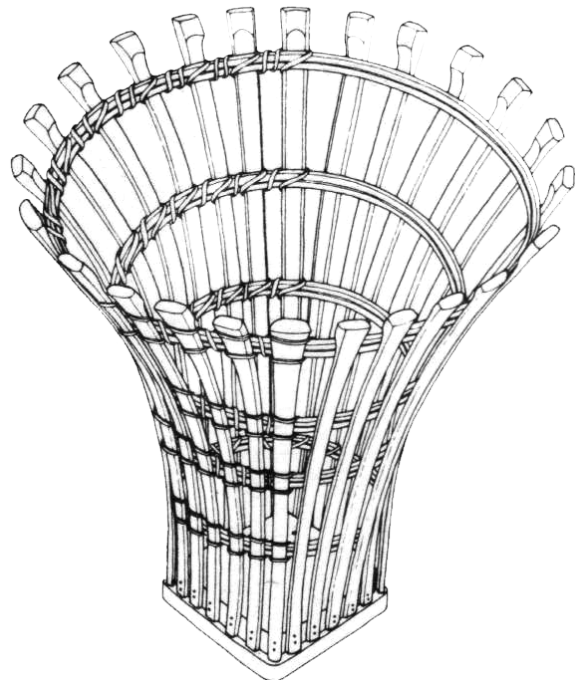


Fig.14. Mould made of bamboo slates

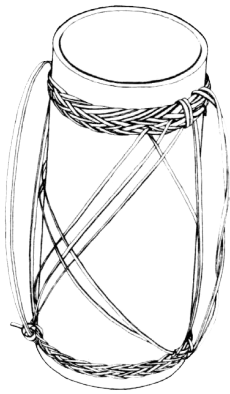


Fig.11. Diagram of Chang naga mug

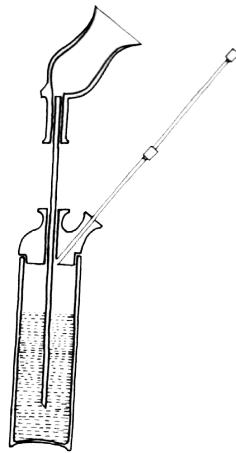


Fig.12. Sectional View of the Tuibur

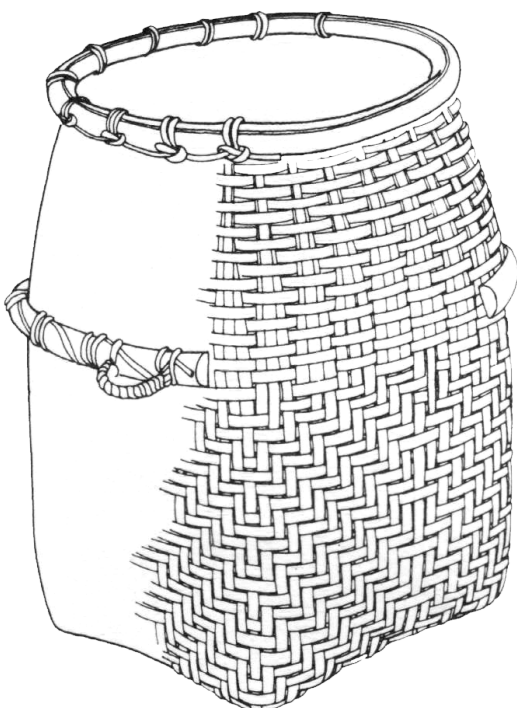


Fig.13. Diagram of Heding Basket

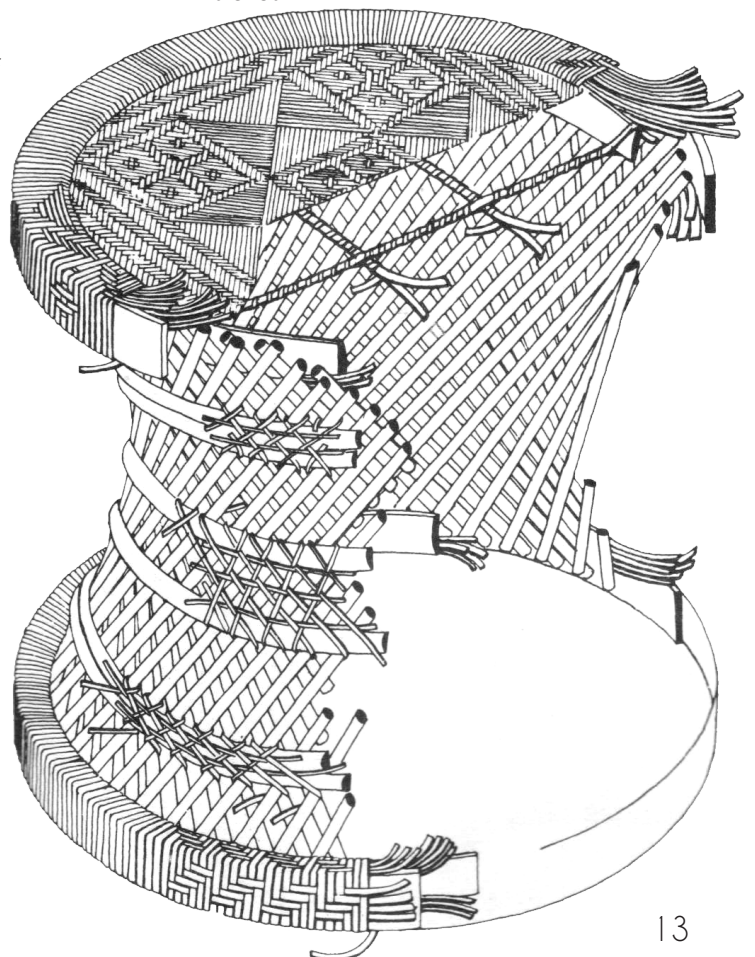


Fig.15. Diagram Showing Construction of Mudah

Life & Bamboo



Fig.16. Bamboo Baskets

"In 1882 Thomas Edison was beginning a light bulb factory the world's first using filaments of bamboo."

Reference

Web:

<http://www.guadubamboo.com/uses-of-bamboo.html>

<http://www.organicjewelry.com/bamboo.html>



Fig.17. Bamboo Jewellery



Fig.18. Bamboo Tea Cup



Fig.19. Bamboo Torches



Fig.20. Bamboo Bicycle



Fig.21. Bamboo Planters



Fig.22. Bamboo Flute

3. Bamboo as a Material

Bamboo is a versatile, strong, renewable and environmentally friendly material. A member of the grass family, subfamily Bambusoideae, it is the fastest growing woody plant producing a mature fiber for use within three years. There are more than 1200 species and 75 genera (Tewari 1993) of bamboo of which 130 are found in India.

Bamboo has been used since 3500 BC and has more than 1500 documented uses. Bamboo is capable of providing solutions for shelter, livelihood, and food security for regions where bamboo grows. They also provide ecological security by timber substitution and efficient carbon sinks.

However bamboo is subject to attack by fungi and insects and untreated bamboo have a life expectancy of not more than five years. The physical and mechanical properties of bamboo are subjected to a greater variability determined by culm height, topography and climate under which the bamboo has grown. Fire presents a potential hazard in any form of construction, but the risk is especially high in bamboo buildings. The combination of bamboo and matting and the tendency of the internodes to burst cause rapid spread of fire. The risk is increased when the joint lashing is destroyed which can cause the building to collapse.

Bamboo is an extremely strong fiber with twice the compressive strength of concrete, and roughly the same strength to weight ratio of steel in tension. In addition, testing has shown that the shape of bamboo is hollow tube gives it a strength factor of 1.9 times over an equivalent solid pole. The reason being that in a beam, the only fibers doing the work are those in the very top (compression) and bottom (tension). The rest of the mass is dead weight. The strongest bamboo fibers have a greater sheer resistance than structural woods, and they take much longer to come to ultimate failure. (Ref: Building with Bamboo, Darrel DeBoer). The structural advantages of bamboo are its strength and light weight whereby properly constructed bamboo buildings are inherently resistant to wind and earthquakes

“Barn swallows and other species built mud shelters reinforced with twigs and fibers. Wattle, daub, and reinforced concrete are recent evolutions of an ancient technology.”

Reference

Book : Building With Bamboo, NMBA, TIFAC, DST (GoI), New Delhi

Web:

<http://www.bbc.co.uk/news/magazine-17568088>

Species

There are many common species that can be used in construction, including *Bambusa bambos* and *Dendrocalamus strictus*, *Bambusa balcooa*, *Bambusa tulda*, *Dendrocalamus asper* and *Dendrocalamus hamiltonii*.

Bambusa bambos is easily recognized by its curving, spreading branches covered in spines, usually in threes. *Dendrocalamus strictus* is also a distinctive bamboo, being smaller in diameter and often solid.

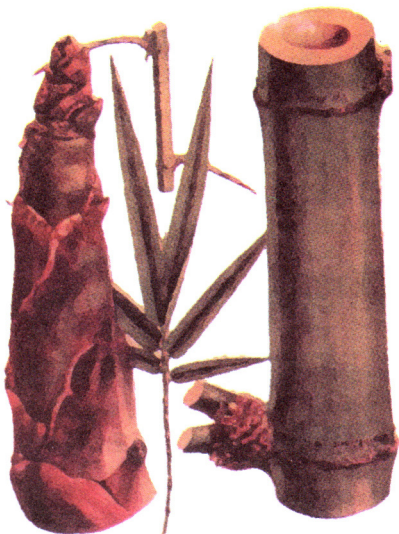


Fig.23. *Bambusa bambos* (spiny bamboo)



Fig.24. *Dendrocalamus strictus* (male bamboo)

Colour	Bright shiny green when fresh, yellow with age
Height	15-30 m
Shape	Curving culms
Diameter	up to 150 mm
Internodes	200 - 400 mm
Thickness	Thick-walled

Colour	Pale blue-green when fresh, dull green to yellow with age
Height	8-16 m
Shape	Curving culms above mid-height
Diameter	25-80 mm
Internodes	300 - 450 mm
Thickness	Thick-walled, often solid

Harvesting & Selection

Harvesting Bamboo

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

Do not cut culms younger than three years.

Do not harvest in the rainy season. In India it is advisable to harvest in the winter season when the soluble sugars are the lowest (Joseph 1958).

Do not harvest from a flowering grove.

Do not cut lower than the second node, or higher than 300mm above the ground.

Remove branches, culm tips, and all harvest debris. Waste material obstructs growth, encourages disease and makes later harvests more difficult.

Retain leaves for mulch. Their 6% silica helps harden later culms.

Leave a minimum of six mature culms uncut in each clump to sustain grove vitality and ensure a steady yield. As new culms grow around the edge a solution is to use the horse-shoe method by cutting a narrow path into the grove and harvest the mature culms from within.

The best natural protection will result by harvesting mature culms during the winter months, leaving them upright for a few days after harvesting and then soaking them in water for 4-12 weeks.

“Soil quality materially influences texture of bamboo. In Japan, a particular mountainside reputedly produces the hardest, flintiest bamboo in the country.”

Reference

Book :Building With Bamboo,NMBA, TIFAC, DST (GoI), New Delhi

Web:

<http://bambus.rwth-aachen.de/eng/PDF-Files/Bamboo%20as%20a%20building%20material.pdf>

Grading of bamboo

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

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

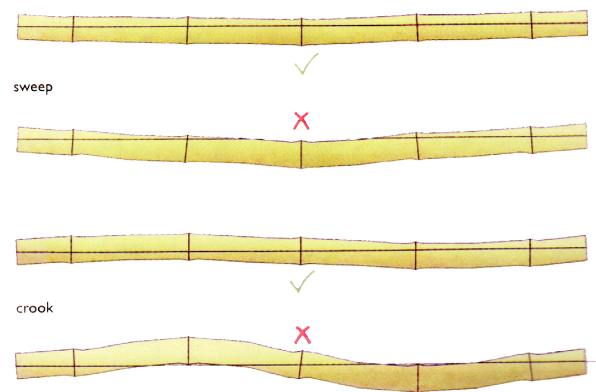


Fig.25.

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

Nodes- nodes are the strong points in the culm and should be used to advantage especially at critical joints. (Follow details as given in drawings).

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

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

Selection and Size of Bamboo

Only bamboos with at least three-year maturity shall be used in construction.

For the main structural elements of the house particularly posts and beams, Bambusa Balcoa or similar in the region can be used.

For roofing elements like rafters and purlins Bambusa Tulda or Bambusa Balcoa or similar in the can be used.

Bambusa Nutans or other bamboos shall be used for the lattice work in wattle and daub walls.

Columns and roof members should be a minimum of 70-100 mm in diameter at thin end of bamboo and wall thickness of bamboo not less than 10-12 mm. The distance between nodes (internodes length) should not exceed 300-600 mm.

4. Joinery

Tool

Bamboo is generally used as it is in required length or in split form. Traditionally this task is performed by only one tool. Though there are few carpentry tools that can be used for different purposes. Usually, below shown traditional tools are used by bamboo artisan for harvesting and construction.

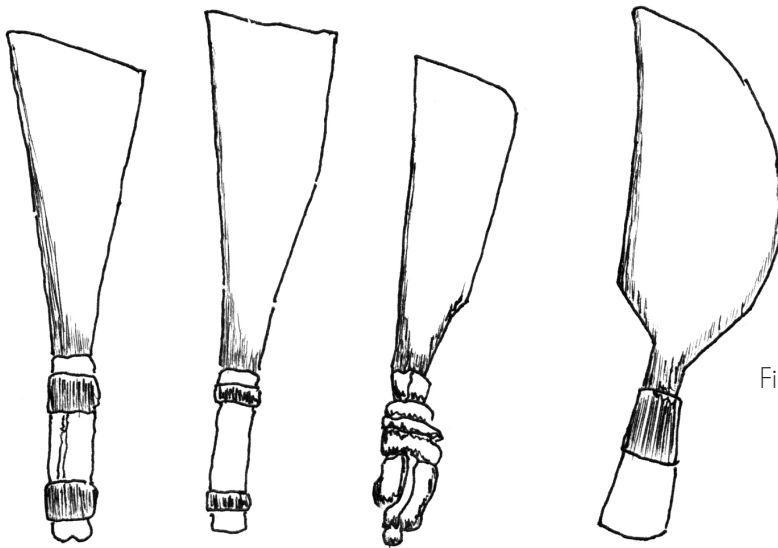


Fig.26. Traditional Tools (Dabiya)

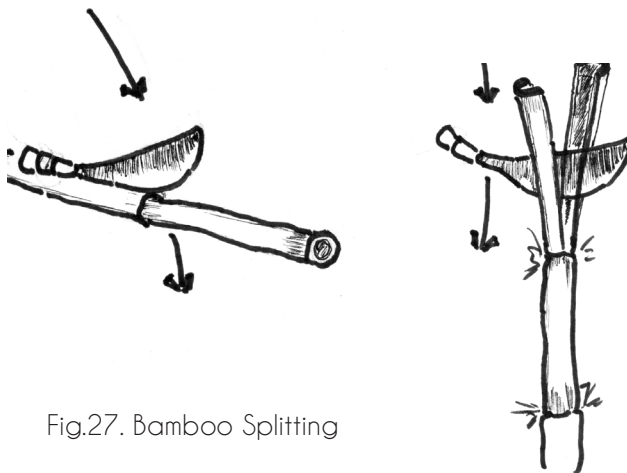


Fig.27. Bamboo Splitting

“The Chinese bamboo tub and bucket maker requires some thirty different tools and gadgets to measure, cut, fit, and assemble his wares. Buy tools as the project requires. Begin simply. Make your own.”

Reference

Web: <http://www.inbar.int/publications/?category=2>

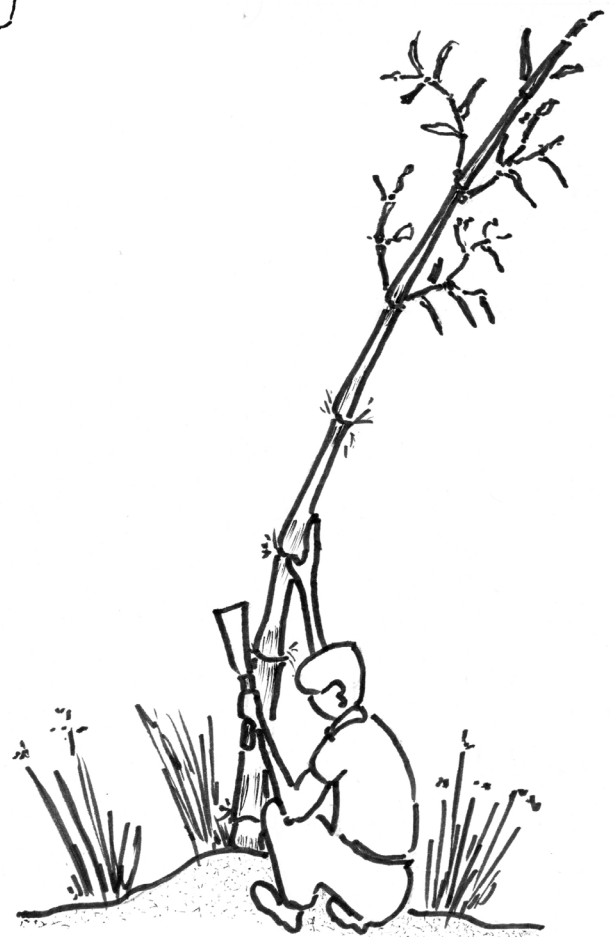


Fig.28. Bamboo Plant Cutting

Joinery of Bamboo

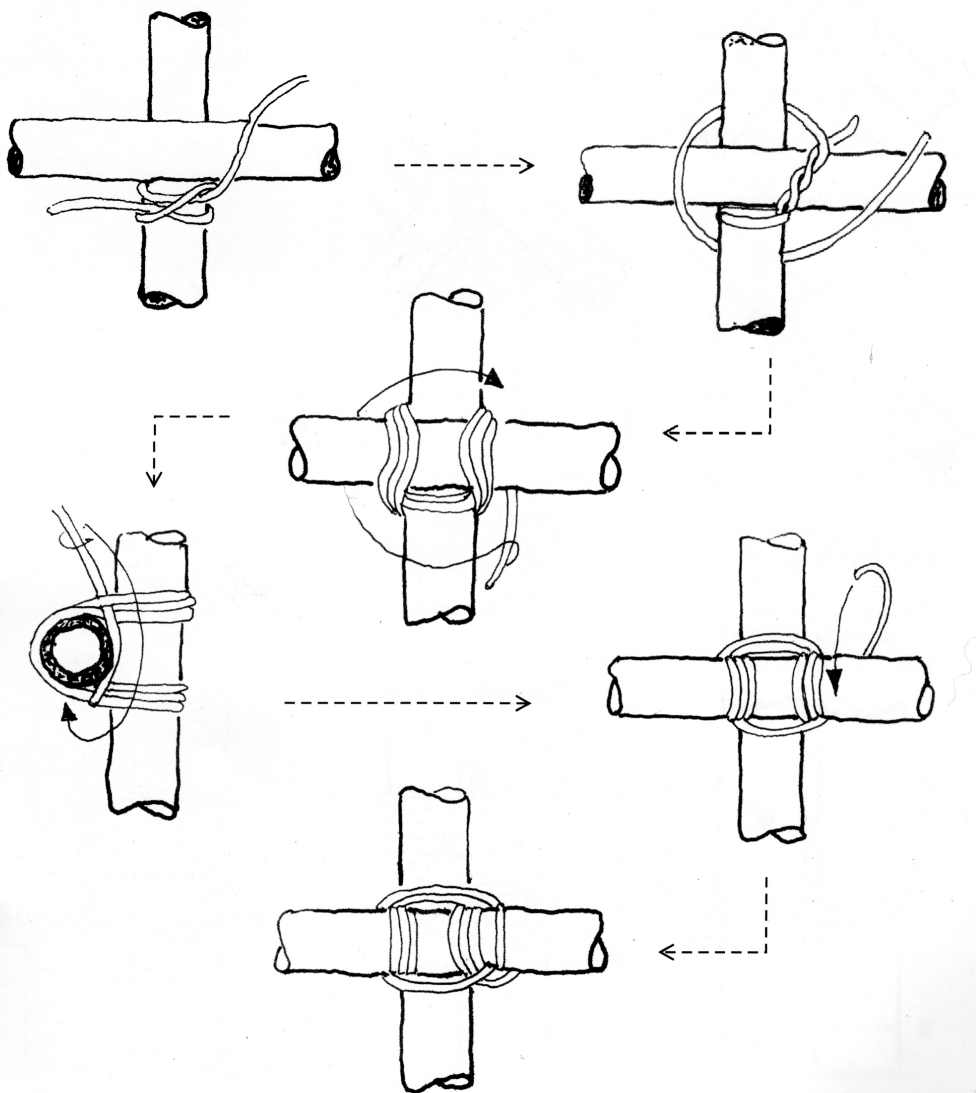
All the joinery in the structure is based on four types of lashing and three types of shear keys. The following terminologies will describe the joinery.

Lashing: Lashing is used for joining two or more poles together with a tying material.

Wrap: A wrap is a turn around two or more poles.

Frap: A frap is turn made between two poles to pull the wrap together.

Dowel: Dowel is a pin (wood or bamboo with fibers in longitudinal direction) of 10 mm. Diameter inserted right through the pole



Clove Hitch: Clove hitch lashing is used for joining two or more poles together with a tying material.

Square Lashing: Square lashing shall begin and end in a clove hitch. It shall be used in a condition where there is no tendency for poles to spring apart.

Fig.29. Square Lashing

Joinery

Diagonal Lashing: The square lashing shall begin and end in a clove hitch. It shall be used in condition where there is tendency for poles to spring apart.

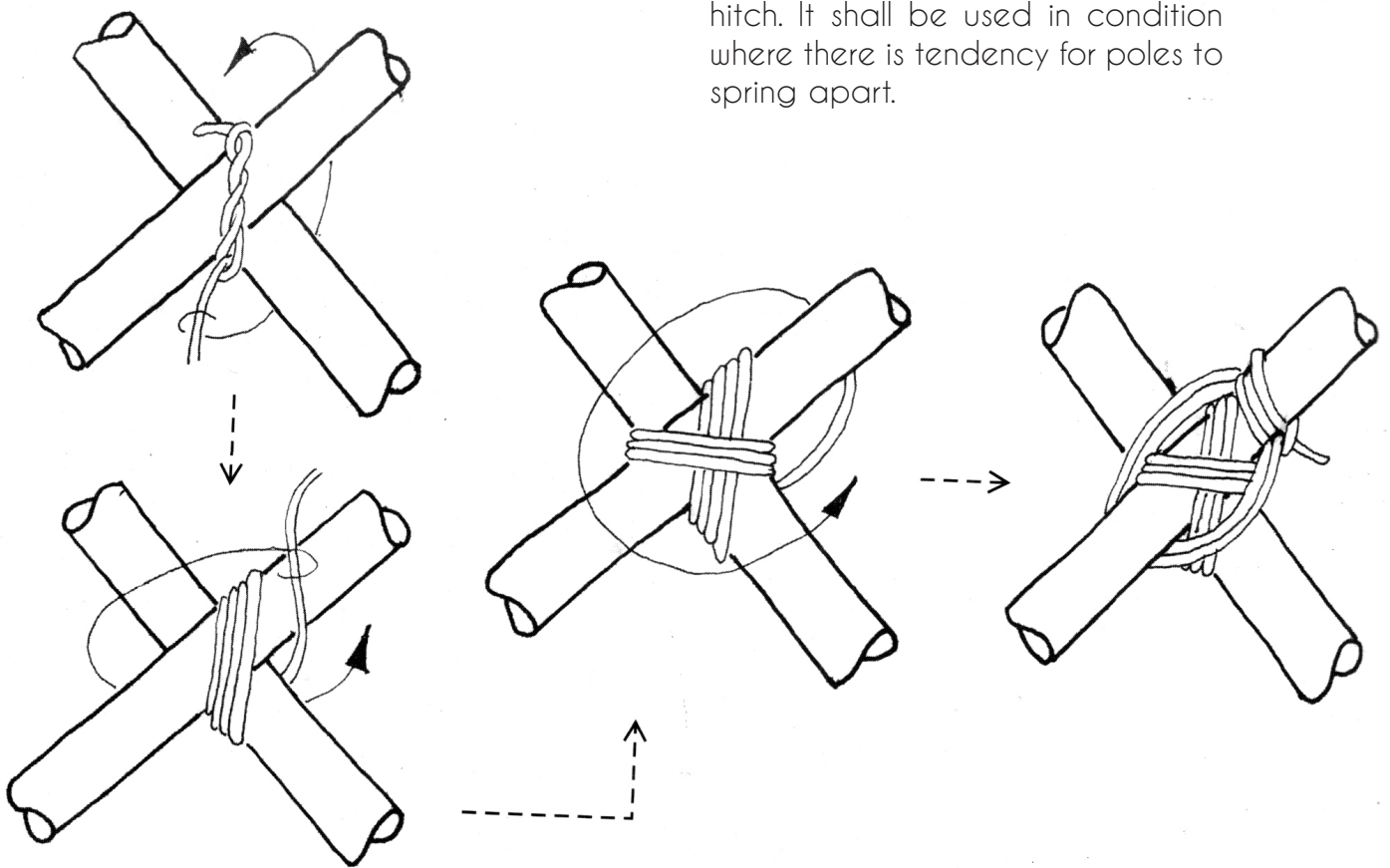
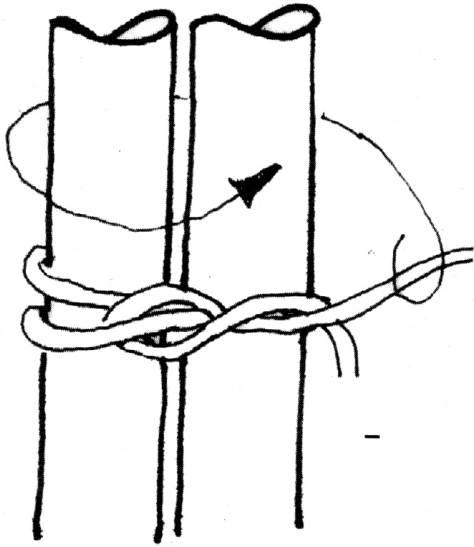


Fig.30. Diagonal Lashing

“Bamboo is unique in that it is strong in both tension and compression. While tensile strength remains the same throughout the edge of the bamboo plant, compressive strength increases as it gets older.”

Reference

Book : B.A.P.E.P.S Government of Bihar,India, Re-construction of Multi-Hazard Resistant house, Part-II Technical Guideline For Bamboo base construction



Shear Lashing: A shear lashing shall begin and end with a clove hitch. Two or more poles shall be first wrapped and then frapped to tighten the poles together.

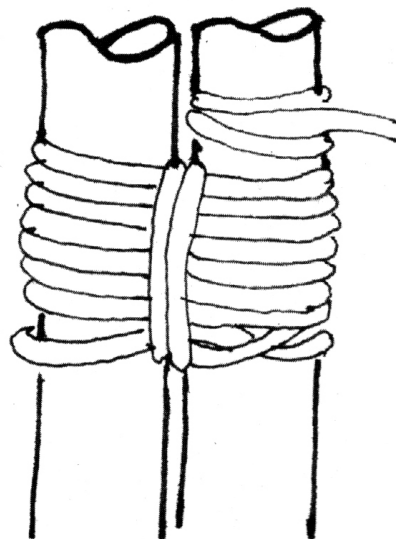
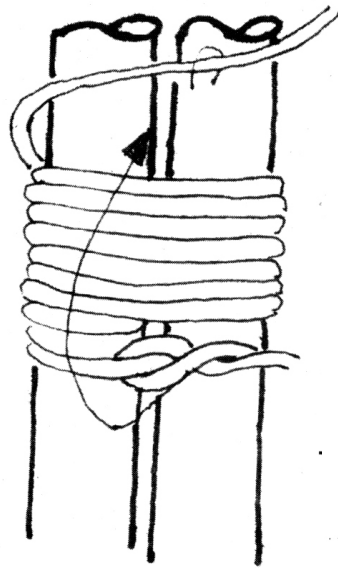


Fig. 31. Shear Lashing

Joinery

Avoid the crushing of horizontal Members

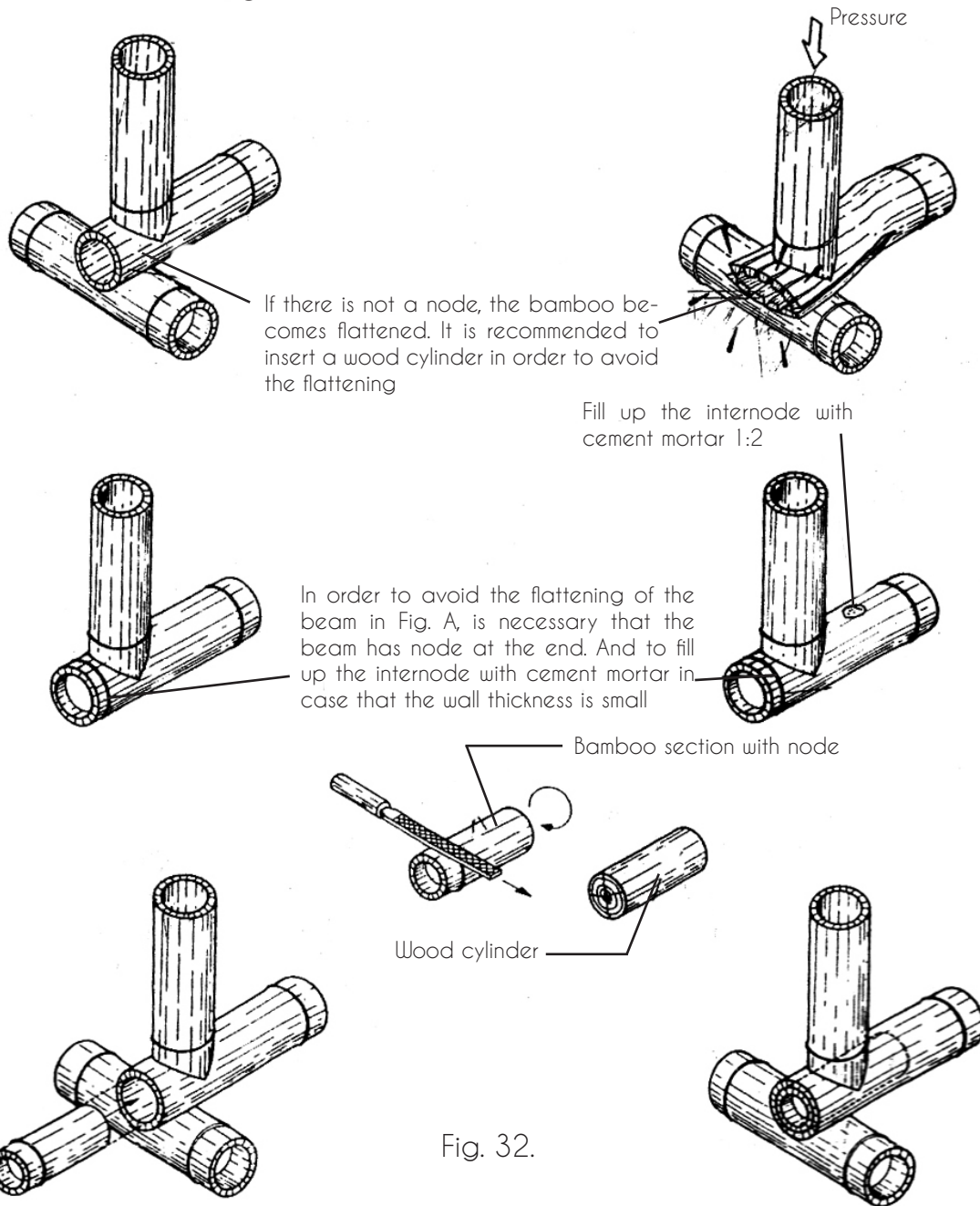


Fig. 32.

"Bamboo is extremely flexible from 6-12 months of age, it can be used to create a number of curving forms."

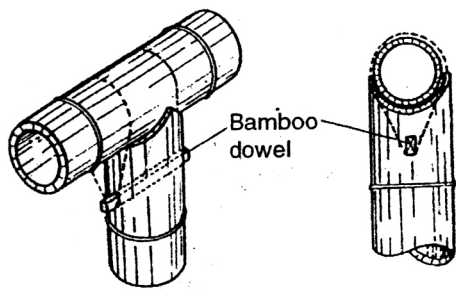
Reference

Book : Oscar Hindalco-Lopez (2003), Bamboo The Gift Of The Goods, By D'vinni LTDA.

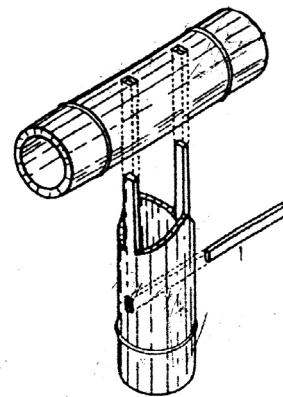
Web:

<http://www.guaduibamboo.com/bamboo-joinery.html>

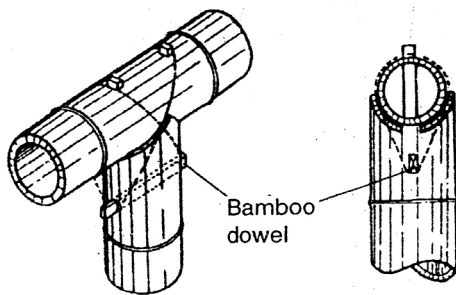
Fixing Horizontal And Vertical Members With Pins And Bolts



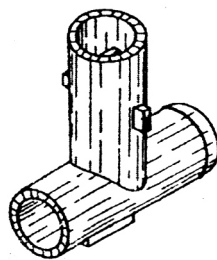
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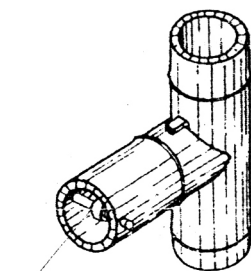
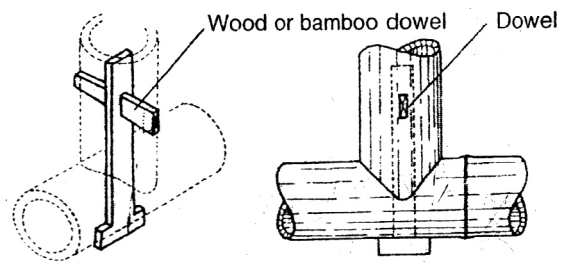
Detail No.2



Detail No.3



Detail No.4



Detail No.5

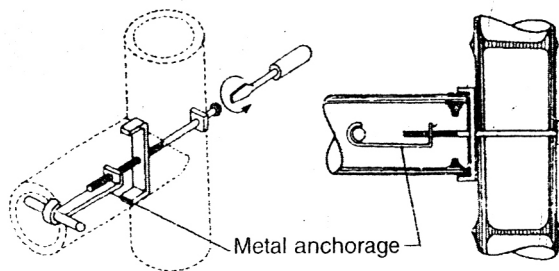
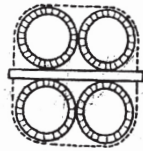
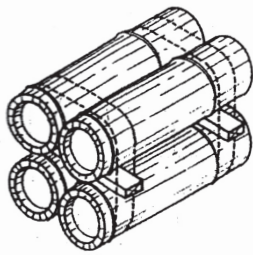
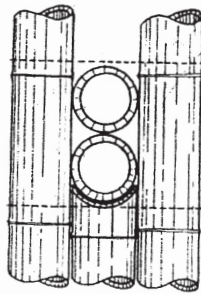
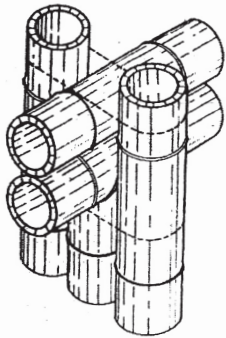


Fig. 33.

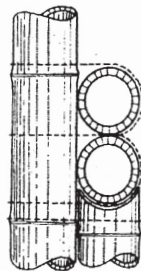
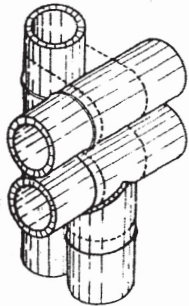
Double And Quadruple Beams - Support



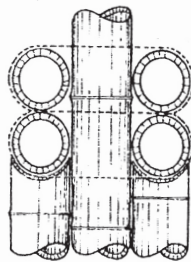
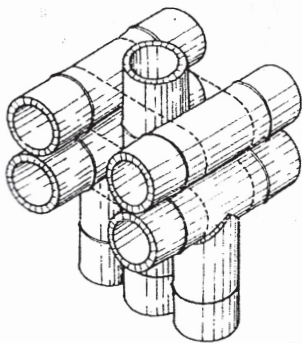
Detail No.1



Detail No.2



Detail No.3



Detail No.4

Fig. 34.

Reference

Book : B.A.P.E.P.S Government of Bihar,India, Re-construction of Multi-Hazard Resistant house, Part-II Technical Guideline For Bamboo base construction

Simple Single Beam Examples



Fig. 35.



Fig. 36.

5. Bamboo Treatment for Longer Life Of Shelter

Bamboo has very little natural toxicity and therefore, is easily prone to fungi and insect attack. The objective of treatment is to remove the starch and other carbohydrates (soluble sugars) that attract fungi and insects and replace it with chemicals in the cells of the bamboo thereby increasing the life of the bamboo. Well treated bamboo has a life expectancy of 50 years without losing its structural properties. The efficiency of the chemical treatment is influenced by anatomical structure of the bamboo culm. There are no radial pathways in the culm tissue, like the ray cells in wood, and lateral cell-to-cell movement of preservative depends on a slow diffusion process. Freshly cut culms are easier to treat due to the water-filled cells providing a continuous transportation channel. Both ends of the culms should be cut up to the next node in order to remove the blockage of vessels.

Whereas there are several indigenous treatment systems like limewash and smoking of bamboo, chemical treatments are known to have longer effect against fungi and insects. The use of water as a solvent to carry the preservatives into the cells of the bamboo. Water-soluble salts are dissolved in water, on treatment the water evaporates leaving the salts inside the bamboo. The recommended salts are boric acid, borax and copper sulphate. Boron salts are effective against borers, termites and fungi (except soft rot fungi). High concentrations of salts have fire retardant properties as well. They are not toxic.

Bamboo cut with moon on wane
Will ensure financial gain
But beetles bore it very soon
If cut upon the waxing moon
Moreover its a well known fact
That ripe bamboo is less attacked
So say the chaops who ought to know-
About it really is not so.
For science reared its ugly head
And knocked these superstitions dead.
The lunar myth is utter tripe
And borers like their bamboo rise.

Necessary Tools Required for Bamboo Treatment

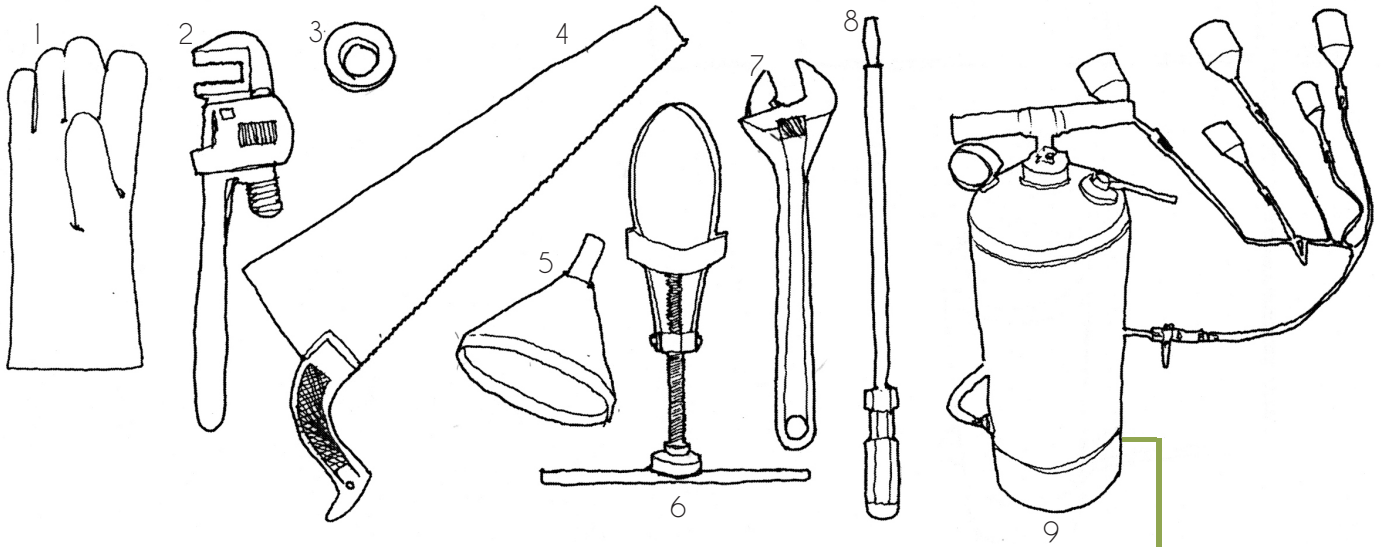
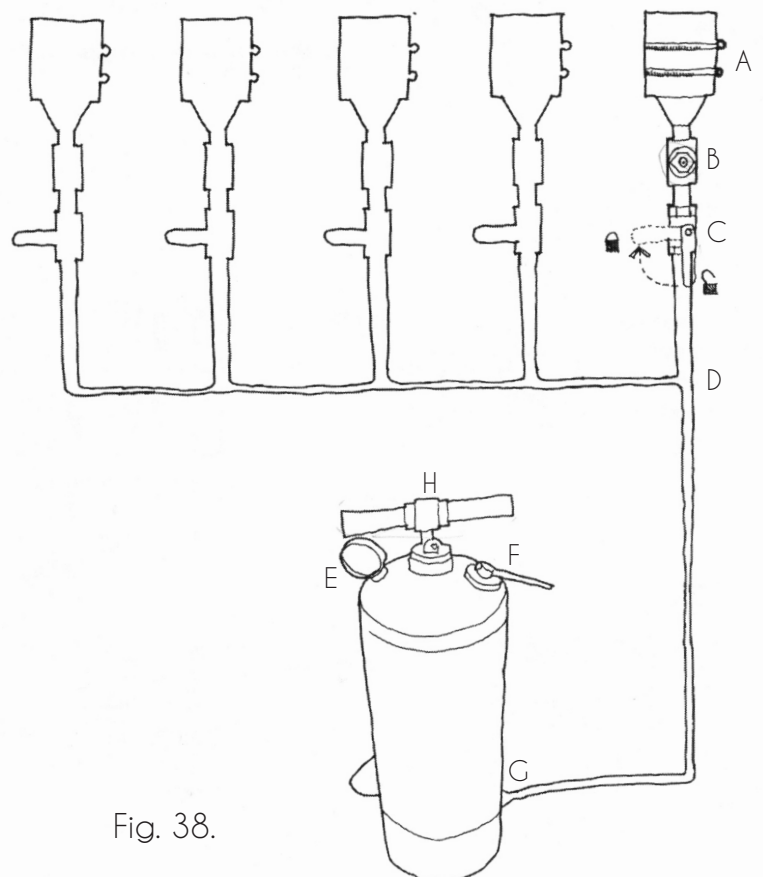


Fig. 37.

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

Hand Operated Pump Detail



- A. Nozzle connection bamboo with envelop
- B. Pressure Regulator
- C. Solution regulator
- D. Hose pipe
- E. Pressure gauge
- F. Solution Input
- G. Solution outlet
- H. Handle for pumping

Fig. 38.

Bamboo Treatment Step by Step

Fill up the Pump
Fill up the Pump Cylinder up to 3/4 with Borax / Boric Acid Solution using a funnel



Fig. 39.

Prepare Bamboo
Make a fresh cut on the bamboo with the Hardwood back saw about 10 cm away from the node.

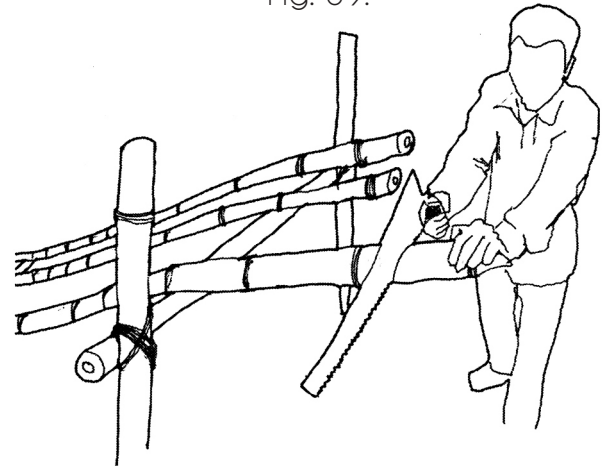


Fig. 40.

Place firstly the clamp and then the Hose Nozzle.

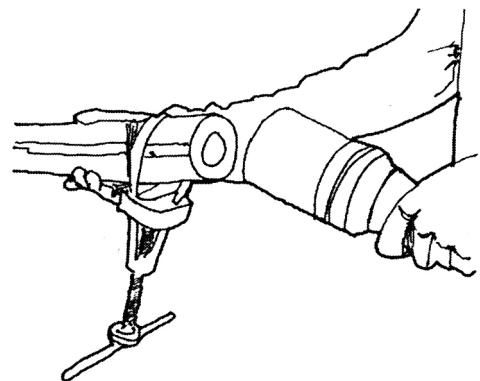


Fig. 41.

Reference

Book : Zahara Childre Centre (ZCC) Building Manual

Web:

<http://www.inbar.int/publications/?did=71>

<http://bambootech.org/files/PRESERVATION%20BOOK.pdf>

Tighten the clamp so that the Nozzle becomes air tight.

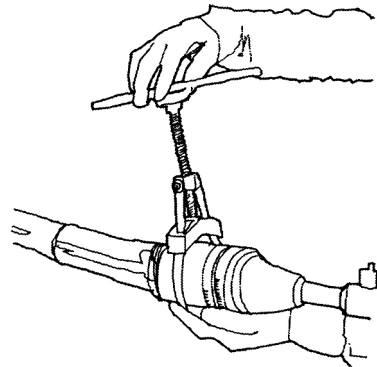
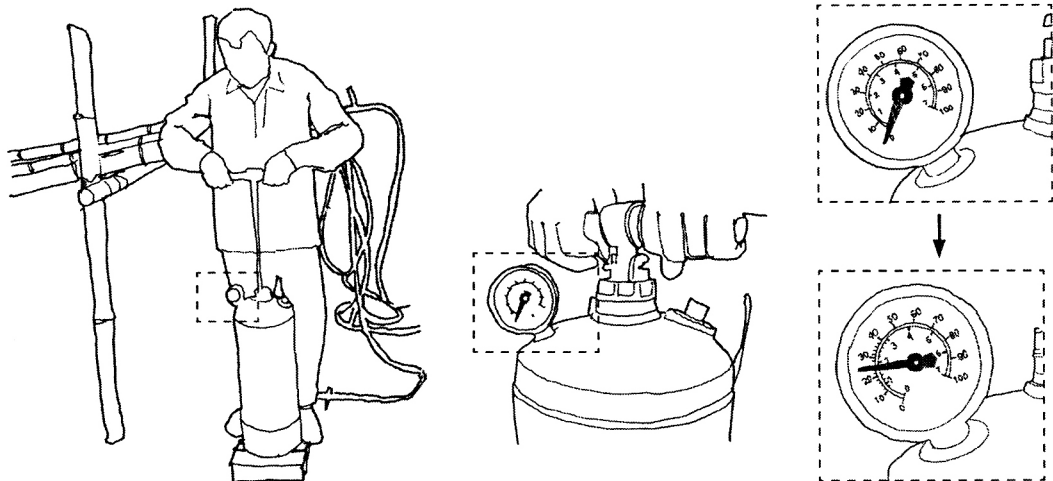


Fig. 42.



Pump until the pressure is between 20-25 psi.

Fig. 43.

Repeat the process to all the available hoses.

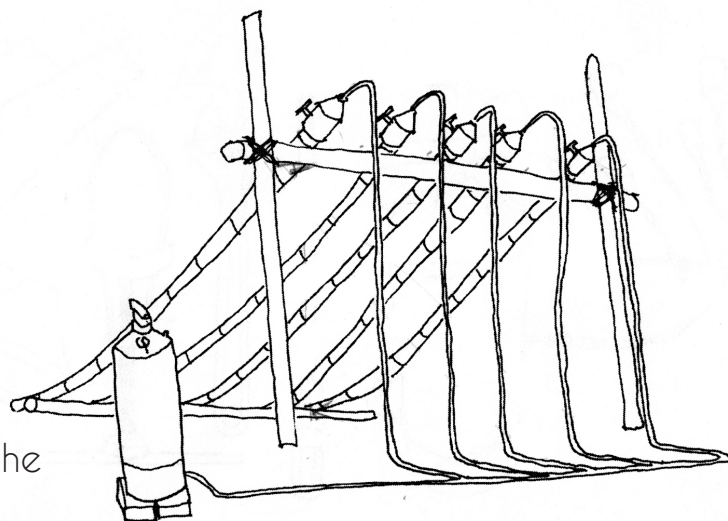
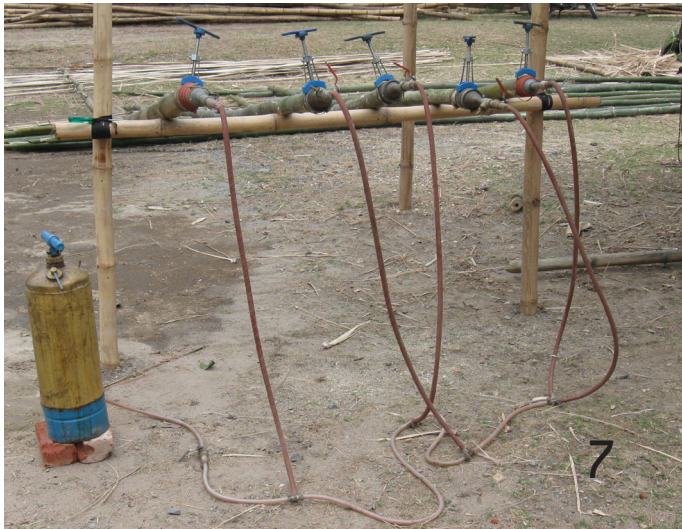


Fig. 44.

Steps of Bamboo Treatment



Chemical for Treatment

For treatment of Bamboo total chemical should be used at 5% of total desolve chemical.

Example: For 14 Litre capicity of pump chemical to be used 700 Grams.

For Structural Bamboo for pole, beam etc Boric acid, Copper sulphate and so-dium or potesium dicromate to be used in proporstion of 1.5:3:4 i.e. for 14 litre of tank



Sodium Dichromate + Copper Sulphate + Boric Acid
325 gm. 250 gm. 125 gm.

= 700 gm.

Reference

Book : B.A.P.E.P.S Government of Bihar,India, Re-
construction of Multi-Hazard Resistant house, Part-II
Technical Guideline For Bamboo base construction

Web:

<http://www.inbar.int/publications/?did=71>



Fig. 45. Sequence of Bamboo Treatment

For Non Structural member like, wall lattice, Splits Boric acid and Borex to be used in 1:1.5: Proportion. i.e. for 14 liter of tank



Borex
420 gm.



+ Boric Acid
280 gm.

= 700 gm.



6. Building Systems & Components

Consideration for Site Selection

We like to share construction method adopted in the context of Kosi Flood Rehabilitation work in Bihar with appropriation one can adopt this in to their context, part or whole.

The site should be chosen on high enough ground, wherever possible, above the normal annual average flood level in the area. Where it is not feasible the height of the plinth is to be at least 150 mm above the normal annual average flood level. After construction of plinth, if required, the land around can be raised by filling soil.

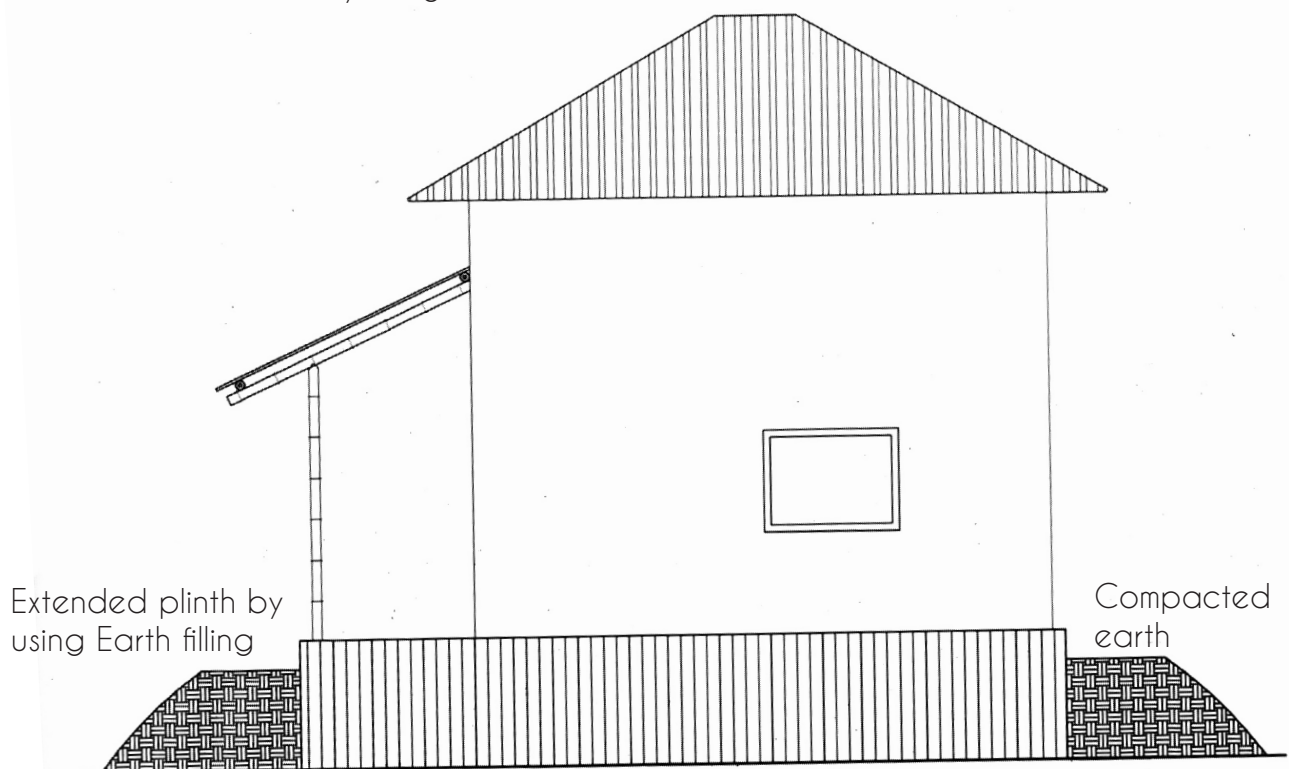


Fig.46. Raising and extending plinth by earth filling

“The system offers traditional materials in a modern engineering context. The result is homely, with the feel of permanence”

Web:
<http://www.bamboocomposites.com/bamboo%20based%20housing%20system.htm>

Foundation and Plinth

The practice of putting bamboo post directly in the ground shall not be permitted. Bamboo posts shall be fixed into the plinth. (See in chapter 7)

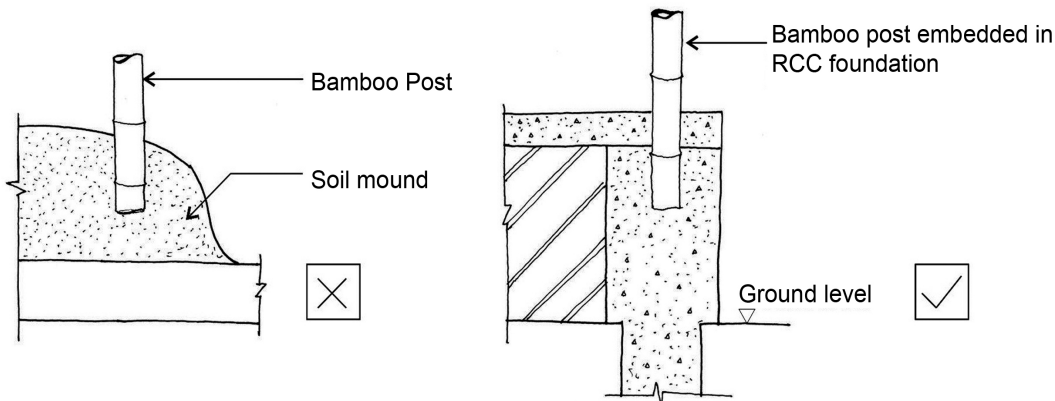
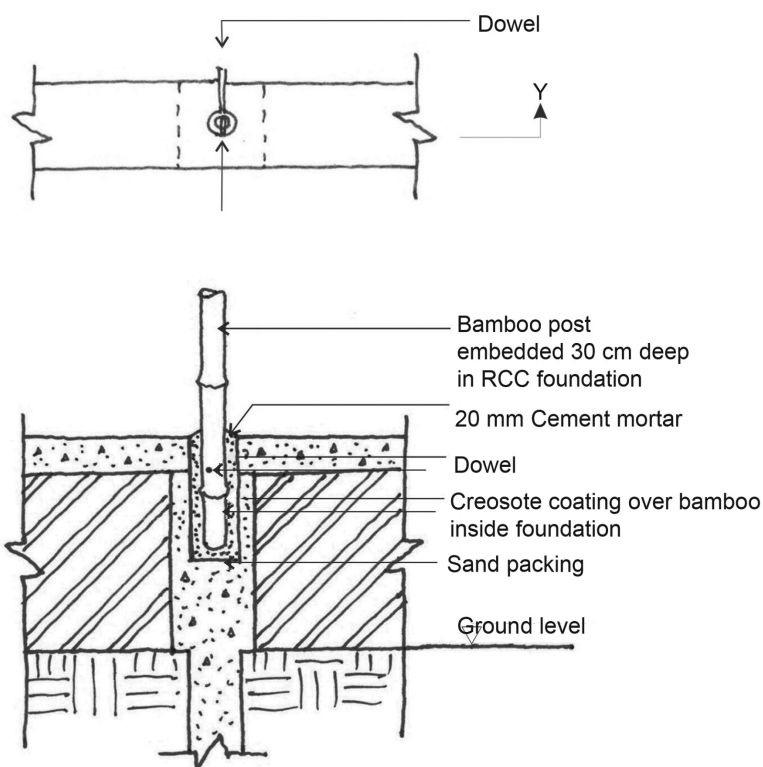


Fig.47. Fixing bamboo into plinth



Section Y-Y

Fig.48. Fixing detail of bamboo post into plinth masonry

The distance between two pedestal footings/ Piles shall not be more than 2.0 m for bamboo based superstructure.

Minimum diameter of bamboo posts at thinner and shall not be less than 70 mm.

Unsupported height of the post shall not be more than 3.0 m. if the height of the post is longer, a horizontal tie of bamboo shall be provided.

Tar or Creosote treatment at the bottom of the post is required that needs to be embedded in the plinth.

A 300 mm deep and 100mm diameter hole shall be made in the plinth beam and the foundation pile/pier below to embed and fix the bamboo post. The post shall be erected in this hole and clean sand shall be filled and compacted around the post in the hole. A shear key of split bamboo shall be fixed through the plinth beam and the bamboo post

Foundation & Plinth

Alternatively, the bamboo post can be fixed with bolts to the plinth. In this case, bolts shall be embedded at appropriate places at the time of casting plinth beam.

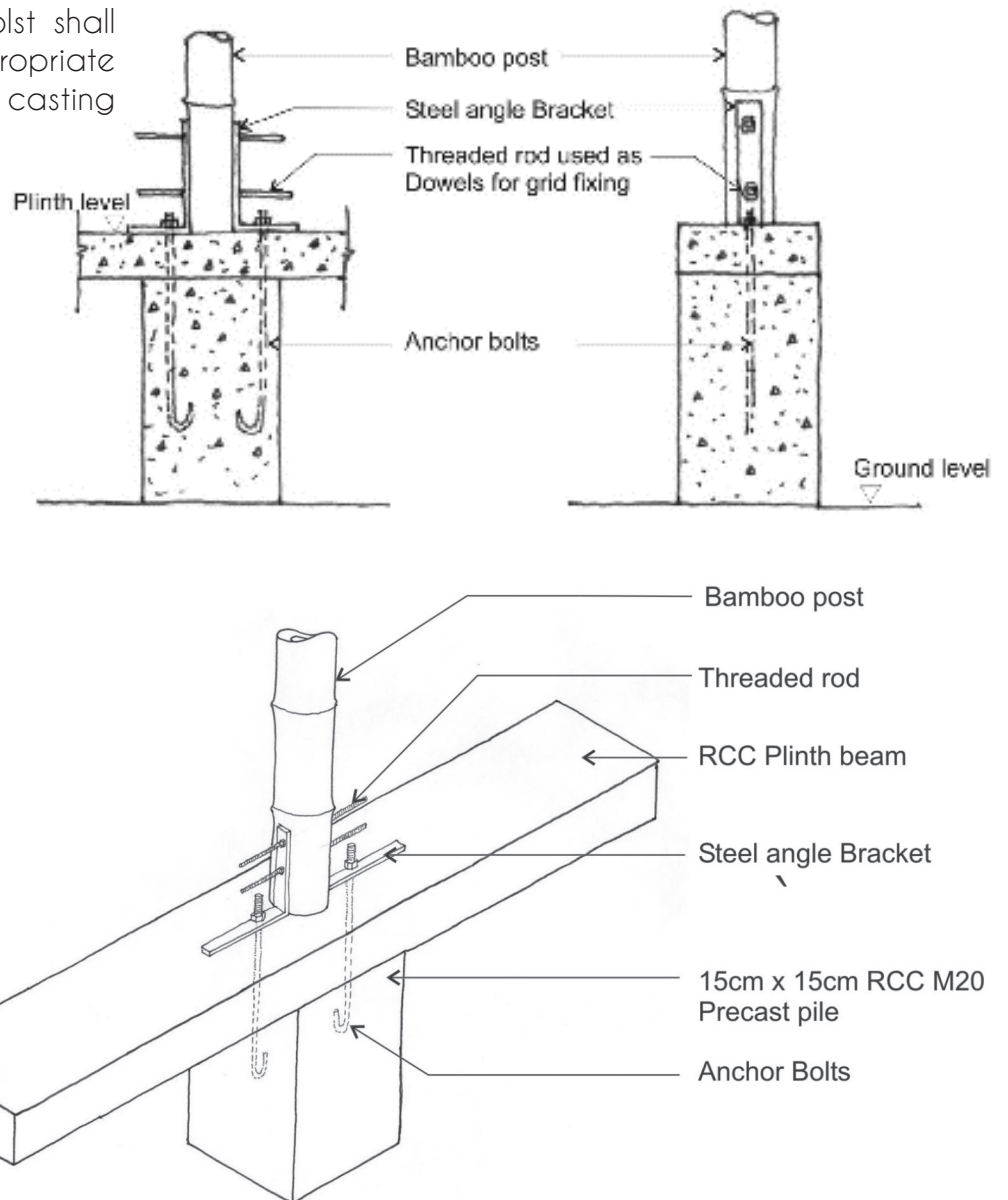


Fig.49. Fixing detail of bamboo to plinth using bolted connection

*“Bamboos , growing thick, standing single-
With all the roots together and all is well;
In the mountains and rivers”*

*- Sengai, 19th century
Japanese Zen master.*

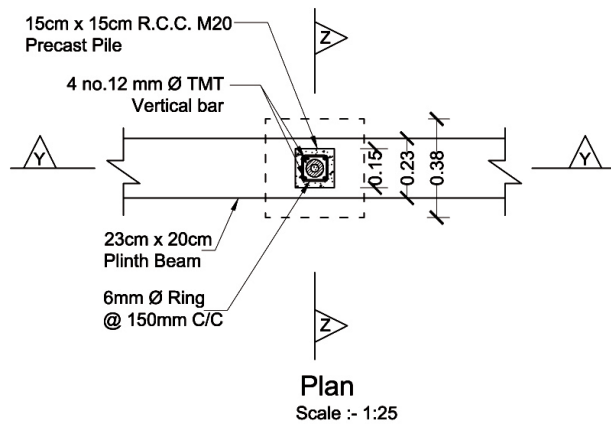
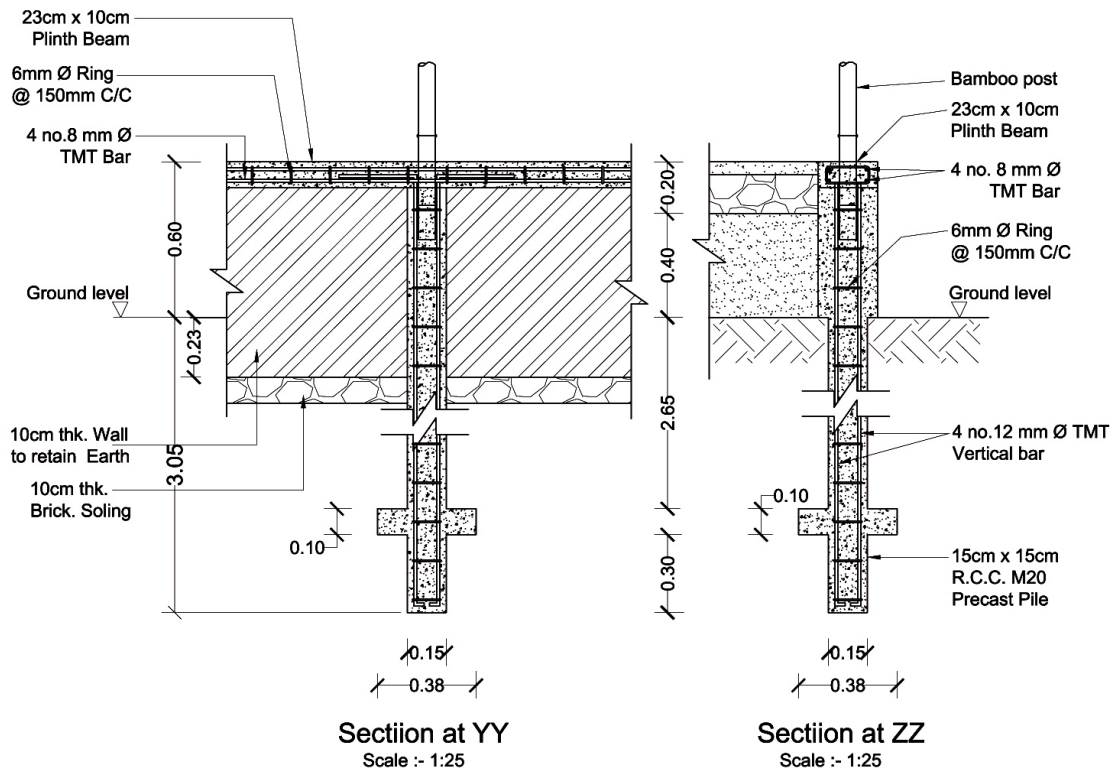


Fig.50. Pile Foundation Detail

Foundation & Plinth



Fig.51. Pile Foundation



Fig.52. Bamboo Fixing at Plinth level

Bamboo is both road and map
where use and beauty overlap
with learning in a roomless school
for the wisest or the fool,
for ancient creeping back to earth
or infants dripping fresh with birth.

Bamboo Superstructure

Bamboo as discussed earlier is prone to fungal and borer attack due to presence of starch. This starch needs to be removed through chemical treatment to ensure longevity of bamboo structures.

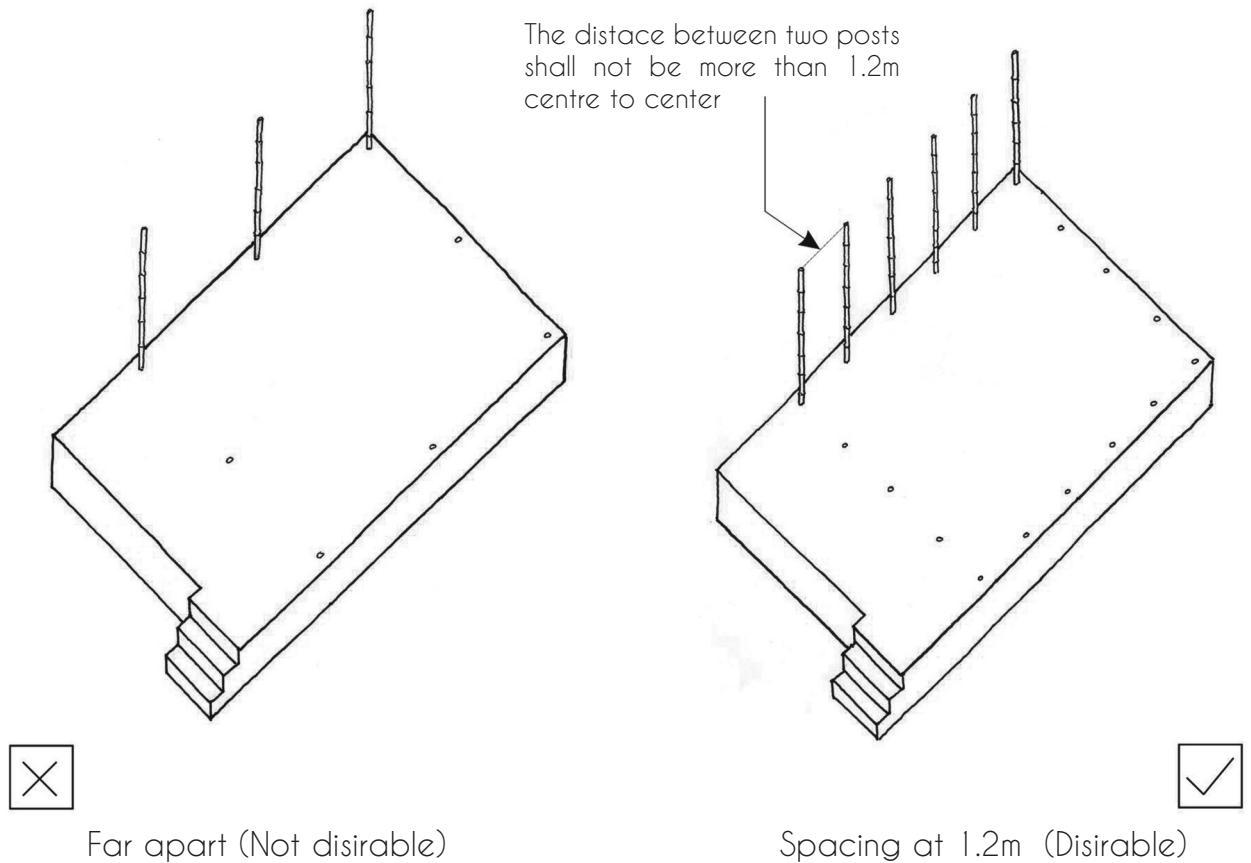


Fig.53

Use only mature Bambusa Balcoa or equivalent variety of bamboo for structural posts and main beams.

All structural bamboo should be treated chemically to conform to IS 9096: 2006

The distance between two posts shall not be more than 1.2m centre to center

Super Structure

Diagonal Bracing

Diagonal bracing between the posts in each wall at the corners from plinth level end to attic level end shall be provided. It shall be mirrored in the opposite corners of the wall.

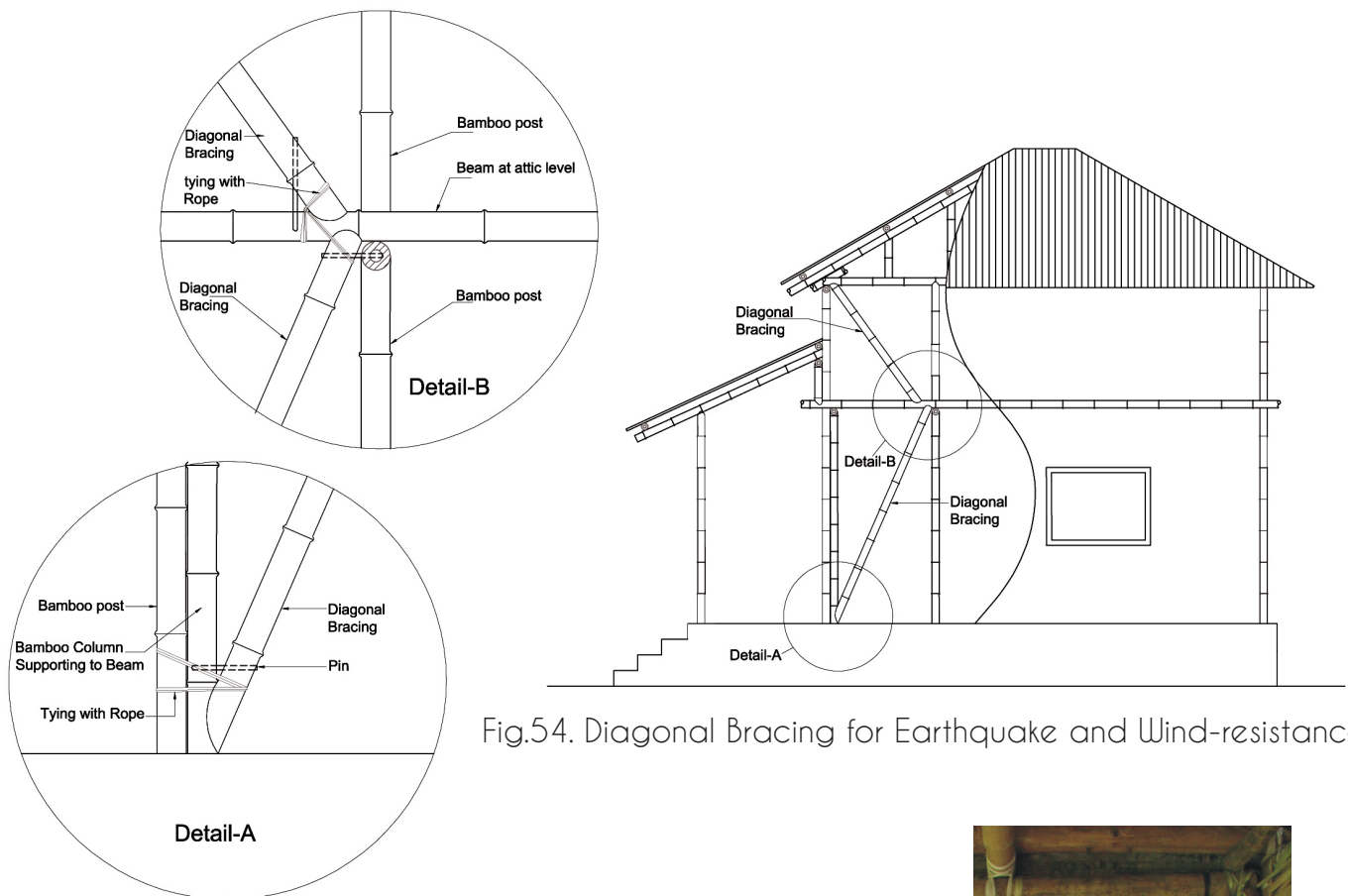


Fig.54. Diagonal Bracing for Earthquake and Wind-resistance

Bridge, baskets, paper, flutes,
In summer, shade, at dinner, shoots-
all from groves whose rhizomes will
mantle an eroded hill.
Count its uses? count instead
fingers of the thankful dead.



Fig.55.

Knee Bracing

Alternatively, knee bracing may be provided at each post to connect post and the attic level beam

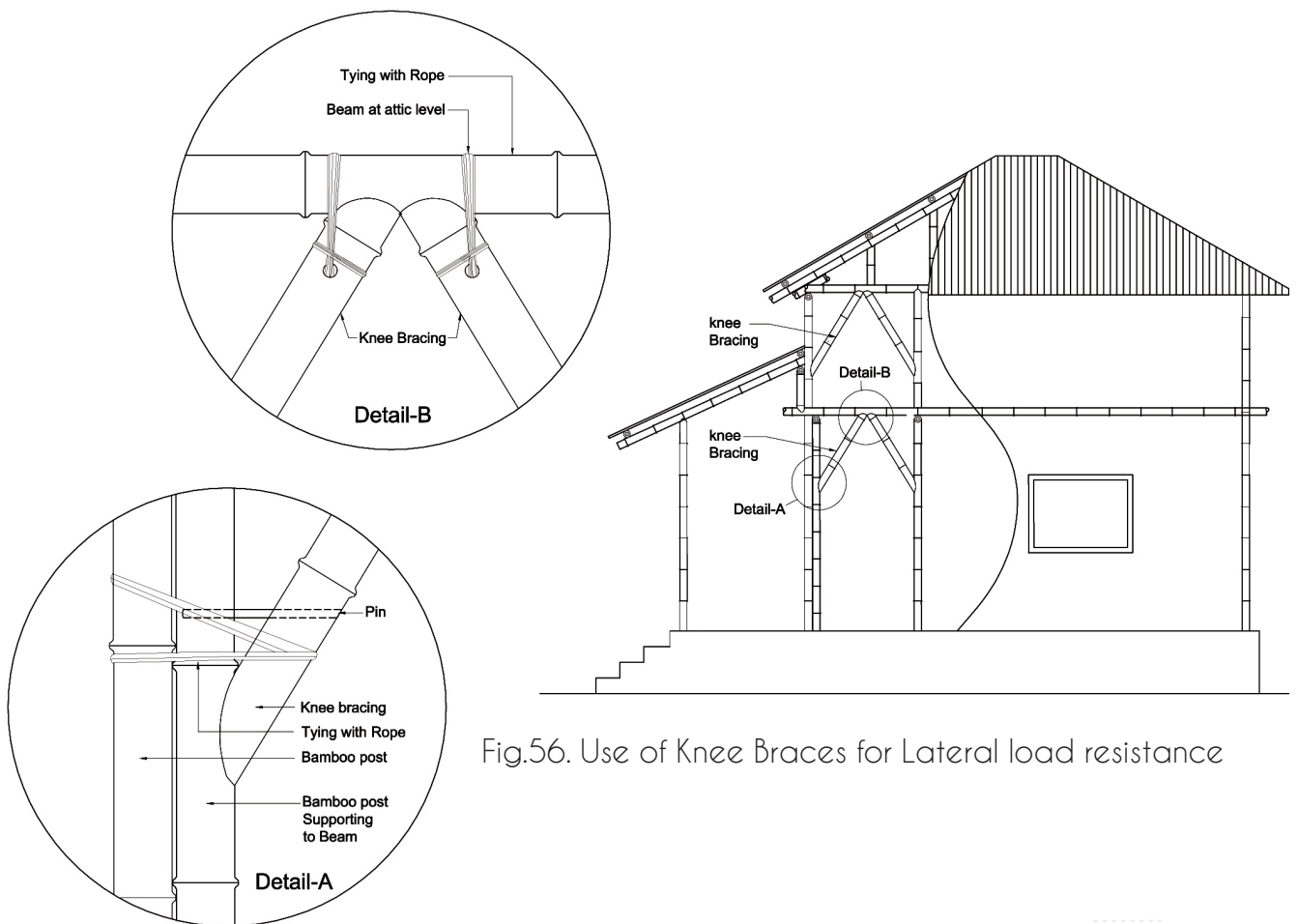


Fig.56. Use of Knee Braces for Lateral load resistance

Super Structure

Wall

Lattice shall be tied properly to the bamboo posts, the attic level or eave level beam depending on the context.

The inside of the wall panel shall be mud/cement plastered while the outside will have to be cement plastered.

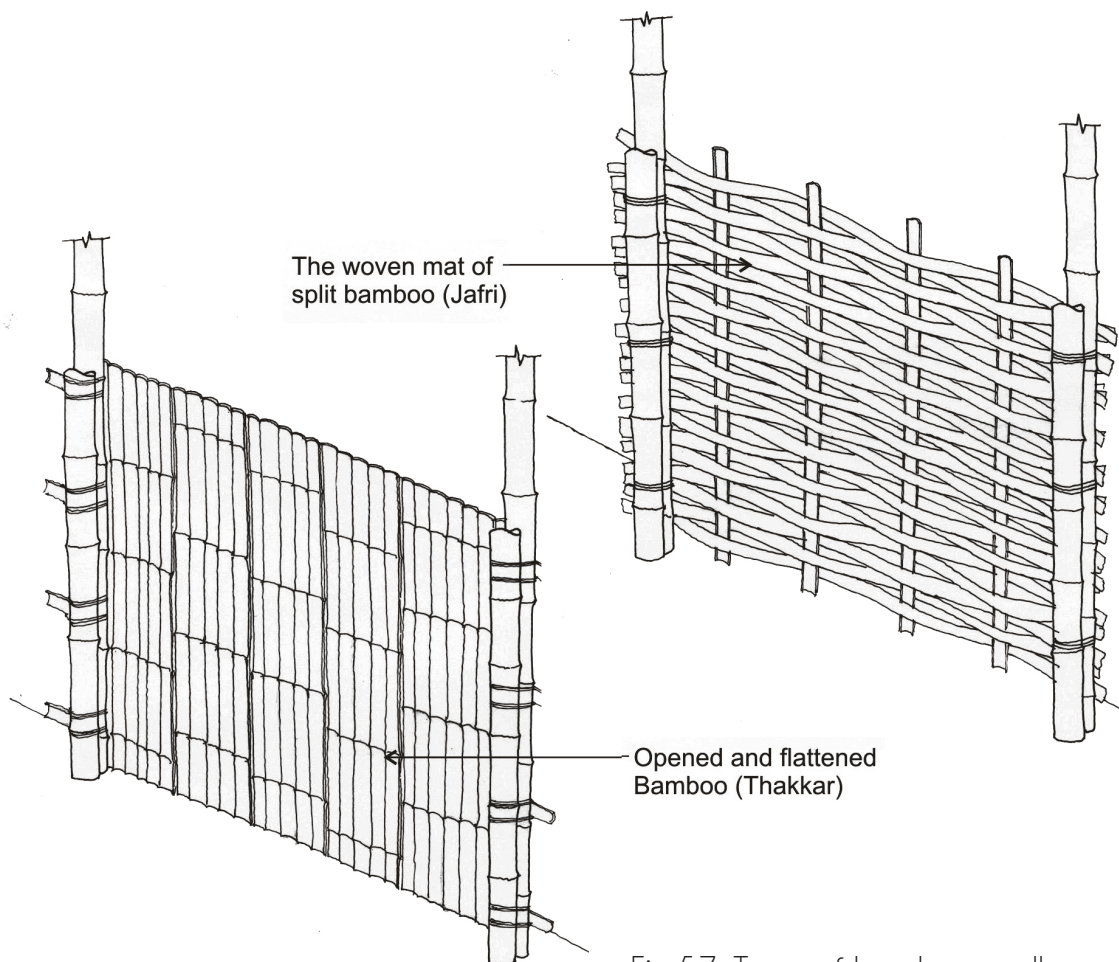


Fig.57. Type of bamboo wall

Reference

Book :
B.A.P.E.P.S Government of Bihar,India, Re-construction of Multi-Hazard Resistant house, Part-II Technical Guideline For Bamboo base construction



Fig.58



Fig.59



Fig.60

Super Structure

Wall

The wall shall be made using wattle and daub technique.

For latticework between the posts, any mature split bamboo shall be used. Traditionally *Bambusa Tulda* is used mor often.

The bamboo strips shall be coarsely woven (vertical weft and horizontal warp). A maximum of two bamboo splits can be used as warp or weft.

This bamboo shall be treated as per the IS 1902: 2006 recommendations for non-structural bamboo (see Annexure B)

For lattice, Jafri(The woven mat of split bamboo) may be used. This provides skeleton for daub work.

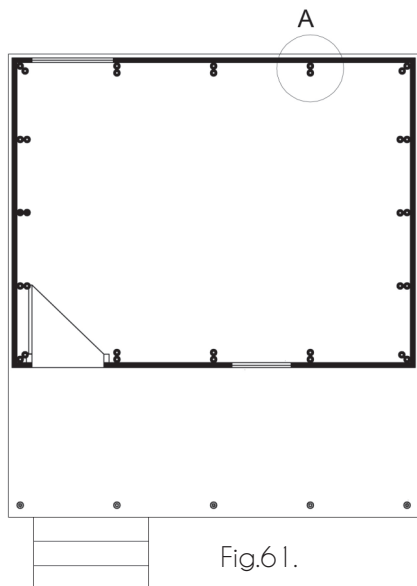


Fig.61.

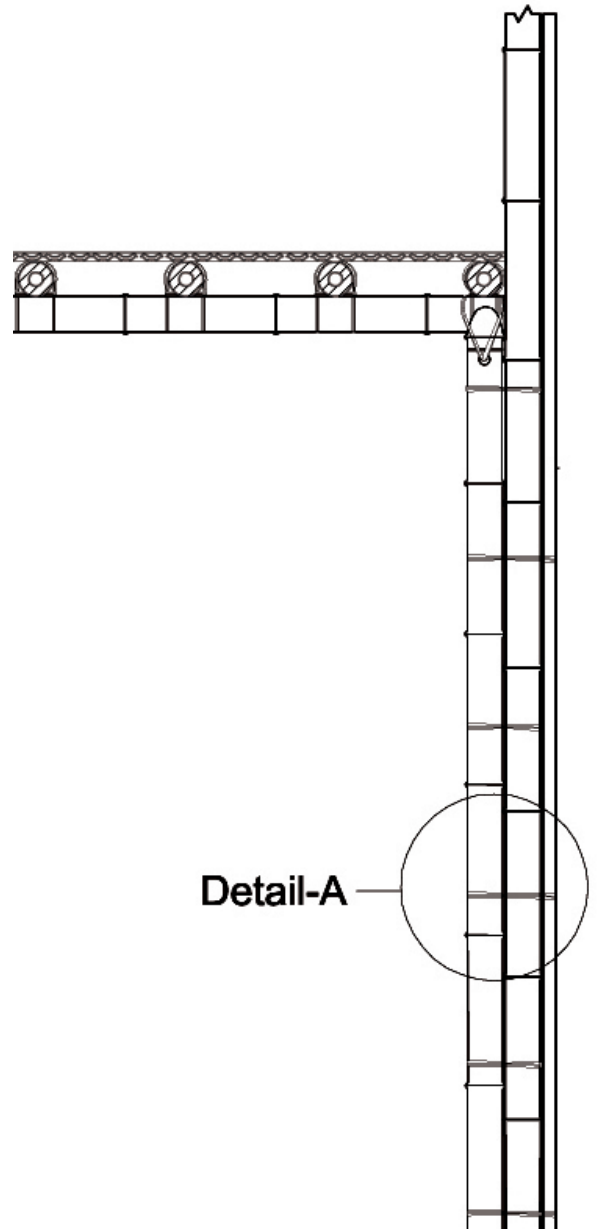
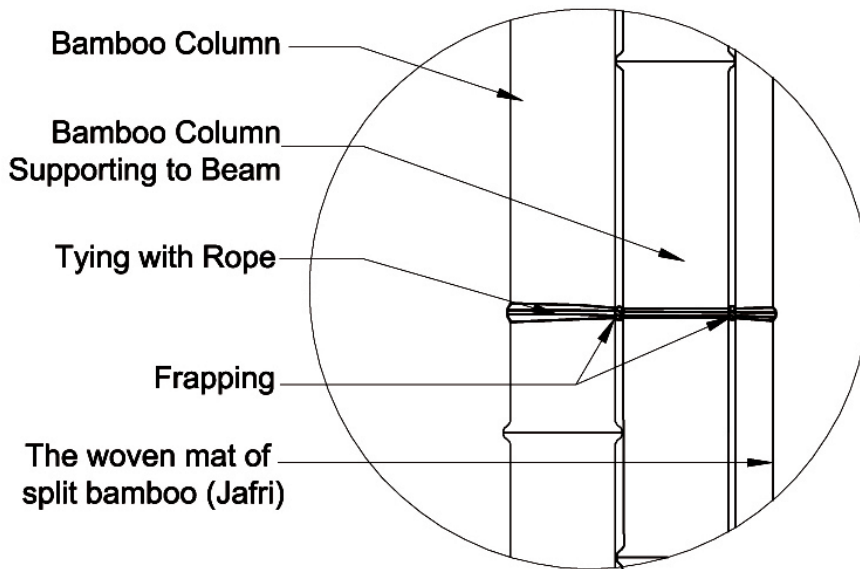


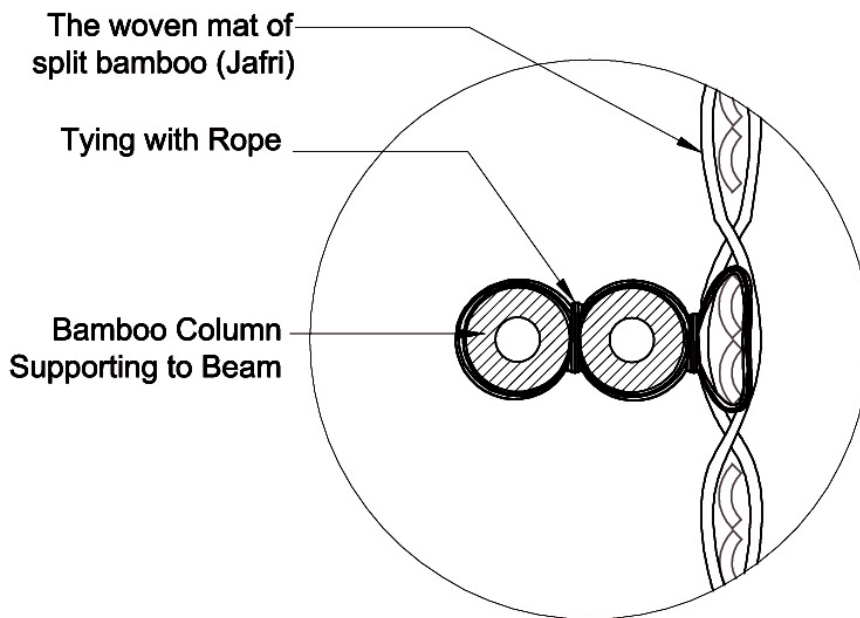
Fig.62.

“Woven bamboo panels were used in Philippines during the 1950 as in experimental low cost covering for wings and fuselage of light airplanes by institute os science and technology”

Wattle fixing detail to bamboo post



Detail-A



Detail Plan

Fig.63.

Roof

Attic Level Floor

In all bamboo houses, attic should be provided for use during floods. It shall be strong enough to take live load along with dead load in flood conditions.

The attic height at the eave level shall be minimum 75cm and the clear story height below attic shall be minimum 2.1 m.

Diagonal bracing or knee bracing in the posts above attic level shall be provided

Only mature Bambusa Balcoa or equivalent bamboo shall be used for beams.

For spans more than 3m, the main beams shall be made by bundling at least 2 bamboo (minimum 75 mm diameter) placed one on top the other and tied together with shear pins. The bundled beams shall be tied at middle of each bamboo culms. For smaller spans, single bamboo beams will suffice.

These bamboo beams shall be placed on bundled posts as explained earlier.

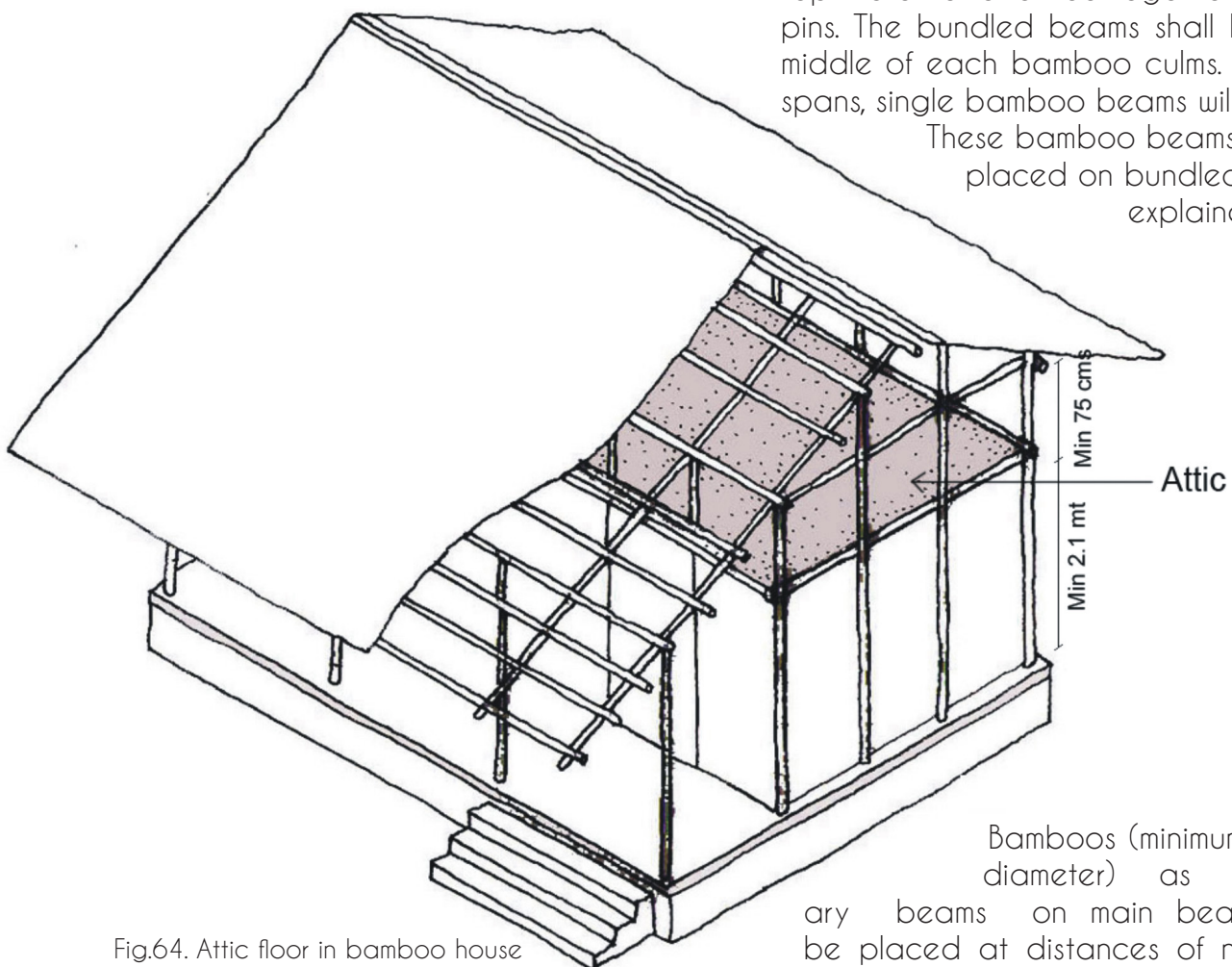


Fig.64. Attic floor in bamboo house

Bamboos (minimum 60 mm diameter) as secondary beams on main beams shall be placed at distances of not more than 60 cm. Secondary beams shall be tied to main beams at each junction.

Web:
<http://books.google.co.in/books?id=v3riDLVenTQC&pg=PA40&ots=MjJI6PKHM4&dq=bamboo%20building%20system&pg=PA61#v=onepage&q&f=false>

Attic Beams, Lattice Topping & Column support

Additional bamboo should be bundled with the posts for Supporting main beam of the attic. This bamboo shall be tied to the post at least at 3 places and will rest on the plinth beam.



Fig.65.

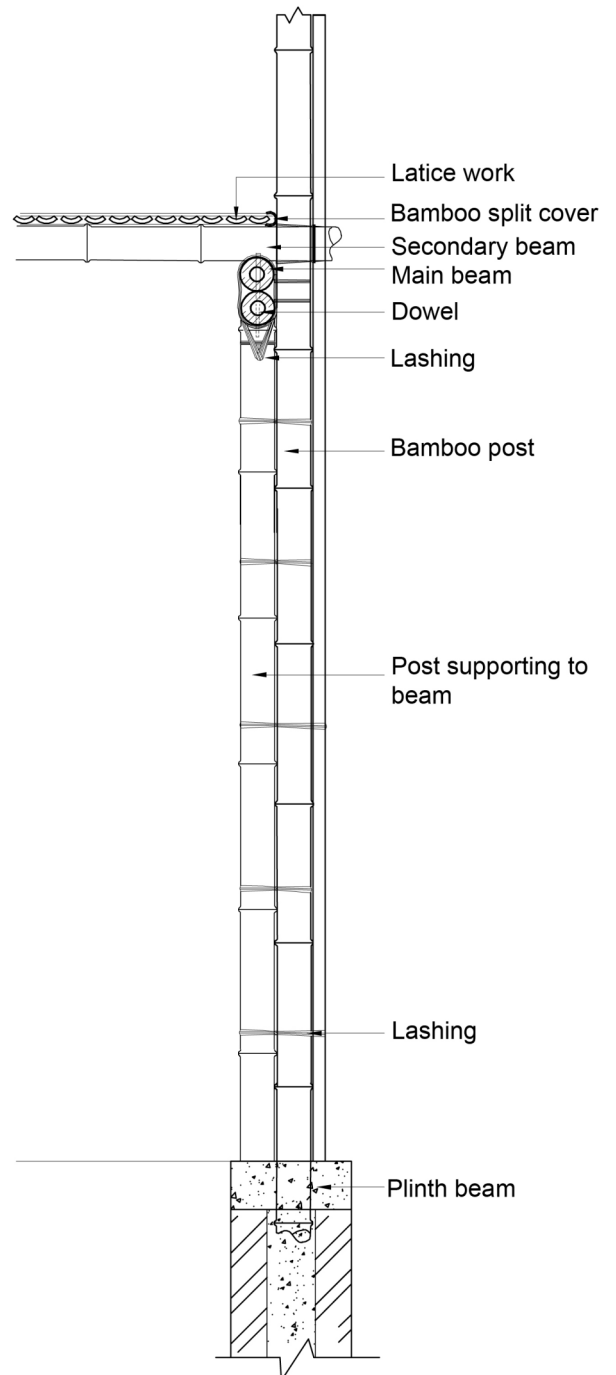


Fig.66. Details of attic beams, lattice topping and column support

Roof

Attic Level Floor

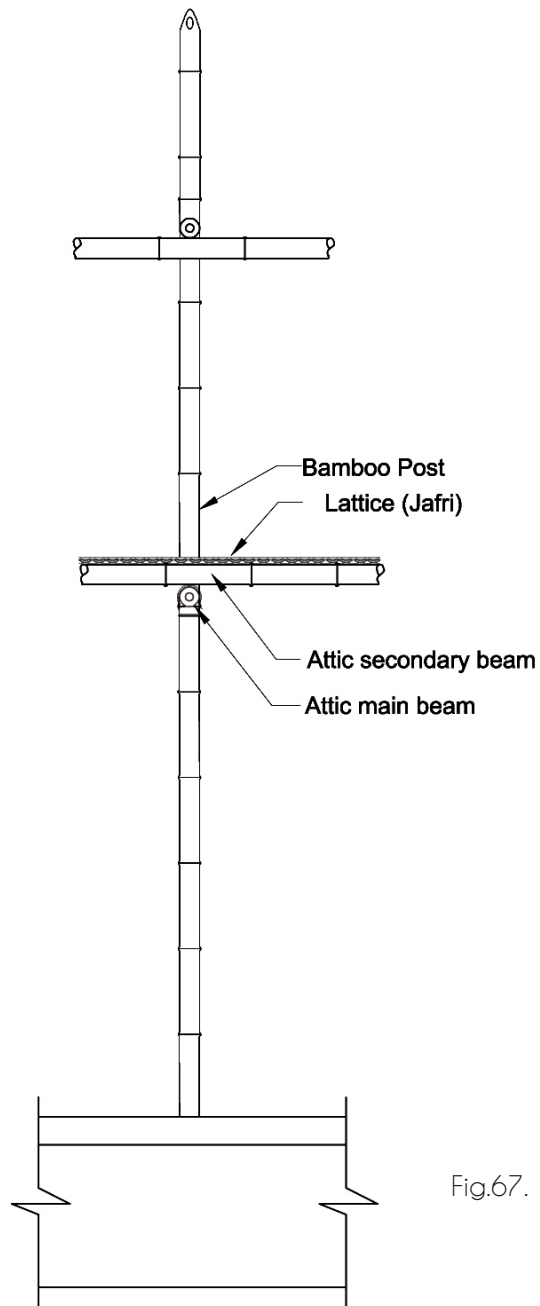
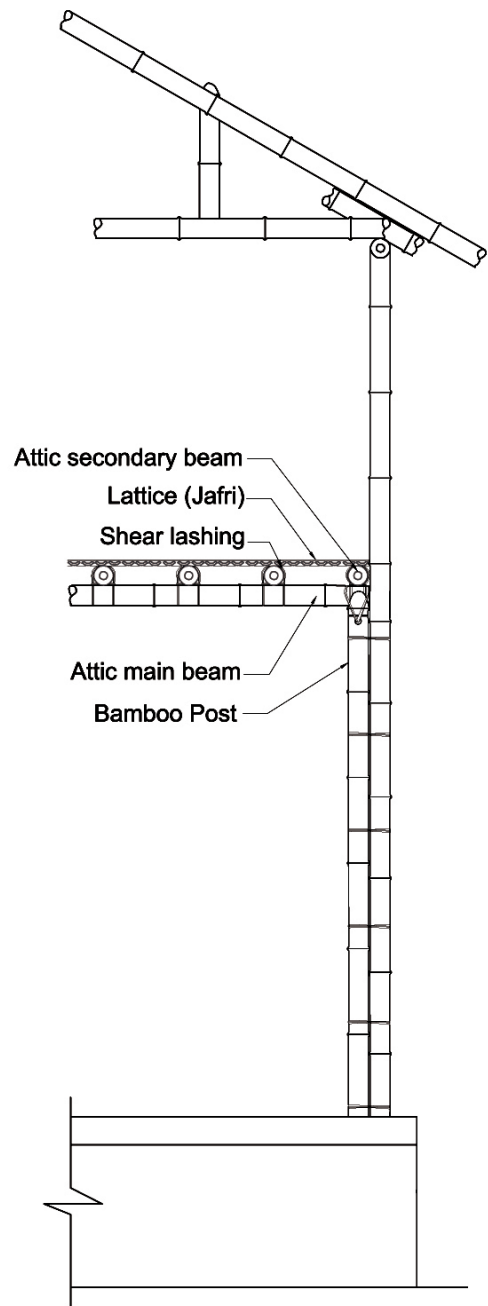


Fig.67.



Web:
http://www.holcimfoundation.org/T1559/ Locally-manufactured_cob_and_bamboo_school_building_Pakistan.htm

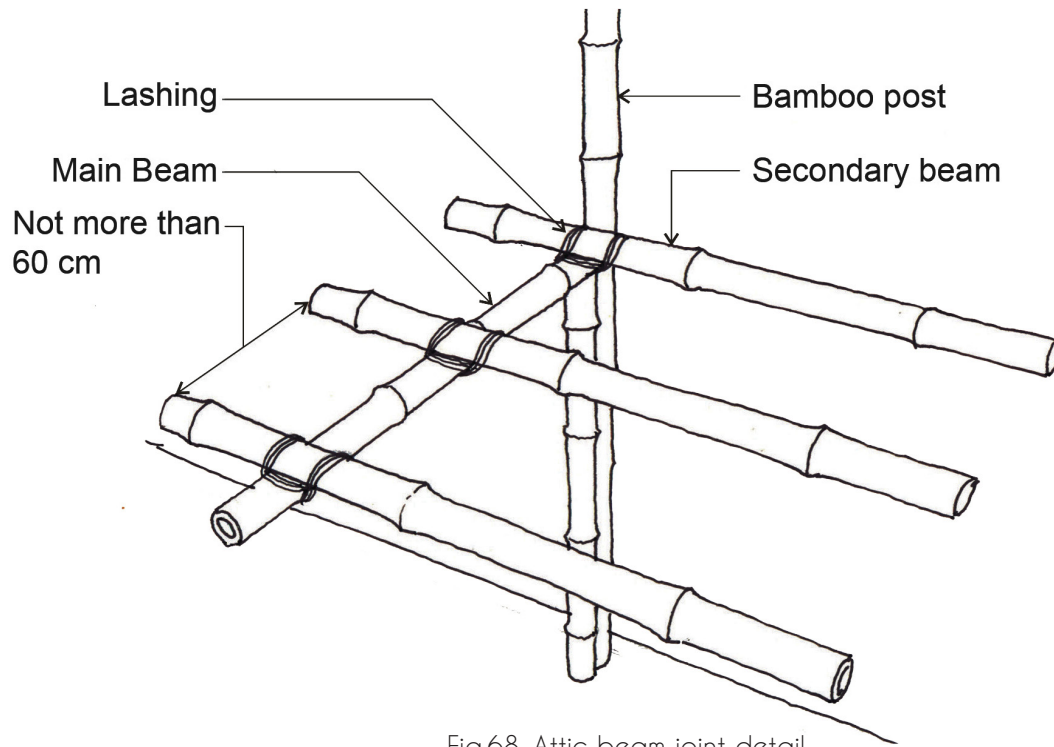


Fig.68. Attic beam joint detail



Fig.69.

Roof

Attic Main Beam as a Bundle of 3 Bamboo

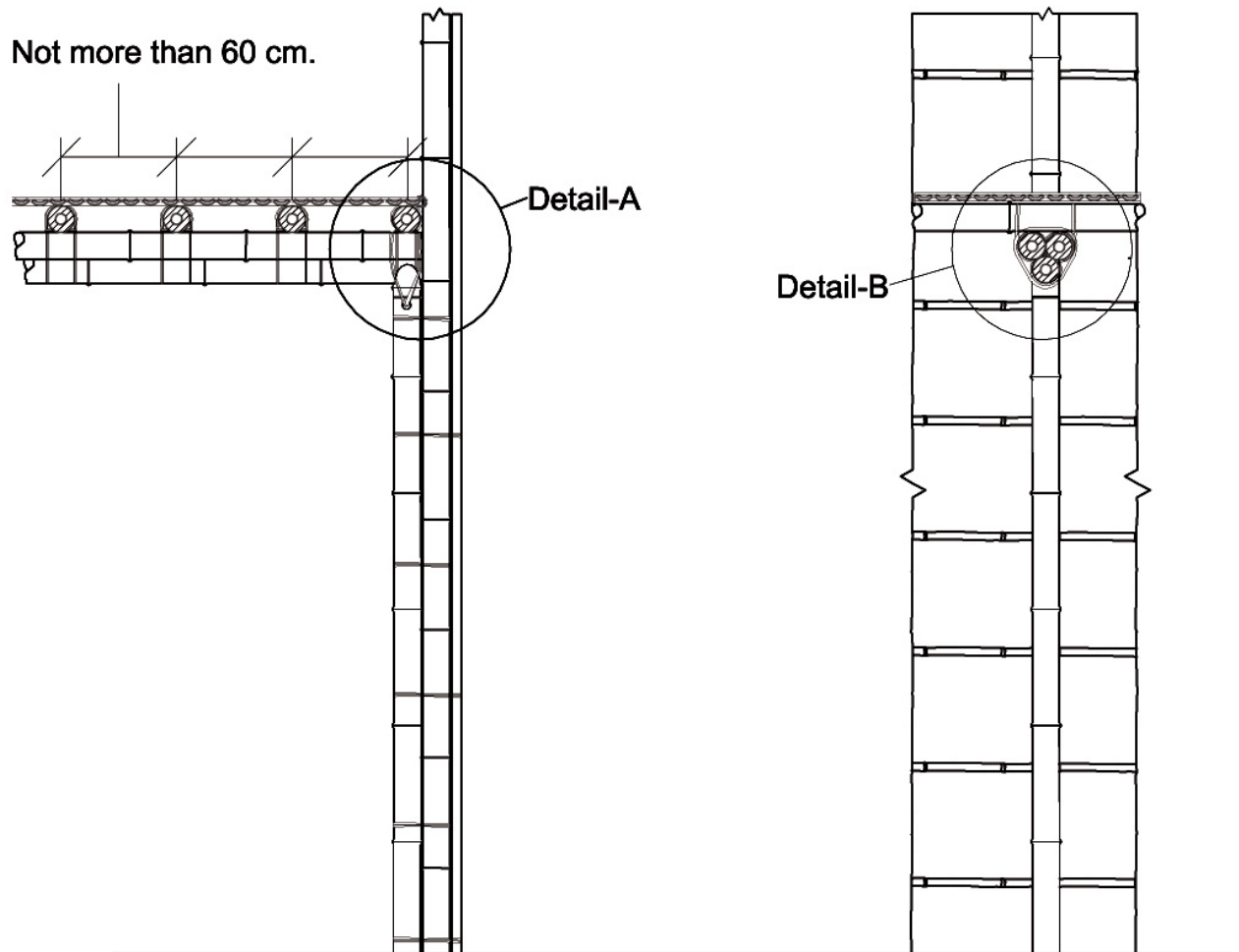
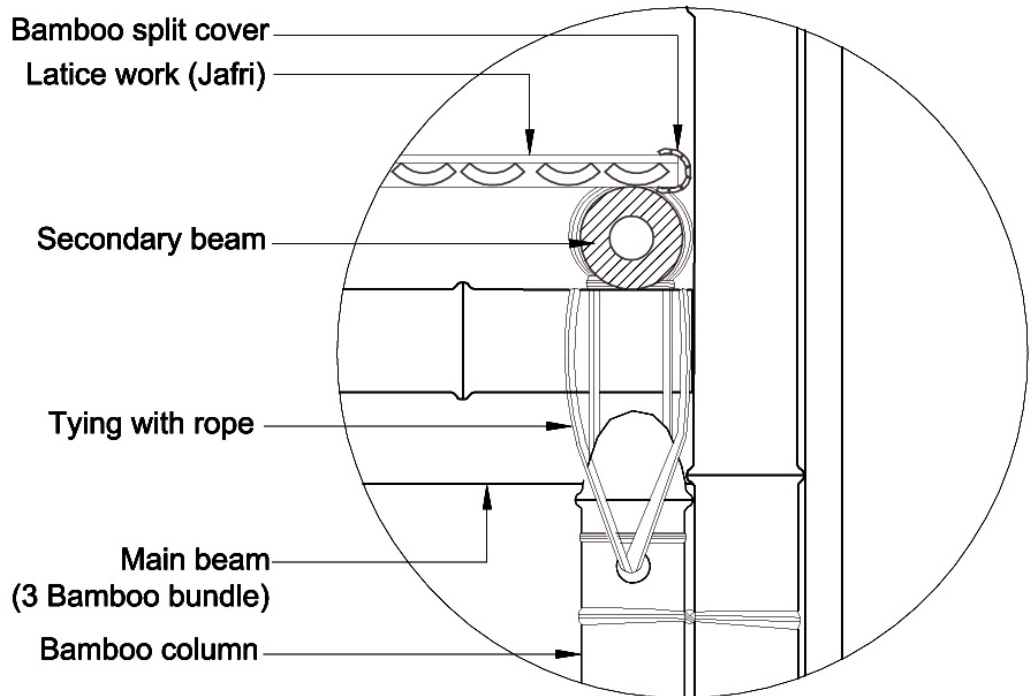


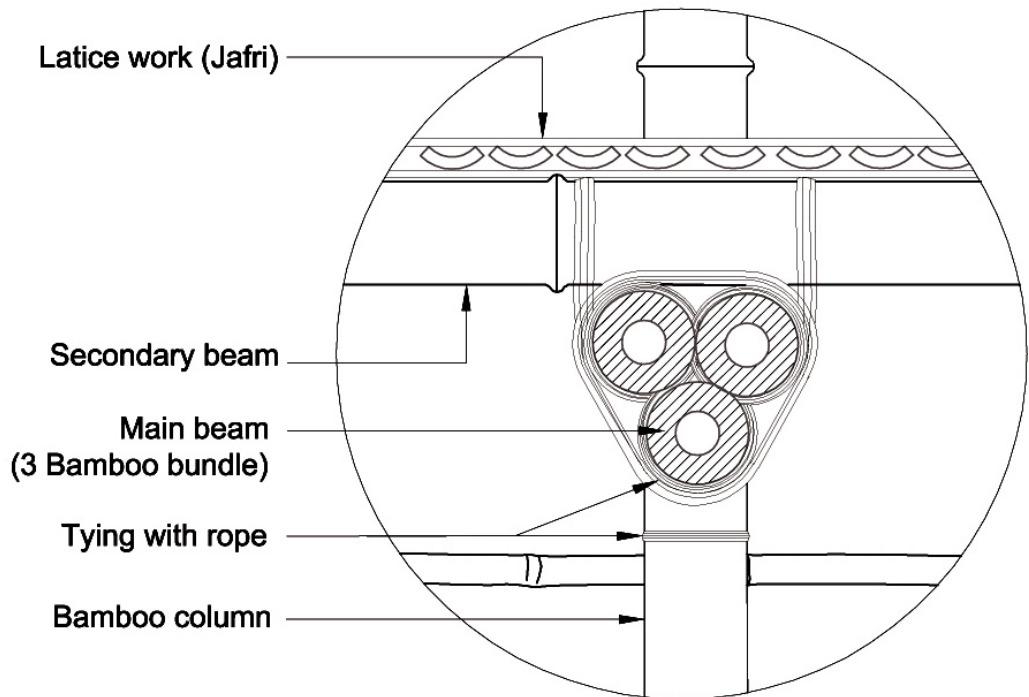
Fig.70.

Reference

Web: <http://bamboo.wikispaces.asu.edu/7.+Types+of+Joints>



Detail-A



Detail-B

Fig.71.

Roof

Pitched Roofs

Houses with bamboo walls can have followings type of roofs.

CGI Sheet roof - hipped or Gable

Burnt clay tile roof - hipped or gable

The understructure for roofs can be made with bamboo or wood.

For roof understructure, Mature Bambusa Balcoa or Bambusa Tulda or equivalent bamboo shall be used.

The spacing between principal rafters shall not be more than 60 cm in case of CGI sheet roofs: In case of burnt clay tiles, it shall not be more than 30 cm.

The bottom most purlins at the end of roof overhang shall be tied to the eave level beam.

The slope of the roof shall be as per relevant IS codes. In case of burnt clay tile roofs, the slope shall be minimum 30°. Conventionally, sloping CGI roofs can range from 22.5° to 35° to avoid suction (negative pressure) on roof covering during high speed winds.

The roof shall have an overhang of minimum 45 cm on all four sides

The end of the cantilever portion of the rafter shall be lashed to the posts.

In case of CGI sheets, it needs to be fixed with the understructure using J bolts and bitumen washers to make it waterproof. Nails shall not be used for anchoring of CGI sheets.

**“ Only the sun on his shoulder
knows where he has come from,
where he is going,
how he'll return,
well laden with wandering,
another morning by another road.”**

The J bolts shall be galvanized and have minimum 6 mm diameter. J bolts shall hold up to at least half the diameter of bamboo purlin.

The spacing between two consecutive J bolts shall not be more than 45 cm.

In case of burnt clay tile roofs, cross bracing shall be provided with wire or bamboo in roof understructure.

The last row of burnt clay tiles shall be held by sandwiching them between split bamboo strips. So as to ensure the tiles are not blown away due to high winds or slide off.

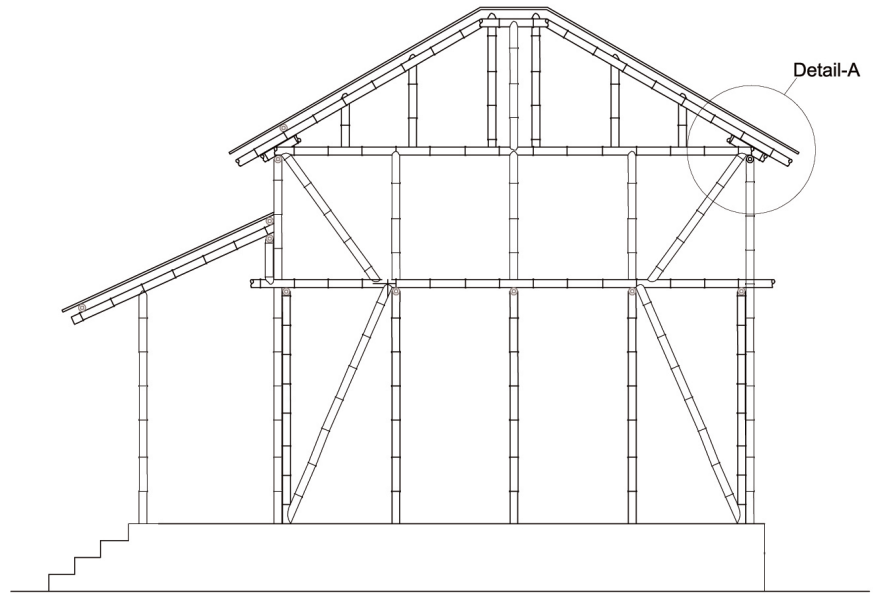
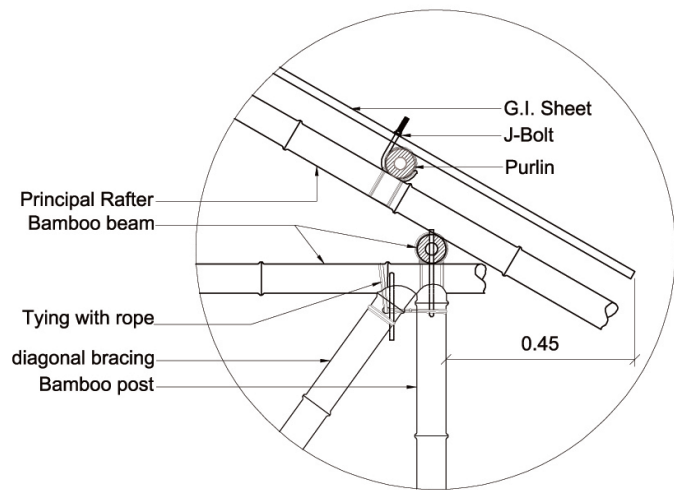
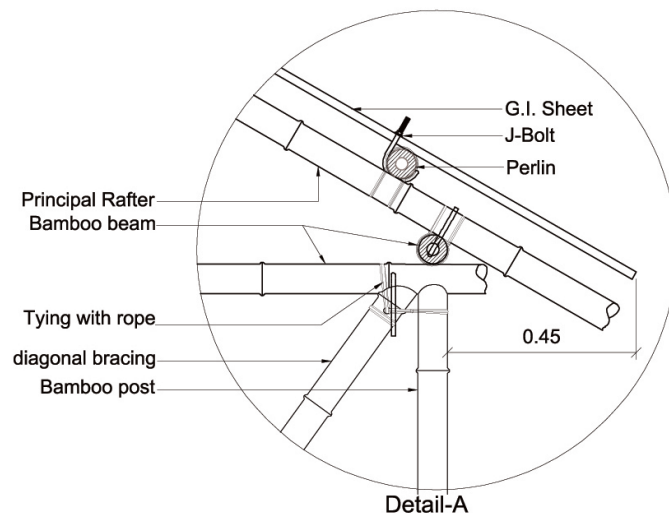


Fig.72.



Detail-A
Tying with column and Beams



Detail-A
Tying with Beam and Rafter

Fig.73.

Roof

Pitched Roofs



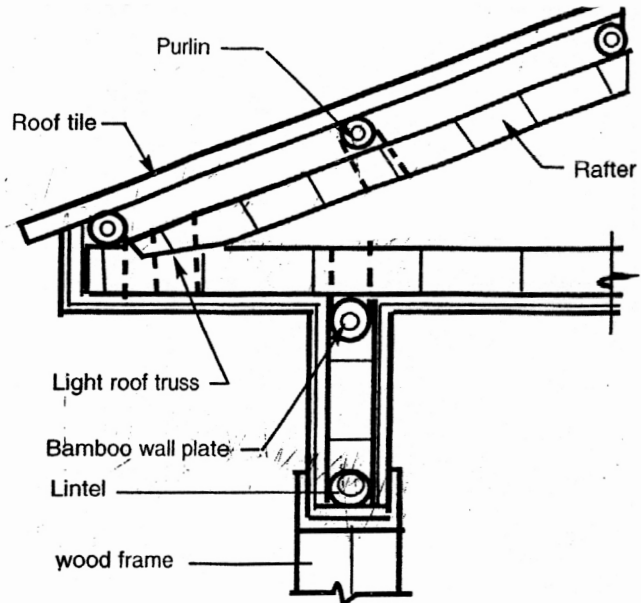
Fig.74.



Fig.75.

“Doors were made to open
roads were made to wind
ten thousand miles before you,
ten thousand more behind...”

A. Cross section of a two story bamboo house with light roof truss



B. Cross section of a story house covered with rafters

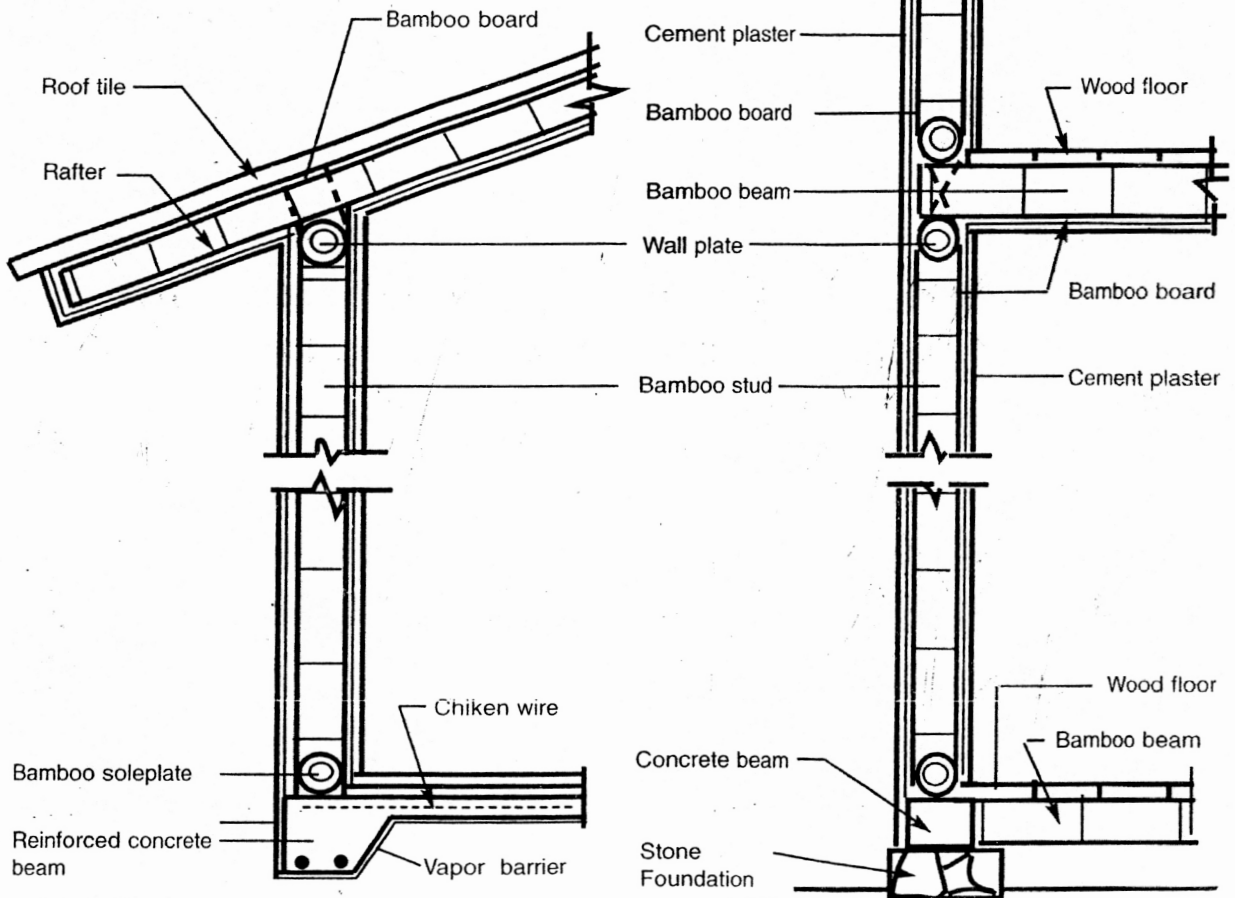


Fig.76.

Couple of Examples

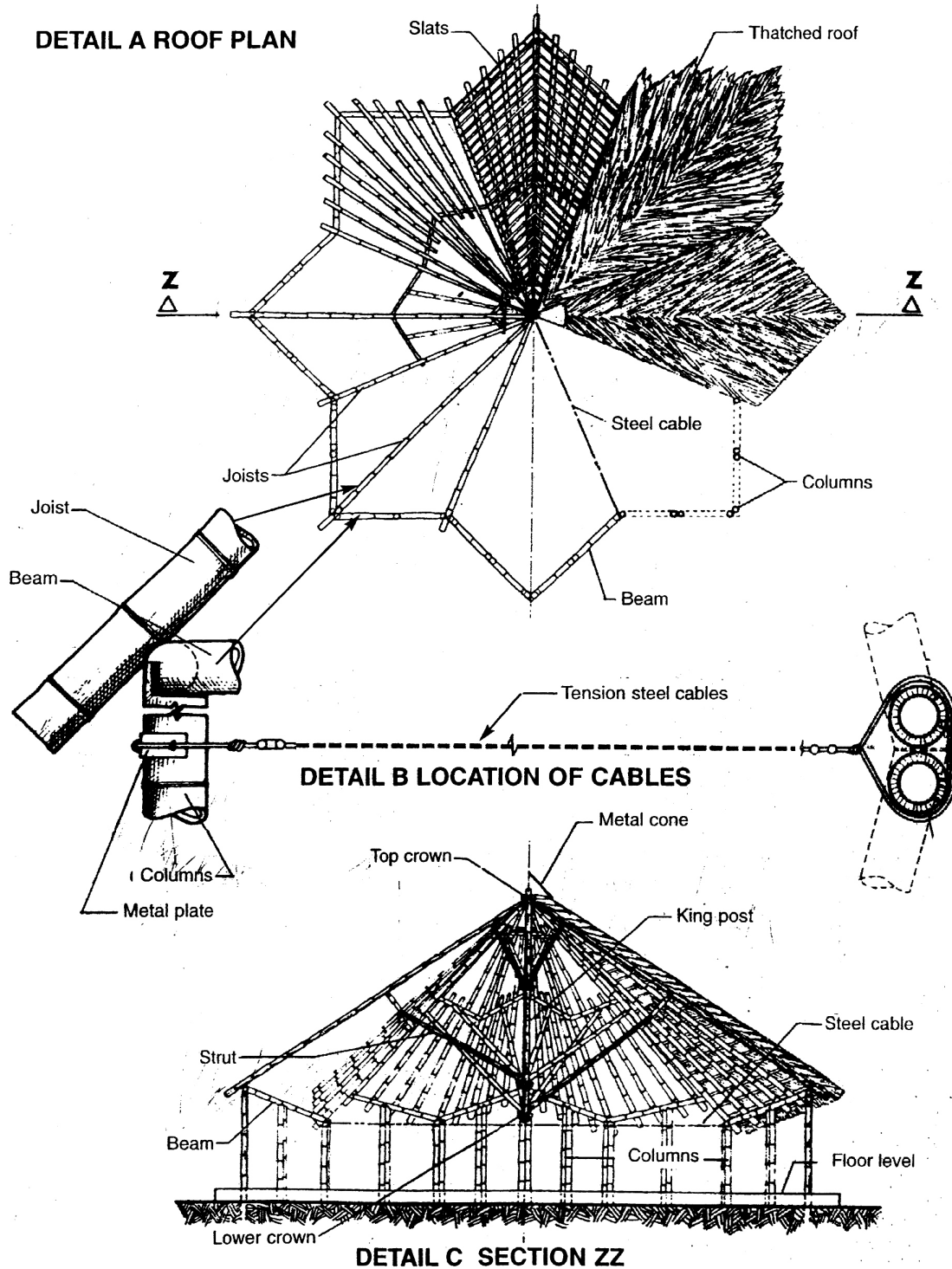


Fig.77.

Web:
http://openarchitecturenetwork.org/projects/dlygad2_nominee_bambooshelter

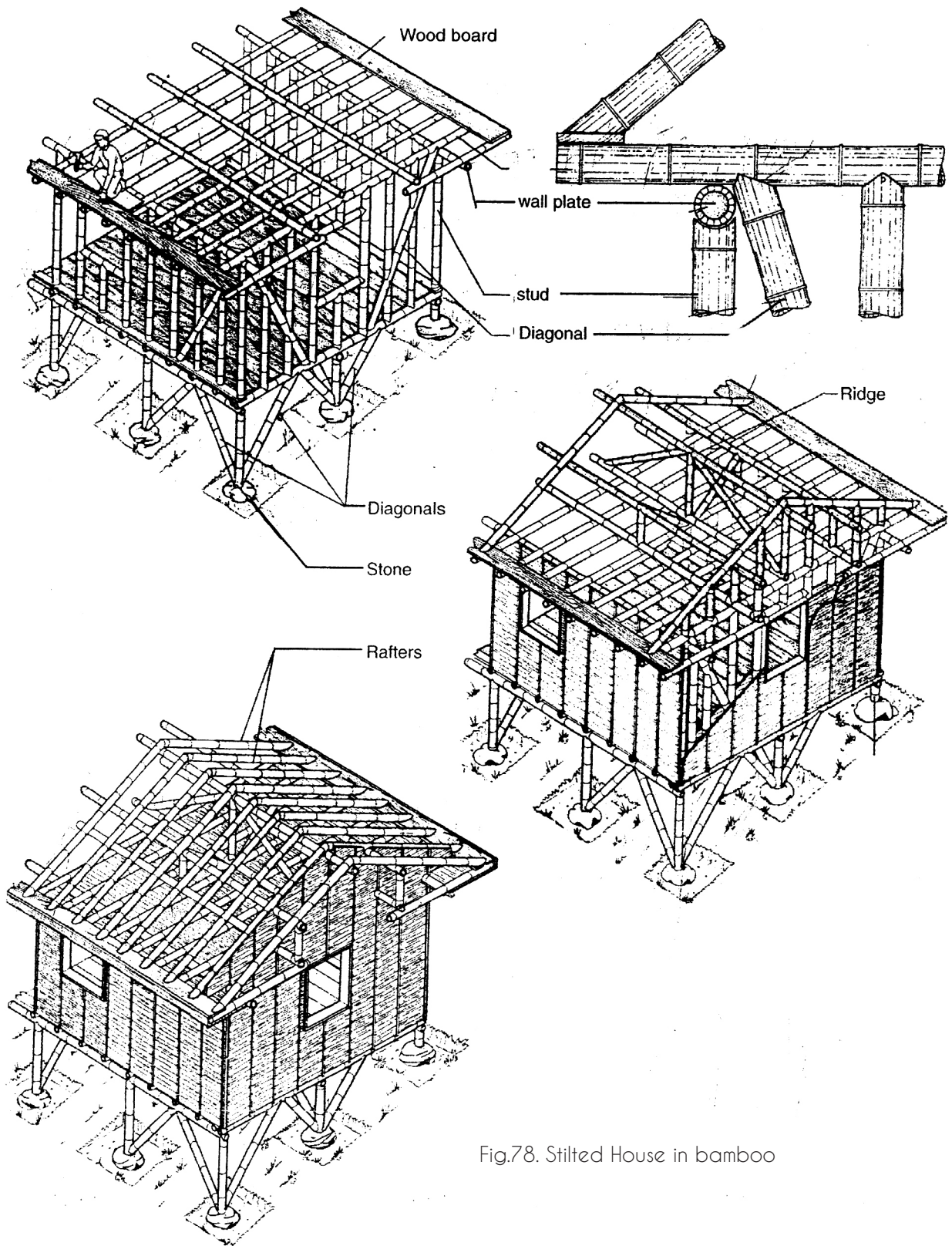
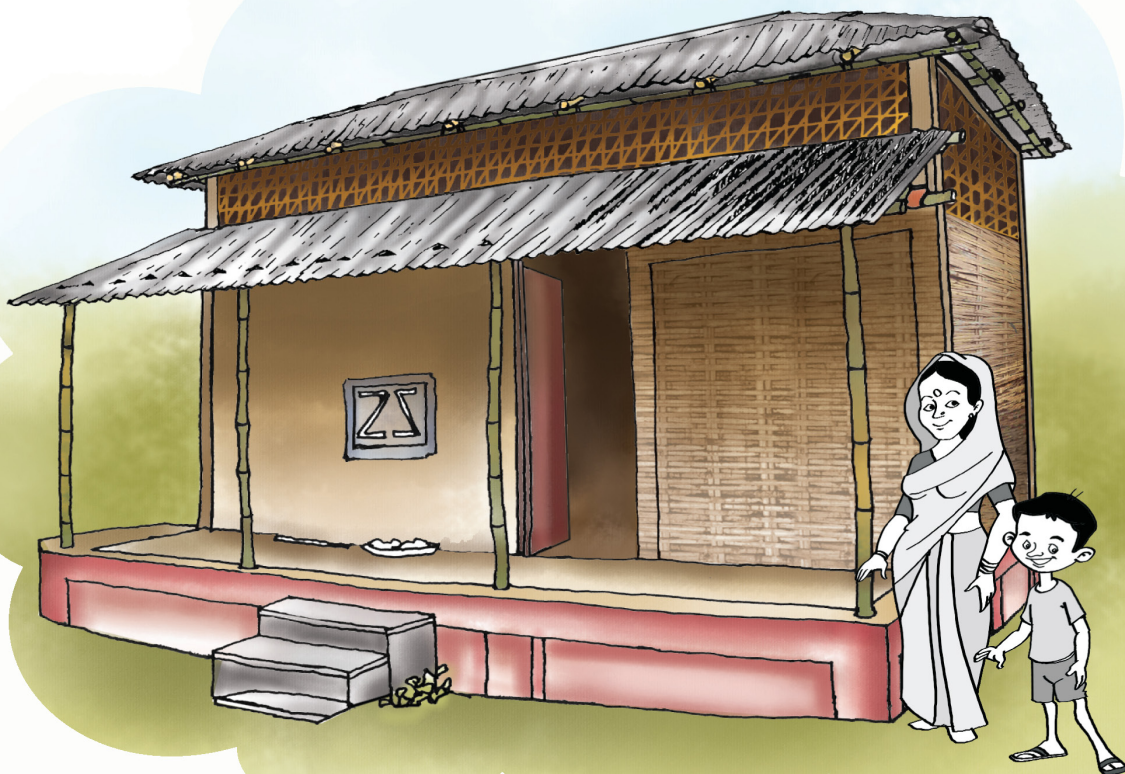


Fig.78. Stilted House in bamboo

7. Steps of bamboo house construction



Reference

Book :
Bihar Disaster Rehabilitation And Reconstruction Society-Bamboo House Construction Manual.

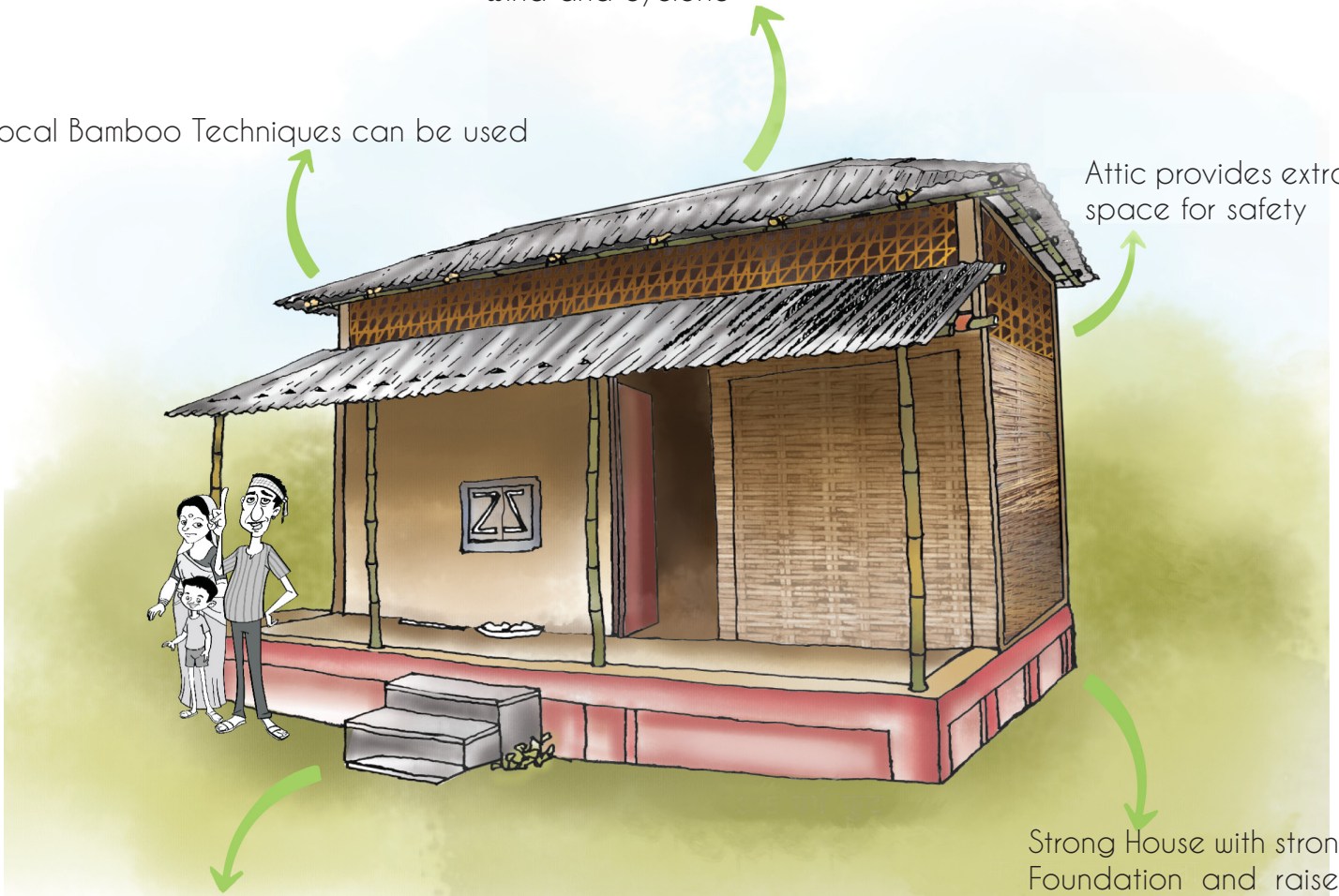


Step By Step Process
Of
Making Bamboo
House

Four sided sloping Roof are stable against wind and cyclone

Local Bamboo Techniques can be used

Attic provides extra space for safety



Our Own Bamboo Techniques,
Our own Strong House

Strong House with strong
Foundation and raised
Plinth

1. Plinth height should be 6" above the normal flood level.
2. Treated bamboo should be used.
3. Diagonal bracing provides stability and safety.

Site Selection

Inappropriate land

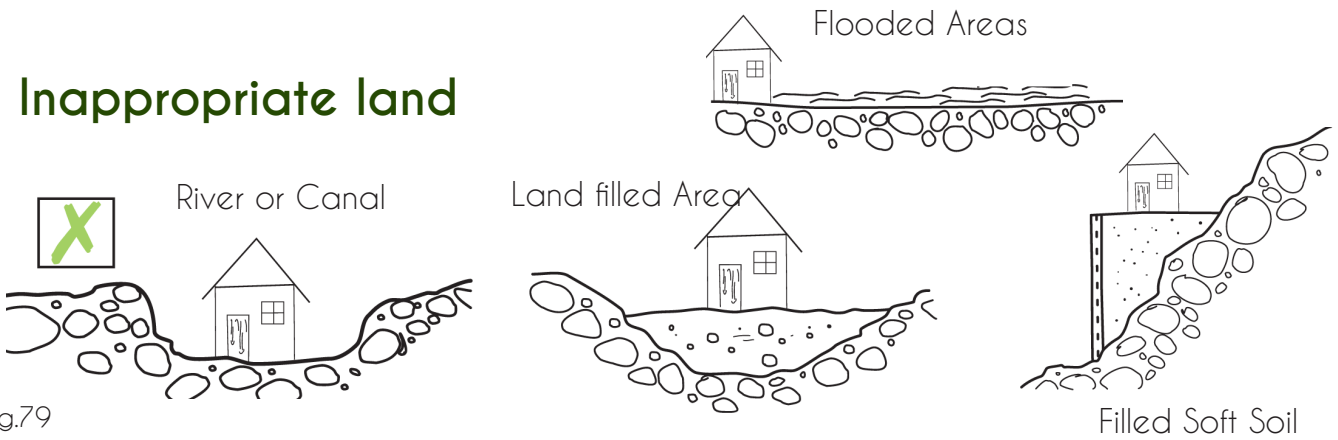


Fig.79

Appropriate land

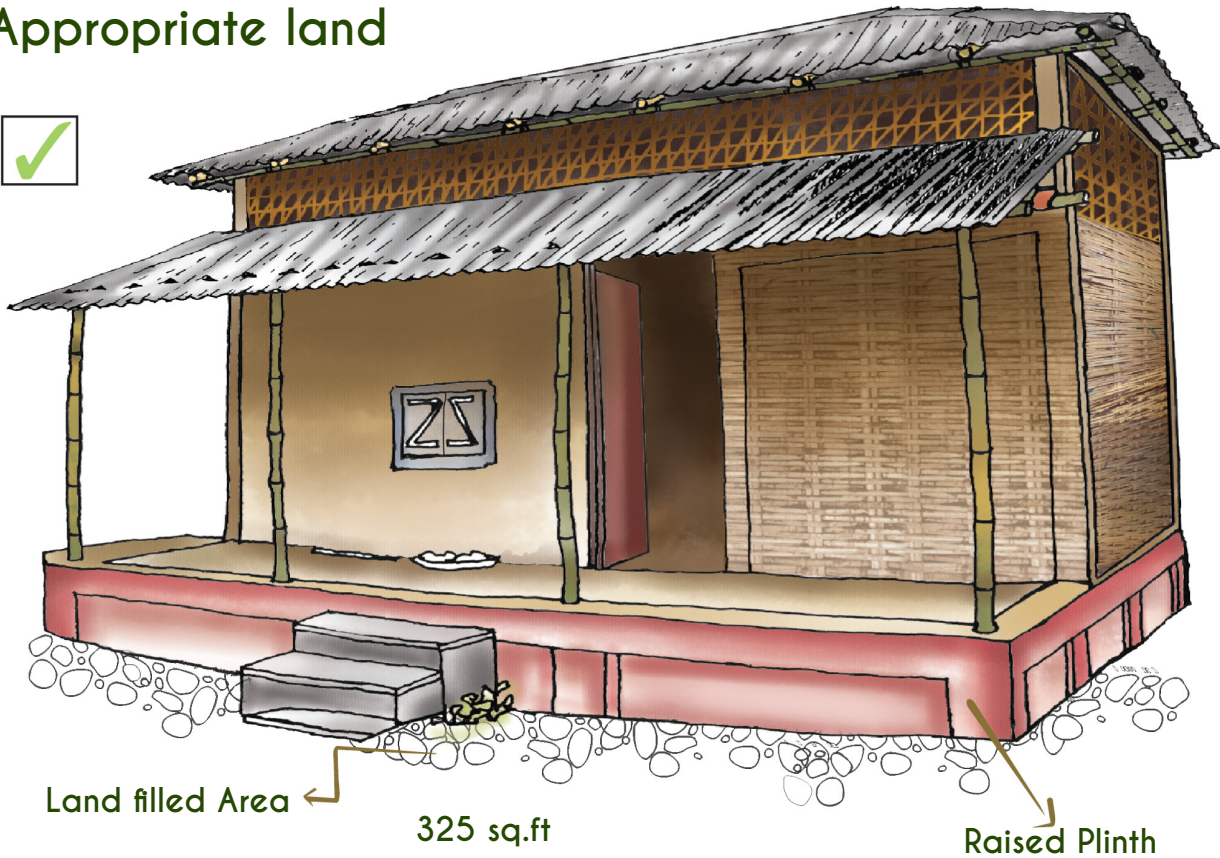


Fig.80

Note:

If the soil is not good for foundation, please contact some engineer.

1. House on inappropriate land may cause damage in disaster.

2. If the shape of the house is square then the roof will be conical. To avoid conical roof the shape of the house should be rectangle.

High Water Table

1. if soil is good, 5' deep stub foundation is appropriate for house.
2. If soil is sandy, precast pile foundation is advisable.

Brick Pedestal

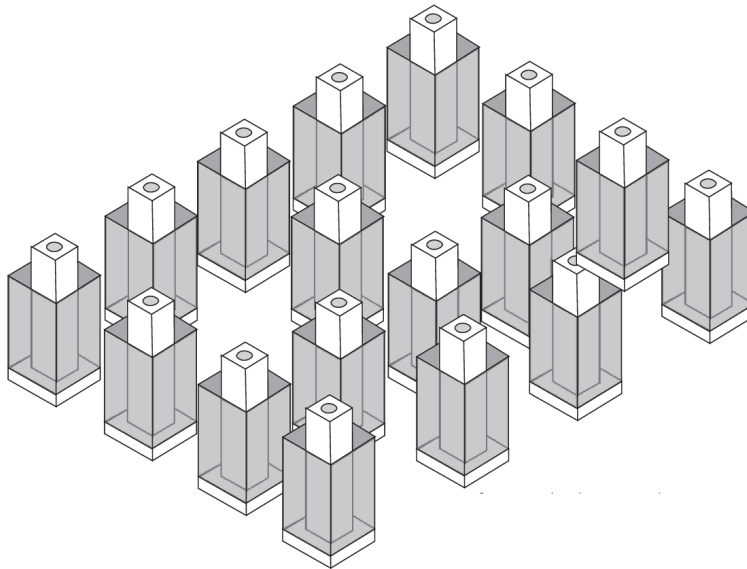


Fig.81.

Pile

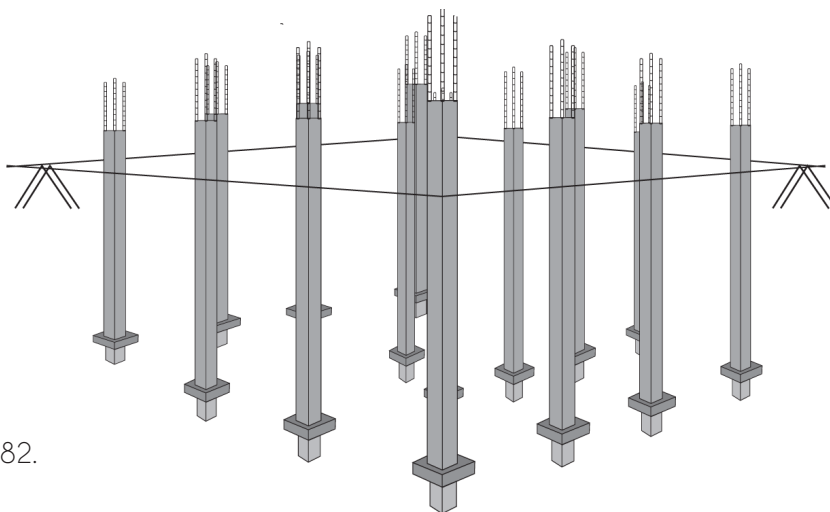


Fig.82.

Setting Out

Take Care in Setting out

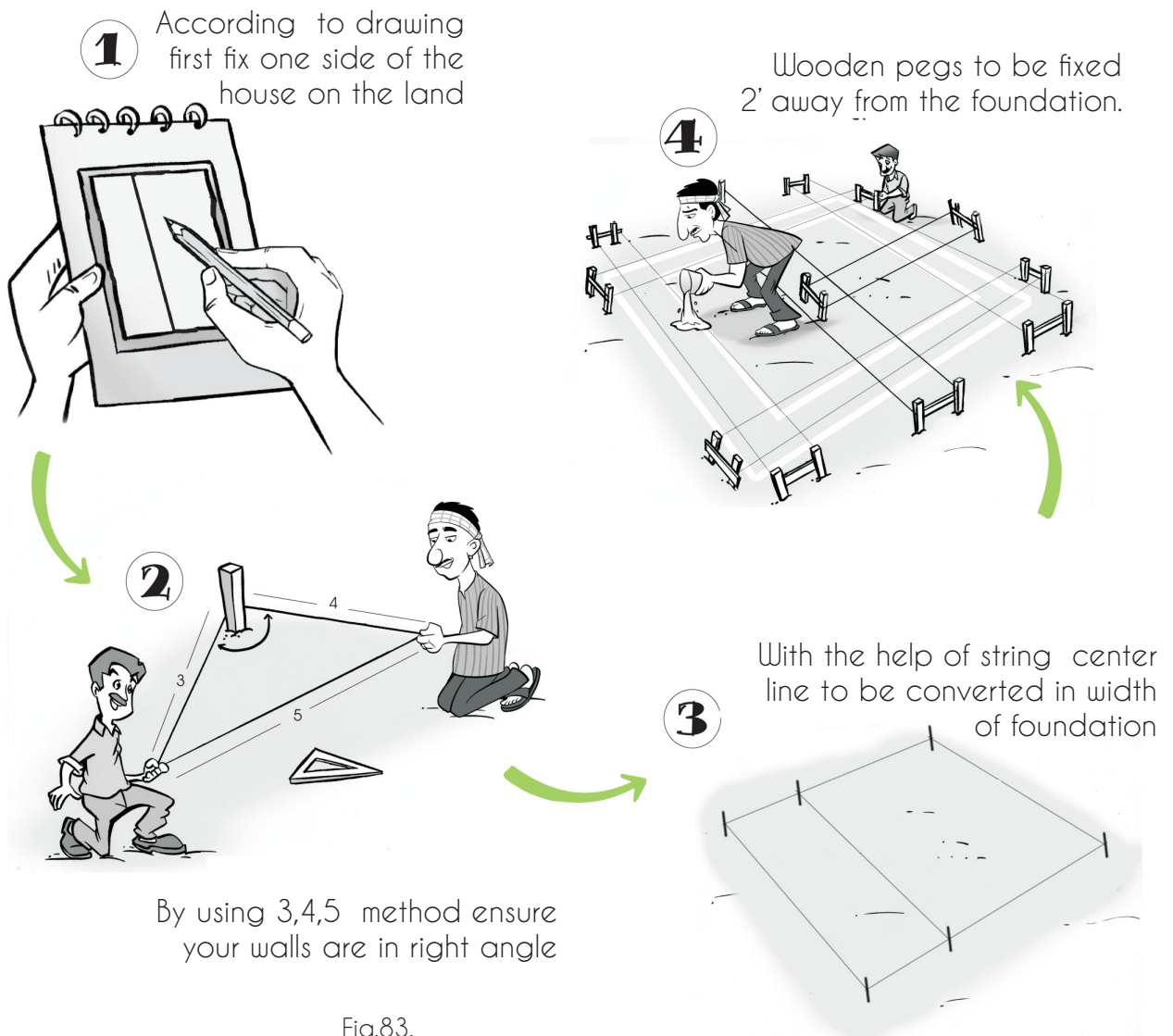


Fig.83.

Note:

1. According to the land and future expansion plans, the house to be set out in such a way that toilet and services are well accommodated.

2. Excavation to be done according to markings on ground.

3. Excavated earth should be kept away 4' to 6' away from the foundation.

Drawing of your house

352 Sq Ft House.

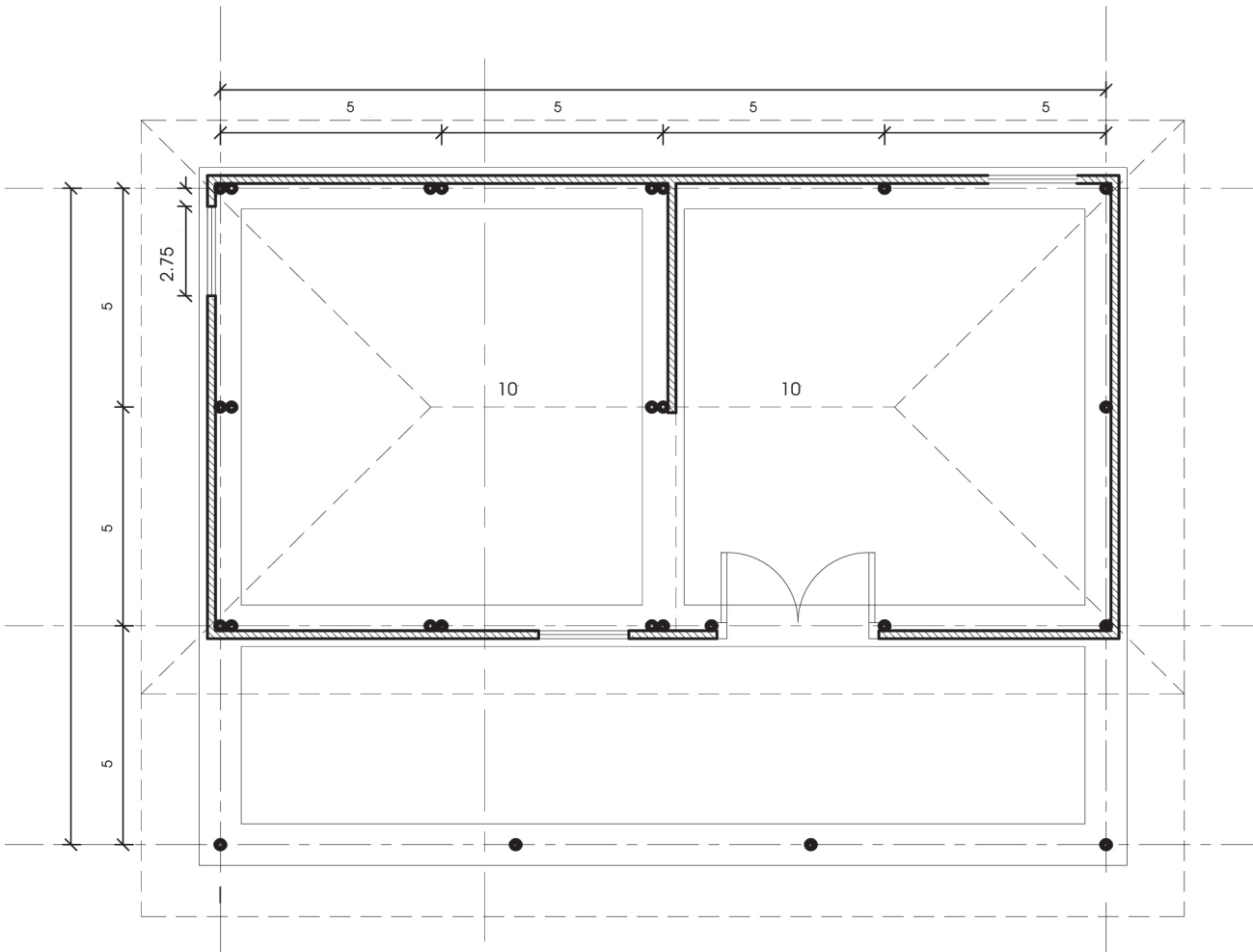


Fig.84.

All Dimention are in Feet.

This book briefly gives idea to build bamboo house as per above drawing. The plan can be vary accordingly to need of house owners

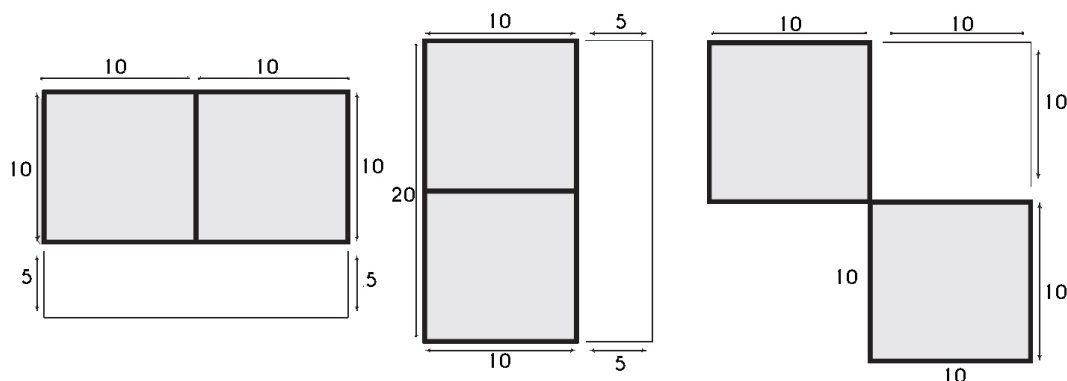


Fig.85.

Foundation with brick pedestal

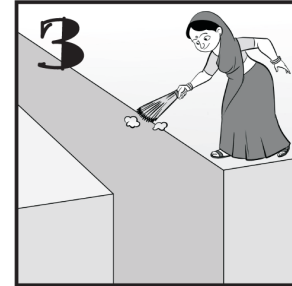
Construction of foundation.



Dig pits up to 3 to 5 feet according to soil



Foundation area should not contain leaves and other things which decay.



Foundation should be in level and clean loose soil to be removed

Fig.86.

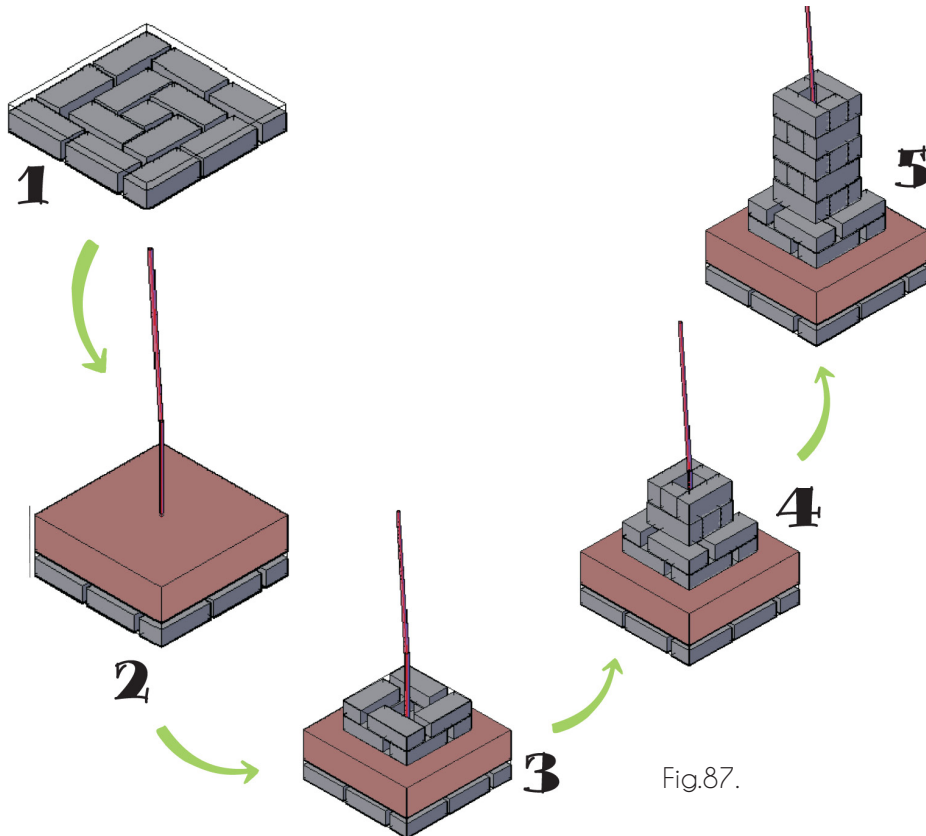


Fig.87.

Reference

Book :
Bihar Disaster Rehabilitation And Reconstruction
Society-Bamboo House Construction Manual.

Web:
<http://www.greenhomebuilding.com/articles/bamboohouse.htm>



Fig.88.

4 2'X2' brick soling to be done



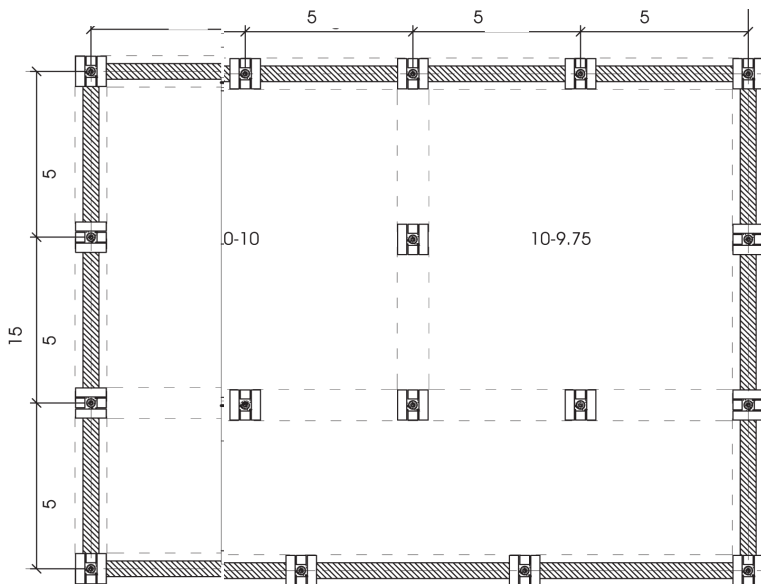
Fig.89.

5 Brick Soling.



Fig.90.

keep vertical bricks on edge of soling as shuttering for concreting ,pour concrete and spread and mark center for vertical bar



All Dimention are in Feet.

Fig.91.

6



Fig.92.

From center mark 15" X 15" and do masonry in such away that you get 5" X 5" gap in between .make two coarse of brick masonry, fill concrete in the center gap .

7



Fig.93.

Repeat the process till you reach up to ground level .



Fig.94.

Same way make 10"x10" brick pillars by using brick one edge ,keep one gap 4"x4" in the center and fill concrete in 1 cement 1.5 sand and 3 aggregate in proportion to the gap of pillars .

Plinth with brick pedestal

Plinth should be 6" above the normal flood level in your area (minimum 1'6" above Ground level)



Fig.95.

Between two pedestal 5" thick brick masonry to be done from 9" below the ground level. Wall and pedestal to be built together up to plinth band level. Last layer of masonry should be 10" wide so that shuttering for the band can be saved.



-Fig.96.

For the bamboo wall plinth band of size 10" wide and 4" thick is required. Place the reinforcement as per the picture. Place the cage of 8mm thick reinforcement. Fill the concrete in proportion of cement 1.5 sand and 3 aggregate.



Fig.97.

Reinforcement detail at the corners and the T-Junctions.

Note :

Same foundation and plinth can be used for brick wall houses. Instead of band of 10" thick beam 12mm dia bars can be used. The total number of main bars should be 4.



Place the pvc pipe of 4" in the pedestal which should be removed before setting of concrete so that bamboo column can be fixed later. At the same time, keep a bamboo pin or 10mm iron rod piece horizontally attached with pipe that should be removed immediately after setting of concrete. This will be used to fix pin to bamboo to hold it with plinth.

Fig.98.

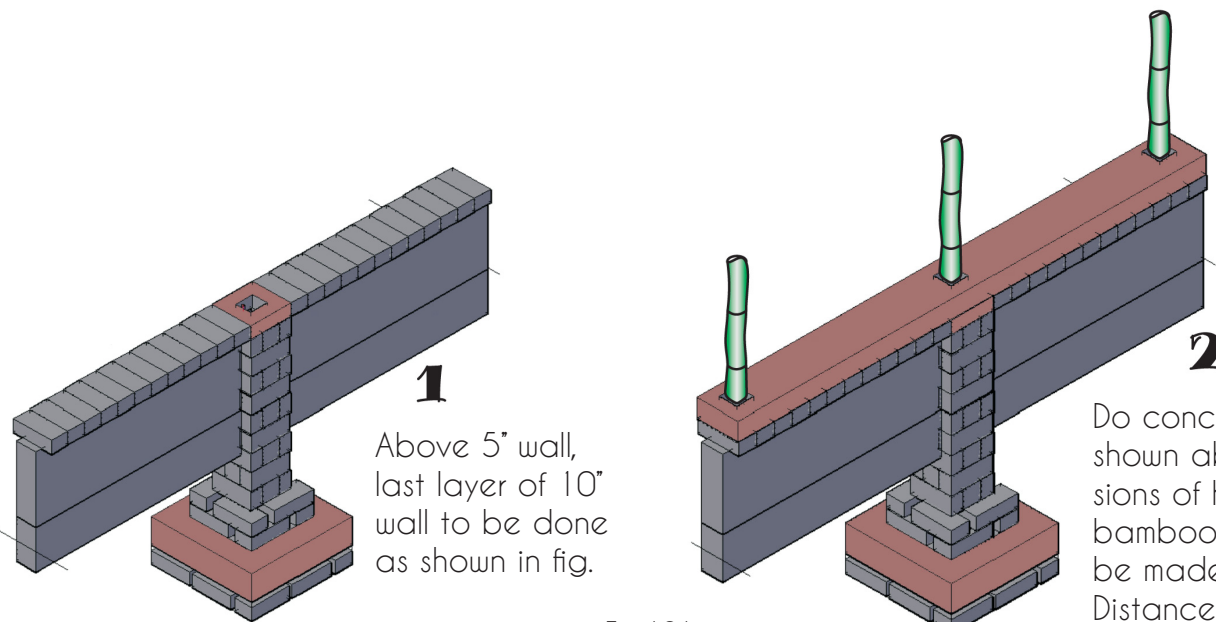


Fig.99.



Fig.100.

Earthquake resistant concrete band at plinth is ready for superstructure.



1
Above 5" wall,
last layer of 10"
wall to be done
as shown in fig.

2
Do concreting as
shown above. Provi-
sions of holes to insert
bamboo later should
be made.

Fig.101.

Distance between two
pedestal should not
exceed more than 5"

Foundation with pre-cast piles

Two important stages are: 1. To make pile
2. To fix pile in foundation

Casting of precast pile



Fig.102.



Fig.

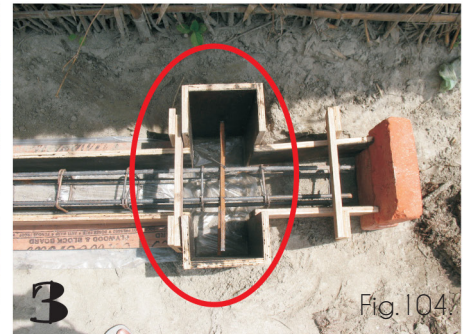


Fig.104.

To cast a pile of 10' long
Make cage of 12' long
from four 12 mm size steel bar.

This cage should be placed
in the wooden mold or brick
mold

1 feet from the bottom, fix 12mm
steel in both the direction



Fig.105.

To cast a pile of 10' long Make
cage 12' long from four 12 mm
size steel. Pour concrete in the
proportion of 1 cement 1.5
sand and 3 water.



Fig.106.

Additional aggregate steel in
the bottom will take shape of
base which will not allow founda-
tion to affect from earthquake

Life winds a lot.
Sometimes it's easy,
sometimes it's not.
Sometimes you talk about it,
sometimes you can't.
But when two friends share one inside,
their hearts are just there,
like wather or air,
and their words smell like flowers.
-Canfucius

fixing of precast pile



Fixing of pile in foundation



Excavate pit for foundation



If water table is too high, use a drum without base, excavate inside the drum and take soil out. Water will remain there, reach up to appropriate depth. Pile to be fixed with help of ropes and wooden poles, drums to be taken out, soil to be filled again. Ensure that reinforcements are long enough to bend inside the plinth beam

Drawing of your house
325 Sq Ft House.

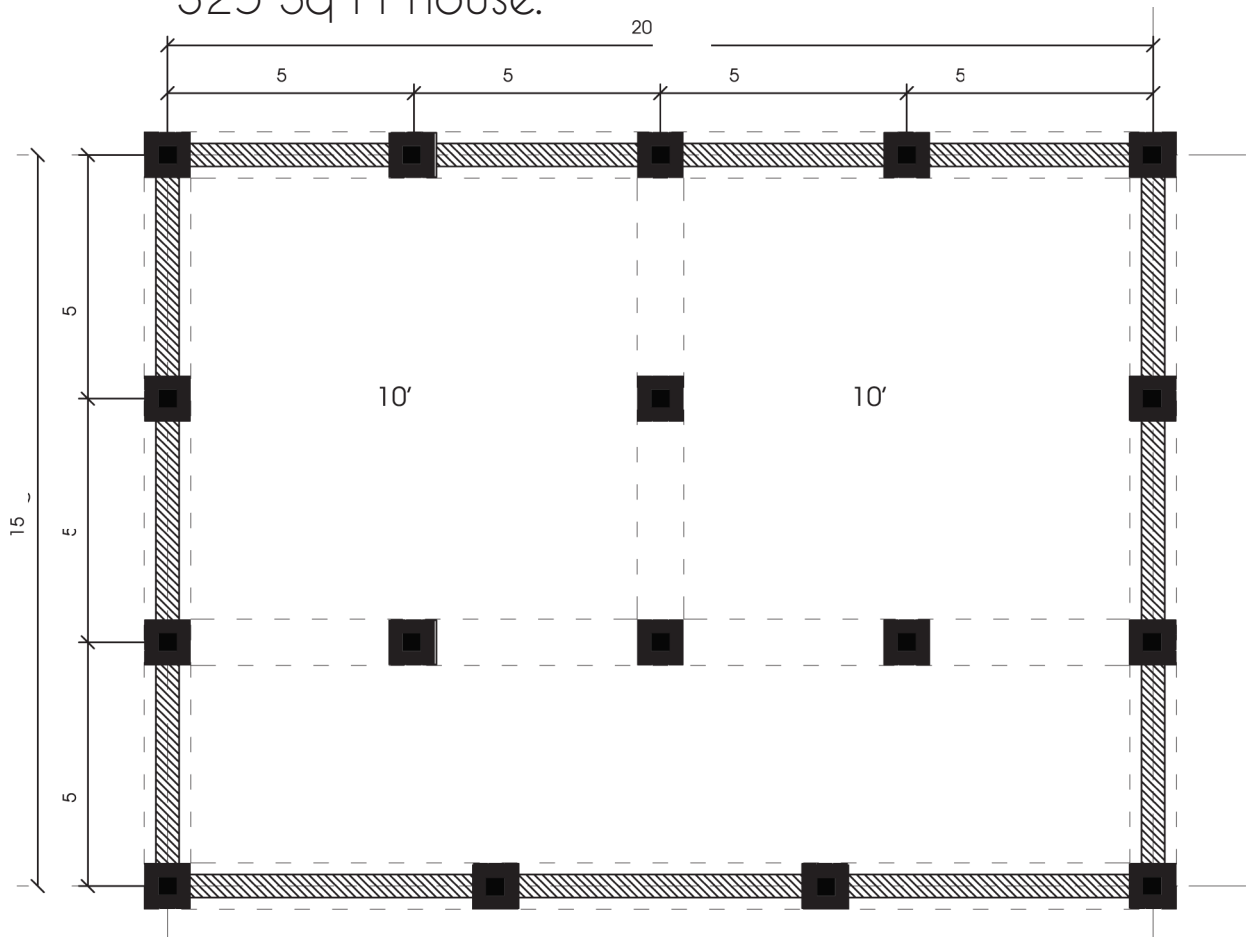


Fig. 110.

Plinth with precast piles

Plinth height should be 6 inch above the average flood level, or minimum 1'6".

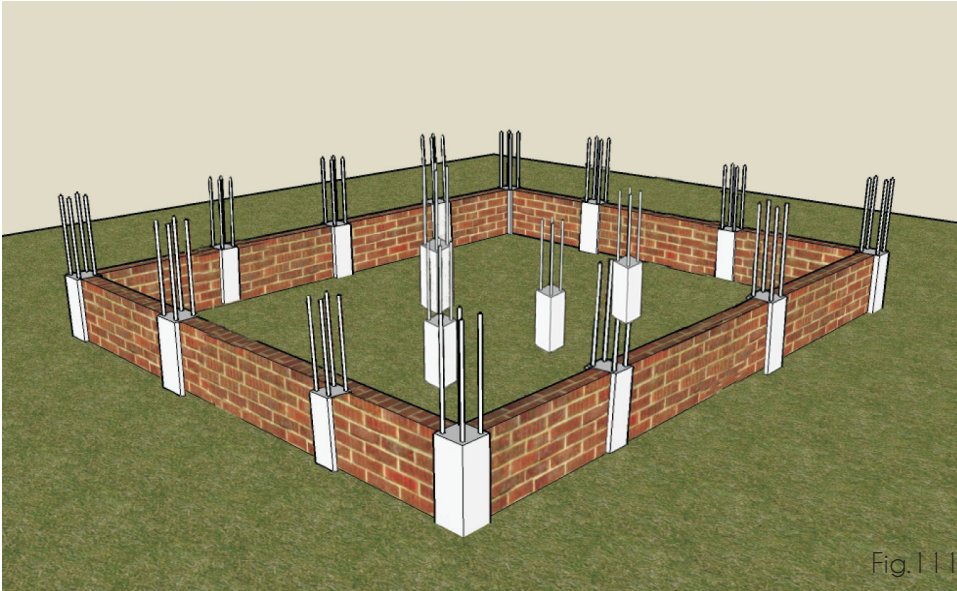


Fig. 111.

- 5" thick brick wall to be built from 9" below ground level, between two piles. The masonry is to be completed till plinth level.

- Last layer of masonry should be 10" wide to save the shuttering cost.

- 4" thick and 10" wide band is required for the bamboo wall.

- Place the cage of 8mm thick reinforcement . fill concrete in proportion of 1 cement 1.5 sand and 3 aggregate.

- Place the pvc pipe of 4" in the pedestal which should be removed before setting of concrete so that bamboo column can be fixed later.



Fig. 112.

Reinforcement detail at the corners and the T-Junctions.

At the same time keep a bamboo pin or 10mm iron rod piece horizontally attached with pipe that can be removed immediately after setting of concrete. This will be used to fix pin to bamboo to hold it with plinth.

Note :

Same foundation and plinth can be used for brick wall houses. Instead of band of 10" thick beam 12mm dia bars can be used. The total number of main bars should be 4.



PVC Pie place in Plinth Reinforcement

Fig. 113.



Hole is ready to house bamboo post.

Fig. 114.

Earthquake resistant concrete band at plinth is ready for superstructure.

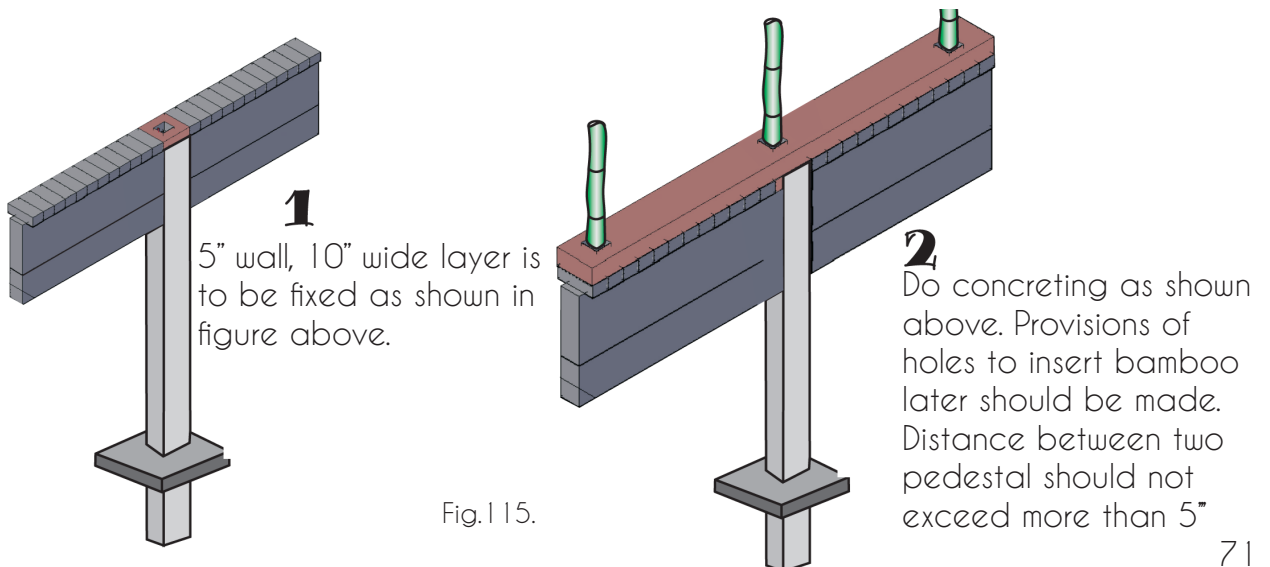


Fig.115.

Construction of Super Structure



Fig.116.

1 To integrate superstructure with plinth, bamboo should be fixed 15" deep in the plinth.



Fig.117.

2 The bamboo poles to be housed in the hole created in plinth

Once the bamboo pole is housed in a plinth put dry fine sand to fill the remaining gap and insert shear pin as shown in figure 118.



Fig.118.

Nessecery Details



Fig.119(a).

To complete the frame next step is to attached bamboo beams with pole For span more than 3 meter, three structural bamboo bundles to be used. As shown figure 119(a)



Fig.119(b).



Fig.119(c).

Detail of at the cross - bracings

Reference

Book :
Bihar Disaster Rehabilitation And Reconstruction
Society-Bamboo House Construction Manual.

3



Fig. 120.



Fig. 121.

4



Fig. 122.

At the attic level, place the structural bamboo band in a manner, so that the load of attic transfers to bamboo columns

5



Fig. 123.

6



Fig. 124.



Fig. 127.

View from inside



Fig. 126.

Bamboo matt and windows fixing detail.



Fig. 125.

Complete House

Technique of bamboo joints

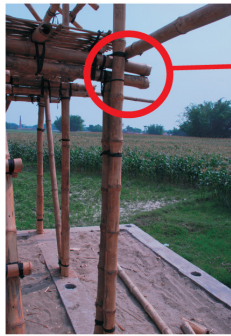


Fig. 128.

Joint at attic corner



2

Joint vertical column with attic



Fig. 129.

3



Fig. 130.

Join middle column with attic



Bamboo Lattice
Tied With Rope

5



Fig. 132.

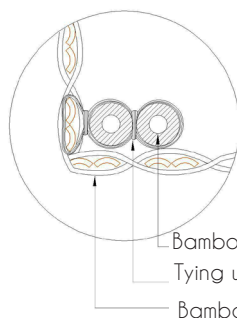
Join Two parallel columns

4



Fig. 131.

Corner poles of the structure



Bamboo Post Supporting to beam

Bamboo column Support to Beam
Tying with Rope
Bamboo Lattice

The Philosophy and know-how of the anonymous builders presents the largest untapped source of architectural inspiration for industrial people

-Rudofsky





6

Roof joinery.
Fig.133.



7

Fig.134.

Joint at main beam with support column of roof.



8

Corner joint.

Fig.135.



9



Joint at main beam of attic

Fig.136.



Tying technique

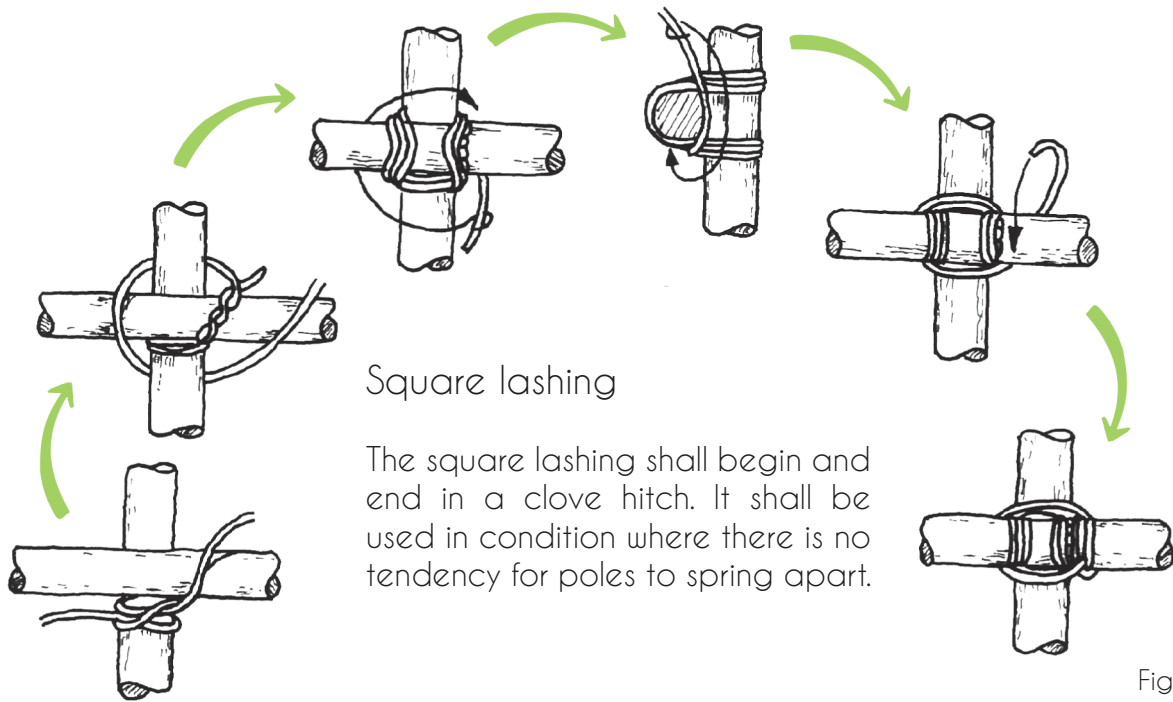


Fig. 137.

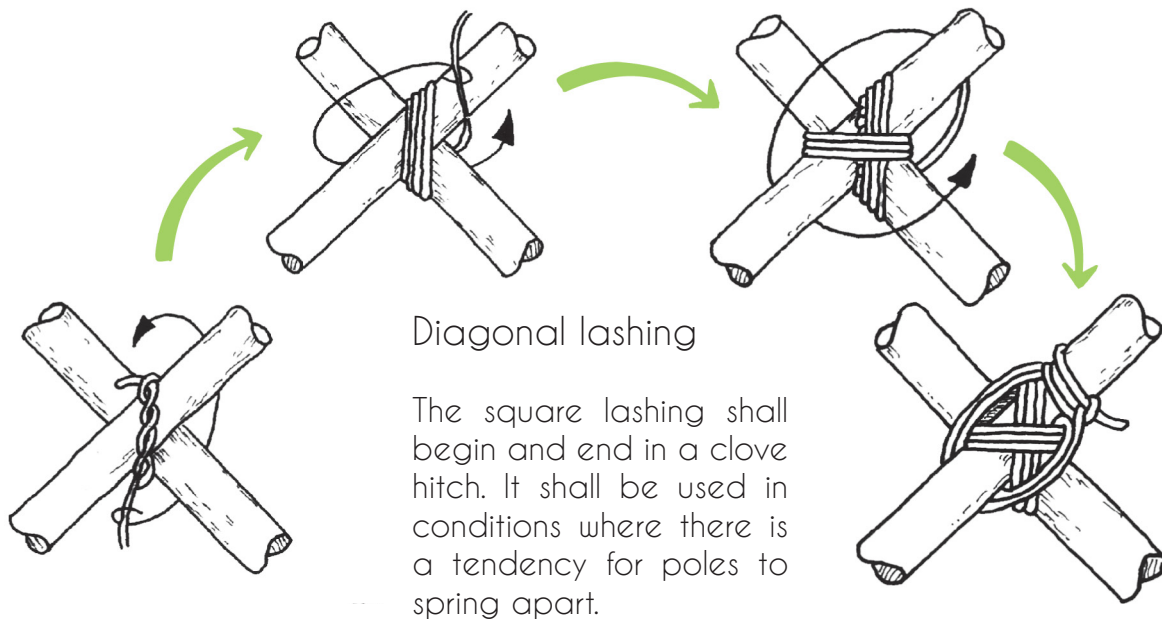


Fig. 138

The hole is greater than the sum of its parts

-Aristotle

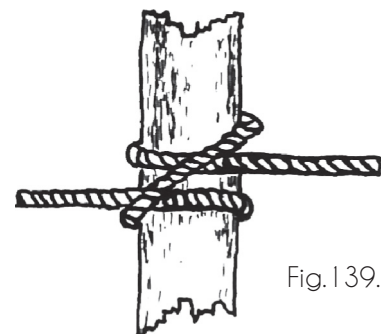


Fig. 139.

This lashing used to hold bamboo tightly.

Construction of roof structure.



Two types of roof can be made.

1. CGI sheets
2. Country tiles

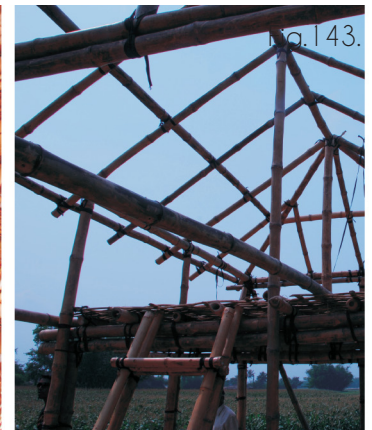
In both types of material, a hip roof is advisable.



Fig. 141.



For country tiles, the distance should not exceed 1 feet.



For CGI sheet, fix rafter over roof's bamboo beam, not exceeding 2' distance.



For CGI sheet use J bolts, at distance not more than 2'.

2 Bamboo in country tile roof



Country Tiles

The last line of country tile to be fixed between bamboos.

Fig. 144.

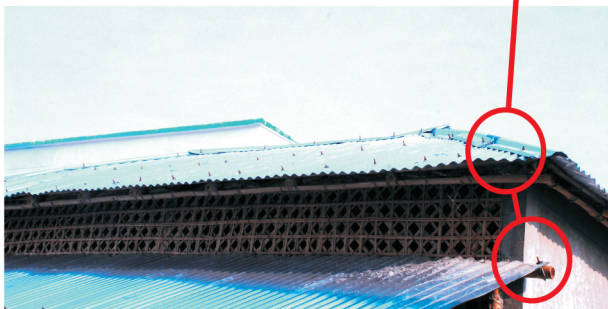


Fig. 145.

Plaster

1



Ensure that the bamboo work is strong enough, apply cement plaster on the exterior and mud plaster inside.

Fig. I 46.

2



Fig. I 47



Fig. I 48

To plaster on bamboo matt, apply first coat of rough plaster for proper bonding with the second layer. Then apply the second finish coat plaster. This plaster can be done upto 7', and bamboo jaafri can be used above that.

3



Fig. I 49.

Note:

To calculate the cost of a house, Fill rate of material and workers in the estimate sheet provided in the next page.

Estimate For 325 Sq Ft Bamboo House

Sr. No.	Item	Quantity	Unit	Rate	Amount
	Plinth				
1	Cement	15	Bag		
2	Aggregate	61	Cft		
3	Sand	90	Cft		
4	Reinforcement				
	10mm	26	Kg		
	8mm	36	Kg		
	6mm	19	Kg		
5	Brick	1600	No.		
6	Binding Wire	1	Kg		
7	Mason	10	Days		
8	Helper	14	Days		
	Super Structure				
1	Cement	8	Bag		
2	Sand	110	Cft		
3	Bamboo	110	No.		
4	G.I.Sheet				
	7 Ft Long	20	No.		
	6 Ft Long	9	No.		
5	J Bolt	200	No.		
6	Zeeper Materail For Fastining	5	Kg.		
7	Bamboo Treatment	110	No.		
8	Door (3' X 6'6")	2	No.		
9	Window (2' X 2')	2	No.		
10	Mason	5	Days		
11	Bamboo Artisan	20	Days		
12	Helper	25	Days		
13	Material For Mud Plaster & Floor	L.S.			
14	Bamboo Mat For Roof Under Ceiling	10	No		
	Total Cost Of House				
	Cost Per Sq Ft				

8. Journey From Past to Present



Fig.150



Fig.151



Fig.152.

Reference

Book:
Made Wijaya (2002), Architecture Of Bali, Archipelago Press And
Wijaya Words.

Web:
<http://www.panoramio.com/photo/34928606>.

<http://webecoist.momtastic.com/2011/06/20/building-with-bamboo-13-super-sustainable-structures/>

Fig.153.

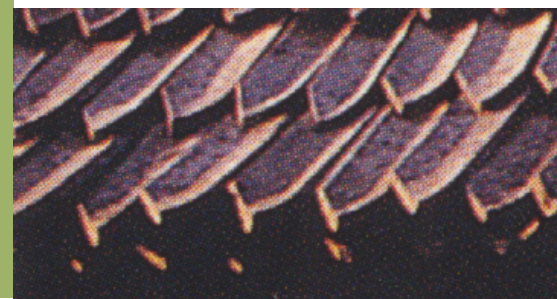


Fig.154.



Fig.155.



Fig.156.



Fig.157.



Journey From Past to Present



Fig.158.



Fig.159.



Fig.160.

Web Links

<http://www.architectoo.com/bamboo-structure-design-at-assembly-room/>

<http://permacoletivo.files.wordpress.com/2008/06/bamboo-building.pdf>



Fig.161.



Fig.162.



Fig.163.



Fig.164.



Fig.165.



Fig.166.

Journey From Past to Present



Fig.167.



Fig.168.



Fig.169..



Web :

<http://inhabitat.com/ibuku-constructs-three-new-bamboo-homes-in-balis-gorgeous-green-village/>

<http://inhabitat.com/co2-bambu-brings-low-cost-low-carbon-bamboo-housing-to-nicaragua/co2-bambu-homes-5/>



Fig.170.



Fig.171.

Journey From Past to Present



Fig.172.



Fig.173.



Fig.174.

Web :
<http://inhabitat.com/balis-new-big-tree-chocolate-factory-is-the-worlds-largest-commercial-bamboo-structure/big-tree-farms5/?extend=1>

<http://naturalhomes.org/bamboo-rice.htm>

<http://arkitektura.ph/posts/the-bamboo-bridge-in-davao>



Fig.175.

Fig.176.

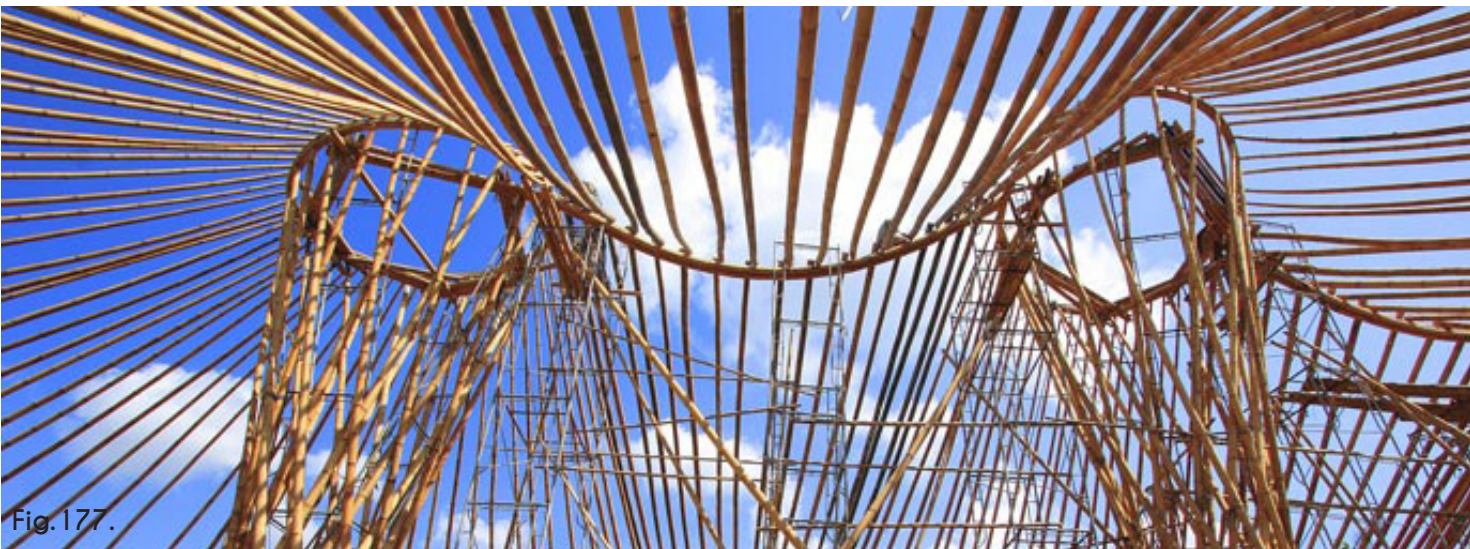
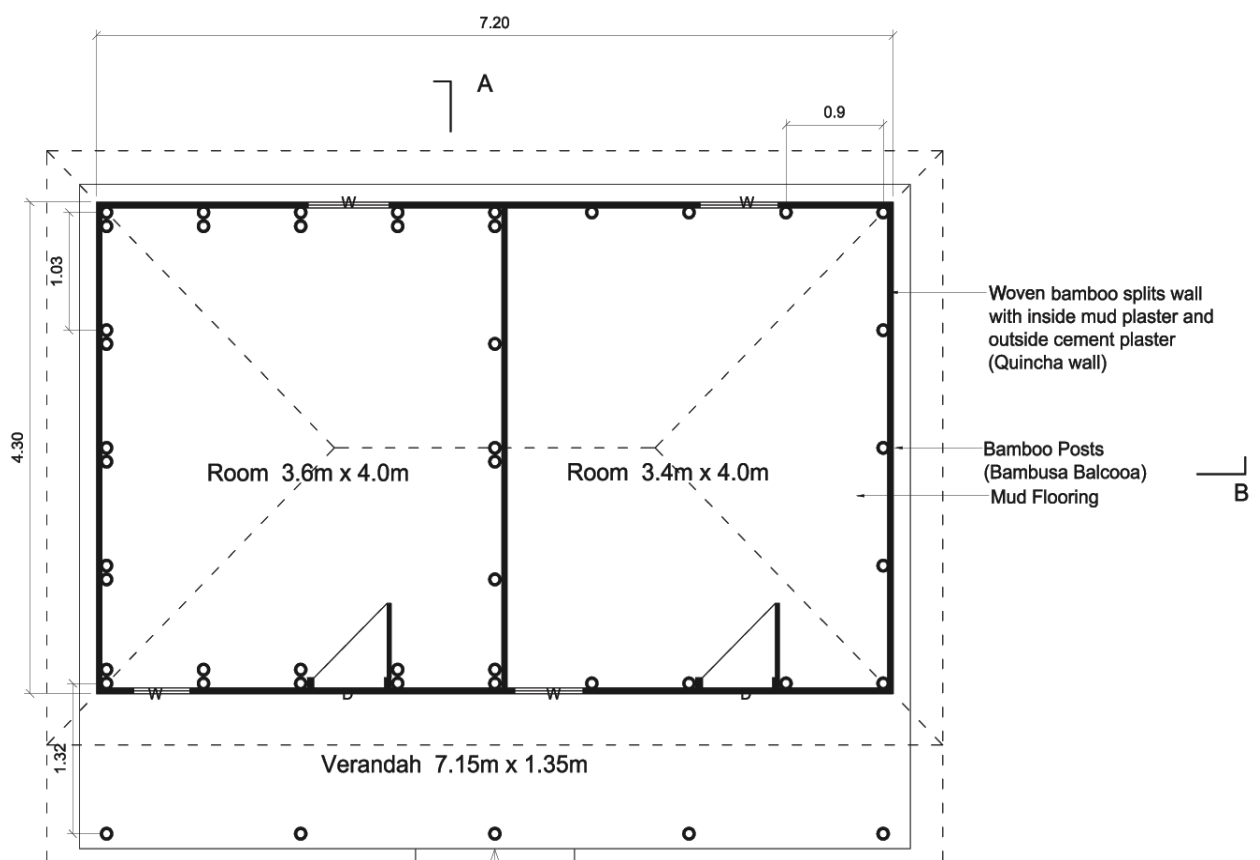


Fig.177.

Annexure-A

Alternative-1

A sample Design of House with Bamboo walls and CGI Sheet Roof

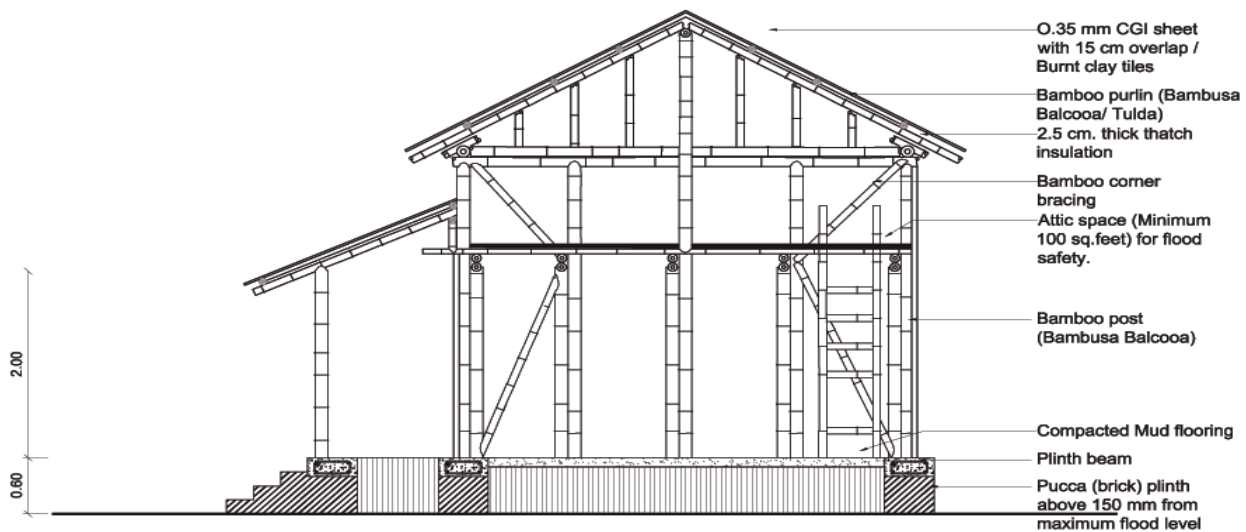


Ground Floor Plan

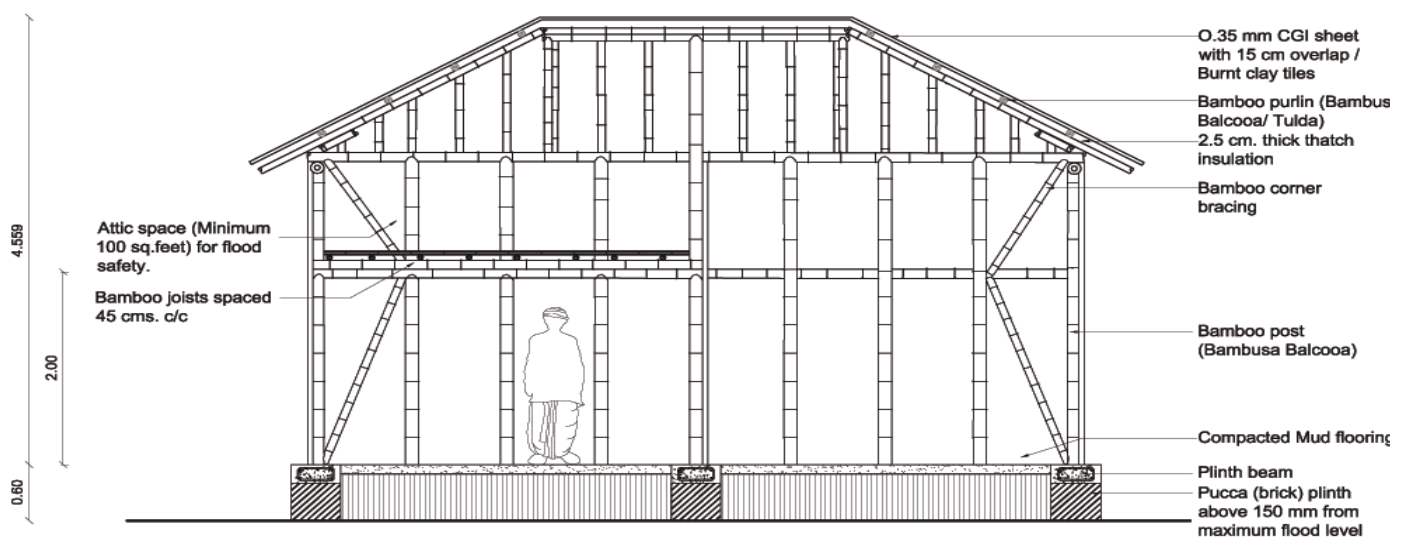
Reference

Book:

B.A.P.E.P.S Government of Bihar, India, Re-construction of Multi-Hazard Resistant house, Part-II Technical Guideline For Bamboo base construction



Section AA

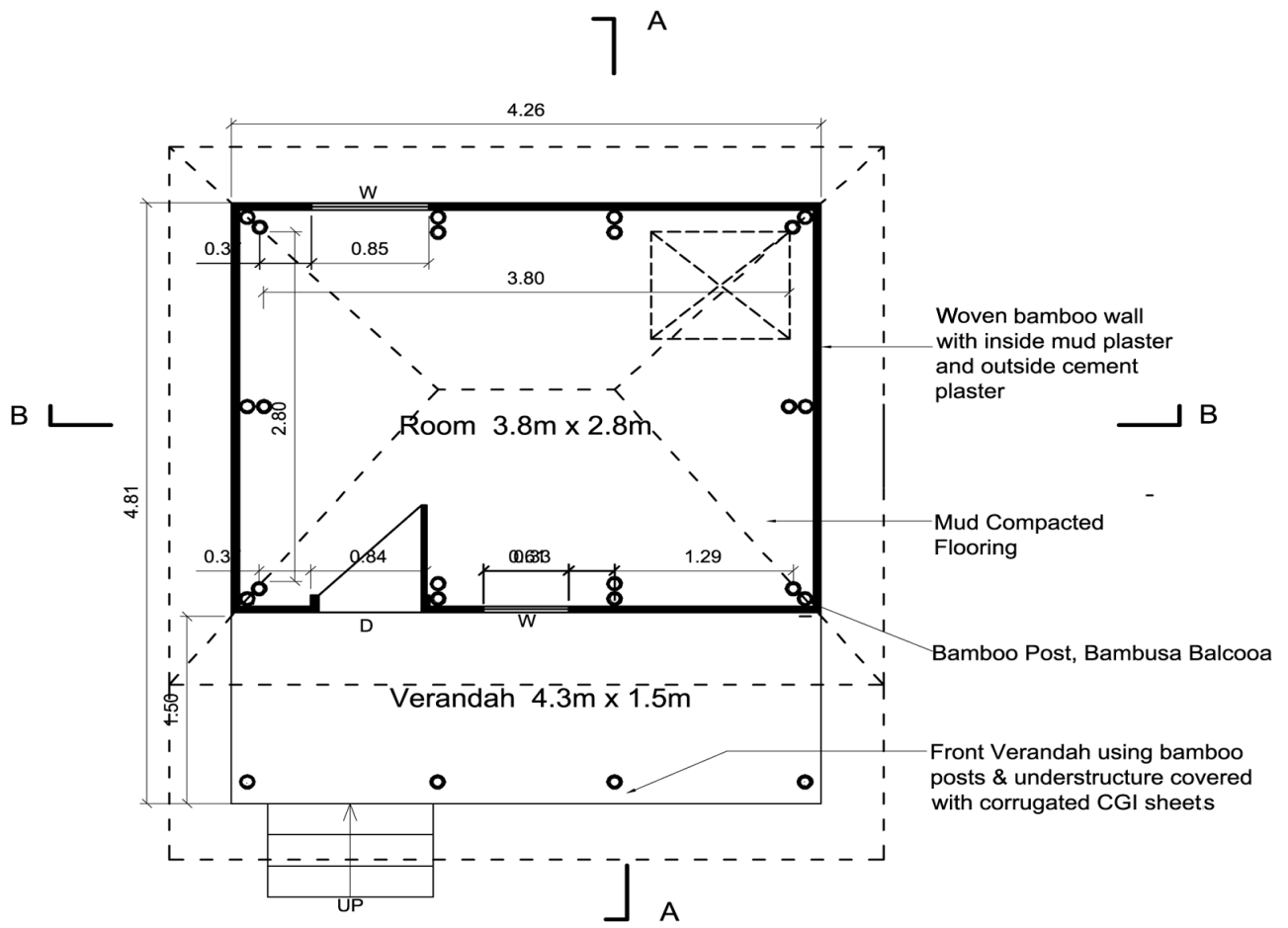


Section BB

Annexure-A

Alternative-2

A sample Design of House with Bamboo walls and CGI Sheet Roof

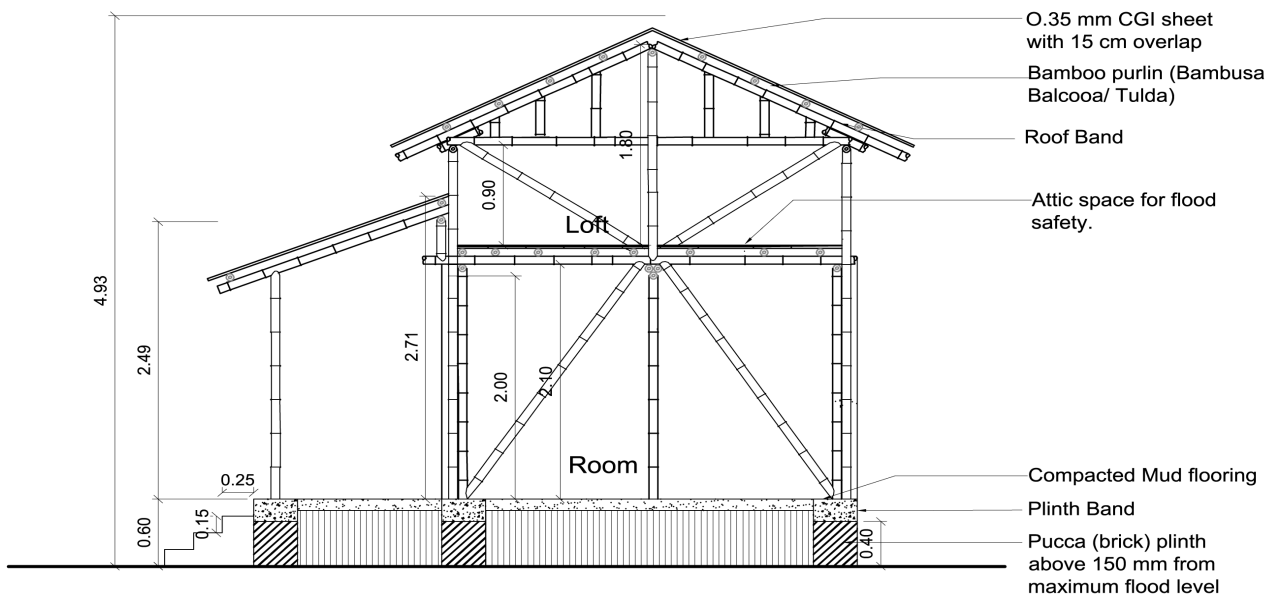


Ground Floor Plan

Reference

Book:

B.A.P.E.P.S Government of Bihar, India, Re-construction of Multi-Hazard Resistant house, Part-II Technical Guideline For Bamboo base construction



Section AA

Section AA

Annexure-B

Table 1 General Properties of Bamboo

Bamboo Species	Description	Culm height	Diameter	Internodes	Wall thickness
Bambusa Balcoa	A tall bamboo, greyish green; nodes thickened with a whitish ring above, hairy below; branches from the lower nodes leafless and hard, mostly spreading, sometimes thorn-like; young shoots blackish-green, green with yellow, brown or orange tinged culm-sheath, clothed sparsely with dark brown hairs.	12-20 m	8-15 cm	20-40 cm	Thick-walled the diameter of the cavity about one-third of that of the culm
Bambusa Tulda	This species is an evergreen or deciduous, tufted, gregarious bamboo. glabrous, green on maturity, some times streaked with yellow, almost un-branched below; internodes white ring below the nodes slightly thickend, lower ones have fibrous roots.	7-23 m	5-10cm	4070cm	Thin walled
Bambusa Nutans	A medium sized graceful bamboo, loosely clumped, much-branched above, usually un-branched below, straight, green, smooth, not shining, white-ringed below the nodes; slightly thickened, often hairy, lower ones bearing rootlets.	6 - 15m	5 - 10cm	25 - 45cm	Thick Walled

Web :

<http://www.bambootech.org/files/mechanicaltesting%20report.pdf>

<http://inhabitat.com/balis-new-big-tree-chocolate-factory-is-the-worlds-largest-commercial-bamboo-structure/big-tree-farms5/?extend=1>

Bamboo Species	Moisture	Specific Gravity	Shrinkage in Wall Thickness	Shrinkage in Diameter
Bambusa Balcoa	100-66% from base to top -green	0.79-0.85	11.1 to 4.8%	4.2 2.5%
Bambusa Tulda	73.6% - green 11.9% - air dry	0.722		
Bambusa Nutans	88% - Green 14% - air dry	0.673	3.8 6.3 % for different ages	4.6 6.6%
References	Kabir et al. 1991		Sekar et al., 1962; Sekar and Rawat, 1964	

Bamboo species	Bending Strength N/mm²	Compressive Strength N/mm²	Sheer Strength N/mm²	Modulus of Elasticity N/mm²
Bambusa Balcoa	12.3	51 to 57.3	11.9 (-1.9+1.2)	9.3-12.7
Bambusa Tulda	12.3	68	9.9 (-1.1+1.0)	10.0
Bambusa Nutans	7.6	47.9	10.5 (-2.2+3.8)	10.7
References	Jules JA Janssen, Bam- boo in Construction, INBAR	KK Seethalakshmi, MS Muktesh Ku- mar, Kerela Forest Research Institute (KFRI)	NK Naik, IIT, Mumbai	KK Seethalaksh- mi, MS Muktesh Kumar, Kerela Forest Research Institute (KFRI)

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Fig.176-177	Jimbawan photo

Aknowlegment

This book is a result of a collective effort made by a large team. The contributions made by each team member is immensely valuable. The names of all key contributors who are part of the larger collective is mentioned below:

Kiran Vaghela	Civil Engineer
Mahavir Acharya	Civil Engineer
Prajesh Jethwa	P.G.D.M.
Henish Kakadiya	Architect
Dipti Tanna	Architect
Dinesh Charan	Design Support
Zumi Shah	Architecture Trainee

“A dream you dream
alone is
only a dream.
A dream you dream
together is reality.”

- John Lennon





Hunnarshala Foundation for Building Technology and innovations
(A Registered Not-For-Profit Organization)

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