Construction Manual

Construction of Low Cost, Earthquake Resilient Bamboo Houses Using Treated Bamboos

Developed under the Project

"Capacity Building on Bamboo Treatment Techniques for Promotion of Earth Quake Resilient Housings and Structures in Hill regions of Tripura"

Developed by

FOREST RESEARCH CENTRE FOR LIVELIHOOD EXTENSION

AGARTALA, TRIPURA

A Unit of RFRI, Jorhat

Indian Council of Forestry Research & Education

An Autonomous Body Under

MINISTRY OF ENVIRONMENT, FOREST AND CLIMATE CHANGE,

GOVT. OF INDIA

TABLE OF CONTENTS

CHAPTER - I
INTRODUCTION

Tripura and North-eastern part of India comes under Zone V of earth quake susceptible zone. It is difficult for marginalized peoples in hilly areas of Tripura to afford pucca house to them. High degree of earthquake susceptibility of Tripura makes pucca houses in hilly region unfeasible for the low income groups of people. North-eastern part of India is blessed with ample Bamboo resources. Tensile strength of 28000 pounds per square inch makes Bamboo one of the strongest building materials. The strong mechanical properties of bamboo enable it to withstand heavy loads of concrete during building construction.

Forest Research Centre for Livelihood Extension, Agartala developed a low cost, earthquake resilient and eco-friendly Bamboo housing design which serves the interest of marginalized people of Tripura. The designs of the houses were developed under the NMHS project titled "Capacity Building on Bamboo Treatment Techniques for Promotion of Earth Quake Resilient Housings and Structures in Hill regions of Tripura". Under the NMHS project construction of bamboo buildings through a participatory approach at both the project sites (Machmara and Barkathal) are in progress by organizing trainings on different bamboo-based construction aspects as per the schedule of the project action plan of the project.

Advantages of Bamboo houses:

1. **Earthquake resilient:**
   - As Bamboo has higher tensile strength than many alloys of steel.
   - Higher Compressive strength to concrete mixtures.
   - Higher strength to weight ratio gives it a light weight but heavy strength.
   - Symmetrical layout in scientifically designed bamboo house structure evenly distributes the load.
   - The whole structure acts as a single entity as walls are interconnected.

2. **Low cost and eco-friendly:**
   - Estimated cost of construction of FRC-LE designed one Bamboo house is Rs. 80,000/-
   - Raw material is easily available.
   - Bamboo houses are eco-friendly and has a soothing micro-climate inside.

Aspects of Designing Construction Manual

There are mainly 4 aspects of this manual:

1) Social aspect
2) Technological aspect
3) Architectural aspect
4) Identification of issues and challenges to take care of

Social aspects:

It is mainly concerned with how to motivate the community and generate awareness on:

I. Sustainable harvesting of bamboos.
II. Application of bamboos.
III. Treatment of bamboos.
IV. Construction of Earthquake resilient houses.
V. To develop community enterprises along with capacity building for skill upgradation.

Technological aspects:

It is mainly concerned with methods of training of the target users on:

I. Sustainable harvesting techniques for different structural components and their storage.
II. Bamboo treatment techniques using different facilities (apparatus and machineries).
III. Fabrication of different building components.
IV. Assembling of components and construction of an earthquake resilient bamboo house.

Architectural aspects:

Ideas and innovations on:

I. Structural designs for different components.
II. Reducing the impact of earthquake on the bamboo buildings.
III. Reducing the impact/increase the strength of bamboo building to make it resistant to high speed winds.

Objectives of the construction manual:

- To provide a comprehensive idea of resources utilized for bamboo house construction.
- Documentation of the stepwise house construction procedure aiming towards the development of a user friendly construction manual.
- To estimate the cost involved in construction of bamboo house and awareness generation on the significance of bamboo houses in hilly regions of Tripura.

Generating awareness among the villagers to accept this technology:

At first we had to motivate the farmers to make them understand the need of the earthquake resilient bamboo houses for their benefit. We undertook some training programs for this purpose. The training methods adopted are Method demonstration and Result demonstration. We made them understand step by step all the procedures of the building of the house, its long-term benefit and also the advantages through proper training.

•

CHAPTER - II

RESOURCES UTILIZED FOR THE CONSTRUCTION

Here is a comprehensive description of the materials used during the construction of the Bamboo houses. The parameters such as durability, cost, protection from harsh climatic condition, maintenance, susceptibility from weathering, locally availability, ease of doing work, environmental friendly, economic feasibility were taken into consideration while choosing the construction materials for the Bamboo houses.

3.1 Location

Bamboo houses are ecofriendly, low cost, earthquake resilient. They can be constructed anywhere. It is built in the hill regions of Tripura by the indigenous people since time immemorial. The design has been evolved since then as there are new construction materials are now available. Bamboo houses made in the rural or hilly area is of low cost as the basic material *i.e.* Bamboo is easily available there but in the cities it may fetch a little high cost as the cost of Bamboo will include the transportation cost. In a highly sloppy land it is advisable to apply suitable engineering mechanism to decrease the slope of land before begin the building works.

3.2 Human Resources

Human labor is needed in three phases during the construction.

3.2.1 Masonry works

Masonry workforce is needed for raising the house foundation, building the half wall by bricks and for plastering work. A strong house foundation tackles the first shock of earthquake hence, skilled and experienced masons are advisable for masonry works as it involves mixing cement, sand in proper ratio. Some heavy laborers are also needed during masonry work while carrying sand, chips and for mixing cement.

3.2.2 Truss making works

Bamboo made truss and rafts is the fundamental structure on which the whole roof extends. Truss making needs a good knowledge of geometry. Skilled carpenters need to be hired for truss preparation.

3.2.3 Bamboo wall making works

Walls are made by binding the torja/splittings together. This job needs skilled craftsman who traditionally binds torja for wall making.

3.3 Material resources

3.3.1 Bamboos

a) Barak (*Bambusa balcooa*)

Bambusa balcooa is a strong, durable and hard bamboo used as a pillar/pole. 8 to 10 cm diameter is best suitable as a pole for house construction.

b) Muli (*Melocanna baccifera*)

Muli bamboo is preferred for making bamboo house wall. The treated Muli bamboo is spitted, expressed peripherally and dried under the sun. These splittings are popularly known as Torja (in Bengali **তরজা**, **চডি**). Muli is also used for making the frame (Khap: **খাপ**) in which the whole bamboo (torja) made wall will be fixed.

c) Kanakaich (*Thyrsostachys oliveri*)

It is a strong, straight and flexible Bamboo which is used in making truss on which the roof tin is fixed. It is one of the highly demanded bamboos grown in Tripura.

Muli bamboo

Kanak Kaich bamboo

Barak bamboo

3.3.1.1. Traditional Methods of Bamboo Preservation:

Traditional practices of preservative treatment are non-toxic which impart some degree of immunity to bamboos against bio-degradation. Such methods are being widely used by villagers and artisans in several countries.

I. **Curing**: The freshly felled bamboo is kept upright, with branches and leaves intact for a few days (10-15 days) when the nutrient and moisture used by the parenchyma cells in bamboo itself. The duration of curing may be estimated by drying up of the bamboo. continue to live for some time This results in bamboo with significantly less quantity of nutrients and moisture and therefore less attractive to biodegrading agents.

II. **Smoking**: Smoking is carried out in chambers / kilns. This produces toxic agents (as vapours) and heat which destroy starch in bamboo thus making them immune to insect attack and also blackens the culms.

III. **Storage in Water**: Bamboos are kept in water bodies like pond, rivers etc. for a period of a month or two for the preservative action to occur. During this process the soluble nutrients leaches out of the bamboo besides such treatment may also imbue some microbes which gives it a protective covering against some rotting fungi

IV. **Controlling starch content in felled bamboos:** Soluble sugars are the principal nutrients for bio-degrading agency. Thus, bamboos with depleted carbohydrates/ soluble sugars become reasonably resistant to them. Sugar content in bamboos varies with season sand maturity of bamboo; it is higher in summer and less in winter and also very mature bamboos. Therefore, it is advisable to harvest bamboos between August and December and use mature bamboo of 4 years and above.

V. Lime/tar coating: Usually, the whole of bamboo is coated with lime/tar to enhance its durability. The cuts ends and openings after removal of branches usually serves as the entry points for the bio-degrading agents and application of such coatings serves as an impenetrable layer to them.

3.3.1.2. Chemical Methods of Bamboo Preservation

Chemical treatment is more effective than traditional treatments. Typical chemical treatment methods uses water soluble preservatives like Gamma BHC 0.5%, Formalin 0.5% , Phenol+ 1 Copper sulphate (1: 2), sodium pentachlorophenate 0.5% and Borax 1.5%. The chemicals are dissolved in water. Bamboo or bamboo mats are either sprayed with the solution or dipped in the solution for 10 minutes. After treatment the bamboo mats are stored in shade till they are processed further. Bamboo is non-durable in its natural state. Durability can be greatly increased by preservation with safe, environment-friendly chemicals, such as boron. Several simple and cost-effective treatment methods are available.

3.3.1.3. Treatment of Fresh Bamboo

I. **Butt end treatment / Steeping:** Freshly cut culms arc immediately placed upright in containers of concentrated solutions of water-borne preservatives (5-10%). The basal end should be kept immersed in the preservative solution up to the level of 25 – 40 cm. Generally, drops of preservative solutions are observed at the nodes. The treatment takes between 7 and 14 days, depending on the length of the culm. Losses in preservative solution in the container are made up to maintain the initial level of solution. Bamboos can be satisfactorily treated by this method without any equipment and technical skill.

II. **Sap displacement:** Round or split fresh bamboos are immersed vertically up to 25 cm, in water-borne preservatives like copper-chrome-boron (CCB) in suitable containers. The preservative solution rises by wick action as the sap is sucked up. Solution level is maintained by adding fresh quantity at intervals. A meter long bamboo can be treated in just six days. Longer pieces can be treated over a slightly longer period.

III. **Diffusion process:** In this process, freshly felled culms or bamboos with high moisture content is kept submerged in solution of water-borne preservatives for a period of about 10 to 20 days. In round bamboos boring holes near the nodes results in better penetration and higher loading. Preservatives that fix slowly, or have high diffusion coefficients like boron-based preservatives, penetrate better.

IV. **Boucherie process**: This is widely recognized process. It is suitable for freshly felled bamboos with or without branches and leaves. In this process, one end of the bamboo is connected to the reservoir containing the chemical preservative through a coupling unit. The gravitational or hydraulic pressure pushes the preservative through the bamboo.

3.3.1.4. Treatment of Dry Bamboo

I. **Soaking**: Air-dried bamboos have only to be submerged in the preservative solution (oil or solvent type) for a period depending upon the species, age, thickness and end use. It requires little equipment and technical knowledge, provided the schedule of treatment is known. Soaking treatments with solvent like pentachlorophenol, copper/zinc naphthenate/ abietate, work better than steeping in water-soluble preservatives. Such treatments may, however; be more expensive in some countries because of the cost of the solvents.

II. **Brushing / Painting**: Decorative items may be brushed or painted with preservative chemical for protection against biodegrading agents.

III. **Spraying**: Bamboo stacks are sprayed with chemical preservative with suitable quantity and concentration of preservative, at various stages of stack preparation so that preservative distribution is uniform. It is then covered with suitable cover like plastic sheet / tarpaulin so that the preservative chemical is properly soaked into the bamboo. This method is suitable for large-scale preservative treatment, both in green and dry, during bamboo storage.

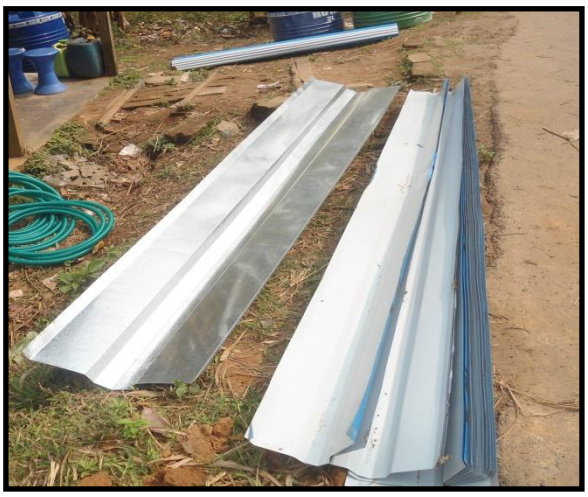
3.3.2 Roof tin

Roof tins are available in the market of various sizes (10 feet, 7 feet etc.) and color. While working with the tins the workers should avoid direct contact with the overhead electric lines (if any).

3.3.3 Ridge (in Bengali: টুলি, tuli)

Metal tin ridges are available in the market of various widths (18 inches, 24 inches etc.). In case of a triangle shape roof structure a gap remains in the inter junction point. Ridges are fitted in the inter junction of the roof tins to cover the gap.

Roof tin



Tin ridge

3.3.4 Brick

Bricks are rectangular blocks of baked clay used for building walls, which are usually red or brown. A good brick should be uniform in size and shape. It should be fine, compact and should meet the required hardness. Bricks should have low porosity and adsorption capacity. Sand in bricks increases the heat resistance, durability, preserves the shape and prevents shrinkage.

3.3.5 Cement

It is calcareous binding or cementing material used in building construction. Cement is excellent binding material better in high strength, quick setting and water tight properties.

3.3.6 Sand

Good quality sand is sharp, clean coarse and gritty in touch. Coarse sand is desirable to get stronger mortar. The ideal pore space for sand is 30-40 %. River sand is made up of pure Silica and suitable for plaster, mortar and concrete works.

3.3.7 Concrete Chips

Concrete Chips are needed making the foundation of house.

3.3.8 Brick Chips

It is made from crushed bricks and used for matrix in mortar. Surki (brick chips) may be made from well-burnt bricks or from half burnt bricks. Now a day it is available ready-made. Brick Chips are needed for making the foundation, flooring etc.

Sand

Brick chips

3.3.9 Nut-bolts

A nut is a type of fastener with a threaded hole. Bolts are fasteners that require a nut or pre-tapped hole to be installed. Nuts are almost always used in conjunction with a mating bolt to fasten multiple parts of bamboo together. Nut-bolts are used in the following ways:

- Fixing of bamboo poles in the building foundation through the iron clamps.
- Fixing and joining of trusses together.

Along with nut-bolts nails are also needed for fixing the L-shaped clamps with the truss for extendi

Bolt

Nut

3.3.10 J- Hooks, washer

J-Hooks are used for fixing the metal tin to the bamboo truss for building the roof. In a set of J-Hook a washer, a rubber washer (Bitumen) and a nut is used for fastening the J-Hook with the truss and the tin.

J-hook

Metal cap (Tupi)

3.3.11 Clamps (Iron)

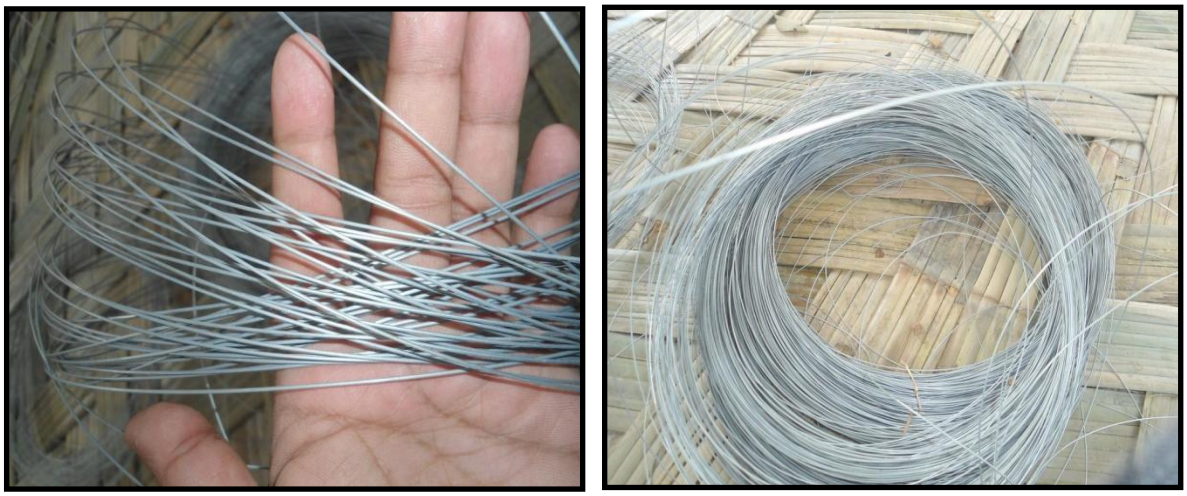
I-shaped and L-shaped clamps are used in bamboo house building. The L-shaped clamp is used in the truss for extending the veranda and I-shaped clamps are used for joining the truss together in the roof structure.

Iron Clamp

3.3.12 GI wire

G.I wire is very useful for binding purposes and also used in various other purposes. It is available in market in various diameters. The G.I wire of medium diameter is worker friendly for binding the bamboo torja/splitting and while fitting it to frame of the house wall.

Fibers extracted from bamboo can also be used for binding the torja/splitting with the frame of the house wall.



GI wire

3.3.13 Sand Paper

Sand paper is needed for smoothen the surfaces of Bamboo.

3.3.14 Paint and burnish

It is good to apply burnishes in the bamboo pole or bamboo wall. Burnish protects the bamboo surfaces from water and other biotic elements and extends its durability.

3.4 Tools and machines

Washer

Bitumen washer for fastening J-hook

ses

- **Drill Machine:** It is used for making holes in the bamboos for inserting bolts.
- **Sly slide wrench:** Used for tightening and loosening the nut-bolts, screws etc.
- **Hammer:** It is needed for various purposes.
- **Hand Saw:** Cutting, sizing of bamboo and bamboo splittings.
- **Bill-hook (in Bengali: হাত দা'ও):** Very useful tool while working with bamboos.

Wedge

Hand saw


Drill machine

Sly slide wrench

Pancho: An Instrument for making hole

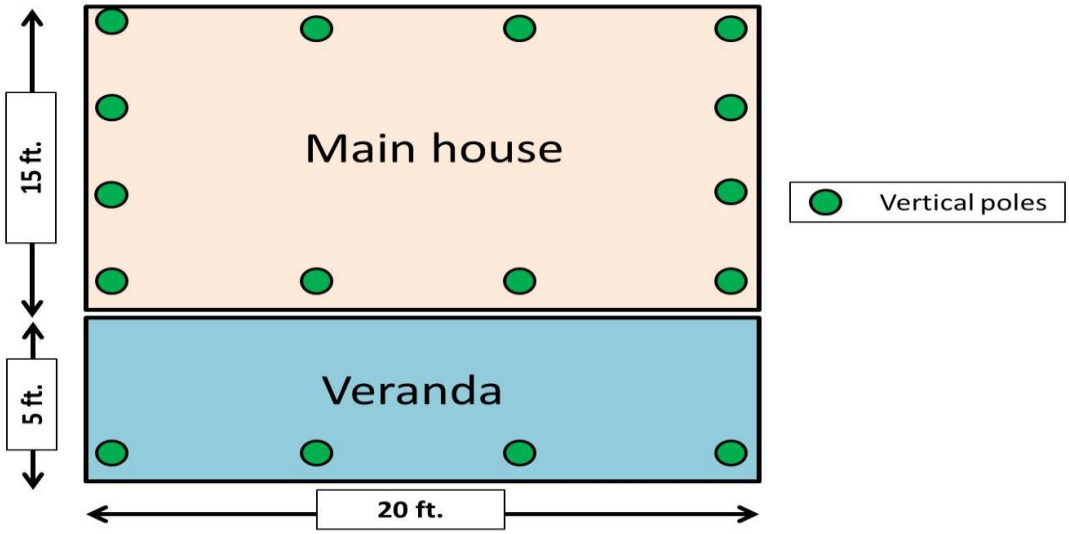
Bill-hook (in Bengali: হাত দা’ও)

Hammer

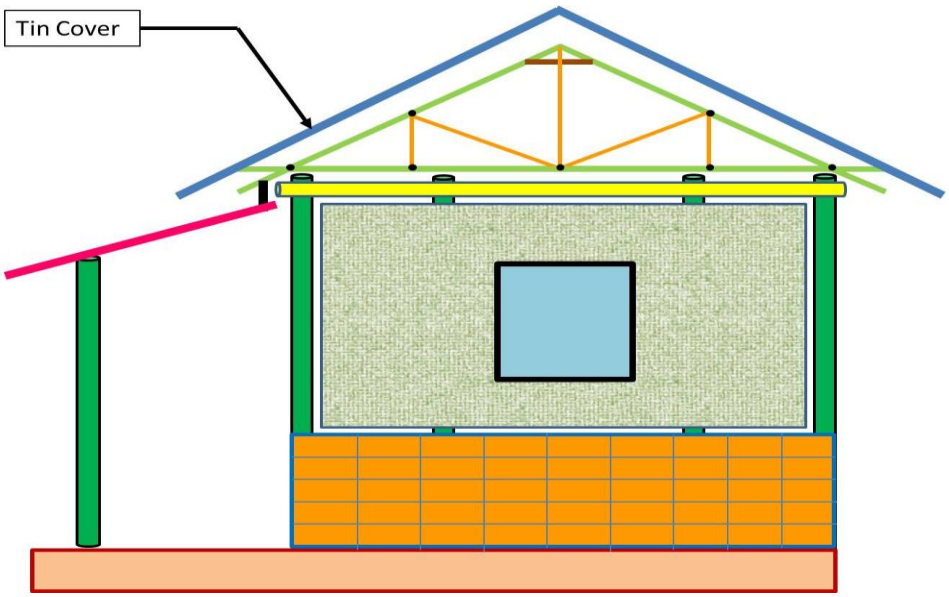
CHAPTER - III

DESIGN AND DIMENSION

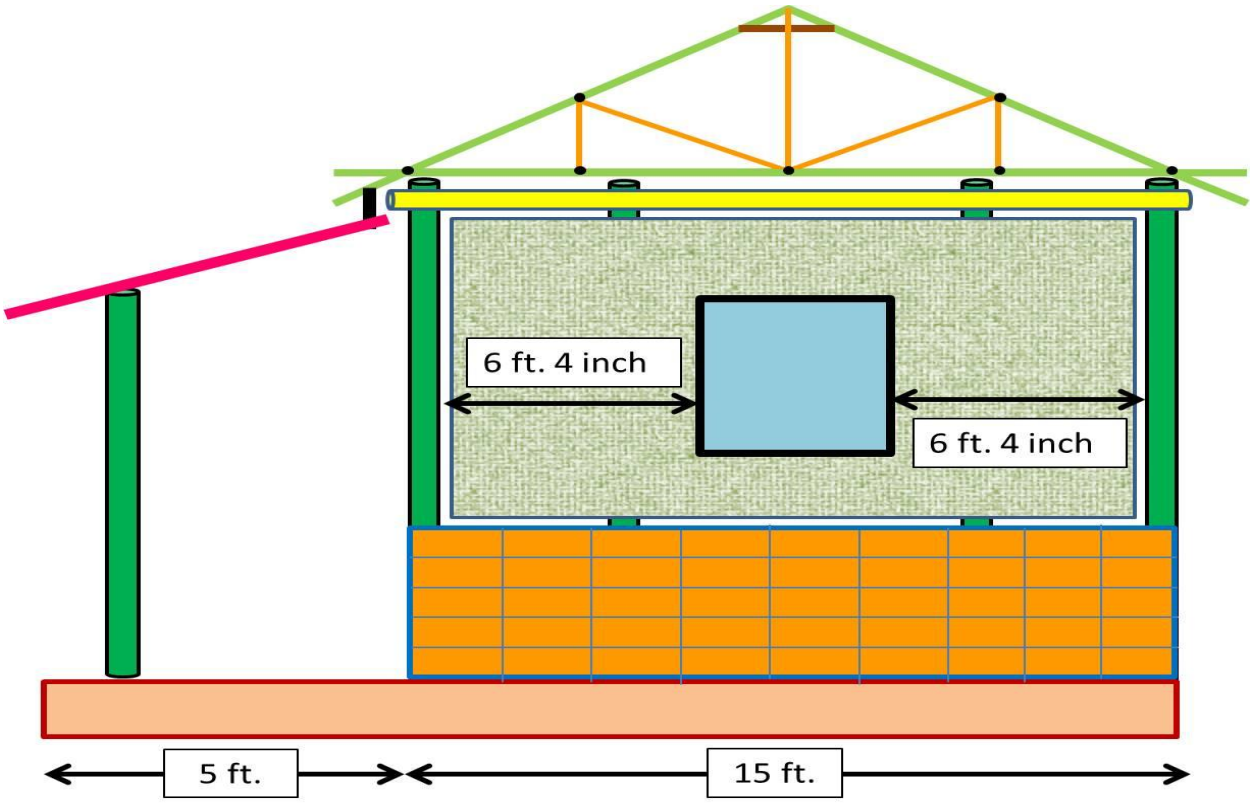
Three different designs have been developed by Forest Research Centre for Livelihood Extension, Agartala for earthquake resilient bamboo houses. These different housing designs, their side views and their dimensions are presented in this chapter. The orientation of the house may vary according to the local conditions like sunshine, prevalence of wind direction, slope of the land etc. The dimension and numbers of the doors and windows also may vary depend on the choice and preferences of the house owner.



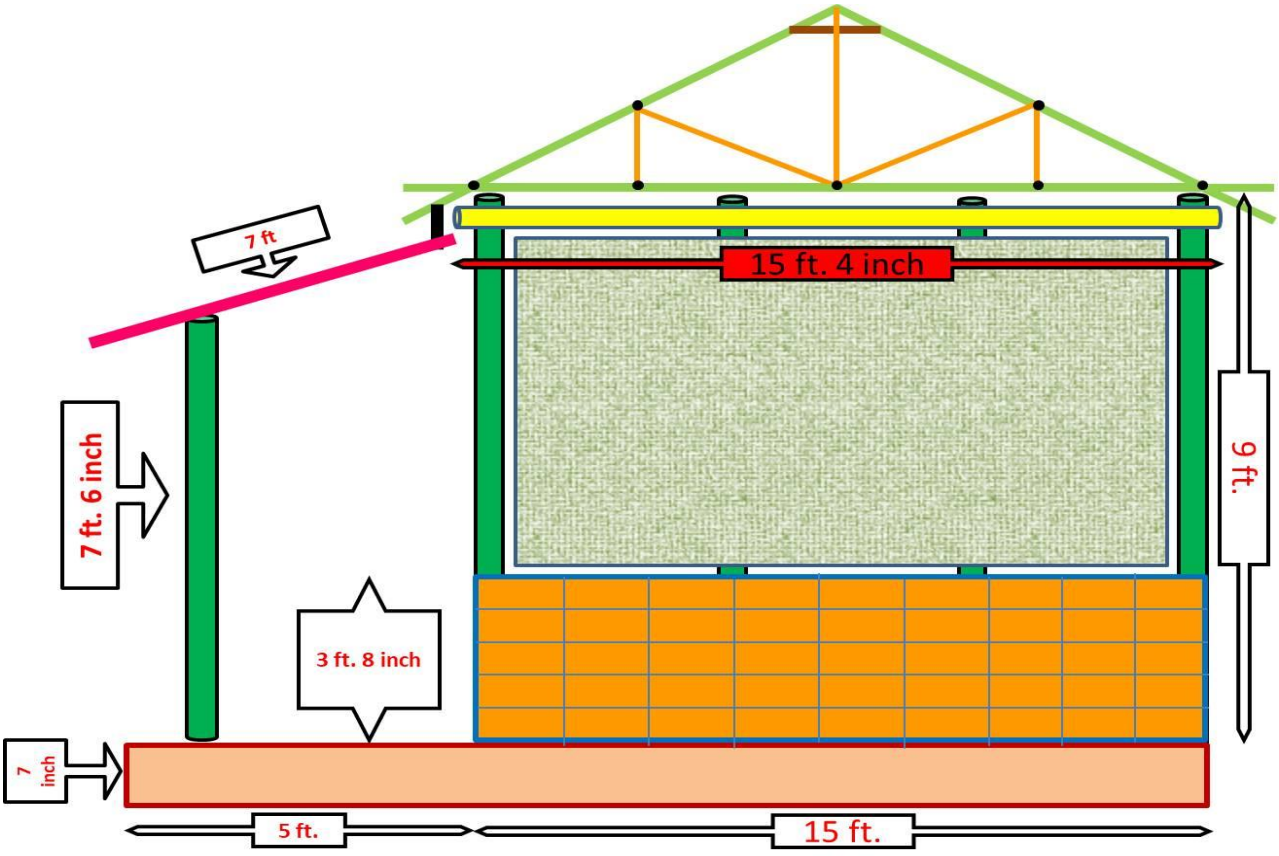
Aerial view: showing the positions of the poles



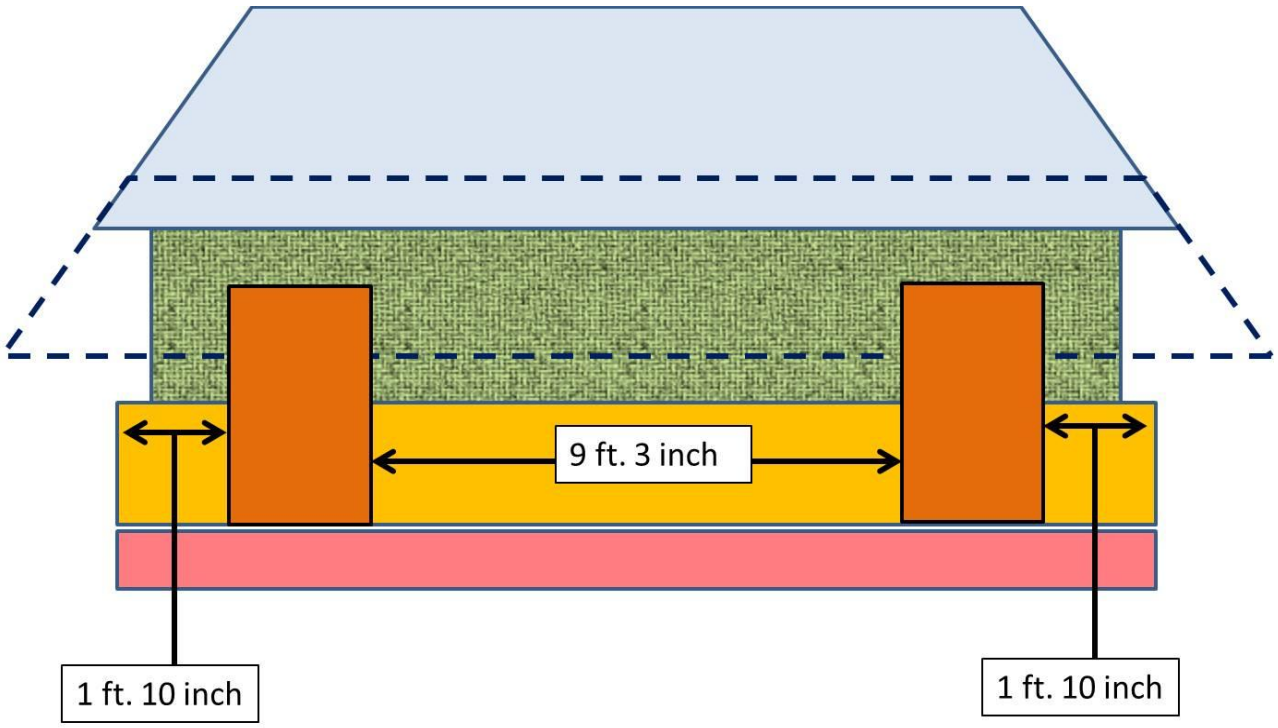
A side view of the house with tin cover



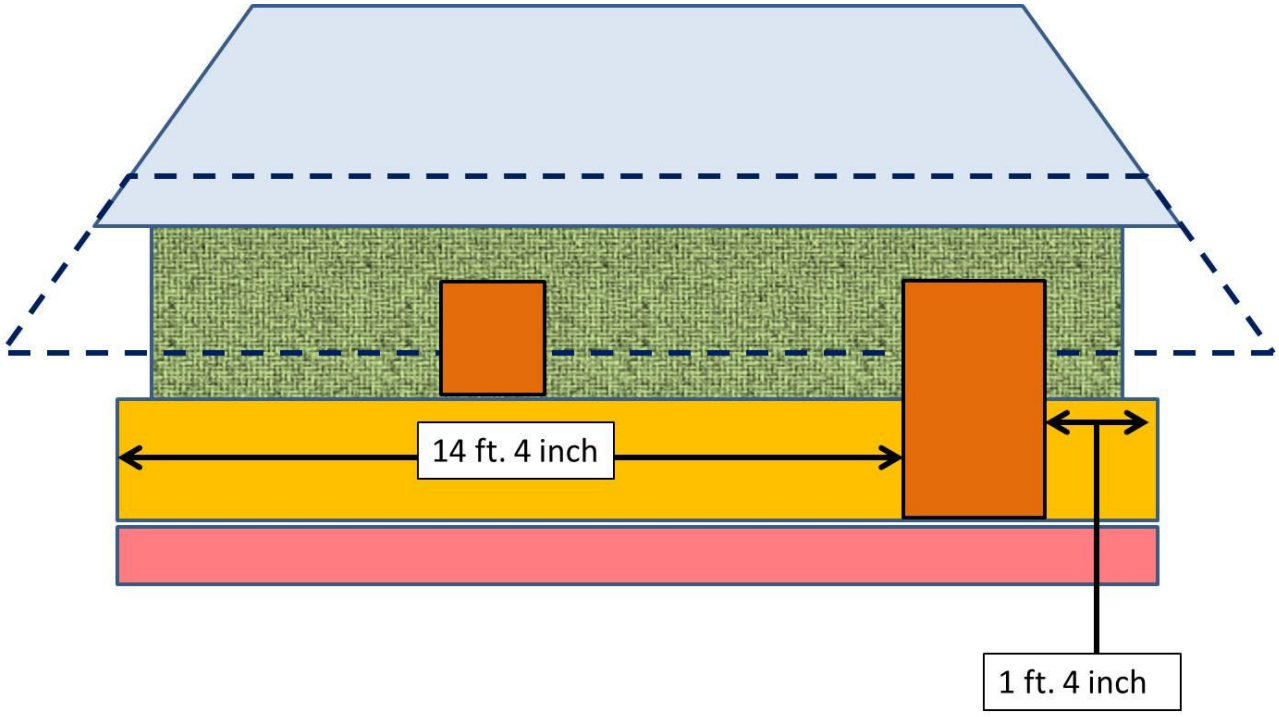
Side view (along the width) of a house with window



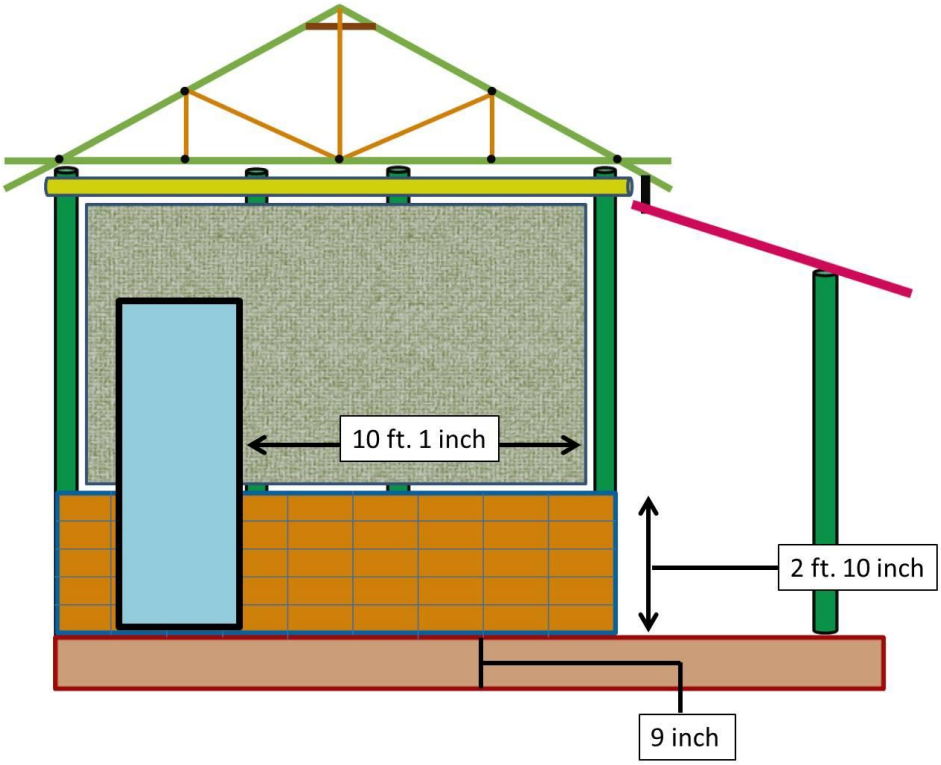
A Side view (along the width) of a house without window



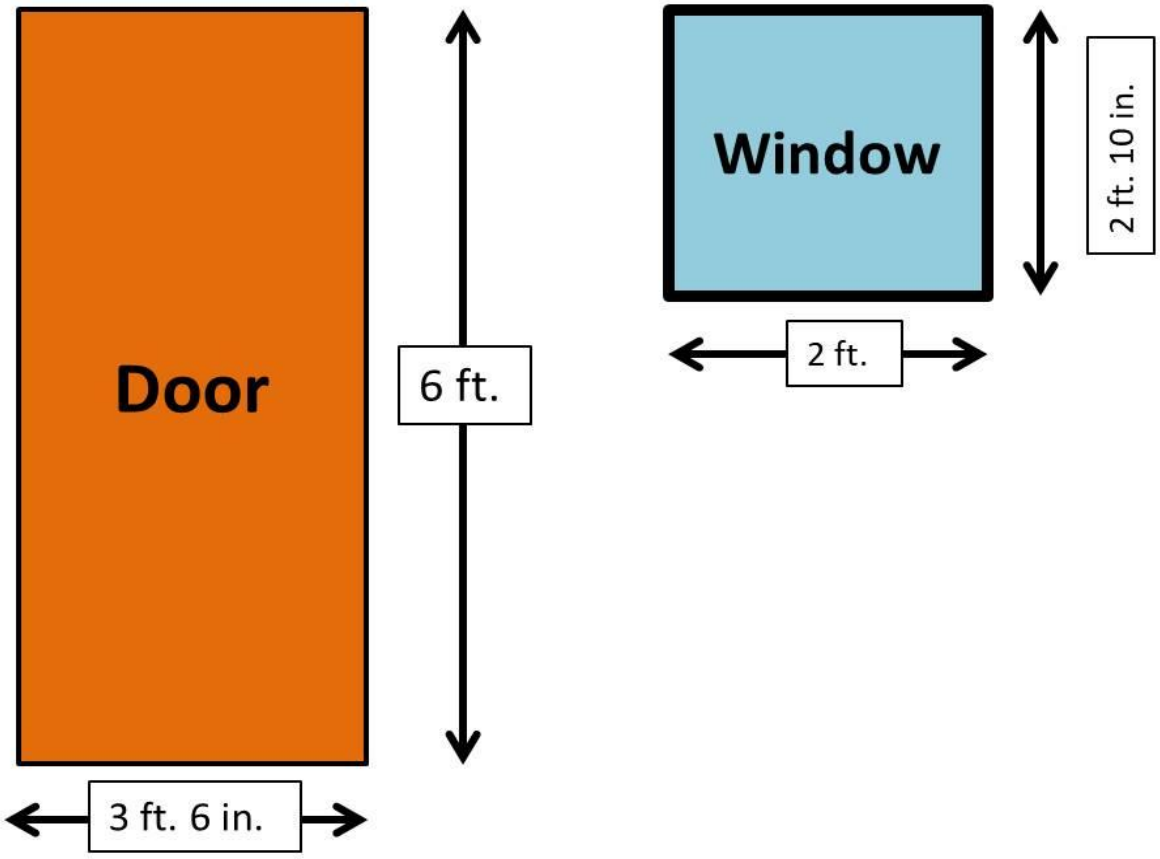
Front side view of a house with 2 doors (dashed structure is the veranda)



Front side view of a house with 1 door and 1 window



Side view of a house with 1 door



Dimensions of doors and windows

Roof structure of the house

CHAPTER - IV

CONSTRUCTION PROCEDURE

4.1 Foundation

Foundation is the extensions of the base of the structures such as walls and columns that are directly supported or kept in equilibrium with earth. Foundation bed is the prepared ground over which the foundation rests. It transmits the load of the structure to the soil. The foundation should be on the hard rock or gritty gravel. A good foundation avoids fracture due to unequal settling of the structure and soil and prevents the over loading of the substratum. The masonry should be kept damp by sprinkling water at frequent intervals.

a) Digging the Foundation Trenches:

Trench of 1 ft. 6 inch is to be made. The depth of the trench depends on the type of the foundation, type of the soil and on slope of the land.

b) Fixing the wooden frames

Sized wooden frame to be fixed on the trench in which the concrete mixture to be poured later.

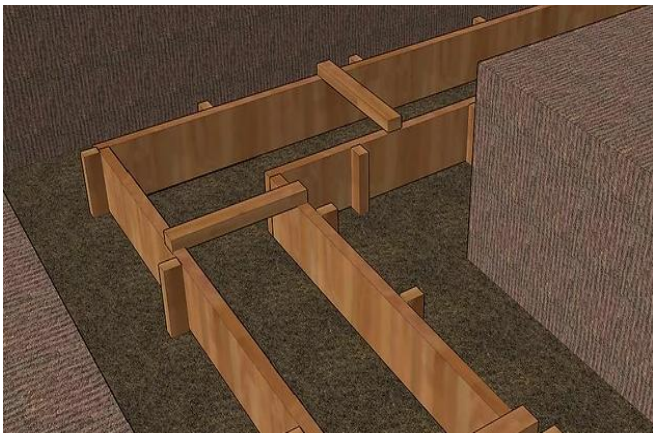
c) Adding sand to the trench:

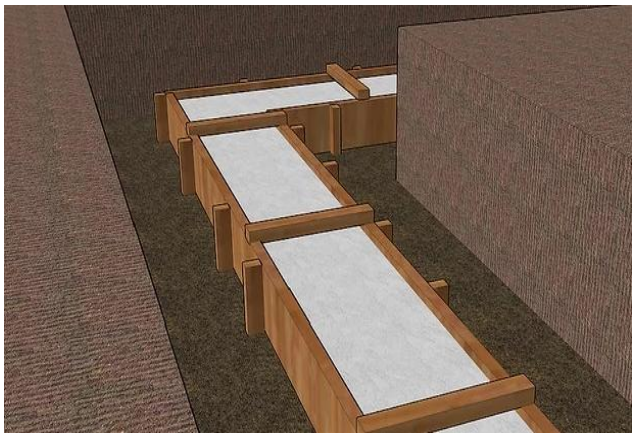
After the trench digging is done fine sand up to 3 inch from the bottom of the trench is poured. Sand prevents the side weathering and any kind of cracking.

d) Pouring the Concrete Foundations:

After the sand is poured in to the trench, the foundation is prepared by putting mixture of chips, cement and sand in the ratio of 4:1:2.6 (cft). The chips/concrete mixture is poured in to the wooden frame. After the chips cement mixture is poured it is allowed to be dried. Wooden frames are removed after the concrete thoroughly dries. This will take at least 24 hours. The concrete needs to be wet for the next few days to avoid cracking.

Cover the pad if it looks like rain.





Fixing the wooden frames for centering **Pouring the Concrete Foundations**

4.2 Brick Half-Walls

Walls are the vertical extension of the base or foundation. The house wall was constructed using bricks. In general 2 ft. 6 inch height of wall is made by placing bricks one above another in a staggered manner. Wall should cover all the sides of the house uniformly and uniform wetting is needed till the mortar/plaster sets.

Raising of the bricked wall

Treatment of Bamboo

Bamboo has enough potential to replace the needs of timber. The susceptibility of Bamboo to fungi and termite attack reduces its durability. To keep bamboo infestation free for a long duration there is need of treatment and preservation in bamboo. Technology developed by ICFRE on preservation and treatment techniques for bamboo has made it possible to extend the durability of bamboo by 3 to 5 times.

There are various traditional processes for bamboo treatment viz. **Soaking and Boiling Method, Butt end treatment / Steeping, Sap displacement, Diffusion process etc.**

Here for treating the bamboos VPI (vacuum Pressure Impregnation Machine), Boucherie machine and soaking method was used.

Boucherie process: This is widely recognized process. It is suitable for freshly felled bamboos with or without branches and leaves. In this process, one end of the bamboo is connected to the reservoir containing the chemical preservative through a coupling unit. The gravitational or hydraulic pressure pushes the preservative through the bamboo.

VPI (vacuum Pressure Impregnation Machine): This is a utility machine which works as per empty cell process. Vacuum is created and bamboo sap is collected by the sap collector machine. Thus a thrust for chemical is made inside the bamboo tissues. Chemical is ejaculated into the treatment chamber with high pressure which impregnates the bamboo culms with the chemical. The excess chemical is recovered in this process.

4.3 Roof

It is erected over the top of the building and other structures mainly to protect their interiors from atmospheric and other elements.

Purlin: A horizontal beam (bar) along the length of a roof, resting on principals and supporting the common rafters or boards. Purlins are fixed along the length and width of the house horizontally.

For this house construction purlin of Barak was used at the topmost horizontal position and Kanakaich was used in the middle position.

Truss: A Truss is a triangulated system of members that are structured and connected in a way such that they only incur axial force.

Strut: A rod or bar forming part of a framework and designed to resist compression.

a) Erection of Poles

After the erection of brick half wall vertical poles are erected from the foundation of the house. There are 12 numbers of poles for the house and 4 in the veranda. Poles are generally of Barak bamboos (8 to 10 cm dia.) which are strong enough to take the load of the roof and the bamboo made wall.

These vertical poles are erected from the foundation and attached to the based by an iron clamp. The concrete bases (foundation) for fixing the pole are made a little (6 inches) deeper than the foundation of the house which also may vary according to the hardness of the soil and slope of the land.

b) Fixing of Horizontal beam along the length and width of the house

Horizontal bars/beams/purlins are attached with the poles which connects the poles together. For veranda only Barak is used at the top of the poles and for house Barak is used as a purlin at the top and Kanakaich is used at the middle position.

Steps showing the fixing of vertical poles and horizontal bars

1: Fixed iron angle with the foundation

2: Making hole on the Barak pole

3: Fixing the pole with the iron angle

4: Tightening and aligning the pole

5: Fixing of the horizontal bar/beam/purlin

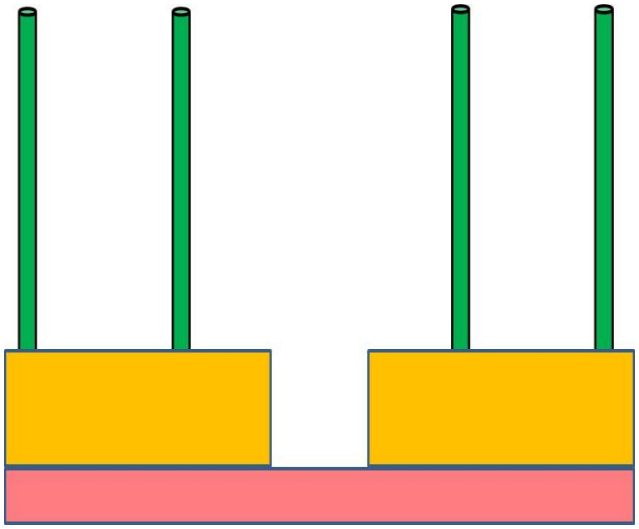

A section of bamboo can be used in case a bolt length go excess



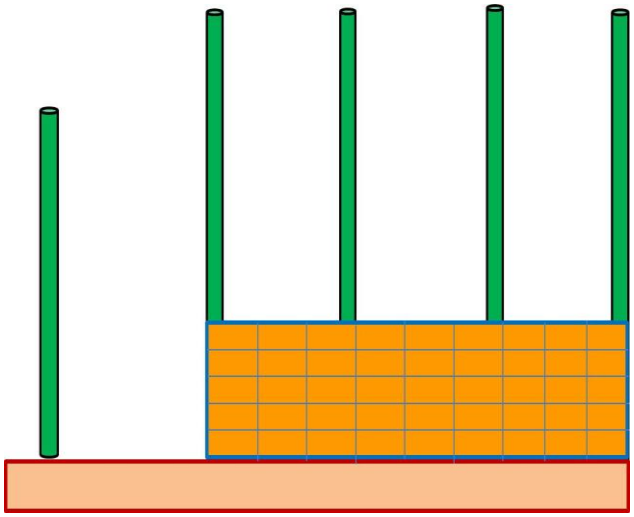
The house with the internal bamboo structure

Erection of vertical poles and fixing of horizontal bars/purlins

Step 1: Erection of vertical poles

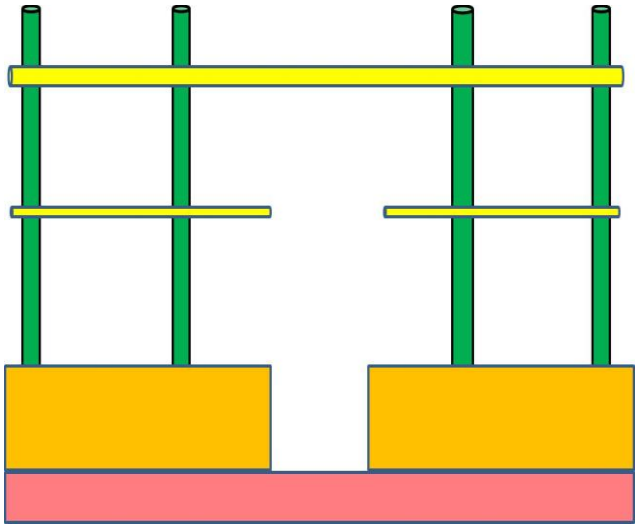


Front view

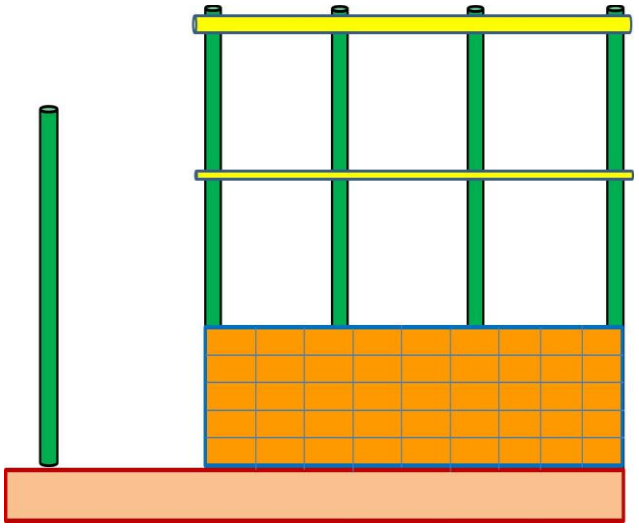


Cross sectional view

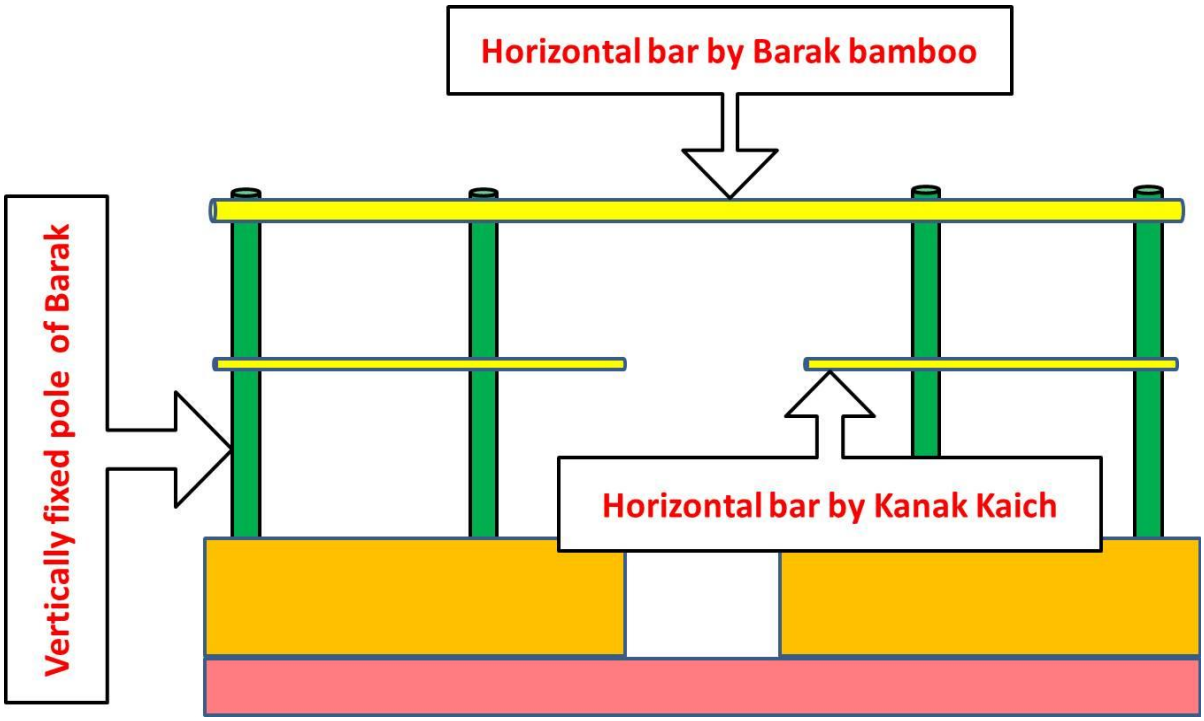
Step 2: Fixing of horizontal bars



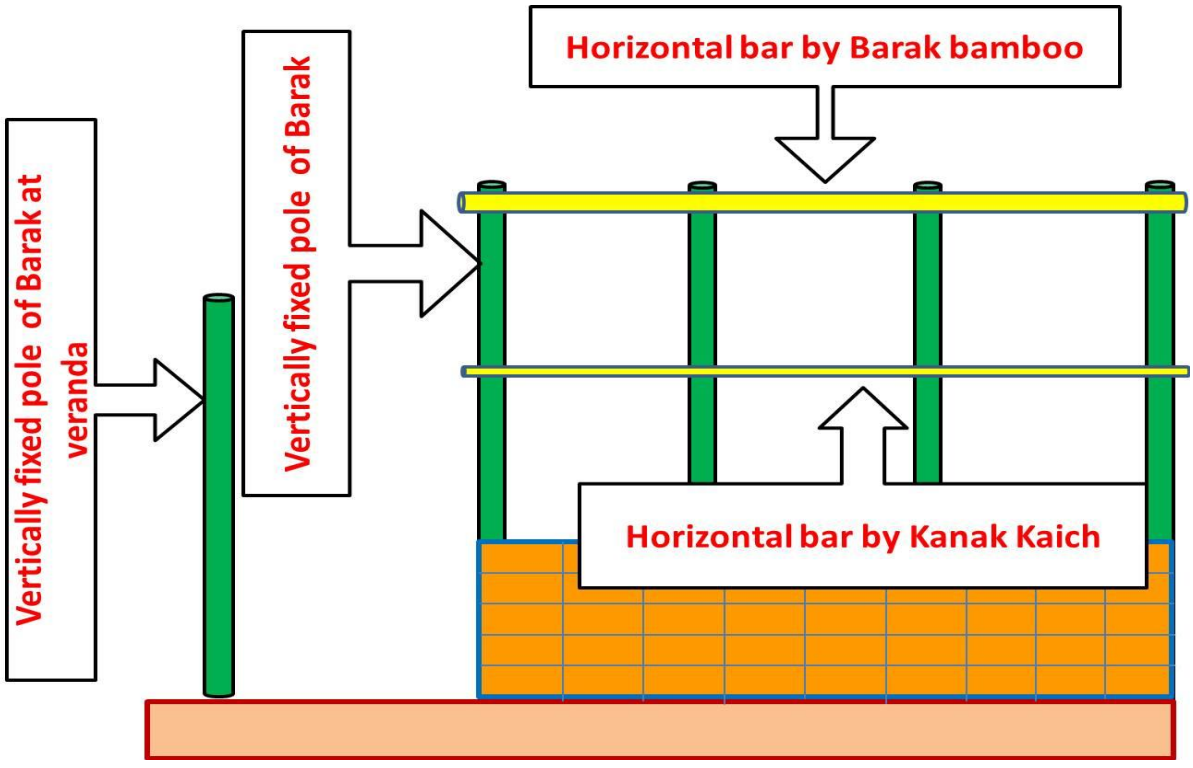
Front view



Cross sectional view



Front side view



Cross sectional (along the width) view

4.3.1 Roof structure

a) **Making the truss:** The truss on which the roof sits is a triangular structure. For this house 5 numbers of triangular trusses were made. The truss is made of Kanakaich bamboo. In order to make the truss the convenient length of the base of the truss was 15 ft. 4 inch.

2 pieces of base (15 ft. 4 inch.) is taken. A triangle is formed by joining 2 more pieces of bamboo of 8 ft. 4 inch which are joined together by an iron clamp and joined with base at their other ends. The so formed triangle is considered as main triangle.

The main triangle is divided in to 2 right angular triangles by placing the one end of a bamboo piece of 3 ft. 9 (piece A) inch between the 2 pieces at the base and joining the other end with the top most corner of the main triangle.

Each of the so formed right angled triangles is again divided by placing a 2 ft. 2 inch of bamboo (piece B) parallel to the piece of 3 ft. 9 inch (piece A).

In the last step of truss formation a bamboo piece 3 ft. 8 inch (piece C) is joined connecting the piece A and B diagonally.

(Note: piece A, B, C is indicated in figure)

b) Joining the truss with the poles:

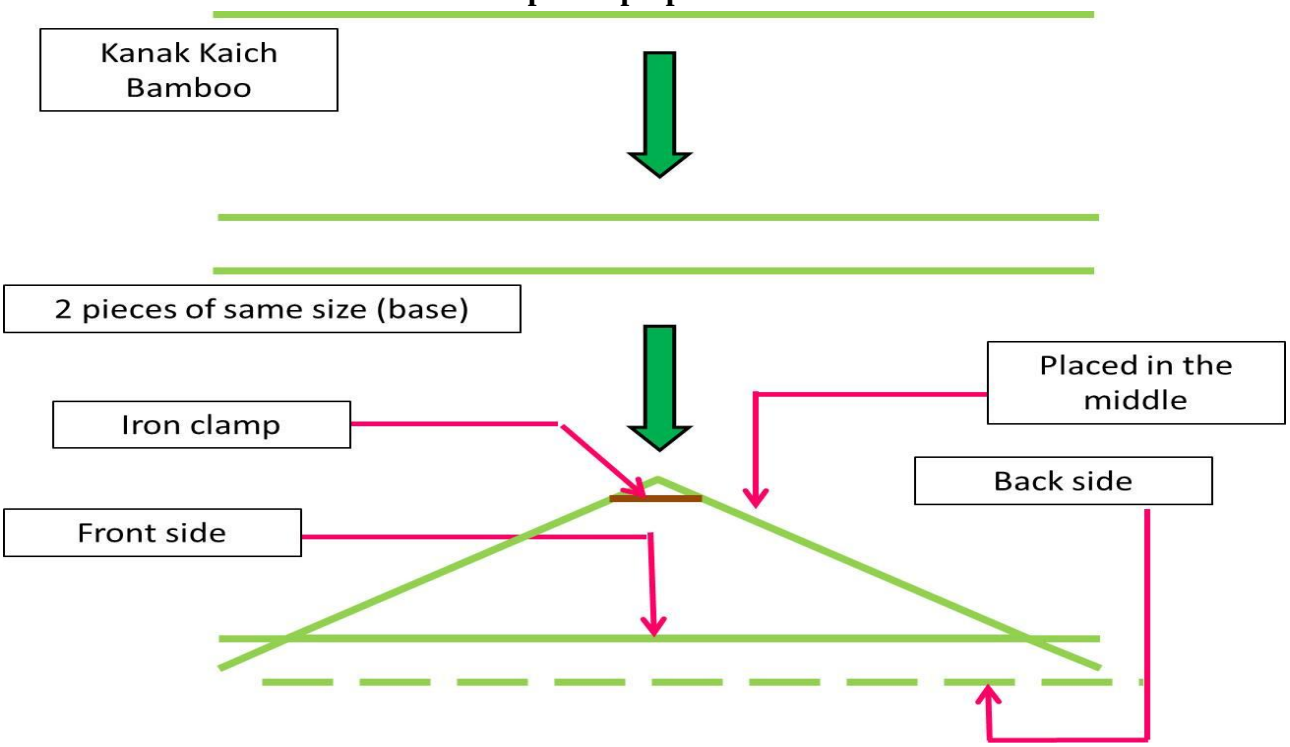
In total 5 number of triangle truss are made and each of the truss are joined with the poles of the house.

c) Inter joining the truss (triangles) by parallel horizontal beam/purlin:

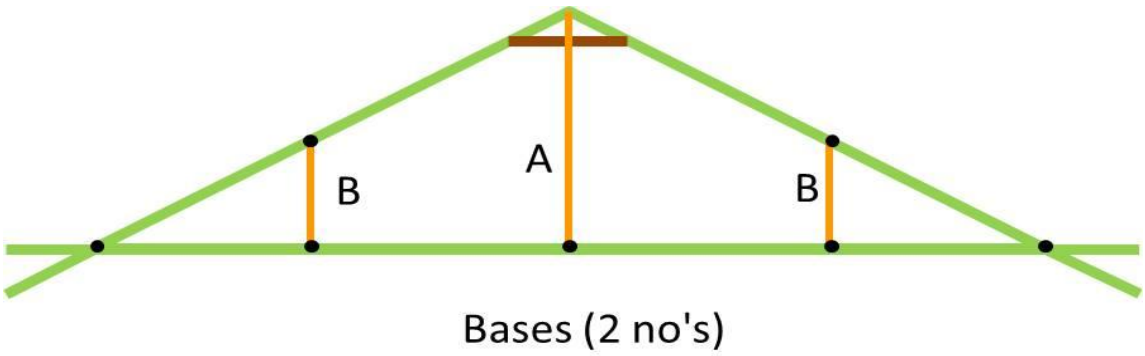
To provide better stability these triangular trusses are inter connected by parallel horizontal beam/purlin of nearly 22 ft. Kanakaich pieces along the length of the house. There are 8 numbers of horizontal beams on the roof of the main building and 3 numbers of horizontal beams on the veranda.

Joining of truss with horizontal bars

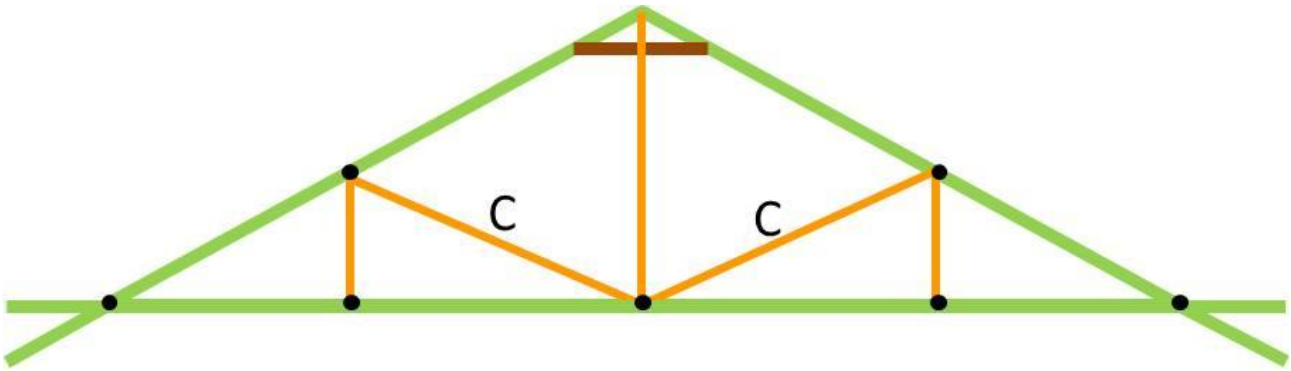
Step wise preparation of truss



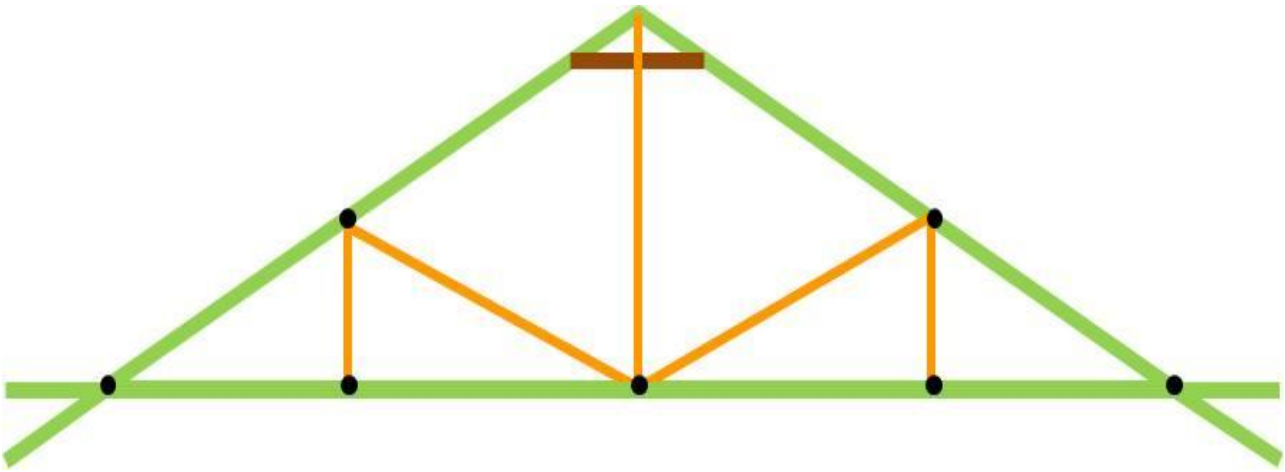
1: Making the base and forming the main triangle



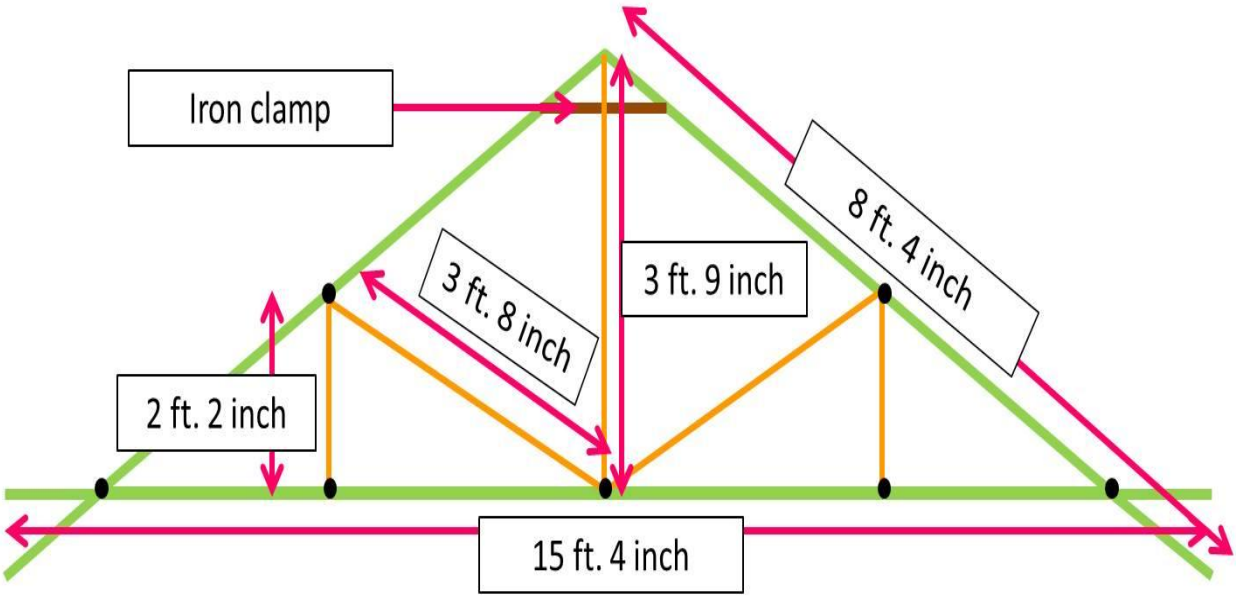
2: Fixing the vertical bars



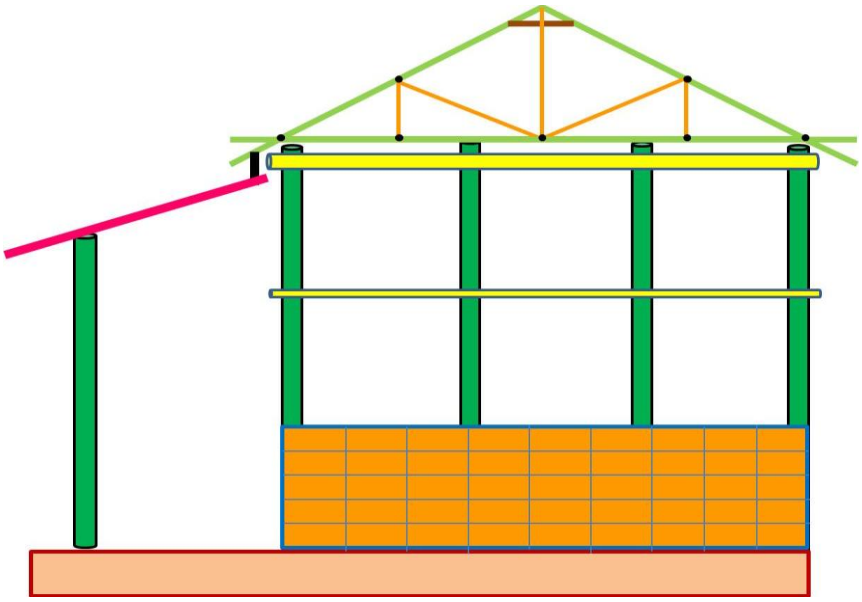
3: Fixing the diagonal bars



4: Final Shape of the truss



5: Dimensions of the truss



Truss fitted on the roof

4.3.2 Roof Cover

Roof covering is fundamental in order to get protection from weather conditions. The roof covering material should be hard enough as it is subjected to different kind of weather parameters. Metals (corrugated iron, tin, lead, zinc) are best suitable for harsh weather conditions as **Roofing Materials**. Metal tin can is easily fitted in the bamboo roof truss.

4.3.3 Fixing of tin with the truss

The truss is the basic structure with which the roofing cover *i.e.* tin is to be attached. It is done carefully to align the tins with the truss.

a) Making hole on the tin

The tin is placed on the roof above the truss structure gently. Adjustment is done to align the tin on all the direction of the roof. Thereafter a hole is made in the tin. The hole should be made near to the raft or to the purlin made of Kanakaich bamboo (22 ft.)

b) Inserting the J-hook

A J-hook is inserted to the tin from the below holding the purlin and tin together.

c) Fastening the J-hook

For fastening the J-hook a bitumen rubber washer and a metal cap is need to be put together. These washer and metal cap is attached to the J-hook from above the tin. The rubber washer and the metal cap serve the dual purpose *i.e.* fastening and attaching the tin with the truss and prevent rain water from leaching down through the hole.

While working with tin the workers need to remain aware of any overhead electric line. An accidental connection between tin and electric line may cause grievous injury.

Fixing of tin with the roof structure

1: Making hole on the tin

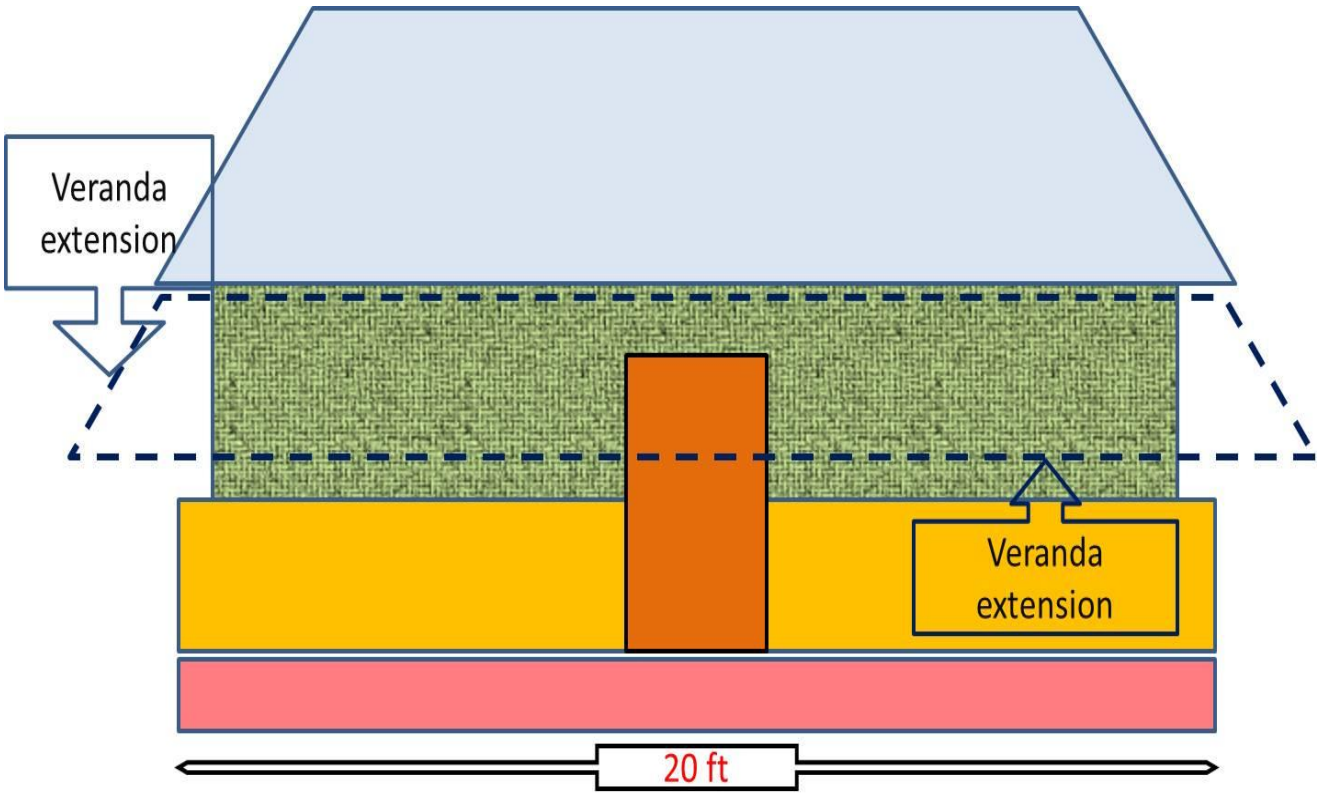
2: Inserting the J-hook from below

3: Putting metal cap, bitumen washer on the J-Hook and fastening it with nut

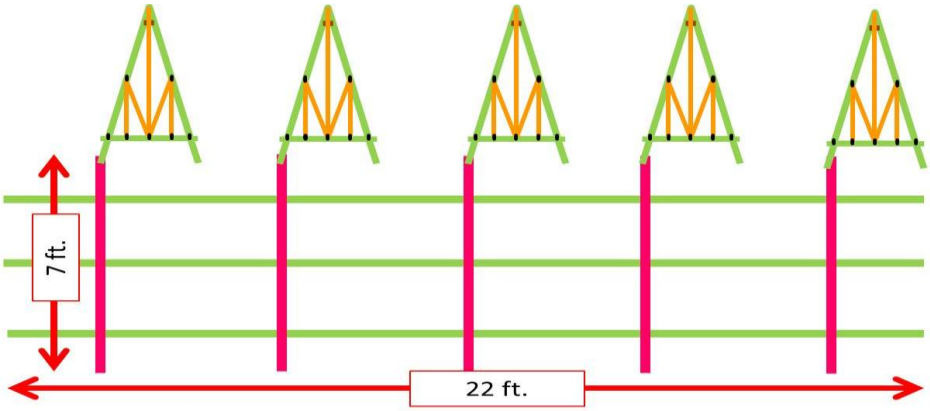
4: Attachment of tin with the Kanakaich structure

4.4 Veranda

A veranda or verandah is a roofed, open-air gallery which is attached to the outside of a building. In this bamboo house design, the veranda extends across the front of the structure. Kanakaich Bamboo was used for making the structure of veranda.



The bamboo house with veranda at the front



Dimension of the roof at veranda

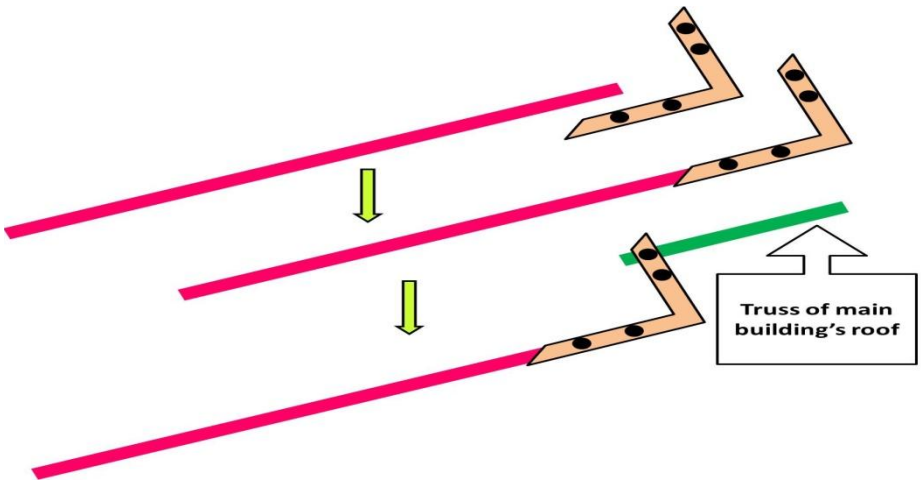
There are 5 pieces of 7 ft. Kanakaich to be attached along the width of the veranda parallel to each other. These 5 pieces are dissected with 3 pieces of Kanakaich truss with 22 ft. length along the length of the veranda.

a) **Sizing of Kanakaich:** The treated Kanakaich bamboo was cut in to 7 ft. pieces. Uniform diameter of the bamboo pieces beautify the roof structure of veranda and provide ease while fitting the tin.

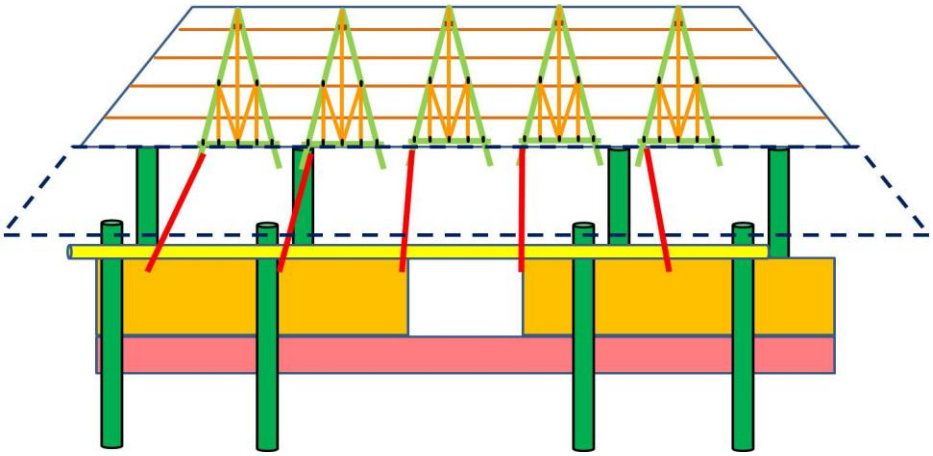
b) **Attachment of L shaped iron clamp:** L-shaped iron clamp are available at market or can be made from welder. These clamps make the connection between the 7 ft. Kanakaich truss with the structure of the main roof of the house. The clamp is attached in one end of the 7 ft. Kanakaich bamboo first by drilling hole in to that and followed by fastening it with nut-bolt.

c) **Joining veranda truss with main building:** For doing this drills need to be made on the extended outer end of the truss of the main building. Then**,** the clamp attached 7 ft. Kanakaich truss is joined with the truss of main building roof.

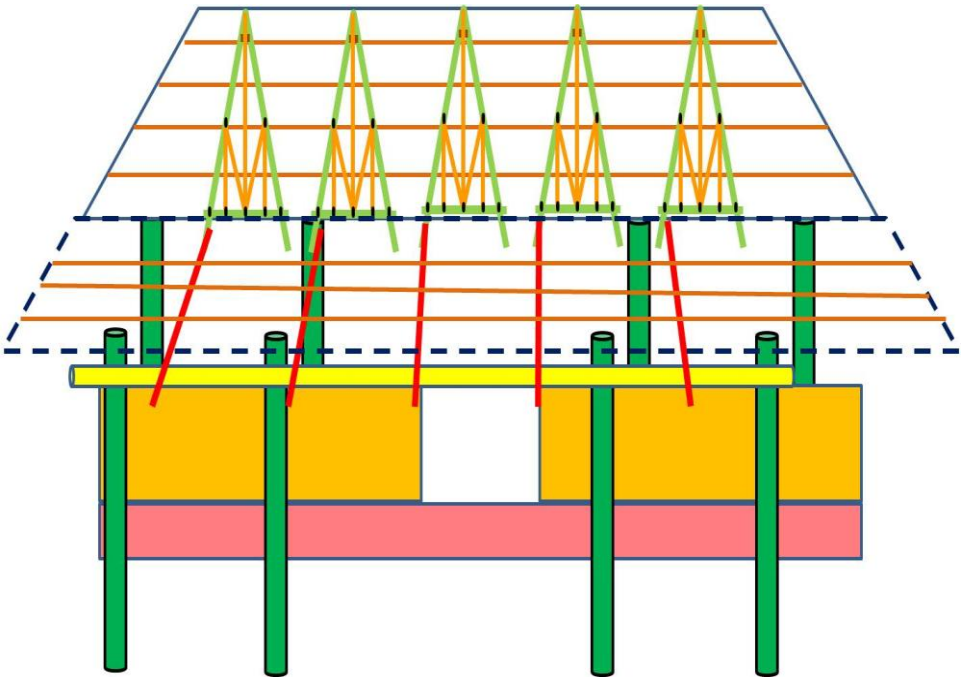
d) **Attachment of outer end:** As one end of the 7 ft. Kanakaich bamboo is attached with L shaped clamp and which is further attached with the truss of the main building; the other end of the 7 ft. Kanakaich is joined with horizontal pole at the outer end of the veranda.



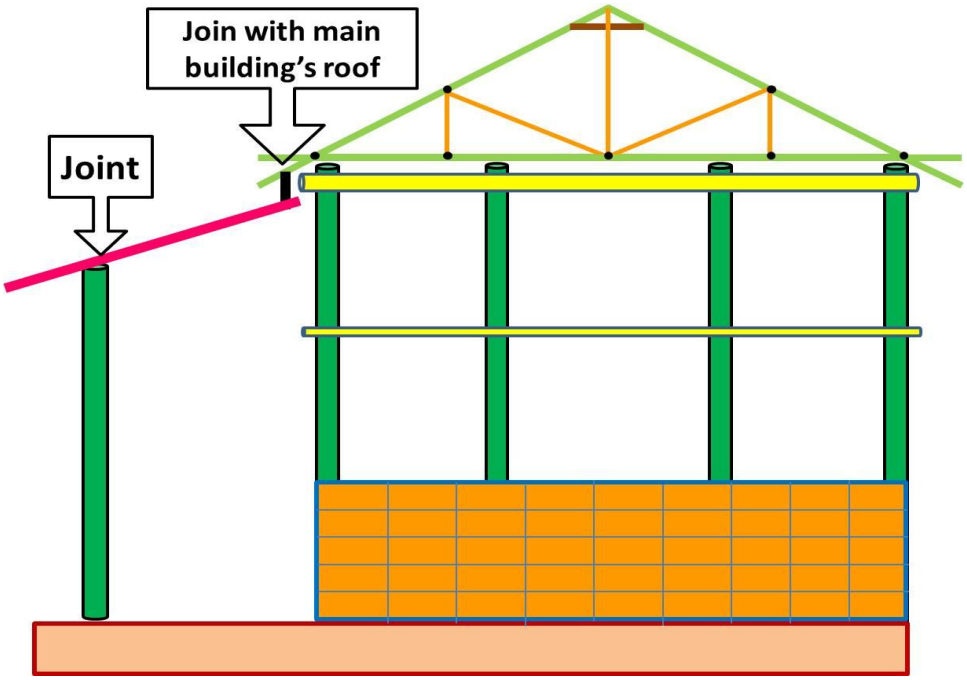
Fixing the K. Kaich with L-shaped clamp for making the structure of veranda



Fixing of K. Kaich (along the width) on the roof structure of veranda



Fixing of Kanakaich (along the length) on the roof structure of veranda



Position of iron clamp and the Kanakaich bar at veranda

Fixing of L-shaped Iron clamp and construction of veranda

1: Marking on the bamboo

2: Making holes on the bamboo

3: Placing the L-shaped clamp and insertion of bolt

4: Fastening the clamp with the bamboo

5: Kanakaich bamboo fixed with the clamp


6: Fixing the horizontal bar/purlin at the veranda


7: Joining of the clamp fixed on Kanakaich bar with the truss on the main building


8: Bamboo structure of the veranda

4.5 Bamboo walls

Muli bamboo is preferred for making bamboo wall for house construction. The treated Muli bamboo is spitted, opened peripherally and dried under the sun. These are called splitting or torja. It is better to make a frame of the wall in the ground using split bamboos. The torjas are bound one after another making a criss-cross manner and designed in a rectangular fashion or as desired. Skilled crafts person are needed for preparation of the wall. The pattern of binding the torja together traditionally called **'Champa bain'** (in Bengali) where the binding is made holding 3 numbers of torja at a time. After such a panel is prepared a bamboo culm is halved longitudinally and attached in both the surfaces using rust free aluminum wire to provide rigidity and durability. This is followed in all the four ends. Using sharp hand saw the panel is given a desired size. When it is ready it is lifted and fitted in the house accordingly.

Doors and windows are prepared separately after fitting the wall to the house. The size of the windows is marked on the wall and the portion is taken out from the wall using sharp hand saw. The already prepared window is attached with the frame of the wall using G.I wire.

Making the bamboo splittings/torja for house wall construction

Preparation of house wall by binding the bamboo torja together

Bamboo torja

Bamboo torja placed for sun drying

Making the frame on which the bamboo wall to be made

“Champa bain”: The traditional process of bamboo wall construction

Tightening the wall structure by GI wire


Removing the unwanted parts of the bamboo wall


Fitting of bamboo wall on the house

4.6 Flooring

The base of the inside room is referred to floor. It should be easy to clean and have hardwearing surface.

4.7 Plastering

By the process of plastering the rough walls or uneven surfaces of the buildings are provided with a hard and smooth surface. The main aim of plastering is to provide better protection, beautification and cover defective works. In case of plastering mixture of sand and cement in the ration of 5:1 (cft.) were used.

CHAPTER - V

ECONOMICS OF HOUSE CONSTRUCTION

Cost involved for constructing one Bamboo house

Construction items	Quantity	Cost (Rs.)
Bamboo		
• Barak • Muli • Kanakaich	15 to 16 culms 500 to 600 culms 50 to 55 culms	2000 6900 3600
Roof tin 10 feet Roof tin 7 feet	20 pieces 11 pieces	17141
Ridging 10 feet Ridging 6 feet	2 pieces 1 piece	
Brick	1200 to 1400*	15765
Cement	20 to 23 bags*	7656
Sand	95 to 125 cft.*	2850
Concrete Chips	35 to 50 cft.*	7600
Brick Chips	82 to 90 cft.*	
Nut-bolts	12 to 15 Kg**	2329
J- Hooks	25 Kg	
Paint and Varnish	Paint (2 litre) Thinner (2 litre)	1000
Sand Paper	5 pieces	100
G.I wire	2 Kg	240
Clamps (Iron)	36 units	1530
Master trainer/Labourers		7000
Other Misc. construction expenses		4289
Total		80000
*Depends on the slope of the ground **Depends on the thickness of the Bamboo culms		

The cost of these items may vary according to the current market prices. The availability of the items may also vary from place to place.

Conclusion

Bamboo houses are eco-friendly and earthquake resilient. Moreover the FRC-LE developed design of Bamboo house is a low cost house design which can be afforded by the low income groups of people in North-East India. Locally available resources were effective used for the house construction to bring down the cost of house construction. A good stock of bamboo is available in Tripura but bamboos are prone to fungal and borer attack. When treated Bamboos are used it makes the house structure more durable and the Bamboo house may be maintained for even 50 years.

Acknowledgement