# Re-construction of Multi-Hazard Resistant Houses for the 2008 Kosi Flood Affected Districts in Bihar

Part-II

## Technical Guidelines for Bamboo based Construction

Department of Planning and Development

**Government of Bihar**

**2010**

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Technical Guidelines for Bamboo-based Construction

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*These technical guidelines are prepared by the technical committee constituted by Government of Bihar to provide guidance for multi-hazard resistant houses as part of initiatives of Government of Bihar to rehabilitate affected families in the Kosi floods of 2008.*

# Re-construction of Multi-Hazard Resistant Houses for the 2008 Kosi Flood Affected Districts in Bihar

## Part-II
## **Technical Guidelines for Bamboo based Construction**


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*(Kosi Reconstruction and Rehabilitation)*

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Department of Planning and Development
**Government of Bihar**
**2010**

# Acknowledgements

These guidelines have been prepared under the stewardship of the present government of Bihar led by the vision of the Honorable CM Shri Nitish Kumar. In February, in a workshop organized on the subject he invited the setting up of this Technical committee under Dr. Anand S. Arya and provided the technical framework for the rehabilitation.

The present Chief Secretary Shri Anup Mukherjee has guided and seen through the preparation of this guideline as the RD Secretary and as the Development Commissioner. Shri Vijay Raghavan initiated this process as the Development Commissioner and the team of officers in the Empowered Committee for the Rehab of Kosi Region have given valuable inputs to make this guideline contextual to the working ethos of present Bihar ñ in particular Shri Rameshwar Singh, Shri Navin Kumar, and Shri Vijay Prakash.

In the Kosi region, also known as Mithilanchal, we would like to acknowledge the support provided by the successive Divisional Commissioners, Sri Hemchand Sirohi and Sri Sudhir Kumar. The DMís of Saharsa, Supaul and Madhepura ñ Mr. R Lakshmanan, Mr. N Sharwan Kumar and Mr. Kumar Ravi, Mr. Atish Chandra and Mr. Birendra Prasad Yadav respectively who have piloted the development of the house prototypes and the construction of two tolas along with the ODR Collaborative to test and develop these technical guidelines. The technical committee members from the departments of Road Construction, Rural Works and Buildings provided technical details for specifications and estimation of costs involved.

We particularly want to mention the contributions made by some Master Artisans in the region. Tribhuvan Mistri, Satya Narayan and Ramesh shared their local understanding of the building practice and worked with our Engineers and Supervisors to first develop several details particularly in Bamboo and then helped two tolas build their homes using these standards for safety. The contribution of the artisans and people of the two tolas of Puraini and Orlaha in Supaul, need to get a special mention for developing and demonstrating several easy ways of implementing the requirements of the guidelines, particularly, pile foundations and easy treatment of bamboo.

The technical and social personnel of several organizations who have enthusiastically worked in the region to build this body of knowledge and practice for North Bihar need to be acknowledged. Whereas they have worked as a multi disciplinary team their special contributions are in the following fields:

Mahavir Acharya led a technical team of Karamshi Rangani, Malaram Bishnoi and Visanji Gajjar from Hunnarshala Foundation that worked on all aspects of the development and implementation of the technical guidelines; Dhiraj Ganatra (Hunnarshala) worked with the technologies developed by Ar.Nripal Adhikari (ABARI, Nepal) and Dr A D Karve (ARTI) for treatment of Bamboo through simple hand operated pumps;

Prof. Neelkanth Chhaya, Dean SA, CEPT University envisioned and provided the students and faculties for participation in the Kosi rehabilitation process and documentation of the indigenous housing tradition of Bihar. Dinesh Charan (Hunnarshala), Tejas, Prashant, Bhavuk, Sankalpa of CEPT University and Milind documented and analyzed the existing housing typologies and participated in the designing of new houses. Dinesh Charan (Hunnarshala) and Maulik Oza drew sketches and drawings. Nikhil Patel and Pratik Zaveri helped in graphics.

Shailesh Rathod (from Unnati and Abhiyan) led along with Eklavya Prasad and Chandrashekhar (Megh Pyne Abhiyan) the social team of Indu kumar, Nirbhay Kumar, Sunil and Dashrath (from Megh Pyne Abhiyan) to identify, mobilize and facilitate the residents of both tolas towards implementing the guidelines in its spirit. They also coordinated with various government departments and supported this process. One important result of their coordination has been the development of management and monitoring systems for ensuring quality of construction. Dharmesh Jadeja from BuildAur coordinated and brought the learning of several experts, particularly in Bamboo, to Mithilanchal and these guidelines.

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We also acknowledge The Ford Foundation for initiating a multi-state project for developing suitable building typologies based on traditional building practices, which has also integrated with the process of scientific validation of the building practices and preparation of guidelines.

Technical Committee

# Foreword

After tackling the immediate challenges of Kosi Disaster, the State Government had to deal with the problem of reconstruction and rehabilitation. The State Government has pledged that Kosi region will improve with this reconstruction. To successfully complete it, the government has declared a policy, whose main objective was to provide such houses that which would be not only functionally useful to the residents but also safe in hazards like earthquake, wind storms and floods. These would be constructed with the help of locally available materials.

The technical designs have to be prepared on a large scale which has taken size of family and its capability to spend, into its account. More over, it is important that all these guidelines reach the locals and the artisans. ODRC (Owner Driven Reconstruction Collaborative) with its experience of community led rehabilitation in Gujarat and other states is providing facilitation support. With active participation of house owners and decentralisation of technical know-how, owner driven reconstruction process was taken up by ODRC through its own resources in Puraini and Orlaha in Supaul district. This was seen as a pilot programme for reconstruction.

On the basis of above mentioned Pilot Programme and with the help of ODRC, Bihar Government Setup a technical committee under the chairmanship of well known expert Dr. A.S. Arya to develop technical guidelines of reconstruction. These guidelines provide us guidance for hazard safe houses that are affordable and well planned.

These guidelines will bring new chapter into providing livelihoods as well as know how of safe house for the owners, artisans and representatives of Panchayati Raj Institutions.

I sincerely hope that these guidelines will enhance safety and will prove as a milestone in creating better habitats for people of Kosi region.

Sd/-

(Anup Mukherjee)
Chief Secretary, Bihar

# Preface

The Mithilanchal Area of North Bihar is drained by the river Kosi which during many centuries has carved out 15 courses for itself through deposition of silt in the plains. These river courses have been protected by earthen embankments due to which the intermediate space is utilized by the populations for agriculture as well as building their habitat. However, when the river overtops or breaches an embankment during flood season, the affected river course gets flooded suddenly and disastrous situation is created in the so called "protected area". Such a situation developed on August 12, 2008 when the river breached its eastern embankment in its upper reach in Nepal and resumed an abandoned course after many decades. Five districts namely Araria, Madhepura, Saharsa, Supaul and Purnia were the worst effected by the flood waters causing loss of more than 200,000 homes and displacing more than a million people.

The Government of Bihar has proposed to reconstruct thousands of houses for the poor in a way that they may not be displaced from their homes in future floods. Since the area is also prone to severe earthquake intensity of seismic zone V and IV of India, and also classified as affected by winds of highest velocity of 47 m/s (about 170 km/h), the reconstruction has to cater for the Multi hazard proneness of the area. For providing appropriate technical guidance the Govt. of Bihar established a Technical Committee not only to consider various facts of hazards but also availability of construction materials and also economy. After considerable deliberations, the Committee has resolved to recommend two types of constructions: i) based on brick work and ii) based on bamboo. Use of bamboo is considered as appropriate by the Committee in view of the fact that i) the bricks may not be available to be extent required in reconstruction, and that ii) bamboos of good quality are available locally and there is a pool of artisans available who are proficient in constructing bamboo houses. Therefore the committee has processed two separate guidelines as follows:

Part-I Reconstruction of Multi Hazard Resistant Houses: Brick Construction

Part-II Reconstruction of Multi Hazard Resistant Houses: Bamboo Based Construction

Both construction type will require proper soil investigation at the house sites to determine if i) the soil is erodable under flowing river water or ii) soil is liquefiable under Intensity VIII or IX earthquake. Based on the observations the depth and type of foundation will be decided. It need not be emphasized that in both types of constructions pucca foundation as well as plinths will have to be provided and the variation between brick and bamboo house will be in the super structure as determined by the financial condition of the beneficiary.

Taking the various conditions into account the committee has proposed three variations in brick constructions

Type A Brick walls topped with RC slab. The brick walls use rat trap bond.

Type B Brick walls topped with RC slab. The brick walls are half brick thick constructed with brick pillars, topped with RC slab.

Type C Brick walls with half brick thickness constructed with brick pillars but provided with sloping CGI sheet roof on bamboo understructure. This type of house also includes the provision of attic floor at 2.1 m elevation above ground floor. In each case, a verandah has been provided in the front which could be used as lounge or partly for kitchen purposes. It is hopped that the Govt. of Bihar will find the recommendations suitable for adoption in its Owner Diven Reconstruction programme.

## ACKNOWLEDGEMENT

As Chairman of the Committee, I would like to take this opportunity to thank the various Senior Officers and Engineers of Govt. of Bihar for their assistance and guidance during the working of this Committee. I would like to convey my hearty thanks to the members of the Committee and the ODR Initiative for cooperation and hard work in the preparation of these Guideline.

Dr. Anand S. Arya,
Chairman, Technical Committee

# Content

# 1. The Kosi Region

The Kosi is one of the important rivers that feeds the Ganges passing through Tibet, Nepal and finally through North Bihar (Mithilanchal) having a catchment area of about 74,000 sq. km. (2008, Mishra, D K). At the foothills of the Himalayas, the gradient suddenly flattens pushing the waters to split up into a number of smaller rivulet. Spanning a large region the river can choose one or more of the fifteen routes it has created for itself over the centuries. Attempts to tame the river with embankments has not always yielded positive results, as often the river bursts its bunds to resume one or more of its historical routes, causing death and destruction on its way. August 18th, 2008 has been one such year. The river within the bunds was left dry as the waters shifted its course inundating five districts leaving many dead and more than 2 million, homeless.

Area falling in river basin of Kosi River is generally referred as Kosi region. The districts of Araria, Purnia, Madhepura, Supaul, Saharsa affected by floods in 2008 fall under this Kosi region. Khagaria, Bhagalpur and Katihar can also be included in this region based on the following FMIS map, shown in Fig. 1.

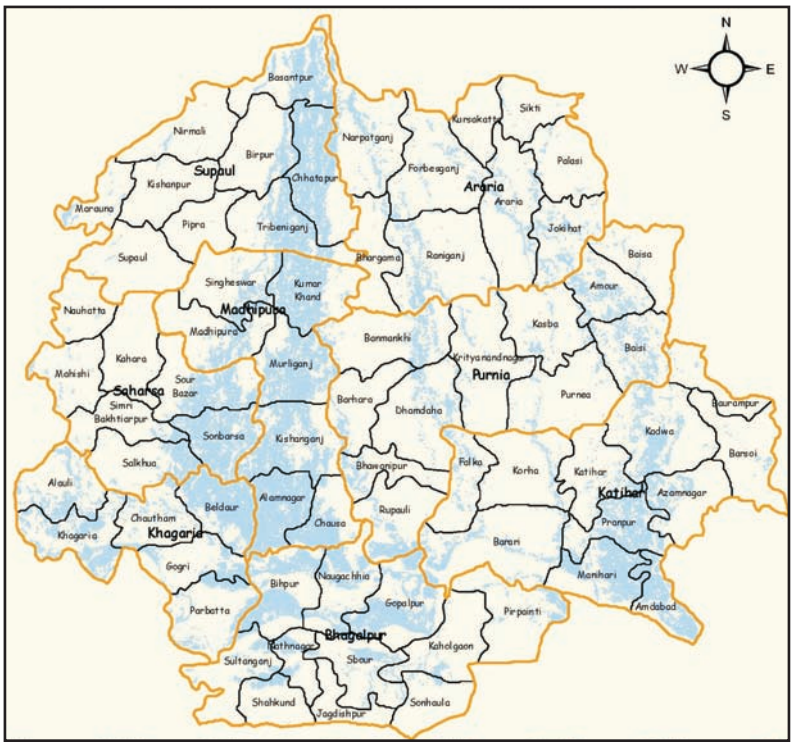



Figure 1 *Map of Flood affected Kosi Region*

Kosi region is prone to different hazards due to earthquakes, floods and high winds. The Seismic Zoning Map and the Flood Hazard Map of the State of Bihar are included in Part 1 of these guidelines. According to these maps, the districts of Araria, Madhepura, Saharsa, Supaul and Purnia have the hazard proneness as shown in Table 1 of Part -II. From the seismic map it is clear that northern districts of Supaul, Araria and large parts of Saharsa and Madhepura fall under the severest Seismic zone V. Remaining parts of Kosi region fall in zone IV. Part-1 of guidelines also indicates the extent of flood hazard and vulnerability of the geographic area.

Besides safety against earthquakes and floods, safety measures against wind velocities upto 47 m/s as specified in IS:875 (Part3) for Bihar State must also be incorporated in the light bamboo super structures as well as in light pitched roofing systems.

# 2. Existing Building Practice in North Bihar

With reference to the Vulnerability Atlas of India (Revised) 2006 and Census of Housing in 2001. It may be noted that mud, grass, bamboo etc based construction make up more than 50% of the houses, with most of the houses in Mithilanchal under this category.
Housing in North Bihar is determined largely by the socio-economic condition of the family; the available materials and the hazards the region faces. The rich used to build court yard houses (Fig. 2, 3) using country burnt brick walls with a joist and plank roof using lime as a bonding material. In the last decade several sophisticated Kiln baked bricks have replaced the country kiln bricks, and the roof is now made with RCC. The Gangetic basin soils make good quality bricks and other pottery products including roofing tiles. The production of bricks largely caters to government projects and the cost is high, averaging 2-3 times the national average. Sand and aggregate needed for RCC is not available in the region and is often brought at high costs. Sand is brought from Kiul and Son rivers of South Bihar or Gangajali from Nepal. The coarse aggregate comes from Pakur district of Jharkhand. The quality of RCC is not good in the region. The shuttering is made from bamboo with a layer of mud to make it impervious. Most buildings in this category do not follow the earthquake safety requirements.

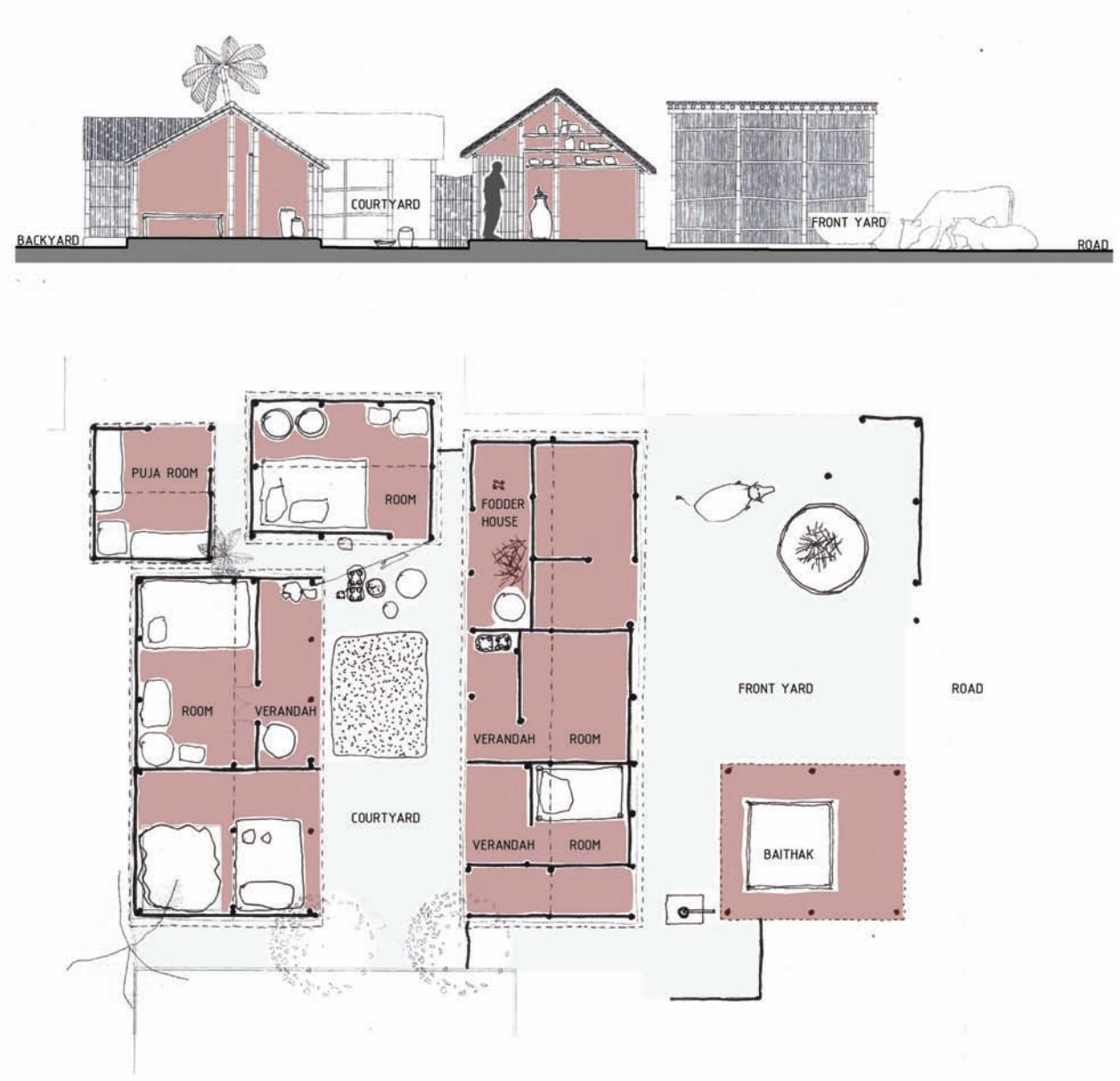



Figure 2 *A Typical House Layout in Koshi Region*

*Views of A Typical House in Mithilanchal*

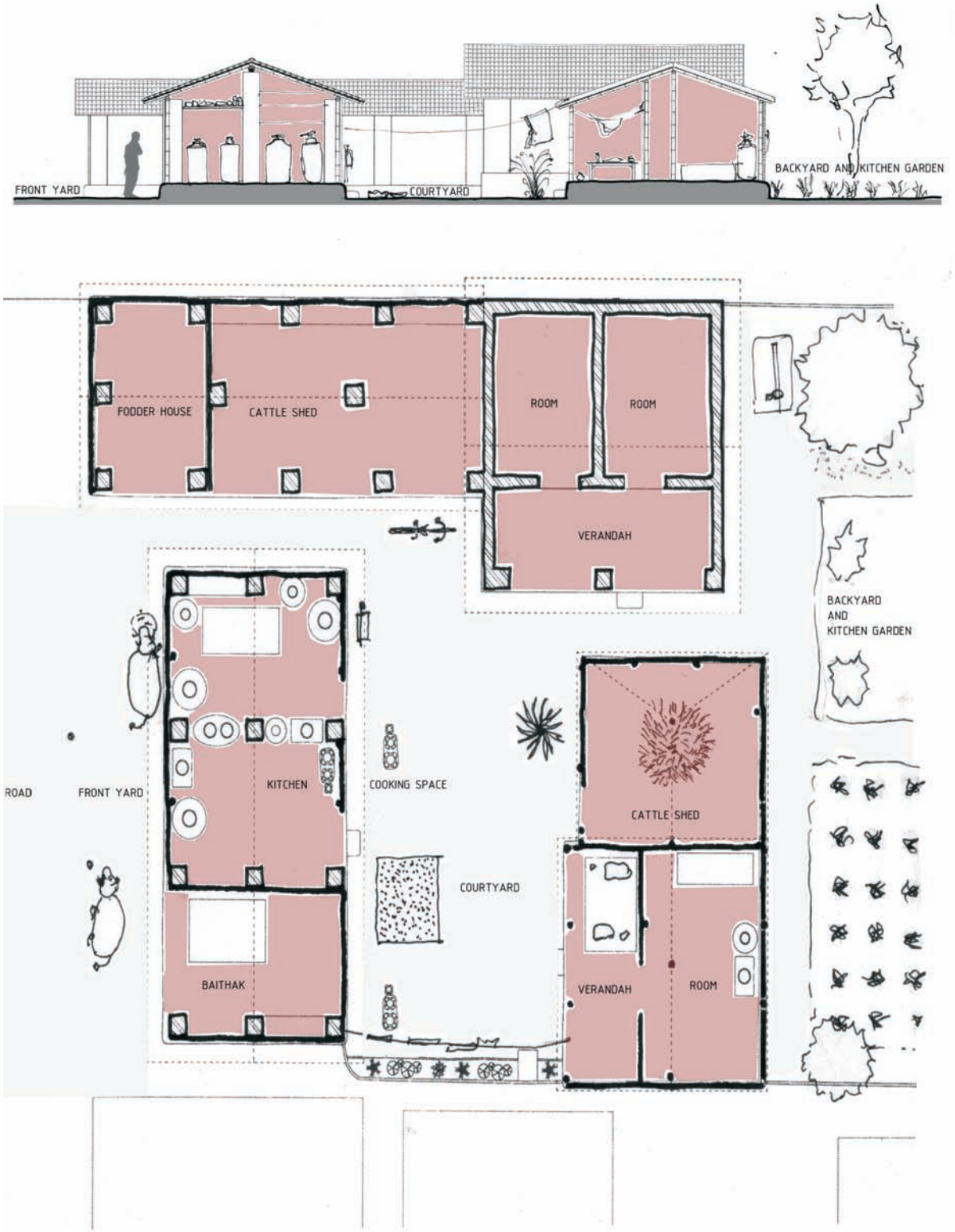



Figure 3 *Another Typical House Layout of Mithilanchal*

Mithilanchal is almost unimaginable without Bamboo. It is used in food, religious rituals, to build their homes with, and make a range of products, for every day use. The three dominant varieties of Bamboo- , The Harotis = Harot's, Chab and Makhaur (Bambusa Balcooa, Bambusa Tulda and Bambusa Nutans respectively) have been used by the mistris for housing, from times unknown. The Harotís strength is used in columns and beams. The Chabís straightness is sometimes used in the roof under structure as well. It is also used for weaving bamboo into a range of products as raised floors, lofts and wall in-fills. The bamboo is lashed together using jute or coir ropes. The gharbandh knot (clove hitch) is the most basic knot. Each knot is carefully tied to ensure structural safety for the home. The house itself is made on a raised mound of earth. The roof panels are either prepared after erecting the columns or are sometimes prefabricated to be assembled on top. The wall panels are infill prefabricated and fixed to the columns. They only use a single tool, a sickle (Dabia), to put the entire house together in 15-20 days.

During floods, the waters can rise up to 6-8 (1.8-2.5 m) feet inside the house, and can sometimes be present for up to a month as it slowly recedes. In parts of Madhubani, families have devised mitigation methods by stocking some dry food (sattu, chura, etc.) on a loft that they can themselves climb into, in case of floods. These lofts are also made of bamboo. The bamboo is unaffected by the stagnant waters, but begins to decay when in contact with mud in the footings. Some families use tar or wrap the end of the bamboo with plastic to protect it from decaying.

# 3. Scope of the Guidelines

These guidelines have been prepared for rehabilitation of houses post the 2008 Kosi floods. It is restricted to ground plus one houses using bamboo as the structural system above plinth. The guideline focuses on ensuring safety of houses in case of floods, earthquakes and high winds.

Whereas the guideline does not specify any house designs it has clearly laid out the necessary non-negotiable features that must be adhered for safety in design and construction technology. The house shall have to have a foundation and plinth made in brick/block and RCC; the bamboo shall need to be chemically treated as prescribed; the joinery shall have to be followed as specified and the design shall have a minimum height for plinth and a first floor or attic capable of taking live load in case of floods.

# 4. Site Soil Condition

**This analysis is based on the soil data obtained from two districts. The samples in each district were obtained from two building sites.**

a) Silty clayey soil with cohesion C = 0.2 - 0.4 range & ¤ = 6°-10° range. Safe bearing capacity at 1.5 to 2 m depth required is 6 to 7 t/m² for square footing.
b) Silty sandy soil with C = 0, & $ = 27°- 28° range. Safe bearing capacity required is 7 - 8 t/m²for square footing.

**Floods occurring in the alluvial plains of the rivers or the costal deltas give rise to the following types of problems during floods:**

a) The bearing capacity of the soil gets reduced because of saturated conditions and buildings of heavy materials may sink and get damaged by differential settlements.
b) The soil can be eroded under the action of flowing water and scouring can take place around and under the foundations resulting in the uprooting of the lighter posts or sinking and tilting of the heavier foundations.
c) Siltation can take place around the buildings when the floodwater recedes away from the site.

**In case of earthquake, following types of problems occur:**
The phenomena of soil liquefaction can take place in Zone IV or Zone V if the soils, particularly non-cohesive soils, are saturated due to floods or high ground water table. It actually happened in large areas of North Bihar during August 1988 earth quake when the area was already under floods.

**All the above site effects can lead to severe damage to the housing units unless constructed using appropriate types of foundations, materials and technologies.**

# 5. Bamboo, The Construction Material

## 5.1 General Description

Bamboo is a versatile, strong, renewable and environmentally friendly material. It is the fastest growing woody plant producing a mature fiber for use within three years. There are 1250 species and 75 genera (Tewari 1993) of bamboo of which 130 are found in India.
More than one billion people (a sixth of the world population), including a large proportion in India, live in bamboo houses. 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 further 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 bambooís hollow tube gives it a strength factor of 1.9 times over an equivalent solid pole (Janssen í97). 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.

## 5.2 Bamboo in Kosi region

The Gangetic basin of North Bihar has several bamboo species that are used by the people in the region. Harotis-Harot (bambusa balcoa), Chab (bambusa tulda) and Makhaur (bambusa nutans) are used for building houses. See Tables 1, 2 and 2 for properties of these bamboo species. Harotís thick wall makes it strong and is therefore used for the main structural elements of the house including poles, trusses, rafters, ridges and purlins; the straightness of Chab is used for the roof rafters and Makhaur along with other bamboos is used for the lattice work in wattle and daub walls.

### 5.3 Prepairing the bamboo for construction

Bamboo has presence of considerable amounts of starch in green or dry state which makes it attractive to such organisms as stain fungi and borer beetles, whereas there are only minor amounts of resins, waxes and tanwins which have sufficient toxicity to impart much natural durability in the culms.

#### 5.3.1 Harvesting bamboo

The time and method of harvesting bamboo affect the durability of bamboo. Since starch forms the main food source of insects and fungi, bamboo should be harvested when its starch content is the lowest, in the dry season. Cut bamboo should be stacked vertically for a few weeks after felling with branches and leaves intact. Such bamboo will continue to live off its reserves, further depleting the starch. Soaking freshly cut culms in water for several weeks also serves to reduce the starch content by leaching.

As several families in North Bihar grow their own culms of 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 ëhorseshoeí 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.

### 5.4 Chemical Treatment of Bamboo

Figure 4 *Cycle Mounted Pump*

As bamboo has very little natural toxicity and therefore are 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 culm should be cut up to the next node in order to remove the blockage of vessels.

Whereas there are several indigenous treatment systems like lime-wash and smoking of bamboo, chemical treatments are known to have longer effect against fungi and insects. This guideline recommends 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. The preservatives are listed in Appendix B.

Figure 5 *Hand Operated Pump*

#### 5.4.1 Treatment for structural use

It involves pumping of recommended preservative solution at a pressure of 0.1 to 0.14 N/mm2 through the cut end of the bamboo till it seeps out from the other end replacing the sap. This can be done with a cycle mounted pump (Fig. 4) or hand operated Pump (Fig. 5).

a) The preservative solution for the treatment purpose shall be made as per appendix B- Table-B1.
b) The treatment of structural bamboo shall be undertaken as early as possible after harvesting and shall not be later than 6 hours. In case delay of more than one day is expected, bamboo shall be kept dipped in water. In such a case also, it shall be treated within 3 days of harvesting. After treatment the bamboo shall be kept horizontally in shade for few hours before it is used.
c) The ends of the posts that are embedded into the plinth need to be treated with coal tar/creosote.

### 5.4.2 Treatment of Bamboo for Non-structural Use

(Walling and Attic floor lattice)

a) All non-structural splits and slivers for walls, floors and roof shall use the soak ing/diffusion system for treatment Fig. 6.
b) The treatment shall be as per the table B2, Appendix B.

Figure 6 *Soaking Pond for Bamboo Treatment*

## 5.5 Selection and Size of Bamboo

a) Only bamboos with at least three-year maturity shall be used in construction.
b) For the main structural elements of the house particularly posts and beams, Harot shall be used.
c) For roofing elements like rafters and purlins Chab or Harot can be used.
d) Makhaur or other bamboos shall be used for the lattice work in walls panels and daub walls.
e) Columns and roof members should be a minimum of 70-100 mm in diameter at thin end and wall thickness of bamboo not less than 10-12 mm. The distance between nodes (internodes length) should not exceed 300-600 mm.

## 5.6 Grading of Bamboo

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

**a) 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.

**b) 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.

**c) Nodes**
Nodes are the strong points in the culm and should be used to our advantage especially at critical joints.

**d) Splitting**
Bamboo split ends shall not be used since such ends can have a serious effect on the structural strength of the bamboo. It is a good practice to cut bamboo lengths bamboo lengths longer than required to allow cutting away of split ends.

**e) Insect/fungal attack**
Bamboo culms that show signs of insect or fungi attack shall not be used.

# 6. 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.

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

**b) Wrap**
A wrap is a turn around two or more poles.

**c) Frap**
A frap is a turn made between two poles to pull the wrap together.

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

## 6.1 Types of Lashing Joints

**a) Clove Hitch (Gharbandh)**
Lashing is used for joining two or more poles together with a tying material.

b) Square Lashing (Chaubandh) (Fig. 7A)
The 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.

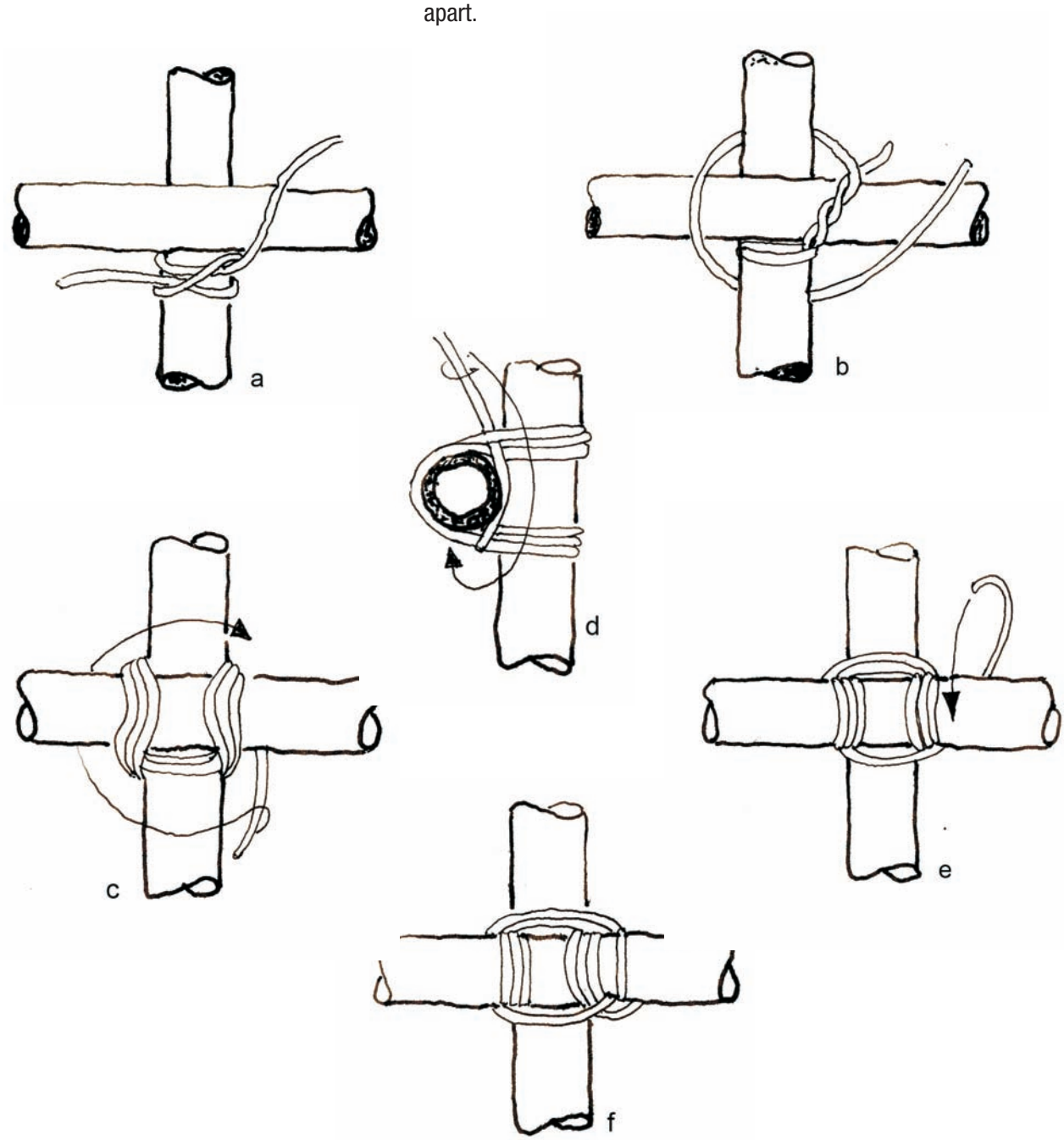



Figure 7A *Square Lashing*

c) Diagonal Lashing (Harladha) (Fig. 7B)
The square lashing shall begin and end in a clove hitch. It shall be used in condition where there is tendency to spring apart.

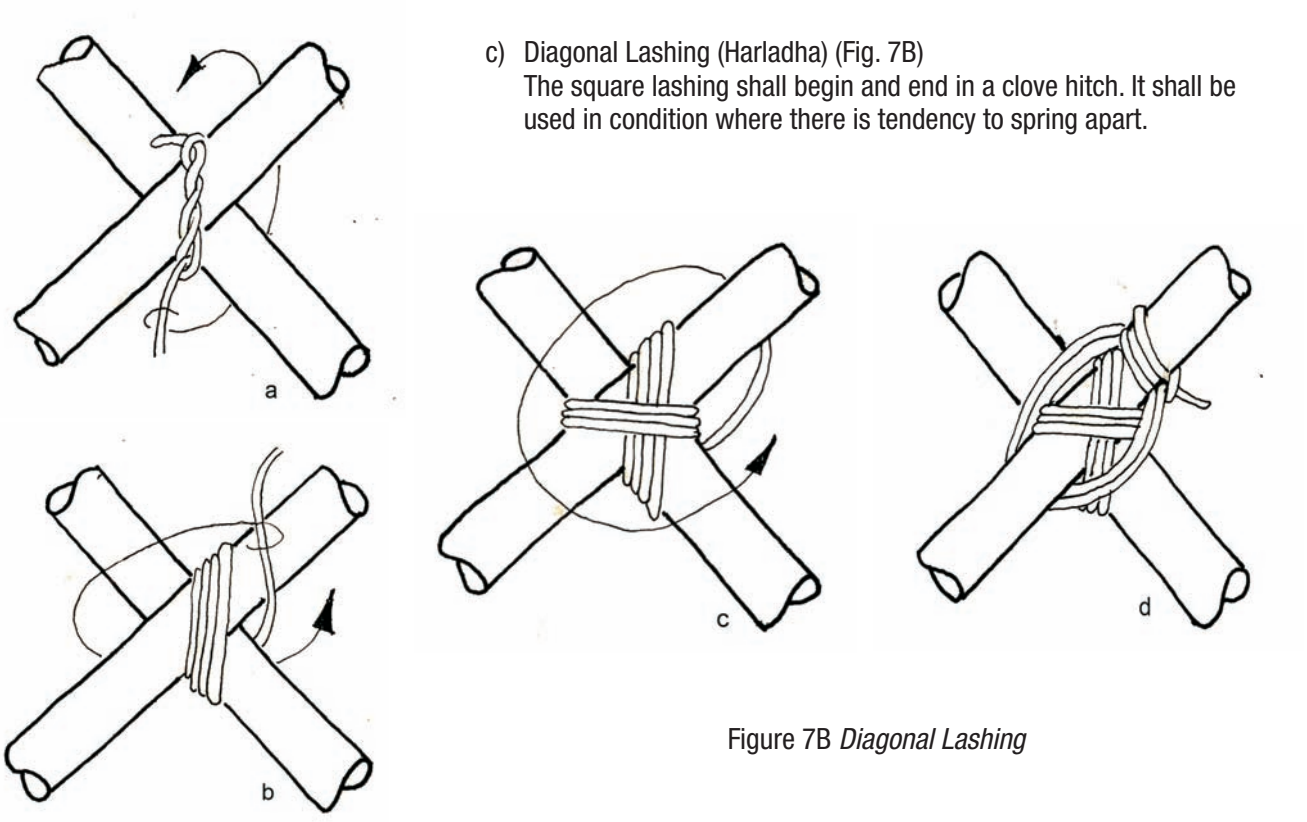



Figure 7B *Diagonal Lashing*

d) Shear Lashing (Fig. 8)
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.

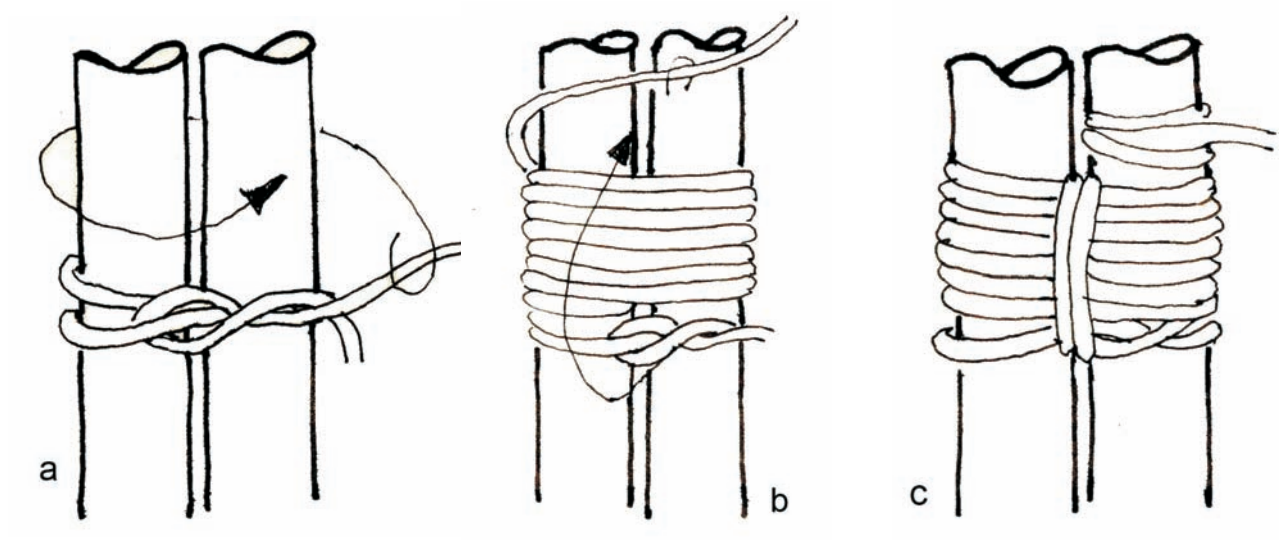



Figure 8 *Shear Lashing*

Figure 10

### 6.2 Types of Shear Keys

a) Post with Plinth Band (Plinth Band Shear Key)

A 30 cm. deep and 100 mm dia. hole shall be made in the plinth beam and the foundation pile/pier below to house 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 as per Fig. 9.

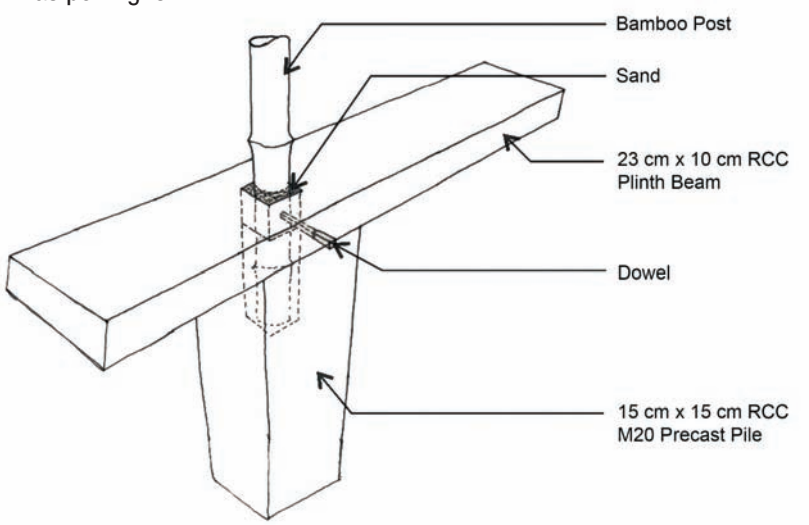



Figure 9 *Plinth Band Shear Key*

b) 'T' and 'L' Junctions (T or L Shear Key)

To connect the post to beam, the beam shall be supported directly on the post. The top of post shall be saddled to ensure proper seating of the beam. The position of the saddle shall be just above the bamboo node of the post Fig. 11. A dowel, of maximum 12mm shall pass from the beam into the node of the post.

Figure 12

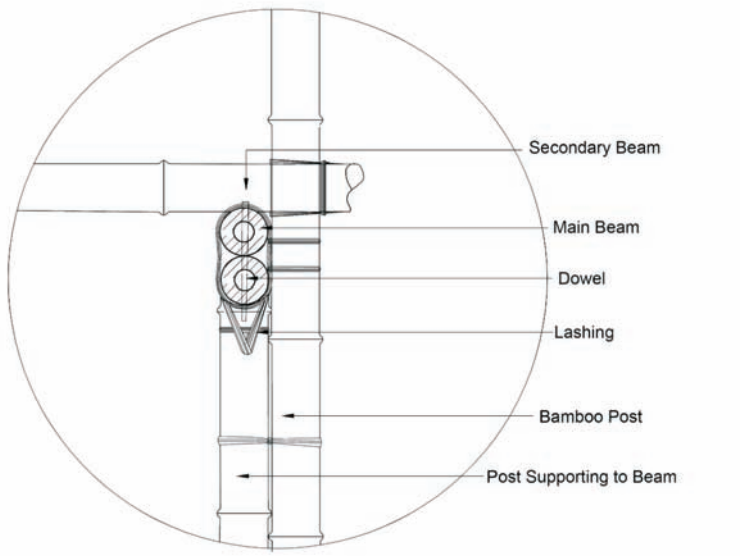



Figure 11 *T and L Junction Shear Key*

Figure 14

c) Cross Junction (Cross Shear Key)
Holes shall be made in a line crossing both the bamboos that need to be con nected. A dowel maximum 12mm shall pass through both the bamboos. See Fig. 13.

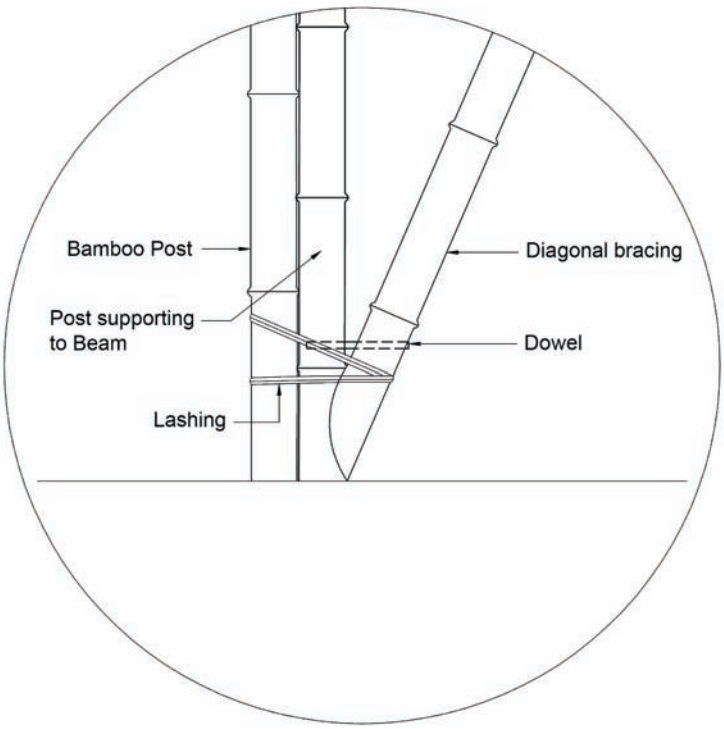



Figure 13 *Cross Junction Shear Key*

# 7. Other Materials used in Bamboo Houses

## 7.1 Bricks and Brick bats

The specifications of bricks should be based on Part-1 of the technical guidelines.

Figure 15 *Brick Bats*

## 7.2 Brick Aggregate

Figure 16 *Brick Aggregate*

a) The brick aggregate under this guidelines shall be restricted to be used for plinth band, stub foundation or similar application in light weight structure.
b) The brick aggregate shall be of size 12-20 mm.
c) It shall be made out of brick having minimum crushing strength of 100 kg/cm2.

### 7.3 Brick embedded Concrete Blocks

This shall be using the specification provided in the Part-1 of guidelines.

Figure 17 *Country Tiles*

### 7.4 Country Tiles

a) The tile shall be well burnt with red color. It shall be neither over burnt nor underburnt.
b) The tile shall give a ringing sound when struck with each other.
c) The size and shape of the tile shall be as per local availability, for details refer to annexure D.

### 7.5 Fine and Coarse Aggregate

a) Sand
   i) The sand used for construction shall be free of organic matter, alkali, clay or other harmful substance (IS: 383-1970).
   ii) It shall be river bed sand from Kiul or Son River and pass through 4.75 mm. sieve and retained by 0.07 mm. sieve.
   iii) Any fine aggregate that passes through 0.07 mm. sieve shall be considered unfit for construction purpose. At no circumstance, fine silt should be used as fine aggregate.
   iv) In case of use of local sand, the specification for fine aggregate shall adhere to IS: 383-1970.

Figure 18 *Sand*

Figure 19 *Course Aggregate*

b) Coarse Aggregate
   i) The coarse aggregate shall be angular in shape and not flakey. It shall be free of organic matter, alkali, clay or other harmful substance as per JS: 383-1970.
   ii) The coarse aggregate of size 12-20 mm. shall be used for all RCC work. The coarse size for PCC shall be 45 mm.

### 7.6 Cement

The specifications for cement are provided in Part-1 of the guidelines and the same shall be used for Bamboo based construction also.

### 7.7 CGI Sheet

CGI sheets should be minimum 24 gange or .35 mm thick as per IS 277:2003 Galvanized Steel sheets (Plain and corrugated) Specification and the overlap between two sheets shall be minimum 15 cm.

Figure 20 *Polyester fabric/strip*

### 7.8 Polyester fabric/strip (feeta) or equivalent

a) The polyester fabric/strip (locally ëfeetaí is a zipper material made of polyester knitted yarn having minimum width 16 mm.) shall be used for the purpose of lashing. A 200 mts. strip (feeta) shall weigh 1 kg. The minimum load carrying capacity of the polyester feeta in tension will not be less than 15 kg.
b) In case of any other tying material the load carrying capacity shouldnít be 15 kg or lashing shall be done to maintain necessary strength.

### 7.9 Wattle & Daub

**a) Wattle**

i) The wattle shall be made out of split bamboo.
ii) Any mature split bamboo ñ Harot (Bambusa balcoa), Chab (Bambusa tulda) or Makhaur (Bambusa Nutans) shall be used. Traditionally, Chab (Bambusa Tulda) and Makhaur is used often.
iii) The bamboo strips shall be thinly woven.

**b) Daub**

i) It is a mix of clayey soil (chikni mitti), sand (baalu), straw (bhusa), dung (gobar) and ash (raakh).
ii) The sand shall be clean river sand (non saline) .The locally available sandy silt soil can be used.
iii) Any fibrous raw material including chopped rice or wheat stalks shall be used.
iv) The fresh buffalo or cow dung shall be used.

Figure 21 *Daub*

Figure 22 *Application Daub Plaster*

**c) Preparation of the Daub mix**

i) The daub mixture shall contain 10 parts of clay, 1 part of sand and 1 part of ash. It shall be thoroughly dry mixed.
ii) The mix shall be made into a heap with crater into which the water shall be poured. It shall be left for several hours.
iii) It shall be regularly pugged for 4-5 days till the material becomes homog enous.
iv) The heap shall be kept wet during this operation.
v) The daub can then be applied as per the standard practice of the region
vi) The outside wall shall be cement plaster.

# 8. Provisions for Multi Hazard Safe Construction

The specifications for cement are provided in Part-1 of the guidelines and the same shall be used for Bamboo based construction also.

### 8.1 Considerations for Site Selection

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. 23).

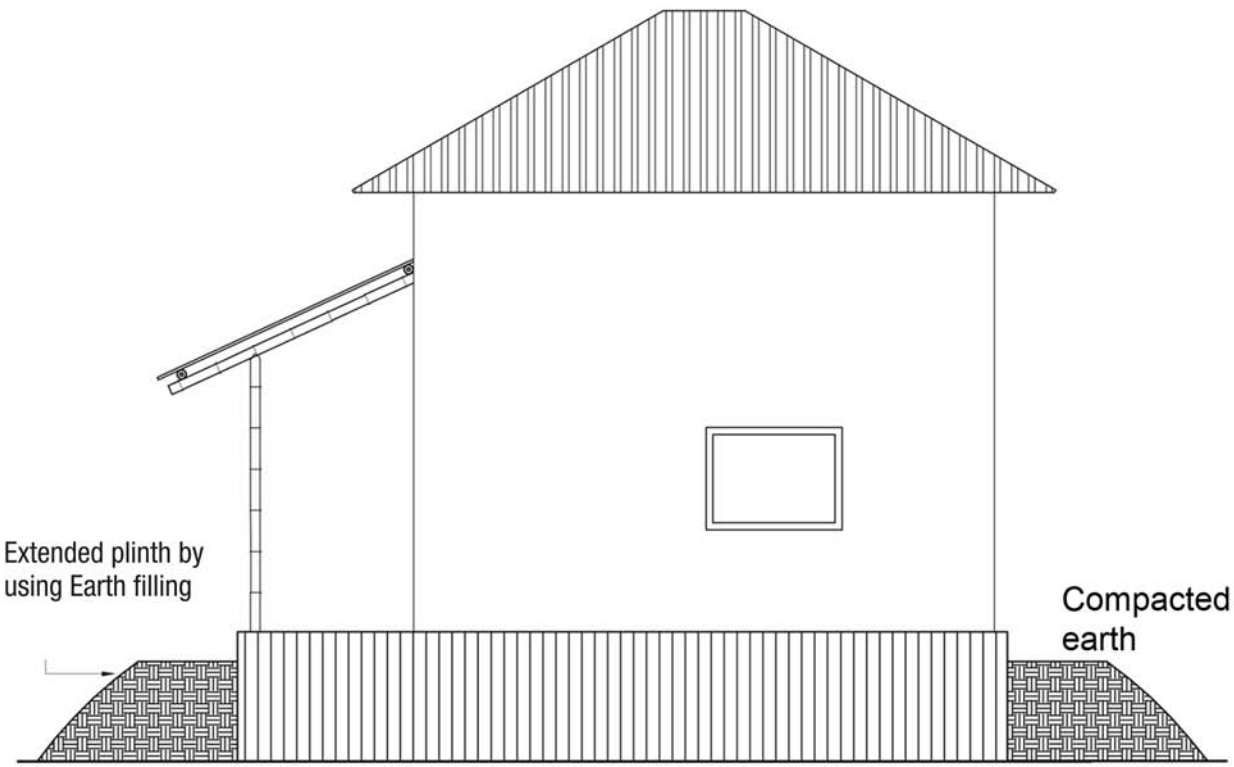



Figure 23 *Raising and extending plinth by earth filling*

**8.2 Safety Provisions for Foundation and Plinth** (See Part-1 of the guidelines for point i to viii)

ix) The practice of putting bamboo post directly in the ground shall not be permitted. Bamboo posts shall be fixed into the plinth. See Fig. 24.

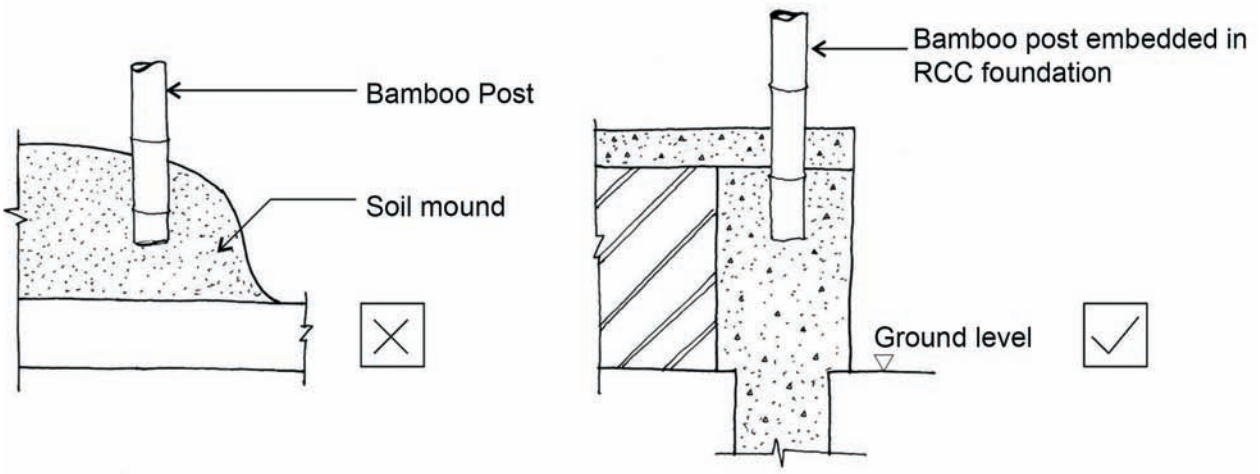



Figure 24 *Fixing bamboo at base*

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

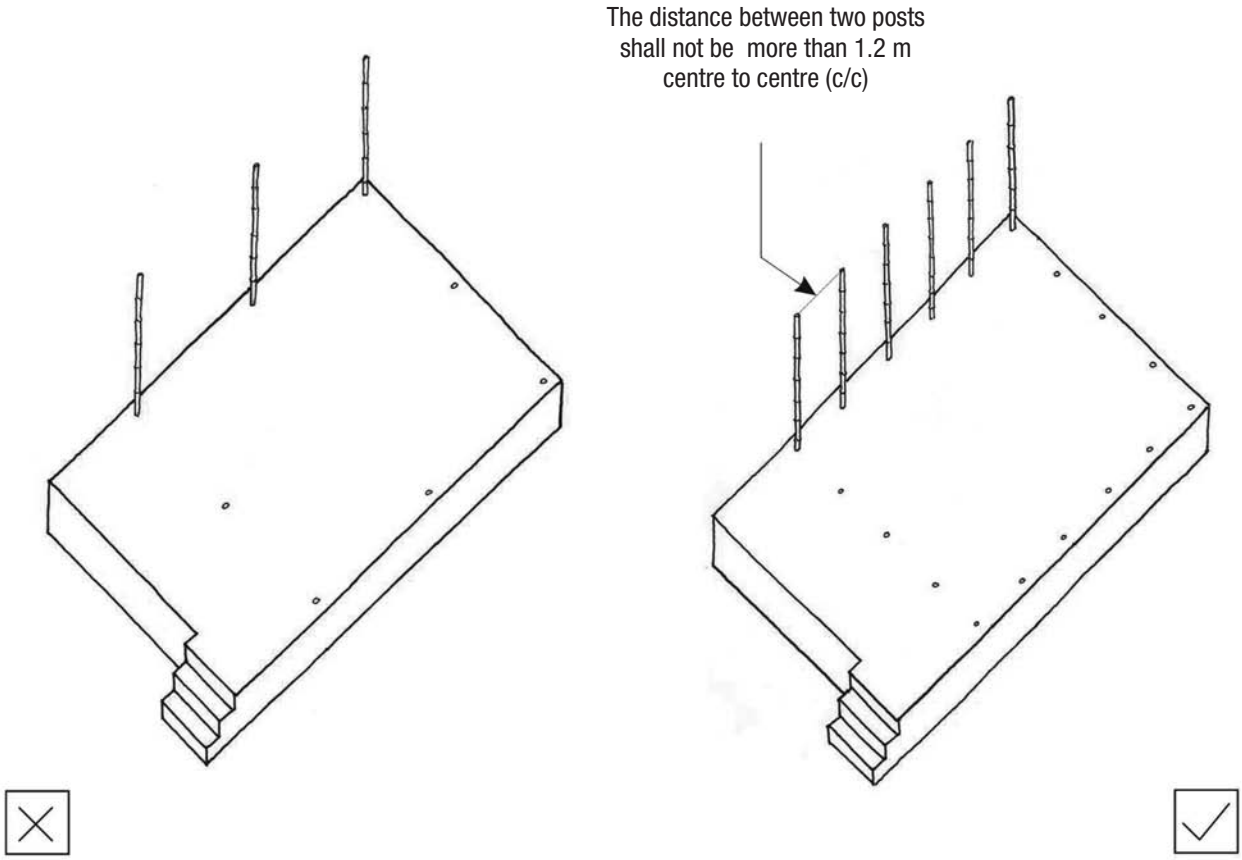
**8.3 Safety Provisions Required for Bamboo Super Structure**

Bamboos has presence of considerable amounts of starch in green or dry state which makes it attractive to such organisms as stain fungi and borer beetles, whereas there are only minor amounts of resins, waxes and tanwins which have sufficient toxicity to impart much natural durability in the culms.

**8.3.1 Posts**

a) Use only mature Harot (Bambusa Balcooa) variety of bamboo for structural posts and main beams.
b) All structural bamboo should be treated chemically to conform to IS 9096: 2006 (see App.-B)

c) The distance between two posts shall be not more than 1.2 m centre to centre. (Fig. 25)




a) Far apart (Not desirable)

b) Speed at 1.2 m (Desirable)

Figure 25 *Spacing of Bamboo Posts*

d) Minimum diameter of bamboo posts at thinner shall be and not less than 70 mm in any case preferable 90 mm but
e) Unsupported height of the post shall be not more than 3.0 m. If the height of the post is longer, a horizontal tie of the bamboo shall be provided.
f) Tar or Creosote treatment at the bottom of the post is required that needs to be embedded in the plinth.

g) A 30 cm deep and 100 mm dia. 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 as per Fig. 26.

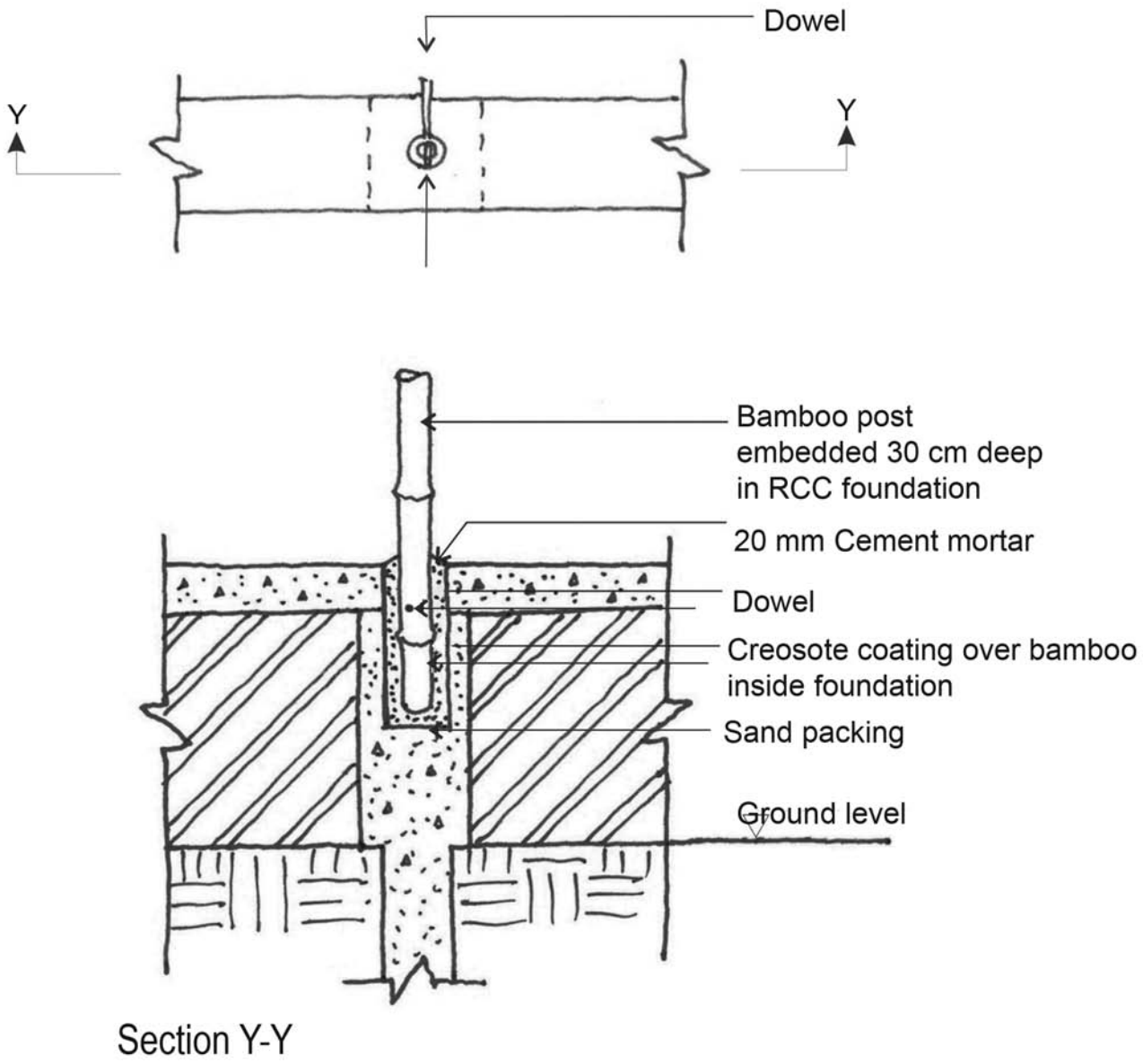
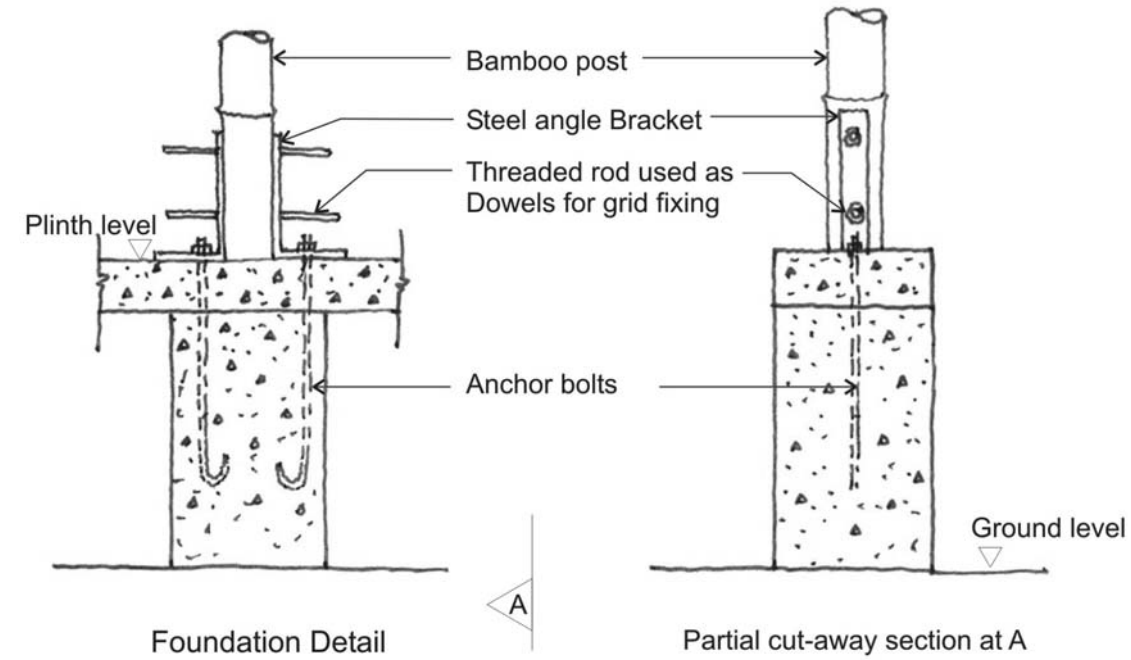



Figure 26 *Fixing detail of bamboo post into plinth masonry*

h) 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. 27).



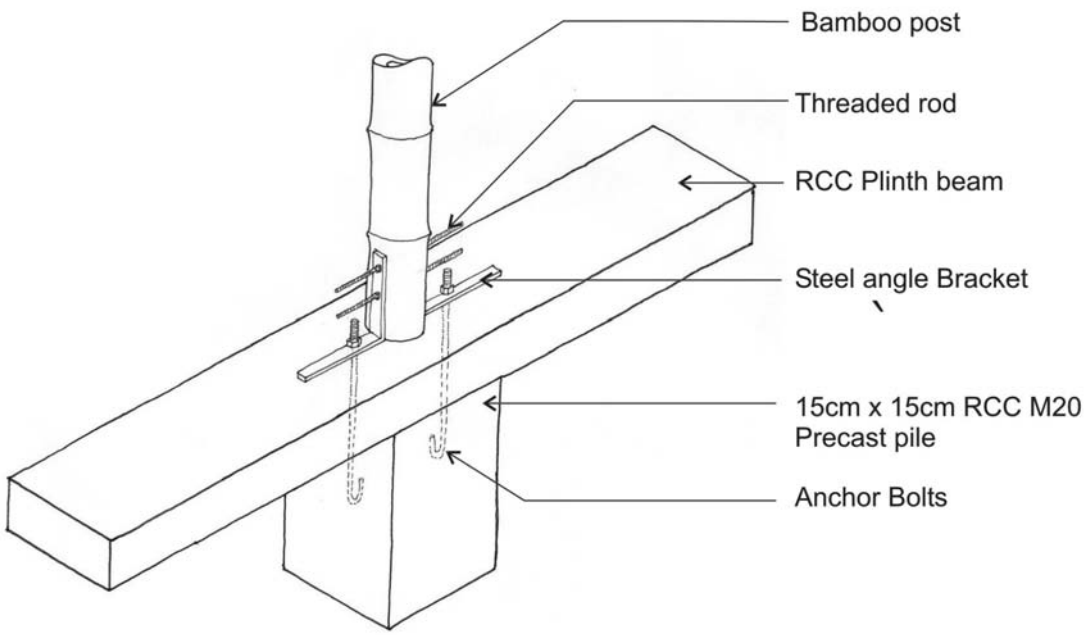




Figure 27 *Fixing detail of bamboo to plinth using bolted connection*

i) 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. See Fig. 28.

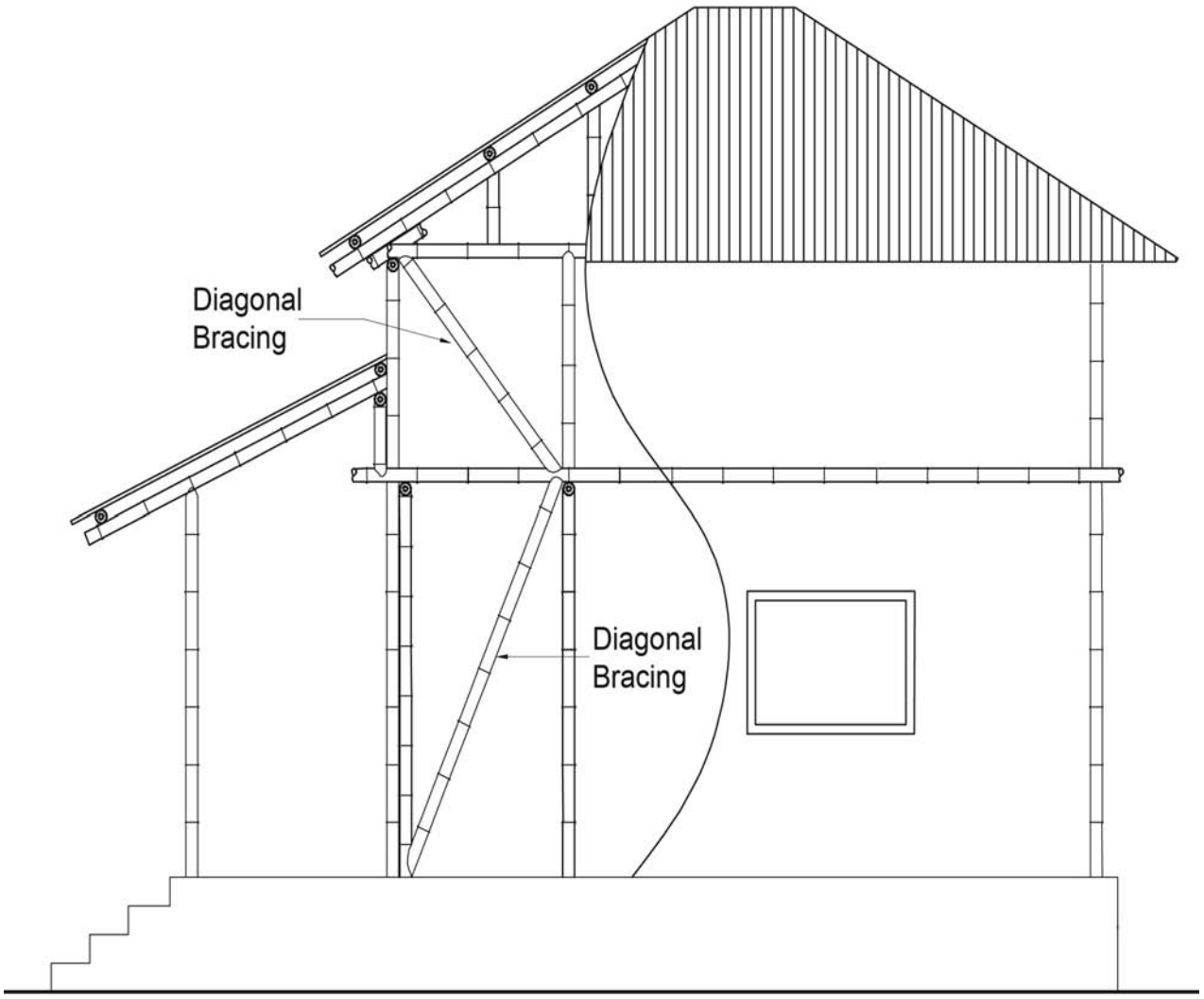



Figure 28 *Diagonal Bracing for Earthquake and Wind-resintance*

j) Alternatively, knee bracings may be provided at each post to connect post and the attic level beam.

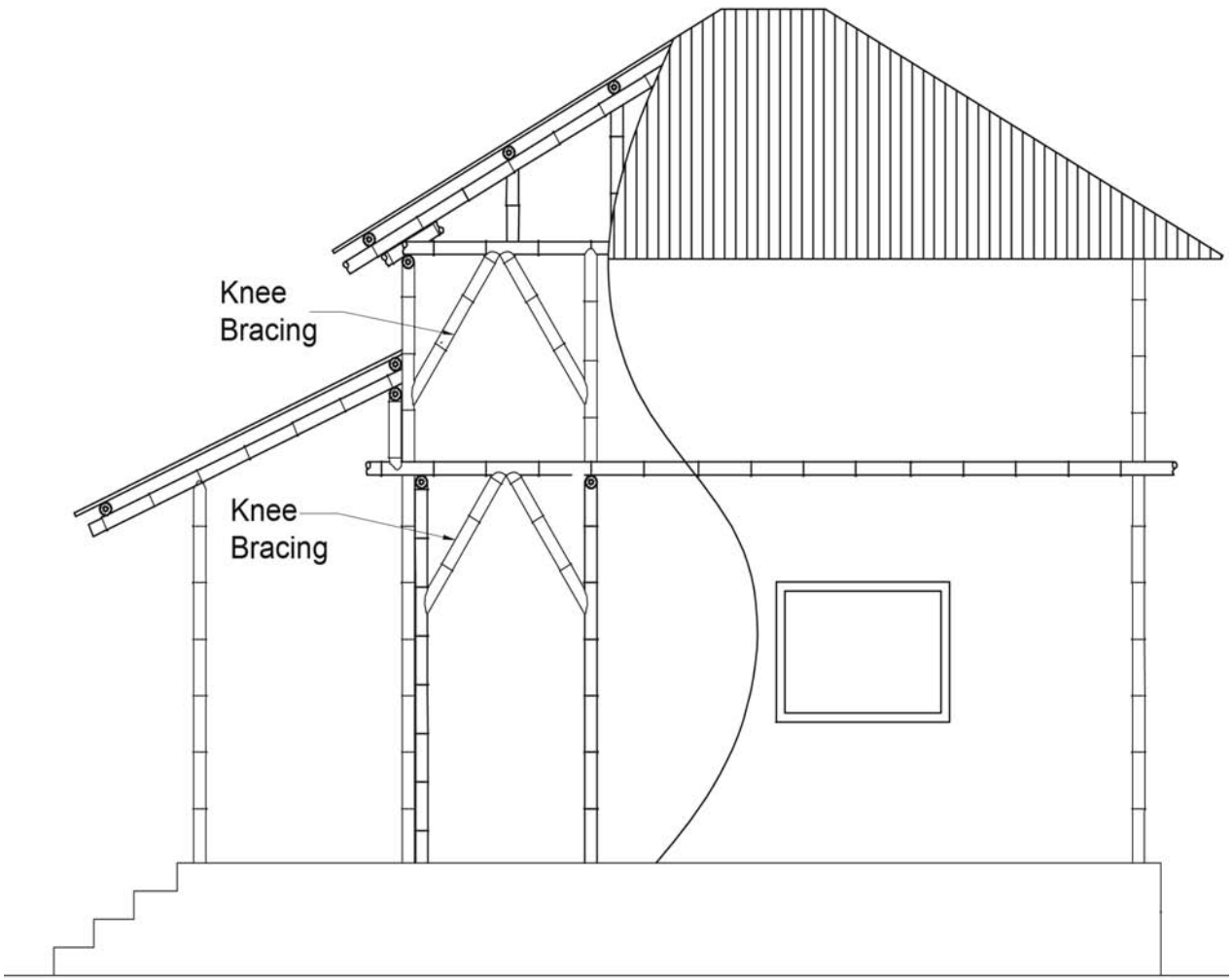



Figure 29 *Use of Knee Braces for Lateral load resistance*

k) Additional bamboo should be bundled with the posts for supporting main beams of the attic. This bamboo shall be tied to the post at least at 3 places and be rested on the plinth beam. See details in two sections in Fig. 30.

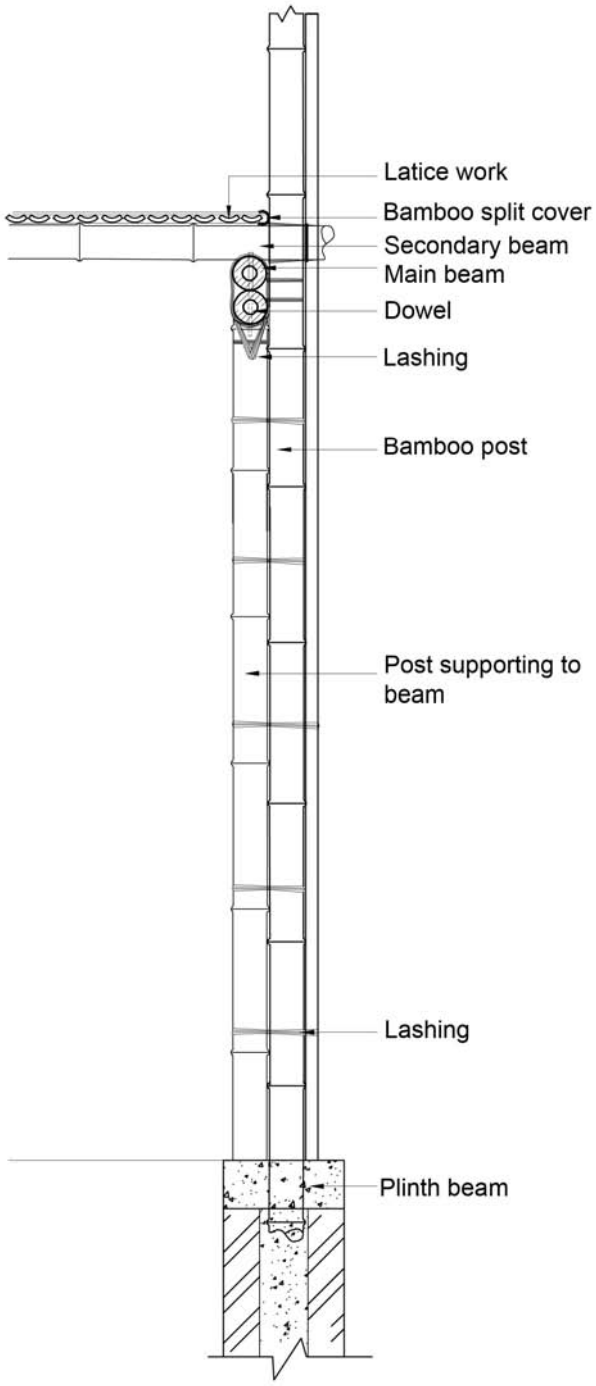



Figure 30 *Details of attic beams, lattice topping and column support*

Figure 31

### 8.3.2 Walling Lattice (Wattle and Daub)

a) The wall shall be made out of wattle and daub.
b) For latticework between the posts, any mature split bamboo ñ Harot, Chab or Makhaur shall be used. Traditionally, Chab is used more often.
c) 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.
d) This bamboo shall be treated as per the IS 1902: 2006 recommendations for non-structural bamboo (see App. B)
e) For lattice, jafri (the woven mat of split bamboo) may be used. This provides skeleton for daub work.

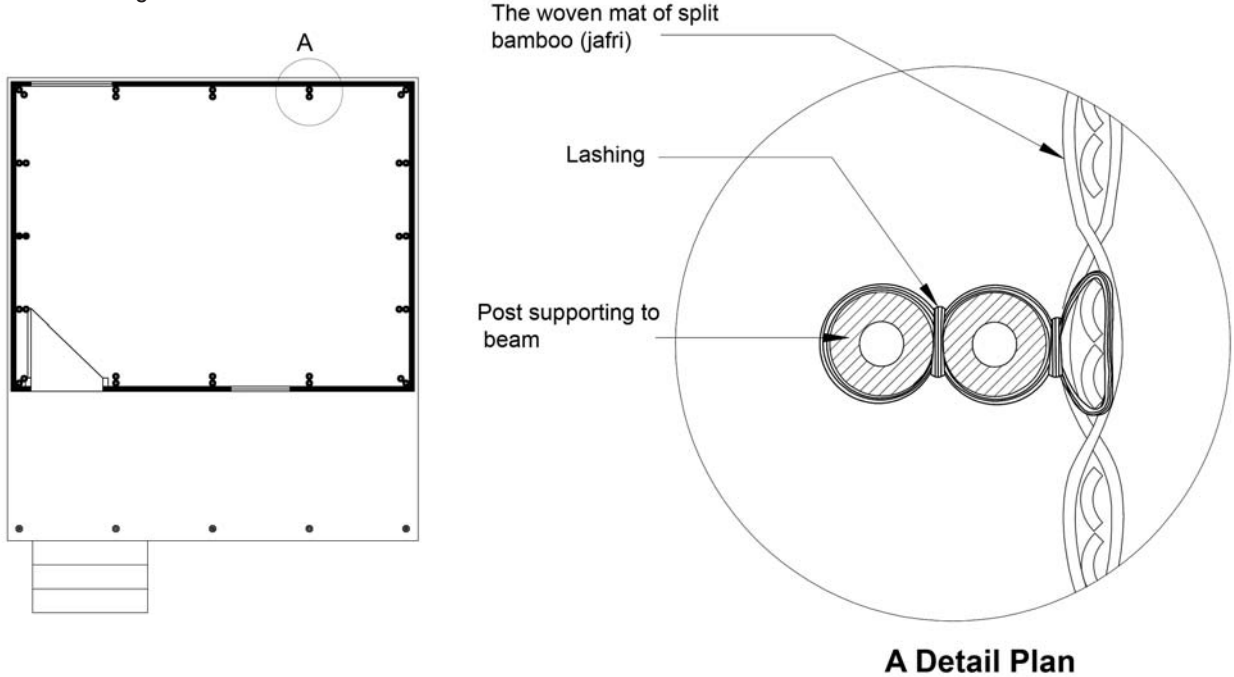



Figure 32 *Wattle fixing detail to bamboo post*

f) Lattice shall be tied properly to the bamboo posts and the attic level or eave level beam depending on the context. A typical tying detail is shown in Fig. 33.

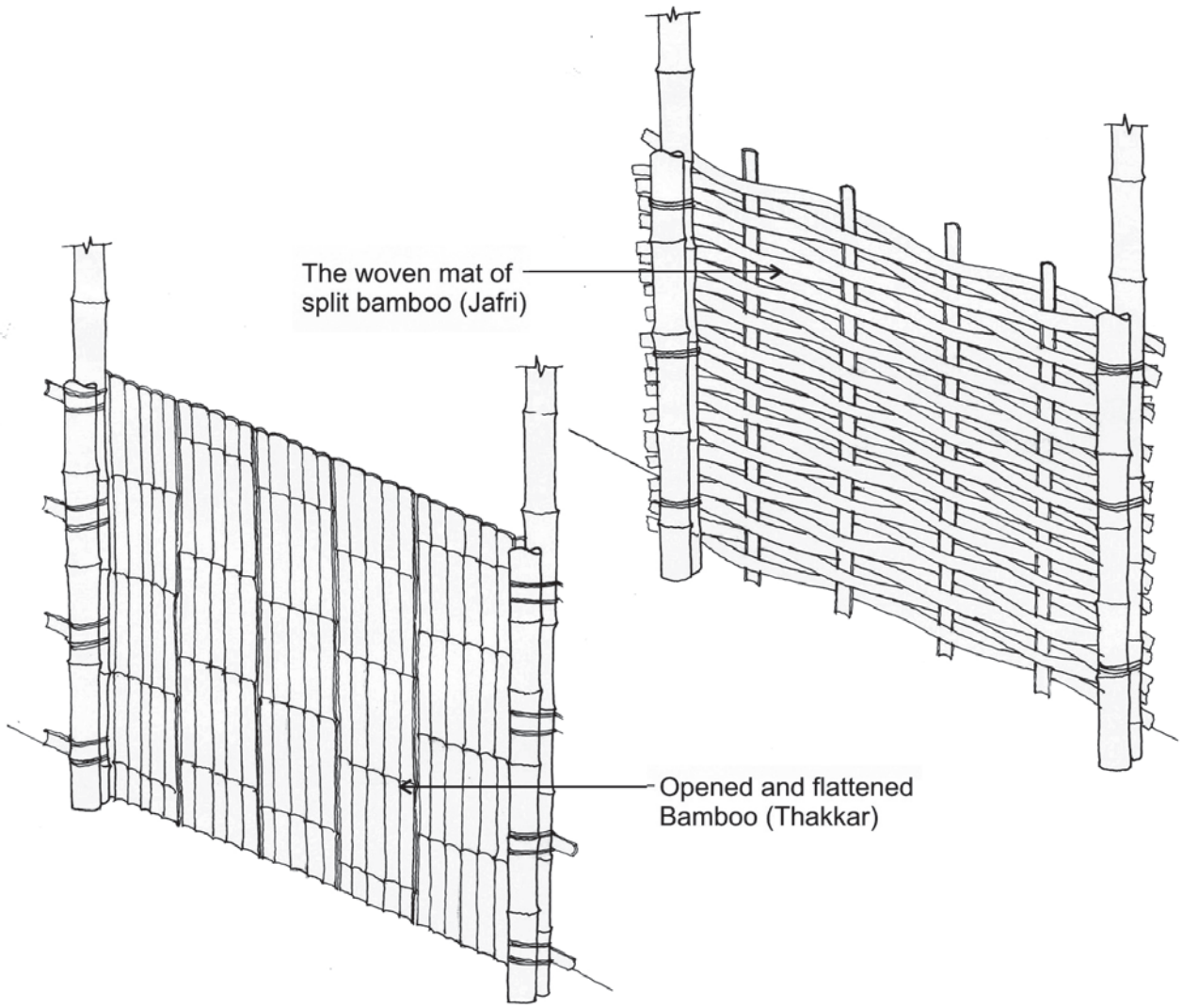



Figure 33 *Bamboo lattice different versions*

g) The inside of the wall panel shall be mud/cement plastered and outside will be cement plaster.

### 8.3.3 Attic level Floor

a) In all bamboo houses, attic is non- negotiable for flood safety. It shall be strong enough to take live load along with dead load in flood conditions.

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

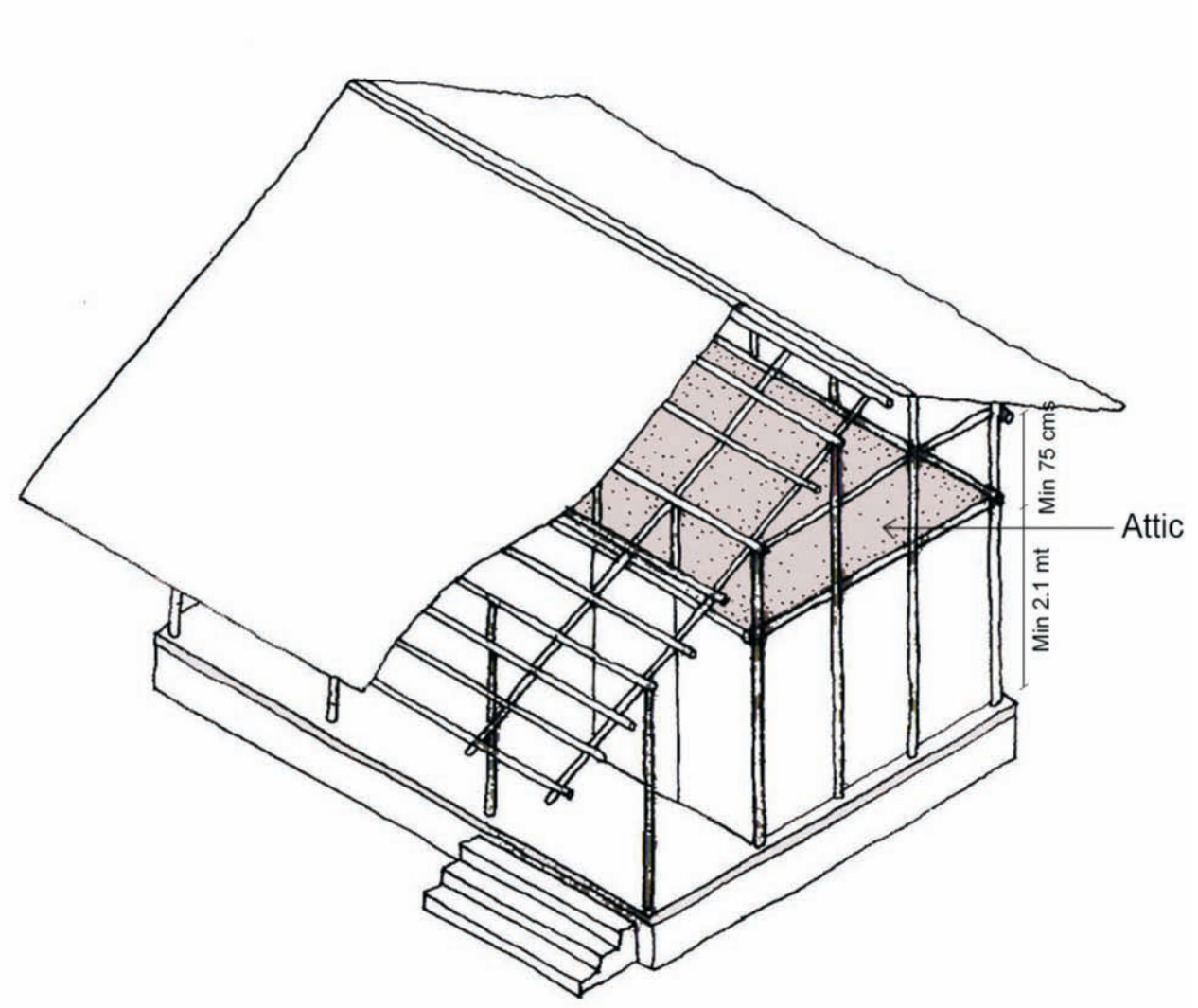



Figure 34 *Attic floor in bamboo house*

c) Total area of the attic shall be minimum10 m².

d) Diagonal bracing or knee bracing in the posts above attic level shall be done.

e) Only mature Harot bamboo shall be used for beams.

f) For the span more than 3 m, the main beams shall be made by bundling at least 2 bamboos (minimum 75 mm) placed one on top the other and tied together with shear pins or three bamboos tied tighter in star pattern as shown in fig. 30. The bundled beams shall be tied at middle of each bamboo culms. For smaller spans, single bamboo beams will be enough. These bamboo beams shall be placed on bundled posts as explained earlier. The detail of the joint is shown in fig. 35.

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

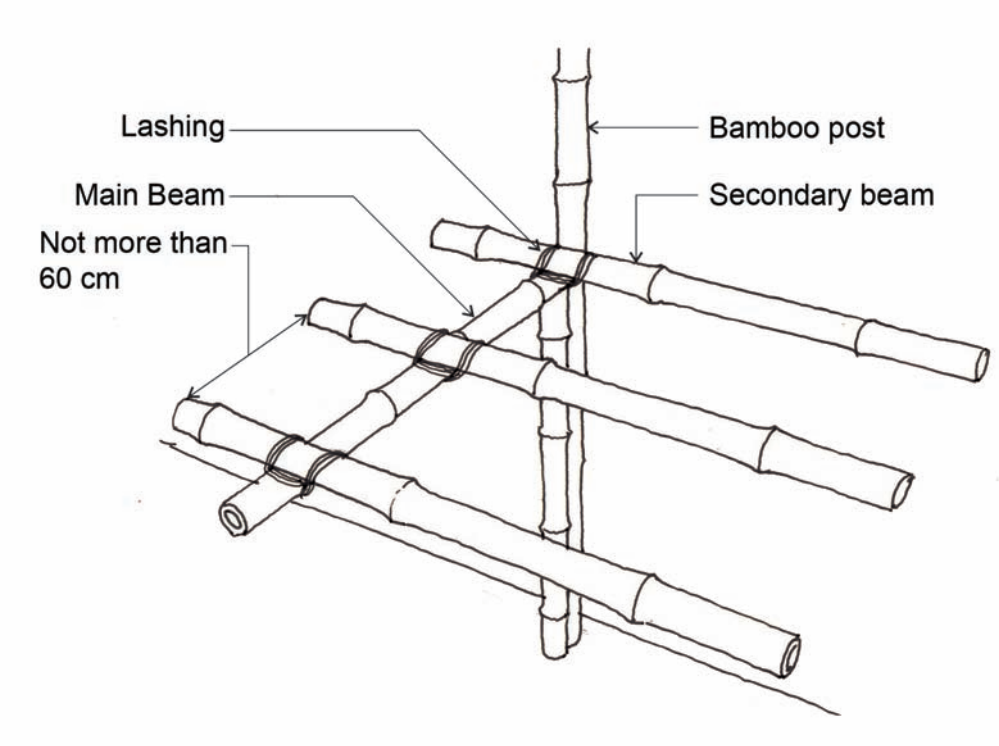



Figure 35 *Attic beam joint detail*

### 8.3.4 Pitched Roofs

Houses with bamboo walls can have following type of roofs.

i) CGI sheet roofs ñ hipped or gable

ii) Burnt clay tile roof ñ hipped or gable

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

b) For roof understructure, mature Harot or Chab varieties of bamboo shall be used.

c) 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 be not more than 30 cm.

d) The bottom most purlins at the end of roof overhang shall be tied to the eave level beam with lashings as per the diagram below.

e) The slope of the roof shall be as per relevant IS codes. In case of burnt clay tile roofs, the slope shall be minimum 29°. conventionally, sloping CGI roofs in Kosi region have a slope of 27° and it can range from 22.5° to 35° to avoid suction (negative pressure) on roof covering during high speed winds. See Fig. 36.

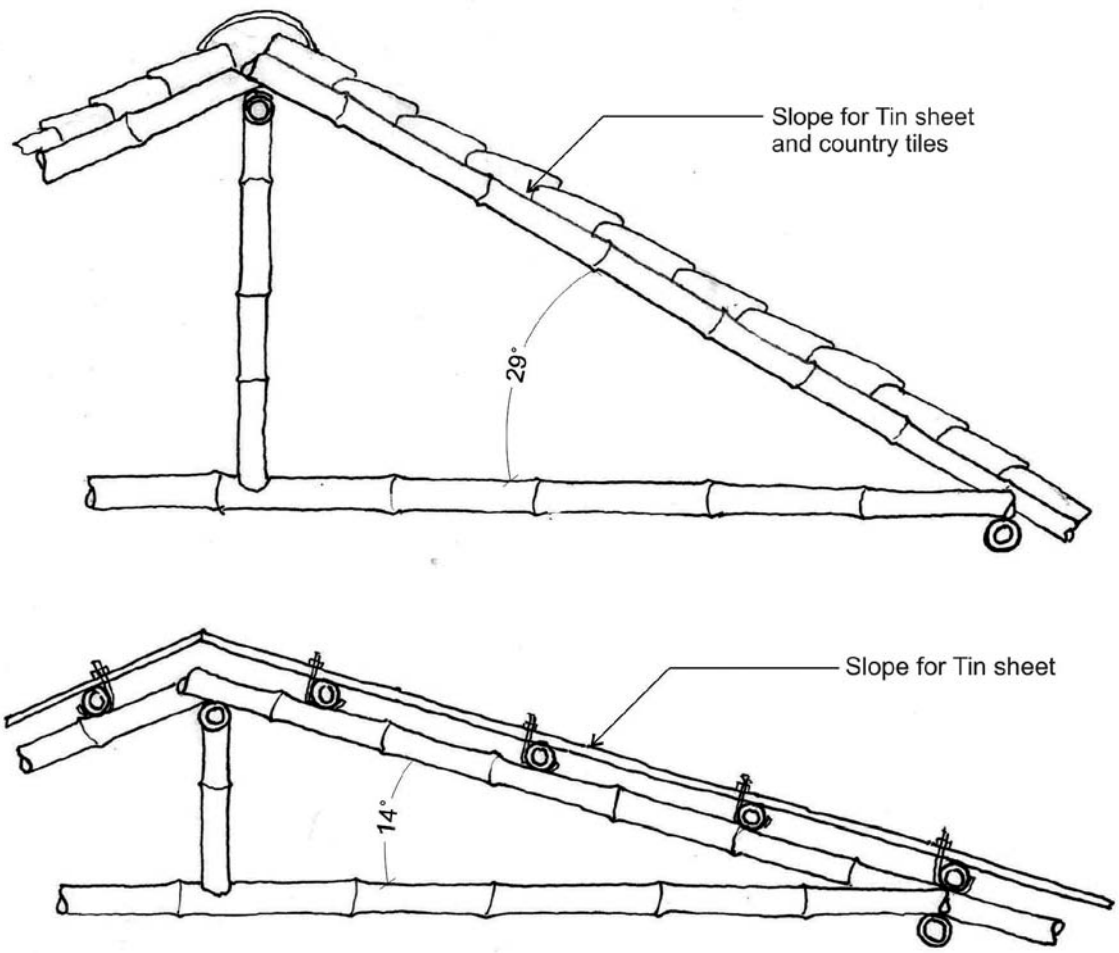



Figure 36 *Roof Slopes Angles*

f) The roof shall have an overhang of minimum 45 cm on all four sides.
g) The end of the cantilever portion of the rafter shall be lashed to the posts.
h) In case of CGI sheets, it needs to be fixed with the understructure by using J bolts with galvanized and bitumen washers to make it waterproof. Nails shall not be used for anchoring.

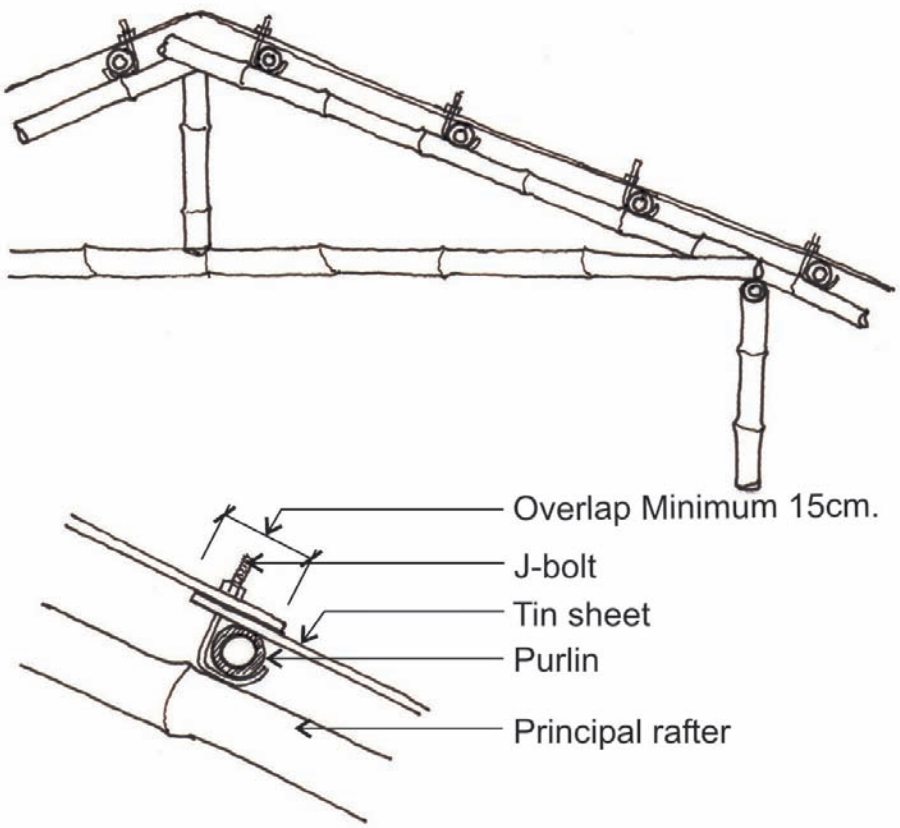



Figure 37 *Fixing details of tin sheets using J bolts*

i) 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 as shown in Fig. 37.
j) The spacing between two consecutive J bolts shall not be more than 45 cm.
k) In case of burnt clay tile roofs, cross bracing shall be provided with wire.
l) The last row of burnt clay tiles shall be held by sandwiching them between split bamboo strips as shown in diagram below so as to ensure the tiles are not blown away due to high winds or slide off.

# References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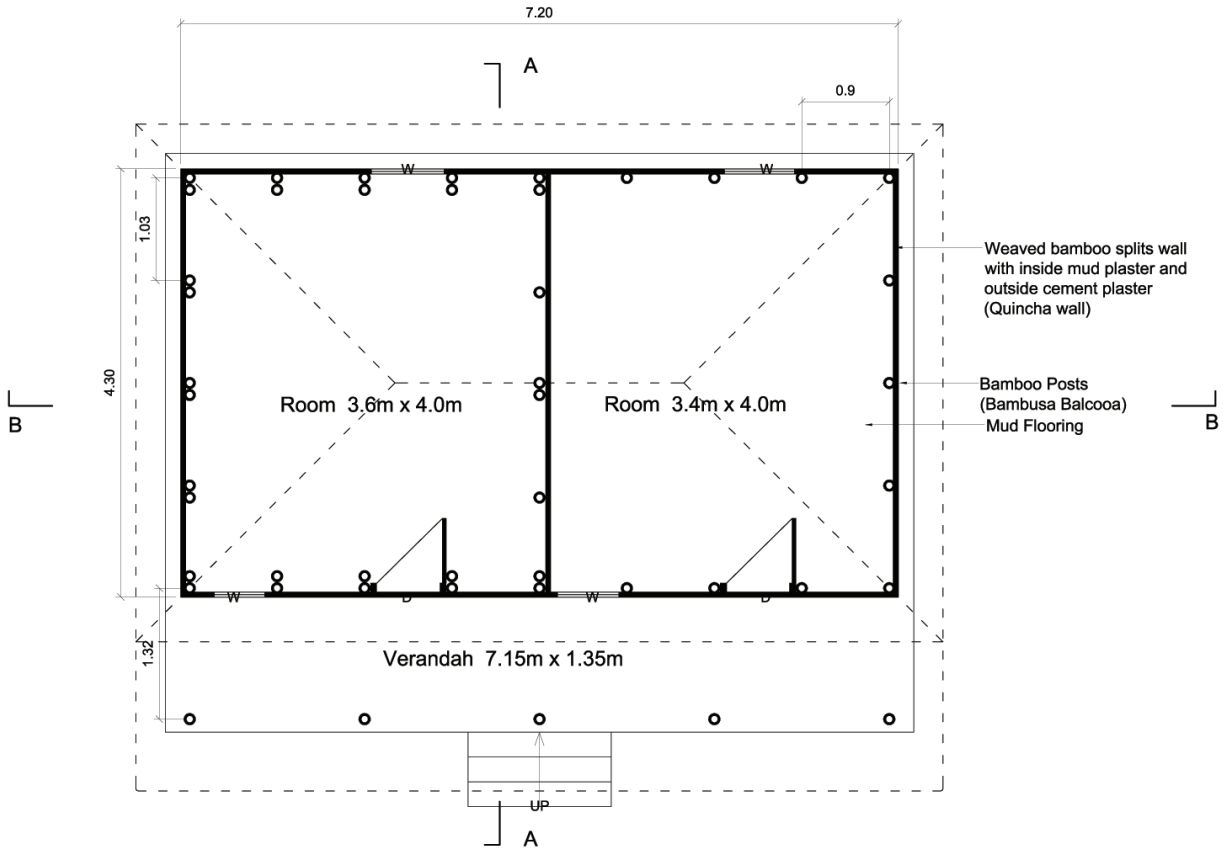
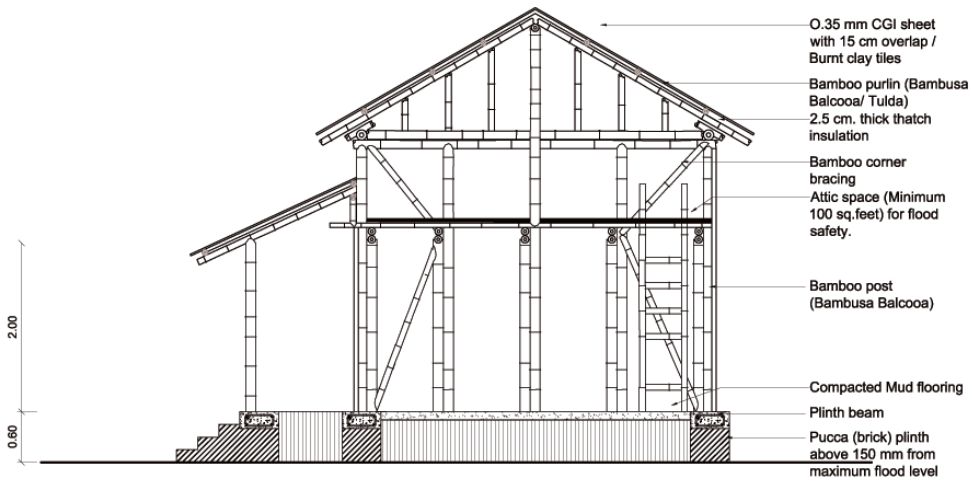
l) The Scout Association (2000). !/8 Scout Skills Simple Knot, Item Code: FS315082, London: The Scout Association

# Appendix-A

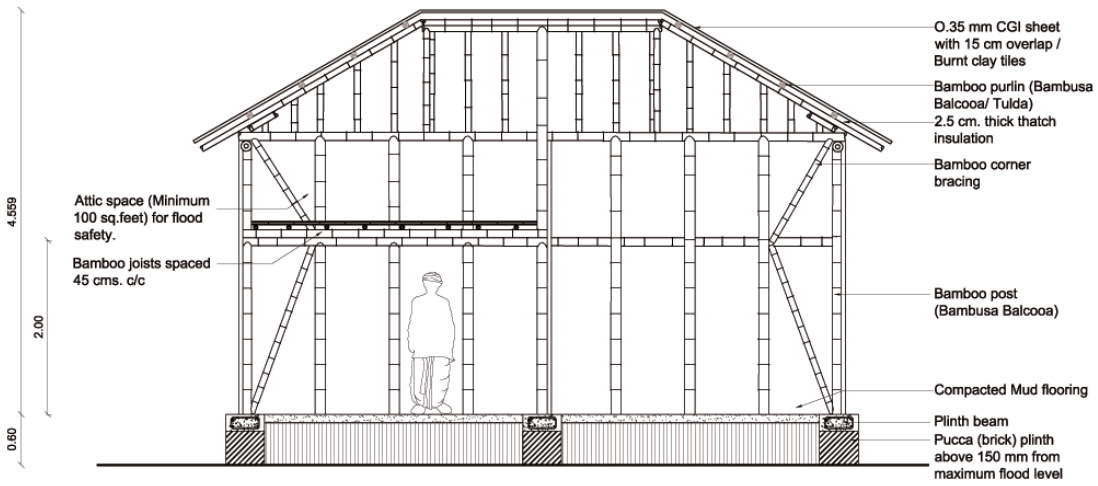
## Alternative - 1
## A Sample Design of House with Bamboo walls and CGI Sheet Roof




GROUND FLOOR PLAN




Section AA




Section BB

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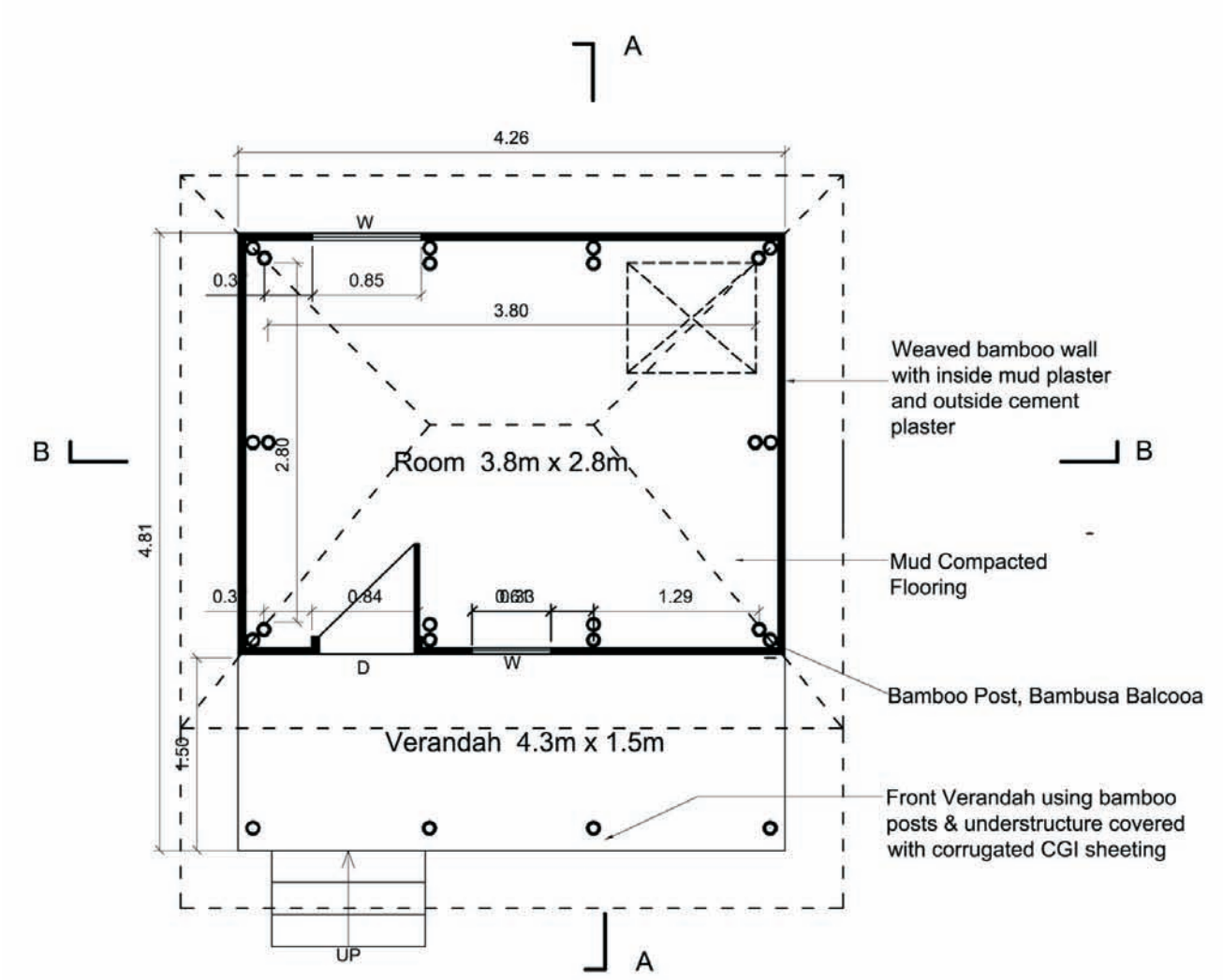
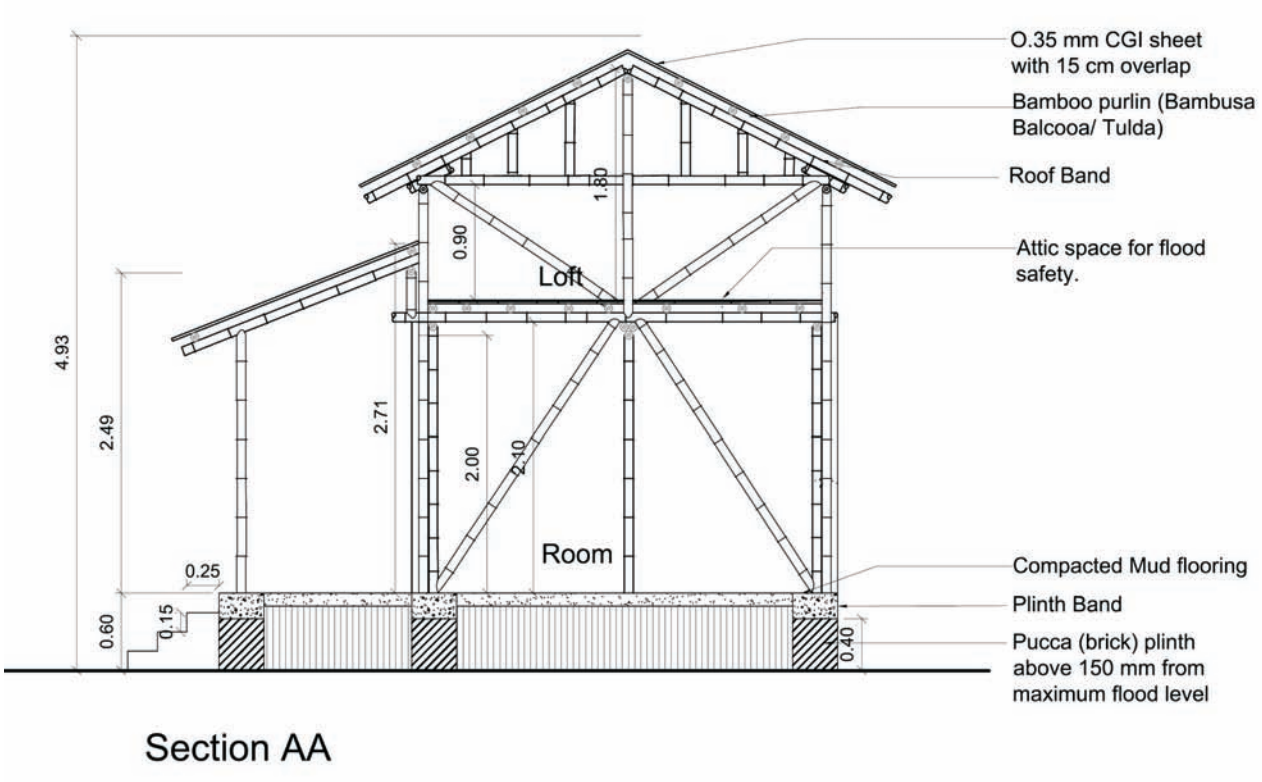
|---|---|---|---|
| PREPARED AS PER MEETING OF TECHNICAL COMMITTEE ON 2 - 3 DECEMBER 2009. | APPROVED BY:-<br>DR. ANAND S. ARYA Chairman, Technical Committee Kosi Rehabilitation and Reconstruction Programme | SHEET TITLE<br>SECTIONS | SHEET NO.<br>A2 |

## Alternative - 2
## A Sample Design of House with Bamboo walls and CGI Sheet Roof




GROUND FLOOR PLAN


O.35 mm CGI sheet with 15 cm overlap
Bamboo purlin (Bambusa Balcooa/ Tulda)
Roof Band
Attic space for flood safety.
Loft
Room
Compacted Mud flooring
Plinth Band
Pucca (brick) plinth above 150 mm from maximum flood level
4.93
2.49
0.60
0.15
0.25
0.90
1.80
2.71
2.00
2.10
0.40

Section AA

# Appendix-B

## Chemical Preservatives for Treatment of Bamboo

All structural and non-structural bamboos shall be chemically treated as per IS 9096:2006 and IS 1902:2006 respectively.

**a] Preservatives**

i) Boric acid and borax (BB)

ii) Boric acid and borax shall be mixed in ratio 1:1.5.

iii) Acid-Copper-Chrome (ACC) composition-

A typical composition comprises 1.68 parts of chromic acid (Cr2O3) (equivalent to 2.5 parts of sodium dichromate), 50 parts of Copper Sulphate (CuSO4.5H2O) and 47.5 parts of sodium dichromate (Na2Cr2O7.2H2O); conforming to IS 10013 (Part1)

iv) Copper-Chrome-Boron (CCB) composition-

A typical composition comprises of Boric acid (H3BO3), Copper Sulphate (CuSO4.5H2O), and Sodium or Potassium dichromate (Na2Cr2O7.2H2O or K2Cr2O7.2H2O) in the proportion of 1.5:3:4, conforming to IS 10013 (Part 3)

v) Acid- Curpric- Chromate (ACCH) Composition

A typical composition comprises of 1.68 parts Chromic Acid (Cr2O3) (equivalent to 2.5 parts of sodium dichromate), 50 parts of Copper Sulphate (CuSO4.5H2O) and 47.5 parts of Sodium Dichromate (Na2Cr2O7.2H2O); conforming to IS 10013 (Part 1)

Department of Planning
and Development

**Government of Bihar**

**2010**