

Low Cost Roof System For Rural Housing

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1. INTRODUCTION

1.1 Near about 5.6% of the total tribal population of India live in “MEWAR” and “VAGGAR” region of Rajasthan state. In this region, lot of tribals are residing in the out-skirts of Banswara, Udaipur, Pratapgarh and Dungarpur districts. They prefer to live in the jungle with the nature and build their huts by using local material and local skill. It is imperative to introduce the innovative technology of the construction of rural cost-effective huts, which is based on the adoption of the local environment and constructed with the house-hold themselves without the need of the modern tools & equipment.

If, we analyze the building costs and its break up, it is observed that the main components of the building are foundation, wall, roof, door & window, flooring and finishing etc. The maximum expenditure for rural houses after construction of walls is in roofs which is 25 % of total expenditure. Therefore, to reduce the cost of the roof of the rural houses this study was under-taken. Necessary sustainable cost-effective techniques are developed for supporting system by use of Bamboo roof trusses and Bamboo spaced column for cost-effective rural huts.

The average cost break-up of rural hut are shown as below

A rural house is a structure providing the suitable place for protecting rural people from heat, cold, rain and wild animals. It can be built with different types of roof covering materials like thatch, tiles, slate, galvanized iron sheets and corrugated asbestos sheets over a supporting structure at present it is a **balk or trunk of a tree** and the mud walls.

In place of the high cost of supporting structure, bamboo trusses are introduced as the cost-effective system for supporting the roof covering

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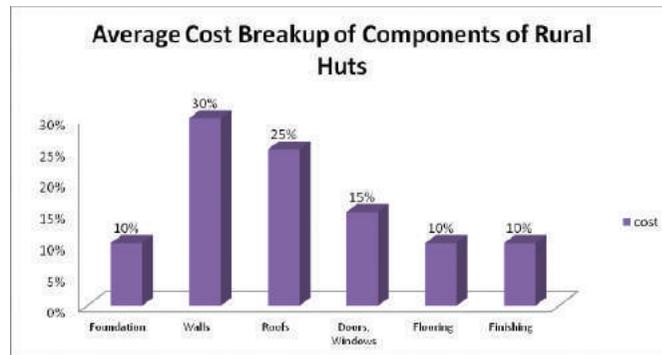


Figure 1: Cost break - up of component of rural hut



Photo 1: A Rural huts which require sustainable technology for longevity

material in place of **bauk or trunk of a tree**. It is a useful system that is simpler and lowers the cost of construction of rural houses.

Use of Bamboo in cost-effective hut construction seems to be a reasonable approach. Bamboo is abundantly available in Rajasthan. Due to its strength it is ideally suited for economical construction of building and structure. By weight it is stronger than steel and some structural timber. Species of bamboo like *dendrocalamus strictus* is tested and have been found to have almost half the yield strength of mild steel.

1.2 Bamboo is a composite material consisting of long and parallel cellulose fibers embedded in a ligneous matrix. Bamboo has been used for many non-structural purposes since long time. As it is a fast growing plant and has a number of versatile usage in the rural areas such as Agriculture, Handicraft,

Food and Feed, Medicinal purpose, Interior Decoration, Furniture, Temporary bridges, Paper pulp etc.

Its use drastically curtails the high costs of high energy materials, reduces the impact on the natural environment. It easily works with simple tools, easy to build and readily repaired in the event of damage.

In Rajasthan it covers 940 square km area. This is approximately 2.5% of total area of Rajasthan state. It is mainly found in regions of Chittorgarh,

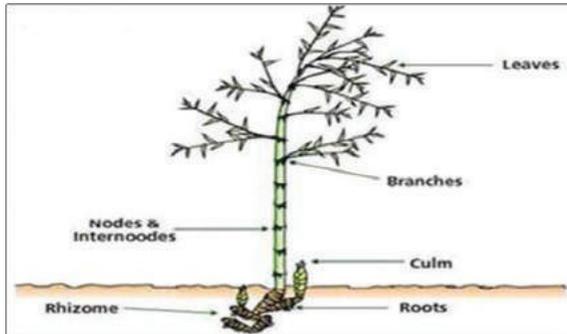


Photo 2: Bamboo branches & leaves

Udaipur, Banswara and Abu Hills. The state produces 120 lakh of bamboo every year.[1]

Bamboo in rural area is popularly known as “Poor man’s timber” in India, “Green gold” in Japan, as “Friend” in China, as “Brother” in Vietnam. It is one of the most important and useful plants in the world. Its strength, straightness, smoothness, lightness and extraordinary hardness makes it most suited for many purposes [1].

2. PHILOSOPHY OF COST- EFFECTIVE CONSTRUCTION

2.1 Cost-effectiveness means value for money, which means that if one spends one rupee, one gets one rupee worth of goods or services. The various factors to achieve cost-effectiveness are as under:

- (i) Materials
- (ii) Design & Innovation
- (iii) Skill & Technology
- (iv) Social responsibility and Eco-friendliness

While striving for the above we should not compromise with the safety and functional compatibility of the structure.

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2.2 The father of nation, Mohan Das Karm Chand Gandhi, narrated that to provide Houses to the masses at low cost we should use local materials and local skill and discard the use of high energy consuming materials like cement and steel etc. To achieve his dreams we should construct mud house with thatched roof supported by bamboo roof trusses and bamboo spaced column.[4]

3. MATERIAL FOR TRUSS AND SPACED COLUMN

- (i) Truss - Bamboo *Dendrocalamus strictus*
- (ii) Gusset plates -Neem Wood
- (iii) Spacer blocks - Neem Wood
- (iv) Dowel pins - Bamboo 10mm in dia.

Bamboo (*Dendrocalamus strictus*) and timber especially Neem wood are most widely available in MEWAR region.

The *Dendrocalamus strictus* variety grows up to 10.0m tall and 130mm in diameter with swollen nodules. Culms are sometimes solid called as MALE bamboo lower stem-sheaths covered on the back with golden-brown stiff hair & Intrados up to 50cm long. In addition to *Dendrocalamus strictus* the other variety of bamboo grown in lignified regions of Rajasthan is *Bamboosa arundinacea* and *Bamboosa vulgaris*.[3]

Neem tree is a popular village tree. It has the ability to grow very fast and survive in drought and poor soil. It is of 30.0 m height with leaf branches. Due to **antifungal, antibacterial and antiviral** constituents of the neem tree it is most widely used in construction of rural houses such as frame and shutters of door and window and in this project work it is used as a gusset plate of bamboo truss [2].

4. TESTING OF MATERIALS FOR SUITABILITY

All physical and mechanical properties of *dendrocalamus strictus* bamboo for its use in structural purpose in construction of huts are tested as per the following IS standard codes:

IS : 6874 - 1973 *Indian Standard* METHOD OF TESTS FOR ROUND BAMBOOS[9]

IS : 8242 - 1976 *Indian Standard* METHOD OF TESTS FOR SPLIT BAMBOOS[10]

The species of bamboo *dendrocalamus strictus* were tested in the laboratory and the values of following properties were recorded.

(a) Physical properties

- (i) Moisture content. 12.63 %
- (ii) Specific gravity - 70.8 KN/m³
- (iii) Shrinkage - 1.19 %

(b) Mechanical properties

- (i) Static bending test - 75.64 N/mm²
 - (ii) Compression along to grain – 42.20 N/mm²
 - (iii) Tension along to fibers - 93.75 N/mm²
-

From above experiments it can be observed that the relative properties of bamboo are comparable to group “C” wooden material as per strength point of view.

5. SELECTION OF TRUSS CONFIGURATION

Following considerations and criteria were considered for selecting the type of roof truss.

- (i) Simple triangles with long sides without lengthening joints
- (ii) Minimum no of members meeting at a joint
- (iii) Member consisting single or double round bamboos
- (iv) Minimum no of two dowel pins at a joint

6. LOAD CALCULATION ON TRUSS AND DESIGN

6.1 Dead Load

For dead loads the roof has been considered to be covered by thatch roof with battens. These are considered to impose a dead load of 350-500 N / m². The self weight including purlins is to be taken as 200 N/ m² (horizontal). The density of bamboo is assumed to be equal to 7.646 KN / m³.

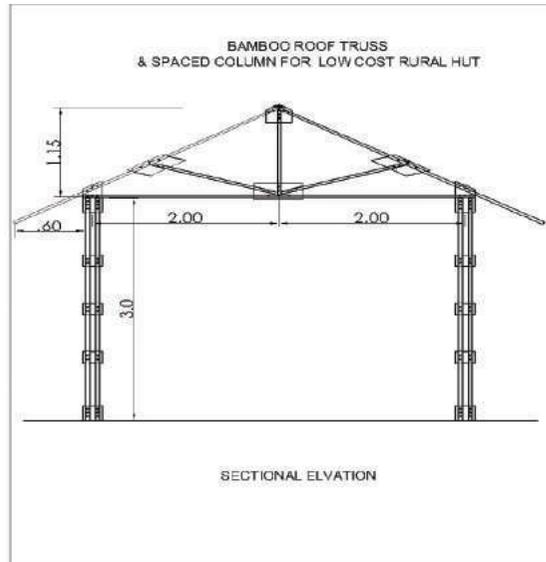
Total dead load = 780 N/m² [7]

The shape of the truss selected is shown as below

6.2 Imposed Load

In accordance with IS 875 part 2, an imposed load of 0.75 KN/m² has been considered for the roof with slopes up to 10 degrees and access not provided. For the roofs with slopes greater than 10 degrees, less 0.02 KN/m² for each one degree over 10 degrees, but subjected to a minimum of 0.4 KN/m² (horizontal).

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Drawing 1: Bamboo Roof Truss & Spaced Column For Low Cost Rural Hut.

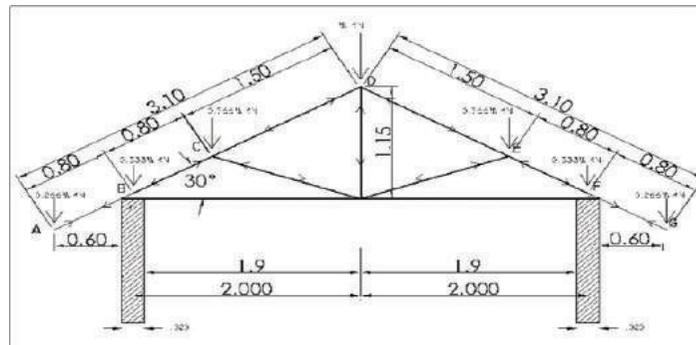


Figure 2: Dead load & Imposed load on each of the top panel in D/W direction on bamboo roof truss.

$$\text{Imposed load} = [0.75 - (30 - 10) \times 0.02] = 0.35 \text{ KN/m}^2$$

Subjected to a minimum of 0.40 KN / m² [7]

6.3 Wind Loads

In this study, the structure is analyzed for wind forces in accordance with IS: 875 Part 3. For Rajasthan region, this code recommends a basic wind speed

V_b of 47m/s. This study has considered the value of the probability factor (risk coefficient) k_1 as 1.0 assuming a mean probable life of 50 years.[7]

Table 1: External and Internal Wind Pressure Co-efficient

| Wind normal to ridge | Total pressure= $(C_{pe} - C_{pi}) P_z$ | |
|----------------------------|---|-----------------------|
| | $C_{pi} = + 0.2$ | $C_{pi} = - 0.2$ |
| Wind ward $C_{pe} = - 0.2$ | -410.6 N/m ² | 0 |
| Leeward $C_{pe} = - 0.5$ | -718.5 N/m ² | -308 N/m ² |

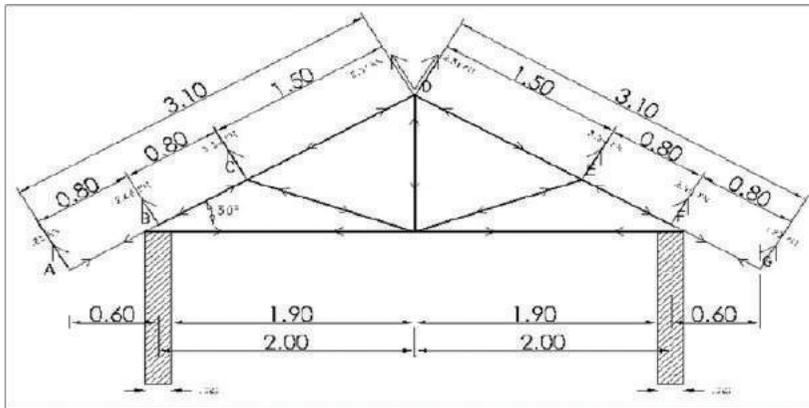


Figure 3: Wind load on each of the top panel on bamboo roof truss in U/W direction

| | | |
|--|--------------------------|------------------------|
| Wind parallel to ridge on both slopes $C_{pe} = - 0.8$ | -1026.4 N/m ² | - 616 N/m ² |
|--|--------------------------|------------------------|

Maximum wind load = - 1026.4 N / m² uplift on both slopes.

7. FACTOR OF SAFETY AND ALLOWABLE STRESSES

The tensile strength and the compressive strengths as per testing in the laboratory is 93.75 MPa and 42.20 MPa respectively. Being natural product, and expecting a large variation of strength characteristics, the large factor of safety is considered in the proposed approach as per the table given below. Hence, the allowable stress in tension works out to be 18.75 MPa. For compression, the allowable compressive stress works out to be 8.44 MPa for a slenderness

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ratio of 80. Each bamboo element is considered to have an external diameter of 40mm and a wall thickness of 10mm [8].

Table 2: Factor of Safety for Bamboo used in inside Location [6]

| Sr. No. | Particular | Factor of safety for Bamboo used in inside location |
|---------|---|---|
| 1. | Maximum fiber stresses in bending for bamboo purlins and tension along grains | 4 |
| 2. | Horizontal shear in beams | 12 |
| 3. | Maximum compressive stresses along grains. | 5 |
| 4. | Modulus of elasticity for calculation of allowable deflections in purlins | 1.5 |

The design forces and details of truss members are shown in table below

Table 3: Design Forces & Details of Truss Members

| Members | Name | Length In meter | Max. Force Design KN | Max. Force Checking KN | Req. X Sec. Area mm ² | Prov. X Sec. Area mm ² | Dia. of Bamboo mm |
|-------------------|------|-----------------|----------------------|------------------------|----------------------------------|-----------------------------------|-------------------|
| Principal Rafter. | AB | 0.80 m | + 2.44 | - 0.51 | 110 | 314 | 20 |
| Principal Rafter. | BC | 0.80 m | - 11.61 | +1.98 | 1161 | 1256 | 40 |
| Principle Rafter | CD | 1.50 m | - 6.97 | +1.98 | 697 | 1256 | 40 |
| Outer Horizontal | AH | 0.70 m | - 2.24 | + 0.97 | 224 | 314 | 20 |
| Main Tie | BI | 2.00 m | +12.15 | - 1.00 | 540 | 707 | 30 |
| King Post | ID | 1.15 m | + 2.34 | - 1.03 | 104 | 314 | 20 |
| Strut Member | BH | 0.40 m | - 9.49 | + 2.00 | 949 | 1256 | 40 |
| Diagonal Member | CI | 1.36 m | - 4.09 | +2.42 | 409 | 707 | 30 |

8. BAMBOO SPACED COLUMN

Spaced column consists of two parallel members separated by spacer blocks at the ends and mid length. The spacer blocks are connected by connectors.

Spaced column is made up by four 40mm dia. Round bamboo with 30mm thick neem wood spacer block to keep the main member at a fixed distance and suitably connected by 10mm dia. And minimum 150mm long Bamboo dowel pin as a connector. This connection is very simple in construction it is made by drilling the bamboo by traditional equipment poker or Hand drill which is made by villagers themselves and insert the bamboo dowel pin in cross direction, this connection transmit the forces to different parts of truss and column successfully.



Photo 3: Connection with Bamboo dowel pin

9. FABRICATION OF ROOF TRUSS AND SPACED COLUMN

Following are the steps taken in fabrication of truss and column.

- (a) Prepare a layout plan on the working plate-form
- (b) Cutting of bamboo for principal rafter, main tie, king post and diagonal web member as per layout on the working platform.
- (c) Placing of principal rafter, main tie, king post and diagonal web on appropriate place with gusset plate
- (d) Temporarily connected to each other with the help of wire and rope.
- (e) Drilling holes with the hand drill in bamboo and gusset plate simultaneously

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- (f) Insert dowel pin with the help of mallet / hammer at each joint as per design
- (g) Again repeat the above process till the completion of joints as per drawing
- (h) Preparation of the spaced column separately with top, bottom, and Intermediate spacer plate
- (i) Connect the roof truss and spaced column as per drawing.



Photo 4: Fabrication of Bamboo Truss

10. ERECTION AND FIELD LOAD TEST

The truss and the columns were erected with the help of ropes and kept vertical with the help of guy ropes tied to pickets. The truss was tested by applying gradual loads through rope cradles at node points by placing sand filled gunny bags on the cradles till the maximum design load are achieved.



Photo 5: Erection of Bamboo truss



Photo 6: Hanging cradles

Table 6: Showing stages of loading

| S. No. | loading | Load at A in kg | Load at C in kg | Load at D in kg | Load at E in kg | Load at G in kg | Visual. observation |
|--------|--------------|-----------------|-----------------|-----------------|-----------------|-----------------|--------------------------------------|
| 1 | First stage | 25 | 50 | 100 | 50 | 25 | deflection & displacement acceptable |
| 2 | Second stage | 50 | 100 | 200 | 100 | 50 | deflection & displacement acceptable |
| 3 | Third stage | 75 | 150 | 300 | 150 | 75 | deflection & displacement acceptable |



Photo 7: Showing load at Third stage

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The maximum load were kept for 15 days in place and it was found there was no excessive deflection of the truss member and also no buckling was seen in the column. Therefore, it can be concluded that the roof supporting system can sustain long term loading.

11. CONCLUSION

It is the first initiative where in the bamboo has been used to form a standard truss and field tested and also the spaced column has been formed by using bamboo members and field tested. This seems to be a viable and sustainable proposition. However, more work needs to be done with the following variables. Different truss configuration, forms of spaced columns, types of roofing materials, types of connecting systems viz. rope connection, wire connection etc, Spacing of trusses and different span of trusses.

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