Chapter 10: Bow Beam and A-Frame for Roof

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Introduction

This project started with two concepts – Bamcrete bow-beam and Bamcrete column. This chapter presents the history and details of the work done by Sudhakar, scientific work done to understand the structures, and observations. It was realized that even though this bow beam was a noble concept, there are severe limitations of this concepts.

In rural housing, the clamor is for RCC buildings with flat roofs that also serve the need of high quality secure drying surface for the agricultural produce. However these use a lot of steel and cement, both of which are energy intensive, expensive and not produced locally in rural areas. This is proving to be a serious constraint in mass rural housing programmes.

Bamboo, a Gift of Mother Nature, is an excellent bio-reactor that churns out Light Weight, High Performance, Cost Effective and Functionally Graded Fully Matured Composite Material every year for several decades, unmatched by any timber yielding plant/tree. A bamboo bush matures in about 5 years. In each established bush, an individual bamboo culm matures in about 3 to 4 years (against 30-40 years for a typical timber tree).

This Chapter first presents the work done by Dr. Sudhakar in establishing the basic concepts before joining IITD. This is followed by the work by Dr. Gupta, Charu Korde and others. Finally the work of Bamboo House India in A frame is introduced.

Intial work done by Dr. Sudhakar HARITHA ECOLOGICAL INSTITUTE :

Blissfully unaware of these developments, both at the national and international level, Sudhakar9 and his school students M.V.N. Satyanarayana and P. Siva Prasad experimented with 'bow' as a load bearing structural element in 1989 at Haritha Ecological Institute, Paloncha, Andhra Pradesh. This was further developed into a full fledged bamboo bow beam with two cross ties of span 6.1 m and was demonstrated in a shed, capable of taking the roof load from a variety of roof covers: from corrugated GI sheets to thatch. This was used as a classroom.

During 1994–95, a new campus of Haritha Ecological Institute was built with over 2000m2 of covered area for class rooms and residences, all with 7.3 m span bamboo bows as roof load bearing elements as shown in Fig.2. These bamboo bow buildings use a variety of roof covers - from corrugated GI sheets to thatch and are still in good condition even after 12 years of regular use. The analysis of these structures was done by SARMET from Mumbai and presented as a report to INBAR10. Subsequently Ferro-cement band as a rigid tie between bamboos has been developed and used in bamboo bows which are separated vertically resulting in stiffened roof load bearing elements. Some demo constructions built with spans from 3m to 7.3m were found to be cost effective in housing. Research in the area of bamboo has been initiated at IIT Delhi with the help of the seed funding by HUDCO for developing a National Resource Facility for Bamboo Technology at IIT Delhi. Later NAIP through World Bank recently provided a substantial grant to help research activities in this field.

Typical Barrel Roof Building

Fig. 3 shows houses of 7.3m span with bamboo bows supporting the roofs which are in use since 1994. The bamboos were not painted and are all in excellent condition and required no maintenance. The steel trusses would have needed painting at least two times in the 13 years and the cost of painting alone would have been more than the cost of the bamboo bow beams. The timber beams are unthinkable for the 7.3 m span buildings.

The erection of bamboo bows; a typical barrel roof of corrugated GI(Galvanized Iron) sheet; and the under side view of the barrel roof with diagonal cross ties with bamboo is depicted in Fig. 3. Steel pegs grouted in the ground define the arch and bamboos are bent using the pegs. Two 5.5 m bamboos with their thick ends (4 cm dia.) starting from each end are used so that there is a substantial over lap between them for almost the entire mid half portion of the bow. The two bamboos are tied with several steel binding wires spaced about 15- 20 cm apart, much like the steel rods in RCC works. One horizontal and two cross ties for each bow are of GI wire of 1.5 to 2 mm and are simple. These involved practically no nailing or drilling, even though the latter could also be used. Each of the two cross ties starts from the base at one end and reaches the bow at close to the three fourth span point on the other side. The bow more or less retains its shape even after it is taken out of the pegs. The crown height of the bow is approximately a fifth of the span. The cross ties concept was an important contribution, Satyanarayana and P. Siva Prasad.

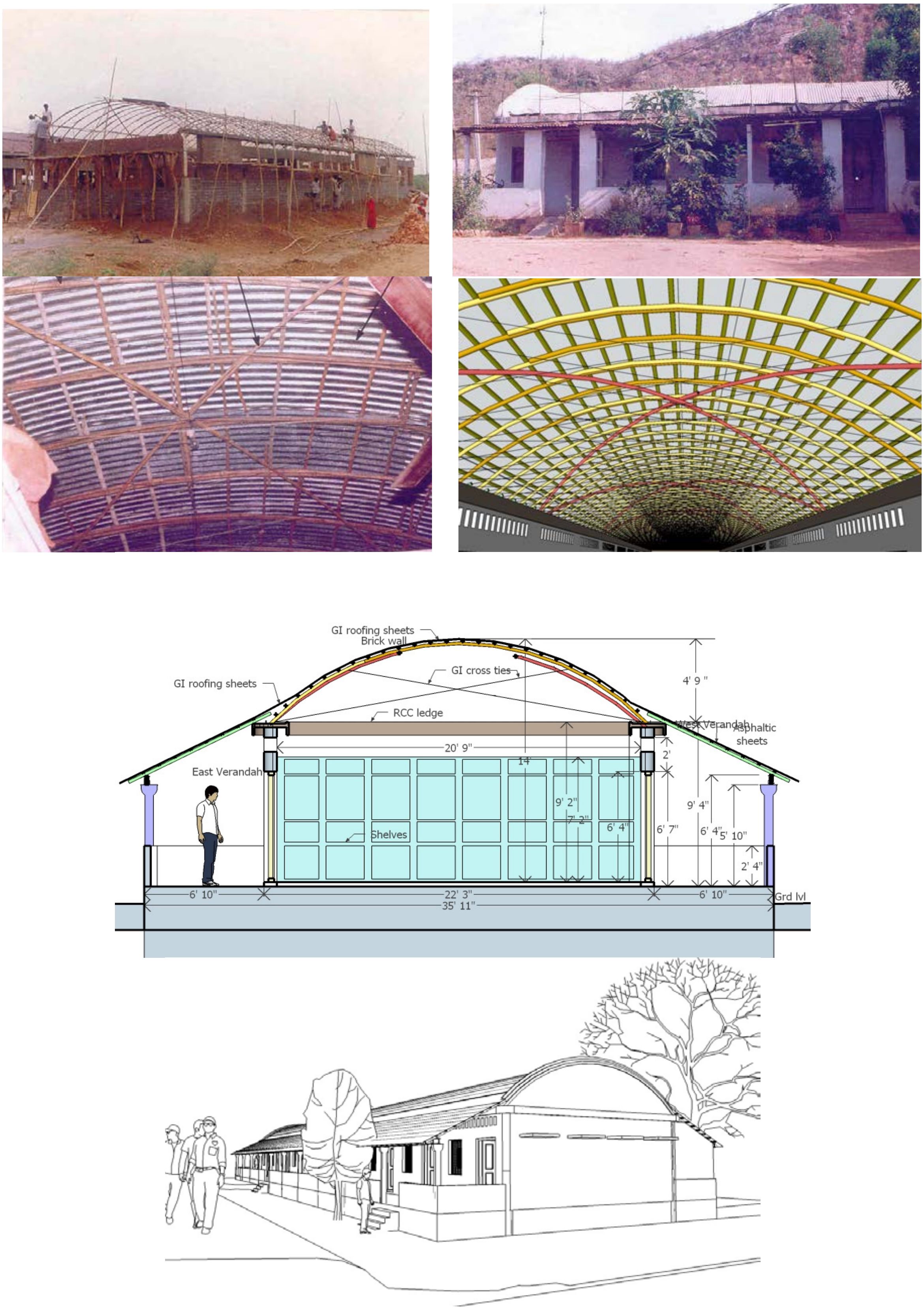


Fig. 1: Barrel Roof for residential and dining hall

Fig. 2 A Frame Structure with Thatched roof for class room

a) Structures with 3.3 m span

b) Structures with 7.3 m span

c) 7.3 m A Frame

d) Bow Beams with Steel Ties

e) Inside View – 7.3 m Structure

f) Crown Details in 4.5 m span

g) Inside View – 7.3 m Structure

h) Creep experiment on Bamcrete Bow Beam

Fig. 3: **Development of Bamboo Bow Elements**[9]

Thatched Roof House with Bamboo Bow Elements

The barrel roof of corrugated GI sheet was elegant but very expensive, costing about 3 to 5 times the cost of the roof supporting super structure of bows and purlins, all of bamboo. Faced by a financial crunch towards the end of the project, the master carpenter, Mr. Rangachari proposed the idea of erecting modified king posts over the crown of the bow and then having a conventional sloped thatched roof. The bow has too small a slope near the central part to be water proof for a thatch roof. Fig. 4 shows the skeleton of a typical house (span of 4.5 m and 35 m2 area) with bamboo as horizontal ties. Some short pieces of bamboos in vertical position connect the horizontal bamboo and the arch bamboo. These enable the formation of a deck over the columns that creates a storage space between the deck and the under side of the roof. The typical cost of a good grass thatch is less than half of the roof support super structure. Thus the house is affordable. It provides excellent thermal comfort in summers when the temperatures in the region soar to around 50º C. But it has the problem of annual maintenance for the thatch roof and a complete replacement of the thatch periodically once in 3 to 6 years.

Development of Ferro-cement Band as a Shear Connector in Bow Beams9:

Supported by INBAR, SARMET of Mumbai, India conducted a study of these structures in 2000[10]. SARMET felt that, even though the structure was absolutely safe for distributed loads, it was not clearly so for asymmetric loads. Decreasing the spacing between the bows was not a promising solution since the bows were already fairly closely spaced: 0.6m for 7.3m span GI roofs and under 5m span thatch roofs and 0.3m for 7.3m span thatch roofs. And even at this spacing, the horizontal and other ties clutter the under side of the roof so much that it is not very convenient to clean up the cob webs. It was therefore felt that the bows be clubbed into groups and each group further into two subgroups that are separated vertically. The bamboo bows in the two sub groups would be joined by a small number of ferro-cement bands spaced properly along their arch lengths. The bands are also expected to improve the stiffness of the beams against asymmetric loads. Figs. 4 and 5 show the developments using bamboo bows with ferro-cement bands. 2000-2001. Each one has 4 bows in it and has several ferro cement bands that tie up the different bamboos of the bows rigidly. One such beam was enough to support the entire roof load of a 7.3 m x 5.5 m thatched house. Eight such houses were built in 2004 in Nagineniprolu, a village in Burgampahad mandal of Khammam district

Fig. 4: Half Split Concrete Infilled Bow Beam and its experiments

Fig. 5 : Twin Vertically Separated Bamboo bows With Wooden Spacers to take roof loads

Fig 6: Bamboo House with Bamboo roof panel before putting on Cellular concrete

in Andhra Pradesh and have been in regular use. Inspection in June 2007 revealed bamboo in good condition with residents happy.

Fabrication of the ferro-cement band involves making at least two stirrups of 6 mm dia ms rods round the four bows separated by about 25 cm, wrapping the bamboos in the region with hexagonal mesh of very thin steel wire (diameter of about 0.8 mm) and cement concreting the region where the gravel aggregate consists of under 6mm chips and course river sand along with fly ash. The only problem was that the weight of the bow beam increased to almost 500 kg. Apart from increased costs of transportation, this requires the use of a chain block pulley system to erect the beam in position over the columns.

Twin vertically separated bamboo bows with Ferro-cement bands9:

A work shop on building with bamboo bows and domes was conducted by the first author in 2004 at VNIT, Nagpur. During the work shop, Prof. Ingle of VNIT suggested fixing the overlapping bamboos in the arch such that they remain one above the other in a vertical plane instead of one next to the other in a curved horizontal plane. He pointed out that it would enhance the stiffness of the bow. Subsequently the Ferro-cement bands were made so that the two bamboo arches remain fixed with a desired vertical separation. Fig. 6 show buildings supported by bow beams with Ferro-cement bands. The structures in Fig 6 show 3.3 m and 7.3 m respectively and have 'A' frames supported by the bamboo bows. These have corrugated bamboo mat boards for the roof. The fig. 6 also show the structures with 4.5 m span with barrel roof of plastic sheet and grass thatch, the plastic providing the water proofing and the grass protecting the plastic from the sun light and heat. These structures are light and can be prefabricated as was the case here, where these were transported about 200 km for installation. The cement bands were cast at site. After curing, the bow beams were erected manually. Fig. 6 shows the 'A' frame supported by twin arch bamboo bow beam with ferro-cement bands with 7.3m span used in the building of fig.6. Fig 6 also shows the interior of the building showing the detail of the landings for the bow beams - the cement band at the base of the beam gets merged into the supporting brick wall. The shelves in the lower part of the side walls below the windows are of half split bamboo cement concrete composites. The gable wall that can be seen is also of half split bamboo cement concrete composite with the concrete on the outer face and convex bamboo surface on the inside. We suggest the generic term 'BAMCRETE' to represent bamboo concrete composite structures of the kind shown in these figures in which a substantial part of bamboo surface is not covered by concrete. It is significantly different from the classical bamboo reinforced concrete.

Sample Preparation:

This section presents the details of the specimen that was made using the bending table constructed at IIT Delhi and was used as a demonstration in a workshop conducted by us to various artisans, architects and other interested members.

Fig. 7 Work Bench for Bending Bamboo

Fig. 8 shows the thick walled bamboo samples from different heights for compressive stress experiment of the Dendrocalamus Strictus. Because of this thick wall, we are able to bend the bamboo.

A bamboo concrete composite arch is made using three bamboo culms - two are used as arch element and one as a tie element. In order to prepare the arch, the workbench as shown in the Fig. 8 is used. Here, as per the crown height and the length of arch to be prepared, the guides are positioned which guide the bamboo culm to take the shape of an arch. One bamboo culm is taken and its base is fixed on the workbench at one end. Now the upper portion of bamboo culm is bent gently along the guides fixed on the workbench. Second bamboo culm is taken and fixed on the opposite end so that the two bamboos have opposite orientations. These two bamboo culms are temporarily separated with the required amount of spacing using wooden wedges. Now, the number of bands to be provided is decided on the basis of the amount of load to be applied on the arch. Here we have provided seven bands. One band at the crown and two bands are placed at the landing of the arch. The rest of the four are placed in regular intervals. The arch can be tied by either a steel wire or a RC beam as shown in Fig. 8 or by a bamboo.


Fig. 8 Connection Details

Fig. 8 shows the construction details of the shear connector. The connections are made using the mild steel rod of 6mm diameter. At the position of the bands the bamboo is drilled along the diameter at a spacing of 15cm between two drilled holes. It is ensured that the holes drilled in one bamboo are in line with the others in the second parallel bamboo. The two parallel sides of the steel rod, bent into U shape, are made to pass through the two bamboos and the extended portions are bent to close the rectangular stirrup with a proper overlap on the fouth side.

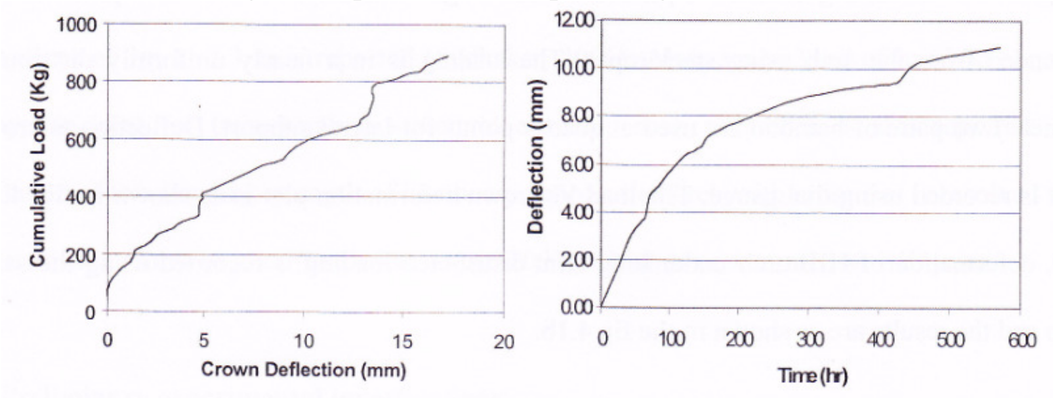
Further, the connection so made is painted with a rich cement paste Tapecrete P151, a polymer cementitious product to make it water resistant in the band region of the bamboos. This is done in order to prevent the absorption of water by the bamboo from the concrete when it is allowed to set. This also ensures a better grip between the concrete and bamboo. The band region is then wrapped with chicken mesh. This ensures uniform bonding between the concrete and the bamboo skeleton. The formwork is prepared by ensuring the requisite amount of cover for the concrete.

Proper compaction while concreting is ensured in the band region that includes the chicken mesh. The concrete is allowed to set. After 24 hours the form work is removed and the concrete surface is painted with water proofing compound such that there is no evaporation and no further wet curing is needed.

Experimental Work On Beam done under Dr. Supratic Gupta and Dr. Sudhakar by Mr. Charu and Experiment on Single Arch/ Double arch

A Bamcrete Arch was loaded as shown in Fig 9. It was placed on brick support with plaster of paris to fill the gap on a steel platform. The weights were distributed over a plank suspended from the arch using steel ropes. The loading was done as uniformly and symmetrically as possible. The deflection at crown point was recorded using dial gauges. The arch was left at the place and deflection was noted. The initial deflection and deflection due to creep effect are shown in Fig. 10. The Length of arch = 4.7 m, Crown height = 845 mm, average outer diameter of bamboo = 36 mm for arch and 33 mm for tie, Average inner diameter = 7.5 mm, spacing between two bamboo in arch = 75 mm, cross-section area = 973 mm^2 for arch and $810 mm^2$ for tie.

Fig. 9: Experimental setup for single bow beam



a) Under Uniformly distributed increasing load b) Effect of creep

Fig. 10: Load deflection behaviour of single bow beam

Experimental Work On Beam done under Dr. Sudhakar by Mr. Charu

The experimental work on bow beam was repeated on 3 more beams under cyclic loadings. Fig 11 shows the three Load deflection diagrams. Fig. 12 shows 4 cases of left or right half loading. The ultimate load was about 50% of both side loading.

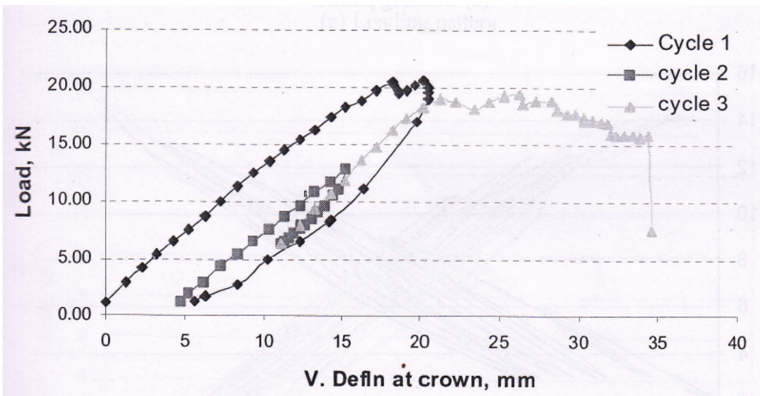


Fig. 11a: Experimental setup for single bow beam

12

Fig. 13 shows the bamboo bridge that was built at IIT Delhi. It is to note that the bridge broke away after 3 years. But conceptually it was proves that if we can protect the bamboo from decay, it will be a very good alternative.

5 bamcrete arches were built 0.5 m apart. One central cross batton is provided. bamboo is placed as top support. To navigate the steel slope , ramps were provided. The span length was 6m and central rise was 1.2 m. A load of 2 ton was placed in the centre. The load was kept for 24 hrs and the deflection noted was only 7 mm. When same load was put of one side, deflection was 6 mm. We had actually taken a car and crossed the bridge.

Fig. 13: Bamcrete Bridge and its loading

The Half Split 'BamCrete' Arch

The Half Split Arch is a simple Bamboo arch which is filled in with Concrete. The Bamboo is first sliced into two equal halves and the two parts are fixed together with some space in between with the help of steel ties, chicken mesh and steel wires. This Space is then filled with Concrete of required grade after the construction of the formwork. The load carrying capacity was 12kN

Fig. 14 Construction of a infilled half split bamcrete arch