2nd International Conference on Counter Measures for Mitigating the Urban Heat Island Effect at Berkeley, California, USA during 21-23 September, 2009

An Experimental Study of Mitigating the Urban Heat Island Effect by Novel Applications of Bamboo as a Constructional Material

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BACKGROUND

- The science is clear and the debate is over: Climate Change is happening and there is a need to act now *(UNDP)*.
- The human activities significantly affect the chemical composition of the atmosphere and therefore the artificially induced climatic trends are becoming one of the most widely speculated aspects of the climate across the world.
- Urban areas absorb and reradiate huge quantities of solar radiations due to massive construction material. The decreased sky view factor *(Rizwan et al. 2008)* in addition to the anthropogenic heat released from vehicles, power plants, air conditioners and other heat sources have resulted in the formation of urban heat islands *(Kikegawa et al. 2003)* which not only deteriorates the living environment but also increases the energy consumption *(Konopacki and Akbari. 2002),* elevates the ground-level ozone (Rosenfeld et al. 1998) and even increases the mortality rates *(Changnon et al. 1996).*

COOL ROOF STUDIES

- Several studies have documented the measured energy savings that result from the ‘cool’ roofs which reflect a large fraction of the incoming sunlight and keep the roof surface at a lower temperature than that of the regular ‘hot’ roofs that absorb most of the incoming solar radiation.
- *Akbari et al. (1997)* reported monitored cooling-energy savings of 46% and peak power savings of 20% was achieved by increasing the roof reflectance of two identical portable classrooms in Sacramento.
- *Taha et al. (1999)* have reported that proper values of surface-albedo could achieve temperature reductions and peak electric energy savings
- *Akbari (2003)* documented energy savings of 31–39 Wh/m2/day in two small commercial buildings with very high internal loads, by coating roofs with a white elastomer with a reflectivity of 0.70.
- *Synnefa et al.* (2006) studied the thermal performance of 14 reflective coatings for the urban environment and demonstrated that the use of reflective coatings can reduce a white concrete tile’s surface temperature under hot summer conditions by 4°C and during night time by 2°C.

MODELLING AND OTHER STUDIES

- *Kikegawa et al. (2006)* carried out computer simulation to report that the reduction of anthropogenic heat and planting vegetation on the side walls of buildings could reduce air temperature up to 1.2°C and reduce space cooling energy demand up to 40 %.

- *Yu and Hien (2006)* have used computer simulation to report that parks and green areas could achieve 10 % reduction of cooling load.

- *Spronken-Smith et al. (2000)* reported that parks could help control temperatures through an evaporation of more than 300 % as compared to its surrounding.

- *Ashie et al. (1999)* used computer modeling and reported air temperature reduction of 0.4 to 1.3°C with building cooling energy savings of as much as 25 % through planting vegetation.

THE PRESENT STUDY…

If the above two themes of study i.e. developing 'cool' materials for reducing the heat gain of the building and 'greening' of the land for reducing the ambient air temperature are juxtaposed, it indicates the importance and urgency of developing 'Cool' and 'Green' constructional materials which should be naturally growing paving the way for economical greening of the land and thereby improving the environmental conditions.

In the background of this, attempt has been made to investigate 'Bamboo' as a 'Cool' and 'Green' constructional material.

BAMBOO

This Plant Grows Very Fast with minimal Resources

Can be Used for multiple purposes at different stages

A few weeks - Food, Fodder and Medicines

Skin of 1 yr old culms for High Tensile Ropes And Soft Interior for Bio Fuel

2-3 yrs old : slivers for weaving – mats, baskets etc.

3-5 yrs old - structural applications Housing, Vehicle frames, Furniture

6-7 yrs old, dried & brittle culms for fuel and charcoal

Every ton of steel Produces 3 ton of CO_2

Every Ton of Bamboo Consumes 1 ton of CO_2

Even a 20% Optimistic Replacement of Steel with Bamboo in any type of Application

It will greatly Contribute in decreasing Global warming

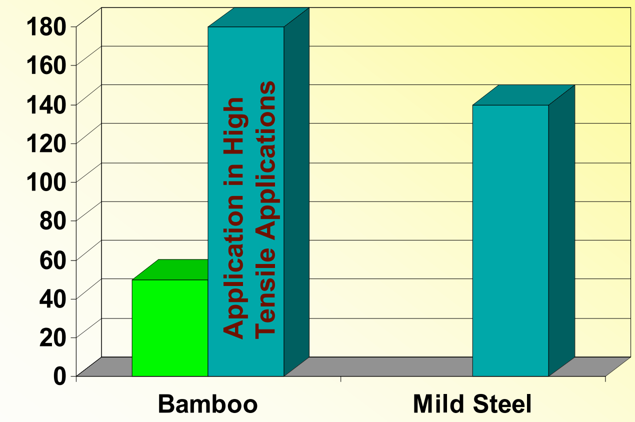
Decreasing the demand for steel and energy.

Provide a source of employment in a self sustainable manner

Bamboo Production should become Economically viable and self-sustainable

BAMBOO : THE WONDER GRASS

Working Tensile Stress in MPa



Structural Application

Excellent Tensile Properties
Potential to Replace Steel

Selective Replacement keeping in mind the strength and weakness of Bamboo

Even a 20% Replacement of Steel
Substantial reduction in CO_2

→ **Reduced Emission due to decrease in production of steel**

→ **Consumes CO_2 while it grows**

Carbon Trading Aids economics of bamboo plantation

Enormity of scope:

20 million hectares of bamboo (just 10% of greenery in the 200 million hectares of degraded lands) to give 20 to 400 million tons of bamboo equivalent to as much steel structurals

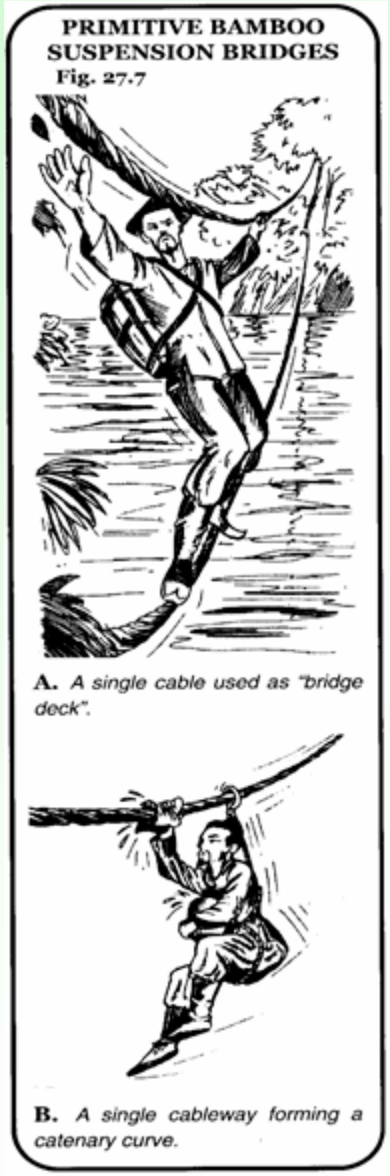
Our current steel production – 40 million tons/yr

target – 100 million tons/yr in the next ten years!

Known reserves of iron ore to last for just about 100 yrs!!

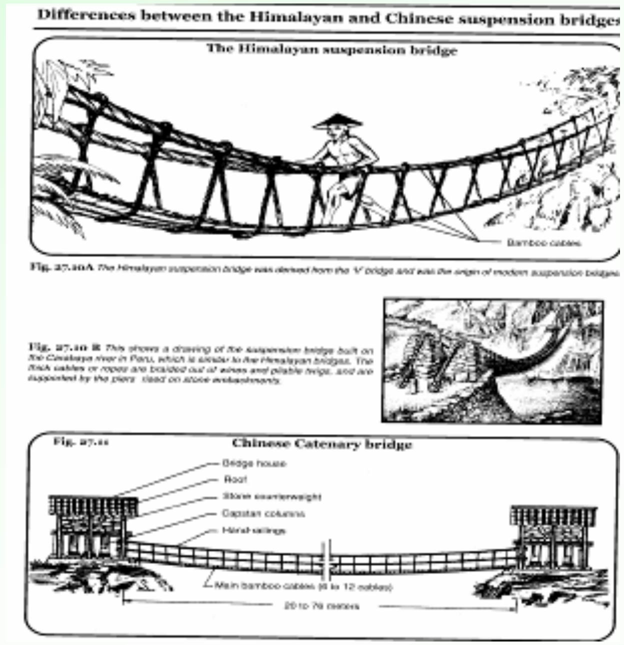
History of Structural Applications

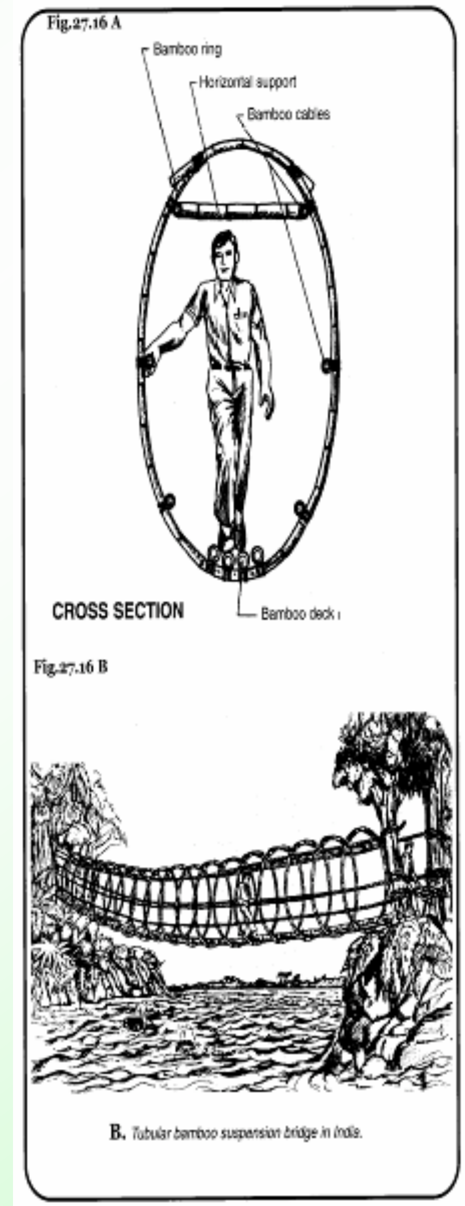
Hidalgo 2003



A. *A single cable used as "bridge deck".*

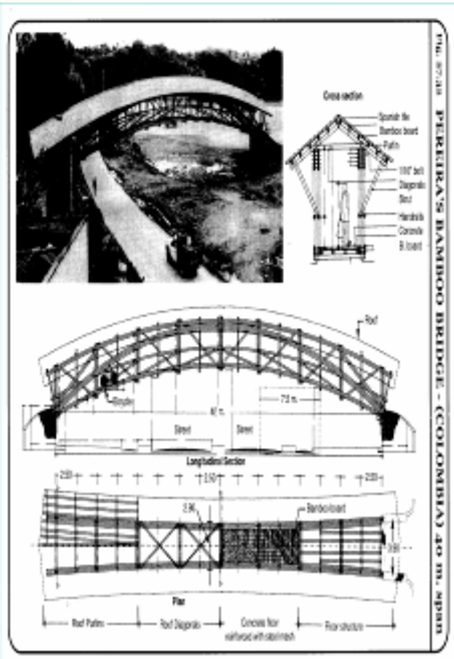
B. *A single cableway forming a catenary curve.*

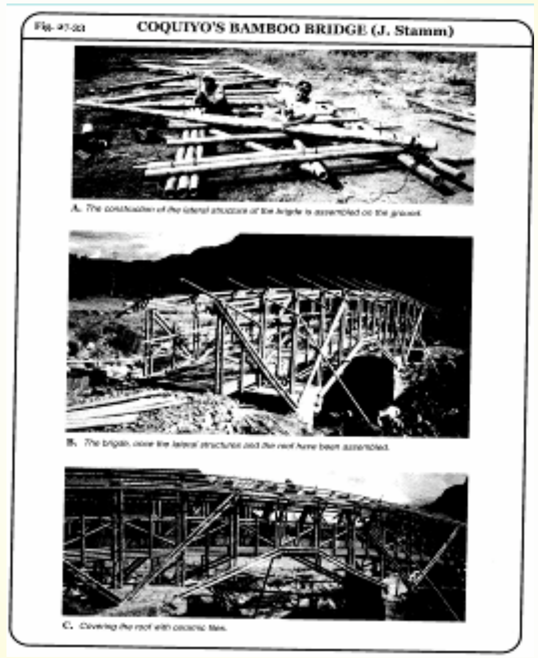




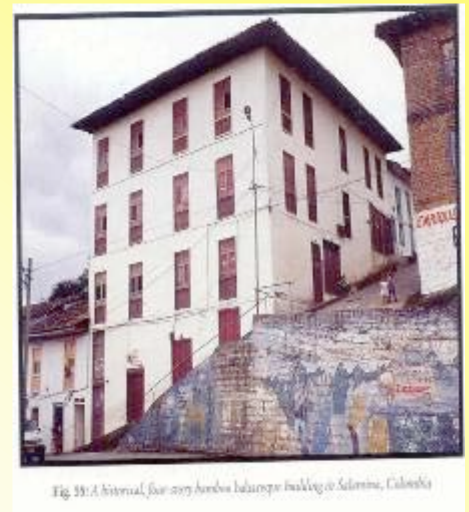
B. *Tubular bamboo suspension bridge in India.*

History of Structural Applications





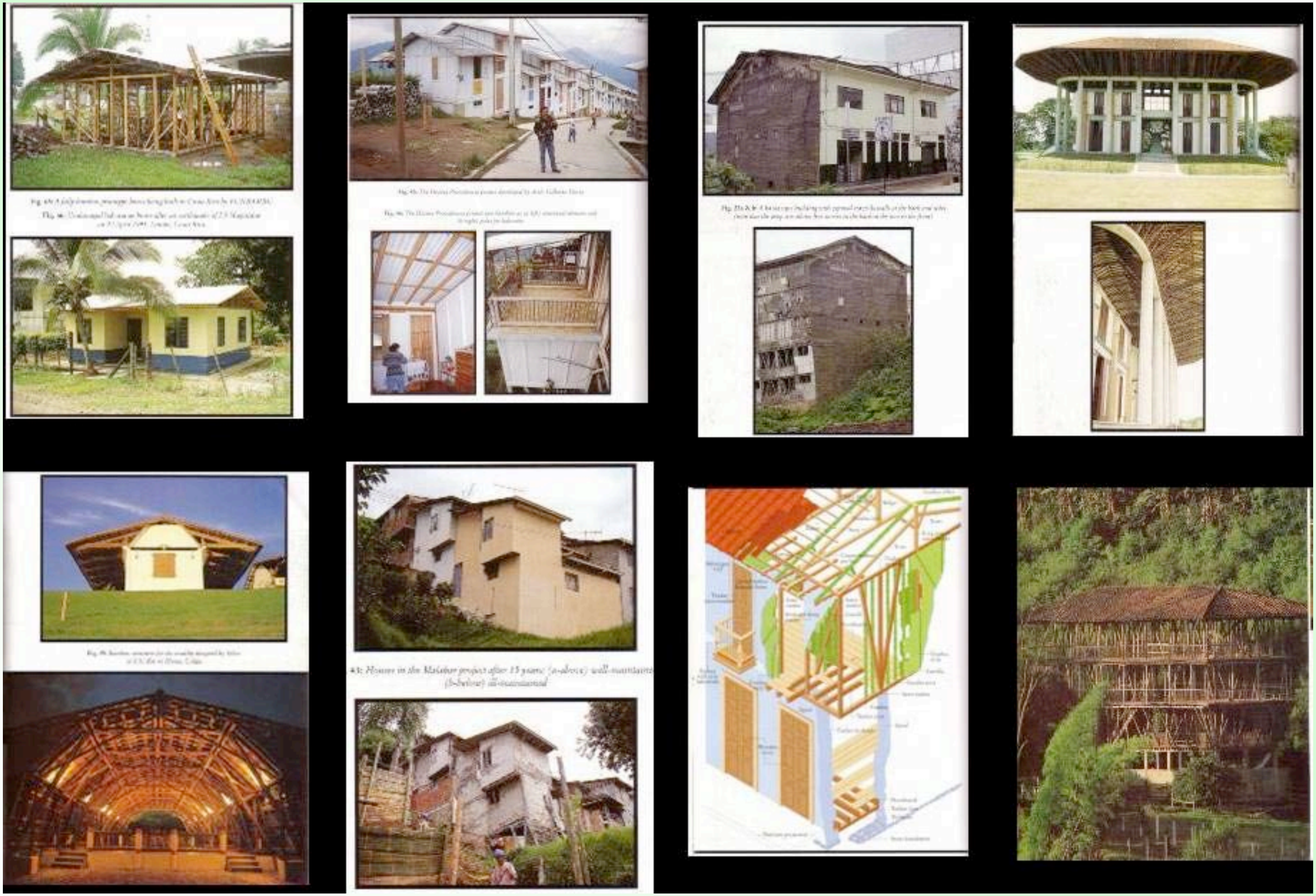
Past two decades in Latin America



Multi-Storied Houses made of Bamboo

Modern German constructions, 2000

Some Beautiful Bamboo Constructions

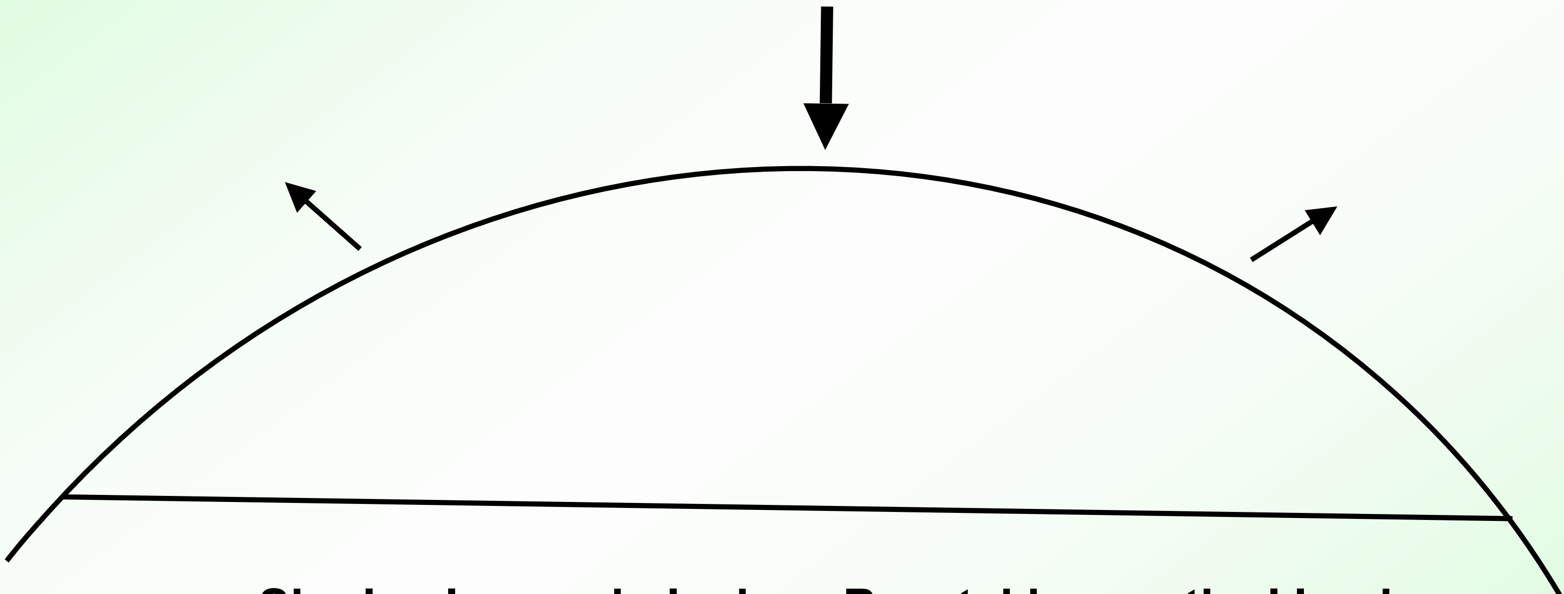


REDISCOVERING BAMBOO
AS A CONSTRUCTIONAL MATERIAL



STRUCTURAL PERFORMANCE OF BAMBOO

STRUCTURAL PERFORMANCE OF BAMBOO



Single ply wood plank as Bow taking vertical load

Bow as a tied arch

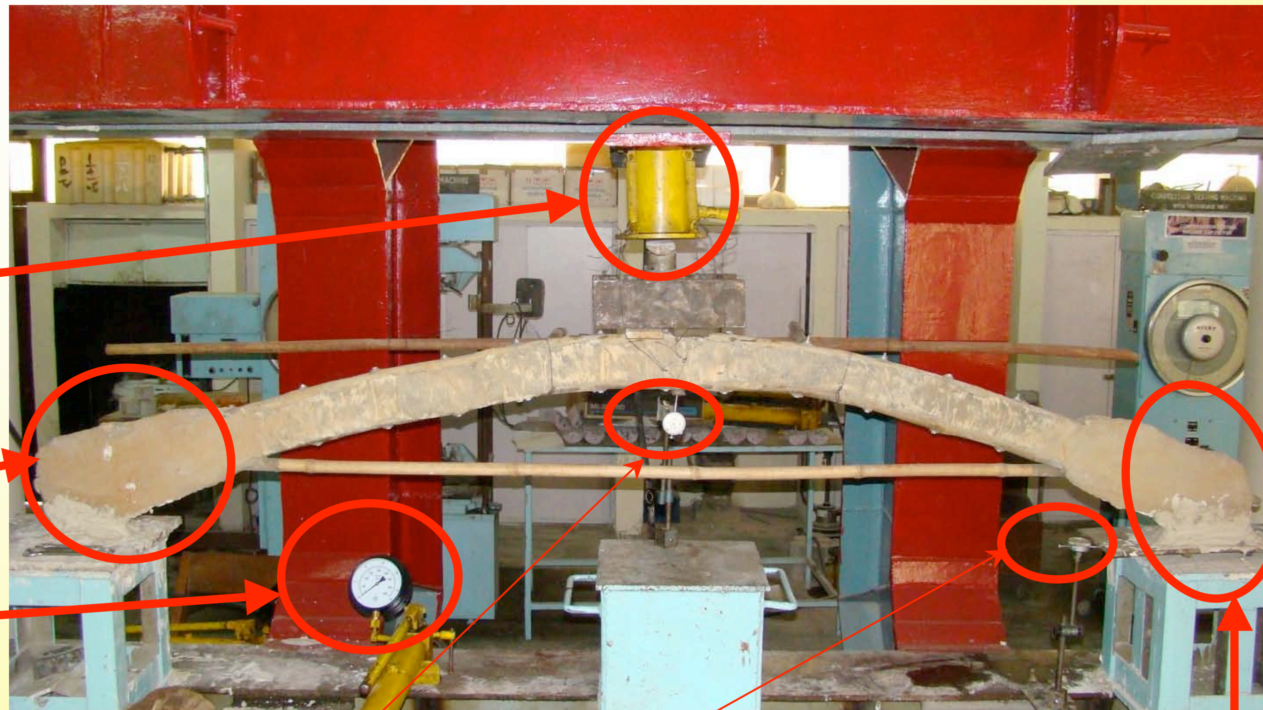
A load bearing Structural Element

FABRICATION OF BAMBOO BOW ARCH

- Bamboo Bow Arch is fabricated using *Dendrocalamus Strictus* species of bamboo.
- The peculiarity of this bamboo species is that it is a thick skin bamboo, varying from 4 - 5 cm as bottom diameter to 2 – 2.5 cm as top diameter. Owing to the thick skin it has, it can be bent into a parabolic form very easily.
- The single bamboo culm is guided along the parabolic profile generated using iron studs.
- Further, another bamboo is put above the previous one and connected using a spacer.
- The bent bamboos are now connected using a bamboo tie, to ensure the parabolic curve profile.
- Thus, the Bamboo Bow arch so fabricated is connected with another such arch, forming a bridge with bracings and cross bracings; which will ensure the lateral stability of the arch during the experiment.

ARCH TESTING FACILITY

ROUND BAMBOO CONCRETE INFILL ARCH TEST SETUP



Hydraulic Jack

Simple Support

Pressure Gauge

Dial Gauge

Roller support

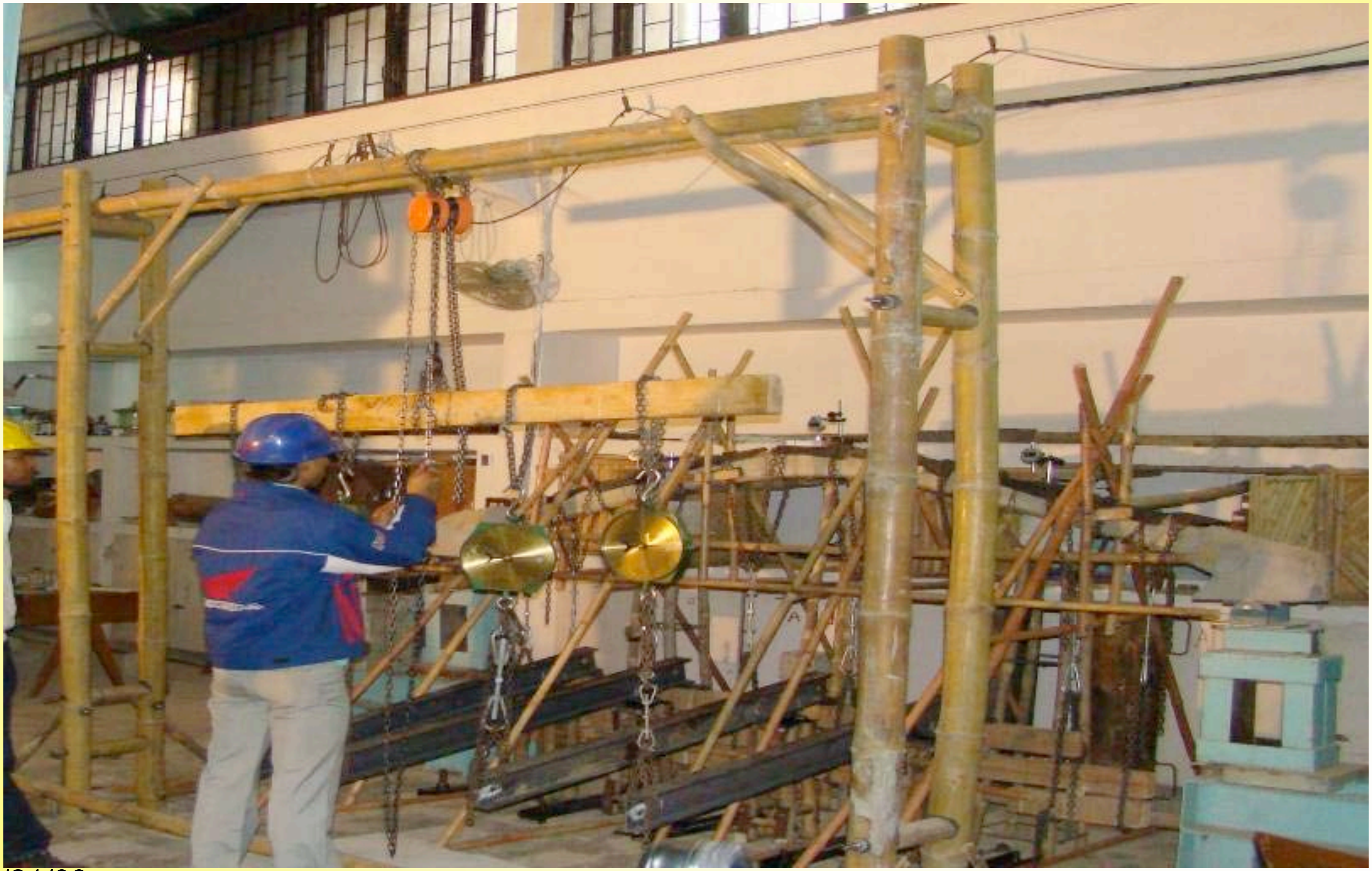
ARCH TESTING FACILITY

ARCH TESTING FACILITY

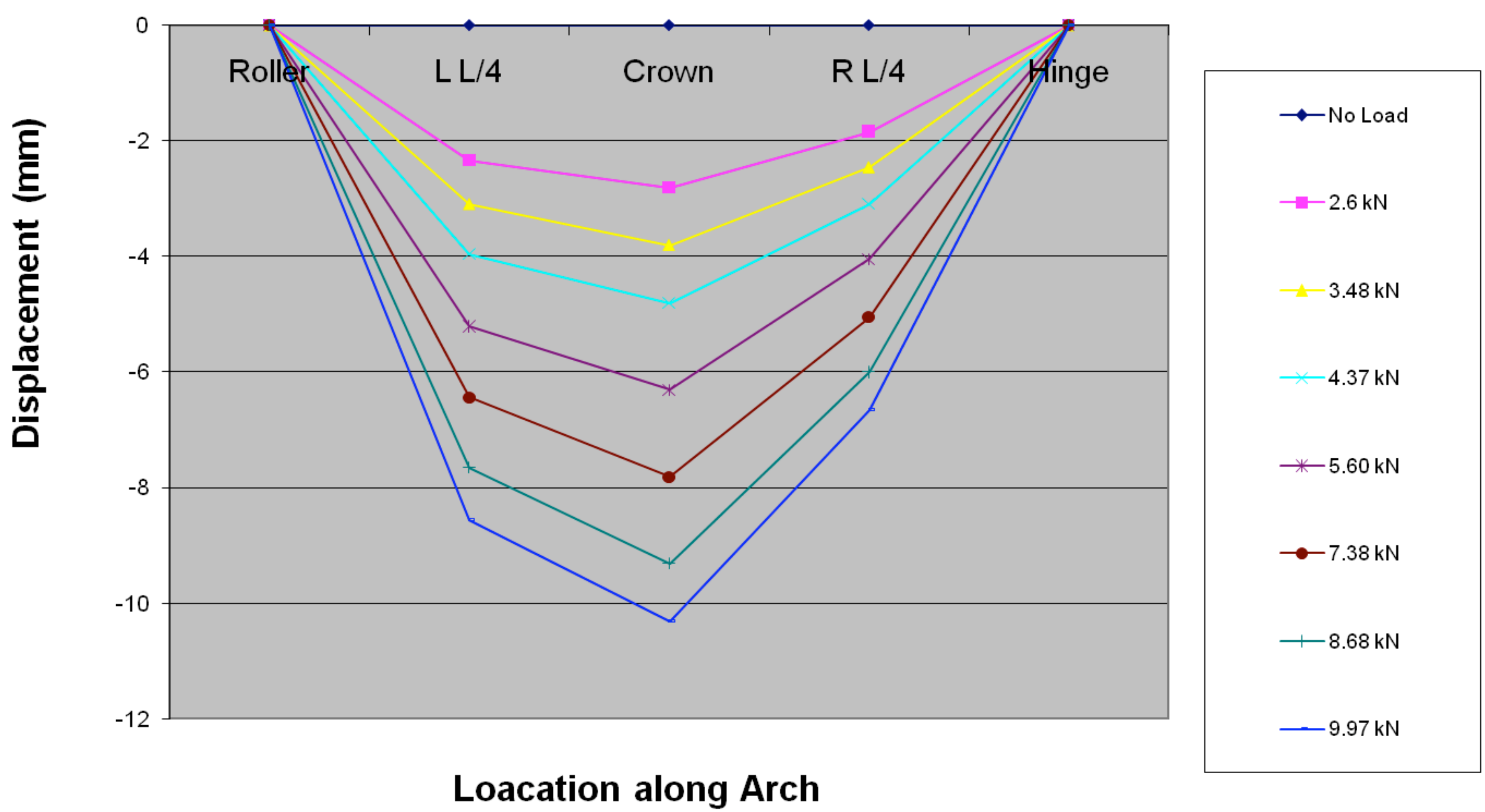
10/21/09

ARCH TESTING FACILITY

ARCH TESTING FACILITY

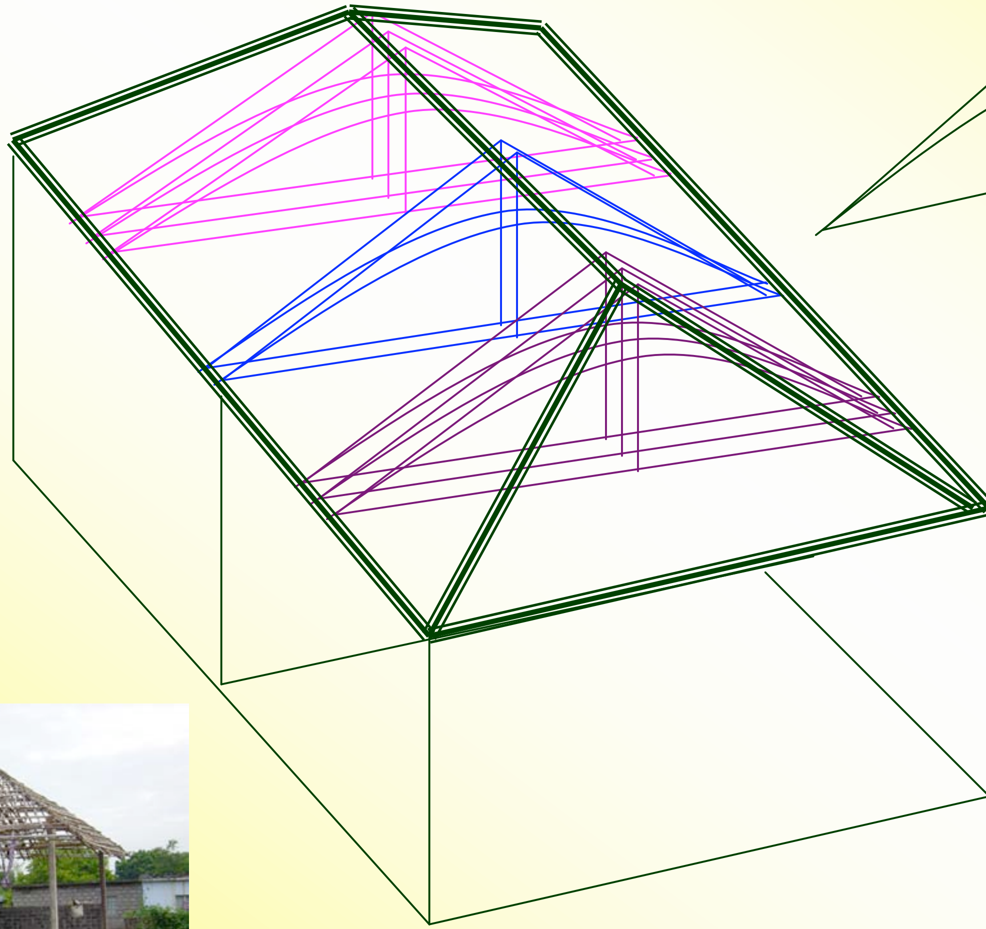


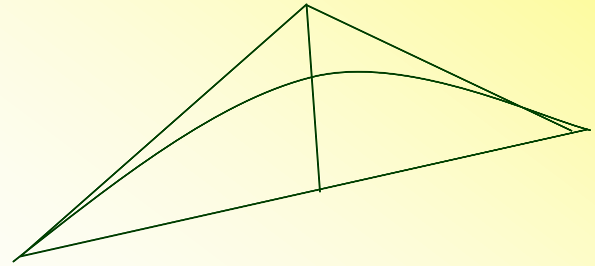
Split Bamboo- Vertical Displacement



Bunching of Simple Bamboo Bows

4.2 m span, 35 m^2 House





Bamboo arch - beam - column connection

Haritha Ecological Institute

3.3m span

Bow with iron ties before cementing

Ferro cement band Bow supported 'A' frames for sloped roofs

7.3m span


Bamboo bows
with
Horizontal bamboo ties
Make up
Tortoise shell like skeleton


Bow reinforced rectangular beam
span - 10 ft


Bow supported 'A' - Frame
span - 14 ft


Bow beam with V- block spacers

THERMAL PERFORMANCE OF BAMBOO

FABRICATION OF TEST CUBICALS

- The thermal behaviour of bamboo as a building material was quantified experimentally by observing the temperature inside the cubicals made of Bamboo, Bamboo-Concrete composite and was compared with the cubical made of brick masonry with cement concrete roof.

- The three cubicals, i.e., one of bamboo, the other one of bamboo-concrete composite and the last one of brick with cement concrete roof were made of size 1m × 1m × 1m each.

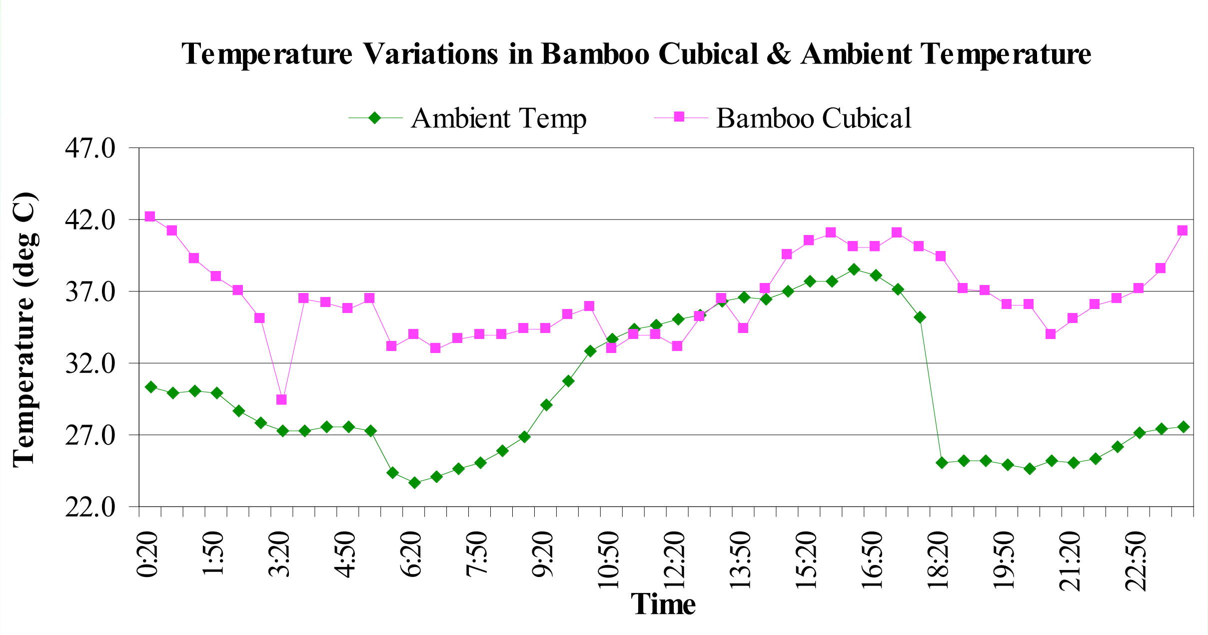
- Half split bamboo of the specie *Dendrocalamus Strictus* was used in the fabrication of the bamboo cubical and the bamboo-concrete composite cubical.

Fabrication … (cont)

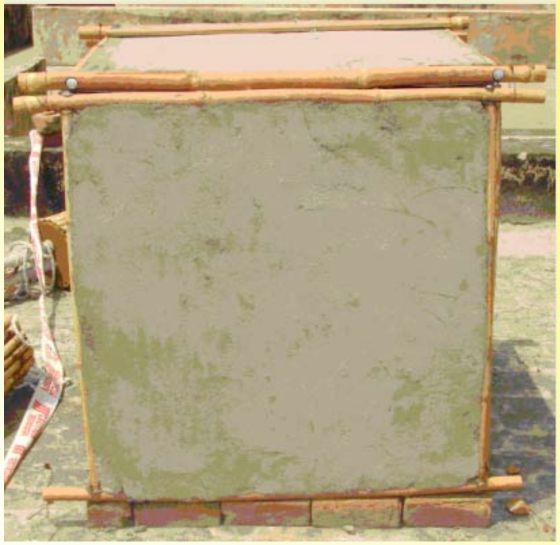
- The thickness of the wall and roof panels of the bamboo cubical was 1 inch. In the bamboo-concrete composite cubical, the exterior surface of the half split bamboo panels (both roof and wall) was covered by plain cement concrete whose mix design is having the following proportion (1:2:4, i.e., 1 part of cement, 2 parts of coarse aggregates and 4 parts of fine aggregates). The thickness of the wall and roof panels was 2.5 inches. Standard size bricks were used for the construction of the brick cubical having the thickness of 4.5 inches. The plain cement concrete roof was of 2 inches thick.

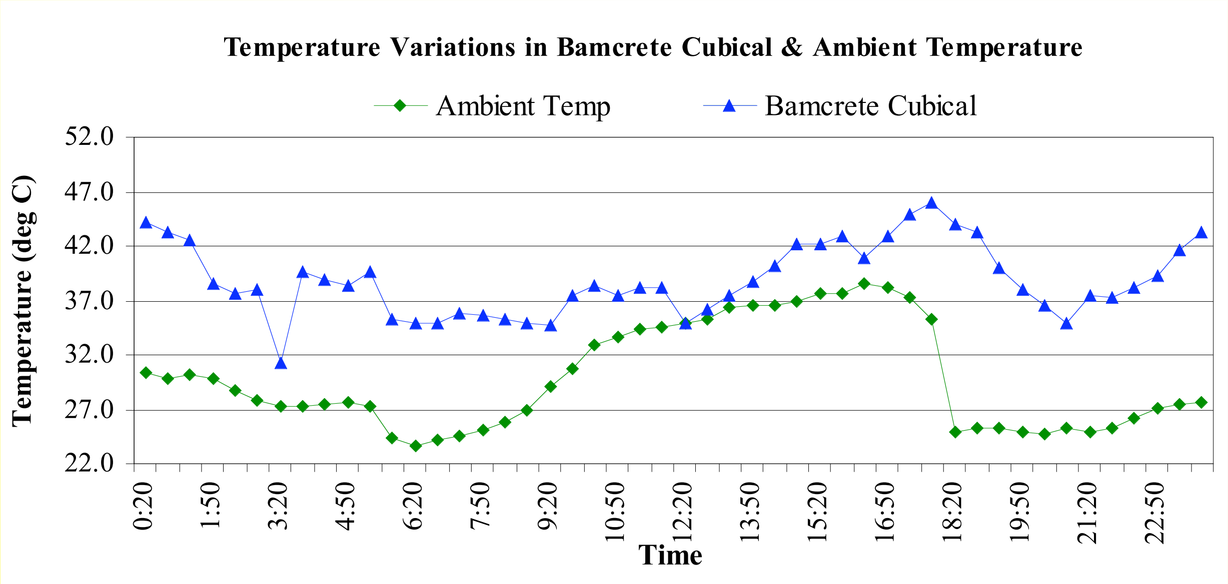
- The three cubicals so made were placed at place where they were exposed to uninterrupted sun shine

BAMBOO CUBICAL

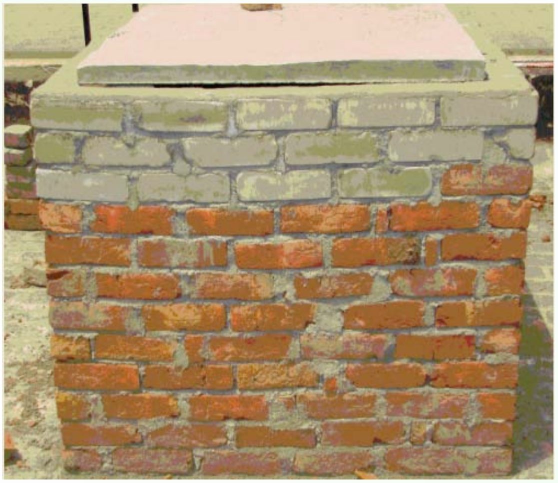


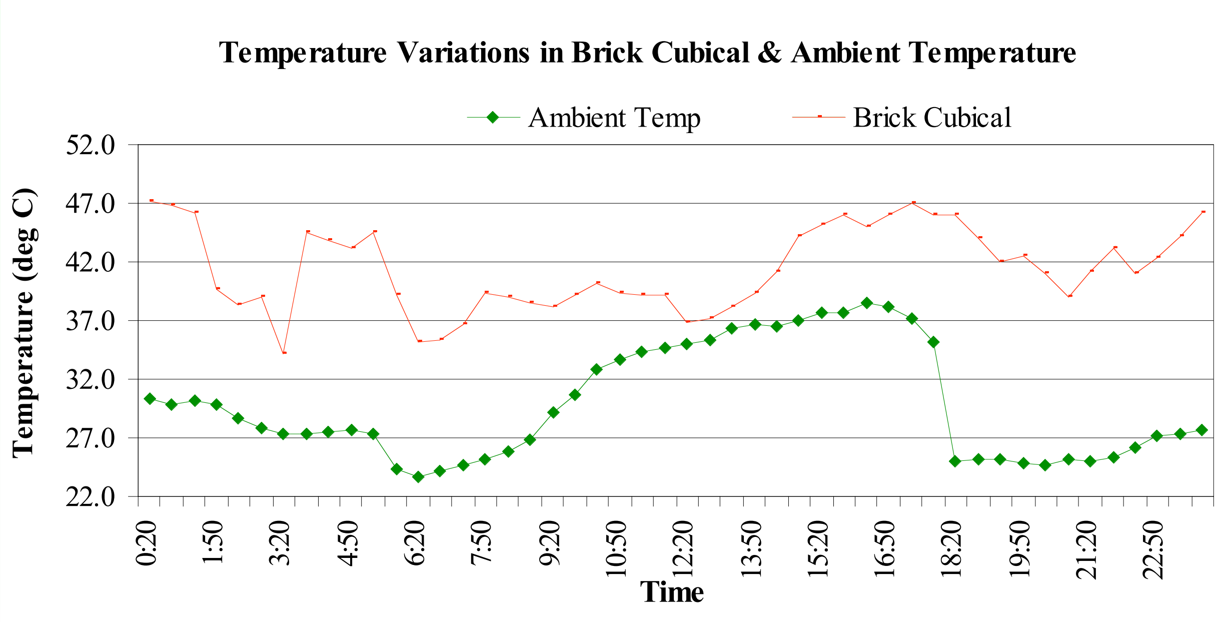
BAMCRETE CUBICAL

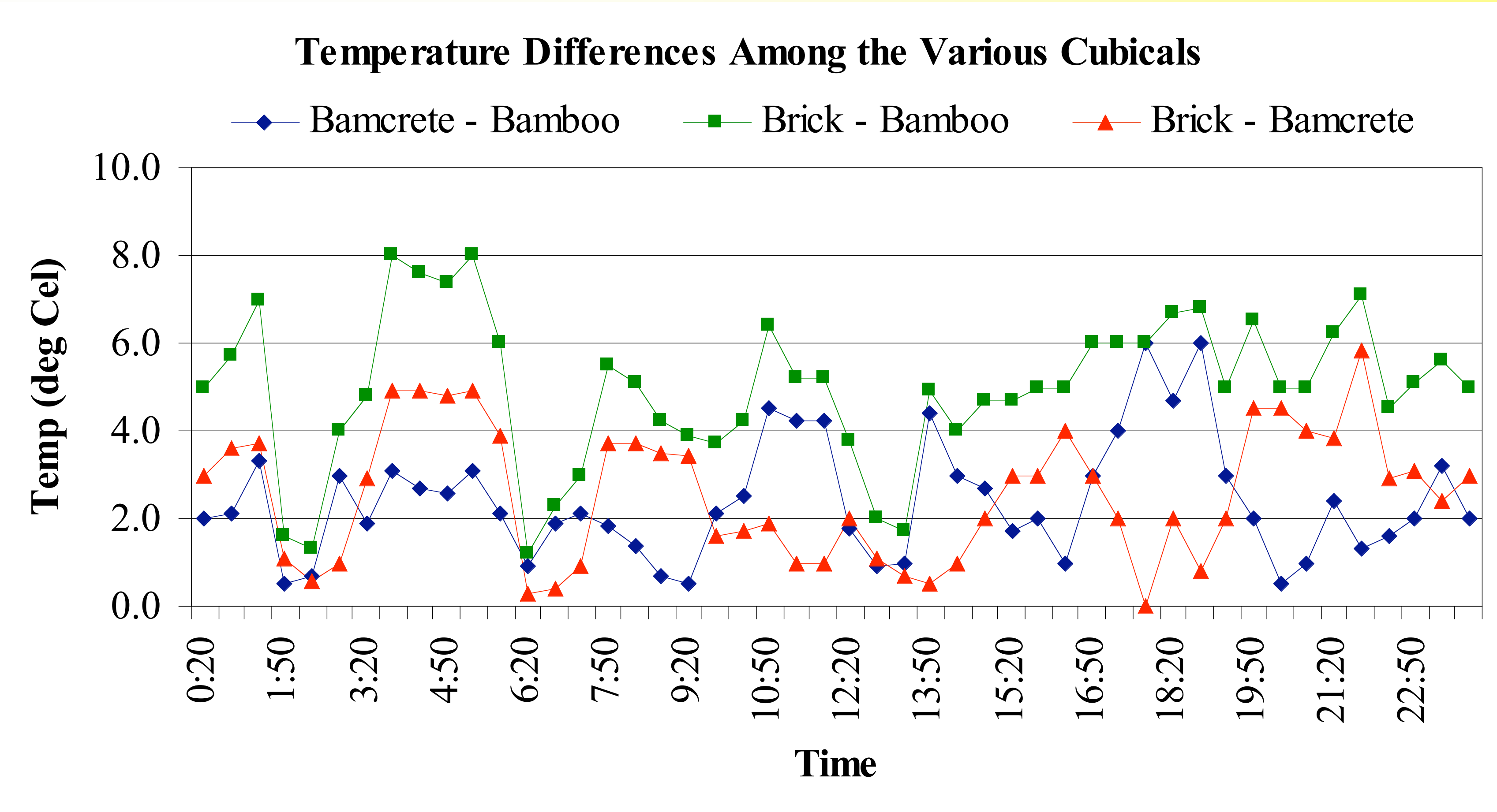




BRICK MASONRY CUBICAL






Temperature Differences Among the Various Cubicals
Bamcrete - Bamboo
Brick - Bamboo
Brick - Bamcrete
Temp (deg Cel)
10.0
8.0
6.0
4.0
2.0
0.0
0:20
1:50
3:20
4:50
6:20
7:50
9:20
10:50
12:20
13:50
15:20
16:50
18:20
19:50
21:20
22:50
Time

THERMAL PERFORMANCE

- The average ambient temperature observed during the study period (28th June to 7th July, 2009) was 29.87 ºC.
- The average temperature observed inside the half split bamboo cubical was 36.49 ºC; inside the half split bamboo concrete composite was 38.89 ºC while inside the brick masonry cubical with cement concrete roof was 41.46 ºC.
- A maximum of 8 ºC and minimum of 1.2 ºC temperature difference was observed between the brick masonry cubical and half split bamboo cubical, while in case of brick masonry cubical and half split bamboo concrete composite cubical a maximum of 5.8 ºC and minimum of 0 ºC temperature difference was observed.

THERMAL PERFORMANCE

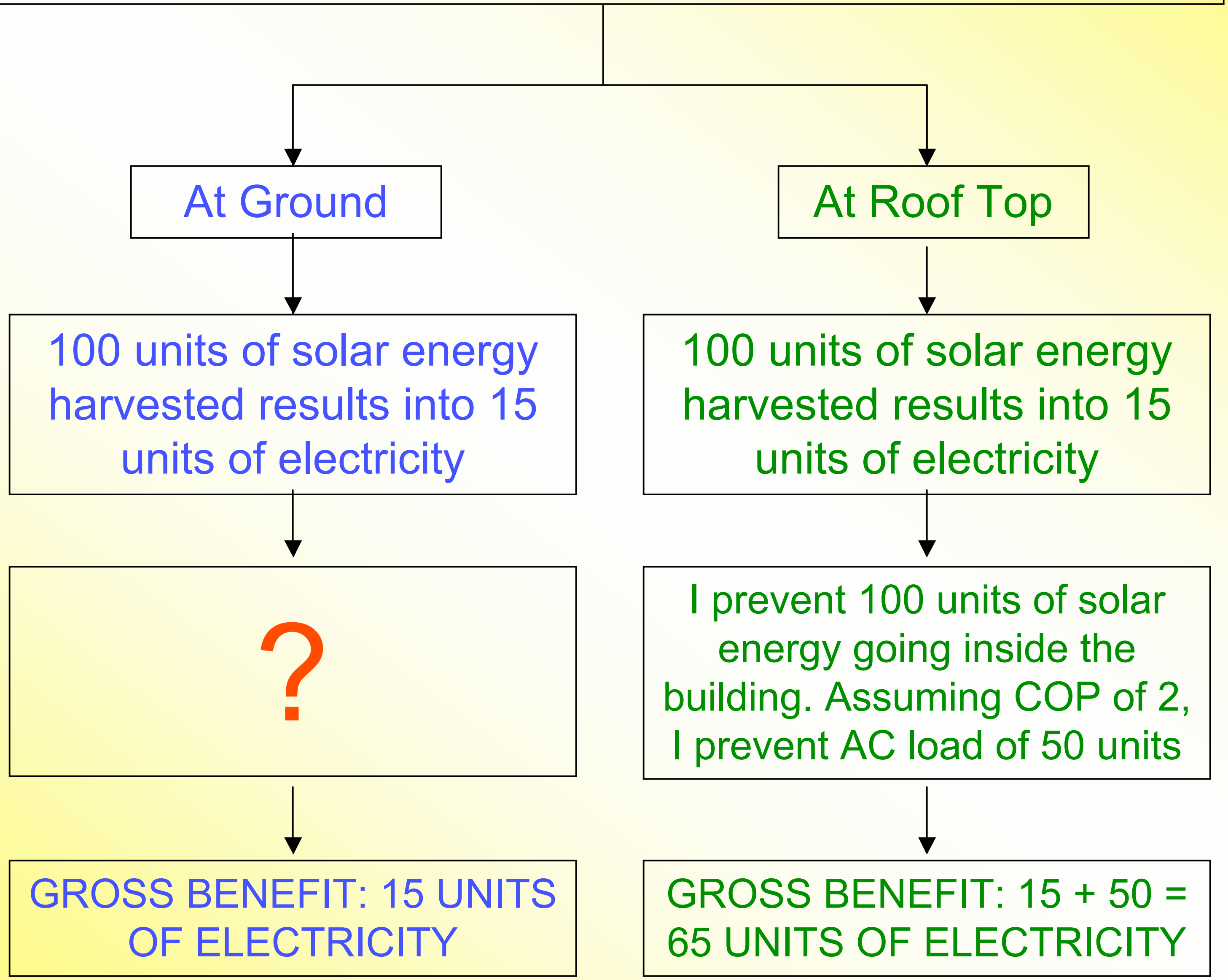
- When half split bamboo concrete composite cubical was compared to that of half split bamboo cubical, a maximum temperature difference of 6 ºC while a minimum temperature difference of 0.5 ºC was observed.

- The maximum temperature differences observed above are quite significant.

- The above study leads to a conclusion that the lowest average temperature was observed in the half split bamboo cubical followed by the half split bamboo concrete cubical. The highest average temperature among the three cubicals was observed in the brick masonry cubical having cement concrete rooftop.

HARVESTING SOLAR ENERGY

HARVESTING SOLAR ENERGY



FABRICATION OF BAMBOO PANELS FOR SOLAR ENERGY HARVESTING

- Half split bamboo panels were used for harvesting the solar energy.
- The half split bamboo panels, which are the proposed building blocks of a roof top, consists of four parts, namely, front glass plate, collector plate, back insulation and the supporting frame
- The dimension of the solar panel was 52 cm × 36 cm. This roof panel was made by joining half split bamboo by fevicol and saw dust
- To make it water proof, it was coated from the both sides with glass fibre mat and general purpose resin (GP resin) mixed with proper hardener.
- In another variant, thermo forming of a suitable plastic sheet was used.

FABRICATION … (cont)

- A black GI sheet was put over it as absorber and then a glass plate which was transparent for the incident solar radiation.

- *The back insulation is an important factor as it arrests the flow of heat inside the building. For this, PU foam, which is an insulator of good standards and cost effective, was used. Tolylene diisocyanate (TDI) and polyalcohols are the basic ingredients for the production of PU (Poly-Urethane) foam. The mixture of polyol & diisocyanate is in the ratio of 1:1 to form Polyurathane foam (PU foam).*

FABRICATION … (cont)

- Approximately 4 cm coating of PU foam was given below half bamboo panel. For this (52 × 36 × 4 = 7528 cm3) 145 g of polyol and diisocyanate each was taken and mixed in a mechanical stirrer until the initiation of foaming. Then it was spread uniformly on the backside of the half split bamboo panel.

- A casing made of wood was covered the spread mixed liquid, so that the foaming got a uniform shape.

- Thermocouple sensors were connected to inlet, outlet, on the black panel over the half split panel and below the half split bamboo panel to record the diurnal variation of temperature at different points with free natural circulation of air and water.

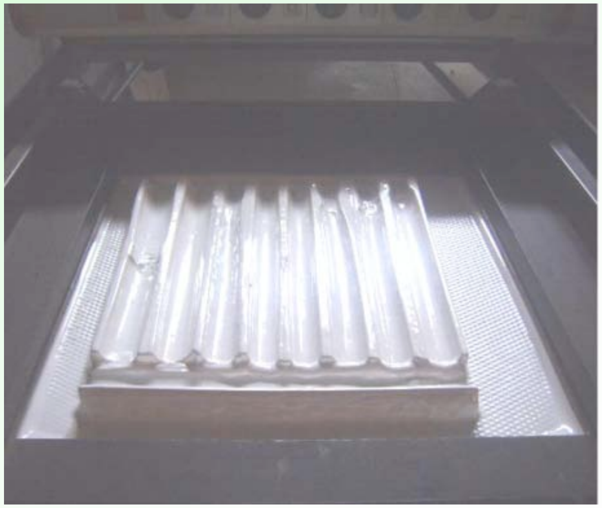
FABRICATION … (cont)

Half split bamboo joined by fevicol

→

Half split bamboo joined by fevicol and saw dust

FABRICATION … (cont)



Half split bamboo panel coated with glass fiber mat and GP resin

Half split bamboo panel with a wooden casing

FABRICATION … (cont)

Half split bamboo panel
with a wooden casing

Half split bamboo panel harvesting
the solar energy

Temperatures (in deg C) at various points in the Half Split Bamboo Panel with Natural Air circulation on 05/06/08

Time	Ambient Temp.	Black Panel Temp.	Inlet Temp.	Outlet Temp.	Below panel Temp.
10AM	25	23.7	31.2	35.9	26.3
11AM	25	29.5	31.9	36.2	27.2
12PM	27	31.6	37.2	50.3	31.2
01PM	27	31.9	40.3	52.5	32.3
02PM	30	41.2	61.5	83.2	41.1
03PM	32	42	62.5	78.8	41.6
04PM	31	36.1	55.6	73.6	39.1
05PM	31	33.2	48.3	65.3	36.2

Temperatures (in deg C) at various points in the Half Split Bamboo Panel with Natural Water circulation on 17/11/08

Time	Ambient Temp	Black Panel Temp.	Inlet Temp	Outlet Temp.	Below panel Temp.	Container RH*	Container (PUF)
09AM	22.7	14.6	17.4	18.6	18.7	16.1	19.0
10AM	25.1	20.2	18.7	18.8	21.9	19.3	21.0
11AM	27.0	29.8	25.6	27.3	25.6	27.0	26.0
12PM	26.8	37.4	32.0	33.9	28.2	34.0	32.0
01PM	26.7	38.1	34.6	37.2	27.7	36.3	36.0
02PM	27.5	34.8	32.5	34.7	26.5	35.6	35.0
03PM	25.1	33.2	31.0	32.8	25.6	34.4	34.0
04PM	21.5	34.3	31.9	34.4	24.1	34.7	35.0
05PM	18.6	29.9	27.7	28.0	20.6	34.1	34.0

CONCLUSIONS

- The present study reveals a strong potential of bamboo as a modern constructional material.
- Though bamboo has been used in hosing since time immemorial but till date it has mostly been used as a load distributing element and not as a load bearing element. However, the present study explores that bamboo can be used as a load bearing element.
- Moreover, with the reduction in the heat gain, bamboo has the potential to act as a 'cool' material.
- There are various engineering challenges involved in developing 'Bamboo' as a 'Modern Engineering Material' (i.e. creep behaviour of bamboo, non-homogeneity, bio degradability, durability, etc.) which require systematic investigation, the results of the present study are encouraging enough to infuse enthusiasm in the scientific community.
- A systematic and scientific blend of the 'traditional wisdom' and 'modern science' would result in a cost effective housing technology which would be socially acceptable. Simultaneously, it would also help in a big manner not only to reduce the building energy requirement and combat the urban heat island effect but also to reduce the green house gas emission and fight global warming and climate change.

FUTURE WORK

- It is proposed to fabricate three respective cubicals, all having their roof top of the proposed half split bamboo panels for harvesting the solar energy.
- Moreover, all the three cubicals would be provided with adequate ventilation to the tune of 20-30 per cent of the wall area to simulate the real time situation. It is in this setup, temperature measurements at the centroid of the cubical would be carried out.
- In addition to the measurements of the centroidal temperatures, temperatures would be observed at the wall surfaces and one foot away from the walls to quantify the effect of the material on the environment.
- The above study aims to quantify the twin benefit of the usage of the material, viz. half split bamboo and half split bamboo concrete composite, on the reduction in the indoor temperature thereby reducing the building energy requirement and also the production of the ‘low grade thermal heat’ which could be used for various purposes.

CHOICE IS OURS

Sustainable Technology

Technology to *Just* sustain

THANK YOU

Acknowledgements

- The financial support extended by the sponsored research projects titled ‘Bamboo as a Green Engineering Material in Rural Housing and Agricultural Structures for Sustainable Economic Growth’ (RPO2011) funded by Ministry of Rural Development Govt. of India, and ‘Bamboo as a Green Engineering Material in Rural Housing and Agricultural structures for Sustainable Economic Growth’ (RP02112), funded by Indian Council of Agricultural Research under component 4 of NAIP is duly acknowledged.

- The cubicals were originally built by our bamboo artisan team, at the suggestion and design of Prof. Supratic Gupta of Civil Engineering Department of Indian Institute of Technology Delhi for the project of his B.Tech Final year student, Ms. Brinda Grover.