# ENGINEERED BAMBOO STRUCTRURES:

## FUTURE GAME CHANGER IN SUSTAINABLE CONSTRUCTION AND RURAL ECONOMY


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**Er. Vijay. K. Saini, CEO&MD**
(South Asia), Intellimart

# BACKGROUND

# WHY BAMBOO FOR CONSTRUCTION

## Construction industry is one of the most polluting industries of the world

**Production of 1 ton of cement emits > 0.75-1.2 tons of $CO_2$ in the atmosphere**

**(Barcelo et al., 2014 )**

**Production of 1 ton of steel emits > 1.9 tons of $CO_2$ in the atmosphere**

**(World Steel Association, 2021)**

# WHY BAMBOO??

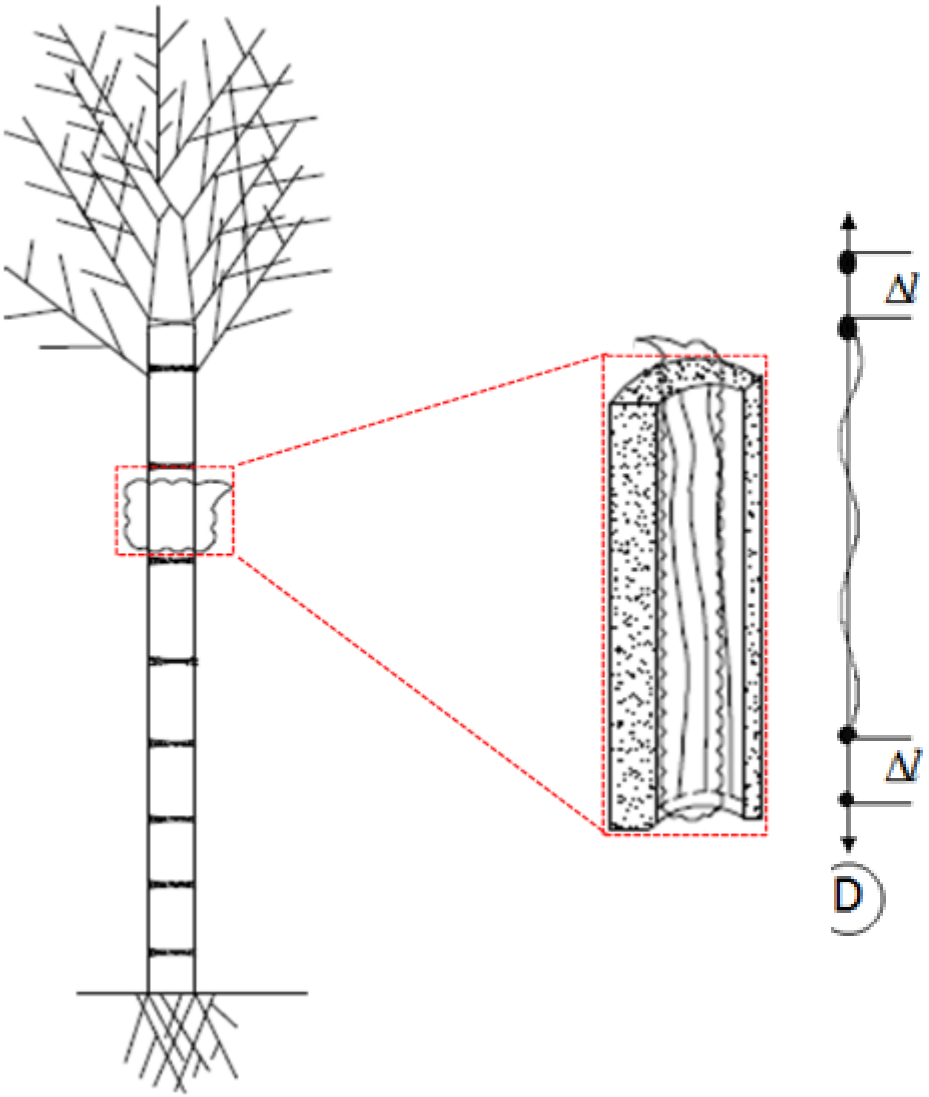
**Production of 1 ton of bamboo consumes> 1 ton of $CO_2$ of the atmosphere**

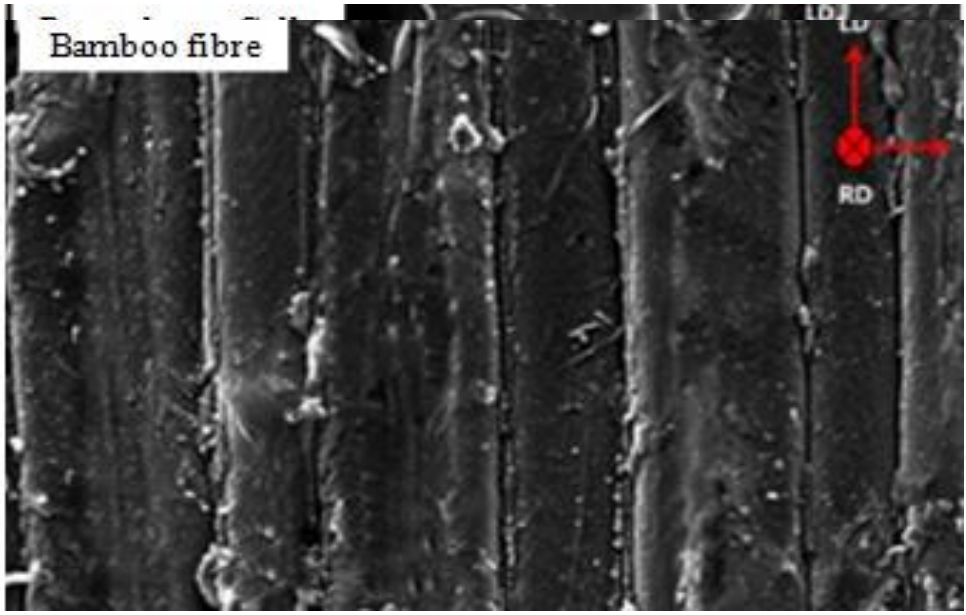
*** Bamboo offers competitive strength to mass ratio ***

*** Unlike timber, matures in 4 to 5 years ***

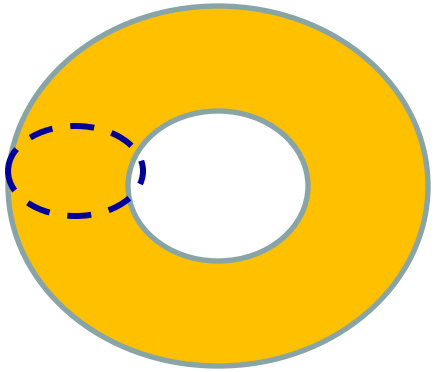
*** Cultivation suitable in tropical climatic conditions***

| | | | | |
|---|---|---|---|---|
| **MILD STEEL** | Ultimate strength = **410 MPa** | Yield strength = **250 MPa** | Young's modulus = **200 GPa** | Density = **7850 kg/m$^3$** |
| **CONCRETE** **(Grade M 30)** | Tensile strength = **3.8 MPa** | Compressive strength = **38 MPa** | Young's modulus = **27 GPa** | Density = **2400 kg/m$^3$** |
| **BAMBOO** **Dendrocallamus giganteus** **(Ghavami, 2007)** | Tensile strength = **120 MPa** | Compressive strength = **55 MPa** | Young's modulus = **140 GPa** | Density = **700 kg/m$^3$** |




**View showing a segment and strand of bamboo fibre**



# INTEGRAL PART OF TRADITIONAL HOUSING TECHNOLOGY SINCE THOUSANDS OF YEARS

https://www.freesoundslibrary.com/rural-village-morning-ambience/

# RIGVEDA

शतं वेणूञ्छतं शुनः शतं चर्माणि म्लातानि ।
शतं मे बल्बजस्तुका अरुषीणां चतुःशतम् ॥
८.०५५.०३

Śatam Veṇūñchatam Śunaḥ Śatam Carmāṇi Mlātāni.
Śatam Me Balbajastukā Arushīṇām Catuḥśatam

GOODNESS (*SATTVA* )

**Bestow upon us a hundred bamboo clumps**

https://www.wordzz.com/lord-krishna-images/

# ENGINEERING SOULUTION:

COMBINE TRADITIONAL PRACTICES WITH MODERN STURCTUAL ENGINEERING

# BAMBOO AS A GREEN ENGINEERING MATERIAL

## IN RURAL HOUSING AND AGRICULTURAL STRUCTURES

## FOR SUSTAINABLE ECONOMY

**R&D project under Component 4 of**

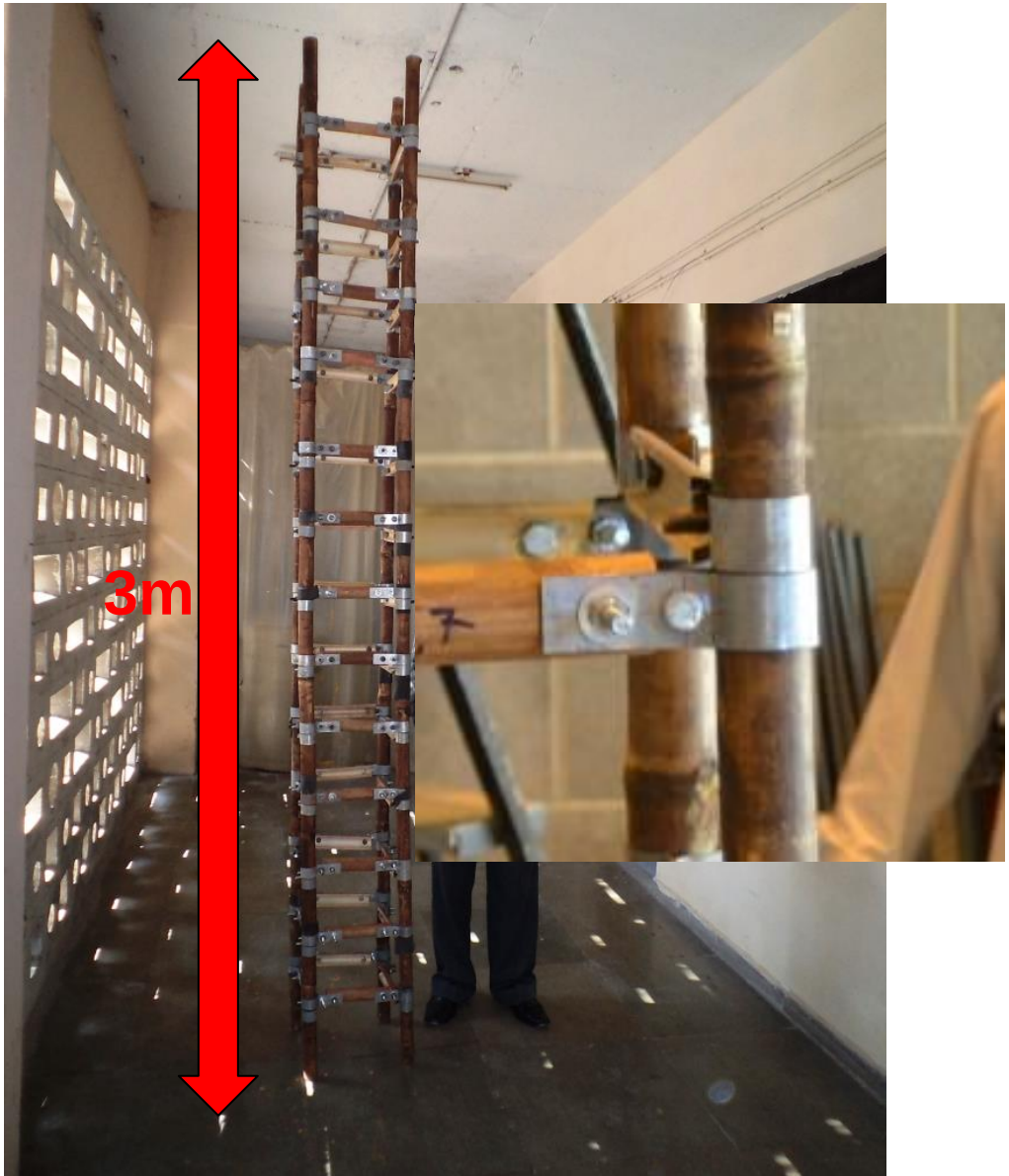
**National Agricultural Innovation Project (NAIP),**

**Indian Council of Agricultural Research (ICAR)**

# P A R T N E R S

# 2008-2013

# LIGHT BATTEND BAMBOO SYSTEM (LBBS)




**Connection of built up bamboo column to steel base plate**

**Connection to concrete pedestal**


INDIAN INSTITUTE OF TECHNOLOGY DELHI
DEPARTMENT OF CIVIL ENGINEERING
DESIGN AND FABRICATION OF MODEL A BAMBOO FRAME FOR COWSHED

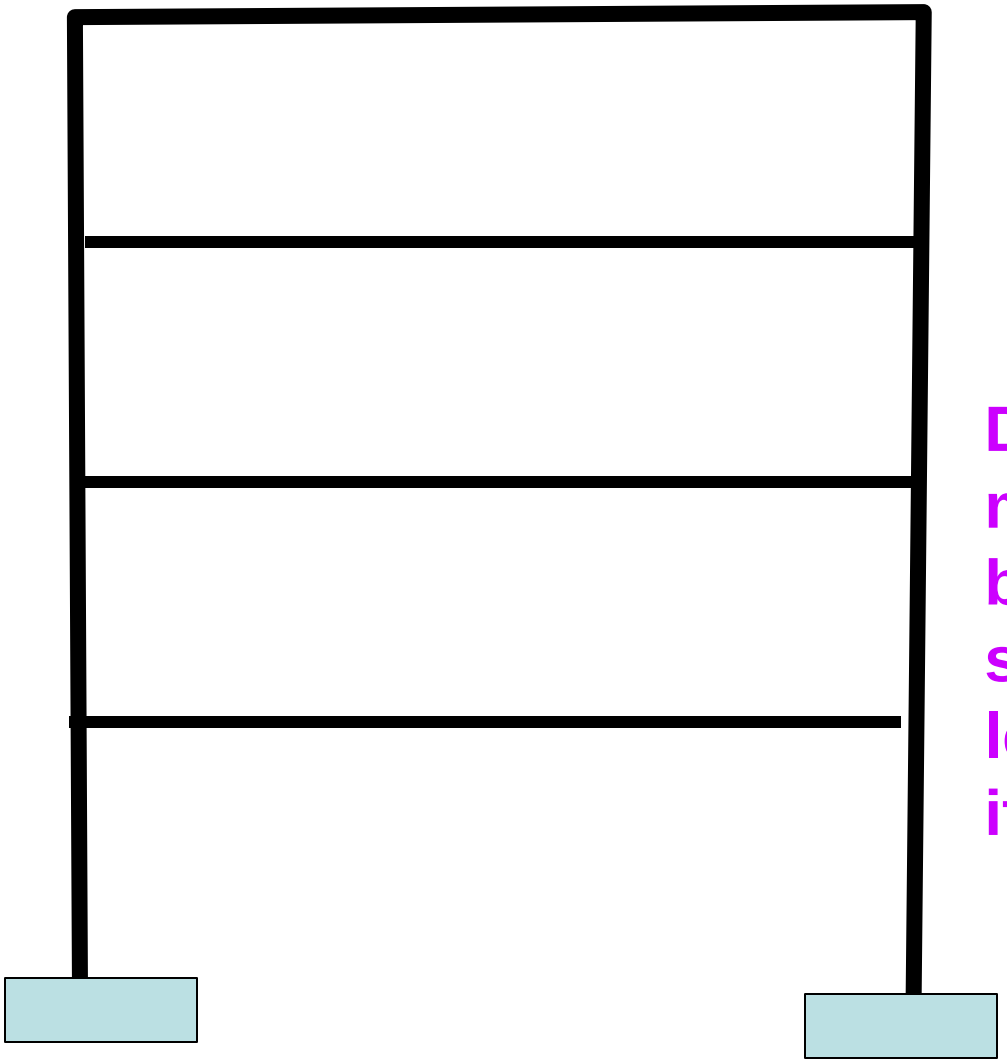

INSTALLATION OF ROOFING SYSTEM

# LIGHT BATTEND BAMBOO SYSTEM (LBBS)

- Fast speedy construction
- Suitable for rural warehouses, cowsheds, cottage industries
- Modular construction
- Wind resistant
- Affordable

Technology disseminated to NGO (e.g. BGIS Mathura)

# HIGH CAPACITY SECTIONS FOR MULTISTOREY FRAMES

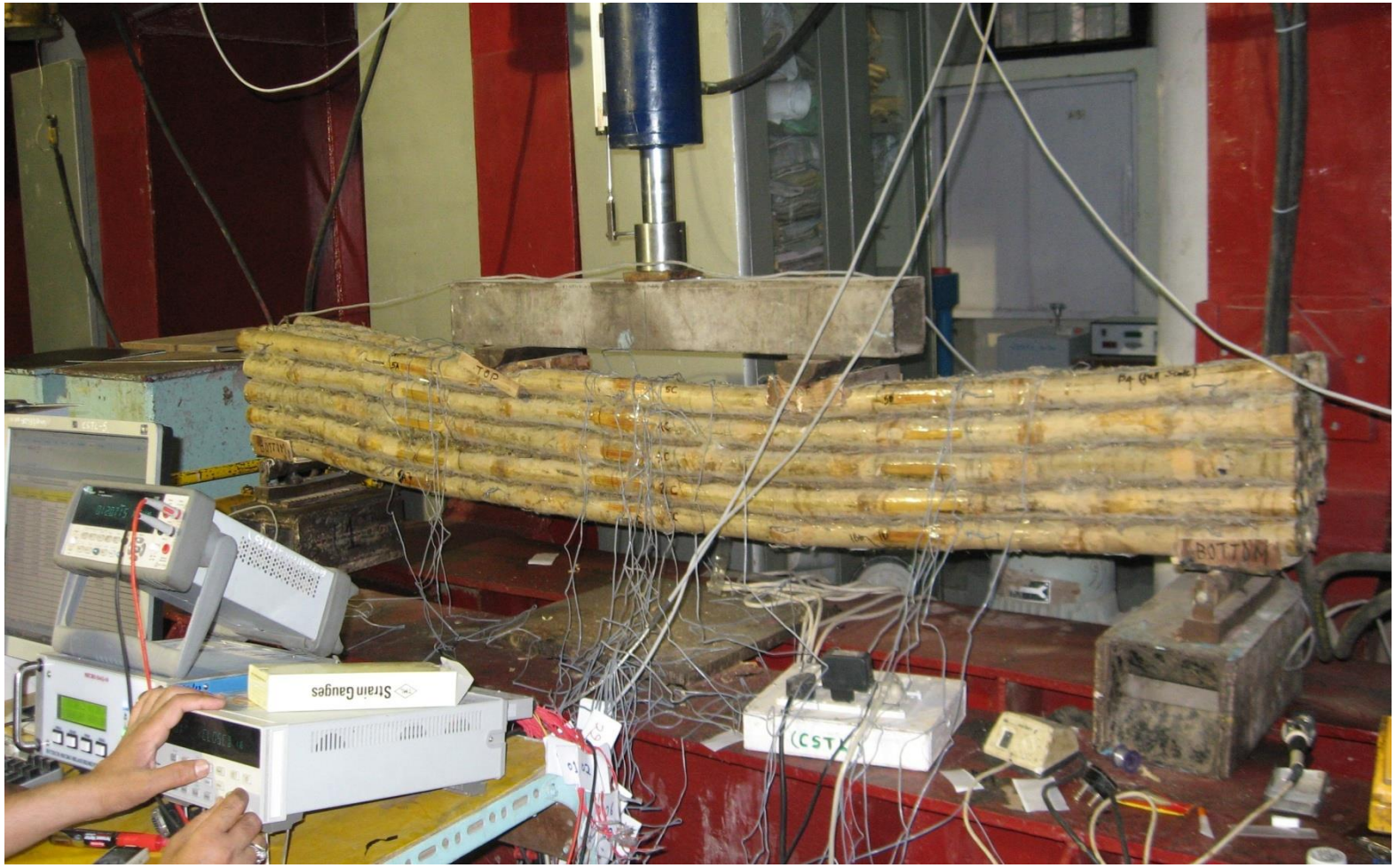


**Despite high strength, the main shortcoming of single bamboo culm is high slenderness ratio, which leads to under utilization of its strength**

# HIGH CAPACITY COMPOSITE MEMBERS

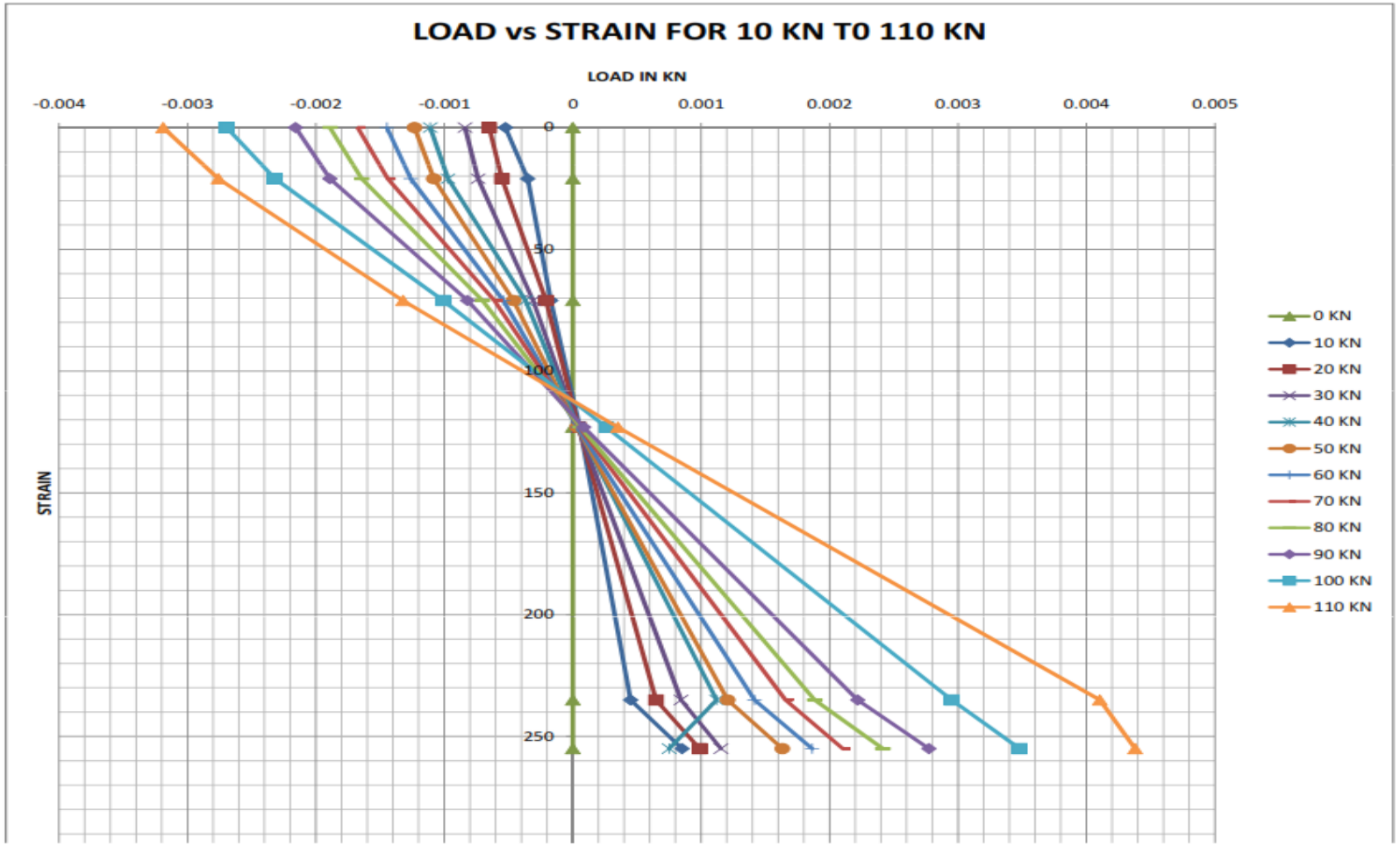
## FRBC (AXIAL/ FLEXURE)….BHAGAT (2017)

# FRBC BEAM UNDER TEST




**BHAGAT, BHALLA, WEST (2021)**

# FRB BEAM – STRAIN ACROSS DEPTH




**Plane section remains plane**

**BHAGAT (2017)**

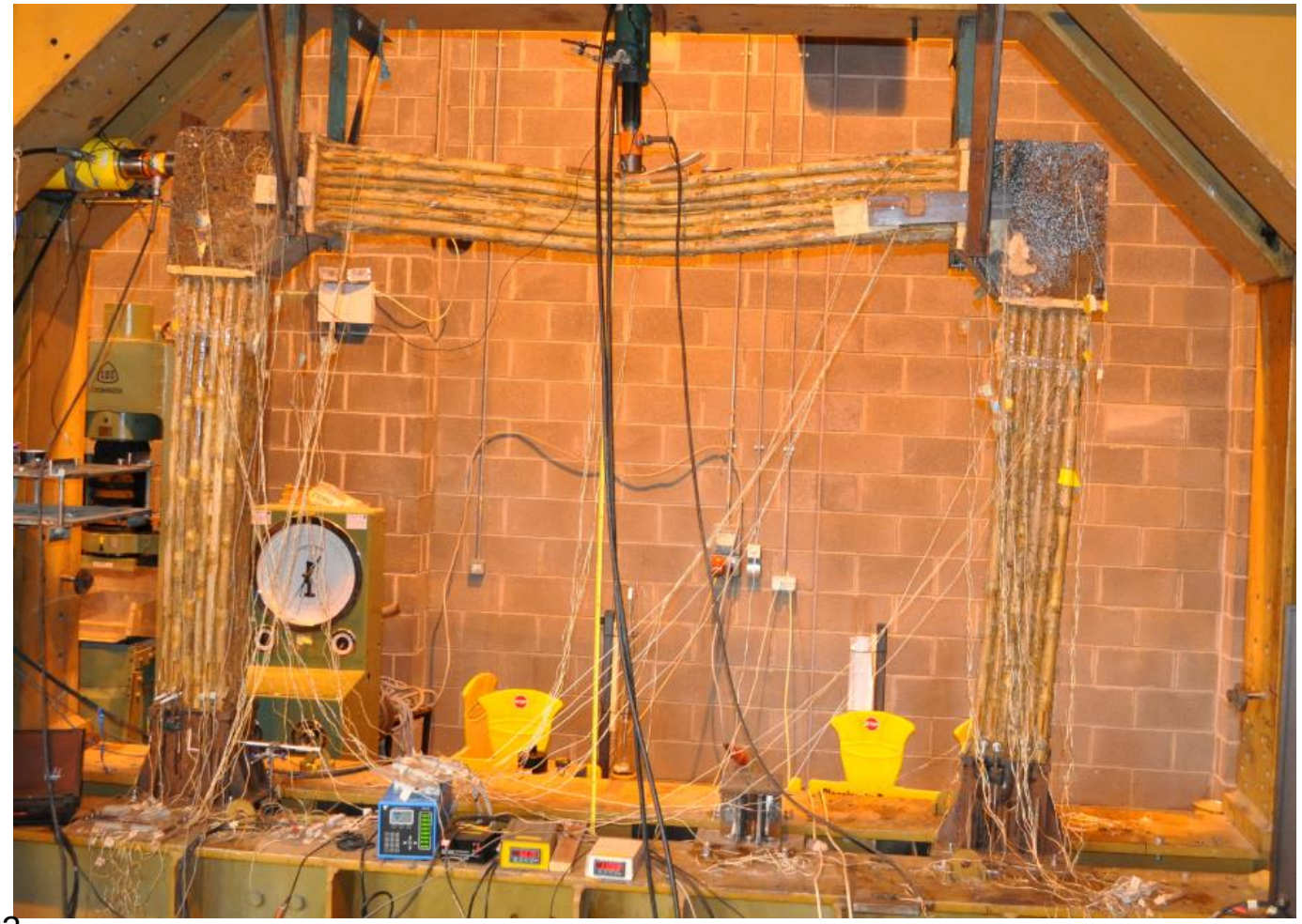


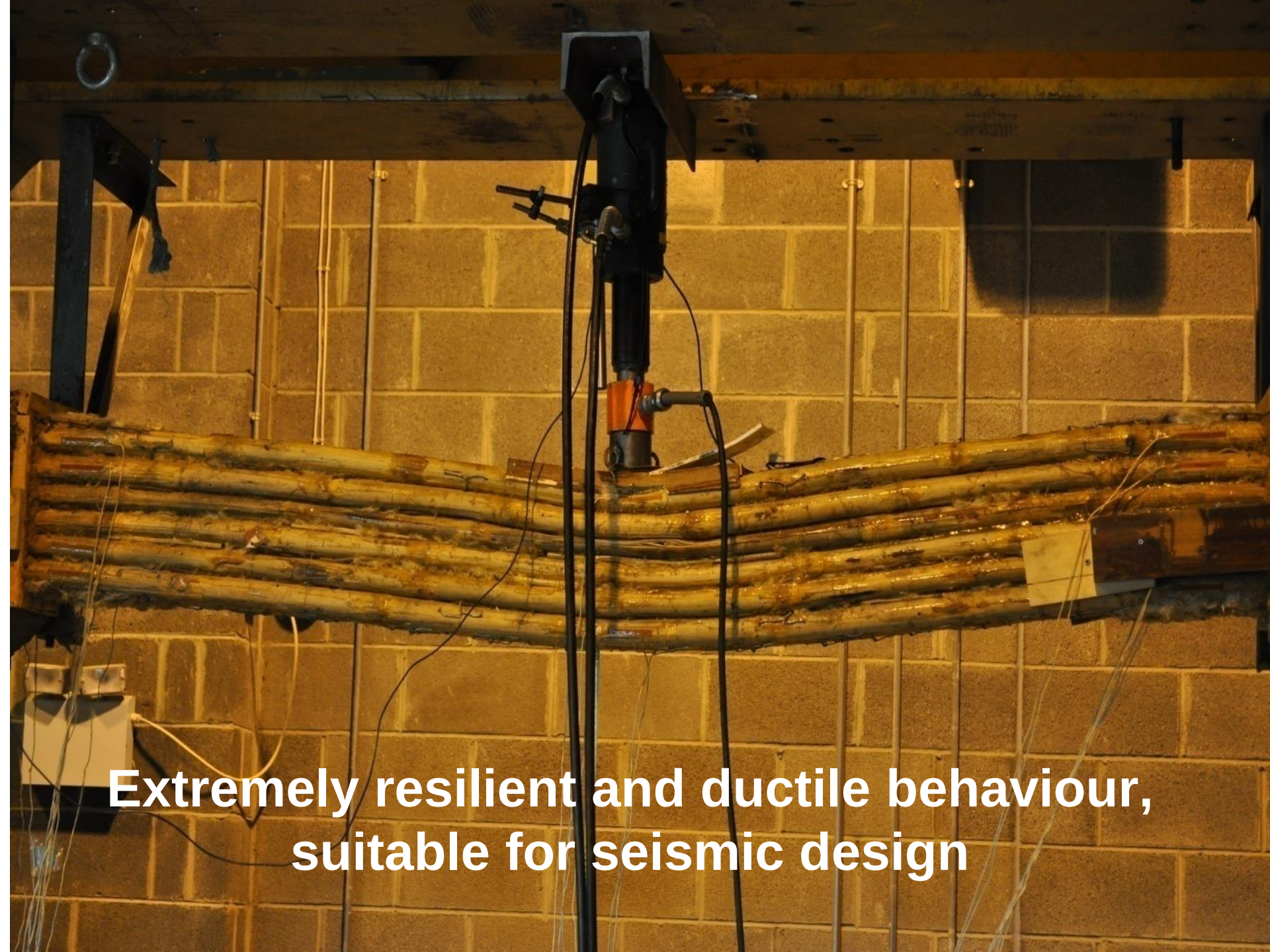
**BHAGAT (2017)**

# BEAM-COLUMN JOINTS

# TESTING AT TRINITY COLLEGE, UNIVERSITY OF DUBLIN

# FRAME 1: UNDER COMBINED MECHANISM




Extremely resilient and ductile behaviour,
suitable for seismic design

| LVL | TECHNOLOGY READINESS LEVEL (Roach and Neidigk, 2011) |
|---|---|
| 1 | Physical principles are postulated with reasoning |
| 2 | Application for physical principles identified but no results |
| 3 | Initial laboratory tests on general hardware configuration to support physical principles |
| 4 | Integration level showing systems function in lab tests |
| 5 | System testing to evaluate function in realistic environment |
| 6 | Evaluation of prototype system |
| 7 | Demonstration of complete system prototype in operating environment |
| 8 | Certification testing on final system in lab and/or field |
| 9 | Final adjustment of system through mission operations |
| | |

# DEVELOPMENT OF ENGINEERED BAMBOO STRUCTURES TECHNOLOGY FOR MODULAR RURAL HOUSING TOWARDS SUSTAINABLE BUILT ENVIRONMENT


**PI: Dr. Suresh Bhalla, Professor,**

Department of Civil Engineering, Indian Institute of Technology Delhi

**Co-PI(1): Dr. Diwakar Bhagat, Principal,**

Government Polytechnic, Saharsa, DST Bihar

**Co-PI(2): Dr. Visalakshi Talakokula, Professor,**

Department of Civil Engineering, Mahendra University, Hyderabad

**Industrial Partner: Er. Sudhakar Bhagat, STCPL**

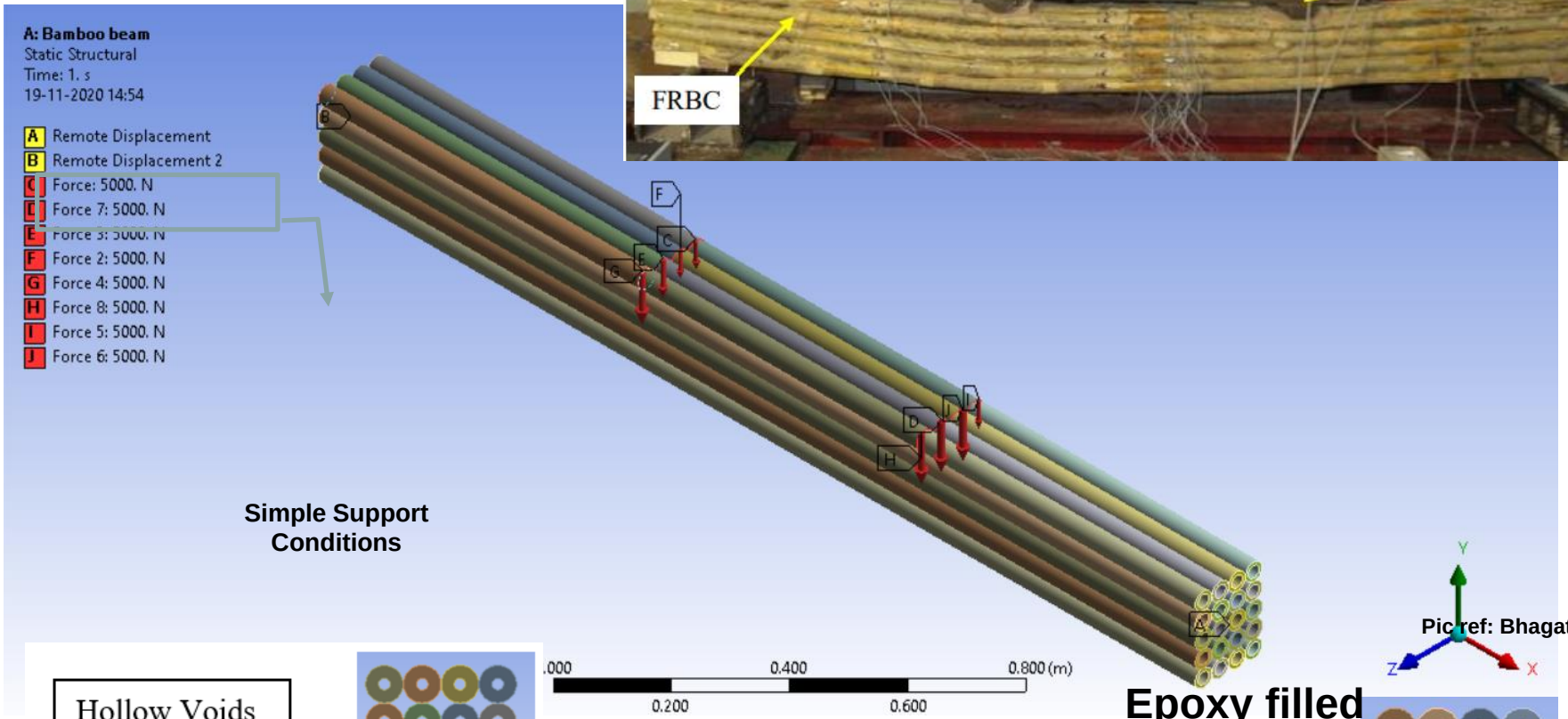

IMPACTING RESEARCH INNOVATION AND TECHNOLOGY

# OBJECTIVES

Fibre reinforced bamboo composite (FRBC), invented by IIT Delhi, is a new environment friendly high-capacity structural member suitable for replacing concrete and steel.

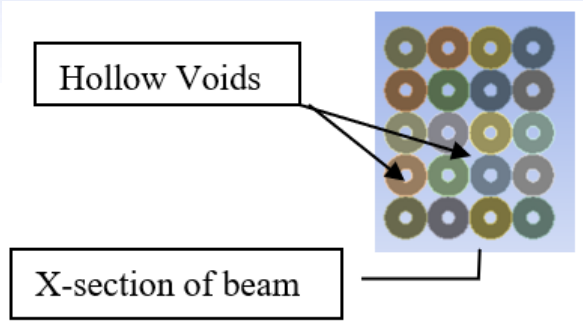
- The main objective of the project is to elevate the technology readiness level (TRL) of FRBC to 9 for affordable green housing segment.
- Utilization of FRBC to devise an affordable house suitable for a small rural family. The house should be modular in nature and amenable for vertical and horizontal expansion.
- Conceptual analysis and design, detailed engineering calculations, of 3D frame based on FRBC members suitable for modular housing unit.
- Non-linear 3D analysis of FRBC beams and frames
- Selection and use of suitable green building materials for walls and interiors.
- Construction of prototype house measuring 23 $m^{2.}$

# NON LINEAR FEA OF FRBC BEAMS

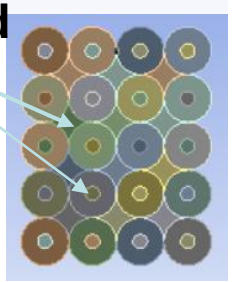




**Simple Support Conditions**

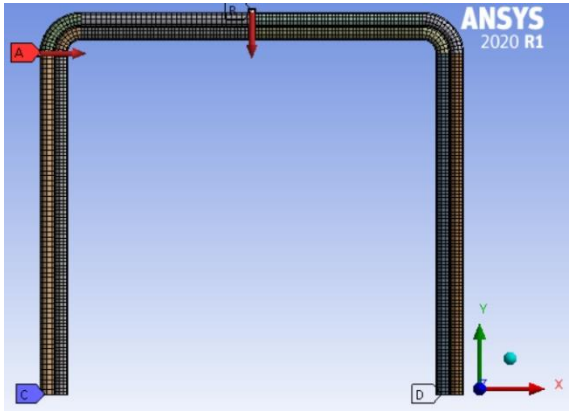
Pic ref: Bhagat, D. (2017)



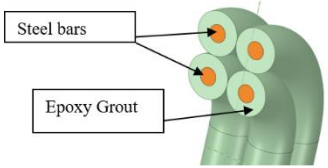

**Epoxy filled voids**

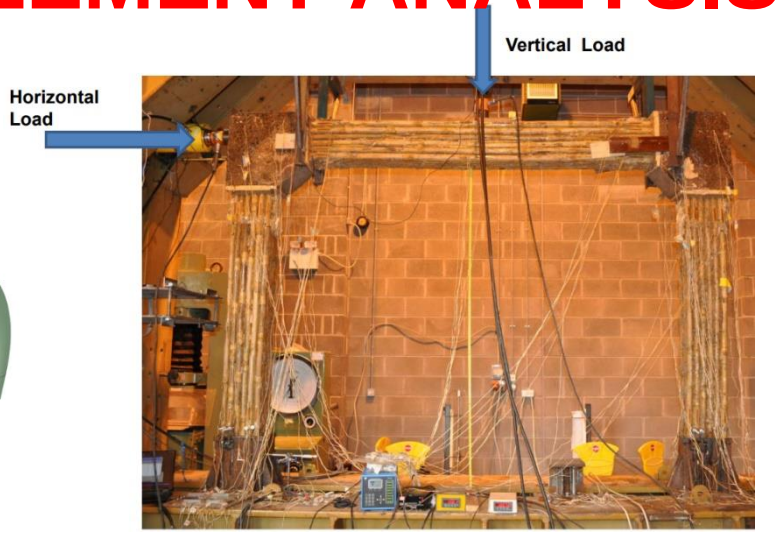


# NON-LINEAR FINITE ELEMENT ANALYSIS

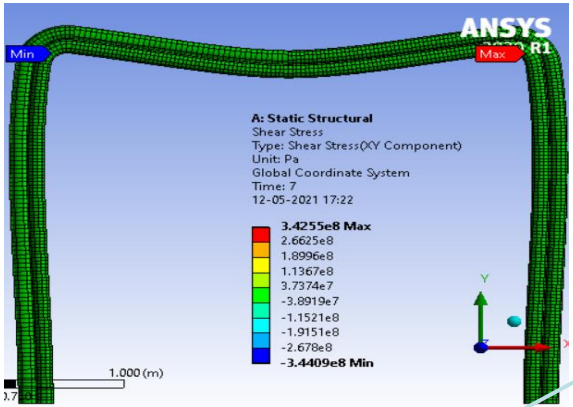



**Numerical Modelling of 2x2 FRBC portal frame**



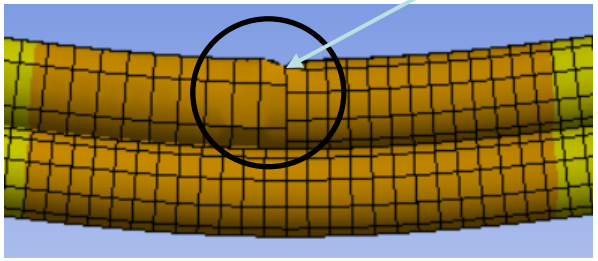




**Experimental Setup of 5x6 FRBC portal frame**

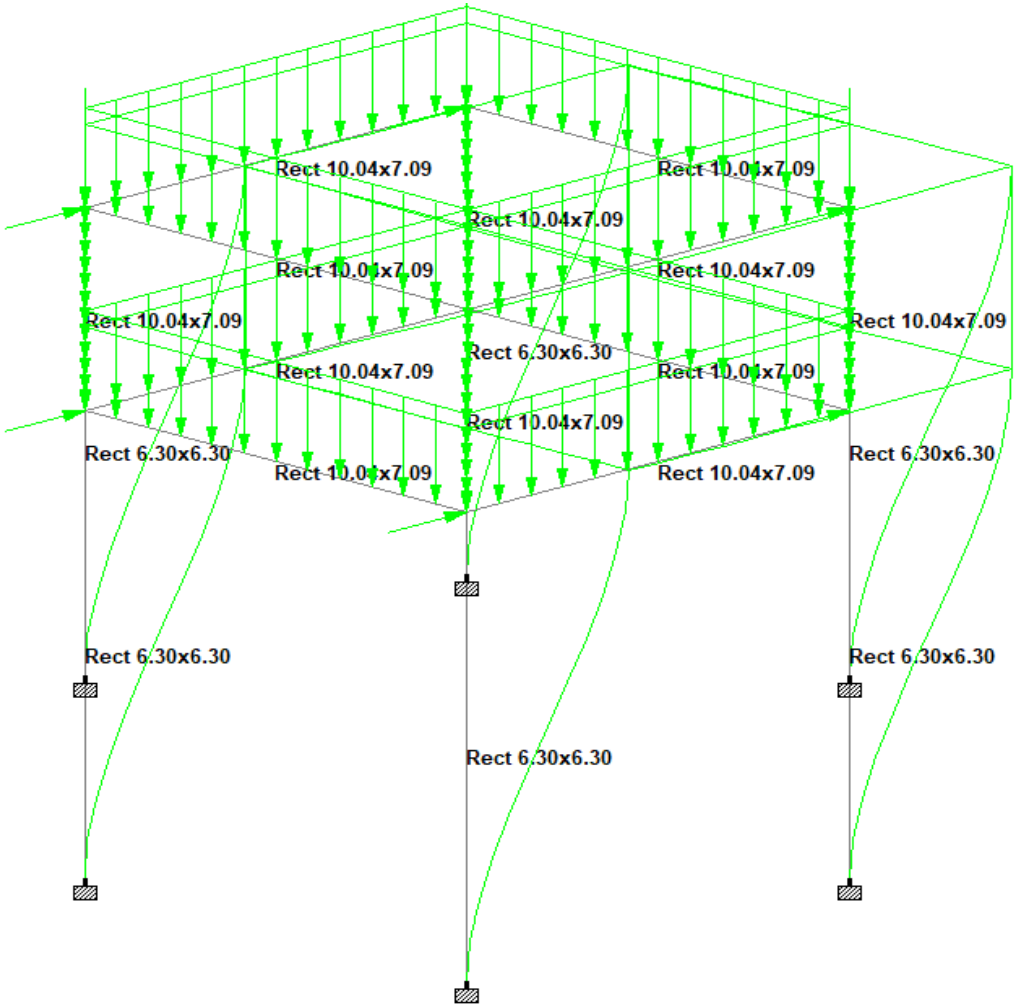


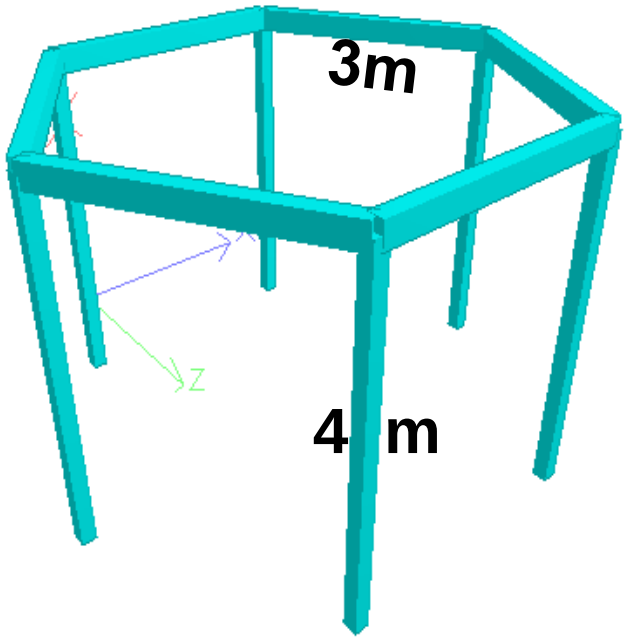

**Plastic Moment Capacity = 40 kN-m**
**(against experimental value of 36 kN-m**

**Plastic Hinge Formation**



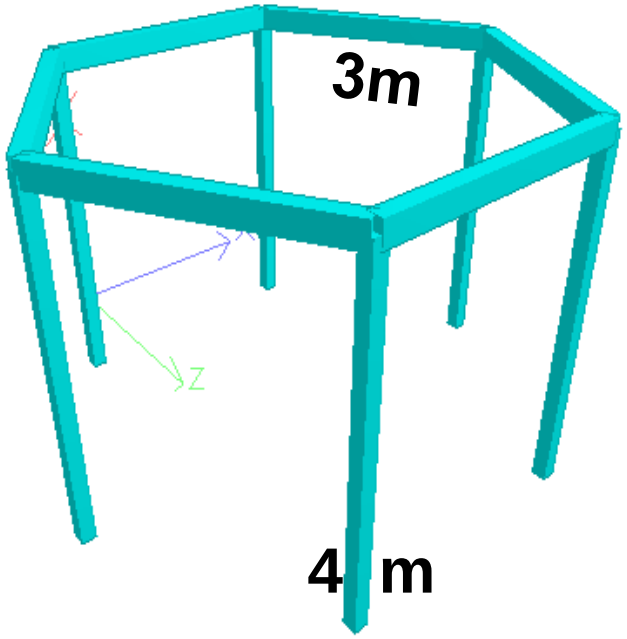
# 3D ANALYSIS AND DESIGN (LINEARLY ELASTIC ANALYSIS)



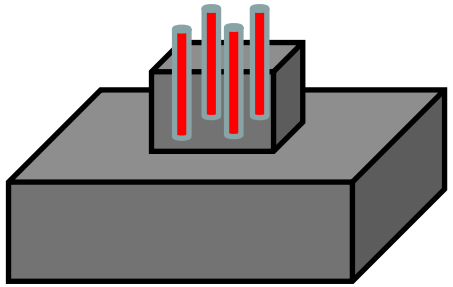
# 3D ANALYSIS AND DESIGN (LINEARLY ELASTIC ANALYSIS)

## ANALYSIS RESULTS (DEAD,IMPOSED, WIND AND EARTHQUAKE)




$$\frac{1.74}{12} + \frac{13.37}{12} + \frac{0.56}{12} = 1.3 < 1.33$$

Column check (1x1x0.3 m)



RC foundation (1x1x0.3 m)

# FABRICATION OF PROTOTYPE UNIT


PREFABRICATED
ELEMENTS


FOUNDATION
1M BELOW NGL


TIE / PLINTH BEAM


24
HOURS

# EXPECTED APPEARANCE


PRIMARY SCHOOL & HEALTH CENTER

# KEY ADVANTAGES

- Environment friendly
- Speedy construction
- Factory production of members => high quality
- Framed structure-much better performance under earthquake/ wind
- Walls are non-load bearing, so flexibility of expansion/ alteration
- Faster curing of epoxycrete

# WALLS AND INTERIORS

# GEOPOLYMER MASONARY

https://www.indiamart.com/proddetail/geopolymer-concrete-block-20624796712.html

**Alumino-silicates**
Calcined clays
- *Kaolinitic clays*
- *Lateritic clays*

Volcanic rocks
Mine tailings
Industry by-products
- *Blast furnace slag*
-*Coal fly ashes*

+

**User-friendly**
**alkaline reagents**
*(Na,K)-soluble silicate with MR $SiO_2 : M_2O$ >1,65*

+

**Water**

= **geopolymer cements**

- **High early strength, Low shrinkage**
- **Resistance to Freeze-Thaw, Sulfate & Acid attack, Corrosion resistance, Fire resistance and**
- **No dangerous alkali-aggregate reaction**
- **Can harden rapidly at room temperature and gain the compressive strength in the range of 20 MPa after only 4 hours at 20$^{o}$C.**

**Prof. Visalakshi Talakokula, Co-PI**

# RAMMED EARTH

*Ramming a corner wall in the first form*

*Adjusting panels of the second form of a corner wall*

*Lifting panels of the first form to the third one of a corner wall*

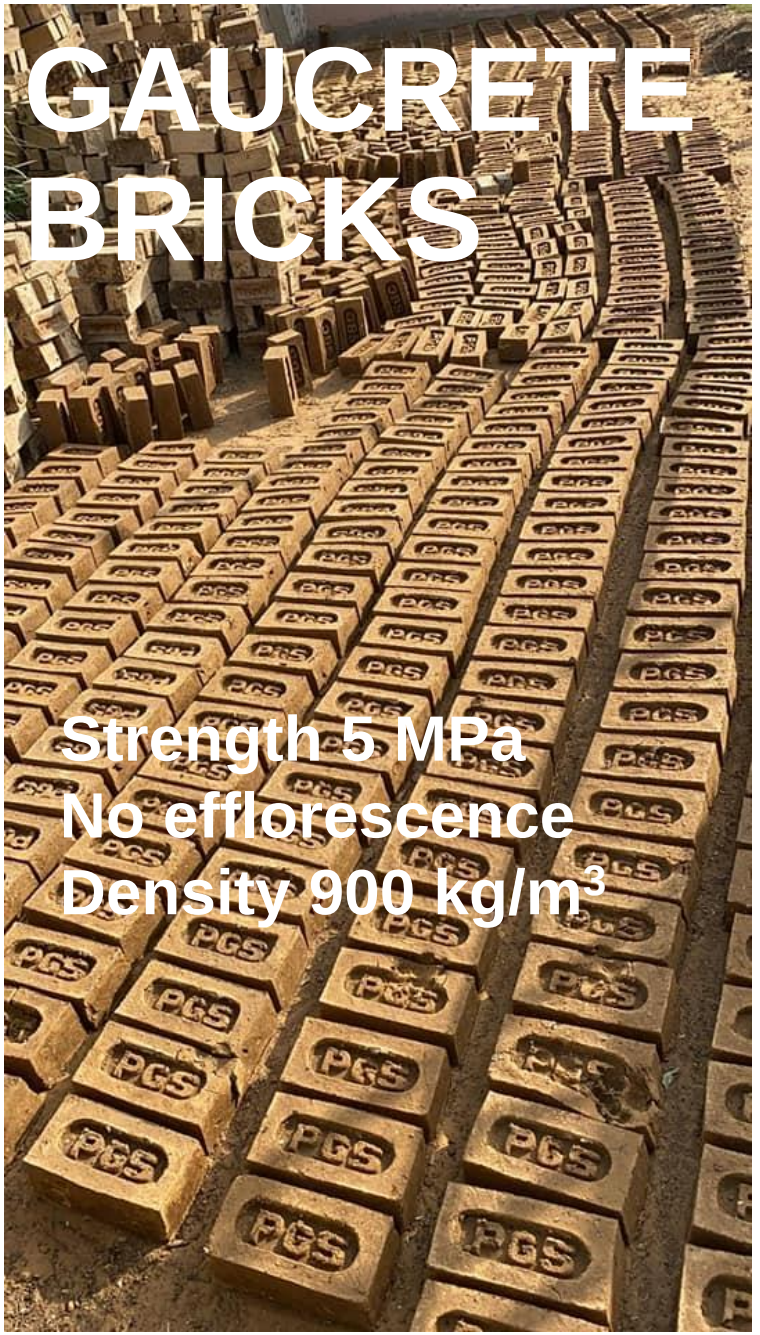
*Adjust panels of the third form of a corner wall*

*Lifting panels of the second form to the fourth one of a corner wall*

*Ramming the fourth form of a corner wall*

*Ramming a long wall in the second form*

**Prof. Visalakshi Talakokula, Co-PI**




Dr. S. D. Malik, https://www.vedicplaster.com/


गौक्रीट

# ROOFING

## OPTION 1: BAMBOO-EPOXY-CRETE



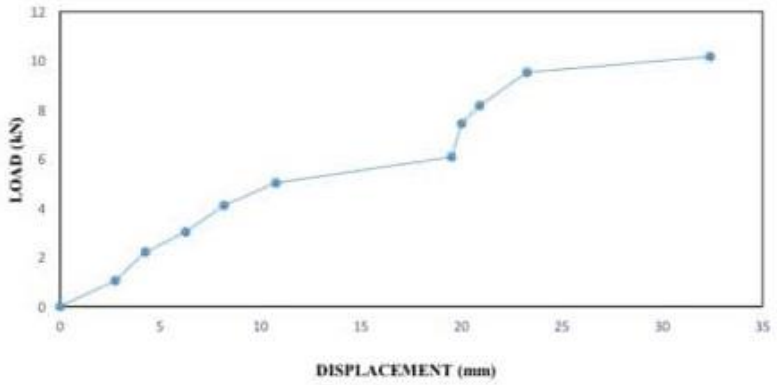



**Fig 5.7:** Load v/s displacement graph for slab 2

# ROOFING

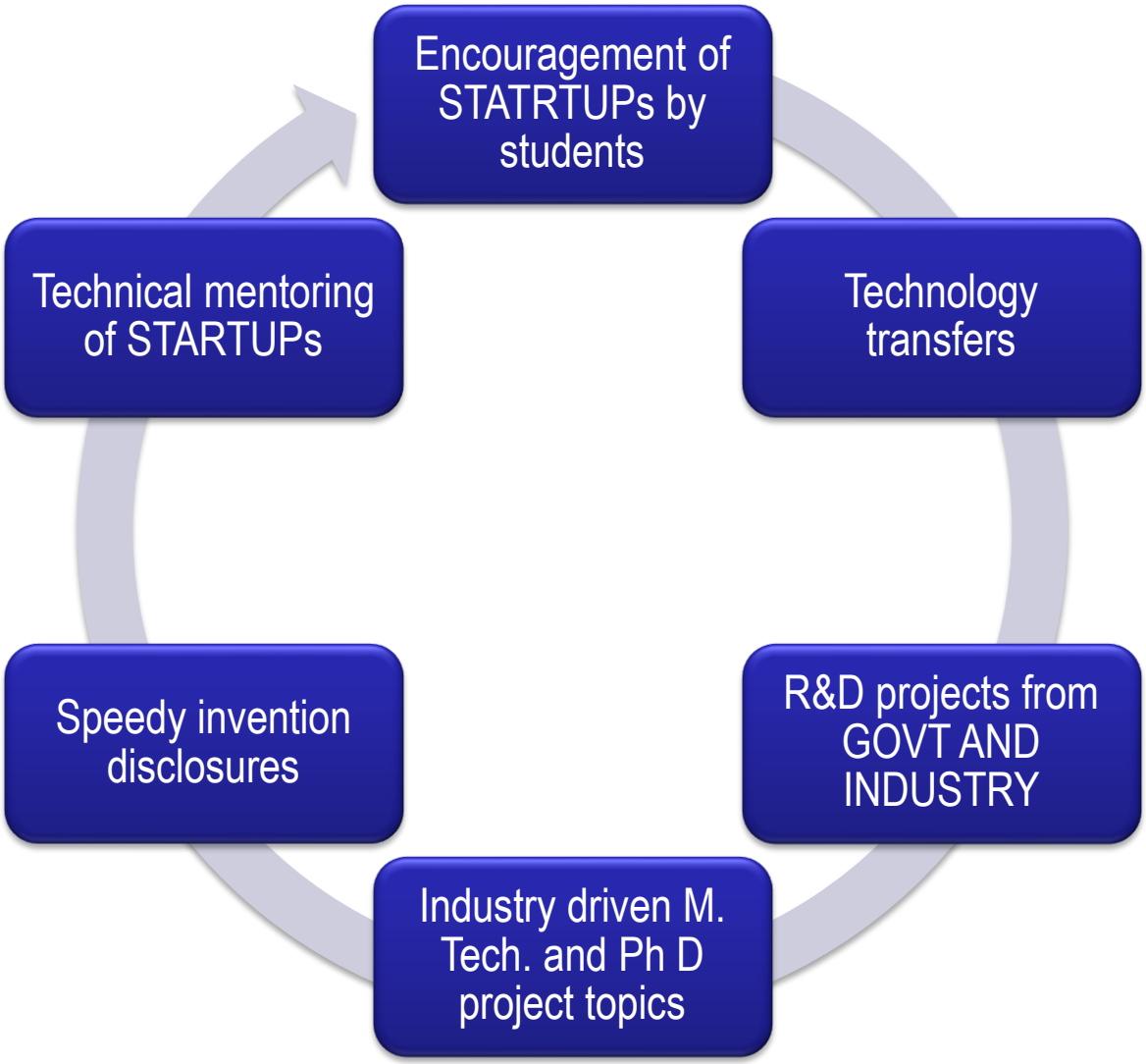
## OPTION 2: BAMBOO-EPOXY-CRETE



PATH AHEAD

# INDIA'S BAMBOO STRUCTURE roadmap

- **Industry-academic joint research**
- **Ecosystem for academicians, Start-Ups, Industry**
- **Policy**
- **Training to artisans and engineers**


Encouragement of STATRTUPs by students
Technology transfers
R&D projects from GOVT AND INDUSTRY
Industry driven M. Tech. and Ph D project topics
Speedy invention disclosures
Technical mentoring of STARTUPs

# INDUSTRY PARTICIPATION/ INTEREST

## Er Sudhakar Bhagat STCPLT
## Industry Partner

**Dr S. K. DHAWAN, CHIEF ENGINEER (RETD.), CPWD**

**OUR SPECIAL ADVISOR**

**INTERESTED IN FRBC TECHNOLOGY**

**Er K. Lalsawmvela, Technical Advisor Govt. of Mizoram**

**Er Vijay K Saini, MD&CEO (SOUTH ASIA), GRAM INDIA INTELLI MART**

**Ms Heena Bhatt, Hexa Int. Pvt Ltd., 9000 crore group leader into textiles, polyfilms etc.**

# Development of High Capacity Bamboo Composite Multi-Storey Framed Structures for Sustainable Housing in High Intensity Earthquake/ Wind Zones


**Project Team:**

**Prof. Suresh Bhalla**

**Prof. Diwakar Bhagat, Principal, DST Bihar**

**Prof. V. Talakokula, Civil Engineering Department, Mahindra Ecole University, Hyderabad**


UNDER EVALUATION


Science and Engineering Research Board

Statutory Body Established through an Act of Parliament: SERB Act 2008

Government of India

Scientific and Useful Profound Research Advancement (SUPRA)

# PROJECT PROPOSAL UNDER SHRI SCHEME

## TECHNOLOGICAL INTERVENTIONS AND CAPACITY BUILDING FOR WIDESPREAD AGRICULTURAL PRODUCTION AND USAGE OF TRADITIONAL BAMBOO TECHNOLOGY IN CONSTRUCTION, BIO-TECHNOLOGY AND ALLIED INDUSTRIES

- Government Polytechnic Saharsa (DST Bihar)
- Indian Institute of Technology Delhi (IIT Delhi)
- CSIR-Central Road Research Institute (CRRI)
- Indira Gandhi National Open University (IGNOU
- Mahendra University, Hyderabad
- Bhaktivedanta Gurukul and International School (BGIS)
- College of Horticulture, Bangalore
- Garden City University, Bangalore
- Industrial Partner: NISARG foundation

# PROPOSED OBJECTIVES

1. Dissemination of modern engineered structural bamboo technology and practices.
2. Capacity building with practical training. Target:500 engineers, 2000 artisans
3. Social Marketing/awareness of bamboo related material/ products for construction, bio-technology, and allied industries. As part of this, one model bamboo structure shall be built in each of 36 states/ union territories of India.
4. Inclusion of modern agricultural practices for bamboo cultivation
5. Standardization of modern testing facilities for the bamboo characterization
6. Industrial production of bamboo composite elements including treatment and fabrication technologies.
7. Production of nanocellulose bamboo composite for bio-based packaging.
8. Synthesis of low-cost carbon materials from bamboo

# Complete listing of theses and publications

**http://web.iitd.ac.in/~sbhalla/brg**

Under links:

***Students** ***Publications**

*** Bamboo Research Group (BRG)**

EMAIL: sbhalla@civil.iitd.ac.in

# THANK YOU

# CONCLUSIONS

- **Deficiencies of single shoot bamboo eliminated**
- **Development of a more reliable and generalized sections using bamboo which is comparable in strength to R.C. and Steel**
- **Rigorous inclusion of the principle of structural engineering, that is ability to predict capacity with reliability.**
- **Bamboo offers built environment conducive for life in the mode of goodness.**

# REFERENCES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7. Kajjam S, Chaudhry DK, Bhalla S, West R. (2012) FABRICATION AND TESTING OF BUILT-UP BAMBOO COLUMNS FOR STRUCTURAL APPLICATIONS. **Proc. Third Int. Conf. Mechanics of Functional Materials and Structures (ACMFMS 2012)**, 05-08 December, IIT Delhi, pp. 433-436.
8. West R, Bhalla S, Bhagat D (2017) FLEXIBLE RESPONSE OF BAMBOO-EPOXY FRAMES, **Journal of Structural Integrity and Maintenance 2(2):**70-77.
9. World Steel Association (2020) http://www.worldsteel.org

# Complete listing of theses and publications

**http://web.iitd.ac.in/~sbhalla/brg**

Under links:

***Students** ***Publications**

*** Bamboo Research Group (BRG)**

EMAIL: sbhalla@civil.iitd.ac.in

# THANK YOU

# WORK COMPLETED (>75%)

- 3D modelling, linear and non-linear analysis of FRBC beam elements as well as 3D FRBC frames completed (One M. Tech. project).
- Analysis and Design and of single and double storey frame model made of FRBC elements in STAAD PRO has been completed (Two M. Tech. projects completed).
- Fabrication of all FRBC beams and columns (total 12 numbers) of the proposed prototype house has been completed.
- RC substructure has been constructed with connection detail amenable to attaching FRBC columns.
- Superstructure FRBC frame with suitable joining details at beam-column junctions has been completed.
- Preliminary evaluation of rammed earth for walls of the superstructure has been completed.