Shear Resistance of portal Frame Reinforced with Bamboo and Steel Rebar: Experimental and Numerical Evaluation

Rajesh Kumar, K., Karthik, S., Ramamohan R., Awoyera, P. O., Gobinath, R., Shivakrishna, A., Murthi P.

Abstract*: *The main objective of this study is to evaluate the shear resistance of portal frame fabricated with bamboo and steel rebar by following experimental and numerical approaches. In support of sustainable construction, bamboo stripes were utilized as a partial replacement of steel rebar at tension zone of members that are subjected to lateral loading. The performance of nominal portal frame, which are fabricated with steel reinforcement was compared to the portal frames having several replacements of steel reinforcement with bamboo, in terms of seismic resistance and lateral load capacity. The experimental data was correlated based on software analysis using ABAQUS. The partial replacement of steel with bamboo under tension zone of the beams in portal frame was found to be highly effective, and also that the flexural rigidity of the partial bamboo reinforced frame was slightly higher than the nominal portal frame. This study provides insight on the possibility of reinforcing structural members with bamboo, when lateral loading is imminent on the structure.

***Index Terms*: ABAQUS, bamboo, steel, seismic failure, shear resistance.**

I. INTRODUCTION

Over the years, there has been an increasing development in the construction of steel reinforced framed structures. It is well known that the steel reinforcements, which are embedded in concrete, resists the tensile forces, while the concrete itself caters for the compressive forces. Over all, the entire composite (reinforced concrete) becomes more versatile, having numerous applications in the construction field. However, the worldwide consumption of these materials is currently on the increase, and it is expected that the demand and consumption of the materials will further increase in the future. On the other hand, the process of steel production contributes to environmental and land pollution as a result of continuous mining of iron ores [1-3]. Therefore, there are several attempts being made by researchers to improvise an alternative ways to reduce persistent use of steel, and control the associated limitations.

In recent developments, reinforcing steel has been replaced in concrete by the addition of synthetic fibres [4-15] such as, glass, steel, rubber and plastics or natural fibres [16-18], jute, sisal, coconut and hemp. In addition, polymer sheets, plates and carbon sheets have also been investigated experimentally for aiding tensile strength of concrete. The studies have reported that there were significant improvement in the performance of the tested elements, in terms of compressive strength, split tensile strength, flexural strength, and failure mechanism. Similarly, bamboo, a natural fibre belonging to grass family and also the fastest growing plant on earth [19, 20], is another material that is widely considered to have potential reinforcing ability, as somewhat close to steel. Bamboo is mostly cultivable in tropical and sub-tropical regions like Asia, Africa and America, which provides environmental, social and economic benefits. Bamboo is strong and dense, with a very flexible and elastic outer layer, and it has resistance to stress than concrete, brick and wood [21]. Bamboo is also highly resistant to corrosion, wear and tear. Quite a number of research outcomes have showcased the viability of using bamboo in concrete, as stripes for reinforcing bars or in fibre form [22-24]. However, the common issue identified in the use of bamboo for concreting, among other factors, has been how to ensure adequate bond between bamboo and concrete paste in order to maximize the capacity of the composite. But, soaking bamboo thoroughly in bituminous fluid prior to use, is the most appropriate means of stabilizing bamboo – concrete bond, as reported in [25]. Despite the extensive studies on the use of alternative materials for potential use in construction, but not so many studies have given consideration to testing large scale members that are produced with bamboo. Such investigations are needed so as to establish the suitability of large scale application. Therefore, this study, investigates the shear resistance of portal frames that are reinforced with bamboo and steel rebar based on both experimental and numerical evaluations.

II. METHODOLOGY

A. Materials

The materials used in this study include: Ordinary Portland Cement (OPC) of grade 53, coarse aggregate of sizes 10 mm to 20 mm and conforming to per IS 2386-3 (1963),

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manufactured sand of particle sizes ranging from 4.75 mm to 0.075 mm, was used as fine aggregate.

The properties of cement, and the coarse and fine aggregates are presented in Tables 1 and 2, respectively. Potable water, having a pH of 7.0, was used for mixing and curing of concrete. A Fe250 grade steel having 437.96 MPa tensile strength, and of 6 mm diameter, was used as main and distribution reinforcing bars. Bamboo was used as a reinforcement material, with same dimension as steel bars, as a partial replacement to steel bars. Its physical and mechanical properties are presented in Table 3.

Table 1. Specifications of cement

Sl. No	Specifications	Value
1	Cube compressive strength	53Mpa
2	Specific surface area	225m^2/kg
3	Initial setting time	30 mins (minimum)
4	Final setting time	600 mins (Maximum)
5	Specific gravity	3.15
6	Consistency	31.5%

Table 2. Specifications of coarse aggregates

Sl. No	Specifications	Coarse aggregate	Fine aggregate
1	Specific gravity	2.8	2.5
2	Water absorption	2%	5
3	Fineness modulus	-	2.43
3	Crushing strength	93.3%	
4	Impact strength	70.4%	

Table 3. Specifications of bamboo

Sl. No	Specifications	Value
1	Tensile strength	312.67 N/mm^2
2	Water absorption	4%
3	Shrinkage	1mm

B. Experimental analysis

A scaled down portal frame (two bay) were cast following the dimensions specified in Figure 1. The steel reinforcement is being replaced by bamboo by 25, 50, 75 and 100 percentages. Their results were compared with conventional steel frame whose dimensions and reinforcement are shown in fig1. The portal frames were demoulded after 24 hours from casting. For the curing process, gunny bags were used to wrap the frames for 56 days so that there will be proper development of strength and durability properties.

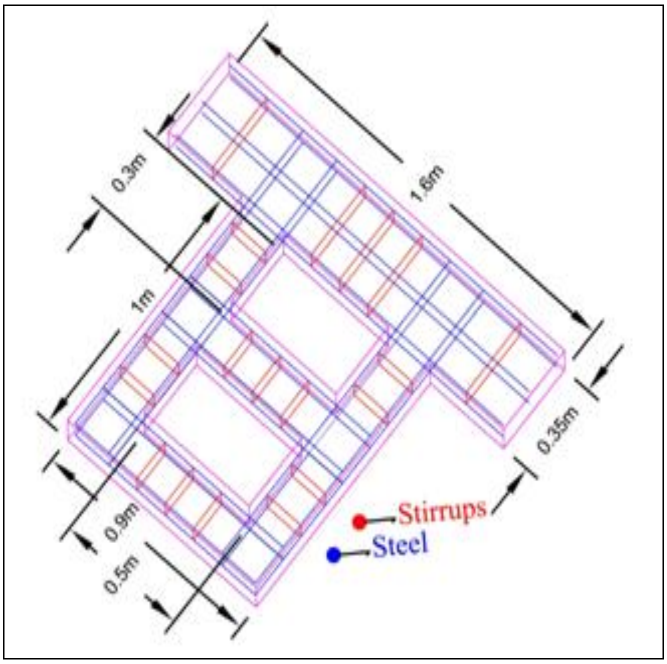


Fig 1 Dimensions of portal frame

After curing, the portal frame specimen was placed under loading frame of 50 kN capacity as shown in Fig 2. The load was applied horizontally at a constant rate by means of hydraulic jack and it was continued until the failure of the frame. The deflection at different loads was measured from the portal frame.

Fig 2. Loading Setup.

III. RESULTS AND DISCUSSION

From the experimental data, the beams with various replacement of bamboo in place of reinforcement are named as shown in Table 4 and the load vs deflection plot has been drawn for all the portal frame specimens as shown in fig 3. The initial crack load and ultimate load was recorded with respect to their corresponding displacements and are shown in Table 5.

Table 4. Description of beams

Description	Specimen name
Frame with conventional steel reinforcement	BWC
Frame with 25% bamboo reinforcement	25-B
Frame with 50% bamboo reinforcement	50-B
Frame with 75% bamboo reinforcement	75-B
Frame with 100% bamboo reinforcement	100-B

Table 5. Failure details of beams

Specimen name	Initial crack Load kN	Ultimate load kN	Crack pattern
BWC	50	100	Diagonal cracks at joints
25-B	38	101	Diagonal and vertical cracks at beam column joints.
50-B	8.2	105	Diagonal and vertical cracks at beam column joints.
75-B	2.4	70.5	Vertical cracks at beam column joints.
100-B	1.3	11	Diagonal cracks at beam column joints.

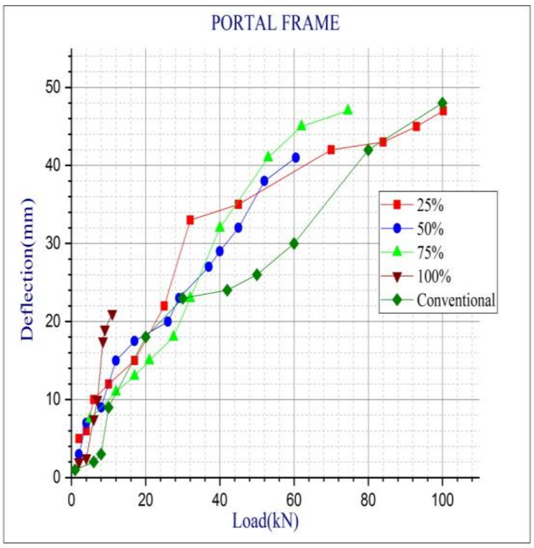
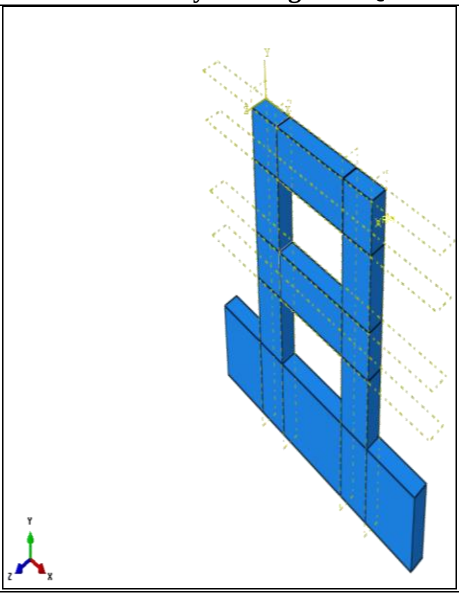
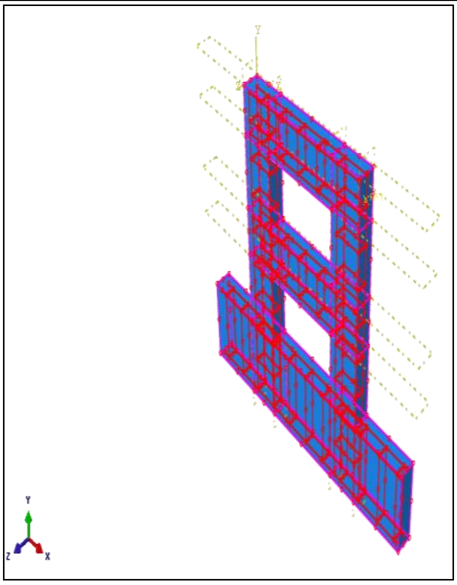
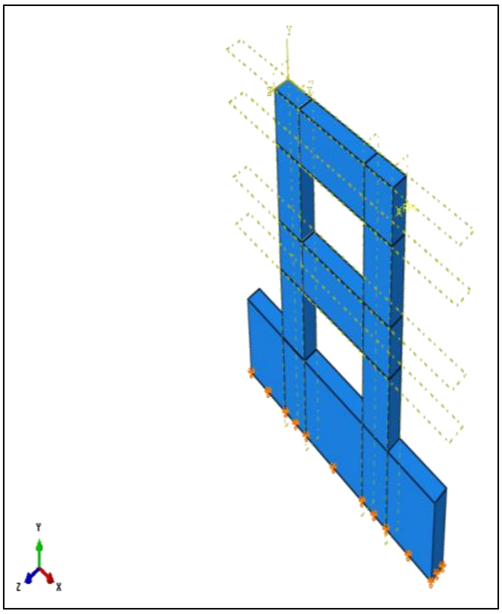
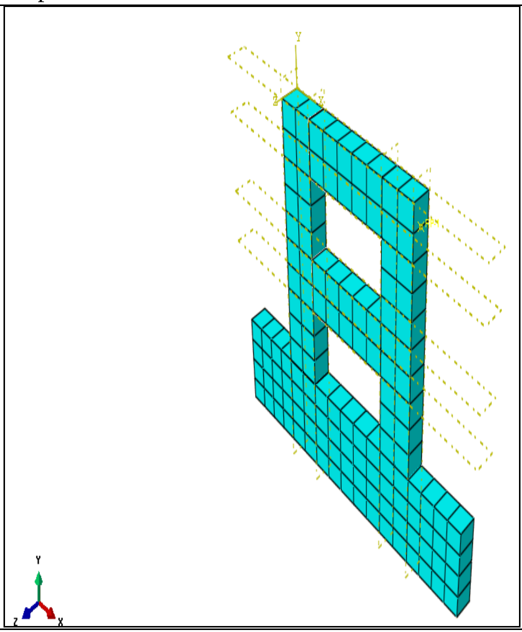


Fig 3. Load vs deflection curve for all specimens

The comparison between all the proportions of bamboo reinforcement was shown in the above figure. From this figure, it was observed that by replacement of 25% bamboo reinforcement achieves good results when compared to other proportions.

For numerical analysis the finite element software ABAQUS is used owing to its flexibility in generating models and producing geometry. The basic concept involved in the finite element analysis is that every structure may be considered to be an assemblage of a finite number of individual structural components or elements. These elements can be put together in a number of ways and hence they can be used to represent exceedingly complex geometries. In Abaqus software, a solid model of portal frame was developed with suitable material properties and then an input file was generated. After that nodes and elements were generated with the help of meshing. A job analysis was created. The step by step procedure is sown in Table 6. Finally, the data is submitted for results and discussions. The sample data for 25-B is shown in fig 4. ABAQUS has vast set of the material library in the engineering data section. Either we can select a material from the library or we can manually enter the properties of the material in ABAQUS/CAE. The numerical and experimental data are compared and re exhibited in Table 7 and the reports of numerical analysis are validated in Table 8.

Table 6: Numerical Analysis using ABAQUS/CAE

	
Step 1:Modelling of portal frame	Step2:Interaction between elements
	
Step 3:Boundary conditions of the model	Step 4:Meshing of the portal frame

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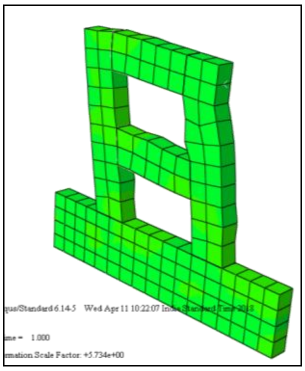

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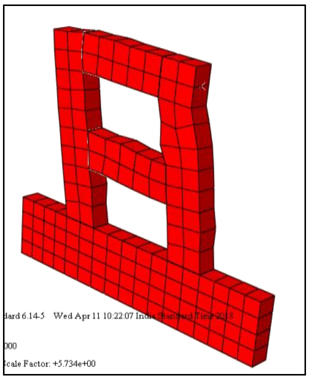

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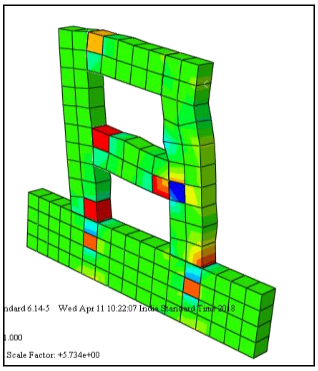
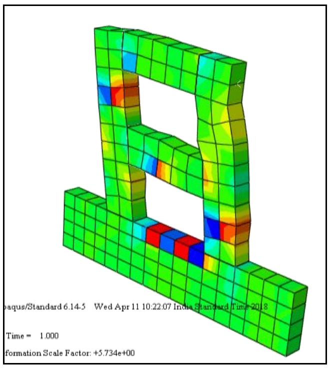


Σz

Maximum Normal stress



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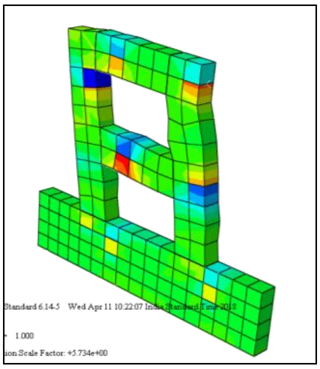

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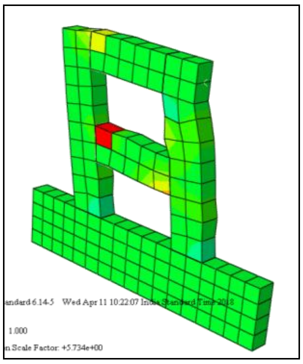
Shear stress



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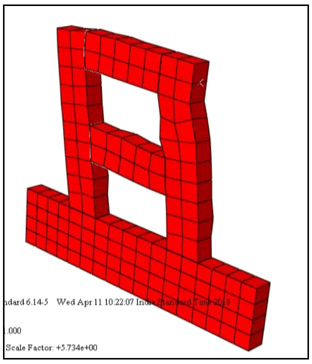

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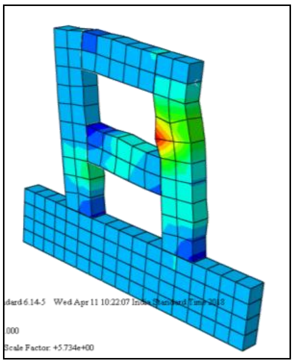

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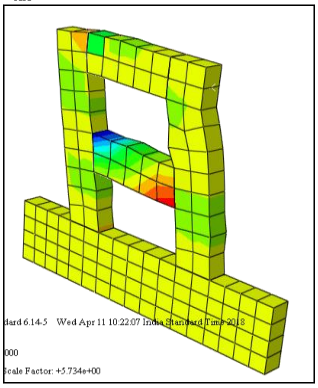

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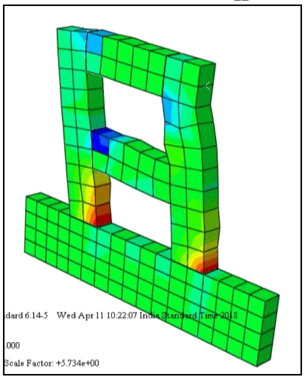


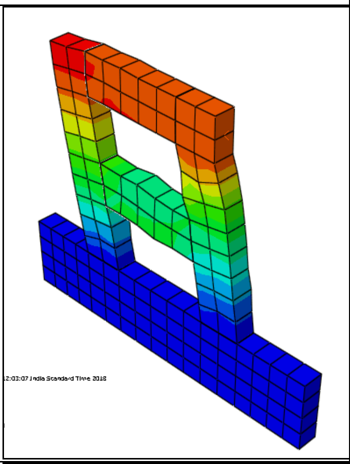
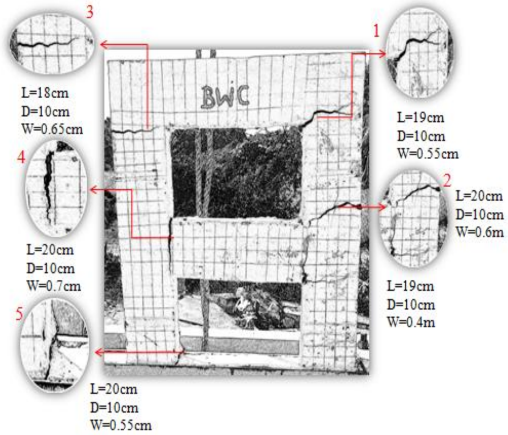
ϵ_{yz}

Strain tensor

Fig 4. Analytical report for the frame with 25% bamboo reinforcement

Table 7: Comparision of crack pattern between Numerical and Experimental analysis

Specime	Crack pattern

<table>
<tr><td>n</td><td colspan="2"></td></tr>
<tr><td></td><td>Numerical</td><td>Experimental</td></tr>
<tr><td>BWC</td><td></td><td>
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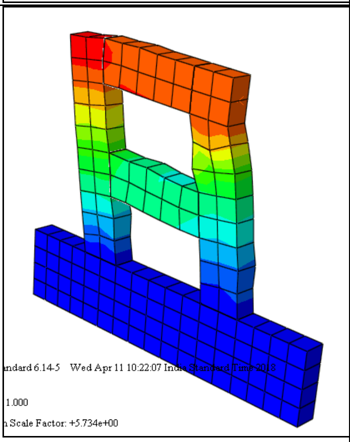
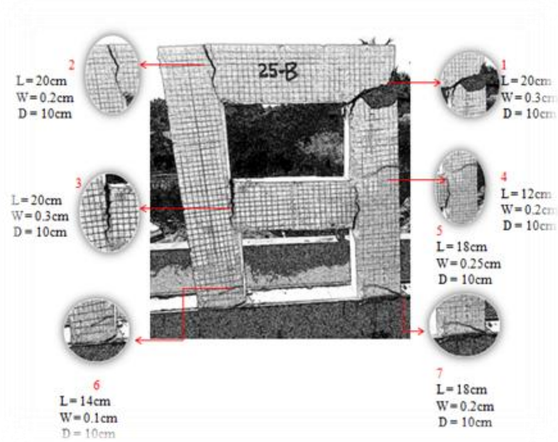
<tr><td>25-B</td><td></td><td>
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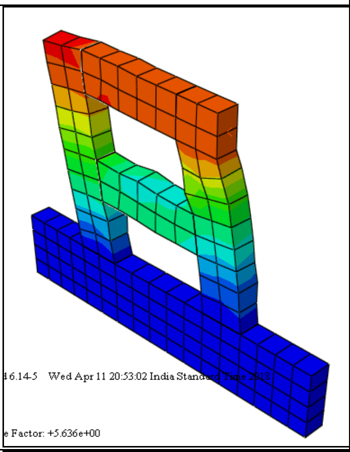
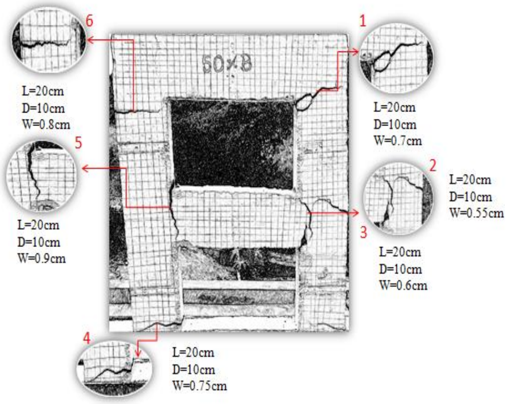
<tr><td>50-B</td><td></td><td>
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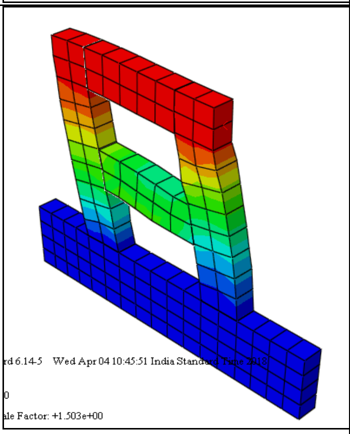
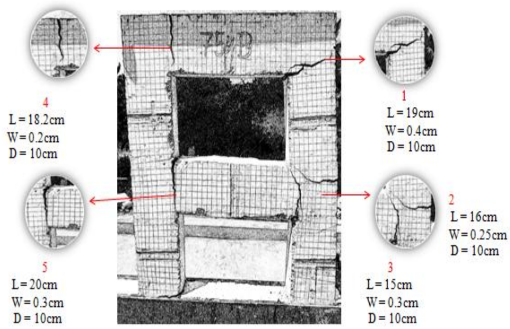
<tr><td>75-B</td><td></td><td>
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</table>

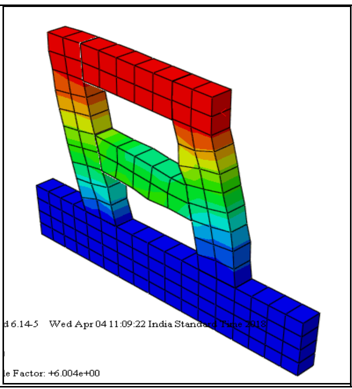
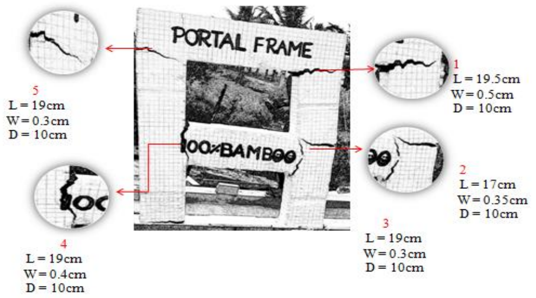
100-B		

Table 8. Validation of report from numerical analysis

Specimen name	Maximum Normal stress (N/mm^2)			Shear stress (N/mm^2)		Ultimate load kN
	σx	σy	Σz	τ_{yz}	τ_{xz}	
BWC	415	7.59	3.46	0.108	0.116	135.53
25-B	69.17	415	3.409	0.212	0.305	128.52
50-B	69.17	415	3.855	0.258	0.256	110.65
75-B	415	415	5.445	0.163	0.192	100.26
100-B	415	5	5.43	0.039	0.086	25.68

Fig 5 shows the comparison of analytical and experimental results in terms of bar diagram. It represents that the analytical results are only slightly in variation with experimental results. The analytical results are quite accurate than experimental results.

IV. DISCUSSIONS

The casted portal frame was tested for lateral load capacity to check the flexural rigidity and elasticity to provide enough structural integrity of the respective portal frame with various replacement of bamboo reinforcement with steel reinforcement. The casted specimens were tested on a loading frame of 500 kN capacity to apply a lateral load with the help of hydraulic jack and the respective deflections were noted by loading cell at regular intervals and were reported.

The beam with conventional reinforcement (BWC) initially cracked at 50kN and failed under an ultimate load of 100kN with diagonal cracks at joints signifying shear failure.The beam with a replacement of 25 percentage bamboo reinforcement (25-B) had an initial crack at 38kN and failed at an ultimate load of 101kN which was very near to the beam with conventional reinforcement signifying with same diagonal cracks stating shear failure. This shows that the structural integrity of the beams are equivalent. Also, since the load carrying capacity is almost equal the flexural rigidity of the beam is also satisfied giving higher resistance to lateral loads like earthquake forces.The beam with a replacement of 50 percentage bamboo reinforcement (50-B) had an initial crack at 8.2kN and failed at an ultimate load of 95kN which was also very near to that of the beam with conventional reinforcement but the initial crack occurs very quickly.The beam with a replacement of 75 percentage bamboo reinforcement (75-B) had an initial crack at 2.4kN and failed at an ultimate load of 70.5k also the beam with a replacement of 100 percentage bamboo reinforcement (100-B) had an initial crack at 1.3kN and failed at an ultimate load of 11kN. In all the three later cases the crack pattern includes vertical cracks indicating low flexural rigidity and also the ultimate strength of the frame against lateral load resistance has a notable decrease.The rigidity nature and the load carrying capacity of the beamswere decreased due to the increase in percentage of bamboo in the place of steel which has altered the integrity of the structure. On numerical analysis the same was executed using ABAQUS and the respective results were checked for their accuracy and to have clear view on the results. From software analysis it was found that the crack pattern and stress – strain distribution of the portal frames were exactly same indicating the correctness of the procedure and accuracy of the results. Also the stress distributions from the software results were in accordance with the crack pattern observed from experimental analysis. The variation of the respective details wasshown in the table 10.The experimental investigation and the numerical investigation were correlated with each other and a chart has been prepared to show the synchronisation between them for their accurate match and is shown in fig 4. From the observations it is clear thatthe load versus deflection for each and every portal frame for both experimental investigation and numerical investigation were in coincidence with each other projecting equivalent values.

V. CONCLUSION

In this study, the lateral load capacity of the portal frames fabricated using bamboo as partial replacement of steel reinforcement was investigated experimentally and numerically using loading frame and ABAQUS, respectively. From experimental investigation, it was found that bamboo can be used as a suitable alternative for steel reinforcement. Bamboo, being an eco –friendly material, the carbon dioxide emission can be made lesser while compared to steel reinforcement. The experimental performance showed that the replacement of steel reinforcement with 25 percentage bamboo provides exact same lateral resistance, increased flexural rigidity and elasticity to that of the beam with conventional reinforcement. The investigation using software reveals that the 25 percentage replacement of bamboo reinforcement with steel reinforcement can be recommended under earthquake prone zones, owing to their flexibility which was observed from the stress strain distribution analysis from ABAQUS software. The correlation of stress strain distribution diagram between experimental and software analysis shows that the replacement of bamboo do not alter the structural rigidity of the frames much and also it was same as that of conventional beam.

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