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A Study on Bamboo Reinforced Concrete Beam Using Numerical Modeling and Comparison with the Experimental Data

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Abstract: Concrete is extensively used construction material in our planet which is quite strong in compression but weak in tension. So, extra reinforcement is required to make it properly utilizable. The tensile strength of bamboo is sufficiently high for using it as reinforcing material. This type of concrete is termed as Bamboo Reinforced Concrete (BRC). Hence, in this study an effort has been made to utilize a type of bamboo named *Bambusa balcooa* as reinforcing material for making concrete beam. Thereafter, a 3D numerical model of bamboo reinforced concrete beam has been created using ABAQUS which uses concrete damage plasticity approach to find the ultimate load carrying capacity of bamboo reinforced beam at different percentage of bamboo reinforcement viz. 0, 0.73, 1 and 2%. Results show that the ultimate load carrying capacity have been increased by almost 4 times using 2% bamboo reinforcement compare to plain concrete. Experimental values obtained from the similar studies are compared with the ABAQUS results and comparison showed a similar trend of increasing ultimate load carrying capacity with up to 2% bamboo reinforcement.

Key words: Bamboo Reinforced Concrete (BRC), tensile strength, numerical model, ABAQUS, reinforcement, experimental values

INTRODUCTION

Concrete is the material which is most commonly used construction material in the modern world. It is good in compression but it behaves inadequately under tensile forces. To overcome this shortcoming of concrete, reinforcement is required. The reinforcing material should have sufficient tensile strength apart from other properties. Steel is the conventional material used as reinforcement in concrete. Availability of steel is not a matter of concern present day but in future extensive use of steel can lead to generate a scarcity of this worthy material. So, it is important to think about new construction materials. Bamboo, the green gold, carries a renowned status as a housing material in the tropical and subtropical region in the world. The abundance and low cost of this green material makes it suitable for low cost housing (Akeju and Falade, 2001). The mechanical properties of bamboo splints had been studied by various researchers with different species of bamboo (Ali and Pama, 1978; Amada *et al*., 1996; Ghavami, 1995). This light weight versatile material possesses a good strength which is comparable to steel (Khan, 2014).

From the past studies it has been observed that several attempts have already been made by researchers to make structural components like beam, column and slab (Bhonde *et al*., 2014; Bhowmik, 2016; Ghavami, 2005) using bamboo reinforcement. The durability was the main question mark regarding bamboo reinforced structures. But over the time researcher developed some techniques to make the bamboo structure durable and serviceable (Ghavami, 1995, 2005). In North Eastern part of India many bamboo species grows. The behavior of these bamboos with concrete was not studied yet.

Reinforced concrete shows a complex behavior under various loading condition. It is not new to study this complex behavior with the help finite element method. Computer simulations help us to predict and visualize the actual phenomena when a structure subjected to loading condition approaching to failure (Jankowiak and Lodygowski, 2005). Researchers enriched this field with their valuable contributions and understandings which are published in various reports and study but still there are many untouched areas and remaining scopes of improvement which are yet to be studied. Study on a bamboo reinforced beam using finite element method is one of the lesser known areas which are needed to be enlightened.

An attempt has been made in this study to model and simulate the behavior of bamboo reinforced concrete beam using ABAQUS using concrete damaged plasticity.

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MATERIALS AND METHODS

For preparing the numerical model various properties of the materials which were used like bamboo, concrete, etc., were find out by conducting laboratory tests.

Properties of material

Properties of bamboo: In the properties two types of bamboo properties were needed. One is for compression and other is for tension. The stress strain data is taken from the tensile and compressive strength test results. Bamboo is considered as an elastic-plastic isotropic material. Plastic strain is calculated by deducting the elastic strain from total strain. Elasticity of bamboo in tensile direction is 43064.28 MPa. Elasticity of bamboo in compressive direction is 3254.73 MPa. Poisson's ratio of bamboo is taken 0.35.

Tensile testing of bamboo samples: The tensile strength of bamboo is the property which makes it good material to be used as reinforcement in concrete. The average tensile strength of the bambusa balcooa found to be 287.69 MPa. The stress-strain curve of bamboo shows that bamboo behaves elastically up to a certain limit of strain. The first point of the stress-strain curve at which the curve levels off is considered as the yield point. Figure 1 shows the stress strain curve of bamboo samples.

Compressive strength test of bamboo samples: The compressive strength of bamboo is very much lower than its tensile strength. The failure of bamboo under compressive stress occurred due to axial cracking and splitting of bamboo fibers. Figure 2 shows the stress strain curve of bamboo samples for compressive strength.

Properties of concrete: Properties of concrete were defined using concrete damaged plasticity model. The stress-strain relation for a given concrete is obtained from the uni-axial compression tests results in the laboratory. To define the stress-strain relation of concrete in concrete damaged plasticity, values of stress inelastic strains correspond to stress values were calculated. The tensile stress-strain curve of concrete cannot be obtained directly therefore indirect methods have been used.

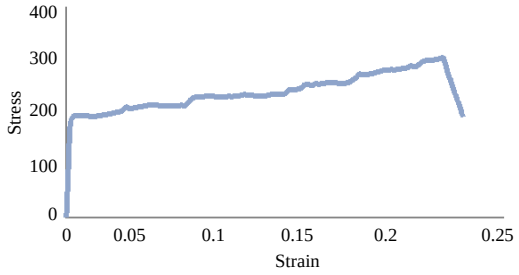

Fig. 1: Stress strain curve of bamboo splints under tension

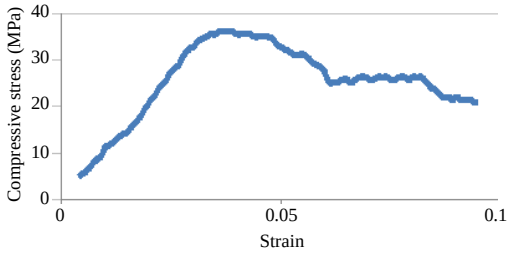

Fig. 2: Stress-strain curve of bamboo cylinder under compression

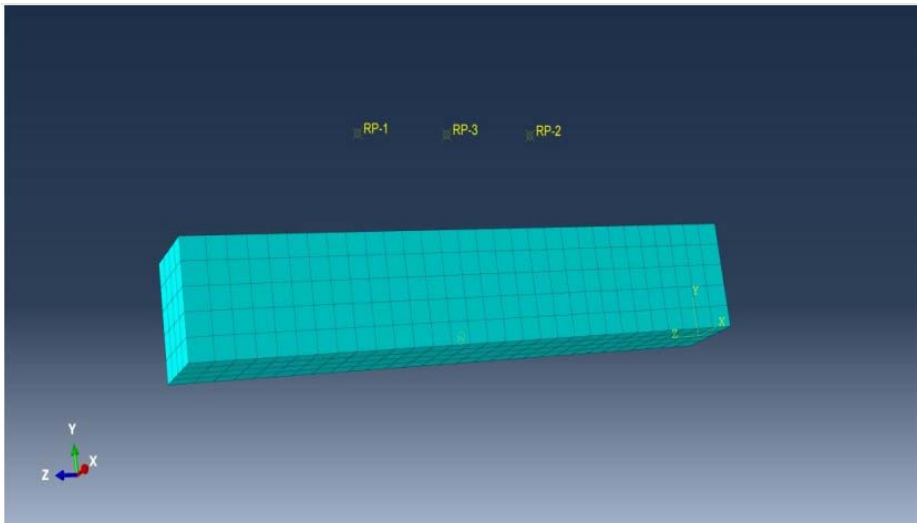

Fig. 3: Image of meshed beam in ABAQUS

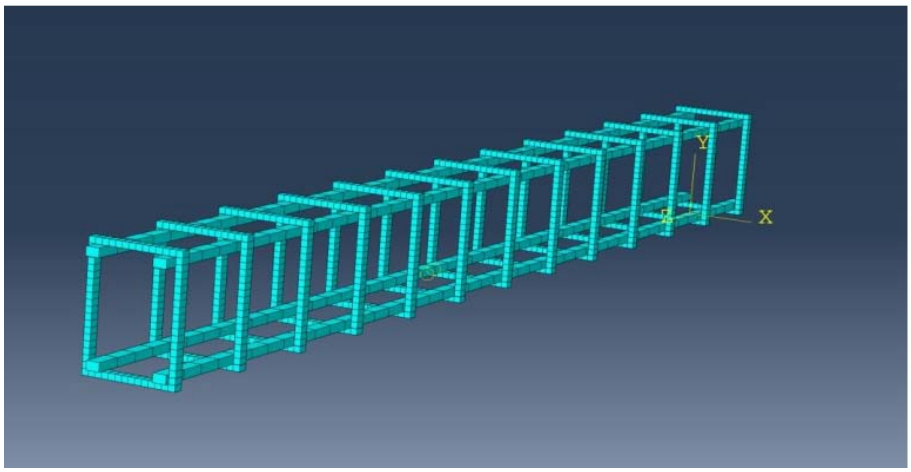

Fig. 4: Image of reinforcement model in ABAQUS

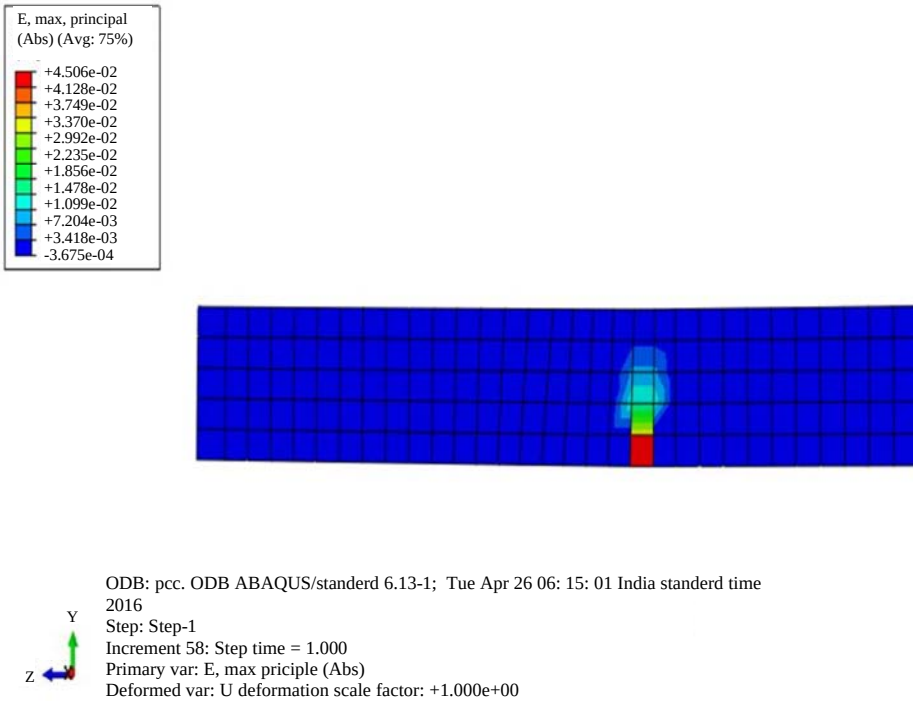

Fig. 5: Plastic strain contour of plain concrete (0% reinforcement) beam

- Elasticity of concrete = Initial slope of stress-strain curve = 12752.36 MPa
- Ultimate collapse load for plain concrete beam is 6.83 kN
- Bending moment for the collapse load for the test setup (M) = P (0.46-0.165)/2 kNm
- Tensile stress at the extreme fiber (fb) = My/I tensile strain at extreme fiber (e) = (6D/L2)×u where total load on beam = P
- Moment at middle span = M
- Moment of inertia = I
- Depth of extreme fiber from neutral axis = y
- Depth of beam = D
- Clear span between supports = L deflection of the mid span = u
- The plasticity parameters used in this model
- Dilation angle (β) = 3
- Eccentricity (m) = 1 fb0/fc0 = 1.12
- K = 0.666
- Viscosity parameter = 0

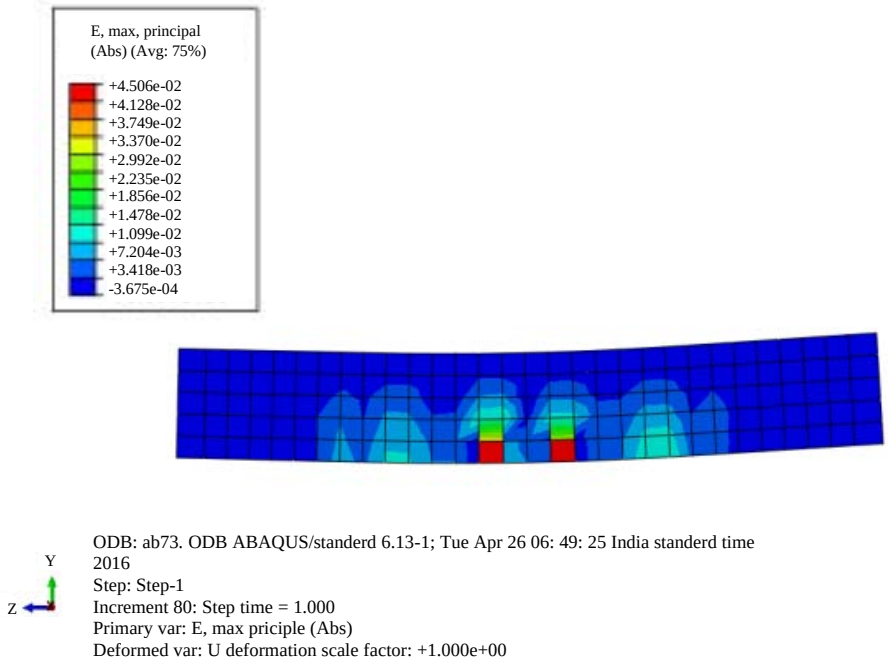

Fig. 6: Plastic strain contour of 0.73% bamboo reinforced concrete beam

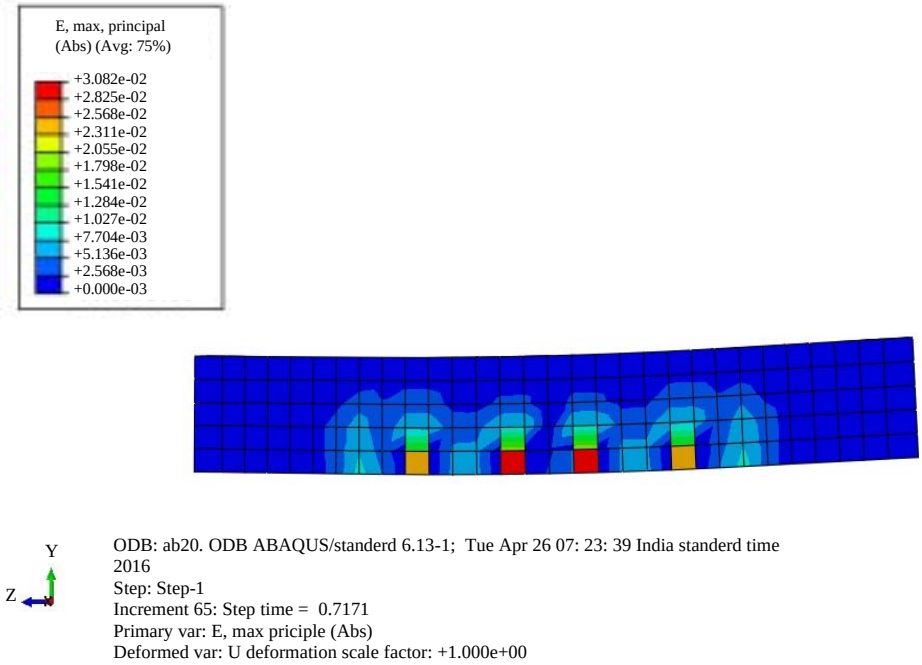

Fig. 7: Plastic strain contour of 1% bamboo reinforced concrete beam

Beam model: The ABAQUS beams are modeled according to the dimension of the test beams 960×150×120 mm. The C3D8 element is used for meshing. The bamboo reinforcement is constrained as embedded region into concrete block. ABAQUS beam models are shown in Fig. 3 and 4.

Results of numerical modeling: Cracking of concrete occurs when concrete is in tension and in plastic state. In Fig. 5-8, the plastic strain zone is shown from which crack zone can be identified for the bamboo reinforced percentage of 0, 0.73, 1 and 2%, respectively. Load-displacement curve for every beam is plotted as shown in Fig. 9.

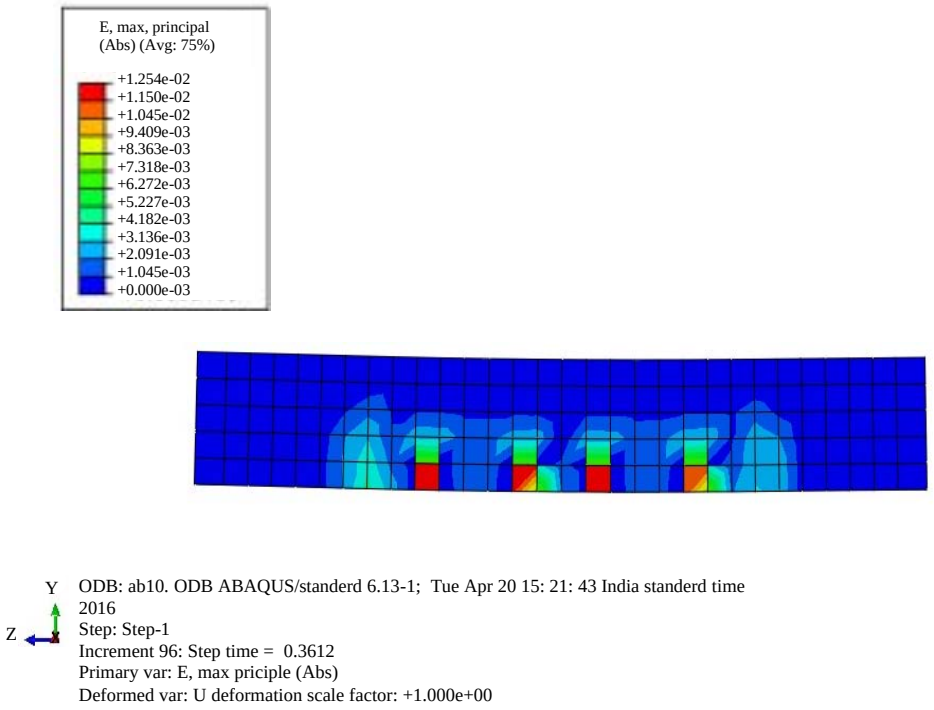

Fig. 8: Plastic strain contour of 2% bamboo reinforced concrete beam

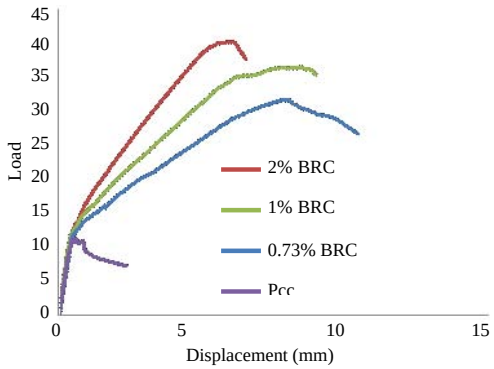

Fig. 9: Comparison of load-displacement curve for different types of test beam

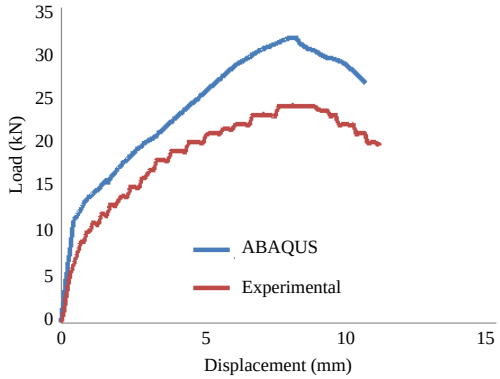

Fig. 10: Comparison between ABAQUS and experimental load-displacement curve for 0.73% bamboo reinforced concrete beam

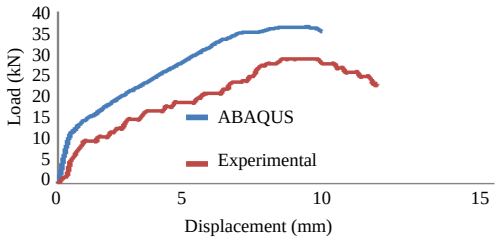

Fig. 11: Comparison between ABAQUS and experimental load-displacement curve for 1% bamboo reinforced concrete beam

The results shows that the ultimate load carrying capacity of the bamboo reinforced beam has been increased upto 4 times with 2% reinforcement compare to plain concrete.

Comparison of the ABAQUS results with the experimental results: The load displacement curve obtained from ABAQUS is compared with the experimental load displacement curve as per (Bhowmik, 2016). Comparison as shown in Fig. 10-11 shows, that the

ABAQUS data has slightly greater value but trend is similar. The difference may be due to assumption in modeling or due to experimental flaws.

CONCLUSION

In the above study an attempt has been made to check the technical feasibility of utilizing Bambusa Balcooa as a reinforcing material in concrete beam. Accordingly, different tests were conducted to evaluate different properties related to bamboo reinforced structure. Based on the results of the numerical model of concrete beam using ABAQUS various conclusions are presented as:

- Bambusa Balcooa possesses good tensile strength as well as ductility. The tensile strength of bamboo is greater than the yield strength of mild steel
- The strength of bamboo reinforced beam increases with the increment of bamboo reinforcement in the range of 0-2%
- Maximum load carrying capacity of 2% bamboo reinforced concrete beam was nearly 4 times than that of plain concrete beam

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