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Experimental Study of Twin Round Bamboo Concrete Infill Parabolic Tied Arch

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Abstract. This paper is concerned about the experimental study of twin round bamboo concrete infill composite parabolic tied arch. Experimental investigation is undertaken to validate the structural load bearing capacity of 'haritha infill arch'. The infill arch is tested under three types of loading condition viz a) crown point loading, b) centre half loading and c) distributed point loading. The experimental results brings out the stiffness of the arch to be 1 kN/mm under crown point loading, 1.67 kN/mm under centre half loading and 1.17 kN/mm under distributed loading. The stresses in the materials are well within their allowable limits. Thus this paper is able to successfully report the structural strength of parabolic tied infill arch which promises to be a structural load bearing element. Since, there is no additional formwork required in casting of the arch, apart from the bamboo which itself acts like the formwork, lesser quantity of steel and very small thickness of concrete being involved, the arch qualifies to be a potential structural element for affordable housing and green constructions.

Introduction

This paper investigates the experimental behavior of bamboo concrete composite infill parabolic tied arch under three types of loading condition. The geometrical design of an arch in the form of a parabola gives an inherent advantage in the form of pure axial thrust under uniformly distributed loading condition. Also, the thrust line passes through the centroid of the cross section, which develops pure axial compression upon the cross section. The only concern is of the horizontal thrust developed, intensity of which is primarily dependent on the geometry of arch. Hence, the arch under present study is provided with a horizontal tie to resist the horizontal thrust.

Bamboo, a wonder grass, having very good mechanical properties in compression (30 -50 MPa; [1] (a), (2005)), tension (150 – 180 MPa; [2]) and bending (130 – 150 MPa; [2]) is now explored as a potential green building material. However, it is difficult to hold bamboo tightly as it is hollow form inside. Also, it has a tendency to split because the orientation of the fibers of bamboo is longitudinal in between the nodes. Thus bamboo, as a structural material like concrete and steel, has some inherent strengths and weakness. Thus developing strong structural load bearing elements by working on the strengths of bamboo and taking care of its weakness with design innovations is a modern engineering challenge.

Various researchers across the world have worked on developing bamboo as a building material in construction. Researchers have studied the composite action between bamboo and concrete. The feasibility of using bamboo in the form of woven mesh as reinforcement for cement mortar has been experimentally investigated. Test results have shown that inclusion of bamboo mesh imparted considerable ductility and toughness to the mortar and increased it's tensile, flexural and impact strengths. However, such improvements, particularly in tension, are associated with wide cracking. Poor bond strength between bamboo and mortar and low elastic modulus of bamboo are the two main factors held responsible [3]. An experimental study performed on flexural behavior of bamboo-fiber reinforced mortar laminates showed that due to its high strength to weight ratio, when reformed bamboo combined with fiber-reinforced mortar, it can remarkably strengthen the mortar and reduce the total weight of the composite [4]. The results of this investigation showed that for the laminates with reformed bamboo plate on the bottom as tension layer and the fiber reinforced mortar sheet on the top as compressive layer, the flexural strength values can be improved to greater than 90 MPa. Bamboo, in replacement to steel in reinforced concrete is test in the form of bamboo concrete composite beams, columns and slab. The results of the investigations showed that bamboo can substitute steel satisfactorily [9]. The structural elements developed and studied could be used in many building constructions. Many investigations are being carried out to establish the durability of bamboo reinforcement, besides improving the bonding of bamboo reinforcing bars.

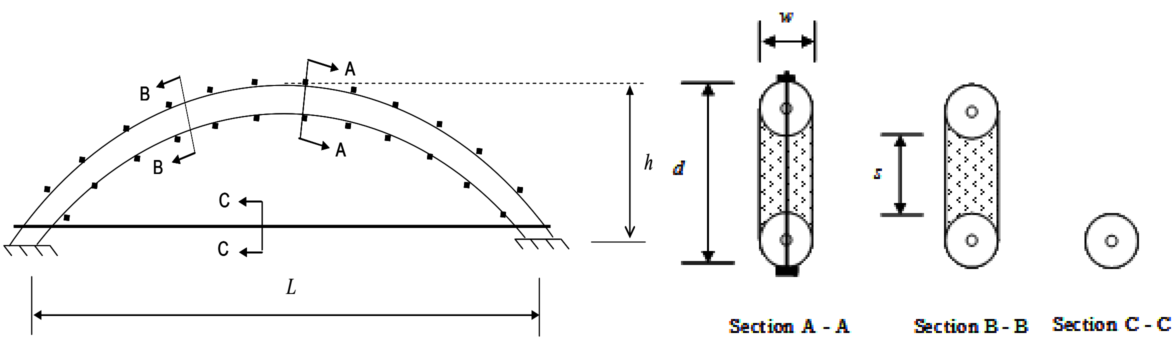
The initial explorations with bamboo in the form of parabolic tied bow arches with cross ties out of X grade school experiments [7], the infinite potential of bamboo is realized and a 18,00 sq m floor area school campus is built with parabolic tied bow arches with cross ties. Further, the potential of composites of bamboo with concrete are explored [7] and a new name is coined as 'Bamcrete technology' [8]. A new innovative concept in the form of concrete infill half split bamboo parabolic tied arch is developed and demonstrated [7]. Further, an experimental investigations are carried out to study the behavior of bamboo concrete composite arch with ferrocement bands & concrete infill [6]. An experimental investigation is undertaken to study the load carrying capacity of concrete infill half split bamboo parabolic tied arch (Chugh, 2009) .

This paper investigates experimentally the load carrying capacity of full bamboo concrete infill parabolic tied arch under three types of loading conditions viz. a) Crown point loading, b) Centre half loading and c) Distributed loading conditions.

Experimental Investigation

General. Figure 1 shows the schematic view of bamboo concrete infill parabolic tied arch. Two bamboos are connected to each other using nuts and bolts. The average diameter of the bamboo used is 30 mm outer and 8 mm inner. They are separated to a required spacing '*s*' of 75 mm and thus the required depth '*d*' of 135 mm is achieved. Since, the species *Dendrocalamus Strictus* is slender with tapering cross section form bottom to top; it is easier to bend it in to a parabolic shape. Here, form the field experience it is noted that, for this species of bamboo, to be bent of a parabolic shape, a rise to span ratio of 0.15 to 0.25 is most suitable range. Hence, the span of the arch '*L*' is 2.84 m and the rise of the arch '*h*' is 0.428 m. The rise to span ratio kept is 0.15

Fabrication. The fabrication of the arch starts form the selection of proper bamboo which is without any defects, culm which is straight or at the most have bent in only one plane, adequately dried and treated. Also, the bond between bamboo and concrete is not effective due to poor adhesion between the two materials (Mansur and Aziz, 1983). Understanding the limitation, a new innovative method of joining two bamboos and integrating it with concrete is proposed which keep the maximum portion of bamboo open, thus providing enough breathing space for the material (Sudhakar, 2006).



(a) Elevation (b) Cross – Sectional Details

Fig.1. Bamboo concrete infill parabolic tied arch details

The arch so fabricated is placed on a plane surface. The beauty of this arch is that it doesn't require any additional form work for casting. Concrete is poured in between the two bamboos, which acts as formwork. The surface is leveled to the depth which is equivalent to the diameter of bamboo. Thus the bamboo concrete infill arch is fabricated to the required dimensions.

Material Test. This infill arch requires mainly two materials ie bamboo and concrete. The bamboo used for this arch is of the species *Dendrocalamus strictus*. This bamboo is around 3-4 years old culm which is adequately dried and treated using a natural leaching process. This bamboo tapers for bottom to top and also the internal diameter varies for 0 at base to 8 – 10 mm at the top. Hence, a pair of samples, with node and without node, each from bottom, middle and top is taken and the average compressive stress determined is 34 MPa. The strength of concrete is determined by testing 3 cubes of 150 x 150 x 150 mm, which when cured for 28 days gives an average compressive strength of 42 MPa.

Setup and Instrumentation. In order to test the *haritha infill arch* the test setup evolved is as shown in the figure 3. Here the deflections are recorded at crown point and at roller support using mechanical dial gauges D1 and D2 respectively. The support condition under the present study is simply supported and roller support as shown in figure 3. The *haritha infill arch* is tested under three conditions of loading, viz. a) Crown point loading, b) Centre half loading and c) Distributed point loading. The schematic diagram of arch under crown point loading is as shown in the fig.3. In order to generate vertical push force on the arch, the hydraulic jack is put on an inverted rigid steel reaction frame.

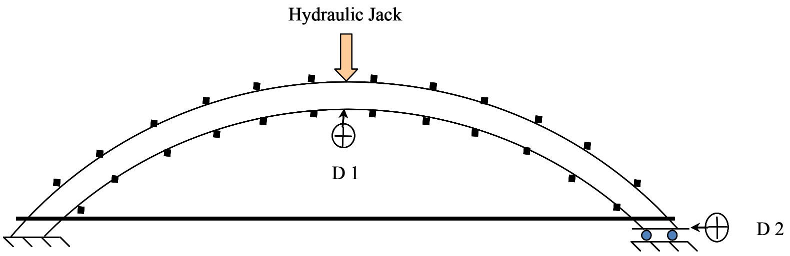
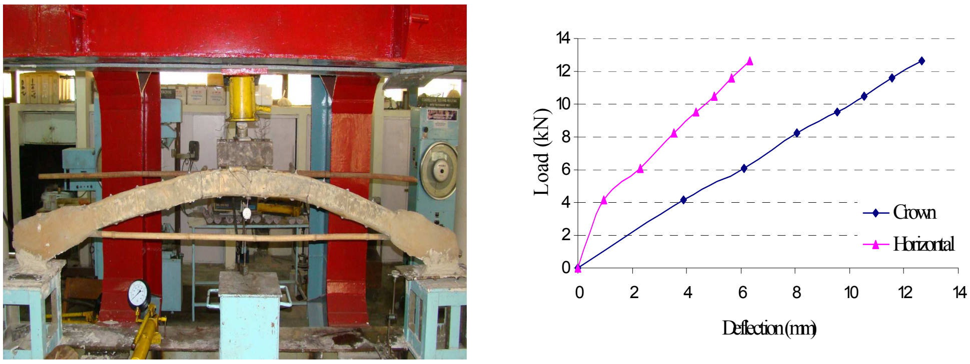


Fig.3. Experimental setup for testing infill arch under crown point loading

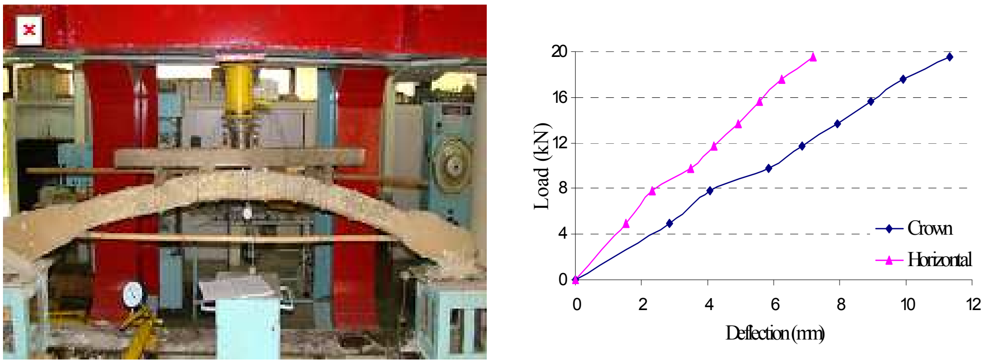
Arch Test. The experimental validation is under taken to study the performance of *haritha infill arch* under a Comprehensive Test Program for experimentally validating the strength of *haritha infill arch*. This paper presents the initial exploratory results of the composite arch. The arch is loaded using the hydraulic jack and the deformations are noted using mechanical dial gauges D1 and D2. The hydraulic jack is calibrated using proving ring against the pressure developed and load delivered. The Load Vs Deformation curve is plotted and the strength of the arch is determined in terms of stiffness of the arch i.e. amount of load carried per unit deformation. The experimental test setup for loading the arch under crown point loading, centre half loading and distributed point loading is as shown in figure 4. The lateral stiffness of the arch is significantly better than bamcrete arch with ferro cement bands [6] as during the testing no lateral supports are required.

Result and Discussion

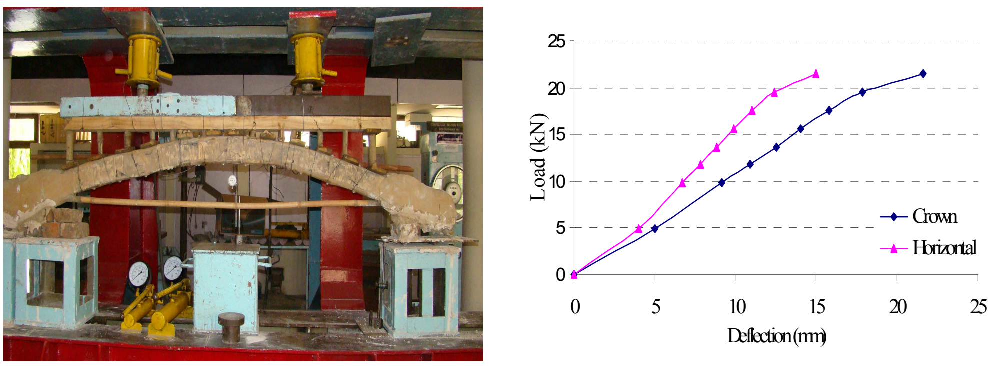
The loading under all the three condition on the infill arch is done to develop a maximum deformation of 12 mm at the crown and correspondingly the deformation at the roller support is measured. This is done as the maximum allowable deformation for a member is given as span / 360 = 8 mm [1, b], when brittle roof covering are used and span / 250 = 12 mm [1, c] which includes all combinations of loads, creep, shrinkage and temperature loading. Hence the behavior upto 12 mm is studied in the present investigation. Here, the load deformation pattern for all the condition is observed to be linear upto 12 mm of loading. The maximum load taken at 12 mm crown deformation in case of a) Crown point load is 12 kN, b) Centre half loading is 20 kN and c) Distributed point loading is 14 kN. During the investigation lateral deformation is observed due to eccentricity in load transfer form the distributed points. Hence, the load carrying capacity of arch under case c is found to be lesser as observed during experimental investigation of bamcrete arch with ferrocement band [6]. Thus the stiffness of the arch is 1 kN/mm under crown point loading, 1.67 kN/mm under centre half loading and 1.17 kN/mm under distributed loading. Also, under distributed loading conditions with load of 14 kN, the stress in concrete is 2.32 N/mm^2 and stress in bamboo is 5 N/mm^2. Also, the tensile stress developed in the tie member of the arch is 9.2 N/mm^2. Thus the stress limits in the material are very well below the allowable compressive stress of 34/3.5 = 9.71 N/mm^2 in bamboo and 42/1.5 = 28 N/mm^2 in concrete. Also, the tensile stress generated is also very low as compared to the material ultimate tensile strength of 150 – 180 MPa [2].



(a) Bamboo concrete composite infill parabolic tied arch: Crown Point Loading



(b) Bamboo concrete composite infill parabolic tied arch: Centre Half Loading



(c) Bamboo concrete composite infill parabolic tied arch: Distributed Point Load

Fig.4. Bamboo concrete composite infill parabolic tied arch under three types of Loading a) Crown Point Loading, b) Centre Half Loading and c) Distributed Point Loading

Conclusion

The experimental investigations of bamcrete parabolic tied 'haritha infill arch' shows that the arch, under above mentioned configurations, is strong enough to carry structural loads. The infill arch qualifies to be used as a main load bearing element for structural applications in housing. Since, there is no additional formwork required in casting of the arch, lesser quantity of steel and very small thickness of concrete involved, the arch holds a good potential as a structural element for affordable housing and green constructions however the novel ways of improving the composite action between round bamboo cement concrete infill should result in better performance.

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