The Viability of Building with Bamboo Reinforced Concrete in Developing Regions

By Greg Morse

Our global population is increasing, more and more people are living in cities, and, as a result, high-density, low regulation ‘slums’ are expanding. Residents of slums often live with unsanitary conditions and structures that are generally unsafe during storms and seismic events. The United Nations Center for Human Settlements has estimated that as of 1993, only 73% of all housing structures in developing regions were permanent structures and only 63% of permanent structures were in compliance with their respective building regulations. [1]

Concrete and masonry are used widely in developing regions because of the abundance of unskilled labour that is typically available. In conventional construction, concrete and masonry structures are reinforced with steel to withstand seismic and storm events. However, steel can be prohibitively expensive or otherwise unavailable in developing regions. Unfortunately, this means many structures are built without adequate reinforcement and fail catastrophically, leading to injury and death. Therefore, identifying alternative methods of reinforcement is crucial for providing safe housing.

Bamboo has a bevy of characteristics that make it a viable, if not preferable, reinforcing material for many developing regions. Reaching optimum strength in just three to four years, it grows abundantly in Asia, Australia, North and South America, and Sub-Saharan Africa. For some species, the ultimate tensile strength is the same as the yield strength of mild steel while the strength to specific weight ratio is six times greater than that of steel. [2] As with steel, bamboo offers resistance to both tension and compression. The energy required to produce one cubic meter per unit stress of bamboo is 50 times lower than the energy required by steel. [3] This means that for two columns supporting the same load, the column made of bamboo requires 50 times less embodied energy than the equivalent steel column.

Bamboo is not without its drawbacks. Like any organic building material, bamboo is subject to biodegradation and variability in dimensions and quality. There are also issues with controlling expansion and contraction due to moisture content. Furthermore, educational systems in developing countries, which are primarily based on programs from industrialized countries, lack formal education and research programs regarding locally available materials such as bamboo. Consumers therefore prefer to use industrialized materials for which reliable technical information is freely available. [2]

Initial experimental studies show that bamboo -- with proper treatment -- has the potential to substitute steel as reinforcement in concrete columns, beams, slabs, and masonry shear walls.

When using bamboo in concrete structures, it is vital to control its expansion and contraction. Bamboo can absorb as much as 300% its dry weight in water and horizontal expansion ranges from 2% to 5%. [1] Bamboo placed in freshly poured concrete tends to absorb water and expand. During the first few days of curing, the concrete does not have the strength to prevent the bamboo from swelling so the expanding bamboo causes the concrete to crack. Once the concrete cures, the bamboo readjusts its moisture content to the environment, drying out and shrinking to its original size. This leaves a gap between the bamboo and the concrete with minimal bonding. Concrete requires a bond

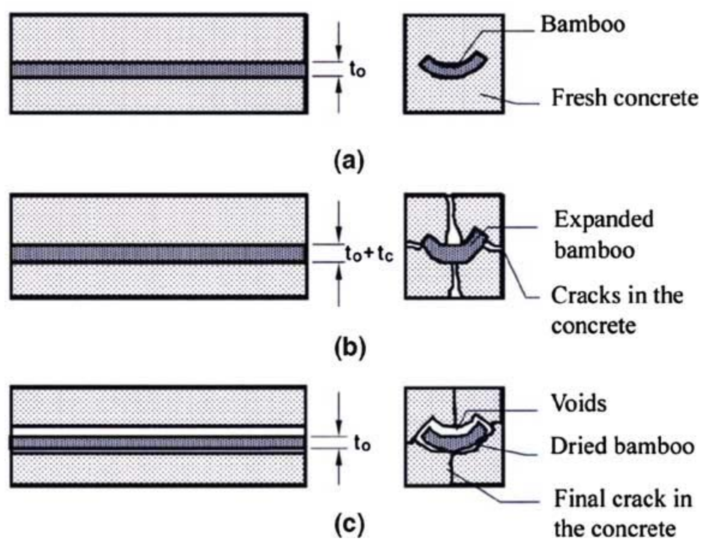

Figure 1

with its reinforcing material to gain any structural benefit from the reinforcing material. If the bamboo's contraction and shrinkage are not controlled, it cannot benefit the structure.

This problem can be overcome by coating or saturating the bamboo with a waterproof material. Materials that have been used successfully include asphalt emulsion, bitumen coatings, Negrolin and metallic wire, sulphur, anti-termite protective coating, and varnish. Two of the most effective treatments are epoxy and fine sand, and a new product Sikadur 32-Gel. [3] Many of these materials may be prohibitively expensive in developing nations but cheaper treatments such as asphalt paints, tar based paints, and other bituminous materials meet the requirements for making bamboo impermeable. [2] Given the wide variety of viable waterproofing treatments, builders in developed regions should be able to acquire the necessary materials to use bamboo as a reinforcing material in concrete.

Steel rebar uses topographical variation (bumps and ridges) to improve its bond with concrete. It is unfeasible to add topographical variation to bamboo; however, studies show that roughing the surface of bamboo before coating it and then applying fine sand to the surface while the coating dries improves its bonding with concrete. [2] Although bamboo contracts and expands significantly, the wide variety of cheap impermeable treatments means builders can use whatever means are available to them to counteract this problem effectively.

After the problem of moisture absorption has been solved, builders still face the problem of knowing how to design safe structures with bamboo reinforcement. Luckily, the fracture behavior of bamboo reinforced concrete beams can be evaluated by the existing formula of steel reinforced concrete beams. [5] This means that, in many cases, designing reinforced concrete structures with bamboo is very similar to designing with steel. Experimental studies have shown that, in tension, bamboo is weakest at its nodes but it has an average tensile strength of 185.93

N/mm^2 or 186.0 MPa compared to 250 MPa for structural ASTM A36 steel. [4] Given this information, we know that you cannot design safe bamboo reinforced structural members using the rules of thumb we use for steel RC members.

In testing performed by Agarwal, Nanda, and Maity, short bamboo reinforced columns exhibited a capacity to absorb energy and ductility. Steel reinforced columns with 0.89% reinforcement were crushed alongside bamboo reinforced columns with 3%, 5%, and 8% reinforcement and plain concrete columns. The 8% reinforced BRC performed most similarly to the steel reinforced columns. [4] Figure 2 shows the axial load-axial deformation curves of the three types of columns. The area under the load-deformation curves for bamboo reinforced concrete is greater than that of the steel reinforced concrete which indicates that the bamboo reinforced columns can absorb energy and are more ductile than steel reinforced columns. Furthermore, the BRCs failed similarly to the SRCs. Both types of columns first showed surface cracking which slowly increased as the pressure grew until the column failed. [4] This is an important safety feature because building inhabitants can see that a column is in the process of failing and can reinforce the structure and/or get to safety. Unreinforced concrete is particularly dangerous because it is brittle and therefore, it fails catastrophically without warning.

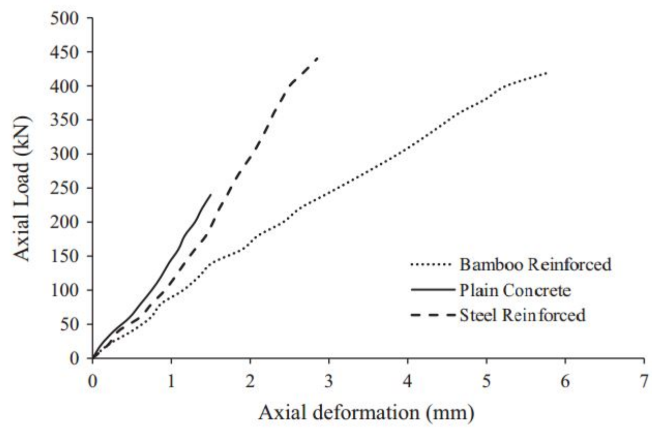

Figure 2

Agarwal, Nanda, and Maity also tested bamboo reinforced concrete beams with two point load tests. Like the columns, 3 beams each were tested with plain concrete, bamboo reinforced concrete (1.49% reinforcement by area), and steel reinforced concrete (0.89% reinforcement by area). [4] Figure 3 shows the load-deflection curves for the beams. The curves show that treated bamboo reinforced beams acted similar to, if not better than, the steel reinforced beams. In fact, the BRC beams had a greater ultimate cracking load and were able to sustain a greater immediate deflection. Another interesting note is that the research team's calculated theoretical ultimate cracking load for the BRC beam, 1404 kg, is very near the experimental result of 1337.6 kg – a 95% accuracy. [4] This suggests that existing methods for calculating ultimate cracking loads can be applied accurately to BRC structural members. Once again, researchers found that the BRC beams failed with a ductile cracking pattern meaning members show signs of failure long before the ultimate failure. These studies, although not definitive, do suggest that bamboo can reasonably be used to reinforce concrete structural members safely.

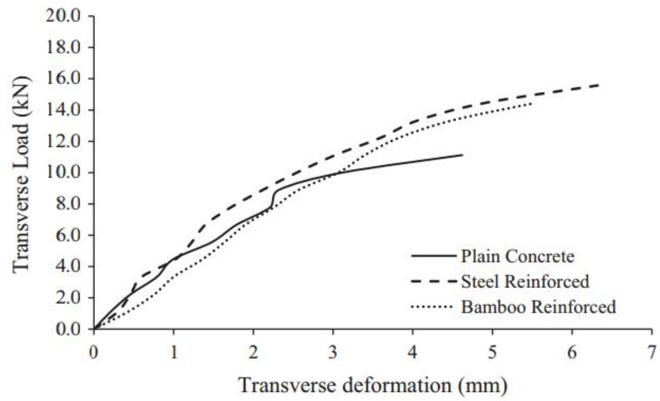

Figure 3

Bamboo can also be used to create concrete slabs with shutter forms. [3] The arrangement, as illustrated in

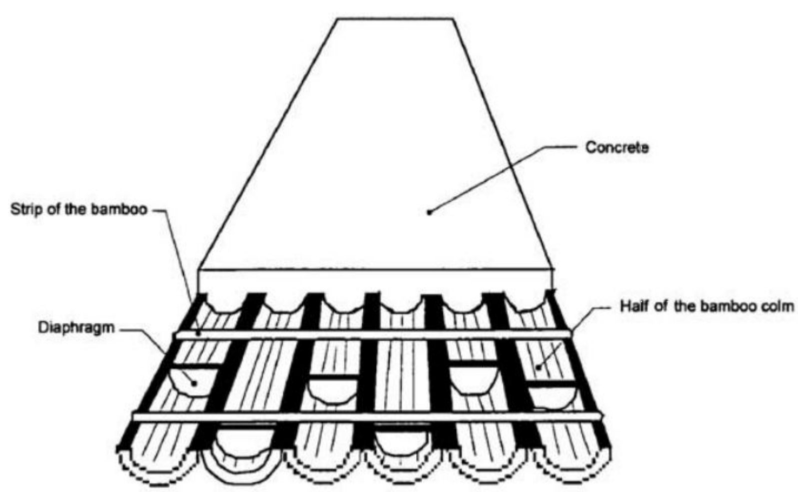

Figure 4

Figure 4, exhibits a composite interaction between the bamboo and concrete. The bamboo culm takes tension forces created by bending and the concrete resists the compressive forces due to bending. Diaphragms located within the bamboo culms ensure the composite interaction between the materials. As with BRC beams and columns, any portions of the bamboo that comes in contact with wet concrete must be treated with an impermeable treatment. In tests, slabs first failed due to de-bonding, followed by failure of the diaphragm, and lastly by concrete compression failure. [3] It is unclear if a failing slab would give any visual indication of failure that would allow occupants to escape to safety or if it would fail catastrophically like brittle, unreinforced concrete. However, this slab assembly is currently being utilized in Brazil but more testing is required before it can be used in broader markets. The use of this technology suggests it may work safely in certain cases, but further research is required to determine design methods and engineering calculations.

Moroz, Lissel, and Hagel tested the performance of bamboo reinforced concrete masonry shear walls and concluded that adding vertical bamboo reinforcement added additional shear capacity while also making the failure more ductile than unreinforced concrete masonry. [1] So given the choice of building a shear wall without any reinforcement or with bamboo reinforcement, it would be a wise decision to add bamboo. They also noted that bamboo reinforced shear walls performed remarkably similar behavior to walls reinforced with steel. [1] As long as the BRC shear wall is built with treated bamboo, one could apply calculations used in designing steel reinforced concrete to bamboo reinforced concrete. As with any bamboo reinforced structural member, further testing and research is required before bamboo can be used in a broad market, but in developing regions, it may be advisable to reinforce concrete masonry shear walls with bamboo if no other reinforcement option is available.

The given evidence may be used to suggest that bamboo reinforced concrete structural members are preferable to unreinforced concrete structural members. For beams, columns, and shear walls, experimental results have shown bamboo reinforced concrete performs comparably to steel reinforced concrete. Bamboo reinforced concrete slabs are currently being used in Brazil, but experimental results, at this point in time, are limited. In all cases, it is vitally important to treat bamboo to make its surface impermeable to water before setting in concrete. Without treatment, bamboo absorbs water, contracts, and shrinks causing cracks in the concrete and a decrease in bond between the two materials. However, this fault can be overcome with a wide variety of treatments, many of which are available in developing regions. Although more research is required before bamboo reinforced concrete becomes a widely accepted structural system, it can be used immediately in developing regions where builders might otherwise use unreinforced concrete.

Works Cited

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