Chapter 21

Structural Performance of Faced Calcutta Bamboo (*Dendrocalamus strictus*) for Use in Joined Structural Assemblies

Jonah Hauptman, Katie MacDonald, Kyle Schumann, Daniel Hindman and Tom Hammett

Abstract

Bamboo has the potential to be a transformative sustainable building material on a global scale but remains underutilized due in part to the natural irregularity of the poles and the subsequent difficulties in predictably harvesting, grading, and applying the material in structural applications. *Dendrocalamus strictus* (Calcutta Bamboo) is a unique species of solid structural bamboo, allowing for applications more akin to a wood product than traditional hollow bamboo. By facing one or more sides of the bamboo and creating a flat surface through stock reduction, opportunities for constructing consistent and reliable joints are created, whether the bamboo is joined to itself or to other more common flat or linear elements. Facing the bamboo poles also creates opportunities for dimensional and geometric consistency as well as the ability to control certain aspects of structural performance through changing the orientation of the faced bamboo. This paper examines the structural performance of faced Calcutta Bamboo through static bending, tensile strength, and hardness. Comparative performance of bamboo that has been faced to varying degrees, from no faces to four faces, is presented, as well as an analysis of the comparative performance of faced and unfaced poles to other traditional and non-traditional forest products.

Keywords: bamboo, bamboo construction, Calcutta bamboo, structural bamboo, bamboo joinery

1. Introduction

Bamboo has well-documented structural and sustainable benefits in comparison to many common structural building materials but remains difficult to utilize reliably in construction due to its irregular form—poles are tapered from bottom to top, have irregular cross-sections, nodes which increase the local diameter, and variable wall thickness along their length—and historical lack of grading standards [1]. These natural inconsistencies result in difficulty design and fabrication of structural joints between poles often requiring laborious hand-worked connection methods [2].

The cross-section of bamboo has increasing fiber density moving from the interior to the perimeter. Because the denser fiber bundles provide greater strength, the perimeter and skin of the pole is stronger than the interior [3]. This is in part due to the fact that when the poles grow, they grow first vertically, and later, their wall sections thicken and grow inward [4]. Given the structural variation across the section, questions remain about the structural integrity of the pole, when it is faced.

Building on previous research, we utilize *Dendrocalamus strictus* (known colloquially as Calcutta Bamboo, Iron Bamboo, or Tam Vong), a unique species of solid bamboo grown in Asia, Indochina, and Latin America. *Dendrocalamus strictus* offers advantages over the relatively thin proportional wall thickness of other bamboo species, producing a flat face through milling impractical due to the compromised structural performance. Current processes for flattening other bamboo species rely on unwrapping or bending the poles, fundamentally changing their structural performance, and possible applications in structural assemblies [5]. Alternatively, selectively facing one or more sides of *Dendrocalamus strictus* to create flat surfaces creates opportunities for constructing consistent and reliable joints in both bamboo to bamboo connections as well as connections between bamboo and other common flat or linear elements in various materials. This chapter examines the benefits of faced *Dendrocalamus strictus* according to quantifiable structural performance and compares the performance of faced *Dendrocalamus strictus* to equivalent structural members fabricated from wood or steel.

We evaluate the structural performance of faced *Dendrocalamus strictus* in several configurations and orientations (top face flat, bottom face flat, both sides flat, top and bottom flat, top and one side flat, etc.) using a series of standard testing methodologies for various loading configurations such as transverse bending (**Table 1**). The results of this testing presented herein demonstrate that processing the bamboo in this way can make the material easier to work with in creating structural assemblies while maintaining much of its inherent structural performance.

The research and testing presented in this chapter provides direction for future application of faced *Dendrocalamus strictus* in joined structural assemblies, demonstrating the species' structural value in comparison to traditional structural

Cross-section geometry	Cross-section terminology
	Unfaced (Omnidirectional)
	Faced 1 side (Down)
	Faced 2 sides (Left & Right)
	Faced 2 sides (Top & Bottom)
	Faced 1 side (Up)
	Faced 3 sides (Left, Right, & Down)
	Faced 4 sides (Omnidirectional)
	Faced 3 sides (Left, Right, & Up)

Table 1.
Cross sections of faced poles.

members in wood and steel. This research paves the way for future testing of the structural performance of joinery enabled by faced bamboo.

2. Methods

Samples for the tests performed in this chapter were taken from a stock of 100 Calcutta Bamboo poles (12 feet in length) grown, harvested, and prepared in Vietnam. These poles were harvested and prepared using the common Vietnamese method, which entails selective cutting of mature poles, straightening by selectively heating and bending over a fire, treatment in a borax bath to insect-proof the pole, and a final air drying typically performed outdoors under intense sunlight.

2.1 Sample preparation

The samples were taken from the bottom and most solid portion of the poles. For the uniform bending tests, three samples were prepared for each condition: unfaced, faced one side (faced side up), faced one side (faced side down), faced two sides (faced sides top and bottom), faced two sides (unfaced sides top and bottom), faced three sides (unfaced side up), faced three sides (unfaced side down), and faced all four sides.

A total of 24 poles were selected from a batch of 100, with preference given to those with the most solid sections at the base of the poles. The selected poles were sorted by largest overall diameter within one-eighth of an inch. The selected poles were then culled for visible defects, charring, and splitting. Next, the poles were marked at the midpoint between two nodes and 10 inches to each side. Finally, the poles were cut into 20-inch-long pieces on an electrically powered circular miter saw using masking tape wrapped around the cut location to minimize tear out. The prepared samples were sorted by greatest overall diameter. The area of each cross section was calculated from scans of crosscuts in a sample set of three for each shape.

2.2 Pre-test documentation

A total of 24 samples were prepared, inventoried, and labeled. Values were recorded for outside diameter at top, inside diameter at top, wall thickness at top, surface area at top, outside diameter at bottom, inside diameter at bottom, wall thickness at bottom, and surface area at bottom.

All samples were documented with a flatbed scanner and a photo scale to document each sample's top and bottom sections. Each of the four elevations was documented with a DSLR camera and a photo scale.

2.3 Testing

Unfaced poles were tested for transverse bending. Poles with one side faced were tested for transverse bending with an upward face, transverse bending with a downward face, axial compression, and axial tension. Poles with two sides faced were tested for transverse bending with one upward face and one downward face, transverse bending, faces with two horizontal faces, axial compression, and axial tension. Poles with three sides faced were tested for transverse bending, with one upward faces and two horizontal faces, transverse bending with one downward face and two horizontal faces, axial compression, and axial tension. Poles, with four sides faced, were tested for transverse bending, axial compression, and axial tension.

3. Results

Tables 2 and **3** catalog the strength equivalent in wood and steel of various faced conditions of *Dendrocalamus strictus* poles. Whole poles were found to offer higher strength than faced poles, which is consistent with the known strength of the bamboo's skin and the density of fibers at the perimeter of its cross section.

Within the range of faced sections tested, variation in strength is significant, leading to a range of structural equivalents in wood and steel for all faced members. In wood, whole poles, poles with one or two side faced, and poles with three sides faced oriented horizontally and downward are equivalent in strength to a wood 2 × 4 No. SPF, while poles with four sides faced or poles with three sides faced oriented upward are equivalent in strength to 2 × 3 No. 2 SPF. In steel, strength equivalents vary for each shape and orientation tested, as cataloged in **Tables 2** and **3**.

Shapes	Orientation	Equivalent strength in wood	Equivalent strength in steel
Whole	*Omnidirectional*	2 × 4 No. 2 SPF	2″ angle, ¼″ wall thickness 1¼″ Standard Pipe 1.25″ × 1.25″ square tube, 8 gauge 2″ channel, 1/8″ wall thickness
Faced 1 side	*Faced side down*	2 × 4 No. 2 SPF	1.5″ angle, 0.187″ wall thickness 1.25″ × 1.25″ square tube, 8 gauge 1.25″ diameter round tube, 3/32″ wall thickness
Faced 2 sides opposite	*Faced left/right*	2 x 4 No. 2 SPF	1.5″ angle, 0.187″ wall thickness 1.25″ × 1.25″ square tube, 9 gauge 1.25″ diameter round tube, 3/32″ wall thickness
Faced 2 sides opposite	*Faced top/bottom*	2 × 4 No. 2 SPF	1.5″ angle, 0.187″ wall thickness 1.25″ × 1.25″ square tube, 9 gauge 1.25″ diameter round tube, 3/32″ wall thickness
Faced 1 side	*Faced side up*	2 × 4 No. 2 SPF	1¼″ Standard Pipe 1.25″ × 1.25″ square tube, 10 gauge 1.25″ diameter round tube, 3/32″ wall thickness
Faced 3 sides	*Faced left/right/down*	2 × 4 No. 2 SPF	1.5″ angle, 0.187″ wall thickness 1.25″ × 1.25″ square tube, 13 gauge 1.25″ round tube, 3/32″ wall thickness
Faced 4 sides	*Omnidirectional*	2 × 3 No. 2 SPF	1.5″ angle, 0.187″ wall thickness 1.25″ × 1.25″ square tube, 13 gauge 1.25″ round tube, 3/32″ wall thickness
Faced 3 sides	*Faced sides up*	2 × 3 No. 2 SPF	1.5″ angle, 0.187″ wall thickness 1.25″ × 1.25″ square tube, 13 gauge 1.25″ round tube, 3/32″ wall thickness

Table 2.
Structural equivalenets of faced poles in wood and steel.

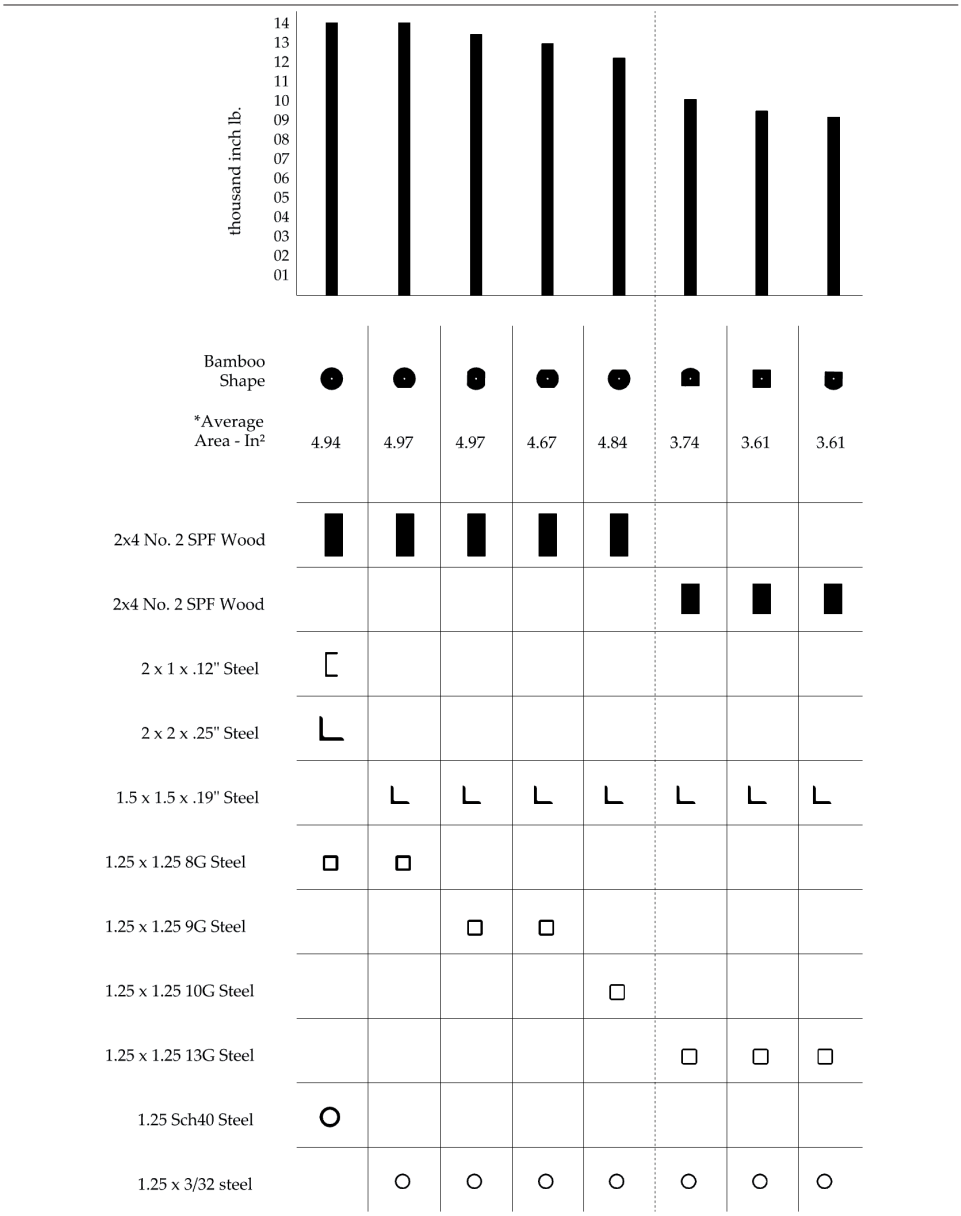


Table 3.
Bending moment comparissons of faced bamboo cross sections.

4. Conclusion

This research suggests comparative advantages of *Dendrocalamus strictus* as a lightweight, structural building material. *Dendrocalamus strictus* poles have a smaller volume and lighter weight than traditional structural members in wood and steel of equivalent strength, meaning that more *Dendrocalamus strictus* can be transported under the same volume and weight vehicle restrictions as wood or steel of equivalent strength. On a construction site, *Dendrocalamus strictus* is also comparatively lighter and leaner to maneuver, saving labor costs, and fostering a safer work environment. In both transport and construction, the relative lightness

and leanness of *Dendrocalamus strictus* requires less energy to move and assemble, resulting in less embodied energy in the material.

The demonstrated lightness and leanness of *Dendrocalamus strictus* also offers advantages for implementation in prefabricated structural systems such as open-web trusses when compared to systems made from other materials. While current open-web truss products are available in wood and steel, the same systems made out of *Dendrocalamus strictus* would likewise be lighter and smaller for transport and construction.

Codifying *Dendrocalamus strictus* structural performance and its resulting advantageous qualities in lightness, leanness, and embodied energy offers opportunities for more widespread implementation of *Dendrocalamus strictus* as a structural building material. *Dendrocalamus strictus*' demonstrated advantages in transport and construction incentivize its use in the construction industry because it offers both sustainable and economic benefits in terms of reducing costs of fuel, energy, and manpower during construction.

5. Future work

This chapter undertakes a study of the effects to the strength of *Dendrocalamus strictus* caused by facing in order to define how faced poles will perform structurally. While facing reduces the strength of the pole, faced poles maintain strength comparable to standard structural members in wood and steel construction. Given these results, the testing will be repeated with a larger sample size as well as include new research to explore potential applications of joinery enabled by facing poles of *Dendrocalamus strictus*. The researchers also will look at other aspects of using faced bamboo poles such as using different species, the transportation logistics, and costs for obtaining bamboo from various sources. We also foresee examining the economics of production, market influences, market-based programs for ensuring sustainability (i.e., certification), and processing efficiencies to further ratify their use in building systems.

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