

A Review of the Flexural Performance of Laminated Bamboo Beams with Bolted Connections

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Abstract

Bolted connections enable the assembly of laminated bamboo members, but local connection behavior can govern the flexural performance of the resulting beam system. This narrative review synthesizes published evidence on laminated bamboo materials, dowel-bearing properties, steel plate connections, and moment-resisting joints. Particular attention is given to the distinction between member bending and connection-controlled response, and between laminated bamboo, bamboo scrimber, and timber. The literature shows that processing and adhesive selection influence material performance, while grain orientation, bolt arrangement, and plate configuration affect local deformation and failure. Studies of moment-resisting joints further indicate that laminate architecture and localized reinforcement can improve resistance and deformation capacity under specific test conditions. These findings cannot be transferred directly across products, joint geometries, and loading protocols. Existing bearing and stiffness models provide useful mechanical descriptions, but their application to beam splices requires assembly-level validation. The review identifies consistent definitions of stiffness and ductility, explicit failure-mode reporting, and verification of timber-based design assumptions as priorities for further development. Reliable design requires coordinated assessment of resistance, serviceability, and failure progression rather than reliance on peak load alone.

Keywords

Laminated bamboo lumber; Bolted connections; Flexural performance; Dowel-bearing strength; Steel side plates

1. Introduction

The demand for renewable construction materials has encouraged research on engineered bamboo as an alternative structural resource. Bamboo products are relevant to regions with established bamboo resources and processing capacity, including China. Research on engineered bamboo describes opportunities for using

these products in structural members and building systems [1, 2]. Their engineering suitability nevertheless depends on product manufacture, material properties, and connection performance rather than renewability alone.

Natural bamboo has geometric and material variability that complicates structural design. Laminated bamboo lumber is manufactured by bonding processed bamboo elements into members with prescribed dimensions. This approach extends the range of feasible structural components and enables comparison with established engineered timber products [1, 2]. Laminated bamboo lumber and bamboo scrimber are distinct products, however, and their mechanical properties should not be treated as interchangeable.

Connections are particularly important when member length or assembly requirements necessitate a beam splice. In a connection with external steel side plates, aligned holes are prepared in the beam ends and steel plates. Bolts pass through the assembly and are secured with washers and nuts. The arrangement offers a relatively straightforward fabrication and assembly process, while the interaction between steel, bolts, and bamboo governs joint response. Local bearing deformation, fastener bending, and bamboo splitting may limit the performance of the assembled beam.

This narrative review examines how connection detailing influences flexural resistance, stiffness, deformation capacity, and failure mode in laminated bamboo beams and bolted moment connections. Existing studies of bamboo moment connections provide direct evidence for this discussion [3]. Evidence from unspliced beams, local bearing specimens, and timber connections is included where it clarifies the response of bamboo joints.

2. Material and Member Behavior

2.1. Processing and Mechanical Properties

The manufacture of laminated bamboo affects both its structural properties and practical feasibility. Mahdavi et al. reviewed processing, performance, and economic considerations, and subsequently examined a low-technology fabrication approach [1, 4]. Correal et al. evaluated the physical and mechanical properties of glued laminated *Guadua angustifolia* [5]. These studies support the development of engineered bamboo as a structural material while emphasizing the need to characterize the particular product used.

Adhesive selection and processing conditions require separate consideration. Sulaiman et al. investigated the shear strength of oil-treated laminated bamboo [6]. Sinha et al. compared the structural performance of glued laminated bamboo beams made with different adhesive systems [7]. The adhesive systems produced different bending strengths, whereas their beam stiffnesses were comparable. Bending strength was limited by interlaminar shear in the constituent laminated bamboo lumber. Adhesive effects therefore should not be generalized across all response

measures. Verma and Chariar examined layered bamboo laminates, while Sharma et al. studied the influence of processing methods and the broader structural potential of engineered bamboo [2, 8, 9].

Mechanical performance also needs to be distinguished from environmental performance. Li et al. assessed the environmental impacts of glued-laminated bamboo through life cycle assessment [10]. The environmental implications of production depend on processing inputs and the assessment boundary. Bamboo's renewable origin alone does not establish that every engineered bamboo product has a lower environmental burden than competing materials.

2.2. Flexural Response of Bamboo Members

Beam-scale behavior introduces considerations that are not captured by small clear specimens. Su et al. tested fifteen simply supported laminated bamboo beams under two-point loading [11]. Observed failures included tensile-side finger-joint rupture, oblique tearing across bonded surfaces, and progressive tensile fiber-bundle failure. These different patterns show that a single label such as ductile bamboo bending can conceal distinct failure mechanisms within the same material category.

The same study found that adopting timber-type deflection limits could make serviceability govern before the full member strength was mobilized [11]. Large deformation at failure therefore does not necessarily indicate acceptable in-service behavior. Finger joints and bonded interfaces also need to be considered when comparing specimen-scale material properties with beam resistance.

For a spliced beam, joint deformation must additionally be distinguished from deformation of the bamboo members themselves. Comparison with an otherwise similar unspliced beam can help identify the contribution of the connection. Unspliced beam tests provide a member-level reference, but they cannot establish the ductility or seismic resistance of a bolted joint.

3. Bearing and Bolted Connection Behavior

3.1. Dowel-Bearing Properties

Dowel-bearing behavior links material characterization to connection design. Sawata and Yasumura investigated methods for determining the embedding strength of timber for dowel-type fasteners [12]. Their work provides a methodological comparison for bamboo testing, but timber-based values cannot be assumed to represent engineered bamboo. Product architecture, grain direction, fastener diameter, and the definition of bearing yield must all be considered when comparing results.

Li et al. investigated bamboo scrimber dowel-bearing strength under loading parallel and perpendicular to the grain [13]. Loading direction affected the observed failure behavior. The distinction matters because a bolt group carrying a moment can develop different local force directions relative to the bamboo grain. Zhang et al.

subsequently examined the dowel-bearing properties of *Neosinocalamus affinis*-based bamboo scrimber across loading directions and dowel diameters [14]. Their study also considered the applicability of existing prediction approaches. For laminated bamboo, Cui et al. examined the influence of specimen geometry and bolt diameter on parallel-to-grain dowel-bearing behavior [15]. A separate study considered laminated bamboo at elevated temperatures [16]. These studies underline the importance of matching material and test conditions before using bearing data in a connection model.

3.2. Steel Plate and Bolt Detailing

Timber connection studies offer useful mechanical comparisons for steel–bamboo assemblies. Chen et al. examined the shear performance of timber connections with external steel side plates, including bolt arrangement and spacing [17]. The distinction between external side plates and slotted-in plates should be retained because the connection geometry and potential failure mechanisms differ.

For laminated bamboo, Zhong et al. studied bearing behavior in bolted connections with external steel side plates [18]. Such studies provide a foundation for examining load transfer between bolts and bamboo. They do not, by themselves, establish the moment resistance of a beam splice with a different bolt group or plate configuration.

Zhang et al. developed an elastic stiffness calculation method for single-bolted steel–bamboo scrimber–steel shear connections [19]. The model is relevant to understanding local connection compliance, but its material and loading configuration differ from those of a laminated bamboo beam splice. Extending a local connection model to a bolt group therefore requires assessment of the adopted assumptions and comparison with assembly-level measurements.

3.3. Moment Resistance and Deformation Capacity

Wang et al. also investigated dowel-type moment-resisting connections in glue-laminated bamboo, including glass fiber-reinforced polymer (GFRP) reinforcement [20]. This work provides a basis for considering deformation capacity alongside resistance. A connection with a higher peak load is not necessarily preferable if its failure remains abrupt. Full load–deflection or moment–rotation curves and observed damage progression therefore provide a stronger basis for comparison than maximum load alone.

Harries and Trujillo discussed opportunities and limitations in designing engineered bamboo structures using timber design standards [21]. Established timber provisions can provide an analytical starting point, but their applicability depends on the engineered bamboo product and governing limit state. Comparisons with design provisions should identify the particular standard, edition, and calculation assumptions.

4. Synthesis of Experimental Evidence

4.1. Distinguishing Resistance from Stiffness

The available findings do not support a single parameter that improves every aspect of connection behavior. Adhesive-related differences in beam strength need not produce corresponding changes in stiffness [7]. Similarly, Chen et al. found that increasing bolt spacing in the tested timber connections increased shear resistance while reducing initial stiffness [17]. Although these were timber shear tests, the result illustrates why resistance and stiffness should be reported separately when interpreting connection detailing.

Initial connection stiffness, member flexural stiffness, and the stiffness of an assembled beam describe different responses. A local bearing or single-bolt test characterizes only part of the deformation mechanism [12, 19]. A moment connection additionally develops rotation through the combined action of its fasteners and surrounding material [3]. Treating these measurements as interchangeable can obscure the source of flexibility and lead to inappropriate comparisons between studies.

Table 1 summarizes selected experimental findings and the limits on their interpretation. The studies span different materials and structural scales, so their reported improvements are not a common performance ranking. Quantitative pooling would require compatible specimen definitions, loading histories, response measures, and reference configurations. The present synthesis therefore retains each finding within its original experimental context.

Table 1. Selected experimental evidence relevant to bolted laminated bamboo beams

Study and test scope	Principal finding	Interpretation limit
Sinha et al. [7] Laminated bamboo beams; two adhesives	Bending strength differed; stiffness was comparable. Interlaminar shear limited strength.	Adhesive effects differ by response measure; unspliced beams.
Su et al. [11] 15 simply supported bamboo beams	Three failure patterns; adopted deflection limits could govern usable resistance.	Member bending evidence, not bolted-joint ductility.
Li et al. [13] Bamboo scrimber bearing tests	Loading direction affected failure; bearing strength depended on bolt diameter.	Scrimber is not laminated bamboo; local bearing only.
Chen et al. [17] 51 timber side-plate specimens	Larger spacing raised shear resistance but lowered initial stiffness; layout affected ductility.	Timber push-out tests; no direct bamboo flexural design value.
Zhong et al. [18] Laminated bamboo plate connections	Initial stiffness and yield load increased with bolt diameter in the tested series.	Joint yield load is not a material yield strength.
Wang et al. [3] Bamboo moment connections	Multidirectional laminate comparison: 2.5-fold ultimate capacity; ductility ratio 1.5 to 1.9.	Configuration-dependent comparison; not a universal splice factor.
Wang et al. [20] 24 inserted-plate bamboo joints	Double-sided GFRP: mean moment 2.56 to 3.51 kN·m; single-sided gains not significant.	One reinforced outlier excluded; monotonic loading and fixed geometry.

Cui et al. [16] Laminated bamboo bearing at 20–250 °C	Bearing strength declined overall with elevated temperature.	Local material response does not establish whole-joint fire resistance.
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4.2. Failure Mode and Deformation Capacity

Increasing resistance does not necessarily prevent brittle failure. Local bearing tests and moment-connection tests address different stages of the load-transfer process [13, 14, 20]. Bearing deformation may contribute to connection compliance, while splitting or damage around a fastener group can limit the deformation available to the assembly. Failure descriptions should consequently identify the damaged component and its role in the measured response, rather than classify a specimen solely by its peak load.

Laminate architecture provides one route to changing connection behavior. Wang et al. examined bamboo–steel–bamboo and steel–bamboo–steel arrangements using unidirectional and multidirectional laminates under monotonic and cyclic loading [3]. The reported comparison showed a 2.5-fold increase in ultimate capacity for multidirectional laminates, with the ductility ratio increasing from 1.5 to 1.9. These values describe the tested configurations and should not be assigned automatically to all external-side-plate splices. Reinforcement provides another route. Wang et al. tested twenty-four bamboo–steel–bamboo joints with an inserted steel plate and compared different GFRP reinforcement arrangements [20]. Double-sided reinforcement increased the reported mean ultimate moment from 2.56 to 3.51 kN·m, approximately 37%, after one reinforced-group outlier was excluded. The corresponding single-sided reinforcement comparisons did not establish statistically significant strength gains. These findings concern inserted-plate joints under monotonic loading, not external-side-plate beam splices. Neither approach establishes a universal ductility value for all laminated bamboo connections.

The direction of the local fastener force also matters. Dowel-bearing investigations show that loading direction and material architecture affect bearing response [13, 14]. A connection carrying a moment cannot be represented simply by assigning a parallel-to-grain bearing value to every fastener without examining its force direction. This is especially relevant when extending local material models to multi-bolt assemblies.

4.3. Implications for Beam Splices and Design Models

Unspliced beam tests establish member-level bending behavior, whereas joint tests characterize localized force transfer and rotation [11, 20]. Both are relevant to a spliced beam, but neither alone describes the complete system. A useful interpretation links material deformation, fastener response, and joint rotation to the overall beam deflection and observed failure sequence. This distinction also prevents joint-level improvements from being presented as equal improvements in whole-beam performance.

The elastic stiffness model for single-bolted steel–bamboo scrimber–steel connections provides an example of a component-level analytical approach [19]. Its application to laminated bamboo or a bolt group introduces additional assumptions about the material, force distribution, and interaction between fasteners. Those assumptions require validation rather than substitution of material names. The same caution applies to established timber design provisions, whose opportunities and limitations for engineered bamboo have been examined explicitly [21].

5. Research Needs and Scope Limits

5.1. Comparable Experiments and Model Validation

Comparable reporting remains necessary to reconcile published findings. Material layup and moisture condition, member dimensions, bolt arrangement, plate configuration, and loading protocol determine the context of each result. Yield definitions and the displacement or rotation used to calculate ductility also affect comparisons. Complete response curves and failure observations are particularly useful because strength, stiffness, and serviceability can change differently [7, 11, 17].

Model validation should address these distinctions. Single-bolt scrimber models do not directly establish the response of laminated bamboo bolt groups [19]. Similarly, peak-load agreement alone cannot verify a model intended to predict stiffness evolution or damage progression. Assessment against assembly-level measurements is needed before extending a model to different plate geometries, bolt layouts, or reinforcement arrangements. The reviewed evidence does not establish a universally applicable optimum bolt spacing or plate thickness.

5.2. Environmental Conditions and Review Coverage

Environmental effects require attention beyond room-temperature resistance. Cui et al. provide elevated-temperature bearing data for laminated bamboo [16], but local bearing results alone cannot establish the fire resistance of a complete joint. Structural evaluation must also account for connection geometry and loading conditions.

This is a focused narrative review of selected studies rather than an exhaustive systematic review or a quantitative meta-analysis. The evidence includes adjacent materials and unspliced members, which are identified as comparisons rather than direct tests of bolted bamboo beams. Conclusions consequently remain tied to the tested products and configurations. Future synthesis would benefit from comparable experimental datasets that connect local bearing, joint rotation, and whole-beam serviceability.

6. Conclusions

The flexural performance of laminated bamboo beams with bolted connections must

be interpreted across material, connection, and member scales. Published studies show that processing, adhesive selection, grain orientation, and connection detailing influence different aspects of the response. Improvements in strength do not necessarily imply proportional increases in stiffness or deformation capacity.

Moment-connection experiments demonstrate the potential of laminate architecture and localized reinforcement to improve performance within specific configurations. Bearing tests and component stiffness models help explain local behavior, but their extension to multi-bolt beam splices requires validation. Timber and bamboo scrimber results remain useful comparisons rather than interchangeable design evidence for laminated bamboo.

Further progress depends on consistent response definitions, explicit failure-mode reporting, and coordinated assessment of resistance and serviceability. Design models should identify their material and configuration limits and be checked against the evolution of structural response. These priorities provide a basis for comparing published findings and developing more reliable bolted laminated bamboo beam systems.

Conflicts of Interest

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References

- [1] Mahdavi, M., Clouston, P.L. and Arwade, S.R. (2011) Development of Laminated Bamboo Lumber: Review of Processing, Performance, and Economical Considerations. *Journal of Materials in Civil Engineering*, 23(7), 1036–1042. [https://doi.org/10.1061/\(ASCE\)MT.1943-5533.0000253](https://doi.org/10.1061/(ASCE)MT.1943-5533.0000253)
- [2] Sharma, B., Gatóo, A., Bock, M. and Ramage, M. (2015) Engineered Bamboo for Structural Applications. *Construction and Building Materials*, 81, 66–73. <https://doi.org/10.1016/j.conbuildmat.2015.01.077>
- [3] Wang, R., Pan, H.Y., Li, Z. and Xiao, Y. (2023) Mechanical Behavior of Glued Laminated Bamboo Moment-Resisting Connections. *Journal of Structural Engineering*, 149(1), 04022220. <https://doi.org/10.1061/JSENDH.STENG-11623>
- [4] Mahdavi, M., Clouston, P.L. and Arwade, S.R. (2012) A Low-Technology Approach toward Fabrication of Laminated Bamboo Lumber. *Construction and Building Materials*, 29, 257–262. <https://doi.org/10.1016/j.conbuildmat.2011.10.046>
- [5] Correal, J.F., Echeverry, J.S., Ramírez, F. and Yamín, L.E. (2014) Experimental Evaluation

- of Physical and Mechanical Properties of Glued Laminated *Guadua angustifolia* Kunth. *Construction and Building Materials*, 73, 105–112. <https://doi.org/10.1016/j.conbuildmat.2014.09.056>
- [6] Sulaiman, O., Hashim, R., Wahab, R., Ismail, Z.A., Samsi, H.W. and Mohamed, A. (2006) Evaluation of Shear Strength of Oil Treated Laminated Bamboo. *Bioresource Technology*, 97(18), 2466–2469. <https://doi.org/10.1016/j.biortech.2005.10.026>
 - [7] Sinha, A., Way, D. and Mlasko, S. (2014) Structural Performance of Glued Laminated Bamboo Beams. *Journal of Structural Engineering*, 140(1), 04013021. [https://doi.org/10.1061/\(ASCE\)ST.1943-541X.0000807](https://doi.org/10.1061/(ASCE)ST.1943-541X.0000807)
 - [8] Verma, C.S. and Chariar, V.M. (2012) Development of Layered Laminate Bamboo Composite and Their Mechanical Properties. *Composites Part B: Engineering*, 43(3), 1063–1069. <https://doi.org/10.1016/j.compositesb.2011.11.065>
 - [9] Sharma, B., Gatóo, A. and Ramage, M.H. (2015) Effect of Processing Methods on the Mechanical Properties of Engineered Bamboo. *Construction and Building Materials*, 83, 95–101. <https://doi.org/10.1016/j.conbuildmat.2015.02.048>
 - [10] Li, J., Yuan, Y. and Guan, X. (2016) Assessing the Environmental Impacts of Glued-Laminated Bamboo Based on a Life Cycle Assessment. *BioResources*, 11(1), 1941–1950.
 - [11] Su, Y., Zong, S., Xu, D., Huang, D. and Zhou, A. (2016) Experimental Study on Flexural Properties of Glued Laminated Bamboo Simply Supported Beams. *Journal of Architecture and Civil Engineering*, 33(1), 54–60. (In Chinese)
 - [12] Sawata, K. and Yasumura, M. (2002) Determination of Embedding Strength of Wood for Dowel-Type Fasteners. *Journal of Wood Science*, 48(2), 138–146. <https://doi.org/10.1007/BF00767291>
 - [13] Li, X., Zhong, Y. and Ren, H. (2013) Dowel-Bearing Strength of Recombinant Bamboo in Modern Bamboo Structure. *Scientia Silvae Sinicae*, 49(3), 122–128. (In Chinese) <https://doi.org/10.11707/j.1001-7488.20130317>
 - [14] Zhang, M., Fan, H., Li, W., Wu, H., Yu, Z., Zhao, S., Zhou, Q., Chen, S., Behnejad, A. and Parke, G. (2024) Experimental Investigation on the Dowel-Bearing Properties of *Neosinocalamus affinis*-Based Bamboo Scrimber. *Engineering Structures*, 304, 117618. <https://doi.org/10.1016/j.engstruct.2024.117618>
 - [15] Cui, Z., Tu, L., Xu, M., Chen, Z. and Wang, C. (2020) The Evaluation of Dowel-Bearing Properties of Laminated Bamboo Parallel to Grain. *Structures*, 25, 956–964. <https://doi.org/10.1016/j.istruc.2020.04.004>
 - [16] Cui, Z., Xu, M., Tu, L., Chen, Z. and Hui, B. (2020) Determination of Dowel-Bearing Strength of Laminated Bamboo at Elevated Temperatures. *Journal of Building Engineering*, 30, 101258. <https://doi.org/10.1016/j.job.2020.101258>
 - [17] Chen, A., Peng, R., He, G. and Wang, J. (2018) Shear Behavior of Bolted Connections with Steel Plate in Assembled Timber Structures. *China Journal of Highway and Transport*, 31(12), 59–70. (In Chinese)
 - [18] Zhong, Y., Ren, H., Zhang, J., Li, X. and Xu, W. (2013) Compression Performance of Bolted-Connection with Metal Plates for Laminated Bamboo Board. *Journal of Building Materials*, 16(4), 642–648. (In Chinese)
 - [19] Zhang, M., Fan, H., Li, W., Wu, H., Yu, Z., Zhao, S., Zhou, Q., Liu, C., Li, Y., Luo, H., Behnejad, A. and Parke, G. (2024) Study on the Elastic Stiffness Calculation Method of Single-Bolted Steel-Bamboo Scrimber-Steel Shear Connections. *Engineering Structures*, 301, 117331. <https://doi.org/10.1016/j.engstruct.2023.117331>
 - [20] Wang, T.-H., Chung, Y.-L., Wang, S.-Y. and Chang, W.-S. (2021) Glue-Laminated Bamboo for Dowel-Type Moment-Resisting Connections. *Composite Structures*, 267, 113848. <https://doi.org/10.1016/j.compstruct.2021.113848>
 - [21] Harries, K.A. and Trujillo, D. (2025) Opportunities and Limitations for the Design of Engineered Bamboo Structures Using Design Standards for Wood. *Journal of Building Engineering*, 114, 114125. <https://doi.org/10.1016/j.job.2025.114125>