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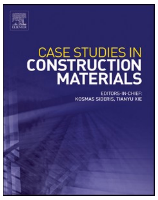

Case study

Bamboo pedestrian bridge: An ecological alternative for the tropical country regions

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ABSTRACT

This article explores the design and optimization of a bamboo pedestrian bridge as an ecological solution for tropical regions, measuring 18.60 m long and 3.10 m wide, featuring bamboo trusses and a deck made of Eucalyptus grandis wood. The study focuses on Dendrocalamus asper (Da) and Dendrocalamus giganteus (Dg), two bamboo species with exceptional mechanical properties. Their longitudinal modulus of elasticity, averaging 20,000 MPa, is nearly double that of glued laminated timber (11,600 MPa for GL24h). The structural lightness of bamboo is also noteworthy, with values of 0.00042 [1/m] for Da and 0.00051 [1/m] for Dg, making them three times lighter than concrete. This reduces loads on supporting elements and foundations, offering material savings and lower construction costs while maintaining structural integrity. A key aspect of this study is the direct comparison of the mechanical properties and structural behavior of both bamboo species. The curved configuration of the lower truss members ensures that two-thirds of these elements are compressed, utilizing bamboo's high compressive strength, comparable to 28-day-old high-strength concrete. The remaining one-third experiences tensile stress, benefiting from bamboo's superior tensile resistance, where concrete falls short. Finally, the global deflection is 8.80 mm for Da and 8.60 mm for Dg, both well below allowable limits, confirming the design's structural efficiency and viability. This research highlights bamboo as a sustainable, ecological, and cost-effective alternative for transport infrastructure.

1. Introduction

The use of bamboo in construction is rapidly growing worldwide, supported by its ecological properties and the increasing demand for sustainable materials. In 2022, the bamboo industry accounted for approximately 68 % of the market in the Asia-Pacific region, with major producing countries such as China and India leading the way. For example, around 30 % of the bamboo produced in China is destined for the construction industry, highlighting the importance of this material in sustainable construction practices [1]. The global demand for bamboo construction materials is expected to grow by 5 % per year until 2032, driven by its ecological reputation and potential as an alternative to traditional materials such as wood and steel [2]. In Indonesia, the bamboo market size is projected to

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reach USD 2.8 billion by 2028, with an annual growth rate of 6.2 %. This growth is fueled by bamboo's high compressive strength, light weight, and ability to reduce carbon emissions.

In the DIANA region of Madagascar, particularly in Antsiranana, the population is rapidly growing at an annual rate of 3.43 % [3]. This demographic pressure puts considerable strain on the existing infrastructure, especially around schools and the Antsiranana gymnasium, where significant volumes of pedestrian traffic, combined with road congestion on National Route 6 (RN6), create dangerous conditions. During peak hours, crossing RN6 becomes a real challenge, especially for vulnerable pedestrians. To address this, the construction of a bamboo pedestrian bridge represents an innovative and sustainable solution. Bamboo, abundant in Madagascar, is an ideal material due to its rapid growth, exceptional regenerative capabilities, and impressive mechanical properties.

The Millennium Bridge in Bali, Indonesia, demonstrated the robust potential of bamboo for large-scale structural applications. The design of the 23 m span bridge, with a unique roof inspired by Minangkabau architecture, illustrates bamboo's ability to support large constructions while offering esthetic appeal. This project has greatly contributed to the global recognition of bamboo as a viable construction material. Similarly, the Jenny Garzón Bridge, in Bogotá, Colombia, is a key example of bamboo use in transport infrastructure. This 45 m span bridge, primarily constructed from guadua bamboo, demonstrated the feasibility of incorporating bamboo into functional and durable structures. These two projects have strongly influenced the design of the proposed bamboo pedestrian bridge in Antsiranana, providing essential insights into the strength, durability, and esthetic potential of bamboo.

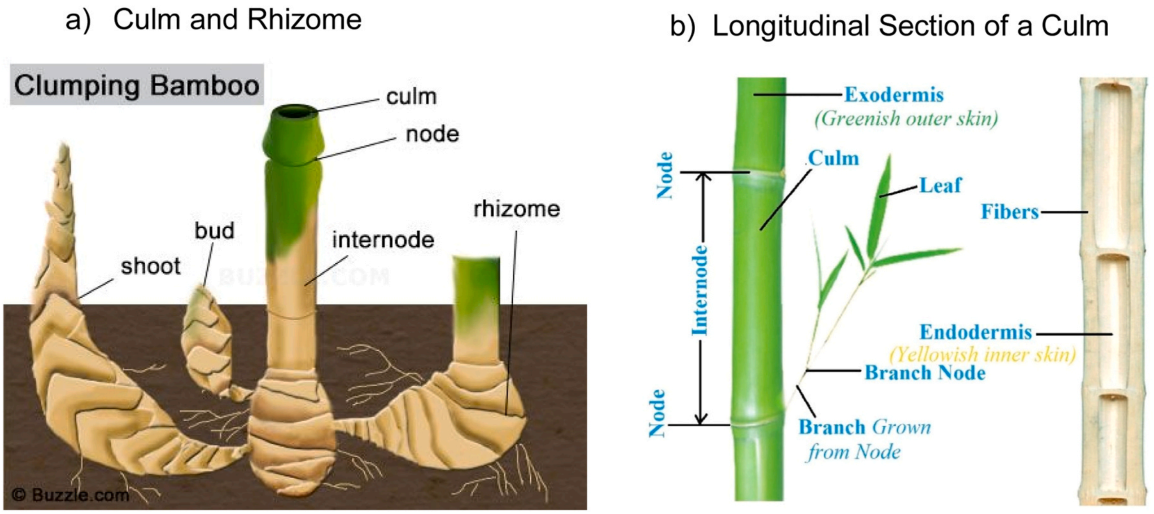
Several studies have highlighted the viability of bamboo in structural applications. Janssen [4] examined the high mechanical strength and flexibility of bamboo, comparing it to traditional construction materials. Ghavami, Marinho [5] analyzed the mechanical behavior of bamboo, confirming its impressive strength and durability in structural applications. Amada, Untao [6] demonstrated the feasibility of large-scale bamboo structures, highlighting its efficiency in tropical climates. Steiger et al., [7] explored laminated bamboo beams, finding that these materials offer mechanical performance comparable to conventional construction woods while being lighter. Correal, Ramirez [8] examined round bamboo joints, supporting the potential of the material for use in complex structural designs. Sharma, van der Lugt [9] focused on the environmental benefits of bamboo, including its ability to reduce the carbon footprint of construction projects. [4] and [10] both affirmed that bamboo can serve as a sustainable and economical alternative to traditional construction materials, especially for infrastructure projects such as transport bridges.

These studies confirm the potential of bamboo as a locally abundant and sustainable material capable of meeting growing infrastructure needs while preserving natural resources. The design of the proposed bamboo pedestrian bridge for tropical countries will begin by establishing the general characteristics and physico-mechanical properties of the local bamboo. The next phase will involve determining the key parameters for sizing the structural elements. Finally, the results will be analyzed, and recommendations will be made to ensure both pedestrian safety and the long-term durability of the infrastructure.

This study aligns with an ecological and economic vision, aiming to demonstrate that bamboo can become a pillar of sustainable development in the infrastructure sector. By harnessing this abundant and environmentally friendly material, the project will not only contribute to the region's infrastructure needs but also to the broader goal of promoting sustainable construction practices worldwide.

2. Material and methods

The objective of this article is to design and size a bamboo pedestrian bridge, taking into account the geometric configuration, implementation sites, and various applicable loads according to current standards. To achieve this objective, we start by determining the physico-mechanical properties of bamboo (Dendrocalamus asper and Dendrocalamus giganteus). We then proceed with the design



a) Culm and Rhizome

b) Longitudinal Section of a Culm

Fig. 1. Characteristcs (a, b) of bamboo.
Source: Buzzle.com

and simulation of the bridge using the structural analysis software [11], followed by verification and discussion of the obtained results.

2.1. General information on bamboo

Fig. 1 illustrates the structure and physiology of bamboo, particularly in relation to its applications in construction and materials engineering.

Madagascar is known for its extensive bamboo diversity, with 11 genera and nearly 40 species, of which 35 are endemic [12]. These species generally reach maturity at around three years of age [13], making them particularly interesting for technological and ecological studies.

Bamboo is a non-timber forest product, widely distributed in tropical regions, including Madagascar, where it plays a crucial role in ecological, economic, and social functions [14]. Surveys conducted in the Atsinanana and Analanjirofo regions have revealed the presence of six bamboo species: *Valiha diffusa*, *Dendrocalamus giganteus*, *Bambusa vulgaris constrictinoda*, *Bambusa vulgaris striata*, *Dendrocalamus asper*, and *Cephalostachyum madagascariensis* [15-18].

These two regions of Madagascar were chosen for the study due to their floristic diversity and the presence of these specific bamboo species, which have a variety of potential uses. According to Tahiana Ramananantoandro and collaborators, the uses of different bamboo species vary:

- *Valiha diffusa*: Furniture, fencing, walls, roofing, poultry nesting, agricultural product baskets, human transport rafts, Malagasy art.
- *Bambusa vulgaris Constrictinoda*: Furniture, fencing, walls, roofing, poultry nesting, small animal cages, cooking fuel, outdoor landscaping, Malagasy art.
- *Bambusa vulgaris striata*: Fencing, cooking fuel.
- *Cephalostachyum madagascariensis*: Walls, fused bamboo flooring.
- *Dendrocalamus giganteus*: Fencing, pillars, flooring, aquaculture drainage, animal feed and watering troughs, nurseries, fused bamboo flooring, stairs, bridges, rafts, outdoor landscaping.
- *Dendrocalamus asper*: Pillars, flooring, fused bamboo flooring, stairs, and bridges.

The two species, *Dendrocalamus giganteus* and *Dendrocalamus asper*, were selected for this study due to their excellent mechanical and technological qualities. They are distinguished by their robustness, adaptability to various structural uses, and potential to replace wood in several applications [19,20]. Additionally, these species are already well-integrated into local practices, which facilitates their acceptance and use in sustainable construction projects [21-23].

3. Mechanical and physical properties of bamboo

To find the physical and mechanical characteristics of the two main species studied, namely *Dendrocalamus giganteus* (Dg) and *Dendrocalamus asper* (Da), several publications were reviewed. Table 1 provides the key characteristics of these two types of bamboo.

To ensure maximum safety, the lower values will be considered in the calculations.

3.1. Structural system and geometry

The bridge, with a span of 18.60 m and a width of 3.10 m, is supported by bamboo trusses. The bridge is elevated and spans over National Road 6 at a height of 5.50 m beneath the trusses. The reinforced concrete stairs, as well as the columns and foundations, will be excluded from the study. The bridge under study consists of four main elements: the trusses under the deck (upper chord, lower chord, diagonals, and verticals), the guardrails (upper chord, diagonal, and verticals), the bracing, and the decking, which is 6 × 16 cm in section and spans 3.10 m transversely across the deck. Figs. 2, 3, 4, and 5 describe the geometric configuration and shapes of our study structure.

Table 1
physical and mechanical properties of bamboo.

Properties	Dendrocalamus giganteus	Dendrocalamus asper	References
Bending stress (MPa)	117.9–120.1	124.4–178.0	[16,24]
Tensile axial stress (MPa)	100–160	90–150	(Sattar, M. A., et al., 1994).
Perpendicular tensile stress (MPa)	2–3	2–3	(Yu, W., and Lu, Z., 2004)
Axial compressive stress (MPa)	40–50	50–60	(Sattar, M. A., et al., 1994)
Perpendicular compressive stress (MPa)	4–5	4–5	(Janssen, J.J.A., 1991).
Shear stress (MPa)	10–15	8–12	(Sharma, B., et al., 2015).
Mean axial modulus (GPa)	11.17	13.72	[24]
5th Percentile Mean Axial Modulus (GPa)	8–12	6–10	(Janssen, J.J.A., 1991)
Mean Transverse Modulus (GPa)	1–2	1–1.5	(Nugroho, N., and Ramdan, T., 2001)
Shear modulus (GPa)	0.5–1	0.5–1	(Nugroho, N., and Ramdan, T., 2001).
Characteristic density (g/cm3)	0.68	0.76	[24]
Mean density (g/cm3)	0.68	0.70 – 0.76	[16,24]
Poisson’s rate	0.278	0.278	Razlan1 et al., [25]

3.2. Truss connections

To better analyze the connections of the structure, the type of joint are presented in Fig. 7.

To ensure the assembly of the bamboo pedestrian bridge, we will opt for the following different connections:

Lateral and central trusses (Upper Chord, Lower Chord, Diagonals, and Verticals)

- Bolted Connections with Steel Gusset Plates: The joints between the bamboo elements of the truss are made using galvanized steel gusset plates. The plates are attached to the bamboo elements through pre-drilled holes and bolts with washers to prevent the crushing of bamboo fibers. The bolts are made of high-strength stainless steel to limit corrosion. Epoxy resin is applied inside the bolt holes to strengthen the connection and reduce local stress concentrations.

  Deck (Eucalyptus grandis Deck Fixed to Bamboo Trusses)
- Bolted Steel Clamps or U-Straps: The decking boards (6 × 16 cm section) are fixed to the upper chords of the central truss and the intermediate chords of the side bamboo trusses using galvanized steel U-straps or clamps wrapping around the bamboo beams.

  Structural bracing (Under the Deck to Stabilize the Trusses)
- Bamboo-Bamboo Cross Connections: The bracing elements are fixed using a combination of bolted steel connectors and tension cables to prevent lateral instability. Steel bands are wrapped around the joints and bolted to the bamboo to improve connection strength. The ends of the bamboo bracing elements are notched for a tight fit at the connection points, increasing stability.

3.3. Advance design software

The following Fig. 8 presents the numerical modeling of the bamboo pedestrian bridge, performed using the Advance Design software, highlighting its geometric configuration, structural elements, and the adopted design principles.

Advance Design is a structural analysis software widely used in civil engineering for the analysis and design of structures. Its main functions and advantages include structural analysis, design and verification of structures, 3D modeling, simulation and optimization, as well as the generation of reports and documentation. The modeling process includes the selection of element types, boundary condition settings, load application, as well as the analysis and verification of the results obtained.

Selection of Element Types

- The bamboo trusses are modeled such that axial forces (tension or compression) develop on each member composing the trusses elements.
- The decking is modeled as a continuous shell element, ensuring accurate simulation of load distribution.
- The bracing system is modeled to reflect their behavior under compression and tension loads.
- Connections between bamboo elements are simulated using pinned joints.

Boundary Condition Settings

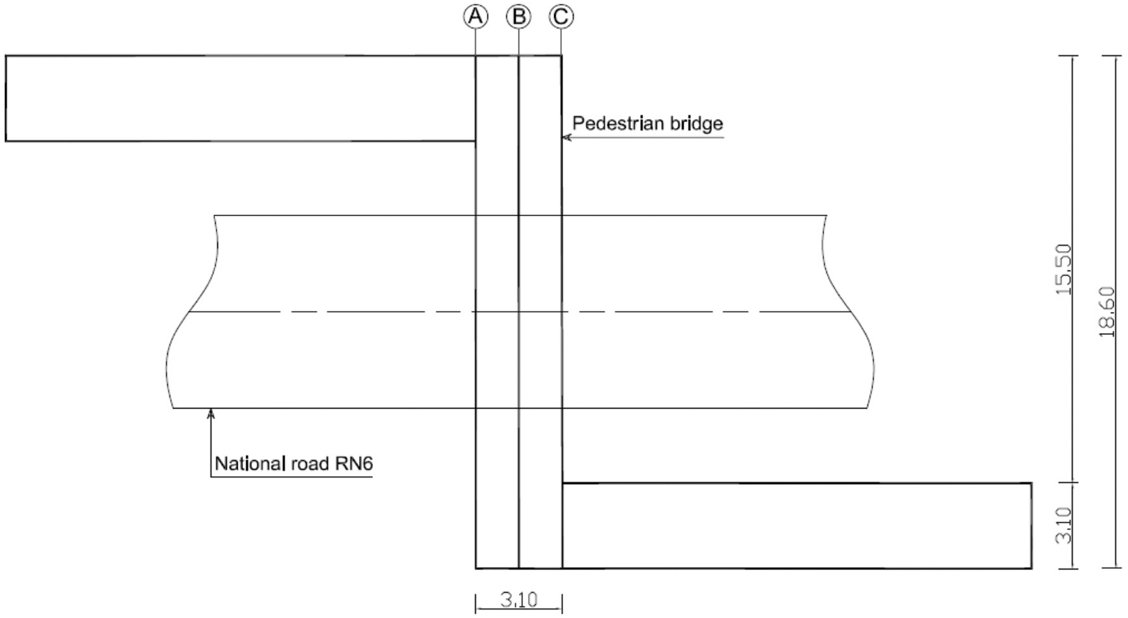


Fig. 2. Plan view of the pedestrian bridge.

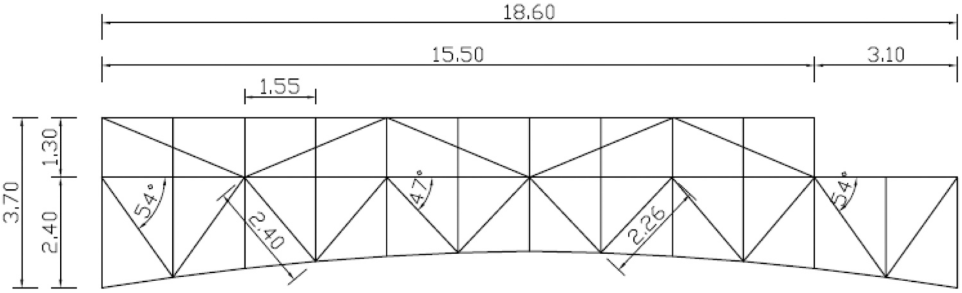


Fig. 3. Lateral trusses.

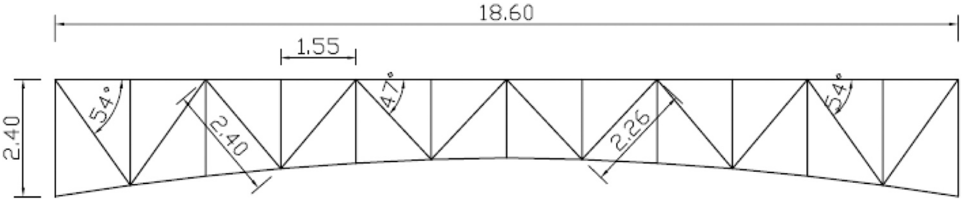


Fig. 4. intermediate truss.

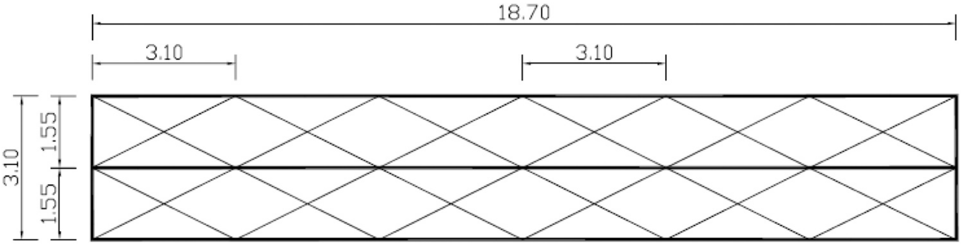
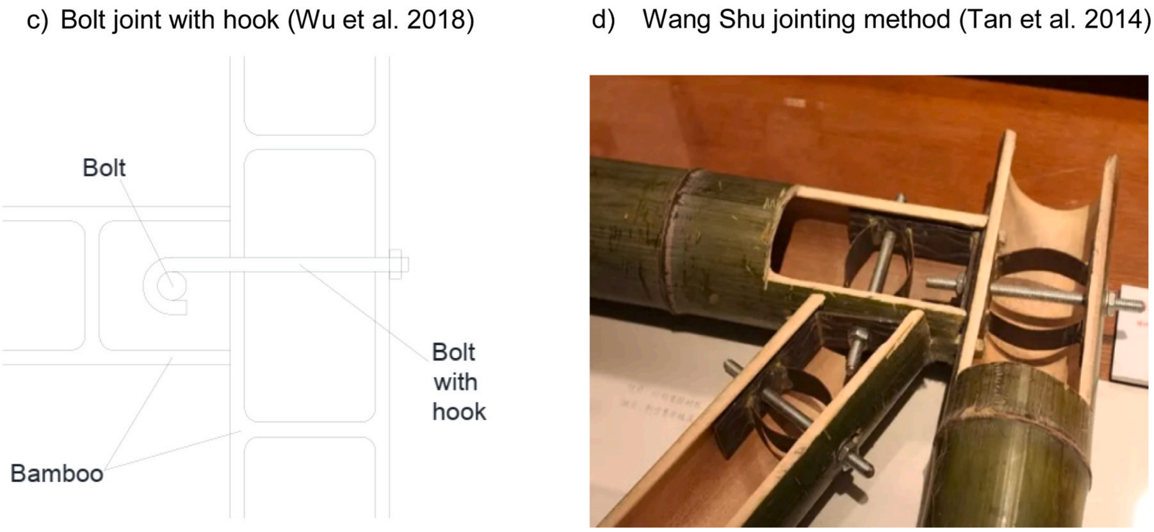


Fig. 5. Structural bracing.

Fig. 6. 3D view of the pedestrian bridge.

- The lateral and intermediate bamboo trusses are assumed to be pinned at their supports, reflecting realistic rotational freedom at the foundation. According to [26], they experimented with concreting the supports of the trusses. Concrete is inserted into the bamboo cavity and sealed with adhesive tape and plastic bags to prevent leaks. This technique strengthens areas subjected to high stresses.
- The decking elements are connected to the trusses using rigid links, ensuring proper load transfer.
- The bracing elements are provided with hinged constraints to allow axial force transmission.



c) Bolt joint with hook (Wu et al. 2018)

d) Wang Shu jointing method (Tan et al. 2014)

Fig. 7. connections (c, d).

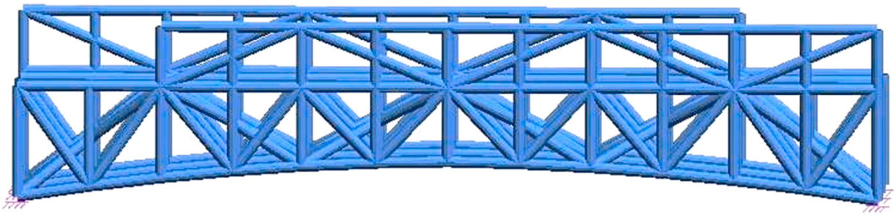


Fig. 8. Structural modeling in Advance design.

Loading Process

- The software automatically accounts for the self-weight of bamboo trusses and decking based on the assigned material densities.
- The live load is applied on the decking to simulate pedestrian loads.
- Load combinations are regulated according to Eurocode 0 and 1.

After this, structural analysis and verification of all obtained results are conducted.

3.4. Bridge class

SETRA (Technical Studies Service for Roads and Highways) has established four classes of pedestrian bridges, ranging from Class I to Class IV. In our case, the bridge will be designed to support the significant loads generated by schoolchildren and local workers during peak hours, as well as by the intense traffic on the nearby national road. Additionally, the presence of a covered gymnasium with a seating capacity of 1,600 further contributes to the increased pedestrian flow. Therefore, our bridge will be classified as Class IV to ensure its ability to handle these high loads and guarantee the safety of all users.

3.5. Self-weight (G)

The self-weights of the entire structure (bamboo trusses, decking) are directly accounted for by the Advance Design software. For our case: *Dendrocalamus asper* (700 kg/m^3), *Dendrocalamus giganteus* (680 kg/m^3). Given the increasing restrictions on the use of hardwoods in Madagascar, the decking will be made of *Eucalyptus grandis*, which has a density of 490 kg/m^3 (Atlas du bois de Madagascar, 2012).

3.6. Live loads (Q)

According to the recommendations of Eurocode 0 and 1, the pedestrian load ranges from 3.00 to 5.00 kN/m^2. By comparing with other references, the American standard (AASHTO: American Association of State Highway and Transportation Officials) specifies a load of 90 psf, which is equivalent to 4.309 kN/m^2 for pedestrian bridges. For our case, we will use the value of 5.00 kN/m^2, which corresponds to the general bending study and ensures maximum safety. This load is directly applied to the deck. In this first article, the effect of wind is neglected.

3.7. *Load combination*

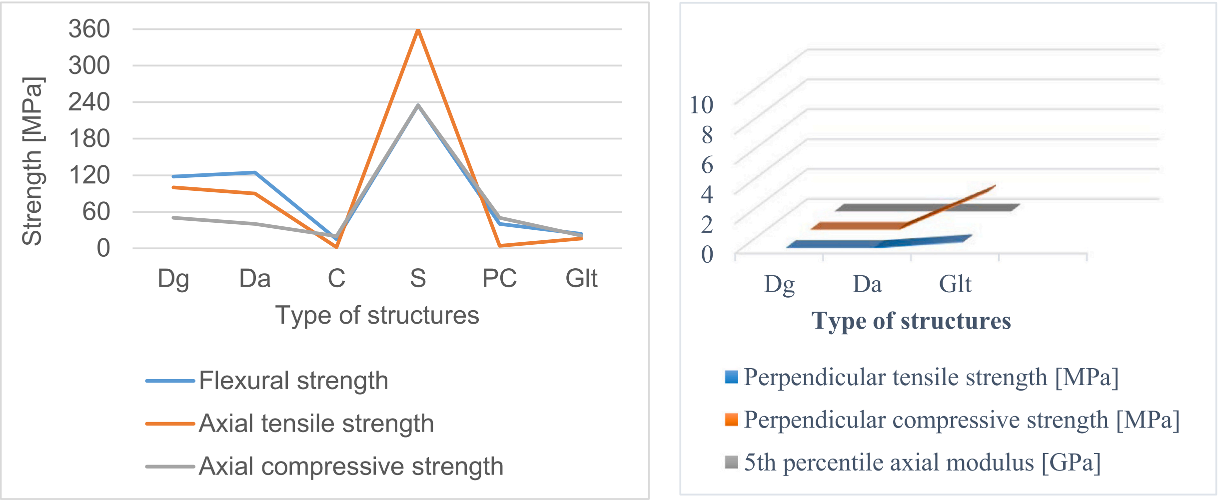
According to Eurocode 0 et 1, We apply this load combination: 1.35 G + 1.35 Q

4. Results

Fig. 9(e, f, g) present comparisons between the physical and mechanical characteristics of various structural elements such as *Dendrocalamus asper* (Da), *Dendrocalamus giganteus* (Dg), Steel (S), Concrete (C), Prestressed Concrete (Pc), and Glue-Laminated Timber (Glt).

Trusses are made up of straight bars assembled into a triangular structure, with stability ensured by the geometry of the triangles. In our case, they are generally designed as pin-jointed structures, meaning that the bars are connected by joints. As a result, no bending moments are transmitted to the joints, and the internal forces in each bar are limited to axial forces, either in tension or compression. In this study, for the two bamboo species under investigation, which are hollow inside, we will consider an outer diameter of 12 cm and a wall thickness of 2 cm.

Before discussing the values of the axial forces acting on the truss members, let us first examine in Figs. 10, 11 and 12 the tensioned



e) Axial and flexural strength

f) Effective Orthotropic Stiffness

g) Anisotropic Stiffness Capacity

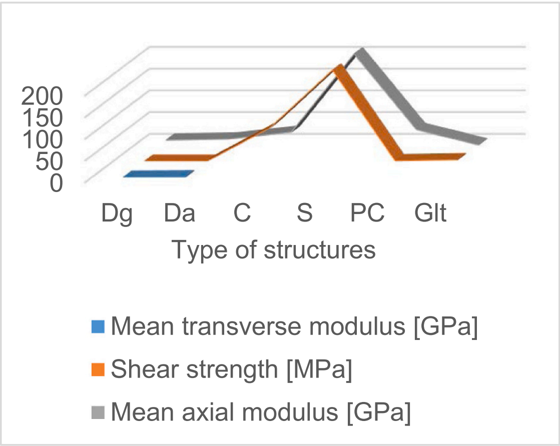


Fig. 9. comparison of the mechanical properties (e, f, g) of different structures.

and compressed elements in each case:

The main structure consists of three Warren trusses covered with Eucalyptus grandis decking. According to Eurocode 0, the loads are modeled as uniformly distributed on the decking. The load path is as follows: the loads from the decking act directly on the upper members of the central truss and on the intermediate members of the side trusses in accordance with the intrinsic properties of the beams. Thanks to the use of curvature in the lower members of the trusses, these are in tension in the central third and compressed on the edges. It is also noted that as the radius of curvature increases, the lower members become completely compressed, in line with the theory of an arch bridge. The diagonals alternate between compression and tension. The verticals of the trusses under the decking are compressed due to the principle of action and reaction, as the load-bearing members are above the verticals. However, the verticals of the side trusses (guardrails) are in tension. The stability of the trusses is ensured by horizontal bracing.

Focusing on the maximum values, Fig. 13 (h, I, j) present the results of the forces acting on the truss members of the bridge structure, as well as the overall deflections for the two bamboo species studied. These figures allow for the visualization and comparison of the structural performances of the different components in terms of stresses and deformations, contributing to a better understanding of the mechanical behaviors of the materials used.

The maximum axial forces are found in the lower chords, two-thirds of which are in compression due to the arch curvature; the upper chords of the intermediate truss and the lateral trusses are subjected to low forces due to the presence of the central truss which redistributes the loads, primarily because of the high axial compression resistance of bamboo, which is equivalent to that of high-performance concrete. The guardrails are characterized by the presence of high compression forces in the diagonals and upper chords compared to the tension forces that develop in the vertical members. In the bracings, the tension bars barely reach half the forces of the compression bars.

5. Discussion

5.1. Comparison of the mechanical properties of different structures

All the data presented in Fig. 5 are based on the minimum values for each material. It is important to note that the flexural strength (minimum values: Dendrocalamus giganteus [Dg] 117.90 MPa and Dendrocalamus asper [Da] 124.40 MPa) and compressive strength (minimum values: Dg 50 MPa and Da 40 MPa) of bamboo are higher than those of concrete and glued laminated timber. Regarding tensile strength, bamboo (minimum values: Dg 100 MPa and Da 90 MPa) significantly exceeds concrete, whose tensile strength is almost negligible.

As for the longitudinal modulus of elasticity (E), which is the ratio between stress and resulting deformation, bamboo ($E = 20,000$ MPa, average value according to ZERI Pavilion results for EXPO 2000 in Hanover) is nearly double that of glued laminated timber ($E = 11600$ MPa, minimum value range corresponding to GL24h: source Eurocode 5).

These data now allow us to determine the structural lightness for all these materials. Lightness is determined by the ratio between the material's density (ρ) and its design strength (R), i.e., $c = \rho/R$. The smaller the value of c, the lighter the structure is relatively.

By referring simultaneously to the Colombian standard [27], as well as the international bamboo standards ISO 22157 [28] and ISO 19624, we can deduce that the partial safety factor for bamboo is equal to 3.0. Based on Eurocode, to find the other parameters, Fig. 14 summarizes the calculation results.

It can be concluded that the lightness values of the structure for Dendrocalamus asper and Dendrocalamus giganteus are comparable to those of glued laminated timber and steel, indicating that both bamboo species are lightweight and strong. This lightness has several positive impacts on the mechanical efficiency of the structure. It allows for a reduction in the loads on the supporting elements, thus facilitating implementation and reducing transportation and installation costs. Moreover, a lighter structure contributes to better load distribution and greater flexibility, while maintaining high resistance to stresses. This can also improve the durability of the structure, as it undergoes less internal stress, which limits the risks of deformation or premature failure.

5.2. Sizing of the structure

It is observed that through the results obtained by Advance Design using the finite element method, in the case of the under-deck trusses, the maximum forces in the bars are found in the lower chords, which are subjected to high compressive forces with values of

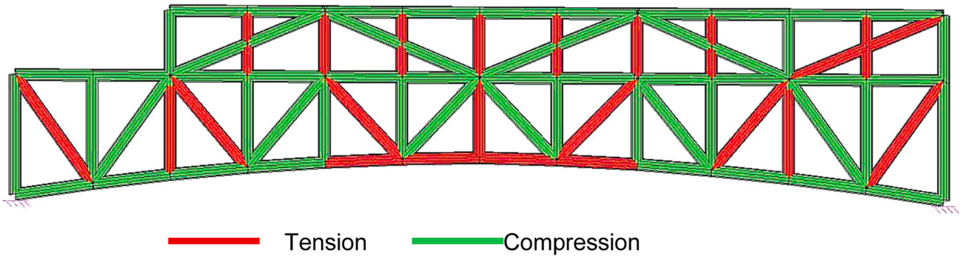


Fig. 10. Lateral trusses.

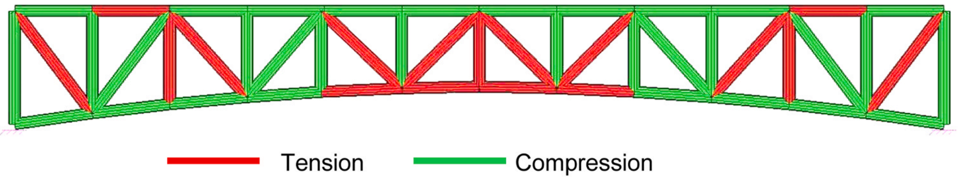


Fig. 11. Intermediate truss.

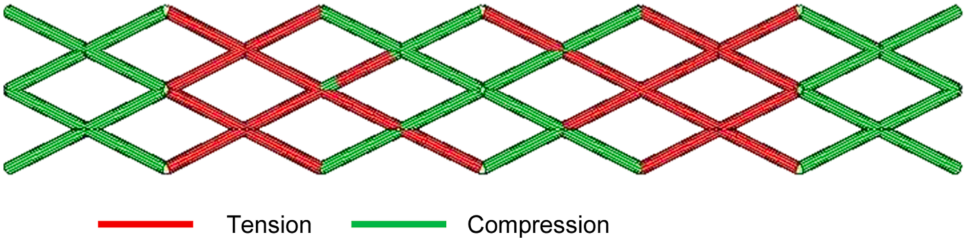


Fig. 12. Structural bracing.

(Dg 68.34 kN and Da 70.02 kN). However, the upper chords exhibit the minimum values (Dg 27.99 kN and Da 28.03 kN). On the other hand, the diagonals are subjected to significant tensile forces of (Dg 34.37 kN and Da 34.49 kN). For the guardrail trusses, the maximum values are found in the upper chords, which develop compressive forces (Dg 43.18 kN and Da 44.39 kN). The posts exhibit minimal compressive forces of (Dg 32.16 kN and Da 32.62 kN). In the case of the bracing elements, both compressive forces (Dg 27.99 kN and Da 28.03 kN) and tensile forces (Dg 46.84 kN and Da 46.95 kN) are developed. Given the higher density of Dendrocalamus asper, its loads are higher than those of Dendrocalamus giganteus.

In the context of serviceability limit state (SLS) verification, the global deflection of the two studied bamboo species was calculated. It is noted that the deflection for Da is (8.80 mm) compared to Dg at (8.60 mm).

According to guidelines for footbridges, the allowable deflection is given by the following relation: $f_{adm} = \frac{L}{500}$ (1), where the span of the footbridge is 18.60 m.

Table 2 presents the stresses obtained in the various truss elements.

The result confirms the evaluations made by [25], which state that the stress calculations for the bamboo species Dendrocalamus asper (Da) are less favorable compared to those of Dendrocalamus giganteus. The compressed bars represent a working ratio reaching a peak of 83 %. However, the compression stress in the lower members of the truss under the deck exceeds the allowable limit. To address this, we increased the net section of the bamboo by assembling two bamboo culms for both studied species. Besides this, the radius of curvature of the lower members of the trusses can be decreased or even the arch shape can be completely eliminated so that the bars of the lower members are 100 % in tension to fully exploit the increased tensile stress of bamboo. As for the tensile stresses, they are well within limits, with a working ratio between 12 % and 25 %, thanks to the high tensile strength of bamboo. Fig. 15 shows the results of deflection calculations at the Serviceability Limit State (SLS).

This difference is mainly due to the choice of an arched truss supporting the deck, which helps minimize the loads. Additionally, our span of 18.60 m is shorter compared to their study parameters. Additionally, [25] opted for a lateral beam bridge structure (lower decking), with the lower member elements and the verticals being entirely in tension, and the diagonals alternating. The bamboo species studied focused on Bambusa vulgaris and Dendrocalamus asper. All this justifies this difference.

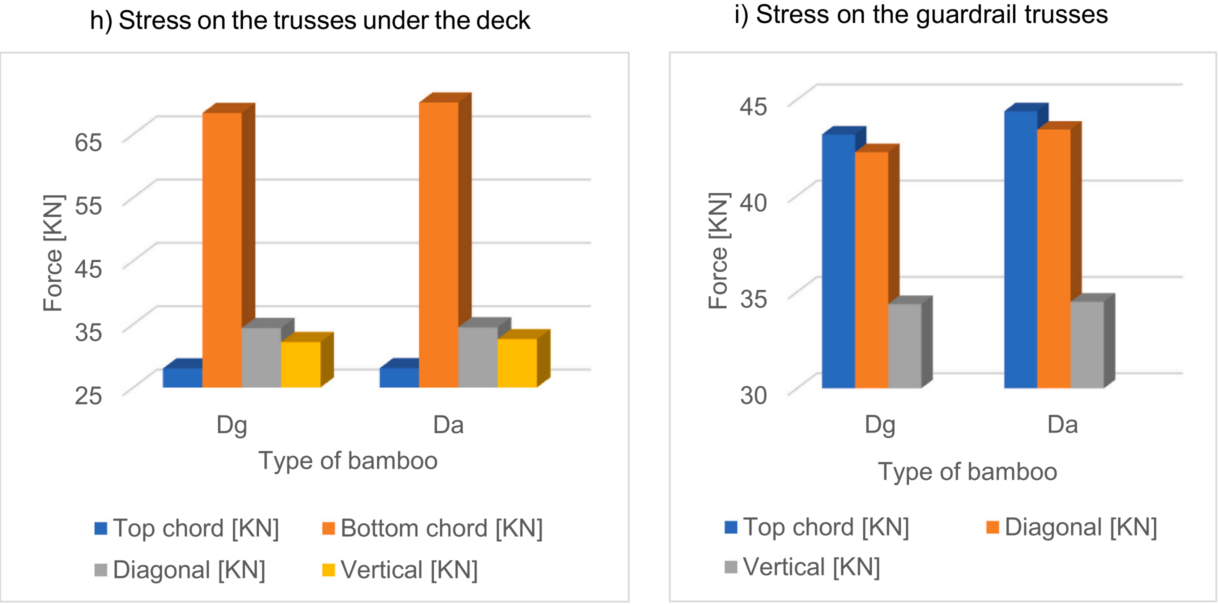
6. Conclusion

To evaluate the feasibility of a bamboo pedestrian bridge as an ecological alternative for tropical regions, this study focused on its design and structural analysis, taking into account geometric configuration, site conditions, and applied loads in accordance with current standards.

The study began with the characterization of the physical and mechanical properties of Dendrocalamus asper and Dendrocalamus giganteus, two bamboo species known for their excellent strength-to-weight ratio. The modeling and analysis of the bridge were then carried out using Advance Design software, allowing for structural verification and performance evaluation.

These two species were selected due to their remarkable mechanical properties. Their bending strength exceeds that of concrete and glued laminated timber, while their tensile strength is significantly higher than that of concrete, which has a low capacity to resist tensile forces. Furthermore, their low density, comparable to that of steel, helps reduce permanent loads and foundation stresses while maintaining structural integrity.

In a truss configuration, bamboo optimizes load distribution, minimizes deformations, and enhances the overall stability and strength of the structure. Its high strength-to-weight ratio allows for efficient use of materials, avoiding oversizing and optimizing structural costs. Its low density facilitates transportation and on-site assembly, allowing for quick installation. Additionally, its


h) Stress on the trusses under the deck

i) Stress on the guardrail trusses

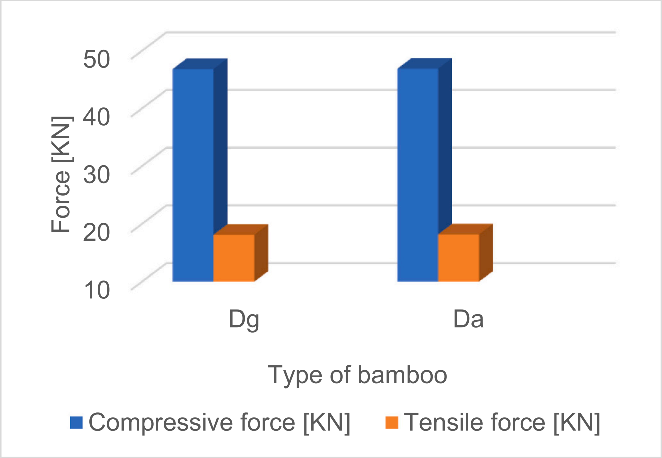

j) Force acting on bracing

Fig. 13. Axial forces (h, I, j) in bars.

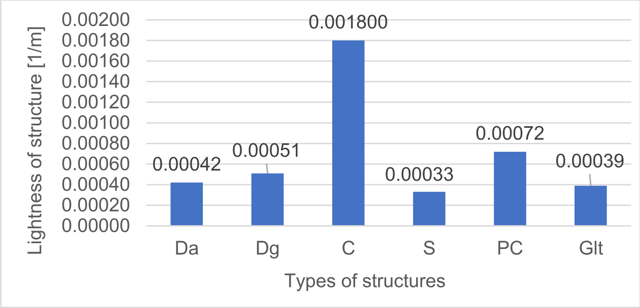


Fig. 14. Lightness of structure.

Table 2
Summarize result of stress.

Pedestrian bridge	Dg	Da	Observation
Trusses under the deck			
Top chord [Mpa]	7.48	7.52	Compressive stress
Bottom chord [Mpa]	18.26	18.80	Compressive stress
Vertical [Mpa]	8.59	8.75	Compressive stress
Diagonal [Mpa]	8.44	8.47	Tensile stress
Guardrail trusses			
Top chord [Mpa]	11.65	12.04	Compressive stress
Vertical [Mpa]	7.89	8.01	Compressive stress
Diagonal [Mpa]	11.72	12.13	Compressive stress
Bracing			
Compressive stress [Mpa]	13.89	14.07	
Tensile stress [Mpa]	4.45	4.47	

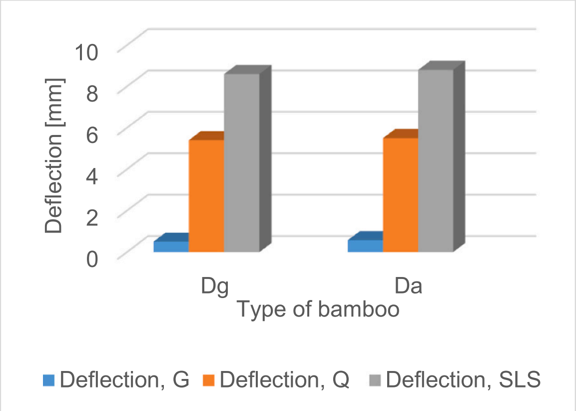


Fig. 15. Deflection result.

elasticity effectively absorbs pedestrian-induced vibrations, limiting resonance effects and ensuring optimal user comfort.

Beyond its structural performance, bamboo offers natural durability. Its fibrous structure makes it resistant to microcracks and thermal variations, thus extending its longevity in various environments. Economically, bamboo is a cost-effective alternative to steel and concrete, as it is abundant and locally available, reducing material import costs. Moreover, its CO_2 absorption properties contribute to reducing the carbon footprint of infrastructures, reinforcing its role in sustainable construction.

In the context of serviceability limit state (SLS) checks, the calculation of global deflection was performed for both studied species, showing a deflection of 8.80 mm for Dendrocalamus asper compared to 8.60 mm for Dendrocalamus giganteus which is significantly below the permissible limit set at 37.20 mm.

While these results confirm the mechanical efficiency of bamboo, further research is needed to analyze its wind resistance, natural degradation in tropical climates, and maintenance strategies to ensure long-term durability. These aspects pave the way for future studies, allowing for the refinement of this research’s conclusions and promoting the integration of ecological infrastructure solutions in Madagascar.

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CRediT authorship contribution statement

Harijaona Rafidison Barisoa: Validation, Software, Resources, Investigation. **Sela Jao Barahimo:** Writing – review & editing, Validation. **Zarasoa Arnole Rasolomampionona:** Validation, Software, Project administration, Methodology. **Rivel Sinta:** Writing – review & editing, Writing – original draft, Visualization, Software. **Sambilason Richard Rafefimanana:** Visualization, Supervision, Methodology, Investigation, Formal analysis. **Chrysostôme Raminosoa:** Writing – original draft, Visualization, Validation, Resources, Conceptualization. **Kameni Nematchoua Modeste:** Visualization, Supervision, Software, Resources, Methodology.

Declaration of Competing Interest

No conflict interest between author.

Data availability

Data will be made available on request.

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