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LOW-COST TIMBER BRIDGES FOR RURAL AREAS: A FIELD SURVEY AND RECOMMENDATIONS OF INTEREST

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KEYWORDS

rural roads, construction recommendations, pre-sizing, periodic maintenance, pathologies.

ABSTRACT

Timber bridges in Brazil, intended for rural roads and rural areas, present several problems due to the lack of design, structural calculation, and periodic maintenance by municipal administrations. This study evaluated a total of 10 timber bridges with a deck of sawn planks connected by nails to natural round beams, aiming to identify their main pathologies and provide minimum pre-sizing values for the used sections. The bridges were inspected on-site to measure the parts and identify the main problems. Subsequently, based on the Manual de Projeto e Construção de Pontes de Madeira and ABNT NBR 7190-1 (2022), we verified whether the diameter of the round beams found on site was adequate from the point of view of structural sizing using an Excel spreadsheet. Most of the analyzed bridges had spans of up to 15 m and problems related to the degradation of the timber and metal connections, reducing their useful life. As a result, the main construction recommendations for bridges are the use of timber treated with chromated copper arsenate (CCA) and galvanized connections to prevent corrosion. The use of the proposed pre-sizing tables is recommended to ensure minimum calculation values, considering the design vehicle classes and the minimum dimensions for the timber sections. This study aims to guide Brazilian municipal administrations and other interested parties in the construction of timber bridges for rural areas, obtaining safe, low-cost, and highly durable structures.

INTRODUCTION

Timber bridges on Brazilian rural roads are essential for the development of states and municipalities. Rural roads are unpaved roads that mostly connect rural areas with urban areas. Timber bridges are socially and economically important, allowing the population to move around rural areas and facilitating the production flow. However, almost all Brazilian municipalities have timber bridges that require some type of preventive maintenance (Milani & Kripka, 2012). In addition, inadequate construction details are common. It is also a fact that the mobile loads (design vehicles) that determine the sizing of timber bridges have changed over the years. Wooden bridges built until the 1930s could only carry 6-ton ox carts and trucks weighing up to 10 tons. Currently, they are sized for mobile loads of design vehicles weighing up to 45 tons (Calil Junior et al., 2006). The maintenance of timber bridges and their protection against the elements are essential. According to Kromoser et al. (2023), even highly durable wood species need to be protected from moisture, as it reduces their strength and rigidity, in addition to increasing their susceptibility to insect and fungal attacks, increasing the risk of destruction and maintenance costs (Simon et al., 2023). In recent years, several studies have been conducted internationally on timber bridges, considering structural analysis, preventive maintenance, and environmental issues, such as those conducted by Bigelow et al. (2009), Oy et al. (2009), Molina & Calil Junior (2010), Franke et al. (2014), Mahnert & Hundhausen (2017), O'Born (2018), Fortino et al. (2020), Rashidi et al. (2021), Ostrycharczyk & Malo (2022), Zhang et al. (2022), Seppälä et

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al. (2023), and Bergenudd et al. (2023). However, Brazilian literature on the subject is still scarce, despite some studies recently published by Ribas Junior & Molina (2020), Scolaro et al. (2020), and Morais et al. (2022).

The basic configuration of a timber bridge with a deck of sawn planks and natural round beams must contain two pairs of double beams, which are positioned under each of the wheel tracks to ensure the safe passage of vehicles. The remaining lower beams are used constructively to attach the guardrails and wheel guards. The standard width of the bridge (4.00 m + D, where D is the diameter of round beams) for a single traffic lane for small (between 3 m and 7 m) and medium (between 7 m and 15 m) spans is suitable for the passage of vehicles with a load of up to 45 tons. Figure 1 shows the basic elements of a timber bridge with a deck of sawn planks (where h is the height or thickness of transverse planks) and natural round beams.

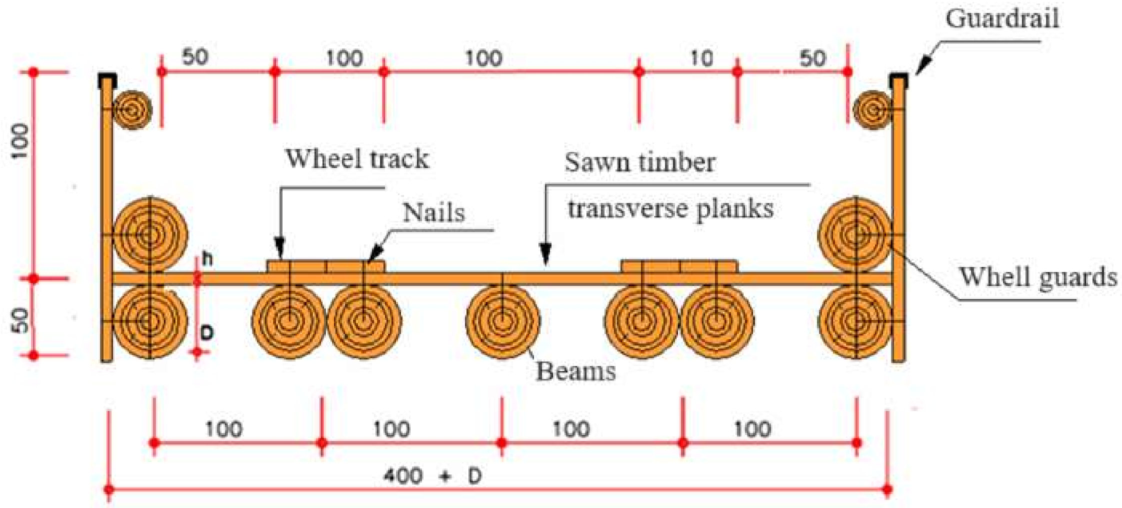
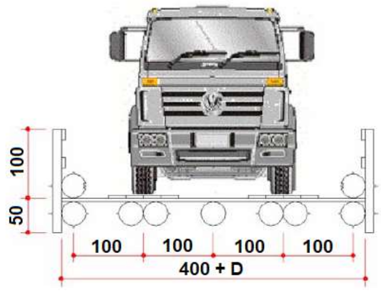
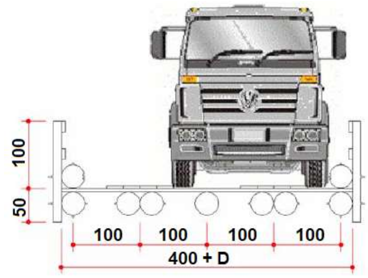


FIGURE 1. Cross-section of a deck of sawn planks with natural round beams [Units: cm].
Source: Modified from Ribas Junior & Molina (2020).

The Manual de Projeto e Construção de Pontes de Madeira (Calil Junior et al., 2006) and ABNT NBR 7190-1 (2022) can be used to design timber bridges. The Ultimate Limit States (normal and tangential stresses) and the Serviceability Limit States (deflections) must be verified. The design vehicle is positioned in the most unfavorable situations for sizing the deck: on the wheel track and the central section of the span (Figure 2a) or even on the center of the span on the bridge and displaced transversely out of the wheel track (Figure 2b). Based on these considerations, the maximum normal stresses and vertical displacements in the middle of the span of the round beams and the maximum normal stresses in the deck planks are evaluated. The permanent actions (self-weight), variables (vehicle load and crowd load), and impact coefficient acting on the deck must be considered. The design vehicle should be positioned on the wheel tracks and close to the bridge supports when checking the maximum shear stresses.



(a) Vehicle on the wheel track in the center of the span.



(b) Vehicle moved out of the wheel track.

FIGURE 2. Critical positions of the design vehicle [Units: cm].
Source: Modified from Calil Jr. et al. (2006).

Table 1 shows the resistance classes for native woods, according to ABNT NBR 7190-1 (2022). Furthermore, this same text indicates values for reforested woods used in other studies (Oliveira et al., 2022).

TABLE 1. Resistance class of native hardwoods, U=12%.

Classes	$f_{c0,k}$ (MPa)	$f_{v0,k}$ (MPa)	$E_{c0,m}$ (MPa)	ρ_{ap} (kg/m^3)
D40	40	6	19500	950
D50	50	7	22000	970
D60	60	8	2400	1000

Notes: Timber properties – $f_{c0,k}$ = characteristic value of compressive strength parallel to the grain; $f_{v0,k}$ = characteristic value of shear strength parallel to the grain; $E_{c0,m}$ = mean value of the modulus of elasticity parallel to the grain; ρ_{ap} = mean value of apparent density at 12% moisture content; D40, D50, and D60 = strength classes of hardwoods, for example, D40 indicates wood with strength $f_{c0,k}$ = 40 MPa.

Source: Modified from ABNT NBR 7190-1 (2022).

This study aimed to identify the main problems of timber bridges with a deck of sawn planks and natural round beams based on a field survey carried out in Itapeva-SP, Brazil, and propose alternatives to improve this system. The aim is to assist municipal administrations and other professionals in the evaluation and pre-sizing of these bridges in rural areas, where there is a high demand for these structures. This document complements the paper published by Ribas Junior & Molina (2020).

MATERIAL AND METHODS

Case studies

The study was conducted in the municipality of Itapeva-SP, located in the southwest region of the State of São Paulo, Brazil. This municipality has a vast rural area (1,826.7 km^2), consisting of the second-largest municipality in the state in terms of size. In this context, there are many timber bridges with various types of problems, frequently closed for repairs, maintenance, or replacements. Heavy traffic (passenger buses and trucks loaded with tomatoes or soybeans) is usually diverted to alternative routes when the larger bridges on the main local roads are closed, overloading the smaller bridges and leading to structural problems.

This study evaluated ten timber bridges with a deck of sawn planks and natural round beams, according to data obtained in the field and shown in Table 2. Most of the considered bridges fell into the category of small-span bridges (up to 14 m) (Calil Jr. et al., 2006). Table 3 shows the main problems (from A to L) considered in the on-site evaluation of the timber bridges.

TABLE 2. Dimension and configuration data of wooden bridges collected on-site.

Bridge	**Width (m)**	**L (m)**	**D (cm)**	**h (cm)**	**n**
01	4.50	12.00	40 to 50	5	6
02	4.50	8.50	42	5	4
03	4.30	12.0	42 to 45	5	4
04	4.20	10.80	43	5	4
05	4.20	6.35	38 to 46	5	6
06	4.20	5.25	35 to 65	5	6
07	4.20	9.90	40 to 44	5	6
08	5.20	6.70	41	5	6
09	4.20	44.4	40 to 45	5	6
10	4.30	20.5	33 to 37	5	6

Note: D = diameter of the round beam under the deck; L = distance between supports of the round beams; h = height of the transverse planks; Width = cross-section width of the bridges; n = number of round beams under the deck of sawn planks.

Source: Prepared by the authors.

TABLE 3. Identification of the problems evaluated in the timber bridges with a deck of sawn planks.

Problem	**Description**
A	Absence of preservative treatment against biological demand
B	Attack by fungi and insects and/or signs of wood rot
C	Use of metal parts and connectors (nails) without galvanization
D	Presence of oxidation on connectors or metal parts
E	Absence of guardrails and wheel guards
F	Columns with inadequate transverse bracing or without locking
G	Loosening of nailed planks and cracking due to the passage of vehicles
H	Surface wear of the planks due to deterioration or abrasion from vehicles
I	Deck settlement due to erosion of supports
J	Use of different types of timber on the deck of the same bridge
K	Use of beams with different diameters or with inadequate notches
L	Absence of central round beam between double beams under wheel tracks

Source: Modified from Ribas Junior & Molina (2020).

The sizing of structural elements of the bridges was carried out following the verifications proposed by Calil Jr et al. (2006) (page 87, item 6), and the minimum diameter (D_{min}) to be considered for the round beams was the largest value obtained among eqs (1) to (3), which consider the verification of the Ultimate Limit States and the Serviceability Limit States:

$$\left(\frac{16 \cdot M_d}{\pi \cdot f_{c0,d}}\right)^{\frac{1}{3}} \quad (1)$$

$$\left(\frac{8 \cdot Q_d}{3.\pi \cdot f_{v0,d}}\right)^{\frac{1}{2}} \quad (2)$$

$$\left\{\frac{360}{L} \cdot \frac{4 \cdot P}{3 \cdot \pi \cdot E_{M,ef} \cdot L}\left[L^3 + 2 \cdot b \cdot (3 \cdot L^2 - 4 \cdot b^2)\right]\right\}^{\frac{1}{4}} \quad (3)$$

Equation (4) was used to check the height or thickness of the deck planks:

$$h \geq \left(\frac{6 \cdot M_{r,d}}{width \cdot f_{c0,d}}\right)^{\frac{1}{2}} \quad (4)$$

Where:

Md is the design flexural moment;

$f_{c0,d}$ is the compressive strength parallel to the grain;

Q_d is the shear force design value;

$f_{v0,d}$ is the shear strength parallel to the grain;

P is equal to 7.5 kN for class 45 vehicle or 5.0 kN for class C30 vehicle;

b is the distance from the beam support to the point of application of the load P closest to the support (vehicle wheel);

L is the distance between beam supports;

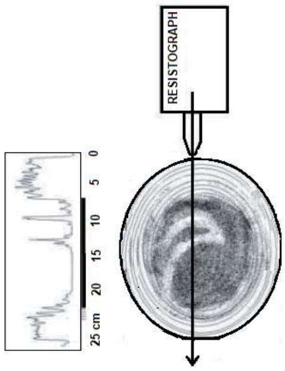
$E_{m,ef}$ is the effective modulus of elasticity in bending of the round timber beam;

$M_{r,d}$ is the design bending moment on the deck, and

width is the width of the wheel of the design vehicle (20 cm for classes 30 and 45).

The values for eqs (1) to (4) were calculated using a sizing spreadsheet built in Excel. This allowed verifying the sizing of the bridge decks and beams according to the calculation hypotheses proposed by the Manual de Projeto e Construção de Pontes de Madeira (item 9.1.2), developed by Calil Junior et al. (2006), for spans longer than 6 m and vehicle classes 30 and 45. Therefore, we evaluated whether the diameters measured on-site followed the minimum diameter (D) of the round beams and the minimum heights (h) of the transverse planks of the bridge decks. In addition to data collection, non-destructive tests were performed using a Resistograph (Figure 3a) to evaluate signs of rot or areas of lower resistance on the inside of the beams. This approach was adopted due to the impossibility of a detailed visual analysis on the inside of the beams and the difficulties in accessing the underside of the deck of some bridges. The Resistograph works by using a long, thin drill bit, similar to a standard drill, that drills through the cross-section of wood pieces. It generates a graph indicating the regions within the piece with different levels of drilling resistance (Figure 3b).

(a) Overview of equipment usage.

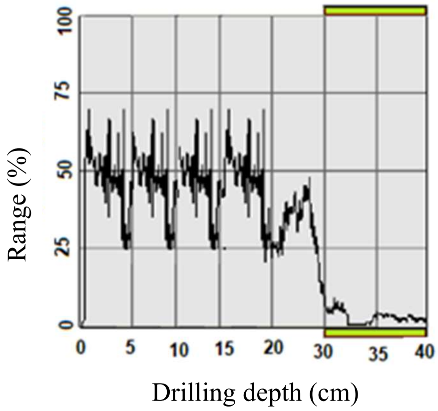


(b) Equipment operation.

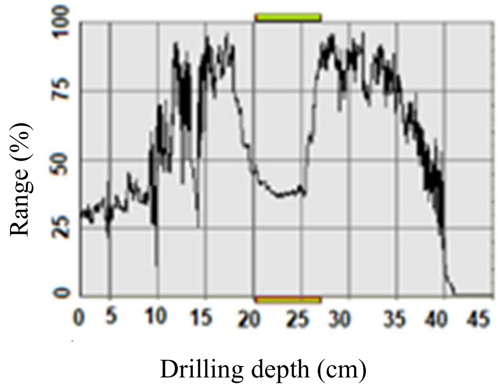
FIGURE 3. Use of Resistograph in assessing wood quality.
Source: Modified from Ribas Junior & Molina (2020)

RESULTS AND DISCUSSION

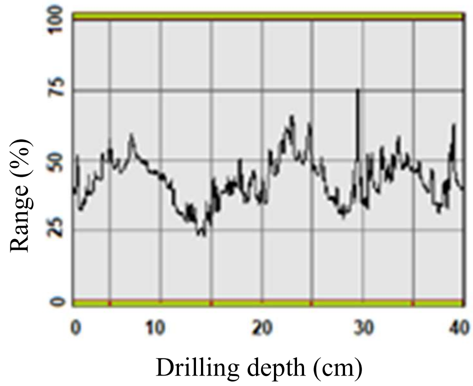
Eight out of the 10 analyzed bridges had small or medium spans (≤ 15.0 m), while two had larger spans (over 15 m), as classified by Calil Jr. et al. (2006) and Jutila & Salokangas (2000). Figure 4 shows the results of the controlled drilling tests obtained by Resistograph for the natural round beams of the analyzed bridges. The range indicated in the graphs, which varied from 0 to 100%, indicates the resistance to drilling of the wood by the equipment's drill.



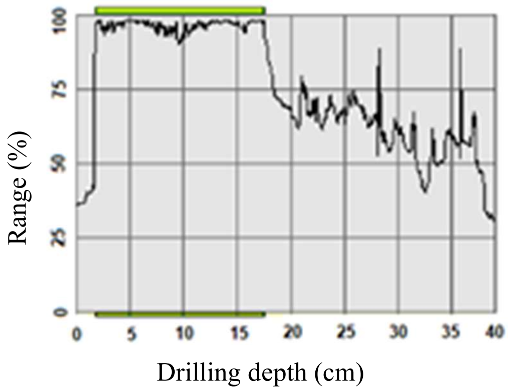
(a) Average resistance to drilling in the section between 0 and 5 cm and free section of the drill without resistance to drilling between 30 cm and 40 cm.



(b) Drop in resistance in the section between 20 cm and 26 cm, indicating the natural variability of the timber's resistance to drilling.



(c) Natural variation in drilling without identifying the presence of defects in the wood.



(d) High initial drilling resistance in the section between 2.5 cm and 17 cm with reduced resistance in the section between 17 cm and 40 cm.

FIGURE 4. Controlled drilling of beams on Bridge 09 with the Resistograph.
Source: Modified from Ribas Junior & Molina (2020).

According to the data in Table 2, all round beams under the decks of the 10 analyzed bridges showed at least one of the four types of drilling illustrated in Figure 4. Sections with different resistances to drilling were observed for the beams and the signs of rot were mostly superficial. Most of the investigated bridges do not undergo preventive maintenance, as also observed by Milani & Kripka (2012). However, timber bridges that receive periodic maintenance can delay the onset of deterioration and increase their useful life, as reported by Srikanth et al. (2022). Figure 5 shows the main problems found during the on-site evaluations.

Absence of preservative treatment **(A)**

Attack by fungi and insects and signs of rot **(B)**

Use of metal connections without galvanization **(C)**

Presence of oxidation in the metal connecting joints **(D)**

Absence of guardrails and wheel guards on the deck **(E)**

Inadequate transverse bracing **(F)**

Loosening and cracking of planks due to the passage of vehicles **(G)**

Plank wear due to abrasion and deterioration **(H)**

Deck settlement due to erosion of supports **(I)**

Use of different types of timber on the same deck **(J)**

Beams with different diameters and notches **(K)**

Absence of round beam and damage to the planks in the central part **(L)**

FIGURE 5. Main problems identified in the timber bridges of the southwest region of São Paulo (Table 3).
Source: Modified from Ribas Junior & Molina (2020).

Table 4 lists the main problems identified in each of the analyzed bridges.

TABLE 4. List of the most common problems for each of the analyzed bridges.

Bridge	Problems	Bridge	Problems
01	A, B, C, D, E, F, G, H, K, L	**06**	A, B, C, D, E, F, G, I, K, L
02	A, B, C, D, E, F, G, H, I, L	**07**	A, B, C, D, E, F, G, K, L
03	A, B, C, D, E, F, G, H, I, L	**08**	A, B, C, D, E, F, K, L
04	A, B, C, D, E, F, G, H, I, L	**09**	A, B, C, D, E, F, G, I, L
05	A, B, C, D, E, G, H, I, K, L	**10**	A, B, C, D, E, F, H, L

Note: See the list of problems in Table 3 and their identification in Figure 5.
Source: Modified from Ribas Junior & Molina (2020).

The following items refer to the discussions on the problems presented by the bridges listed in Table 4:

A – Preservative treatment with chromated copper arsenate (CCA), chromated copper borate (CCB), or creosote was not observed in the analyzed bridges. In Brazil, timber treatment against biological agents is not common. Some hardwood species, which have high resistance, may suffer deterioration in the sapwood region, which is more porous and susceptible to insect attack.

B – Only bridge number 07 showed no signs of rot or attack by fungi and insects, as it was recently renovated. However, it also showed no signs of preservative treatment, which means that it may face the same problems within a few years.

C – None of the analyzed bridges had galvanized metal elements. In Brazil, it is common to fix the timber elements of bridges with nails (25 x 72, i.e., 7 mm in diameter x 165.60 mm in length), clamps, and metal sheets without anti-oxidation treatment.

D – All the analyzed bridges showed signs of oxidation of the metal parts both in the connectors and in the metal sheets.

E – None of the analyzed bridges had wheel guards or guardrails. This configuration increases the insecurity of users on timber bridges.

F – Most bridges had deficient bracing systems.

G – Most bridges had cracks in the sawn transverse planks or loosening due to the passage of vehicles. The deck planks are not securely fastened because they are nailed without initial pre-drilling, and they easily come loose from the round beams with the dynamic movement of vehicles on the bridge.

H – A significant part of the bridges showed superficial wear or deterioration of transverse planks and wheel tracks caused by abrasion from vehicles. High-strength timber (class D 60 or higher) is not always used in the wheel tracks, which favors wear. In some cases, a layer of soil is applied over the deck planks to protect against wear and reduce the vertical impact on the bridge. However, this soil layer allows water to percolate, affecting not only the timber but also the metal connections.

I – The bridges presented problems with uneven decks due to foundation settlement or soil erosion in the support areas. Some unevenness was in the order of 40 to 60 cm, caused by the passage of trucks loaded with soybeans and tomatoes (approximate load of 30 tons). Generally, proper soil compaction in the support regions is not considered, nor is an adequate support system for the deck implemented during bridge construction.

J – One of the bridges had different types of timber to repair the same deck. There is no suitable criterion for replacing damaged timber elements with identical ones.

K – Seven bridges had round beams under wheel tracks with different diameters, requiring some type of support or notch to correct the leveling of the deck. The use of beams with different diameters compromises the strength of the bridge, while the notches, widely used in bridges without proper calculation to correct leveling problems, can cause splitting of the timber in the regions where they are used.

L – All the analyzed bridges did not have a central beam on the deck between double beams of wheel tracks to prevent the breakage of the planks due to accidents caused by vehicle wheels. There is no standardization in Brazil for the construction of timber bridges, resulting in various widths used for the cross-section of the bridges.

Suggested pre-sizing table

Table 5 shows a pre-sizing of the round beams for bridges with spans between 6 m and 10 m, considering design vehicle classes 30 and 45. Figure 6 shows how the equivalent diameter for the round beam must be obtained.

TABLE 5. Equivalent diameter of round beams at 1/3 of the top of the parts (Figure 6).

Length (m)	Span (m)	Class C30			Class C45		
		D60	**D50**	**D40**	**D60**	**D50**	**D40**
6.0	5.5	38 cm	40 cm	44 cm	44 cm	46 cm	49 cm
7.0	6.5	41 cm	44 cm	46 cm	47 cm	50 cm	-
8.0	7.5	44 cm	47 cm	50 cm	51 cm	-	-
9.0	8.5	47 cm	50 cm	-	-	-	-
10.0	9.5	50 cm	-	-	-	-	-

Note: Classes C30 and C45 refer to the weight of vehicles (30 t and 45 t); timber resistance classes D40 to D60 (compressive strength parallel to the grain ranging from 40 MPa to 60 MPa).
Source: Modified from Ribas Junior & Molina (2020).

Table 6 shows the heights of the planks expected for the respective decks. Tables 5 and 6 consider the verifications proposed by Calil Jr et al. (2006).

TABLE 6. Heights of the deck planks.

Design vehicle	Timber		
	D60	**D50**	**D40**
Class C30	6 cm	7 cm	8 cm
Class C45	8 cm	9 cm	10 cm

Note: Timber strength classes D40 to D60 (compressive strength parallel to the grain ranging from 40 MPa to 60 MPa).
Source: Modified from Ribas Junior & Molina (2020).

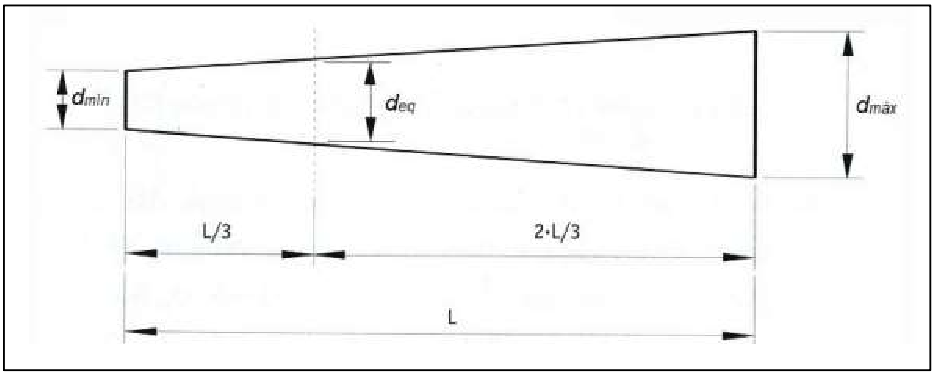
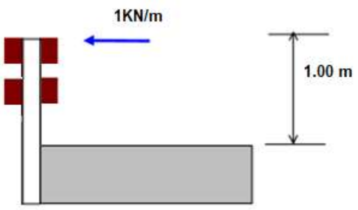


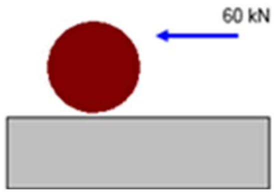
FIGURE 6. Diameter equivalent to 1/3 of the top of the round beam (L = beam length).
Source: Modified from ABNT NBR 7190-1 (2022).

Suggested calculation procedure for sizing guardrails and wheel guards

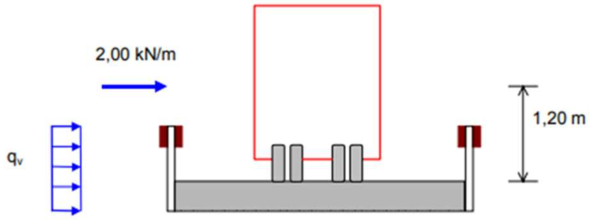
Figure 7 presents a suggestion for guardrails and wheel guards for wooden bridges. The sizing of bridge guardrails should consider a horizontal action with a characteristic value equal to 1.00 kN/m (horizontal) applied at a height of 1.00 m above the rolling surface, as shown in Figure 7a. For sizing the wheel guard, a strength of 60 kN must be applied horizontally at its top, without impact (Figure 7b). A characteristic value equal to 2.00 kN/m (horizontal) applied at a height of 1.20 m above the rolling surface should be adopted for the action of wind on the design vehicle, as shown in Figure 7c.



(a) Horizontal strength considered on the guardrail.



(b) Horizontal strength considered in the wheel guard.



(c) Horizontal action of wind on the vehicle.

FIGURE 7. Suggestion of guardrails and wheel guards for bridges with a deck of sawn planks and round beams and wind action on the vehicle.
Source: Calil Junior et al. (2006).

CONCLUSIONS

The use of the tables proposed in this study is recommended for the preliminary sizing of the round beams and heights of transverse planks in case of the absence of more precise recommendations.

The dimensions of structural elements of the bridge (diameter of round beams and height of sawn planks) found on site were higher than the minimum recommended values. It indicates that the structures are oversized, resulting in higher costs than necessary.

All timber parts used in bridges must be treated with preservatives and metal parts protected against corrosion.

The deck planks must be spaced at least 1.5 cm apart and no more than 2.5 cm apart. Furthermore, the round beams must be leveled at the top and the use of notches is not recommended.

Wheel tracks should be made of high-density timber with a minimum thickness of 4 cm. Soil on the deck must be avoided, as moisture can reach the timber planks and metal connections.

The fixing of the deck planks should preferably be done with self-tapping screws and, in the case of nailed connections, the initial pre-drilling should be 0.95 d (where d is the nail diameter).

A suitable bracing system should be used, and periodic maintenance should be carried out every 5 years.

REFERENCES

ABNT - Associação Brasileira de Normas Técnicas (2022) ABNT NBR 7190-1:2022: projeto de estruturas de madeira – Parte 1: Critérios de dimensionamento. Rio de Janeiro, ABNT, 2022. 81 p.

Bergenudd J, Battini J, Crocetti R, Pacoste C (2023) Dynamic testing and numerical modelling of a pedestrian timber bridge at different construction stages. Engineering Structures 279:115429. http://dx.doi.org/10.1016/j.engstruct.2022.115429

Bigelow J, Lebow S, Clausen CA, Greimann L, Wipf TJ (2009) Preservation treatment for wood bridge application. Transportation Research Record (2018):77-85. http://dx.doi.org/10.3141/2108-09

Calil Junior C, Dias AA, Góes LNG, Cheung AB, Stamato GC, Pigozo JC, Okimoto FS, Logsdon NB, Brzolin S, Lana EL (2006) Manual de projeto e construção de pontes de madeira. São Carlos, Suprema. 252p.

Fortino S, Hradil P, Koski K, Korkealaakso A, Fülöp L, Burkart H, Tirkkonen T (2020) Health monitoring of stress-laminated timber bridges assisted by a hygro-thermal model for wood material. Applied Sciences 11(1):98. http://dx.doi.org/10.3390/app11010098.

Franke B, Franke S, Müller A (2014) Case studies: long-term monitoring of timber bridges. Journal of Civil Structural Health Monitoring 5(2):195-202. http://dx.doi.org/10.1007/s13349-014-0093-4

Jutila A, Salokangas L (2000) Research on and development of wooden bridges in Finland. Structural Engineering International 10(3):182-185. http://dx.doi.org/10.2749/101686600780481455

Kromoser B, Spitzer A, Ritt M, Grabner M (2023) Wooden Bridges: strategies for design, construction and wood species: from tradition to future. International Journal of architectural heritage 18(4):652-668. http://dx.doi.org/10.1080/15583058.2023.2181719

Mahnert KC, Hundhausen U (2017) A review on the protection of timber bridges. Wood Material Science & Engineering 13(3):152-158. http://dx.doi.org/10.1080/17480272.2017.1403955

Milani CJ, Kripka MA (2012) Identificação de patologias em pontes de madeira: diagnóstico realizado no sistema viário do município de Pato Branco - Paraná. Revista Eletrônica de Engenharia Civil 4(1): 23-33.

Molina JC, Calil Junior C (2010) Development of timber-concrete composite bridge decks in Brazil. The Structural Engineer 87(1): 26-33.

Morais WWC, Oliveira TM, Vivian MA, Barni PE, Morais JBF (2022) Proposta de protocolo rápido para a inspeção visual de pontes de madeira. Advances In Forestry Science 9(2):1761-1771. http://dx.doi.org/10.34062/afs.v9i2.13532

O'Born R (2018) Life cycle assessment of large-scale timber bridges: a case study from the world's longest timber bridge design in Norway. Transportation Research Part D (59):301-312. http://dx.doi.org/10.1016/j.trd.2018.01.018

Oliveira KA, Oliveira CAB, Molina JC (2022) Physical, chemical and mechanical characterization of Acrocarpus Fraxinifolius cultivated in Sao Paulo. Maderas-Ciencia y Tecnologia 24:1-8. http://dx.doi.org/10.4067/s0718-221x2022000100409

Ostrycharczyk AW, Malo KA (2022) Network arch timber bridges with light timber decks and spoked configuration of hangers – Parametric study. Engineering Structures 253:113782. http://dx.doi.org/10.1016/j.engstruct.2021.113782

Oy RL, Pham HS, Foret G (2009) New wood composite bridges. European Journal of Environmental and Civil Engineering 13(9):1125-1139. http://dx.doi.org/10.1080/19648189.2009.9693178

Rashidi M, Hoshyar AN, Smith L, Samali B, Siddique R (2021) A comprehensive taxonomy for structure and material deficiencies, preventions and remedies of timber bridges. Journal of Building Engineering 34:101624. http://dx.doi.org/10.1016/j.jobe.2020.101624

Ribas Junior AS, Molina, JC (2020) Wooden bridges with deck of sawn board and round beams: main orientations. Australian Journal of Structural Engineering 22(1):1-9. https://doi.org/10.1080/13287982.2020.1862968

Scolaro TP, Pereira LE, Trombetta J (2020) Comparativo de impacto ambiental de sistemas construtivos de superestruturas de pontes. Mix Sustentável 6(3): 107-116. http://dx.doi.org/10.29183/2447-3073.mix2020.v6.n3.107-116

Seppälä M, Ilgın HE, Karjalainen M, Pajunen S (2023) An analysis on finnish wooden bridge practices. Applied Sciences 13(7):4325. http://dx.doi.org/10.3390/app13074325

Simon A, Jahreis M, Koch J (2023) Improvement of the durability of timber bridges by intelligent design and responsible maintenance. In: World Conference On Timber Engineering (WCTE 2023). http://dx.doi.org/10.52202/069179-0396

Srikanth I, Arockiasamy M, Nagarajan S (2022) Performance of aging timber bridges based on field tests and deterioration models. Transportation Research Record 2676(10):315-327. http://dx.doi.org/10.1177/03611981221089297

Zhang F, Shi L, Liu S, Shi J, Shi C, Xiang T (2022) CFD-Based fire risk assessment and control at the historic dong wind and rain bridges in the western hunan region: the case of huilong bridge. Sustainability 14(19):12271. http://dx.doi.org/10.3390/su141912271