

Fiberglass and resin composite deck for temporary bridges

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RESUMO: O tabuleiro é o componente com maior desgaste em pontes temporárias. O interesse pelo uso de materiais compósitos na engenharia é crescente mundialmente, sendo o de fibra de vidro e resina (GFRP) o com melhor custo benefício. Esta pesquisa, tem por objetivo avaliar, experimentalmente, um tabuleiro em GFRP para aplicação na ponte Bailey. Os painéis avaliados do tabuleiro foram fabricados por pultrusão e laminação manual. O programa experimental consistiu em ensaios de caracterização dos materiais componentes do painel, ensaios de flexão até a ruptura e de fadiga na flexão. A carga-tipo adotada foi correspondente à roda da viatura Astros 2020. Os resultados dos ensaios, indicaram elevada resistência à flexão dos tabuleiros, porém grande deformabilidade e baixa resistência ao cisalhamento, esperados para este tipo de material. Os painéis atendem aos limites de flecha e resistência para veículos com carga de serviço de até 25 kN por roda.

PALAVRAS-CHAVE: Tabuleiro. GFRP. Ponte Bailey.

ABSTRACT: Decks suffer the greatest deterioration among the various components of a bridge. The interest in using composite materials in engineering applications is increasing worldwide, and Glass Fiber Reinforced Polymers (GFRP) offers the best cost- benefit ratio. The aim of this research is to evaluate experimentally the performance of GFRP deck for application in a Bailey bridge. The tested deck panels were manufactured by pultrusion and manual lamination. The experimental program consisted in obtaining physical and mechanical properties of the panels' materials and the bending and fatigue behavior of the panels. The load applied corresponded to the wheel load of an Astros 2020 vehicle. The bending tests revealed that the decks present high bending resistance, great deformability, and low resistance to shear. The panels meet the limit deflection and resistance required for vehicles with service loads up to 25 kN per wheel.

KEYWORDS: Deck. GFRP. Bailey bridge.

1. Introduction

Temporary bridges are useful to society in case of floods and bridge collapses and to overcome obstacles in the field or in military operations. These bridges are usually manufactured with metallic materials, mainly steel and aluminum, having high own weight and being exposed to corrosion, in the case of steel, which causes premature deterioration of its components. The bearing structure of the bridge deck, made up of metal stringers and steel or wooden platforms, is the component with the most wear and tear because it remains exposed to the weather, or because it is in direct contact with the vehicles that travel there. [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11] In the United States of America, for example, there are more than 600,000 bridges, in which around 25% of them have decks that are structurally deficient or obsolete. [7, 9].

Fiber Reinforced Polymer – FRP (Fiber Reinforced Polymer) is a composite material formed by a fiber reinforcement embedded in a polymeric matrix. The most used fibers are glass, carbon and aramid. The most common resins are polyester and vinyl ester. The polymer reinforced with carbon fibers - CFRP (Carbon Fiber Reinforced Polymer) has a higher modulus of elasticity and greater resistance, but has a higher cost. The polymer reinforced with glass fibers - GFRP (Glass Fiber Reinforced Polymer) presents mechanical resistance compatible with those of steel, lower cost, having, therefore, a greater tendency of use among composite materials for structural projects in civil engineering. [1]

Its main advantages are: immunity to corrosion, high mechanical resistance in relation to low own weight, resistance to fatigue and the possibility of being molded in different formats. [2, 3, 4, 5, 6] Despite the higher initial costs compared to other conventional materials

used in civil engineering, such as concrete and steel, characteristics of composite materials such as immunity to corrosion and lower own weight reduce maintenance costs throughout the useful life of the structure. [7, 8, 9, 10] Fiberglass composite materials may exhibit premature wear when subjected to direct UV rays. [1, 2, 3, 10]

The first bridge entirely made of GFRP, which is known, was built in 1982 in China. [6,11] In recent decades, the use of GFRP decks in bridge rehabilitation or construction has increased considerably. [2, 3, 9, 10, 11] In the United States of America, research with this type of material began in 1980 and, in 1995, the study of bridge application began. [9, 12] In Europe, since the beginning of the 2000s, there has been great interest in the use of FRP in the bearing floor of new or existing bridges. [3] South Korea began research, funded by the government, in 2000. [4, 10] In these regions, there are many reinforced concrete bridges, which suffer oxidation due to the frequent use of salt to thaw the tracks during the winter.

FRP decks are easy to install and have high impact absorption energy, guaranteeing a useful life close to 50 or 60 years, much longer than the 15 to 20 years expected for concrete structures in these regions [3, 10] The transport and handling of the trays is a point to be observed, considering the possibility of damage to the material during these procedures. [1, 2, 10, 13, 16]

GFRP decks can be classified as sandwich or pultruded. The first consists of two plates of steel, aluminum or composite materials, “stuffed” with a lighter material, such as foam (polyvinyl chloride, polyurethane and other organic polymers), plywood or even composite material. The second comprises profiles manufactured by the pultrusion process, with triangular, rectangular, trapezoidal or hexagonal shapes. [2, 13, 14] The deck can be manufactured as a single piece or the profiles can be glued or screwed together. [6, 14] Hybrid boards, manufactured with GFRP and steel, for example, have already been studied. [4, 15]

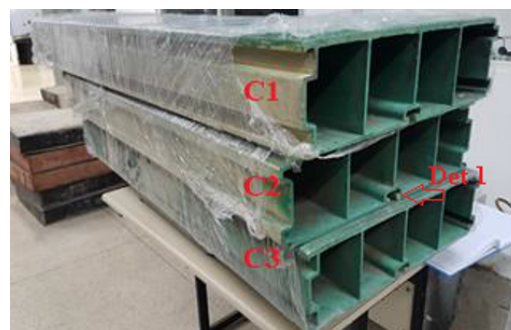


Fig. 1 – Panels tested in this research. Source: [1].

In the researched literature, the authors performed static flexion tests [2, 4, 5, 6, 7, 10, 12, 13, 14, 16, 17] and dynamic bending tests. [2, 4, 7, 14, 17] The failures most commonly observed by the authors in GFRP decks were detachment of the profiles and delamination of the material. [1, 2, 4, 6, 7, 10, 13, 18] Experimental results confirm that sag and shear strength are the most critical parameters in GFRP decks. [4, 5, 6, 9, 10, 11, 12, 16]

One of the first uses of composite decks for military applications was on the Composite Army Bridge in 1999. [19, 20] The Brazilian Army established as one of its strategic objectives the development of a demountable dual-use bridge. The bridges manufactured in Brazil are still from the 1940s and 1970s, being mainly made of steel and, therefore, heavy and susceptible to corrosion.

Research available in the literature on bridge decks in composite materials has limited information. There is no scientific exploration into the use of decks made of composite materials or the manufacture of components for this purpose in Brazil. So, this is a nationally pioneering research on the subject, whose main objective is to evaluate the experimental behavior of a deck made of polymer reinforced with fiberglass and resin (GFRP) in replacement of metallic spars and wooden platforms of Bailey bridges.

2. Proposed Board Panel And Bailey Bridge

The panels evaluated in this research were manufactured by the Italian company Top Glass, provided for the research by the company Cogumelo, located in the city of Rio de Janeiro – RJ. These panels are entirely pultruded, forming a single piece (**figure 1**), and were manufactured with polyester resin and type “E” glass fibers.

The original application of this deck panel was for use as a helipad, the panels being fitted together and screwed (**see detail 1 in figure1**) in the lower fitting below the central internal web. For the present research, the objective was to use the panels to compose the deck of temporary bridges, with variable width, according to the need.

The measurements of the panels are 500 mm wide and 153 mm high. Two 1280 mm long panels were tested, one 1600 mm long and one 960 mm long. The three longest panels were flexion tested and the shortest panel was used in the manufacture of samples used in the physical and mechanical characterization tests of the material. The panel dimensions are shown in **figure 2**. The table top has a 3mm layer of non-slip material.

The Brazilian Army has several bridge crews, with emphasis on the Logistic Support Bridge, M4T6 and Bailey. [1] The deck under study applies to temporary bridges such as the Bailey Bridge, and has the function of replacing the metallic spars and wooden platforms of this bridge, as shown in **figure 3**.

The Bailey Bridge originated in the Second World War, and can be mounted in a self-supporting way or on floating supports. The panels that make up the longitudinal beams are latticework, and the structure can be assembled in up to three rows with up to three floors high each. Thus, bridges can be assembled as single-single to triple-triple. **Figure 3** features a simple double bridge. The distance between the crossbeams is 1,524 mm and the width of its upper table, which supports the metal beams of the deck, is 114 mm. The bridge is demountable,

designed for military use and spans up to 64 meters, with a load capacity of up to 333 kN. [21, 22, 23].

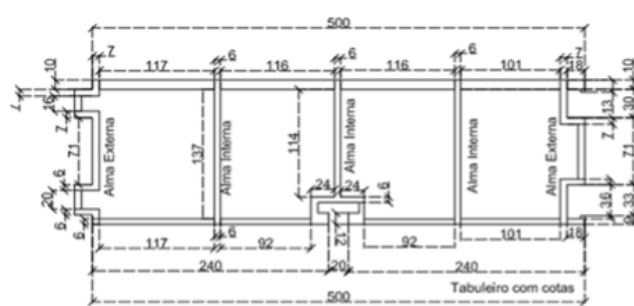


Fig. 2 – Geometry of the tested panels (dimensions in mm). Source: [1].

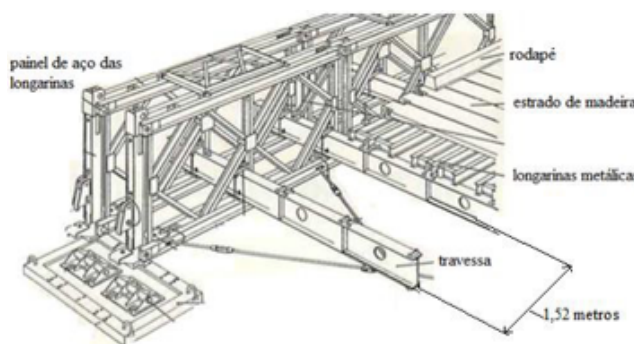


Fig. 3 – Main constituent elements

Figure 4 shows a Bailey bridge supported by uniflotes. Its construction does not require special or heavy equipment. Its knowledge and assembly are part of the school curriculum of all career military personnel (officers and sergeants) in the Engineering branch. The bridge deck suffers a high level of wear due to the rotting of the wooden planks and consequent corrosion of the metallic deck panels. [1, 21-23]

The Brazilian Armed Forces have several military vehicles, the Astros 2020 being the heaviest on wheels, which will be adopted in this study. The vehicle consists of six wheels, with a maximum load of 48.9 kN per wheel and 326 mm x 345 mm the contact area of its wheels with the ground, which is the area for carrying out the flexion test.

3. Experimental Program

The experimental program consisted of characterization tests of the physical and mechanical properties of the component materials of the panels, static bending tests and fatigue in bending the panels.

3.1 Characterization tests of physical and mechanical properties



Fig. 4 – Bailey bridge (supported on unilocks). Source: [23].

The following tests were performed: specific weight [24], percentage of fibers [24], traction [25, 26], shear, [27, 28] longitudinal compression to the fibers [29] and compression transverse to the fibers [29], according to the American Society of Testing and Materials (ASTM) and International Standardization for Organization (ISO), as there are no similar standards established by ABNT for composite materials.

The samples were divided into three groups: upper table, lower table and inner core. **Table 1** presents the summary of the results of percentage of total fibers, percentage of long fibers, specific weight (γ) longitudinal modulus of elasticity in traction (E_t), Poisson coefficient in traction (ν_t), tensile strength (f_t), shear strength transverse to the fibers (σ_{23}), shear strength parallel to the fibers (σ_{12}), resistance to longitudinal compression to fibers (f_{cl}), compressive strength transverse to the fibers (f_{ct}), modulus of elasticity in longitudinal compression to the fibers (E_{cl}) and Poisson's coefficient in the longitudinal compression of the fibers (ν_{cl}). The board samples from company C were manufactured from a 960 mm long panel cross-section, as shown in **figure 5**.

From the analysis of **table 1**, we have that the percentage of long fibers is high in relation to the total

fibers in the cores and in the tables. The parameters of γ , E_t , ν_t , f_t , σ_{23} , σ_{12} e f_{cl} are lower than those found in [1, 5, 13], which shows a lower quality of the analyzed material.

3.2 Methodology of bending tests

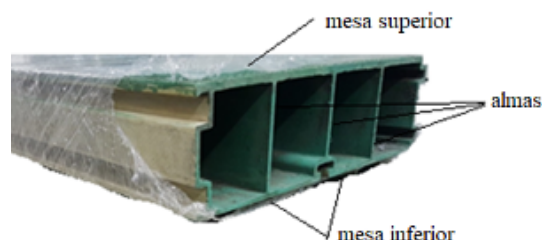


Fig. 5 – Division of sample groups in the tested panel. Source: [1]

The panels shown in **figure 1** were supported on metallic “I” profiles with a width of 114 mm, simulating the sleepers of the Bailey Bridge (see **figure 3**). **Figure 6 and 7** present the scheme of the test carried out. The “I” profiles were fixed in two reinforced concrete blocks (350 mm x 350 mm x 1000 mm) by means of screws. Panel C1 was tested with a span of 1,450 mm and panels C2 and C3 with a span of 1,220 mm. The load was applied centrally on the panel, in an area of 345 mm x 326 mm. A 25.4 mm thick steel plate was used over a 9 mm thick neoprene plate.

The tests were carried out at the Construction Materials and Concrete Laboratory at IME. An MTS brand hydraulic actuator with a capacity of 1000 kN was used. For the acquisition of deformation and displacement data, the data acquisition system model ADS 2000, from the Lynx brand, was used, connected to a computer.

Tab. 1 –Physical and mechanical properties of the composite material of the decks.

Perfil	Alma	Mesa Superior	Mesa Inferior
% de fibras totais	59,0% ± 0,9%	49,2% ± 1,3%	62,1% ± 1,8%
% de fibras longas	52,2% ± 1,2%	45,5% ± 1,4%	54,8% ± 1,7%
γ (N/m³)	23,6	19,6	21,4
E_t (GPa)	26,4	28,7	28,3
ν_t	0,28	0,29	0,28
f_t (MPa)	384,5	389,8	345,7
σ_{23} (MPa)	22,1	15,0	22,0
σ_{12} (MPa)	9,2	5,3	8,6
f_{cl} (MPa)	325,5	281,1	248,7

The panels were instrumented with four electrical resistance strain gauges, in the longitudinal direction of the panel and two LVDT, all in the lower part of the panel. **Figure 8** shows the arrangement of strain gauges and LVDT on the bottom of the deck and **figure 9** shows the instrumented panel on the supports.



Fig. 8 — Instrumentation of the panels. Source: [1].

Given that there is no standardization for carrying out tests on GFRP trays, an attempt was made to base the test on the literature studied [2, 4, 5, 6, 7, 8, 9, 10, 12, 13, 14, 15, 16, 17, 30, 31], with adaptations for the conditions and objectives of this research. In this way, it was decided to load at a constant speed of 5 kN/min, and divided into steps of 15 kN, 25 kN and 35 kN. When the loading reached one of these thresholds, the sample load was kept constant and the panel was inspected before the test continued. Após o último patamar (35 kN), samples were loaded to failure.

4. Results And Analysis Of Bending Tests

The results of the static and fatigue tests are presented below.

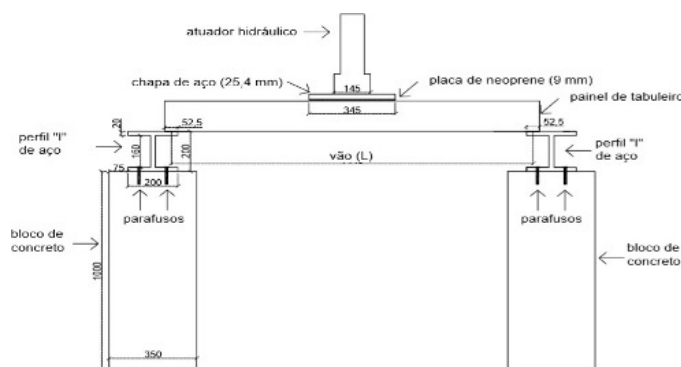


Fig. 6 – Test scheme adopted (dimensions in mm). Source: [1].

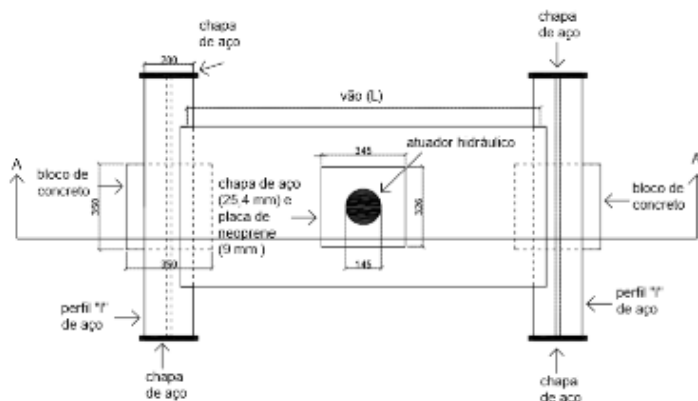


Fig. 7 – Top view of the adopted test scheme. (dimensions in mm). Source: [1].

4.1 Static bending tests

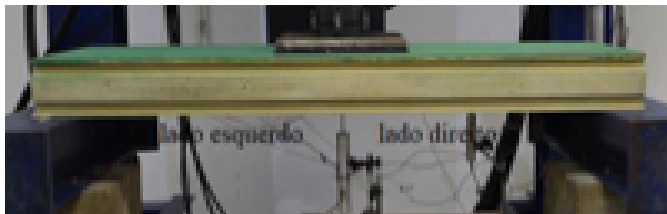


Fig. 9 – Front view of the static test. Source: [1].

Panels C1 and C2 were subjected to static bending tests in spans of, respectively, 1,450 mm and 1,220 mm. Both panels withstood all three applied load levels well, showing no signs of visible or audible damage. When reaching the load of 48.9 kN, corresponding to the load per wheel of the Astros 2020 vehicle, the deflection in position 1 was approximately 8.86 mm (L/157) for C1

and 7.22 mm (L/169) for C2. Fig. 10 shows panels C1 and C2 after failure.

From a load of 60 kN onwards, cracking noises were heard with panel C1. First, there was the appearance of a shear cut in the connection to the bolt in the central internal web. This effect increased until the deck ruptured, which occurred with a load of 90.8 kN, with a deflection of approximately 17.58 mm (L/82). The rupture was characterized by the shearing of the first internal web close to the lower flange and the connection for the screw in the central internal web and by the delamination of the lower flange close to the third web.

In the test with panel C2, the first damages become audible under a load of 50 kN, although no apparent damage was observed. The failure occurred under a load of 59.4 kN, with a deflection in the central span of 12.41 mm (L/112). The rupture was characterized

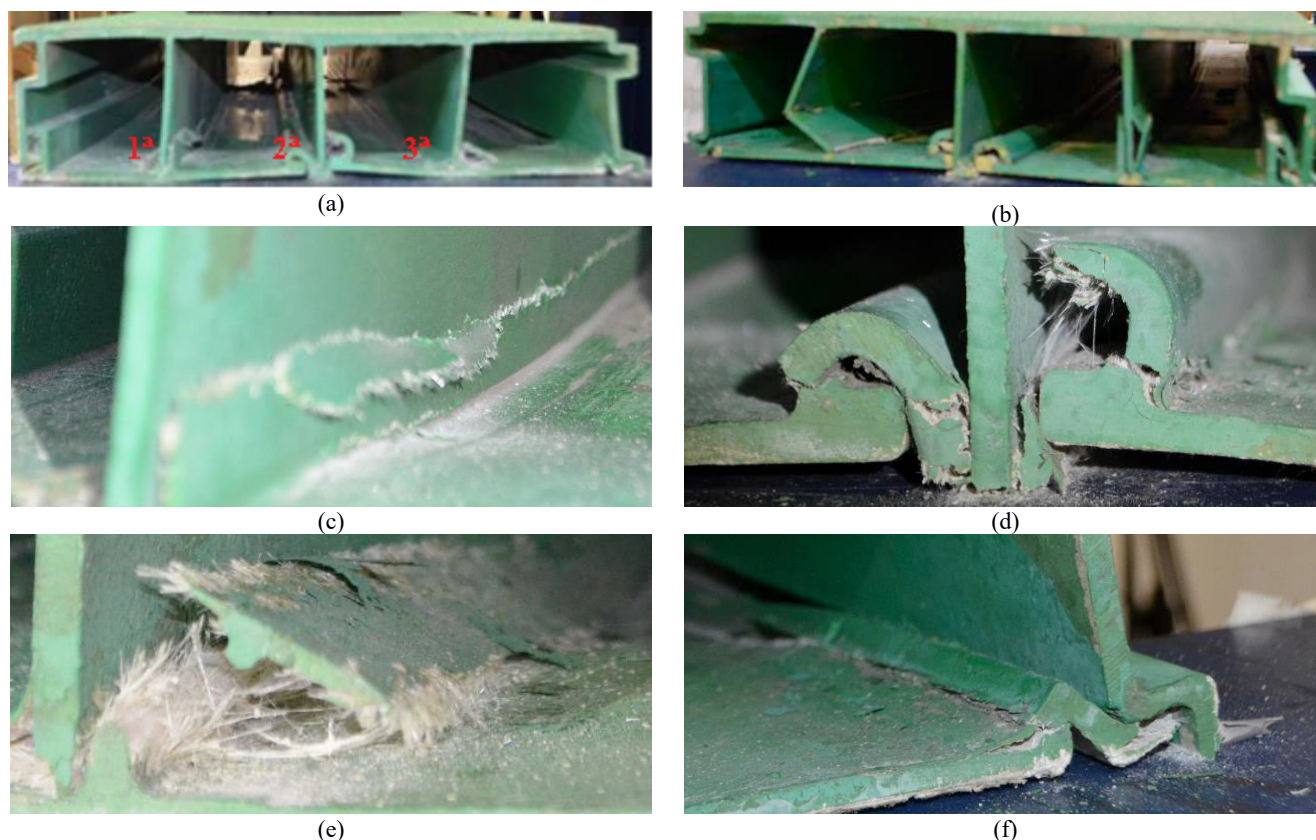


Fig. 10 – Panels after rupture: (a) panel C1; (b) panel C2; (c) shear of the inner web and (d) of the connection for the bolt in the central inner web; (e) delamination of the lower table; and (f) shear of the outer web. Source: [1]

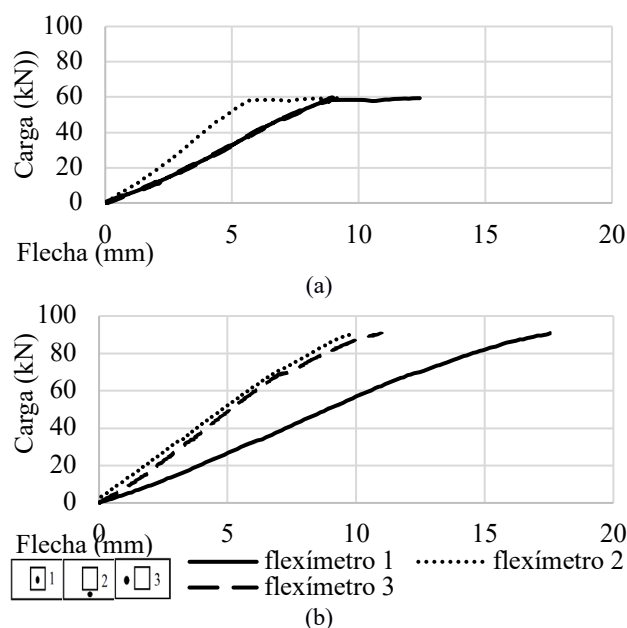


Fig. 11 – Load x sag curves of panels (a) C2 and (b) C1. Source: [1].

by the shearing of the three inner webs, including the connection for the screw in the central inner web. It is observed that there was distortion of the section until failure, caused by failure of the web by transverse bending.

Table 2 presents the loads, deflections and rupture strains of panels C1 and C2. Positions 1, 2, 3 and 4 correspond to the same ones shown in **figure 9**.

Figure 11 presents the load x deflection curves of the panels. There is a slight loss of stiffness of panel C1 after a load of 68.9 kN. Panel C2, shortly before failure, before the load of 58.4 kN, LVDT 1 and 2 jumped from 8.8 mm and 5.73 mm to, respectively, 11.0 mm and 7.7 mm, indicating damage to the panel. The breaking load was 59.4 kN. The load x deflection curves of the panels show that the central web absorbs more loads than the others.

Figure 12 shows the load x specific deformation curves for panels C1 and C2. Panel C1 showed a linear behavior up to a load of 68.9 kN, when strain gauges 2 and 3 undergo a course change, indicating the occurrence of damage to the material and confirming the loss of rigidity of the deck already verified in the load x displacement curves. Faced with a load of

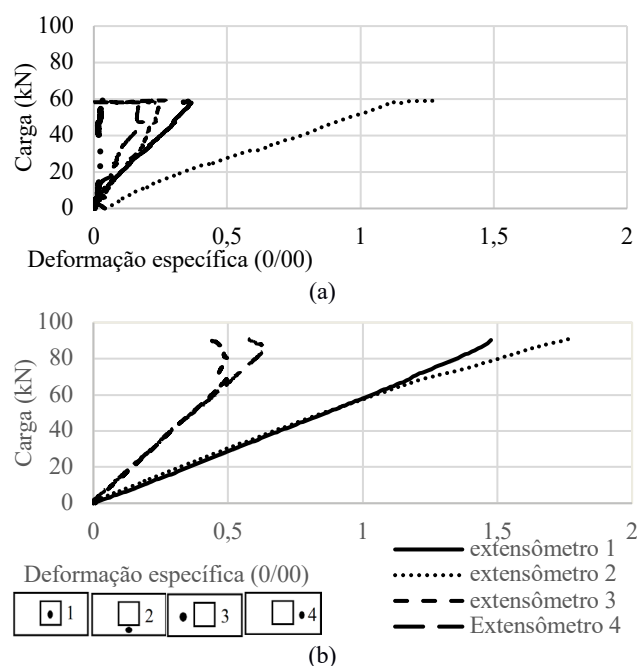


Fig. 12 – Load x deformation curves of panels (a) C2 and (b) C1. Source: [1].

86.3 kN, extensometer 4 underwent a course change, indicating a serious failure in the structure.

4.2 Bending Fatigue Test

The bending fatigue test was carried out on panel C3 with a span of 1,220 mm. The adopted frequency was 3 Hz, up to 2.11 million charging cycles. The maximum test load was defined based on the performance of panels C1 and C2, considering the limit deflection in service of $L/250$. In panel C1, this load corresponded to 30.3 kN, and in panel C2 it corresponded to 29.9 kN. Thus, the average load of the tests was increased by 10%, resulting in 33 kN, which corresponded to 36% of the breaking load of panel C1 and 55% of the breaking load of panel C2. The minimum force applied was 10% of the maximum force (3.3 kN). The applied load was of the sinusoidal type.

Amos- tra	P _{rup} (kN)	Vão (m)	Flecha _{rup} (mm)			Deformação(°/00)			
			1	2	3	1	2	3	4
C1	90,8	1,45	17,6	9,9	11,0	15	18	4	6
C2	59,4	1,22	12,4	9,2	-	4	13	3	2

Tab. 2 – Loads, deflections and rupture deformations.

The LVDTs were withdrawn on cycle 113,313 for fear of equipment damage due to cyclic loading and possible panel rupture. **Figure 13** presents the load x sag curves of the LVDT in position 1 (see **figure 8**). From the analysis of the curves, it is verified that there was no loss of stiffness of the C3 panel due to the fatigue test up to cycle 113.313.

The extensometers did not show any considerable increase in deformation throughout the test. The panel was inspected during the test and no visible signs of damage were found. A detailed inspection was carried out at the end of the test, and also no damage was found.

After carrying out the fatigue test, the bending panel rupture test was carried out. In this test LVDT were used in positions 1 and 2 (see **figure 8**). The load levels adopted were the same as for the other panels. The panel held up well to all landings, showing no visible signs of damage and no creaking of the material having been heard. At the standard load of 48.9 kN, the recorded deflection was approximately 6.36 mm, corresponding to $L/192$, having been 11.7% smaller than the deflection obtained in the C2 panel test for the same span and load.

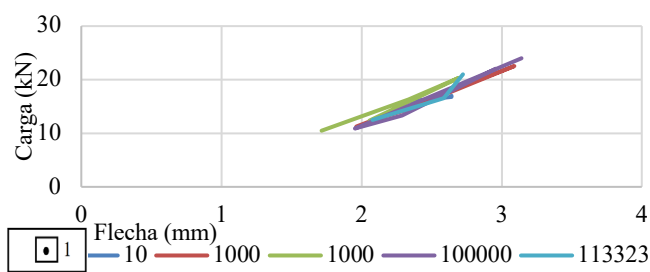


Fig. 1.
1. Source: ...

The LVDTs were maintained until the end of the test. From a load of 50 kN onwards, crackling of the material began to be heard, but without visible damage. The breaking load was 77.8 kN, a value higher than that obtained in the C2 panel test. The recorded deflection was approximately 10.06 mm, a lower value than that obtained in panel C2.

Figure 14 shows the panel after performing the test. The second and fourth inner cores ruptured by shear, and there was delamination of the lower table next to them. It can also be observed that the shear failures of the outer webs, in addition to the failure of the screw engagement, below the intermediate inner web.

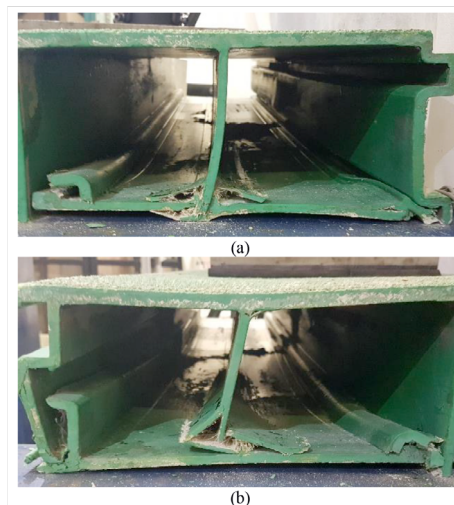


Fig. 14 – Panel C3 after rupture: (a) view of the first and second cells, (b) view of the third and fourth cells.

Figure 15 compares the load x sag curves of LVDT 1 and 2 and load x deformation of extensometer 2 obtained in panels C2 and C3. It can be seen that the load x sag and load x deformation curves of panel C3 have a greater inclination than those of panel C2, indicating a more rigid behavior of panel C3.

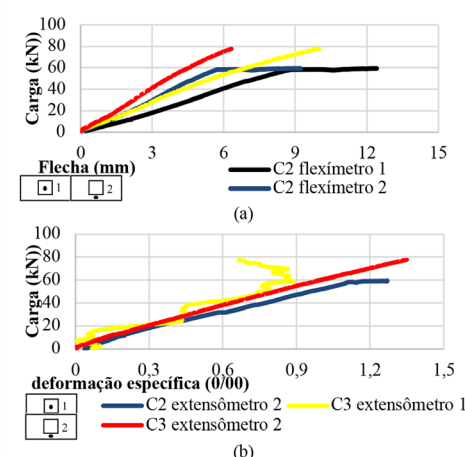


Fig. 15 – Curves (a) load x deflection and (b) load x deformation, regarding the comparison between the static tests of panels C2 and C3.

By comparing panels C2 and C3, it can be concluded that the performance of panel C3 was superior, indicating that the maximum load in the fatigue test can be increased, given that no damage was observed on the panel.

4.3 Results Analysis

The experimental results obtained, despite the small amount of samples, allowed some interesting analyses. The panels supported the wheel load of the Astros 2020 vehicle (48.9 kN), although it is not recommended to adopt these panels for the passage of this vehicle, considering that the ratio between the wheel load and the rupture (59.4 kN) in panel C2 was 1.21, lower than the standard of 1,39 recommended by EUROCOMP [30], as shown in **table 3**.

The arrow recommended by the FHWA [31] is L/800. This parameter considers aspects such as user comfort and traffic speed, and is therefore high for temporary bridge standards, whose main purposes would be military or humanitarian use, situations where user comfort and traffic speed are secondary.

The EUROCOMP [30] recommends a maximum sag of L/300 for vehicle load considered to be of short duration. The panel's own weight was neglected, as it corresponds to less than 1% of the vehicle's weight. The arrows obtained in panels C1 and C2 were greater than L/300 (see **table 3**), indicating the great flexibility of the material. The loads corresponding to a deflection of L/300 were 25.6 and 25.5 kN, respectively, for panels C1 and C2.

The fatigue test showed that the GFRP deck withstood the 2.11 million load cycles without suffering damage, corroborating results already highlighted in the literature. [2, 4, 7, 14, 17] The load x arrow curve for panel C3 approached the load obtained for panel C1.

Tab. 3 – Static test results for panels C1 and C2.

Painel	C1	C2
Vão (mm)	1.450	1.220
P _{tip} (kN)	48,9	48,9
δ_{tip} (mm)	L/164	L/169
P _{rup} (kN)	90,8	59,4
P _{rup} / P _{tip}	1,86	1,21
Peso próprio (kg)	42,8	33,8
σ (MPa)	29,7	19,4
FS (P _{rup} /P _{tip})	1,9	1,2

Tab. 4 – Size and weight of deck C

Dimensões (H x L) (mm)	153 x 500
Peso do painel (N)	388,3
Peso por seção (A = 12,8m ²) (N)	6628,6
Peso por m ² (N/m ²)	517,8

Panel C3 had a superior performance, even after the fatigue test, in relation to sample C2, which was tested only statically, indicating that the material has good resistance to fatigue.

The use of LVDT throughout the test is fundamental for a more detailed analysis of the behavior of the decks. The use of electrical resistance strain gauges in internal locations, such as internal cores, internal parts of tables and plates, would allow a better investigation into the forms of rupture. It should be noted that this was not carried out in this research because the samples were ready, making it impractical and ineffective to place extensometers in these places. It was found that the use of transverse extensometers in the direction of the fibers is unnecessary, since they are subjected to almost zero efforts. However, this statement needs further study to be conclusive.

All samples showed rupture at the bottom. Panels C showed rupture due to shearing of the webs and delamination of the lower flange, caused by the instability of the structure, which suffered torsion due to the small thickness of the webs.

Table 4 shows the dimensions of panel C. The Bailey bridge deck has a total mass of 1262 kg. If the bridge were completely filled with C panels, it would have a total weight per section of 665.1 kg (considering an area of 4,200 mm wide by 3,048 mm long), which

would correspond to a reduction of 47.3% in relation to the weight of the original Bailey bridge deck.

Although other aspects have to be taken into account, such as the placement of metal couplings or even the removal of couplings for the deck panels on the transoms, it can be concluded that GFRP decks would allow a substantial reduction in the structural weight of the Bailey bridge deck.

5. Conclusions

This work proposed the use of a GFRP deck for use in temporary bridges. The Bailey bridge was chosen as a parameter of dimensions, given that it has the shortest distance between sleepers and has its original deck made of steel and wood, as well as being the most widely used military bridge within the Brazilian Army.

Panels C have a self-weight corresponding to 0.46% of the breaking load of panel C1 and 0.56% of panel C2. The panel with the smallest span had a lower breaking load, which highlights the need for more tests. Tensile stresses in bending were low at failure when compared with the results of tensile tests. The rupture was characterized by instability of the structure, causing cuts in the supports and shearing in the web of the beams.

The dynamic test was performed without any apparent damage. A high breaking load was observed after the fatigue test, characterizing a superior result in relation to the static bending test conducted under similar conditions.

From the analysis of the results of static and dynamic tests, it was obtained that deck C can be used in temporary bridges subject to service loads of up to 25 kN per wheel. Although all samples presented rupture greater than the type load, it does not meet the safety coefficient and deflection criteria ($L/300$) established in EUROCOMP. [30]

The rigidity of the panels is much lower than most of the boards presented in the literature review. These works demonstrate the years of research and improvement

of the geometry of the decks, with a view to increasing resistance and rigidity and reducing weight.

Due to the high deformability of GFRP manufactured by pultrusion, this parameter ends up being load restrictive. Finally, the GFRP decks studied are 49% to 62% lighter than the original deck of the Bailey Bridge, making its use a great constructive advantage.

Acknowledgements

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