SUSTAINABLE PEDESTRIAN BRIDGE USING ADVANCED MATERIALS

SUPERBAM

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Fiber-reinforced polymer (FRP) pedestrian bridges are becoming a competitive alternative to conventional concrete and steel pedestrian bridges in spans ranging from 5 to 30 m. FRP materials are light-weight, high-performance, and durable materials which have a proven track record in a range of corrosive environments. Multiple life-cycle costs analyses have shown FRP bridge construction to be an economic competitive option when considering the associated costs to design, construction and maintenance operations. One way of achieving the cost competitiveness is by producing standardized systems to create a catalog of pre-engineered and versatile solutions for small and medium span pedestrian bridges.

Pedelta has led a research project to develop SUPERBAM, a new cost-effective and standardized pedestrian bridge. SUPERBAM provides the benefits of being high-strength, light-weight with the excellent durabilty of FRP materials. The emphasis on this Research Project has been to develop an efficient, competitive and aesthetically appealing structure system for small and medium span pedestrian bridges. The research has focused on conceptual studies and numerical models to validate and optimize the concepts. The constructed prototype has been tested in a research lab.

A detailed structural analysis and optimization of various cross-sections and laminate solutions have been carried out by using the Finite Element Method (FEM) under both static and dynamic loads to achieve the most cost-effective design. A specialized finite element analysis software has been developed with features that include pre-defined laminates database, automatic geometric construction and standard load cases definition. By using these tools, it is possible to make highly reusable molds for laminates which in turn will lower the overall cost of FRP bridges.

Figure 1

Introduction

The development and improvement of sustainable mobility around the world is urging the construction of pedestrian bridges in urban, rural, and remote areas. Meanwhile, developed countries around the world are coping with aging of transportation infrastructure. A significant number of bridges require periodic maintenance, even after major repairing or replacement to safely fulfill their functions. Construction of public infrastructure has a significant impact on sustainability, and the use of advanced materials such as FRP and stainless steel (SS) contributes to their sustainable development.

The goal of this research project is to use high-strength, light-weight, and reusable materials that require minimum maintenance and accelerate the construction. Most of the existing FRP pedestrian bridges are trusses made with pultruded standard profiles. There are technical limits on the use of these systems, mainly because of

Figure 2.1

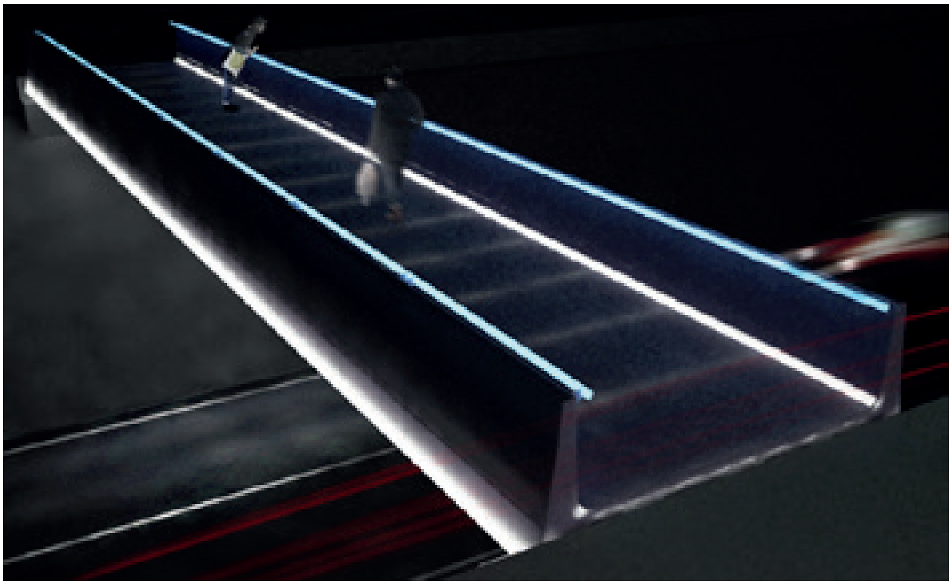


Figure 2.2

PAGE 36
Figure 1. Cross section of SUPERBAM bridge.

PAGE 37
Figures 2.1 & 2.2. Rendering views of the bridge by day and night.

PAGE 39
Figure 3.1. Graphic user interface of SUPERBAM software.

Figure 3.2. Graphic user interface window.

the fabrication process and the poor aesthetics. In addition, the connections are typically bolted and their design is one of the most critical challenges. Adhesive connections can also be used in combination with bolts. There is a need in the bridge industry for the development of new structural concepts using FRP or hybrid structures.

> “The goal is to use high-strength, light-weight reusable materials that require minimum maintenance and accelerate the construction”

The SUPERBAM Research Project was initiated accordingly, and it has developed specific geometries and aesthetically pleasing structural concepts to take full benefit of advanced materials (i.e. high-strength, light-weight, durable, and sustainable) by using modular systems.

Objective of the research

The objectives of the SUPERBAM Research Project include the following tasks:

1) Develop a catalog of standard pedestrian bridges made with advanced materials to cover small and medium spans (spans from 10 to 30 m). The structures will be assembled using light-weight modular members/profiles. Focus will be on the connections between members, which should be reliable and easy to build.
2) Prepare a standardized new concept by using railings as a part of the structure to optimize the use of materials.
3) Minimize the amount of connections in the structural system by using modular construction techniques.
4) Enhance the bridge aesthetics and provide room for customized details such as integrated lighting, handrailing and colours.
5) Develop specific methods for the design and sizing of the FRP structure.
6) Develop specific structural software for the detailed design, including tools for the design of connections.

Technological steps and how they have been addressed

The purpose is to develop specific FRP or hybrid structural concepts for pedestrian bridges instead of repeating the same solutions already being used for concrete and/or steel structures. This conceptual design includes the design of a modular construction structural system, the analysis of the dynamic behavior of ultra-light structures to mitigate vibration, and the design of connections and methods of assembly.

A feasibility study of deployable foldable structures has been conducted to assess the possibility of obtaining a structure with the ability to change its geometry from a compact configuration to a functional shape. A deployable structure requires active elements during installation. The new concepts are validated by using a specific numerical software, or adapting advanced numerical codes used in other industries (e.g. aerospace and naval industry).

An analysis of the manufacturing process was also conducted to select
i) the most suitable materials (e.g. GFRP, CFRP, Stainless steel, hybrid structures),
ii) the fabrication process (e.g. pultrusion, vacuum infusion, hand layout, etc.),
and iii) the structural shapes.

Fabrication technique

The traditional techniques that are used in the fabrication of the FRP components include:

Mold

The main structure has a U-shaped form and profiles will be constructed using separate molds. The molds should allow for the creation of various identical sections with minimal efforts. They must be cost-effective and reusable, and thus continued experimentation is being done. Molds are typically constructed by using a model.

To start, a prototype of the section is prepared and refined to eliminate imperfections. Successive layers of fabrics pre-impregnated with liquid resin are then placed to create an inverted self-supporting structure (i.e. the mold). Both single-use molds and permanent molds are possible. Molds can also be divided into male and female molds. A male mold is used to form the interior of the structure, and a female mold is used to form the exterior of the structure.

External laminate

The mold surface is stabilized at a high temperature and undergoes a vacuum integrity test. A release agent is applied on the stabilized mold surface. This is then typically followed by a thick layer of gelcoat, which is intended to provide a uniform finish with the desired color. A liquid resin is then applied and the first layer of reinforcing fabric is placed on top of it. Rollers are used to apply pressure over the fibers to infuse and deaerate the layer. These steps are repeated by applying layers of fabric and resin until the desired thickness is reached while ensuring that layers fit perfectly to the complex shape of the mold. Vinylester is used as a mat and is placed between consecutive thin fabric layers to absorb the resin and to achieve the thickness. An evolution in the structural design and resin matrices has allowed for a reduction in the use of the mat and a substantial increase in direct fiber proportion in the laminate. This reduces the number of layers necessary to obtain the design strength.

Vacuum technique

The incorporation of vacuum techniques in traditional contact lamination leads to important advances in physical and mechanical properties of composite materials. A soft closed container shrinks and eventually collapses if external pressure increases. The same effect occurs if the internal pressure decreases. By enclosing the laminate in a sufficiently sturdy bag and removing the air within, a uniform pressure of approximately 1 atmosphere (101.325 kPa) can be obtained at any point even if the form is complex in shape. The results obtained by vacuum lamination present significant advantages over traditional contact lamination. Benefits from this technique include reduction in thickness, air content and final weight. In addition, homogenous and uniform quality along with fewer imperfections is being achieved.

Sandwich infusion

The most basic and common process of all infusion techniques consists of first placing layers of fibers – the core – and other inserts over the outer surface of the mold without using resin. This can be done slowly to ensure a clean shape, which is an important factor for the final quality of the piece and the entire project. Once this first step is completed, the vacuum bag and other items specific for the infusion are placed over the group. When the assembly is sealed with the help of the vacuum, the first compaction is carried out to stabilize the piece, to increase fiber content per volume, and to reduce voids. After reaching the desired level of compression, inlets are opened to saturate the piece with liquid resin while all the air inside is expelled using vacuum tubes.

Assembly and finishing

The various pieces that comprise the pedestrian bridge are put together with mechanical connectors and structural adhesives. The final assembly will require final finishing, painting and polishing, until the desired finish is achieved.

Cross section

W: 1000 mm
A3: 1.15 deg
r: 100 mm
A2: 90 deg
H: 900 mm
A1: 15 deg
Thickness (t1): 100 mm

Figure 3.1

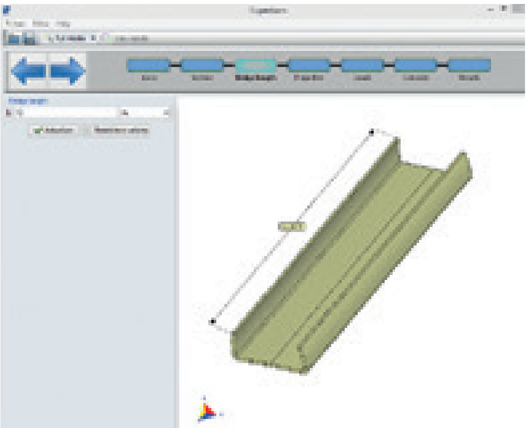


Figure 3.2

Software design

There are standard structural FEM analysis codes that can be used to model the behavior and design an FRP bridge. However, they are quite general and it takes time to prepare all the data required for analysis. It has been considered key for this project to develop a specialized structural modelling package to facilitate the design of FRP bridges. The RamSeries software package is a complete FEM environment for structural analysis. The software includes a composite module that allows an easy definition for materials and geometry, including laminate sequences and ply orientations. Static and dynamic analyses are both possible by using this software, and result verification is based on LaRC04 failure criterion that considers six failure modes

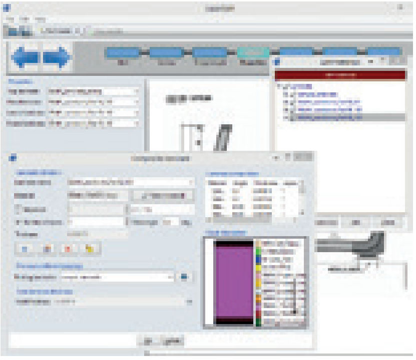
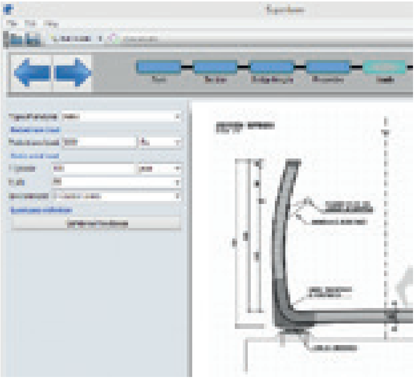


Figure 4



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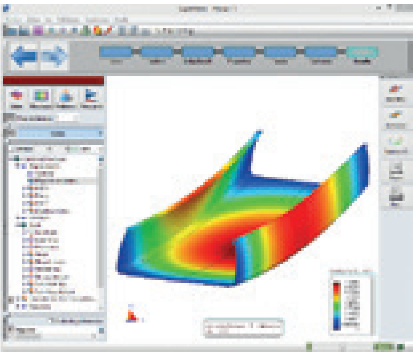

Figure 6

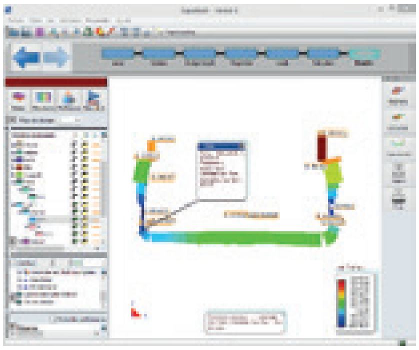

Figure7

and Tsai-Wu criterion. This new developed tool includes the latest algorithms and libraries involving graphical interfaces, database communication, and CAD geometry parametric creation. Furthermore, one of the main design objectives of the tool was to allow the user to obtain results quickly, with an automatic creation of the geometry and computer aided engineering (CAE) model.

> “ A new customized FEM SUPERBAM module is incorporated into the RamSeries software (© Compass Engineering) for the design of FRP bridge designs ”

As a result, the user is just requested to insert a few geometrical design parameters and data related to normative loads. In addition, sets of materials are pre-loaded to libraries, so the user can simply select them saving the time of creating the lamination sequences for the composites.

SUPERBAM FEM program

The bridge design tool developed by Compass Engineering for the SUPERBAM Project has an advanced Graphic User Interface (GUI) that allows a non-expert user to perform optimization on bridge design. The tool allows an easy definition of the geometry of the section and automatically creates a 3D CAD bridge model. It also automatically applies the boundary conditions, loads and material properties selected by the user. Finally, it generates the FEM mesh, calculations, and directly proceed to the post-process view, where the different results can be visualized and extracted as a report based on the user’s needs. Design guidelines for the software are summarized below.

Bridge geometry definition

The bridge cross-section has been designed to maximize the structural efficiency. Handrails are considered as structural components, minimizing the structural depth below the walkway surface. The cross-section is defined and modified using up to seven parameters. The defined cross-section is then extruded automatically up to the bridge length defined by the user.

Materials definition

It is possible to assign different laminates to different parts of the bridge, including top, floor, lateral or round laminates. The predefined materials can be modified and new ones can also be created.

Loads definition

In addition, the software also defines load items, such as wind, live, and accidental loads, partial safety factors, and structural verifications requirements. In the “Loads” section, the user can modify load parameters, which will be automatically applied to the model. Both static and dynamic loads can be inputted. For static analysis, it is possible to define the full set of combined load cases. For dynamic analysis, pedestrian loads are created. These loads have been implemented according to the theory in “Dynamic Behaviour

Figure 8

Figure 9

Figure 10

Figure 11

of Footbridges Subjected to Pedestrian-Induced Vibrations” [3]. Additional verifications have been made in accordance with the technical guide “Footbridges, Assessment of Vibrational Behavior of Footbridges under Pedestrian Loading” [4].

Results

The GUI also allows showing of the deformed shape of the structure, the stress contour under loads, and stress tensors in laminates. Extensive reports are auto-generated.

Prototype manufacturing

Among the different possible mold options such as inner/ outer mold, inner mold only, outer mold only, we decided to go with the inner mold only as the simplest option. We also decided to set up an arrangement for a single use, and the same approach applied to the environmental control. Profiles are in medium-density fibre boards (MDF); pine strips are used for reinforcements; plywood planks are used for shaped panels; and top sides are built with plasticized oriented strand boards (OSB), treated with demolding wax. For the manufacturing process, we chose the wet lay-up/hand lay-up technique where the resin is impregnated into sheets of fibers by hand by using metallic and soft rollers. The work is done under normal atmospheric conditions. To extend the working time for jellification and curing, we used a moderated amount of activator (1.25 - 1.75%) based on the ambient temperature. We sequenced the two types of fibers (Qaxial/ CSMat) in six layers, each according to their specifications table, overlapping the cloth over the bottom raised edge and always closing with a mat to ensure that the intermediate sanding is done over the previous one. The core selection includes two types of cross cut and one plain, applied by layers with care so the cuts do not overlap. The adhesive is fabricated by adding silica and chopped fibers to the resin of the basic laminate to achieve a specific density and to fill gaps. The outer skin in the lower section is laid up at the end. At the sides, they are laid up in a series of steps to stabilize the whole piece before turning over.

PAGE 40
Figure 4. User interface materials definition.

Figure 5. User interface loads definition.

Figure 6. Displacements.

Figure 7. Tsai-Wu criteria.

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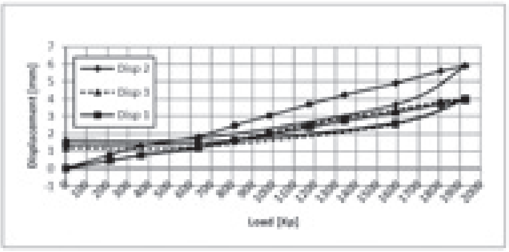
Figures 8 to 11. Manufacturing steps.



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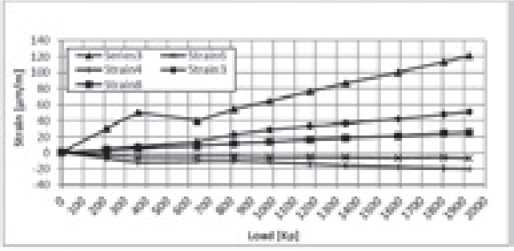

Figure 13

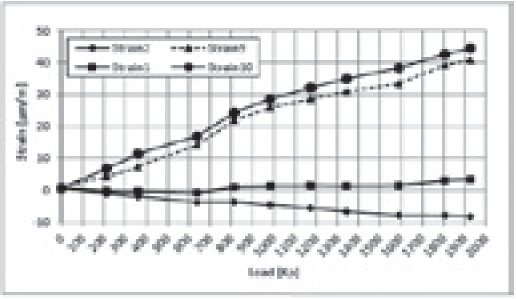

Figure 14

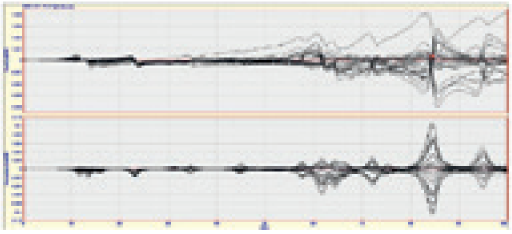

Figure 15

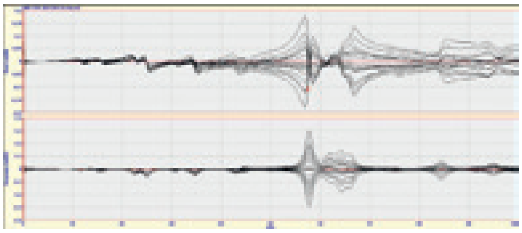

Figure 16

Edges are cut immediately before turning over. The front and the back sides are closed by overlapping the inner and the outer skins, so double thickness is achieved. This will be convenient if assemblies by spigots or other mechanical junctions between bridges are envisioned. Demolding is done immediately afterwards. The inner skin has a glossy finish at the sides but there is an anti-slip pattern in the middle (hidden by a peel-ply). This walkway is flanged by the drainage channels.

Prototype testing

Loads tests

Static and dynamic load tests have been performed in laboratory using a prototype created specifically for this verification. Prototype dimensions are 2.37 m (length) x 2.20 m (width) x 0.94 m (height).

Static load test

The prototype is supported over two simple wood supports with a 2 m clear span (L). Load was applied at the midspan by using sand bags. The load was progressively increased in 2.0 kN steps from 0 to 19.0 kN (Figures 13 and 14). The maximum measured deformation at midspan was 6 mm, which was below its maximum predicted value, L/205.

Dynamic load test

The objective of the test is to estimate the main dynamic parameters, including natural response frequencies, vibration modes, and damping of the prototype. To do so, a dynamic load is applied by using an instrumented hammer. Two dynamic tests were performed (Figures 15 and 16). One in the horizontal plane and the other in the vertical walls. From our practical experiences with other glass fiber reinforced polymer (GFRP) footbridges, the ranges for the first vibration mode damping are around 2.0 to 3.5% of the critical damping. For example, the measured damping for the GFRP Lleida pedestrian bridge designed by Pedelta is 2.5%. As expected for this test model, the measured damping was lower because additional damping from non-structural elements like railings does not exist. Only intrinsic damping from the composites is measured in this test.

Conclusions

SUPERBAM has been demonstrated as a competitive alternative compared to traditional solutions when considering life-cycle cost. SUPERBAM benefits of the high-strength, light-weight and excellent durability of the FRP materials. Moreover, these solutions are particularly suitable when there are special needs or constrains, like bridges located in remote areas or with difficult access, requirements for accelerated construction, and structures in corrosive environments.

The Pedelta research team has developed pre-engineered solutions for small and medium span pedestrian bridges. An advanced FEM structural software has been developed to analyze FRP composite laminate structures with a sandwich type panel using a polyethylene core and external GFRP laminates ●

PAGE 42
Figure 12. Displacement vs load.

Figure 13. Axial deformation vs load.

Figure 14. Shear deformation vs load.

Figure 15. Frequency response function horizontal.

Figure 16. Frequency response function vertical.

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Figures 17 to 20. Experimental tests.

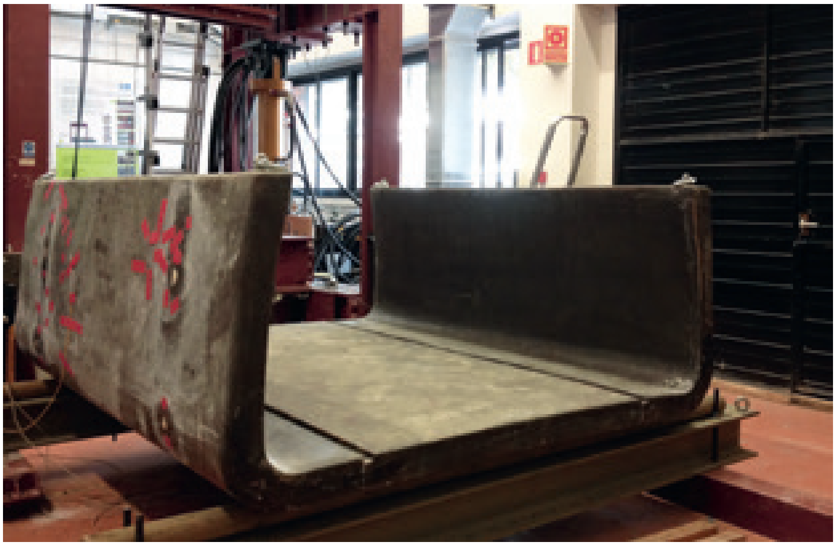
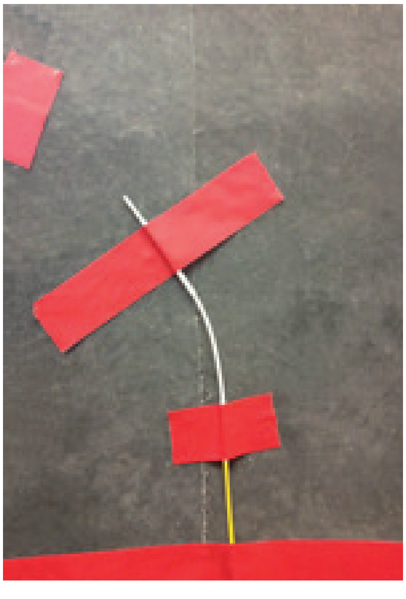


Figure 17

Figure 18



Figures 19 & 20

The authors would like to acknowledge ACC1Ó (Generalitat de Catalunya) and ERDF (European Regional Development Fund) for the funding support for the Research Project. And to the companies COMSA, StyleCarbon and Compass Ingenieria y Sistemas for their contribution.

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