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Economical solutions for short-span bridges using reinforced glue laminated timber and steel

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Abstract

The aim of this research was to develop new composite bridge concepts that are easily buildable and have a high grade of prefabrication by using reinforced glue laminated timber beams and steel trusses. All structural parts are designed so that minimal assembly is required and all elements are easily transportable.
Glue laminated timber reinforced with synthetic straps was chosen due to its superior resistance, enhanced elastic behaviour under loading-unloading cycles, and other good mechanical properties, all based on previously conduced experimental studies, as well as other known advantages of classic glue laminated timber elements.
A modular prefabricated bridge model was proposed that could cover small and medium spans and is both economic and easy to build.
These timber beams combined with the rigidity and light weight of steel trusses could make an affordable and strong alternative for concrete slabs or other prefabricated elements that are mostly used for short-span bridges.

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Keywords: glulam;timber;composite;lightweight;bridges

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1. Introduction

In modern civil engineering, efficiency and economy are key words that describe successful structural designs. By respecting these two guidelines and combining them with the use sustainable materials such as glue laminated timber and other recycled products we would like to promote a simple bridge structure that uses best of timber and steel as structural materials.

As an alternative to classic internal reinforcements such as steel rods, or external reinforcements FRP(fiber reinforced polymers), CFRP(carbon fiber reinforced polymers)[1] this paper promotes the use of plastic straps commonly used in the shipping and packaging industries witch are significantly cheaper, have a great tensile strength and are easily recyclable.

Glue laminated timber, further referred to as glulam, and proves to be the most efficient way of using wood with minimal waste in order to produce superior quality beams and other structural elements while providing a more homogenous dispersion of natural defects in the woods fibers throughout the length of the element.

2. Materials

As stated before the aim of this paper was to promote the use of sustainable and recyclable materials for a more eco friendly approach to building bridges. The main materials that were used in this study are as follow:

- Glue laminated timber
- Synthetic reinforcements
- Steel

2.1. Glue laminated timber

Glue laminated timber beams were used as main elements of the proposed structure for its superior strength to weight ratio though lowering the dead weight of the bridge by over 50-60%. Pressure treating the beams is highly recommended for an extended life span of the bridge.

Using timber for the construction of bridge decks offer several advantages compared to conventional methods, such as form-in-place concrete decks, mainly that no form work or lost time during the concretes curing process is required once the abutments are done so that the new or replacement structure can be deployed rapidly.

Other advantages are the use of lightweight and smaller erection equipment due to it's lower dead weight as compared to similar steel or reinforced concrete structural elements, and most of all the elimination of problems associated with the corrosion of steel deck elements or reinforcing steel in used in the concrete deck that is caused by the use of deicing salts.

2.2. Synthetic reinforcements

PET and bonded polyester yarns straps are two cheaper alternatives to standard reinforcements and form previous studies [2] proved to add significant amount of strength and elasticity to glue laminated timber beams.

These straps are relatively cheap and are used worldwide in the packaging industry and are really easy to recycle with minimal energy use. They have a great amount of tensile strength witch is exactly what it was required for this project and are only sensible to the sun's UV radiation from witch they are heavily protected between the wooden laminates.

The main advantages over standard steel reinforcements are: the price since they are made out of one of the cheapest materials that exist, superior resistance to corrosion and other harmful agents and also low self weight since it is important to use the lightest materials possible in order to lower the bridge's dead weight.

Experimental results regarding flexural behavior under loading-unloading cycles and until failure made on reinforced and non-reinforced glue laminated timber beams are presented and compared in the following figures.

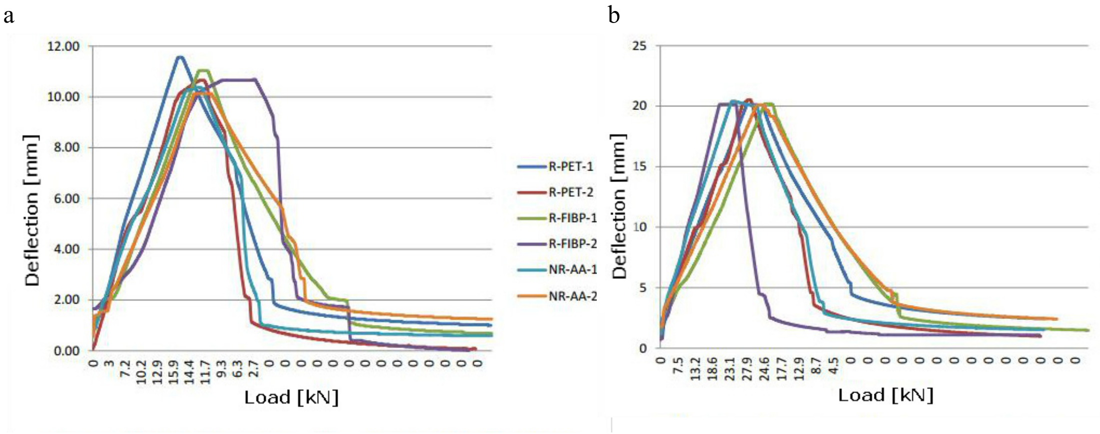

Fig. 1. (a) First loading-unloading cycle; (b) second loading-unloading cycle.

Four point bending tests were conducted on six glulam beams: two reinforced with PET straps (R-PET-1 and R-PET-2), two reinforced with polyester yarns (R-FIBP-1 and R-FIBP-2) and two non-reinforced ones (NR-AA-1 and NR-AA-2). All tests were conducted according to EN 408-2010 regulations regarding the preparation, testing and result gathering on timber elements [3].

The two loading cycles were meant to study the reinforced beams capability of returning to its initial shape, meaning zero deflection after the load was removed. For the first cycle the load was increased until a 10 mm deflection was obtained followed by an immediate unloading of the element and the second one, similar to the first cycle with the difference that the targeted deflection was 20 mm.

Not only that the reinforced beams showed an improved elasticity and recovery but the bonded polyester reinforced beams were the only ones to return to zero deflection and it was under 120 minutes after the load was removed, as non reinforced beams still had some remaining deflection even after several hours.

At the final stage of testing superior bending behavior was observed on the reinforced beams, with increases up to 26% in strength.

All beams had a similar elastic behavior and failure occurred suddenly and was manifested by longitudinal cracks throughout the elements as well as failure in the fibers from the compressed part of the beams.

In conclusion glulam beams reinforced with these synthetic straps are a superior alternative to non reinforced beams with a minor increase in the production costs.

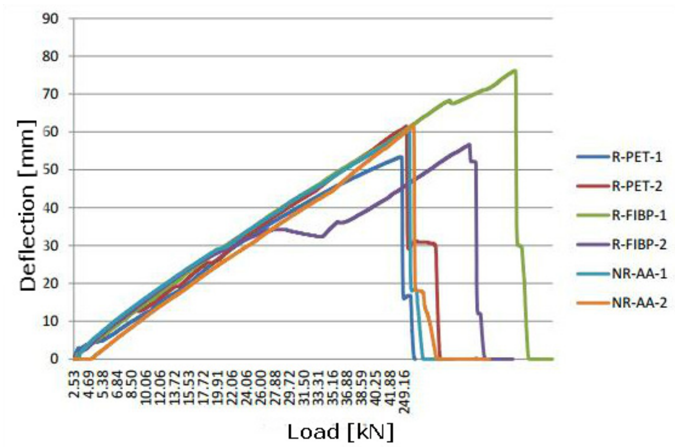

Fig. 2. Bending strength of tested beams.

2.3. Structural Steel

Since the last centuries steel is one of the most important building materials known to man, and evolved to the diversity of profiles with their optimized cross sections that we use today. Also now more than 80% of the structural steel that is fabricated comes from recycled metals making it a sustainable material.

3. Proposed modular bridge structure

For the proposed bridge structure the main elements that form the deck are some different sized reinforced glue laminated beams, that were presented earlier, witch are stress laminated together, with the help of threaded steel rods, in order to form a solid deck[5], reinforced by modular lateral trusses that are also the hand rails.

Optional cross girders are suggested for larger spans for witch I beam profiles are for their superior bending strength and ease of connection with the hand rail modules for witch different prefabricated profile can be used such as U, I, or L laminates.

The trusses are composed out of prefabricated diamond modules referred to as type 1 modules and one triangular module that closes the truss beam referred to as type 2 module. These modules connected between them and together with the cross girders and timber deck will form a solid, rigid structure for the future bridge.

All modules are two meter long so that the covered span can have a minimum of four meters and will have a two meter increment. This type of increments can cover most cases for short to medium spans.

The following figures present the proposed modular structure.

Modules are connected together using bolted joints and additional steel plates when needed to provide the extra tensile strength.

Alternated glue laminated timber beams with different heights could be used so that the dead load is reduced and that the material is used more economically and therefore more responsibly.

The prestressing rods connect not only the glue laminated beams, but also the lateral trusses so that they work together when loaded, though adding the needed extra strength.

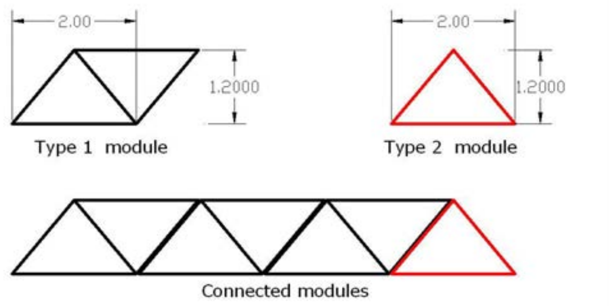

Fig. 3 Truss modules and assembly

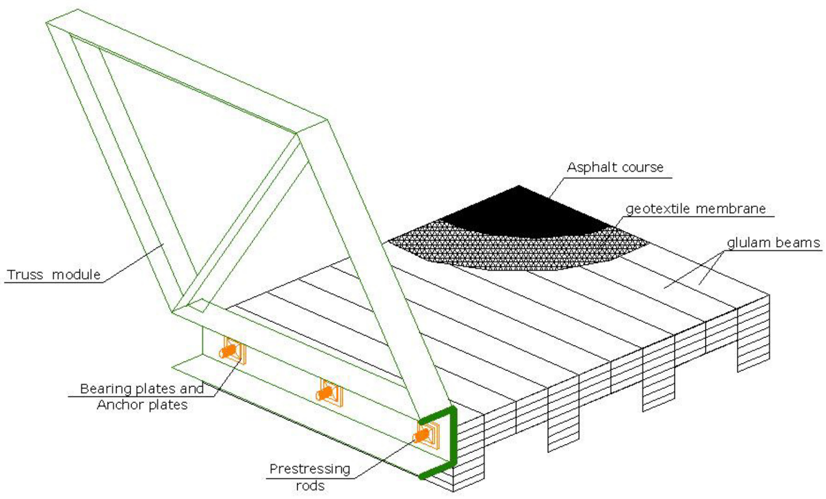

Fig. 4 Bridge assembly and components for lower loads

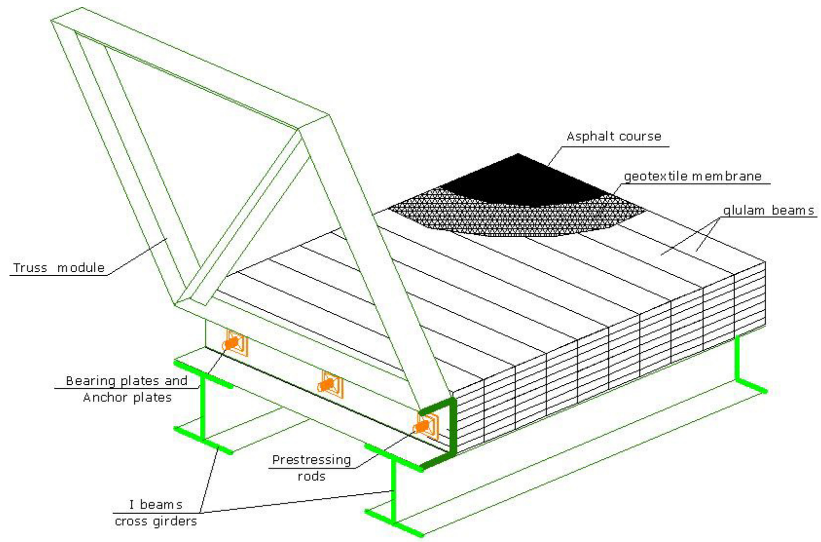

Fig 5 Bridge assembly and components for higher loads

An asphalt wearing course over a geotextile membrane is an option for the pavement on the bridge, adding extra protection for the wooden deck from the upcoming traffic and natural element as well as providing additional grip and continuity with the road on witch it is placed.

There is an imperative need to develop new wearing surfaces for modern timber bridges that limit the transport of moisture to the underlying wooden bridge deck and substructure for an increased life span.

4. Comparative structural analysis

A comparative structural analysis on a concrete deck versus the timber steel composite deck was made to determine their bending characteristics and determine the advantages of the previous proposed bridge structure.

4.1. Data input

Three spans lengths were chosen for a seven meter wide deck, as follows: six meters, ten meters and twelve meters in order to see how the structural response changes according to the span length.

For the concrete deck we chose its height to be at around one eighteenth of the span length, same for the stress laminated timber deck.

As live loads, Load Model 2 (LM2) was chosen according to EN 1991-2 [4]. This is a single axle model, which is applied when a local verification for short structural elements is required, elements such as decks or deck panels.

The internal forces due to LM2 may then be more critical compared to those of LM1. LM2 is applied at any location of the carriageway and it consists out of a single axle with two equal loads βQ x Qak, where βQ is an adjustment factor. For this study 200kN forces for each wheel was considered.

In the structural program the steel trusses were connected to the timber deck by replacing the prestressing rods with compression loads witch equalled the prestressing force.

As we can see in the following table the dead weight of the deck alone is reduced with more than 75% by using glue laminated timber instead of concrete, and adding that the dead weight represents a big percentage from the total load that the bridge supports.

Tab 1 Deck geometry and dead loads

Deck length [m]	Deck width [m]	Deck height [cm]	Stress laminated timber deck weight[kN/m^2]	Concrete deck weight [kN/m^2]
6	7	35	1.75	8.75
8	7	45	2.25	11.25
10	7	55	2.75	13.75

4.2. Results

Results were as expected, all timber composite decks had a superior bending behaviour with lower deflections, mainly because of the reduced dead loads.

Deflections for the timber composite decks were significantly lower because of the rigidity added by the lateral trusses, low self weight and lateral prestressing.

Both bending moments and deflections were higher for the longer spans but the proportion between the values for the reinforced concrete deck and the timber composite structure were similar with no major differences.

5. Conclusions

An original alternative to classic reinforced concrete decks was presented in this paper with experimental studies on reinforced glue laminated timber beams, using PET straps, glue bonded polyester straps in order to create an efficient lightweight composite bridge structure that uses recycled and sustainable materials for a greener way of building for the future.

These synthetic straps have an impressive tensile strength of around 200-400 N/mm^2 and are significantly cheaper than any other material such as steel or standard fiber reinforced polymers(FRP) and carbon fiber reinforced polymers (CFRP).

The results obtained from this experimental study described the bending behavior of reinforced and non reinforced glue laminated timber beams and highlighted the superior bending strength of the beams reinforced with glue bonded polyester straps witch had more than 20% increase in bending strength over standard non-reinforced beams. Reducing the dead load of the deck was the main objective and it was a major success since it was reduced with more than 75%.

Promising results were obtained in the numerical analysis proving once again that lightweight materials are the future of bridge engineering.

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