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Strengthening and rehabilitation of deteriorated timber bridge girders

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HIGHLIGHTS

- Deteriorated timber girders can be rehabilitated using fibre reinforced polymers.
- Fibre reinforced polymers enhance the strength and ductility of timber girders.
- Timber bridge girders can be rehabilitated using "off the shelf materials".
- FRP's increase strength and stiffness by bridging local defects and crack openings.

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ABSTRACT

Research has shown that strengthening of degraded rectangular timber is possible via the use of Fibre Reinforced Polymers (FRP). Tests were conducted at James Cook University (JCU) using three round timber girders removed from a railway bridge in North Queensland, Australia. These were retrofitted with either a Carbon Fibre Reinforced Polymer (CFRP) or Glass Fibre Reinforced Polymer (GFRP) composite in one of three different strengthening profiles. Due to extensive deterioration, two of those girders failed during preliminary tests and thus were repaired as opposed to strengthened. The repaired members sustained enhanced moment capacity and ductility from their initial failure values. The unbroken girder when strengthened, produced a 30% reduction in deflection for the same moment while bending stiffness was increased by 30% from its initial un-strengthened state.

1. Introduction

Until modern times, timber has been the material of choice for building bridges in Australia. There are an estimated 40,000 bridges in Australia with many over their intended design life [1]. Due to an inability to adequately rate these structures many asset managers face the prospect of decommissioning or placing load restrictions on these bridges. Most of these aging structures are in rural areas where detours may amount to hundreds of kilometers of extra travel distance.

Fibre reinforced polymer (FRP) technology is currently the focus of timber strengthening research around the world. Improvements in flexural and shear strength by using FRP strengthening techniques in degraded timber specimens as well as new members have been well documented [2–4]. FRP's have far superior mechanical properties over more traditional materials and can increase strength and stiffness by bridging local defects, confining local ruptures and arresting crack openings [5–7]. FRP display excellent strength to weight ratios and outstanding durability in many environments [8,9]. Much research has also gone into different FRP configurations. Although many different styles have been tried they are generally a variant of three main techniques.

Externally bonded reinforcement (EBR) is a technique whereby FRP is attached to the exterior surface of the timber either through application of an epoxy or utilizing pre-pegging technology [10]. Plevris et al. documented increases in stiffness of 60% using CFRP strips in area percentages as low as 1% [11]. The EBR method can be adapted to increase flexural or shear strength in timber members [9]. An alternative form is the wet layup technique which involves applying an adhesive to the prepared timber surface before layers of uni- or bi-directional sheets are applied [12]. Multiple layers of sheets may be attached in this way [13]. The EBR method is recommended where time restrictions apply or access to the repair site is limited [7].

Near surface mounted (NSM) FRP involves creating a groove along the length of the member parallel to the grain, filling with a thixotropic glue and placing either stiffened FRP strips or

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pultruded rods into the channel before the adhesive hardens. This technique was used by the University of Manitoba to increase the strength of rectangular timber bridge girders by 30% using 10 mm diameter GFRP rods [14].

Shear or "Z" spiking is a dowel applied vertically through the centre of the member perpendicular to the grain which can lead to significant increases in bending stiffness [3,15]. Svecova and Eden showed an increase in modulus of rupture (MoR) of 35% using dowels only, while a 50% increase was noted using a combination of dowels and NSM [5].

Most of this research has focused on small, clear, laboratory scale timber members while little study has gone into the effectiveness of using FRP in strengthening full-scale timber girders. The objective of this paper is to present the findings from a series of full-scale instrumented load tests carried out on strengthened and rehabilitated timber girders sourced from a Queensland Rail (QR) bridge. The degraded timber girders were first tested in four point bending in the original state to establish benchmarks for un-strengthened moment, deflection and stiffness capacities. The girders were then strengthened with either carbon or glass FRP in one of the three different strengthening profiles: (a) EBR, (b) NSM, and (c) NSM with shear spikes and subjected to the same testing program. The performance of the girders before and after strengthening was then analyzed.

2. Laboratory test program

The experimental program involved full-scale testing of three deteriorated timber girders strengthened using different FRP profiles and materials. Baseline values for strength and deflection of the members were determined by loading the three girders in four point bending in their un-strengthened state. Due to severe loss of material properties through age, two of the girders were damaged and sustained structural failure during the initial testing. The remaining girder exceeded safe operating limits on the test structure in both un-strengthened and strengthened states. Due to the failure of two members during initial testing, the repaired and strengthened girders were analyzed differently. The repaired girders were compared on load carrying capacity at failure, type of failure and deflection at failure. For the strengthened girder, analysis involved comparison of before and after values for bending stiffness and deflection.

All tests were conducted using four-point bending setup (Figs. 1 and 2). The reaction frame had a maximum load capacity of 440 kN with the loads being applied on the girders using an Enerpac hydraulic ram and load cell with capacity of 600 kN. Vertical deflection at mid span was measured using an LVDT. Strains in the timber and FRP were measured using strain gauges (Timber: PFL-30-11-3L and FRP: FLA-2-11-3L) attached at midspan on both the compression and tension faces in the region of pure bending.

2.1. Material properties

Aged girders (Fig. 3) removed from service out of a rail bridge were donated by QR from their El Arish stockpile in North Queensland Australia, approximately 120 km south of Cairns. The dimensions and properties of the three test specimens are listed in Table 1.

A QR Supervisor of Structures assessed the girders after delivery. A visual inspection and hammer tap test were used to determine any areas of internal piping. Suspected hollow areas were then drilled with an 8 mm auger allowing the operator to feel the depths of any pipe. A hammer pick test was used in areas of visual rot on the external surface to determine the depth and extent of any decay.

Species testing was conducted by the Department of Agriculture, Forestry and Fisheries. Girder 3 was determined to be Flindersia Ifflaiana, also commonly known as Hickory Ash. This was the only specimen where no published data regarding the species material properties were available.

The least deteriorated girder (Girder 1, Fig. 3a) as nominated by the QR inspector, was repaired using an EBR method using CFRP strips. The most deteriorated girder (Girder 3, Fig. 3c) was repaired using a combination NSM and shear spiking profile using GFRP rods. Girder 2 (Fig. 3b) was strengthened with GFRP in an NSM profile with four GFRP smooth dowels inserted into the end bearing the largest snipe due to the possibility of shear failure at this point (Table 2).

The shear spikes were not included in any GFRP area percentage totals for Girder 2 or Girder 3. This was due to the difficulty in assigning the shear spikes a cross sectional area in relation to the rest of the member as with the rods and strips.

For the EBR strengthening technique, CFK 150/2000 laminate 50 mm × 1.2 mm CFRP strips (Table 3) sourced by JCU were used. [16].

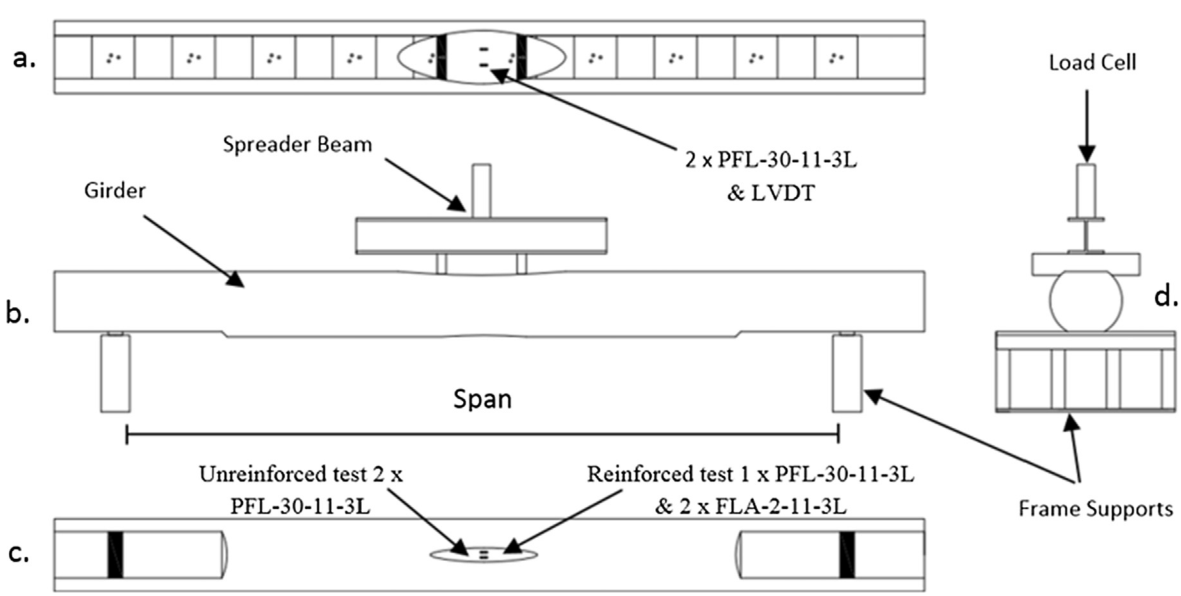

Fig. 1. Schematic view of test setup. (a) top view, (b) side view, (c) bottom view, (d) end view.