Technical Note 54

Fibre Composite Projects

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1 Introduction

Since 1997 the Queensland Department of Main Roads has worked with the fibre composite industry to develop structural engineering concepts for new bridge, timber girder replacement, and underwater bridge pile repair applications.

In 2002 the Queensland Government commenced sponsorship of the fledgling fibre composite industry through Toowoomba firm Wagners Composite Fibre Technology (CFT), and the University of Southern Queensland's Fibre Composite Design and Development (FCDD) also located in Toowoomba.

As a result of the success of a variety of infrastructure projects constructed by the fibre composite industry, Main Roads is now investigating the use of fibre composites in two main areas:

a) construction of fibre composite bridge decks (superstructure) for new structures on standard concrete foundation (substructure); and

b) construction of a fibre composite girder as an alternative to hardwood girders in timber bridges.

Main Roads, together with the NSW Roads and Traffic Authority, is continuing to contribute design input into FCDD's underwater bridge pile repair applications. It is hoped that these applications will be trialled in the next few years.

Main Roads' involvement with the fibre composite industry assists the cross-fertilisation of concepts from a range of fibre composite research projects undertaken by different industry players. This includes investigations into railway sleepers, railway over-bridge beams, power pole cross-arms, portable bridge structures, floating river walkways, 'no-rust' structures, and building panels. Main Roads' involvement assists in increasing the understanding of fibre composite technology in relation to public infrastructure and provides an infrastructure owner's perspective.

The purpose of this Technical Note is to provide general information about fibre composites as well as more details about Main Roads projects using fibre composite technology.

2 What is a fibre composite?

Fibre composites consist of polymers (plastics) reinforced with carbon, glass and/or aramid (Kevlar) fibres. These materials are four to six times stronger than steel and concrete but are only a fraction of the weight. They are also non-corroding, non-magnetic and can be designed to place strength and stiffness where it is needed. The potential whole-of-life cost advantages are thought to be significant, however these will need to be monitored in the future to ensure they can be realised.

Fibre composites were originally developed for the aerospace industry and have found their way into a much wider range of applications including transportation (automotive, railway, boats), sports (squash, tennis, golf, skiing, bicycles), medical science (prosthetic devices, wheelchairs) and more recently the building and construction industries (bridges, structural frames, offshore structures, and architectural products).

The application of fibre composites in the construction industry creates the opportunity for a new and innovative approach to structures that have undergone little change over the past 100 years. The unique mechanical and chemical characteristics of fibre composites combine to challenge the supremacy of conventional materials such as steel, timber and concrete particularly in areas that are weight and/or corrosion sensitive.

3 Advantages of fibre composite materials

Fibre composites are meeting an increasing demand for construction materials that are strong, economical, easy to assemble and durable. They are often directly competitive on initial installation and less expensive to maintain. The whole-of-life cost is often less than for traditional construction materials.

Fibre composite structures are commonly smaller/ more slender - demonstrating high strength and low weight with excellent design flexibility qualities which blend with their environment.

Environmentally, fibre composites negate the need for further chemical treatment or protection. With the development of bio-polymers future environmental benefits may include manufacturing fibre composites from renewable resources.

By way of example, Wagners CFT is supplying power pole cross-arms to Energex (shown in Figure 1), replacing the timber equivalent previously used. The beneficial properties that fibre composites offer in this area are also desirable in bridge members: lightweight, corrosion resistant, inert, easy and fast to install.

Figure 1: Cross-arm installation

In certain circumstances the corrosion-resistance properties of fibre composites are even more important. It was this property that prompted Brisbane City Council to approach FCDD in late 2001 to see whether this new fibre composite technology could be used in the innovative floating walkway project for the Brisbane River.

The 800m-long structure required a new type of structural beam system to tie the individual pontoons of the walkway into a unified structure. Traditional hardwood timber and steel solutions were projected to deteriorate in the aggressive salt water environment in 10-15 years resulting in unacceptably high maintenance costs. Having developed a new polymer concrete technology, CDD created a unique “waler beam” concept (as shown in Figure 2) which could accommodate the high structural loads of the walkway while still meeting the 100-year design life imposed by Brisbane City Council.

Figure 2: FCDD's fibre composite Waler in the Brisbane City Wharf Project

4 Engineering properties

A brief outline of the key engineering properties for two types of fibre composites is compared to steel, concrete and timber in Table 1 below. They are listed from heaviest to lightest, as indicated by the density.

Table 1: Comparison of engineering properties (typical)

Material	Engineering Property			
	Stiffness E (GPa)	Tensile Strength (MPa)	Comprehensive Strength (MPa)	Density (Kg/m^3)
Steel	200	300	300	7650
Concrete	28	5	50	2500
Glass Composite (V_f = 0.5)	90	900	800	1300
Timber (F27 Seasoned Hardwood)	18	50	60	1100
Softwood (Pine)	10	5 – 10	5 – 10	800

Structural design using a mixture of these materials enables the construction of bridge beams (for example) to fit a range of desired bending strengths and deflection limits (stiffness criteria).

A combination of steel, glass fibre and concrete or a bridge beam application can be designed to display the following properties:

- Concrete is the cheapest compression material, and is used in the compression zone of a beam.
- Steel is stiffer than glass and carries most of the initial tensile forces. When the steel yields, the beam becomes less stiff as the extra load is now carried by the glass fibres in tension.
- "Softening" of one beam under increasing load transfers the load to adjacent beams, so the full load capacity of all beams can be used to carry the applied loads in extreme overloading conditions. This behaviour ensures adequate safety, while minimising material costs.

While many corrosive environments that require light weight infrastructure would use a high proportion of fibre composites in their design, it is fair to say that other infrastructure would use the most economic use of a combination of materials, including fibre composites, to achieve the desired outcome. Fibre composites are very flexible in this regard.

5 Main roads projects hardwood timber girder –fibre composite alternative

The goal of this project was to investigate viable cost effective alternatives to timber girders, which are becoming increasingly scarce and expensive. Harvesting timber from old growth hardwood forests of sufficient diameter, length and quality is becoming increasingly difficult. It is clearly evident that this activity is not environmentally sustainable in the long term, and it is quite feasible that Government policies will markedly limit the use of these timbers in the near future.

Main Roads has approximately 500 timber bridges to maintain and it will take some years before the concrete bridge replacement programs are able to eliminate this timber bridge stock. It is estimated that there are around 20,000 timber bridges across Australia's road and rail network. Numerous other old timber structures such as wharfs, warehouses, and buildings are also in poor condition. It is believed that the work performed by this project will have flow-on benefits to the construction industry as a whole.

Generally, it is not economically feasible to replace a whole timber bridge when only some components have deteriorated; therefore replacement timber components are required. Concrete and steel beams are generally not suitable to interchange with timber girders as they have markedly different properties. Most significantly is the difference in stiffness. Current engineered timber products generally struggle to perform 'like an old ironbark girder', while maintaining similar geometrics and flexibility of installation. Fibre composites can provide a suitable alternative because they offer:

- flexible designs to exhibit strength and stiffness properties similar to good quality timber girders whilst maintaining geometric constraints;
- weights around 700 kg – 800 kg, which is around 50-60% of that of an existing timber girder;
- ability to be cut and drilled onsite so that bridge carpenters can fit the product using traditional techniques;
- product uniformity far superior to that of a naturally grown timber girder;
- girders that are generally inert, do not rot in wet/moist environments and are termite-proof; and
- fibre resistance equivalent to current material options.

As at 2005, trial fibre composite girders ($7000 - $7500) are around two to three times more expensive than current timber girders. However, the whole-of-life cost for fibre composite girders is expected to be less due to the advantages listed above. It is anticipated that the cost of hardwood timber girders will rise substantially in the future as more forests become restricted from commercial use. It is also expected that fibre composite girders will reduce in price as 'mass production' can be implemented. Prices could be in the range of $4500 - $5500.

5.1 Main Roads engineering criteria

Recent timber girder research allowed Main Roads to define the engineering properties of a typical high quality ironbark timber girder. This work was used to develop the engineering performance criteria required to assess the fibre composite alternative girder. Details are shown in Table 2.

Other criteria assessed included weight, durability, appearance, coatings, cappings, dimensional stability, handling, compatibility of installation with traditional girder installation techniques, and resistance to impact chemicals and fibre. Full scale destructive and fatigue testing was undertaken to prove the design theory of the two distinctly different alternatives from Wagners CFT and FCDD.

5.2 Wagners' CFT fibre composite girder

The Wagners fibre composite girder is predominantly made up of glass reinforced pultrusions (made by a process of introducing resin while pulling fibres through a heated die) and incorporates some steel to meet the stiffness requirements. Two 9.7m-long girders weighing around 700kg were installed as inner and outer girders by Main Roads RoadTek on an existing timber bridge. The bridge crossing was over Horse Trough Creek on the Gatton – Clifton Road in Main Roads' Toowoomba district. Works were completed on 10 May 2005.

The Wagners girder met the performance criteria in all respects with the following results noted:

- It is expected to have excellent durability because of the inert materials used. The steel component is well protected by fibre composites and no timber components are used. Therefore, it is not susceptible to termite, fungal attack, weathering or corrosion.
- It is compatible with conventional trimming, bolting and fixing methods. However, diamond cutting tips were required on quickcut blades and drill bits. There were also some minor installation issues that require improvement, but overall the installation was compatible with timber bridge processes.

A comprehensive testing program to ensure the performance of the proposed girder in bending, shear and fatigue was successfully performed. Destructive testing proved a 'soft' or 'pseudo ductile' ultimate failure, with the results shown in Figure 3. Photos of installation are provided in Figure 4.

Figure 3: Beam load testing (170 mm maximum deflection); Load/Deflection Graph

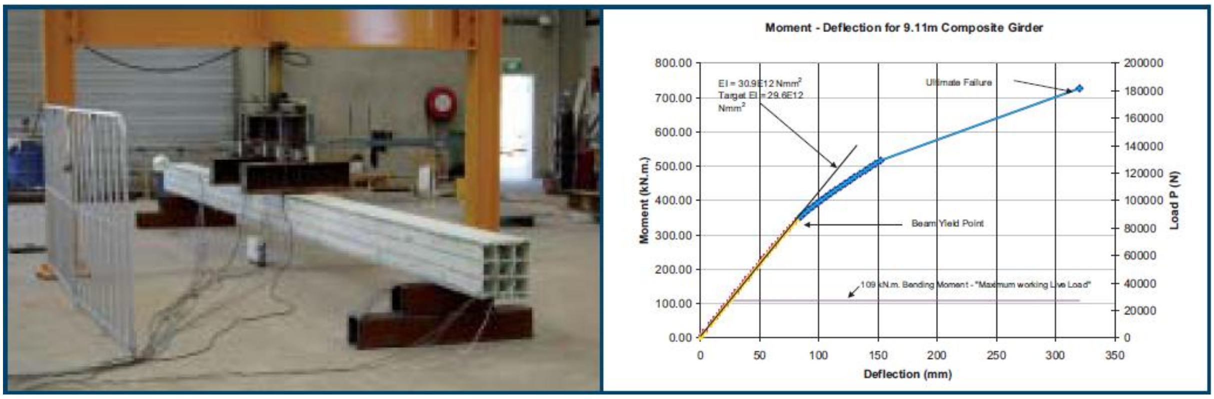


Figure 4: Beam installation and working under load

The cost of the trial fibre composite girder was $7500 (plus freight) which is approximately three times the current cost of timber. It is hoped that larger production runs will reduce this cost to $5000 (plus freight). At this early stage of review it is expected that the rotting and termite-proof advantages would tilt the whole-of-life cost equation in favour of the fibre composite girder. The product should be in good condition well beyond a timber equivalent.

5.3 FCDD's fibre composite girder

FCDD's fibre composite girder is made up of chemically treated plantation softwood Laminated Veneer Lumber (LVL) with several glass pultrusion/steel modules incorporated to meet the strength and stiffness requirements. Importantly, the softwood plantation timber is a renewable resource. Three girders (2 x 9.1 m, 1 x 9.7 m) weighing around 800 kg were installed at inner and outer girder locations by RoadTek on an existing timber bridge. The bridge crossing was over Heifer Creek No. 5 on the Gatton – Clifton Road in Main Roads' Toowoomba district. Works were completed on 13 April 2005.

FCDD's girder met the performance criteria in all respects with the following results noted:

- The LVL is Ammoniacal Copper Quaternary (ACQ) treated to H3 level (outside, above ground) in accordance with AS/NZS 1604.5 to resist rot and termites. The 3 mm veneers which make up the LVL are impregnated with the H3 treatment. Although it is expected that the product will meet the minimum 30- year design life, rot and termite activity will need to be monitored.
- The installation is 100% compatible with conventional trimming, bolting and fixing methods.

A comprehensive testing program to ensure the performance of the proposed girder in bending, shear and fatigue was successfully performed. Destructive testing proved a 'soft' ultimate failure with details shown in Figure 5. Figure 6 shows the girder being placed insitu.

Figure 5: Beam load testing (deflection 230 mm); Load Deflection Graph

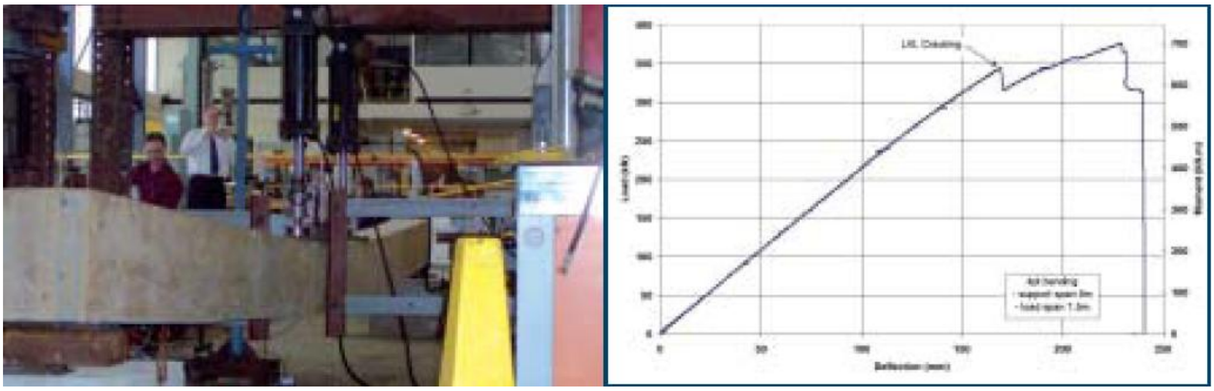


Figure 6: Installation of FCDD girder

The cost of the trial fibre composite girder was $7250 (plus freight) which is approximately three times the current cost of timber. It is hoped that larger production runs will reduce this cost to around $5000 (plus freight).

6 Main roads projects fibre composite bridge decks (FC superstructure)

Fibre composites have a number of features which make them attractive for use in bridge structures including; low weight, high strength, excellent corrosion resistance and durability, ease of transportation, and lower energy consumption[1] during manufacture.

[1]Environmental Considerations to Structural Material Selection for a Bridge R. A . Daniel, European Bridge Engineering Conference Light Weight Bridge Decks, Rotterdam, March 2003.

- This project will allow a thorough evaluation of fibre composite bridge technology for Queensland's future bridge needs. In particular, the completion of the following projects will allow Main Roads to:
- Evaluate state-of-the-art fibre composite bridge technologies from engineering and manufacturing perspectives;
- Develop an understanding of the economics of fibre composite bridges in the Australian context;
- Identify niche applications of fibre composite bridge technology that may allow such technologies to be nurtured and developed until they become more applicable to general bridge applications, eg remote or island based projects;
- More fully understand the current nature of the fibre composite industry in Australia, and identify growth needs of the industry such that this emerging industry is compatible with Main Roads requirements;
- Identify issues associated with combining fibre composite superstructure technologies with conventional bridge technologies.

In addition, subsequent investigations (beyond the current projects) will allow Main Roads to evaluate the long-term performance of fibre composite bridge structures.

It is often the case that the square metre cost of a given bridge varies little with different span lengths because sub-structure cost saved by using longer spans is re-distributed into increased super-structure cost resulting from the longer spans. The relationship between span length and the cost of superstructures and substructures is well understood for conventional structures.

The relationship between these parameters has not previously been investigated for fibre composite structures. This project provides an opportunity to evaluate this relationship. Fibre composite materials are generally lighter and more expensive than traditional materials. It is assumed that maximum advantage can be gained by combining these attributes with long span solutions, thereby off-setting the greater material expense of composites by reducing sub-structure requirements. There is an inherent assumption in this proposal that the viability of fibre composite bridges will improve with increasing span. This project will also evaluate that assumption.

6.1 Wagners CFT fibre composite bridge deck – Taromeo Ck Bridge

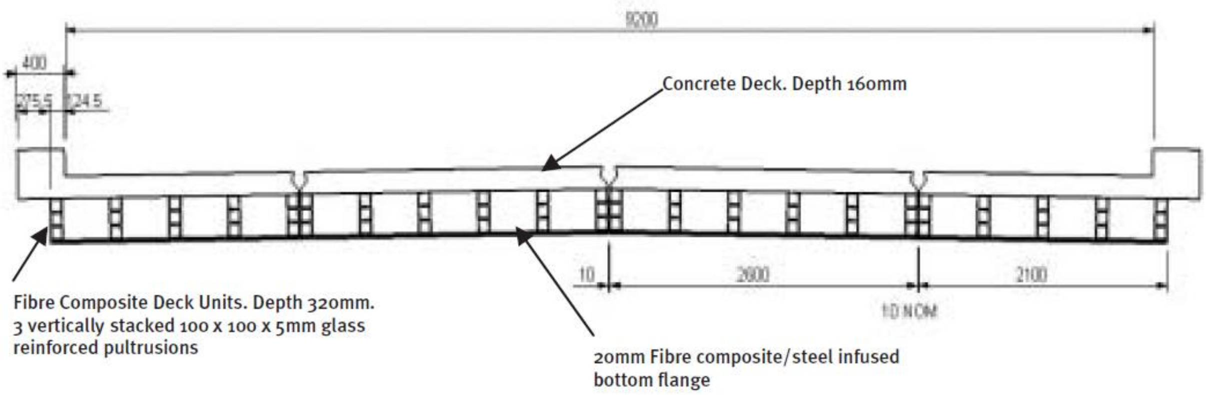
Wagners CFT has designed, manufactured, tested and installed several fibre composite bridge decks in Australia and the USA over the past three years. Construction costs within the three years have been reduced tenfold. Wagners' aim is to bring the installed price of composite fibre bridge decks in line with concrete and steel. The cost of the trial fibre composite superstructure for this project was $1500/m$_2$, including transport to site and installation. This cost is between two to three times more than the cost of a standard concrete deck unit bridge superstructure used in Queensland. However, it is expected that with the knowledge learnt from this trial, fibre composite bridge costs will be further reduced in the future.

The Taromeo Creek bridge, shown in Figure 7, is Wagners CFT's first bridge for the Queensland Department of Main Roads and the largest fibre composite bridge to date. The Taromeo Creek bridge is located on the D'Aguilar Highway at Blackbutt in Queensland. The traffic volume is around 2500 vehicles per day with approximately 400 (16%) heavy vehicles per day. The new bridge replaces an old timber bridge with a new two-span bridge (10 m + 12 m spans) using a traditional concrete substructure and fibre composite bridge deck. Bridge construction works were completed on 1 June 2005, with approach roadworks finishing around mid-August 2005.

Figure 7: Wagners CFT bridge installation

Wagners CFT 'Generation 4' design used four prefabricated units of 2.1m and 2.6m width as shown in Figure 8. All eight deck units for the two spans were placed on the substructure within one day. Longitudinal joints were cast insitu using a high strength grout. The weight of these deck units is almost 50% of the standard Main Roads concrete deck unit bridge. By way of example, the 12m span fibre composite bridge deck weighed around 70 tonne as opposed to an equivalent Main Roads standard 12m span concrete deck unit system which weighs around 155 tonne including asphalt.

Figure 8: Wagners CFT: Taromeo Ck Bridge deck cross section



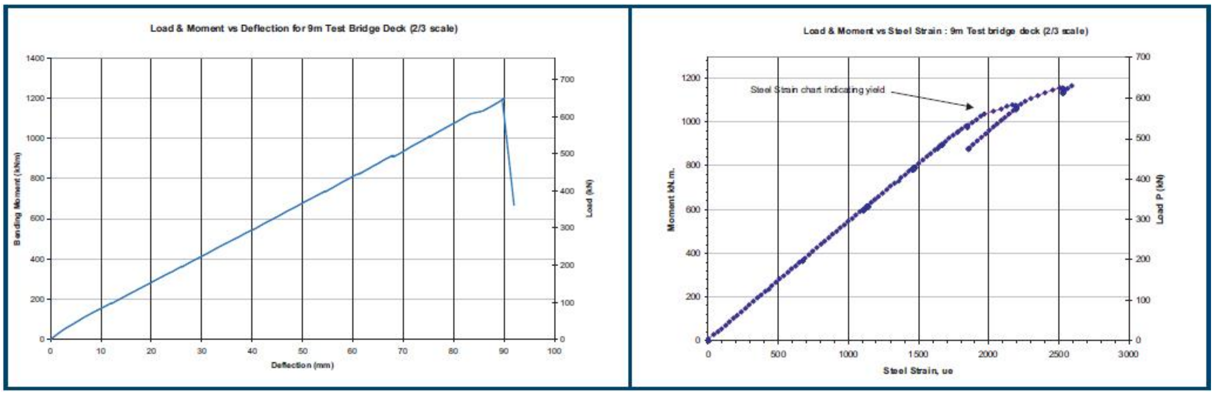
There were many challenges in ensuring the design met all of the bridge requirements, however some of the design challenges that required innovative solutions included:

- Bonding concrete slab to fibre composite webs;
- Design of pre-camber in decks to allow for concrete shrinkage;
- Mechanical connection of adjacent decks; and
- Provision of a ductile failure mode.

Stringent load testing required life size models to be load tested to destruction in bending and shear. Fatigue testing to 2 million cycles was also undertaken, with no signs of deterioration shown. The actual load testing results correlated exceptionally well with theoretical finite element models. Load testing details are also shown in Figures 9 and 10.

Figure 9: 2/3 scale bridge deck load testing

Figure 10: 2/3 scale bridge deck Load/Deflection Graph; Steel Load/Strain Graph



Overall, the trial has been a success and has led to a greater understanding of fibre composite technology in the application of bridge infrastructure. The performance of the current bridge design will continue to be monitored while the key lessons learnt are fed back into new design models.

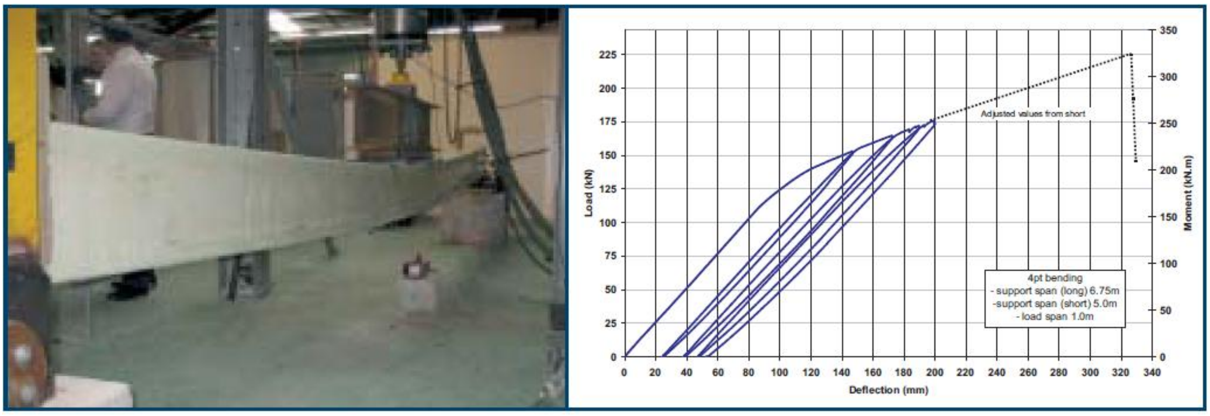
6.2 FCDD's fibre composite bridge deck – Sandy Creek Footbridge

The department has recently been working with the Darling Downs Region to deliver a fibre composite pedestrian bridge at Sandy Creek, Nanango. The concept and design stage was conducted by AECOM and the department conducted an independent design check.

6.3 Testing

To date the performance of the structural system has been demonstrated by testing a number of trial beams to failure as shown in Figure 12. The results of this testing has been encouraging, and further testing is planned to verify the connection details planned for the bridge concept.

Figure 12: Load testing of FC trial bridge beam



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