FIELD APPLICATIONS AND CASE STUDIES OF FRP IN CIVIL INFRASTRUCTURE: THE AUSTRALIAN EXPERIENCE

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Abstract

The application of fibre composites in civil infrastructure has been an emerging trend globally in the last decade. In Australia, the pioneering work was initiated at the University of Southern Queensland (USQ) within the Centre of Excellence in Engineered Fibre Composites (CEEFC) in late 1990s resulting in the installation of the first Australian fibre composite bridge. Since then, several infrastructure projects which involve new and innovative design and structural concepts using engineered fibre composites as a suitable solution and cost effective alternative to existing construction materials were implemented. This paper will discuss the recent applications and case studies on fibre composite materials in civil infrastructure taking place around Australia. These projects include sustainable fibre composite bridge girders, pile rehabilitation and composite pile systems, railway sleepers, strengthening of existing structures, and other innovative applications of fibre composites. Education campaign and training to engineers and students on composites for civil infrastructure are also presented.

Keywords: Bridges, Case studies, Civil infrastructure, Fibre composites, Education.

1. Introduction

During the past decade, there have been considerable activities on the use of fibre composites for civil infrastructure in Australia. This work has involved not only the initial concept development but also the construction and deployment of full-scale prototypes. Through close involvement of major asset owners including state road and rail authorities and city councils, a wide range of exciting new structural technologies and projects utilising fibre composites has been constructed and are now in actual service. These structures have demonstrated how pioneering composites technology can be used to successfully develop a range of new components to provide a structural solution not possible in traditional materials.

This paper highlights the recent applications and case studies on fibre composite materials in civil infrastructure taking place around Australia. These projects include the development of the Australia's first fibre composite bridge, marine and waterfront structures, strengthening and rehabilitation systems using fibre composites, railway sleepers and other innovative applications of engineered fibre composites in civil infrastructure. Overcoming challenges and lessons learned in the implementation of these projects are also presented.

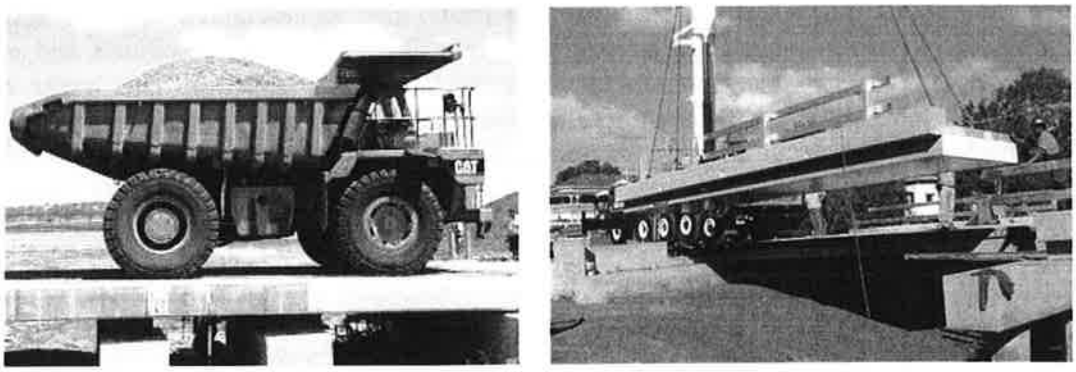
2. Fibre composite bridges

Numerous large-scale demonstration projects around the world have shown that fibre composites are viable structural materials for bridge applications. The following projects present some of the fibre composite bridges installed in Australia.

2.1 Australia's first fibre composite bridge

The CEEFC partnered with Wagners Composite Fibre Technologies (CFT), a Toowoomba based company, in collaboration with Queensland Department of Transport and Main Roads (QDTMR) and the Roads and Traffic Authority of New South Wales (RTA) to develop the first fibre composite bridge in Australia (*Fig. 1a*) in early 2002. The composite bridge is designed based on a traditional plank bridge concept, where the high tensile strength and low weight characteristics of fibre composites was combined with the high compression capacity of plain concrete. The beam is made up a 100mm deep concrete compression flange on top of 350mm deep box girders formed using glass-reinforced isophthalic-polyester pultruded profiles. Additional carbon fibre reinforcement was incorporated into the base of the deck to enhance stiffness. Currently, the technical performance of the composite beam is under field test at Wagner's owned quarry site near Toowoomba, Queensland.

The first application of fibre composites in a highway bridge in Australia occurred in 2005 when Wagners CFT reconstructed the Taromeo Creek Bridge (*Fig. 1b*) on the D'Aguilar Highway at Blackbutt, Queensland for the QDTMR [1]. The highway bridge, which was constructed using fibre composite girders and reinforced concrete deck slab, is of two spans, 10m and 12m, and replaced an existing timber bridge. The bridge was completed in June 2005 and opened to traffic in July 2005.



(a) First fibre composite bridge in Australia (b) Taromeo Creek Bridge

Figure 1. Innovative applications of fibre composite bridges in Australia.

2.2 Road bridges

The deployment of the first prototype bridges lead to several road bridge projects using fibre composite in Australia. Wagners CFT which specialises in structural composite sections as load carrying members in a variety of structures has developed modular methodology of creating a variety of sections able to be tailored to specific requirements. For road bridges, Wagners CFT has designed and developed an I-beam bridge girder made up of pultruded laminated fibre composite sections such as 125x125x6.5mm SHS and 300x6 mm flat laminates bonded with rubber toughened epoxy adhesive [2]. This technology has been applied in the reconstruction of the Manly Road Bridge in Brisbane where the composite I-girder section and concrete deck (*Fig. 2a*) was used to replace the damaged reinforced concrete bridge [3]. Another project that utilised the composite I-girder section is for road bridge replacement in Hawkesbury Council, Queensland. The council needed a solution to replace an aged timber bridge in a limited time frame as is was unlikely to survive another wet season in this flood prone rural district.

Another technological development in Australia was the construction of a prototype bridge at

USQ, a new generation of fibre composite bridge using sandwich panels (*Fig. 2b*) that could potentially increase the span by two folds. This new technology has been realised through the partnership with QDTMR and CarbonLOC Pty Ltd, a start-up company based in Toowoomba. The CarbonLOC has patented an innovative sandwich panel technology, which has paved way to provide innovative solutions to civil infrastructure [4]. A hybrid composite beam is another composite bridge technology that went into actual field application. This hybrid beam is made from laminated plantation-grown timber, with fibre composites and steel reinforcements and bound with polymer resin to increase the beam's strength and stiffness [4].

(a) Manly Road Bridge (www.wagnerscft.com.au)

(b) New generation composite bridge at USQ

Figure 2. Road composite bridges

2.3 Pedestrian bridges and walkways

Pedestrian bridges and walkway structures made up of fibre composites are now common all across Australia. Due to its unique characteristics to withstand the harshest environments while providing a low maintenance, fibre composites are now the preferred materials in the construction of structures near to costal, marine, and environmentally sensitive areas such as tidal flood plains, protected mangrove swamps, alkaline desert and corrosive mining facilities.

An example of a pedestrian composite bridge designed, constructed and installed by Wagners CFT for the Brisbane City Council (BCC) as part of their pedestrian infrastructure upgrade program is shown in *Fig. 3a*. The Bowman Parade is a 3 span, 30 metre structure, and multi-use pedestrian bridge, and is made up of pultruded composite sections for the main structure and glue-laminated composite sandwich panels for the deck [3]. Similarly, Wagners CFT was commissioned to design and supply materials for 850 metres of the Mackay Bluewater Environmental Trail (*Fig. 3b)* by the Mackay City Council. The 4km long project snakes its way through the environmentally sensitive tidal belt of the Pioneer River just north of the Mackay Central Business District. As the area is subject to regular cycles of submersion from both tidal forces and storm flooding, fibre composite solution was sought by the council.

(a) Bowman Parade pedestrian bridge

(b) Mackay Bluewater Environmental Trail

Figure 3. Fibre composite pedestrian bridges and boardwalks (www.wagnerscft.com.au).

3. Rehabilitation and strengthening of existing structures

Engineered fibre composites offer an extremely versatile option to strengthen or rehabilitate existing structures to solve structural problems arising from environmental exposure, inadequate designs, increased traffic loads, and continuous aging. Road and bridge authorities in Australia have become actively involved in these type of projects as many of its existing bridge structures requires replacement and major rehabilitation.

3.1 Replacement composite girders to timber girders

Australian hardwoods are an excellent general purpose building material. However, in recent years they have become more expensive, less available and of poorer quality. Fibre composite bridge components have shown to be compatible as a replacement material for rapidly dwindling hardwood bridge components. The CEEFC, in conjunction with Wagners CFT and CarbonLOC has successfully developed and installed composite beam solutions for timber bridges (*Fig. 4*) in recent years in collaboration with the QDTMR and other major timber bridge asset owners. These systems can either replace damaged and deteriorated timber bridge components or provide a complete overhaul of the whole bridge structure.

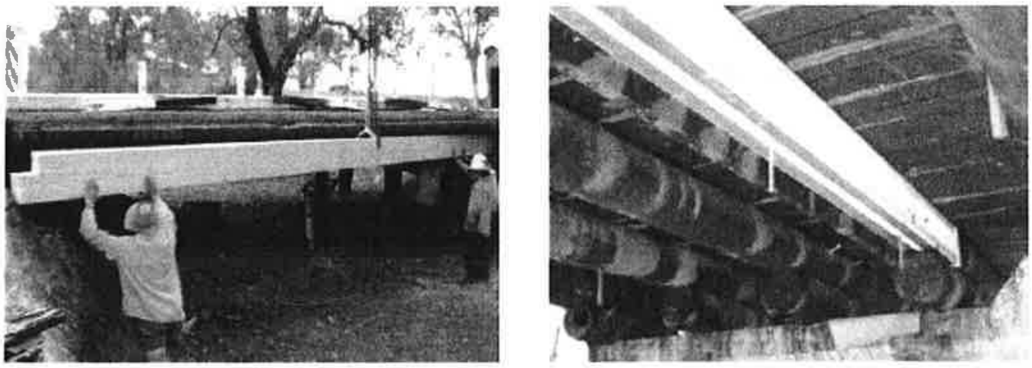


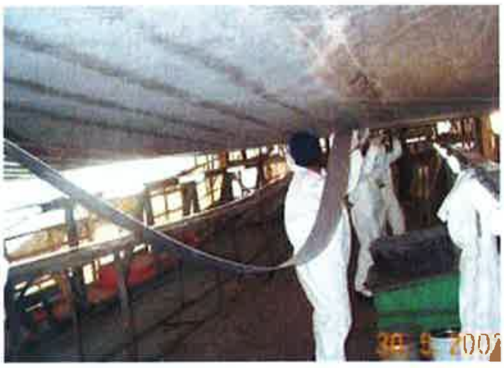
Figure 4. Fibre composite girder replacing timber bridge girders.

Currently, the CEEFC, CarbonLOC, Wagners CFT, and QDTMR are in collaboration as part of 'Bridging the Gap' project on developing fibre composite bridge girders to replace degrading girders in existing timber bridges in Queensland. This project aims to develop improved production processes and systems which will lead to the availability in the Australian market of commercially viable fibre composite bridge beams through the use of advanced manufacturing research. A total of 120 composite beams were manufactured, proof-loaded and passed the performance criteria (stiffness and strength) provided by the QDTMR. These beams are now waiting to be installed in bridges.

3.2 Rehabilitation and Strengthening of Concrete Structures

The QDTMR reported that a total of 500 pre-stressed concrete piles in Houghton Highway in Redcliffe, Queensland were repaired with glass and carbon fibre wraps (*Fig. 5a*) [5]. Rehabilitation was conducted to prevent the propagation of vertical cracking on the piles due to alkali-silica reaction. Another strengthening project that uses carbon fibre fabric was reported by Shepherd and Sarkady [6]. The Little River Bridge is an 84 year old, 4 span continuous reinforced concrete structure on the Princes Freeway between the cities of Melbourne and Geelong in Australia. As part of the upgrading and widening of the road to a 6 lane freeway, the bridge beams required strengthening for positive moment and the solution selected was to use MBT MBrace CF130 Carbon Fibre Fabric Composite. The strengthening works started in late August 2000 and was completed in November 2000.

In 2001 one of the world's largest carbon fibre strengthening programs was undertaken in Melbourne, Victoria (*Fig. 5b*). The West Gate Bridge (constructed in mid 1960's) was originally designed for a maximum of 8 traffic lanes and thus strengthening was required to accommodate the construction of additional traffic lanes. The project involved extensive use of carbon fibre laminate and fabric strengthening to both the underside and top side of the bridge deck including the central spine girder, the cantilever bridge deck support beams and the bridge deck infill panels [7]. Strengthening of the structure was achieved through a combination of external post-tensioning using longitudinal steel tendons, as well as the application of bonded FRP strips and sheets for flexural, shear and torsion. With over 50,000 m of carbon fibre laminates and fabrics installed, this project continues to be the largest carbon fibre composite strengthened bridge anywhere in the world.



a) Repair of pre-stressed concrete piles (b) Structural strengthening of West Gate Bridge [12]

Figure 5. Repair and strengthening projects using fibre composites.

4. Innovative infrastructure projects

4.1 Marine and floating structures

On the coastline of Australia, boardwalks, jetties, pontoons, and marine structures operate in a very corrosive environment. This results in serious durability problems for steel and reinforced concrete. Hardwood has traditionally been used to overcome some of these problems. The CEEFC has developed and built a new type of fibre composite waler (*Fig. 6a*) for an 800m long floating riverwalk project with the BCC [4]. As part of this project, over 100 tonnes of structural composites, including 550 3m long beams, several 12m beams and a 16m truss were fabricated. In another project, Wagners CFT designed and constructed the Cameron Rocks fishing platform (*Fig. 6b*) for the BCC. Located on the northern bank of the Brisbane River, this project represented the first time the BCC tapped the services of Wagners CFT in the construction of a structure in a marine environment. The platform was constructed with composite supports fixed to the existing concrete piles with a completely composite substructure to ensure long life in the highly corrosive marine "splash" zone. Composite decking was also installed to increase the overall resilience and maintenance return on this structure. In the January 2011 Brisbane floods, the structure remained intact and ready for continued use, a testament to its inherently robust material and design.

a) Fibre composite waler (b) Cameron Rocks fishing platform

Figure 7. Marine and floating structures projects which uses fibre composites.

4.2 Fibre composite railway sleepers

Railway industries in Australia are now trialling the use of fibre composite sleepers to replace deteriorated hardwood railway sleepers. One of the earliest composite sleeper technologies is made of polymer concrete and glass fibre reinforcement (*Fig. 8a*) that was used as replacement for timber, steel and concrete sleepers. A trial section of track was manufactured, trial tested and found to perform well under actual service conditions. Another development is the fibre composite railway transom (*Fig. 8b*) which is now being trialled on an actual railway bridge in Australia [4]. The composite railway transom is made up of a new type of fibre composite sandwich panel with additional fibre reinforcements. The first transoms were installed by the Australian Rail Track Corporation on a steel railway bridge located on a heavy and busy haulage line in November 2007 with monitoring done by Austrak Pty Ltd. The trial installation verified that the composite transoms are performing to expectations.

(a) Sleeper made of polymer concrete and fibre composites (b) Fibre composite transoms

Figure 8. Innovative fibre composite railway sleepers.

4.3 Fibre composite piles

Deep foundation industry has historically involved the use of traditional pile materials such as concrete, steel and timber. However, there are problems associated with the use of these materials especially when installed in corrosive and marine environments. In the marine environment, fibre composites can be selected for their corrosion, rot, and pest resistance as well as their high strength-to-weight ratio. Given the significant number of timber-piled piers in the Australian coastline, there is an increasing interest for a cost-effective fibre composite system. Recently, BAC Technologies Pty. Ltd. has developed and supplied more than 50 piles to BCC for the rehabilitation of the Shorncliffe Pier in Brisbane (*Fig. 9a*). This project used 300 mm diameter hollow composite tubes for partial repair and total replacement of damaged timber piles [8]. Similarly, Wagners CFT used 125 mm square pultruded FRP piles to shore up the Jack Evans Boardwalk in Tweed Heads, New South Wales (*Fig. 9b*) [9]. This 2,250 square metre project was Wagner CFT's first use composite piles in the field where a total of 410 piles were driven to set the boardward structure in reclaimed soil and near the shore.

(a) Timber pile replacement at Shorncliffe pier (b) Composite piles for Jack Evans Boardwalk

Figure 12. Application of hollow fibre composite piles.

5. Challenges and issues

The current field applications show that Australia is not far behind from the rest of the world in using fibre composites in building efficient and reliable civil infrastructures. However, the issues and challenges in making these projects into a reality have been well documented. While these difficulties are substantial, all parties have worked together to ensure that these barriers are minimised and the best outcome for the project is achieved. The following are the main issues which continue to limit the growth of fibre composites in civil infrastructure.

5.1 Design codes and guidelines

Engineered fibre composites have huge potential for civil infrastructure applications. However, there is a great challenge for the structural designer when there are no specific design standards and familiarity with the behaviour of such new materials. To overcome this situation, all strength calculations were performed with standard theory as well as finite element techniques backed up by strength and fatigue testing at both the "material level" and the "bridge component" level since each fibre composite design is new and unique. At the same time, the construction of the different infrastructure projects enabled several industries and authorities to document activities which laid out several design and construction guidelines in using fibre composites [10]. These have provided them valuable information on the quality of on-site practices and procedures and developed trained and competent personnel. More importantly, this has given engineers with foundation guidance and confidence to begin exploring new structural systems utilising composites.

5.2 Economy of scale

Capital cost is the key driver for infrastructure projects. Consequently, the types of materials used, and the manner in which they are used differ from other industry sectors such as marine and aerospace. However, what could a fibre composite bridge cost if all the materials and components were produced on an industrial scale? To a large extent, there will be no clear answer to such a question until a fair amount of extra development work is done. As a way of promoting their product, CarbonLOC and Wagners CFT have both adopted a policy of establishing a market for a simple basic product (waterproof building panel or pultrusion) which enables efficient production in larger quantities than would ever be used in bridge construction. This approach will eventually lower construction costs and makes fibre composites competitive with other conventional materials.

5.3 Innovations

As documented in this paper, real-world structures using fibre composites are achievable. However, most of these new composite systems take significantly different form than those traditionally targeted at the infrastructure market. As fibre composites engineered systems are typically high strength but has low stiffness in nature, it was realised that combining this material with traditional engineering materials can be an effective means of managing capital cost provided it does not compromise the reason for using fibre composites (e.g. corrosion resistance). As a result, several projects were constructed by combining fibre composites with steel, concrete and timber to modify their behaviour. These hybrid structures exhibited higher serviceability stiffness, enabled pseudo-ductile behaviour as the steel yields and enabled "strain hardening" as the load capacity continues to increase with increasing strain.

5.4 Education and training for civil engineers

The Australian industry has developed expertise in the application of fibre composites in civil infrastructure. Several successful infrastructure projects are a testimony to this. However, there is still a lack of practicing engineers who are trained to design and use fibre composite materials. To fill this gap, postgraduate level courses in fibre composites and advanced structural engineering was developed and offered at USQ for engineers to upgrade their knowledge to be suited for this developing industry. Similarly, the CEEFC is now proactively promoting fibre composites for civil infrastructure applications. Short activities as part of practice courses at USQ are being convened every year by the authors to introduce different manufacturing processes and engineering applications of fibre composites to senior engineering students. These activities are anticipated to help in filling the gap in the skills and knowledge shortage in this emerging industry in Australia and internationally.

6. Conclusions

This paper has presented recent developments and field applications of fibre composites into civil infrastructure in Australia. Several new and innovative structural systems have shown that fibre composites are reaching a point of commercial reality in the Australian construction industry. Still, there are barriers that need to be overcome for the continued growth of fibre composite infrastructure. By forming an alliance with the designer, client and the manufacturer, working towards the best outcome for the project within the constraints had led to the successful completion of the fibre composite structures discussed in this paper. It is believed that such model could be very effective in gaining acceptance of this innovative material in civil infrastructure. Other challenges faced by the structural designer in such cases are the understanding of the behaviour of the fibre composite materials, its failure mode and adopting available design guidelines to the local needs. This also emphasise the need to train structural engineers in fibre composites and the development of relevant design standards/guidelines in Australia. When these are achieved, the fibre composites will become more competitive with the traditional construction materials and it would be possible to harness its potential in civil infrastructure.

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