SUSTAINABLE CONSTRUCTION FOR THE FUTURE

Refereed Paper

FIBRE COMPOSITE INNOVATIONS IN AUSTRALIA’S CONSTRUCTION INDUSTRY

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Abstract

During the past 5-10 years there has been considerable activity in research and development of fibre composites in the Australian construction market. Areas of activity have included; bridge systems, replacement of large section hardwood girders and waterfront structures. Fibre Composites Design and Development (FCDD), a Centre of Excellence at the University of Southern Queensland (USQ) has played a leading role in these developments. 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, these technologies have evolved from initial technology demonstrators to become viable commercial alternatives to traditional structural solutions. This paper presents a review of these developments and examines the process involved in taking these new systems from a novelty to a viable and credible alternative for local asset owners.

Keywords: composite structures; innovation; bridges; beams; marine structures
1.0 INTRODUCTION
Australian asset owners are actively seeking solutions for the rehabilitation and replacement of deteriorating civil infrastructure. They are faced with the problem of decreasing budgets to address an ever increasing demand for structural replacements and/or upgrades. To address these issues, Australian asset owners have invested significant funds into the development of new structural systems utilising fibre composites. Fibre Composites Design and Development has played a major role in these developments. This work is now paying dividends with a range of new systems providing design solutions which not only offer high levels of functionality, but do so at a cost which is often directly competitive with traditional structural solutions. Several of these systems have been successfully demonstrated in real world projects and are now being developed into commercial offerings. This paper presents an overview of these developments, specifically in the areas of bridge systems, alternatives to large section hardwood bridge girders, and waterfront structures. It describes the path, participants and activities that lead to the successful outcomes, and highlights important lessons which have been learnt about the integrating of new composites technology with mainstream civil engineering.

2.0 BRIDGE SYSTEMS
In February 2003, the first fibre composite bridge in the Australian road network was opened to traffic. This structure, located near the village of Coutts Crossing west of Grafton in northern New South Wales, was the culmination of a development program stemming back to the late 1990’s.

2.1 BACKGROUND
While the lack of harsh winters and associated salting of roads removes one of the major causes of bridge deterioration that exists in the USA and Europe, Australia too faces a major bridge replacement program. There are approximately 40,000 road bridges of 7m span or larger in Australia, with a total asset value estimated around $10 billion. Of these, about 10,000 are of timber construction, mostly on the Eastern Seaboard. While old forest hardwood timber is a durable material, many of these bridges, in excess of 60%, were built before the 1940’s and were designed to lower loading standards than would be required today. Many of these structures require major rehabilitation or replacement now or in the near future. Hardwood as a structural material is a rapidly diminishing resource and infrastructure owners are actively seeking alternative solutions. With their purported high durability and ability to mimic timber performance through judicious design, fibre composites have become an area of significant interest.

Figure 1: Installation of Australia’s first fibre composite bridge
The first fibre composite bridge in the Australian public road network was installed on 19 February 2003 (Figure 1). This installation was the culmination of a development and innovation process lasting over 5 years and involving a wide range of interested parties including; Queensland Department of Main Roads (QDMR), the Roads and Traffic Authority of New South Wales (RTA), the Department of Industry Science and Resources (DISR), Fibre Composite Design and Development (FCDD), Wagners Composite Fibre Technologies (WCFT), the Cooperative Research Centre for Advanced Composite Structures (CRC-ACS) and consulting engineers Connell Wagner and Cardno MBK.

The project originated with a generic design exercise commissioned by the RTA which sought to identify which particular fibre composite bridge technologies should be encouraged. This involved the development of a performance specification that met RTA requirements and the submission of two conforming design concepts. One of these was a novel local concept developed by FCDD, the second was put forward by the CRC-ACS together with engineering consultant Cardno MBK. This design incorporated the latest technology from the United States.

The FCDD solution was selected as the preferred alternative based on a set of agreed selection criteria (Dutton & Cartwright 2001). The concept combined the high compression capacity of plain concrete with the high strength/low weight characteristics of fibre composites. The design concept was based on the traditional plank bridge concept, where individual beams are laterally post tensioned to create a bridge, as shown in (Figure 2).

![Figure 2: Bridge Cross-Section of FCDD Proposal](image)

The advantages of this concept include:

- No joints between deck and girders (the girders are the deck);
- Excellent resistance against flood loading and side impact;
- Significant redundancy in the structure due to large number of beams;
- The concept is well understood by bridge engineers;
- Significant understanding of the bridge behaviour can be obtained through testing of individual beams.


FCDD partnered with Wagners Composite Fibre Technologies, the RTA and QDMR to develop the concept into a working prototype which was installed on a Wagner's owned quarry site near Toowoomba, Queensland (Figure 3) in early 2002. An extensive series of field tests followed, revealing that the concept exceeded expectations in terms of its technical performance (Heldt, Marsh, Van Erp, Cattell, & McCormick, 2002). Based on this...
development work, RTA developed a project to install one of these new generation bridges for trial purposes.

![Figure 3: Full scale prototype of composite bridge under test](image)

The selected installation site was an existing timber span (circa 1940) on a bridge over the Orara River at Coutts Crossing in northern New South Wales. Consulting engineers Connell Wagner were engaged by WCFT to review and modify FCDD’s fibre composite bridge concept to suit the site specific requirements at Coutts Crossing. The new bridge deck design was seen to offer substantial benefits over traditional bridge deck design, including:

- Installation in 5 days, instead of 8 weeks for the conventional alternative,
- 90% savings on traffic control costs, and
- 75% saving on bridge transportation costs.

The bridge was constructed by WCFT under the supervision of FCDD and installed in February 2003. Initial site testing shows that the bridge is performing well. The RTA will continue to periodically monitor the bridge in coming years.

### 2.2 LESSONS LEARNT

Investigating the viability of new technologies (particularly in fields such as bridge engineering) is a long and involved process, involving careful deliberations by many interested parties. Translating an innovative concept into a safe practical result also requires a critical review of the underlying assumptions associated with conventional solutions. Leadership from the client/owner is critical, as is close collaboration between innovators and practitioners. Without active client involvement, innovation is likely to be stifled. All parties (particularly the owner) must assume and manage risks that exceed those addressed in routine projects. Such innovation also requires enthusiastic support from those with the resources to pursue innovative ideas and work towards a practical conclusion. WCFT not only took on the commercial risk of the Coutts Crossing project, but also assumed the greater responsibility of subsequent development of the concept into a fully commercialised product. This is a significant challenge.

The collaborative approach adopted by the Australian Road Authorities has been very successful and the project outcome suggests significant potential for fibre composite bridges in Australia in general, and the hybrid bridge concept in particular. This type of hybrid solution is being increasingly recognised as a sound approach to developing superior competitive products.
3.0 THE BRISBANE RIVERWALK PROJECT

3.1 BACKGROUND
The centrepiece of Brisbane City Council’s RiverWalk initiative is an 850m long floating walkway stretching from New Farm to the Story Bridge (Figure 4). This innovative floating walkway demonstrates how pioneering composites technology can be used to create world class engineering outcomes.

While floating marinas are used around the world, the Brisbane project posed a range of unique challenges. In addition to a very high dynamic load scenario, Brisbane City Council (BCC) requirements mandated a 100-year design life for the structure in what is an extremely aggressive environment. The traffic surface of the walkway is positioned a mere 50cm above the water surface, requiring that most primary structural components function continuously in the salt water splash zone or underwater.

The five meter wide walkway consists of a series of 288 floating concrete pontoons each weighing around 13 tonnes. The key to transforming the individual pontoons into a safe public access system were the interconnecting beams known as “walers”. A 3m long waler beam is used on either side of a pontoon to tie it to its neighbour (Figure 5). The walers are connected to the floats by stainless steel through-rods, which pass through the floats and walers and have a nut on each side. The floats consist of two polystyrene blocks encased in stainless steel reinforced concrete. The walers must be capable of transferring all required structural loads while maintaining overall walkway stability such that the public can transit freely and confidently. With most walers being on the outer edges of the walkway, the beams must also be capable of resisting impact loads from passing river traffic.
3.2 DESIGN SOLUTION

While the pontoon/waler concept is used in most floating marinas, no available waler solution was capable of providing a service life in excess of 10 to 15 years. Not only were traditional hardwood timber and steel/timber solutions projected to deteriorate in the aggressive environment within 15 years, but the high dynamic loads due to river traffic and tidal movements were expected to result in serious fatigue problems for steel walers. Usage of these traditional solutions would have required major maintenance of the walkway every 10 years and with some sections of the walkway requiring assembly in a dry dock, such a path would have created an unacceptable burden of access disruption and maintenance costs on the people of the city.

Facing a problem to which there was no known solution, BCC looked to the use of fibre composites to create a new type of waler beam which successfully addressed required performance and durability demands. An R&D team including BCC, International Marine Consultants (IMC), FCDD and Longhouse Green was put together to tackle this challenging problem. The team developed a number of new composite technologies to produce an innovative, environmentally sustainable solution capable of meeting the demanding requirements of the project (Figure 6). Although being twice the cost of timber and steel, the significantly reduced whole-of-life costs of the new waler concept made this technology an attractive economical option. The team based its pioneering approach around an innovative casting technique that combined a new polymer concrete formulation with a novel three dimensional glass fibre reinforcement system.

The waler concept was extensively tested before being applied in the floating RiverWalk. A range of static, dynamic, impact and fire tests were conducted to assess the performance of the walers (Figure 7). Test results demonstrated that the proposed waler design met all the project specifications. The walers have been installed now for more than a year and are performing well.
As with most innovative construction ventures, various issues arose during the floating walkway project which could not be envisaged at the outset. Following the success of the waler development program, the research team was invited to develop solutions to overcome a number of these issues. One area of the floating walkway that presented a serious structural challenge was the downstream end. This section of the walkway supports a 20m span, 5m wide pedestrian bridge, which provides access from the waterfront onto the floating walkway. In order to distribute the highly concentrated loads from the bridge over a number of pontoons, an 18m long structural member was required. A large part of this member is submerged in saltwater. The extremely high dynamic loads and harsh environment made traditional design solutions (steel and/or concrete) a prohibitive option. A special fibre composite truss was developed for this application (Figure 8). Because of its low weight (5000 kg), the truss offered significant benefits in terms of construction and installation time. Estimates on an alternative stainless steel solution were nearly three times the price of the composite truss. The truss has been designed to carry an ultimate bending moment of 700kN.m, is 2.5m deep and has a 1.4m deep cut-out to accommodate the pedestrian bridge. It provides an extremely durable and high capacity solution to a difficult engineering problem.

Figure 8: Fibre Composite Truss Developed for the RiverWalk Project

3.3 LESSONS LEARNT
There is an increasing recognition in Australia that the whole-of-life cost of infrastructure needs to be considered in the evaluation, not just the up-front costs. On this basis Brisbane City Council recognised that the composite walers offered a solution which was both technically and economically superior to traditional methods.

It is important that organisations like Brisbane City Council continue to undertake this type of innovative infrastructure project, despite the political and technical challenges. Researchers need projects like the floating river walkway in order to continue to push forward the boundaries of structural technology.

4.0 ALTERNATIVE HARDWOOD BRIDGE GIRDERS

4.1 BACKGROUND
Australian hardwoods are an excellent general purpose building material. This was recognised by early road builders in Australia, and hardwood timber bridges proliferated, particularly during the first half of the 20th century. Timber used in these structures was typically the best of the old growth forests. Australia currently has a large number of timber bridge structures in both its road and rail networks, possibly as many as 20,000. A large proportion of these are in the high maintenance phase of their useful life. As a result, many bridge asset owners are confronted with the following realities regarding these structures:
1. There is an increasing shortage of large section hardwood suitable to repair and rehabilitate these structures;
2. There are insufficient funds available to construct replacement structures;
3. The assets must remain in a safe usable condition;

This situation has created a need for effective alternatives.

4.2 A HYBRID COMPOSITES-TIMBER ALTERNATIVE

The hybrid beam concept uses plantation softwood in the form of laminated veneer lumber (LVL) for the bulk of the beam, with composite reinforcement modules to increase the strength and stiffness to a level equivalent to that of high quality hardwood (Figure 9). The timber provides the shear capacity for the beam, maintains the separation between the composite reinforcement modules, and provides the functionality and workability associated with timber.

![Figure 9: Schematic Cross Section of a “Hybrid” Girder](image)

The concept of a reinforced timber beam, utilising relatively low-performance timber as a core, and other higher performance materials providing additional stiffness and strength is not new. The main novelty involved in the approach relates to the combination of materials used to form the reinforcement.

The reinforcement modules use a patented combination of composite materials and have a Modulus of Elasticity of 60GPa and a failure load of around 500kN (Heldt, Marsh, Van Erp, Cattell, & McCormick, 2002, Heldt, Cattell, Van Erp, & Marsh, 2004, Heldt, Cattell, Oates, Prasad & Van Erp, 2004 and Heldt, Cattell, Oates, Prasad, Arthur, & Van Erp, 2004). The modules are bonded to the timber using a high strength epoxy adhesive. The stress in the adhesive is relatively low due to the large surface area of the modules. The hybrid nature of this reinforcing system provides a great degree of flexibility to engineer specific properties into the end product.

Considerable development was necessary to advance this concept towards a pre-engineered alternative hardwood girder. Figure 10 shows the results of some relatively small-scale testing of the hybrid girders. It shows the behaviour of a beam of solid F14 grade ply, and the behaviour of a hybrid beam of the same dimensions, along with the typical design values for similar beams made of high quality Australian hardwood. In addition to the increased stiffness and strength of the beam, the addition of the reinforcing modules resulted in a pseudo-ductile failure mode, providing significant warning of failure through cracking of the ply and the associated large deflections.
4.3 APPLICATIONS TO DATE
Prototype girders have already been installed by the Roads and Traffic Authority of NSW (RTA), Queensland Department of Main Roads and the Rail Infrastructure Corporation of NSW (RIC). Broadly, the hybrid beam is used in two main applications:

1. Existing hardwood bridges where this new girder concept is used as a direct substitute for traditional hardwood girders;
2. New light-weight structures such as road and pedestrian bridges, where the properties of each beam are engineered to meet specific (strength and stiffness) requirements.

Figure 11 shows two hybrid girders installed in an existing bridge as a direct replacement for hardwood girders, while Figure 12 shows 18m long hybrid beams for use in road-over-rail bridges which require shallow abutment depth to minimise earthworks, and a flat sofit to maintain minimum track clearances.
4.4 ENVIRONMENTAL BENEFITS
This hybrid beam development has received significant support from the Australian Rainforest Conservation Society and the Queensland Department of Environment as it reduces the need for hardwood beams which have traditionally been obtained through unsustainable logging of mature native forests. The concept is also unique in its large utilisation of plantation timber, thereby positioning it as an enabling frontier technology for the timber industry rather than a competitor. This has had a major positive effect on the industry acceptance of this new development.

In addition to the more sustainable raw materials associated with this new concept (90% plantation timber), the beam only incorporates one-sixth the embodied energy in its manufacture compared to conventional steel and concrete beams while providing superior load carrying capacity at an equivalent cost (Daniel 2003). The beam also has a positive environmental impact in terms of greenhouse gas generation, as it stores more CO₂ than it releases.

4.5 DISCUSSION
This hardwood replacement project has shown that there is much to be gained for all concerned by exploring new possibilities, and that this requires collaboration between asset owners, product developers, bridge maintenance staff, manufacturers, and indeed the community. This project clearly demonstrates that alternative solutions can be found, and that these provide exciting opportunities for new products. It has also highlighted that by establishing composites as a synergistic agent which can work in conjunction with traditional structural materials, market acceptance is greatly improved.

5.0 UNDERWATER REPAIR OF SUBMERGED BRIDGE PILES AFFECTED BY AAR

5.1 BACKGROUND
In late 2002, The Roads and Traffic Authority of NSW (RTA) noticed a serious structural problem that is affecting a number of their bridges. These bridges are relatively new bridges that have been constructed using concrete piles that now suffer from a serious decay mechanism known as Alkali Aggregate Reaction (AAR). This mechanism causes expansive forces within the piles which eventually lead to large cracks at the pile surface. These cracks result in serious corrosion of the reinforcement, in particular in submersed piles. This mechanism is significantly well understood to be largely prevented in new structures, but many existing bridge structures require major rehabilitation. In recent times the Queensland Department of Main Roads (QDMR) has also become actively involved in this project as they have a number of bridges with similar problems. In order to address these problems a team of experts including RTA, QDMR, FCDD and Lightning Composites developed a fibre
composite pile wrap concept that can be applied to submersed piles (Figure 13) (Carse 2004 and Heldt, McGuffin, Marsh, Youngberry & Carse, 2004).

Figure 13: Schematic of Pile wrap

The team produced a number of prototype pile wraps and a series of underwater trials were conducted to test the effectiveness of the concept (Figure 14). A special pressure test was also carried out to establish that the concept could sustain the required high pressure loads. These tests have shown that the wrap exceeds the stringent requirements. Further work is currently being planned to turn this exciting development into a commercial product.
6.0 CONCLUSIONS
This paper has reviewed several areas of research and development undertaken by FCDD over the past few years aimed at providing Australian asset owners and infrastructure authorities with new design solutions which are both highly functional and economical. Several of these systems are now in the process of commercialisation following successful demonstration and testing. It is anticipated that these products and technologies will make significant inroads into the Australian civil infrastructure market over the next five years.

FCDD has shown that it is possible to develop fibre composite technologies for the civil infrastructure market which provide end-users with the performance and cost structure they are seeking. Through close interaction with the end-users through the product development process, it is possible to develop systems which are readily accepted into the marketplace. Also by concentrating on areas where composites and traditional materials provide a synergistic interaction it is possible to overcome some of the cost barriers normally associated with composites technology.

In addition to the support from Queensland Government Departments, FCDD has greatly benefited from a $7.5M infrastructure grant made available by the Queensland Government from the Smart State Research Facilities Fund (SSRFF) support scheme.
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