

# **Australia's First Fibre Reinforced Polymer Bridge Deck in a Road Network – The Anatomy of Innovation**

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## **SYNOPSIS**

In Europe, Japan, China, the USA and Canada over seventy bridges employing composite materials have been built as technology demonstrators. Australia's first Fibre Reinforced Polymer (FRP) Bridge Deck on a road network was installed on 19 February 2003. This was the culmination of over 5 years of development and innovation involving a wide range of interested parties.

This paper documents the path, participants and activities that lead to Australia's first fibre composite bridge in the road network. It provides an overview of the development from preferred concept to installed structure. The rationale behind selection of the preferred structural concept is summarised, before an overview of the product development process is of the concept is described including some of the technical issues that required resolution. Evaluation of the resulting prototype structure is then described.

The rationale used to extend the prototype structural concept to a bridge in the public road network is described, including organisational and management issues that were critical to enable delivery of the project. The importance of organisational inputs that facilitated this innovation are then summarised.

## **1 INTRODUCTION**

Fibre reinforced composites have a number of features which make them attractive for use in bridge structures including; low weight and high strength, greatly improved corrosion resistance and durability, ease of transportation and lower energy consumption during manufacture. These features have been recognised by many road authorities around the world (particularly in the past 10 years), and a range of structural forms have been investigated or trialed.

Australian road authorities have been observing international developments for some time, and there was considerable interest in investigating fibre composite bridge technology under local conditions by the end of the 1990's. In February 2003, the first fibre composite bridge deck was installed in the Australian road network near Coutts Crossing, west of Grafton in Northern NSW. This was the culmination of over 5 years of involvement by Australasian Road Authorities.

This paper traces the development of the project that resulted in the Coutts Crossing Bridge, both for the sake of documenting the process, and because it illustrates some of the issues involved in introducing new technology. The paper then discusses issues affecting the development of this emerging technology in Australasia.

## **2 WHY COMPOSITE BRIDGES?**

Polymer composite materials, i.e. materials that consist of a polymer (or plastic) reinforced with fibres such as glass or carbon, are found in many applications. Inherently these materials offer high strength, low weight and are corrosion resistant. While these materials have found extensive applications in marine and aerospace applications, they have yet to be universally accepted by civil engineers. Considerable research has been directed at the use of composites in bridge structures (particularly since the early 1990's), especially in countries that suffer from harsh winters and the associated deterioration of traditional bridge structures due to de-icing salts [1]. In the USA alone, the damage to concrete bridge decks caused by salting roads during winter runs into billions of dollars. The inherent resistance of fibre composite structures to such an aggressive operating environment made it an obvious vehicle to pursue structural systems with improved durability.

Fibre composite structures also offer the potential to be significantly lighter than structures made from more traditional materials. The on-going drive to increase transport system efficiency by increasing legal vehicle mass means that there is the potential to replace older and deteriorated bridge superstructures with new light weight superstructures. This can result in a structure with improved live load capacity without the expense of new sub-structures and approach works. Other consequences of inherent light-weight include the potential for:

1. Faster installation because component mass is less limiting on construction operations;
2. Longer spans, which may offer significant advantages under certain site conditions.

These drivers for the development of fibre composite bridges are common to bridge developments with more conventional materials, and are therefore not unique. The viability of composite bridges must therefore be evaluated against:

1. On-going development of bridges manufactured from conventional materials;
2. Unique performance advantages offered by fibre composite materials;
3. Development of technologies, systems and organizations to support fibre composite bridges as a viable alternative in the Australasian bridge market.

Australasian road authorities pursue the most appropriate solutions for their bridging requirements. While there is a distinct advantage to have fibre composite bridge technology available, extensive use of this technology will only occur if the potential can be realised in the market place. The installation of the Coutts Crossing Bridge represents an important step in the introduction and evaluation of this emerging technology.

## **3 CHRONOLOGICAL SUMMARY**

Activities that lead to the installation of the Coutts Crossing Bridge can be traced back at least 5 years prior to the project completion. Fibre Composite Design and Development (FCDD) at the University of Southern Queensland (USQ) was established as a leading Civil Engineering Fibre Composites Research Centre by 1996. By this time, interest from road authorities in this technology was increasing. In particular, the Department of Main Roads-Queensland (DMR) became actively involved in research that FCDD had been undertaking, which added to the support given by Connell Wagner Consulting Engineers. This involved investigations into fundamental material behaviour, analysis techniques and concept development.

In 2000, the Department of Industry Science and Resources (DISR) provided funding to the Cooperative Research Centre – Advanced Composite Structures (CRC-ACS) to undertake a feasibility study into the viability of Fibre Composite Bridges for Australia [2]. The CRC-ACS

collected background information on Australian Bridge Infrastructure needs. Subsequently, a concept design competition was conducted by the CRC-ACS, with various road authorities acting as the concept evaluation panel. As a result of the design competition, a preferred concept was chosen, and the Roads and Traffic Authority – New South Wales (RTA) indicated an interest in installing a demonstrator bridge based on this concept, subject to satisfactory proving of the concept and related technology. The main tasks that resulted in installation of the Coutts Crossing Bridge were:

1. Design concept competition;
2. Research, development prototyping and proof of concept;
3. Concept evaluation;
4. Development, design, fabrication and installation of the Coutts Crossing bridge.

Organisations involved in these tasks are summarised in **Table 1**.

*Table 1. Chronological Summary of Activities and Organisations*

<b>Year</b>	<b>Activities</b>	<b>Participating Organisations</b>	
1998-1999	Research and concept evaluation	USQ DMRQ	Connell Wagner
2000	Feasibility study, research and concept evaluation	CRC-ACS University of Newcastle USQ DMR (Q) RTA Cardno MBK VicRoads	Department of Industry Science & Resources CSIRO ADI (Australia) Martin Marietta Composites University of California (San Diego) Composites Institute of Australia
2001	Research, development & Prototyping	AusIndustry State Development (Qld) USQ WCFT	DMR (Q) RTA Longhouse Green Huntsman Composites Zoltec
2002	Prototype evaluation & fabrication of first bridge for the Road Network	USQ WCFT DMR (Q)	RTA Connell Wagner Longhouse Green
2003	Installation of first bridge in road network	WCFT Connell Wagner RTA	USQ Longhouse Green

### **3.1 Design Concept Competition**

In 2000, the Department of Science and Resources (DISR) commissioned an investigation through its Technology Diffusion Program (TDP) to investigate the feasibility of constructing a fibre composite road bridge in Australia as a demonstrator project. The Cooperative Research Centre – Advanced Composite Structures (CRC-ACS) coordinated the study under the direction of a Steering Committee chaired by the RTA. In general terms the composites industry internationally had identified civil engineering infrastructure as a major potential market, while road authorities (including the RTA and DMR) were aware that composite materials may provide useful solutions in parts of the bridge market. The consensus was however, that a demonstrator project would have to be undertaken in the Australian context to investigate the “real” feasibility of such solutions [2].

The study evaluated the viability of constructing a road bridge using polymer composite materials with the aim of demonstrating and disseminating information on the effectiveness of these materials for bridge and other civil infrastructure applications. It identified a wide range of parties interested

in participating in a demonstrator project, including pre-existing specialist overseas expertise. Issues of management, responsibility and liability were also addressed as part of the study.

A design concept competition was established as the vehicle to assess the viability of fibre composite bridges in the Australasian context. Environmental challenges met by many overseas composite bridges are not necessarily the same for bridges in the Australian environment. Particular local issues included the effects of bush-fire, UV radiation and moisture uptake. The RTA as part of this Feasibility Study prepared a detailed Design Specification for a Fibre Reinforced Polymer Composite Bridge. The Specification was necessary to define the requirements of a composite bridge before the feasibility of proposed design concepts could be measured.

After some initial investigations, two teams were requested to submit proposals to a specification drawn up by the RTA Bridge Design Group, namely:

1. Cardno MBK;
2. FCDD.

These designs were to meet the generic Specification for a single span, two-lane Highway Bridge prepared by the NSW RTA as part of the Study.

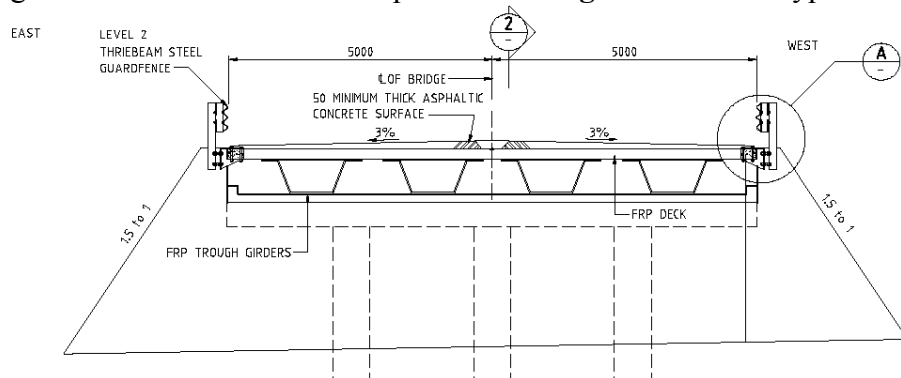
Each team was requested to justify their concepts against the specification. In particular, the successful FRP bridge proposal had to:

- equal the performance expected from a design based on traditional materials;
- meet the traffic load requirements of SM1600, and
- address the concerns that had been voiced by various professionals.

Each of the study participants submitted a design proposal to the RTA in December 2000. Each of the proposals met the specification requirements and is summarised below.

### 3.1.1 Cardno MBK Proposal

Cardno MBK's proposal was based on a deck and girder concept and employed technology from the United States. This was a single simply supported span of overall length 10.92 m, and width of 10.0 m. Two-way 3% cross-fall was provided by a variable depth asphaltic concrete wearing surface. The deck was formed from nominal 150mm deep pultruded fibreglass profiles glued together. The girders were U-shaped channels approximately 600 mm deep, manufactured by hand laminating of glass fibre laminates over simple moulds. **Figure 1** shows a typical cross section.



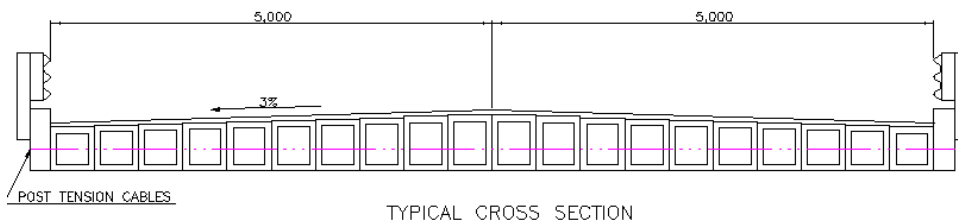
*Figure 1. Typical Cross-Section of Cardno MBK Proposal*

The pultrusion process produces continuous lengths of fibre reinforced polymeric sections similar to extrusion for metal sections. It is a process that can economically produce large quantities of uniform section, but involves relatively high set-up costs. Consequently Cardno MBK proposed that many of the components for the first bridge would be imported from the USA. The deck would be assembled into sections suitable for transport to the bridge site by truck, where it would be glued to

the girders. The asphalt would be then be applied, and the roadside guardrails and hardware attached. Components used would be considerably lighter than conventional steel/concrete solutions, allowing for a small installation crew and lighter cranes to be used on-site.

### 3.1.2 FCDD Proposal

The original FCDD proposal was based on the plank bridge concept but employed filled polymer resins and carbon and glass fibres rather than the traditional concrete and steel. A cross-section of this proposal is shown in **Figure 2**. These materials and technology (and a range of others) had been under development at FCDD since 1995. The proposed design was 10 m wide and 10m long and comprised 22 beam/planks laterally post-tensioned to provide slab-action. Cross-fall was provided by means of staggering the heights of adjacent longitudinal beam/planks. Conventional asphalt would be applied for the wear-surface and conventional Level 2 barriers were to be bolted to the outermost beam/planks.



*Figure 2. Typical Cross-Section of FCDD Proposal*

The system was based on one of FCDD's developing technologies. Carbon fibres were to be used for stiffness reinforcement and glass fibres used for strength in other areas. A polymer resin mixed with readily available particulate was used as a 'core' material to provide section bulk for the planks. Nominally 575 mm deep hollow planks would be produced, and these would be robust, durable, and lighter than equivalent steel/concrete planks. The planks would be manufactured in Australia and pre-assembled into modules that could be easily transported to the bridge site by truck. At the site a light crane was to be used to locate the deck modules on the foundations. The modules would then be laterally post-tensioned in a manner similar to concrete plank bridges.

### 3.1.3 The Result

While both of the proposed concepts were considered to meet the specification, the study suggested that solutions being pursued overseas would not be cost effective in Australia. The overseas focus is on replacement decks that are most affected by the use of road salts for ice clearance. This is not the primary driver for bridge replacements in Australia, where in most cases the entire bridge will need to be replaced and a solution that cost-effectively integrates the deck and support structure is the most desirable. It was decided that the FCDD proposal offered better potential to meet Australasian requirements, and had strong potential to be commercially attractive as well as successful from a technical point of view [2].

Having indicated a preference for the FCDD concept, the RTA suggested that it would consider installing a structure based on this concept in its road network if it were first developed and proven as a prototype. The demonstrator bridge could then be installed in the road network using the prototype as part of the concept validation. FCDD lacked the resources to pursue this development on its own, so an arrangement was developed between FCDD and Wagner Investments (with later assistance of an AusIndustry START grant) to facilitate development and proving of the prototype. Subsequently a new division of Wagners– Wagners Composite Fibre Technologies (WCFT) was

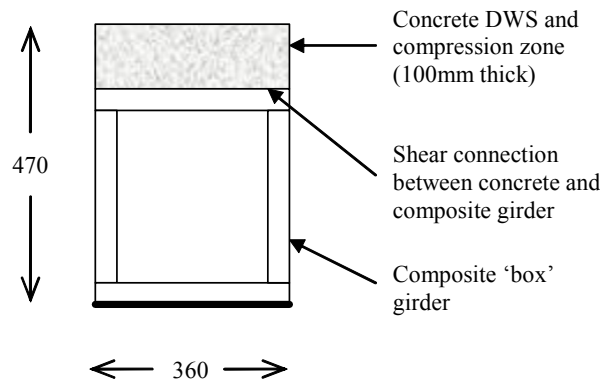
formed this purpose. In return Wagner Investments (later WCFT) would retain the rights to commercialise the concept (including the right to produce the first demonstrator bridge).

### 3.2 Research, Development and Prototyping

A programme of development was planned in early 2001 that would see the first prototype structure under evaluation in early 2002. The programme included:

1. Verification testing of small scale (approximately 3 m length) prototype beams including proving of production techniques;
2. Benchmarking of the preferred beam concept with several other beam concepts that FCDD was investigating;
3. Conducting a value engineering exercise where the known requirements of the bridge concept were compared with the benchmarking results;
4. Test a half scale (5-6 m span) beam to investigate the behaviour of the preferred beam concept, and prove the associated production processes at that scale;
5. Design and manufacture of a half scale prototype bridge (5 m span) to investigate the behaviour of the bridge system, and further develop production and installation technologies;
6. Design, manufacture, test and prove a full scale girder and/or girder segments subject to agreed loading requirements consistent with the new SM1600 loading requirements;
7. Finalise the prototype bridge design based on (1) to (6) above;
8. Manufacture and install the prototype structure on the first evaluation site;
9. Conduct initial evaluation of the structure based on high speed behaviour testing and overloaded vehicle testing;
10. Move the prototype structure to a new site, subject it to regular heavy vehicle traffic, and monitor the on-going health of the structure.

While the initial evaluation process was completed as part of (10) above, monitoring and evaluation of the prototype was intended to continue.



*Figure 3. Cross-Section of Hybrid Beam Concept used in Prototype Structure.*

The value engineering exercise (3) revealed that the type of beam proposed in the feasibility study [5] was not the most appropriate for further development of the concept. Rather, a hybrid beam concept then under consideration by FCDD had more potential in this particular case, both in terms of its technical performance, and cost effectiveness. A typical cross-section of this beam is shown in **Figure 3**, and is described in more detail in Van Erp et al [6]. The half scale beam testing (4) showed that behaviour of the hybrid concept was consistent with the requirements of the project, so a half scale prototype structure was constructed.

Among other things, half scale prototype testing (5) was used to investigate functioning of the girders as a deck unit bridge (**Figure 4**). In particular, transverse stressing trials were conducted.

These revealed that the form of the hybrid girders made them difficult to transversely stress using a conventional approach because the bottom half of these girders consisted of relatively flexible pultrusion elements, rather than large pieces of rigid concrete typically used in concrete deck unit bridges. Consequently, transverse stressing was not used in the prototype structure. Instead transverse (unstressed) glass reinforcement would be used to combine individual hybrid deck planks into “half-width” slabs, with a mechanical field joint being used to join each half on site [3].



*Figure 4. Half-Scale Prototype Bridge Trials.*

Based on these investigations (1 to 5), prototype full scale girder and girder sections were designed, manufactured and tested (6) satisfactorily as described in [6]. The design of the prototype bridge was then finalised (7), before the full-scale prototype structure was manufactured and installed on the first evaluation site (8). The prototype structure (**Figure 5**) consists of 14 individual girders, fabricated into two halves (each 2.6 m wide). One end of the bridge rests on a rubber pad bearing, while the other rests on a grout bearing. A mechanical joint was used to join the two halves. The mechanical connection was arranged such that shear bolts joined the bridge halves at the top and bottom. These shear bolts were located at 400 mm centres longitudinally. This joint was intended to allow for research into the joint behaviour, rather than represent a production joint. By progressively placing the bolts in the top and bottom of the joint, the effect of increased transverse joint stiffness on bridge behaviour could be investigated.

### 3.3 Concept Evaluation

Considerable behavioural testing was conducted on the first evaluation site and this is described in Heldt et al [3] (and elsewhere in Van Erp et al, [6]). This was done using conventional 6 axle articulated heavy vehicles with tri-axle groups at approximate load levels as follows:

1. Half legal load;
2. Legal load;
3. 1.5 times legal load.

In addition, an off-road mine haul truck was used to apply load substantially in excess of legal loads (**Figure 5**). In some cases the gross vehicle mass (GVM) was approximately 75 tonnes with a rear axle load approaching 50 tonnes.

On the basis of the test results, the behaviour of the prototype bridge was generally found to be consistent with analytical predictions [6], with the most important observations being:

1. Measured static strain and deflection values were consistent with analytical predictions;
2. Adequate field joint behaviour (for structural purposes) could be obtained through the use of a shear connection at the top of the adjacent deck halves;
3. Lateral distribution of load was consistent with analytical predictions;

4. The dynamic behaviour of the structure is generally consistent with similar bridges manufactured from conventional materials.



Figure 5. Prototype Bridge with 769C Off-road Mine Haul Truck (GVM approx. 75 t).

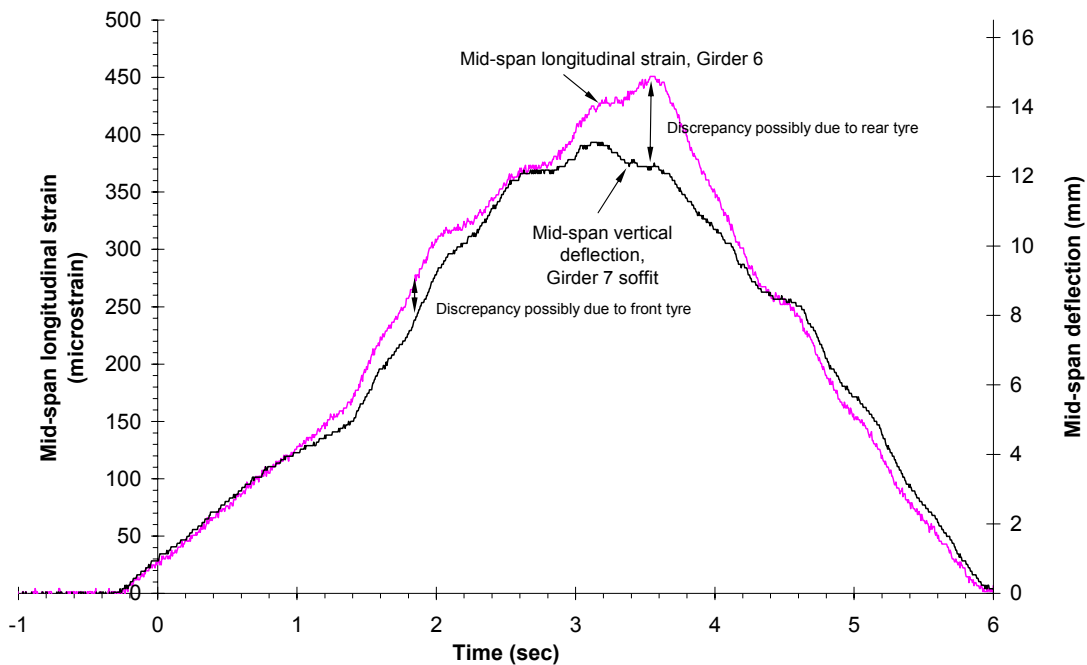


Figure 6 Centre Deflection of Bridge Soffit for 769C at Crawl Speed Travelling South.

There was some evidence of locally increased strains in the vicinity of large wheel loads. **Figure 6** shows strain and deflection plots (waveforms) against event time. Both waveforms have been scaled and superimposed, showing apparent discrepancies between strain and deflection. This appears to be caused by localised deformation of the composite structure. While the wheel loads that caused this effect are much larger (almost an order of magnitude) than those likely to be seen in service, they show the importance of a careful and thorough evaluation of the detailed behaviour.

The consistent relationship between measured static strain and deflection, and predicted values was very encouraging. However one of the important aspects of the behavioural testing was to investigate whether the dynamics of the structural system were consistent with conventional bridges of a similar span, thus allowing the provisions of the bridge design code relating to dynamics to be applied to this type of structure, and the proposed Coutts Crossing Bridge in particular. This was investigated extensively [3]. The natural frequency, damping and dynamic amplification resulting from bridge-vehicle interaction were all found to be consistent with conventional structures. As part



of a separate collaborative investigation, Heywood [4] also concluded that “...the fibre composite bridge exhibits behaviour consistent with short span high frequency bridges.”

### 3.4 Coutts Crossing Demonstrator Bridge

Bridge structures are invariably designed with the aid of Design Standards/Codes; however these resources relating to polymer composite structures are limited. Consequently the prototype project (particularly the bridge testing and evaluation) were key elements required for the RTA to allow a new fibre composite bridge technology into their road network. The evaluation process had established among other things, the following key points:

1. Based on extensive development (albeit over a relatively short period of time), the prototype concept as developed by FCDD and WCFT was “fit-for-purpose” as a short span bridge;
2. The static behaviour of the bridge concept could be predicted relatively accurately based on modelling approaches developed by FCDD;
3. The dynamic response of the prototype structure was consistent with conventional short span bridges, therefore it was reasonable to apply the dynamic loading provisions of the 1996 Australian Bridge Design Code.

Consequently, the RTA progressed with the installation of a trial structure in the road network based on the prototype project, and rational design using standard bridge design procedures.

Some important design issues had not been fully addressed as in the prototype project, particularly:

1. Resistance of the structure to fire;
2. Provision of a compliant traffic barrier system;
3. The development of a suitable field joint

These issues were not critical to the objective of the prototype project (proof of concept), but had to be addressed as part of the demonstrator project. FCDD and WCFT believed that the most appropriate solution to provide fire resistance would be to coat any exposed areas with a fire resistant material (either paint, or FC sheeting). Provision of a compliant traffic barrier system was a reasonably straight-forward exercise in engineering design once the basic bridge concept had been proven. The prototype testing verified that a relatively simple shear connection was all that was required for a field joint, which could be done by extrapolating the approach already used to produce the prototype deck. With these minor issues yet to be resolved, the decision was taken by RTA to proceed with the installation of a demonstrator bridge.

Two sites were considered by the RTA as being appropriate for the installation of this new structural concept. Both sites required a single span two lane structure with a span of approximately 10 m. After initial project development by RTA, WCFT and FCDD, it was decided to replace an existing timber span on a bridge over the Orara River, constructed in the 1940's at Coutts Crossing in northern NSW. Discussions proceeded between the key parties (RTA, FCDD and WCFT) to develop the idea of using the site as a trial site for the new concept into a properly formulated project. Issues included:

1. Project roles and responsibilities;
2. Project risks;
3. Timeframe;
4. Legal liabilities;
5. Alternate plans if problems were discovered with the concept;
6. Contractual arrangements.

Effective collaboration continued between the parties with the RTA, FCDD and CFT developing the early stages of the Coutts Crossing project. The Coutts Crossing project had to be undertaken using standard commercial design and contracting implements. The RTA was both client and

superintendent and had already engaged Cardno MBK to design and certify the sub-structure design prior to entering into subsequent arrangements with WCFT. In due course, the RTA engaged FCDD to provide expert advice and reporting on the design, manufacture, installation and field-testing of the demonstrator bridge.

WCFT undertook to deliver the project on a design and construct basis. WCFT were therefore responsible for delivery of the project (Head Contractor), manufacture and installation of the demonstrator deck. WCFT required a conventional civil engineering design organization to verify that the prototype concept applied to site conditions complied with relevant Australian standards and to certify the superstructure design. Connell Wagner Consulting Engineers were selected as the superstructure designer as a result of their extensive interest and general involvement with composites engineering, particularly their involvement with FCDD. In addition to engaging Connell Wagner as designer, WCFT also engaged:

- FCDD - to assist them with project establishment, and resolution of outstanding issues;
- Longhouse Green – to provide quality assurance and management services.

FCDD was subsequently engaged by Connell Wagner to brief and train them on the prototype system including its behaviour, and appropriate analytical procedures to be used for the design of the Coutts Crossing structure.

After several discussions regarding outstanding technical issues, the following decisions were made:

1. No additional fire resistant coatings were required for the structure give the low fire threat, and the desire to keep as much as possible of the actual superstructure visible for inspection;
2. FCDD proposed, built and tested level-2 traffic barrier system on behalf of WCFT. Details of this were subsequently provided to Connell Wagner, who subsequently certified a slightly modified design for use on the Coutts Crossing demonstrator project;
3. FCDD proposed a field joint detail, which was subsequently developed by Connell Wagner for use at Coutts Crossing.

One additional issue remained to be resolved. RTA policy requires that longitudinal construction joints in bridge decks should be transversely stressed when installed on major routes. In order to ensure that results for the demonstrator project could be extrapolated to other projects, RTA required that provision for stressing of the longitudinal construction joint be provided in the event that the proposed un-stressed joint should fail. Connell Wagner developed a stressing detail that was proven on the original prototype structure to meet this requirement. This form of transverse stressing was based on that used in stress laminated timber bridge decks, rather than that used on concrete deck unit bridges (which had been investigated previously by FCDD) Provision for transverse stressing was therefore provided in accordance with RTA requirements.

Manufacture of the demonstrator bridge deck by WCFT proceeded while the final design details were resolved by Connell Wagner. Following completion of each half deck, they were subject to a proving load in WCFT's Toowoomba facilities. This consisted of placing the tri-axle group of a float in the centre of each half-bridge deck. The tri-axle group was then statically loaded up to a mass producing a total applied load of approximately 65 tonnes (**Figure 7**). Mid-span deflection of the half deck was then measured and compared with analytical predictions, and good agreement was observed. While the proving load test may appear to be relatively severe, it provided a level of assurance regarding the validity of both design and manufacturing techniques.



*Figure 7 Proving Load Applied to Half Bridge Deck.*



*Figure 8 Coutts Crossing Demonstrator Bridge Deck During and After Installation*

Following installation of the demonstrator deck (**Figure 8**), behavioural testing (using a standard 42.5 six axle articulated vehicle) was conducted by the RTA to verify performance of the bridge deck as installed. This also provides benchmark data for future testing and evaluation. Currently the RTA intend to repeat the behavioural tests after 1 year, and again after 5 years to verify that the behaviour of the new fibre composite bridge deck has not deteriorated over time.

#### **4 DISCUSSION**

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 was critical, as was 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 required enthusiastic support from those with the resources to work with the technical staff and issues and pursue innovative ideas 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 successful project outcome suggests significant potential of fibre composites in general, and this bridge concept in particular. The viability of the concept has been subsequently recognised internationally, with significant interest from North America. The concept successfully combines

fibre composite technology with concrete technology to produce a hybrid product. This type of hybrid solution is being increasingly recognised as a sound approach to developing superior competitive products [7].

## 5 CONCLUSIONS

The background and anatomy of development of Australia's first fibre composite bridge has been described in this paper. The process of achieving this outcome was relatively (and of necessity) quite complex and required active involvement from a range of organisations. This project represents a milestone for Australia in the evaluation and adoption of fibre composite materials for civil engineering infrastructure applications.

## 6 ACKNOWLEDGEMENTS

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