More than just a pedestrian link – The Goodwill Bridge, Brisbane

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SYNOPSIS

Since opening in October 2001, the Goodwill Bridge has attracted large numbers of pedestrians and cyclists, both commuters and casual users eager to take advantage of the new link formed between Southbank and Brisbane's CBD.

The spectacular steel and concrete bridge has a unique form that was initially established in an architectural concept design competition. The winning concept broke the 460m long bridge in to visually different sections to enliven the journey for users with the middle section being an extraordinarily slender arch that spans over the navigation channel of the Brisbane River.

The daring form has generated great interested in the previously neglected southern end of Southbank and has revitalised QUT's Gardens Point campus. The visual and functional contribution that the bridge makes to the urban fabric of inner city Brisbane has been recognised in awards for architects Cox Rayner, and the quality of the engineering design and construction techniques has been recognised by a series of industry awards for Engineers Arup and contractor John Holland.

The paper outlines the main features of the design, and describes the role that close cooperation between designer and contractor played in the successful prefabrication and erection of the bridge. The paper also provides insights in to the challenges and rewards of working with architects on infrastructure projects that have traditionally been driven primarily by engineering considerations.

1 INTRODUCTION

Infrastructure projects are commonly designed and constructed using well-established precedents, with the basic form of the construction determined largely by engineering considerations and basic functional requirements. The Goodwill Bridge is an unusual piece of infrastructure in that the form of the structure was heavily influenced by an aesthetic and sculptural concept that was selected by the client via an architectural design competition. Unlike most infrastructure projects, there were few if any precedents upon which the engineers could draw.

The desirability of a bridge linking the southern end of South Bank with Brisbane's CBD was identified in the early 1990's during initial masterplanning of the South Bank development. A bridge was proposed in this location as one of the main elements in the 1997 South Bank Masterplan. Recognising the importance of the appearance of the new bridge to the success of the redevelopment of South Bank, the South Bank Corporation decided to conduct an architectural design competition to find a design concept worthy of the location.
In late 1997, a design concept prepared by Cox Rayner Architects was selected by the Corporation, and Cox Rayner were engaged as project architects. In early 1998, Arup was

appointed by South Bank Corporation as structural and civil engineer for the project. Siting studies, structural concept and scheme designs and public consultation were carried out from early 1998 to mid 1999. In mid 1999 State Government approval was granted to proceed with the project, and control of the project was assumed by the Coordinator General to facilitate the complex approvals involved in a project that extended well beyond the confines of the South Bank Corporation's jurisdiction. Arup's commission was extended to include geotechnical, transportation and environmental engineering, and detailed design and documentation was completed between August and November 1998, with tenders called for construction in late 1999.

Following a period of negotiation when the scope of the project was adjusted to suit budget constraints, inclusion of additional works at either end of the bridge, and enhanced provisions for reduced mobility users, a contract for construction of the project was awarded in April 2000. Construction commenced in May 2000, and was completed in September 2001. The project was officially opened to the public in October 2001.

The initial architectural design concept which was selected by the client was a striking departure from traditional bridge architecture, with conventional notions of symmetry, repetition and uniform support arrangements eschewed for an eclectic collection of disparate structural forms combined in an absolutely unique manner. The Architect's concept was to create a bridge in three parts to provide a variety of experience for bridge users, and to maintain a sense of place by distinguishing the two approaches from the central navigational channel span by use of a series of visual cues. The client's stated goal was that the bridge should be far more than an efficient transport link for pedestrians and cyclists.

Photo courtesy of Stefan Jannidies

Figure 1: Aerial view(Maritime Museum and Southern Approach in foreground)

The completed project is indeed more than a transport link. The bridge attracts huge crowds, with recent counts recording daily usage equating to over 3 million crossings per annum. The daring form has generated great interest in the previously neglected southern end of South Bank and has revitalised QUT's Garden Point campus. The visual and functional contribution that the bridge makes to the urban fabric of inner city Brisbane has been recognised in a series of recent Architectural awards, and the quality of the engineering of both the design and the construction of the bridge has also been recognised by industry and professional association awards. Most importantly, the public has embraced both the bridge itself, and the concept of architectural merit being a key driver for public infrastructure projects.

There are some in the engineering profession who are concerned that the pivotal role that the architect played in the design of the Goodwill Bridge represents a potential diminution of the importance of the role of the engineer in infrastructure design, or that achieving architectural goals is of less importance than more traditional criteria such as structural performance and economy. The authors believe that this is an ill-founded and narrow view of the opportunities that the input of Architects and other designers can present for bridges and other infrastructure projects. This is not to say or advocate that the success of every bridge design must now be judged solely on Architectural merit, or that compromises to structural efficiency that can result from the creation of particularly daring Architectural forms are appropriate for all bridges. It is clear however from the success of the Goodwill Bridge that Architectural outcomes can be every bit as important as satisfying traditional design criteria such as structural elegance, structural robustness, environmental impact and efficient use of resources.

This paper aims to briefly describe the features of the Goodwill Bridge design, and to demonstrate the important role that collaboration between project participants plays in the success of complex projects. This collaboration from the traditionally close interaction between engineering designers and constructor so necessary for the safe and efficient erection of complex structures, through to the intense collaboration between Architectural and engineering designers that is perhaps less common in traditional bridge projects.

2 MAIN FEATURES OF DESIGN

The absolutely unique form of the Goodwill Bridge generated a new range of terms including "axle", "pavilion", "viewing platform", "arch extensions" and other descriptors that are not encountered in more conventional designs. The extracts from the engineering general arrangement drawing below provide the basic terminology used throughout this submission.

The winning concept broke the 460m long bridge in to visually different sections to enliven the journey for users. Starting at the Queensland Maritime Museum the bridge deck sweeps through and over the heritage listed Museum before reaching the extraordinarily slender arch that spans over the navigation channel of the Brisbane River. A mid river mast and cable "pavilion" marks the end of the main span and provides support to the main span. Moving north from the pavilion and its cantilevered viewing platform, the northern approach of the bridge gently descends towards Gardens Point, passing under the Captain Cook Bridge. At Gardens Point the new bridge links in to existing pedestrian and cyclist networks that lead to various city destinations and QUT. During the concept design phase of the project, numerous options for materials and bridge form were explored to test the initial concept. These included cable stayed concrete and steel framed arrangements (both symmetric and asymmetric), through trusses, and steel and concrete box girders.

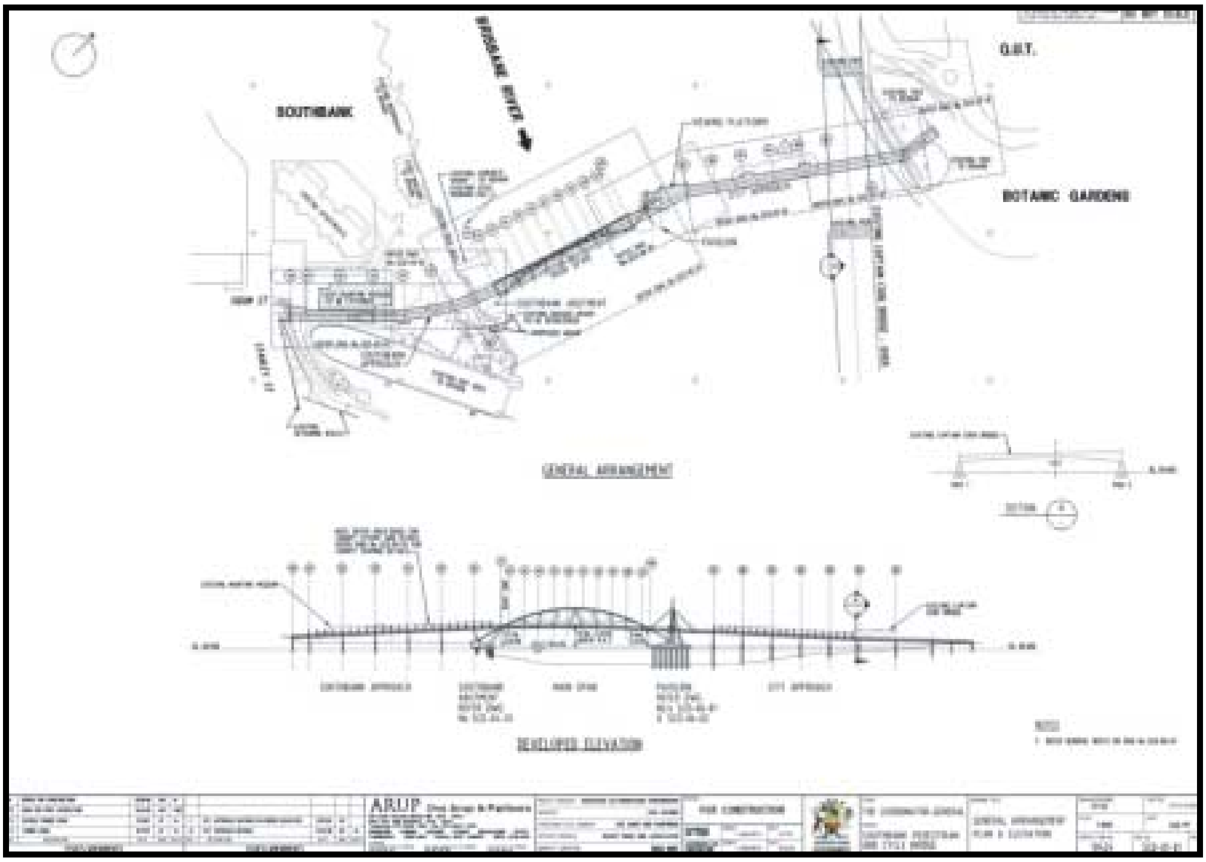

Figure 2: General Arrangement Drawing

Following an exhaustive process of comparative assessment, the design described below was selected as providing the optimum combination of economy, appearance and functionality. The primary client objectives that were used as the criteria against which all options were:

- To produce a recognisable and distinctive structure that would enhance the urban fabric of the inner city and revitalise South Bank
- To produce a comfortable and efficient link between the southern end of South Bank and the CBD for the widest possible range of cyclist and pedestrian users (including those of restricted mobility)
- To design and deliver the project in a way that maximised community benefits and minimised environmental impact
- To deliver the project in a way that maximised the involvement of local designers and suppliers, and represented sound value for money

The project consisted of the following works:

- Construction of a three-storey extension to the Queensland Maritime Museum display building. These works incorporated an elevator, AC systems, toilet and shower amenities, landscaping and "whole of building" presentation rework.
- Construction of a new wharf for the Queensland Maritime Museum, together with associated landscaping works within the museum grounds.
- Construction of the South Bank Pedestrian and Cycle Bridge (later named the Goodwill Bridge). The bridge comprises the South Bank Approach which passes through the extensively heritage listed Queensland Maritime Museum premises, the

South Bank Abutment structure which is on the Brisbane River bank boundary of the QMM, the bridge's feature Arch main span, the structurally complex and unique mid stream Pavilion structure and the City Approach which completes the bridge from the Pavilion to the Queensland University of Technology Gardens Point Campus. The City Approach passes under the Captain Cook Bridge. The bridge is 461m in length, with 270m being over water. The bridge deck provides a clear 6.5m pedestrian and cyclist corridor between handrails, with viewing platforms and rest areas provided at regular intervals along the length of the crossing.

- Construction of the QUT Domain landscaping works. These works form the interface between the QUT Campus, Brisbane River Cycle and Pedestrian pathways, Brisbane Botanic Gardens and Brisbane City Council facilitates. The northern end of the bridge ramps down from beneath the Captain Cook Bridge, turning towards the QUT campus. The QUT Domain landscaping works were co-ordinated with QUT's bridge-link project, resulting in an integrated link from South Bank to George St.

Whilst each of the project components summarised above contained interesting and innovative features, the most innovative component was the Goodwill Bridge itself, and the following sections concentrate on this element.

3 OVERALL STRUCTURAL DESIGN DRIVERS

The structural design of the bridge was driven by the varied and sometimes competing demands of:

- Architectural Form – the unusual juxtaposition of the arched main span, the cable stayed pavilion and the "pier" and "rampart" approaches.
- User Comfort and Safety – the provision of a generously proportioned 6.5m wide clear deck, strict limitations on grades to facilitate access for users with limited mobility, provision of extensive shading elements, detailing to safely accommodate the needs of pedestrians and cyclists, provision of load capacity and clearances to allow emergency vehicles to traverse the bridge, and "comfortable" dynamic performance.
- River Navigation – the provision of vertical and horizontal clearances matching the nearby Captain Cook road bridge, and design for resistance for river vessel impact and river flooding.
- Economy, Buildability and Durability – finely tuned structural design to minimise material costs, maximum use of prefabricated and standard components, robust detailing to allow the Contractor several erection options, use of durable materials and detailing to avoid corrosion traps.

3.1 Main Span

The 120m long main span consists of twin inclined tied steel arches that are supported by a raking concrete abutment at the southern bank, and a combination raking steel struts and inclined cables at the mid-river pavilion.

The 102m long inclined tied steel arches support a reinforced concrete deck. The two arches are inclined differently, with one arch in a plane that lies approximately 7 degrees from the vertical, and the other arch in an inclined plane that lies approximately 29 degrees from the vertical. The arch members are fabricated trapezium shaped box sections ranging from 500mm to 1000mm in depth. The ends of the tied arches are supported on stainless steel pot bearings that provide lateral restraint, but allow free expansion and contraction of the main span relative to the pavilion and southern abutment.

The ends of the arches are tied via longitudinal tie members that consist of fabricated steel box beams that support “UB” cross beams. These beams support and act compositely with the reinforced deck. The deck comprises precast soffit and edge forms that act compositely with an in-situ structural topping slab. The longitudinal tie members are suspended from the arches by CHS hangers that are arranged to provide adequate shear resistance to longitudinal patch loading whilst still maintaining an uncluttered and elegant appearance.

Linear and non-linear analysis was required to ensure acceptable structural performance of the main span under all possible loading conditions. Asymmetry of the twin arches added to the complexity of the design challenge. Despite these challenges, the final structure is a highly efficient arrangement, with the use of stressed tendons in the longitudinal tie members proving to be an effective and efficient innovation. The tendons were able to be used to firstly lift the arch off its temporary supports during off-site prefabrication of the main span, and then to finally provide a means of fine-tuning the main span camber and plan straightness after erection of the main span.

Figure 3: Main span during load test, with pavilion stay cable in foreground

Dynamic performance of the main span (and it interaction with the pavilion structure) was extensively investigated to ensure that responses to pedestrian loads would be acceptable and comfortable.

3.2 Pavilion

The pavilion deck and the northern end of the main span arch are largely suspended from a single steel mast and a series of stay cables. The nature of the structure as dictated by aesthetic requirements required that the mast and stay cables be installed and progressively stressed and preset in a predetermined sequence to facilitate landing of the prefabricated main span. The complex derivation of progressive stay cable installation and stressing sequence involved linear and non-linear analysis of the structure at each stage of the installation sequence. The design, analysis and erection of the pavilion structure was complicated by the nature of the main span to pavilion "axle" connection that results in a highly asymmetrical arrangement. In order to ensure that this lack of symmetry would not induce unacceptable twisting in the deck, the stiffness of supporting cables and inclined struts was carefully "tuned".

The steel framed deck and the mast and cable stays are supported by a shaped reinforced concrete shaft and two inclined steel struts that are in turn supported by a reinforced concrete pliecap. The pilecap and the piles that support the cap are designed to safely withstand the impact of a loaded coal barge (1500 tonne vessel travelling at 8 knots). The piles penetrate through deep alluvial deposits to bedrock, and were installed under strict environmental controls from barge mounted and land based rigs. The majority of the piled footings were composite reinforced concrete filled steel tubes. The pile caps constructed over water incorporated permanent and temporary steel and precast concrete formwork systems acting compositely with reinforced concrete.

Photo courtesy of Stefan Jannidies

Figure 4: Main span with Southern Abutment in foreground

3.3 Southern Abutment

The desired architectural form of the southern end of the main span was structurally achieved by twin tapering, raking reinforced concrete columns that support a reinforced concrete headstock. The headstock supports the southern end of the main span via bearings, and is in turn restrained by steel members that anchor the headstock in to a buried counterfort footing that is rigidly connected to the pilecap. The steel members that restrain the headstock are aligned with the main span arches so as to appear as extensions of the arches. The geometric constraints dictated by the very sculptural forms required development of innovative connection details between the steel and concrete components.

3.4 Approaches

In order to satisfy budget constraints and provide the desired "pier" appearance, the approach structures consist of a combination of standard steel and concrete components, albeit carefully shaped and connected to achieve composite structural action. The basic structure consists of standard WB section beams spanning approximately 20m between support portals. The longitudinal beams support tapered UB cross beams that in turn support precast deck soffit panels and kerb units. The northern approach consists entirely of straight beams, whilst the southern approach incorporates beams that are curved in plan.

Figure 5: Northern approach during construction

4 COLLABORATIVE DESIGN

The success of the Goodwill Bridge project was in large part due to close collaboration between the client, the designers and the contractor. Collaboration between Architect and design Engineer, and between Design Engineer and Contractor were particularly important. Examples of the nature of these collaborations and some of the specific results are presented below.

4.1 Architect and Design Engineer

In addition to the overriding importance of realising the overall architectural form selected by the client in the initial architectural design competition, the highly exposed nature of the bridge required that every joint, every bolt, every concrete surface was carefully designed and constructed to demanding aesthetic standards. The final result is a testament to the ability of the Architect and Engineer to each bring particular skills and knowledge to the design tasks, and through mutual respect of each others abilities to produce seamlessly integrated solutions.

The planning and design of an alignment that satisfied the competing demands of stringent gradient limitations for access by users with limited mobility, river navigation clearances and the existing physical constraints offered by the Captain Cook Bridge also provides a graphic illustration of the benefits of close architectural and engineering integration. The placement of rest areas and platforms cantilevered from the side of the deck, and the creation of a mid river viewing platform by cranking the bridge alignment in plan, and the provision of generous shading to most of the deck ensured that the bridge is equally effective as a venue for viewing river and fireworks displays, as a commuter corridor, and as a leisure destination for users of all mobility classes.

The design, fabrication and erection of extraordinary “axle” detail at the junction of the main span arch and the pavilion provides a further example of the benefits of close architectural and engineering integration.

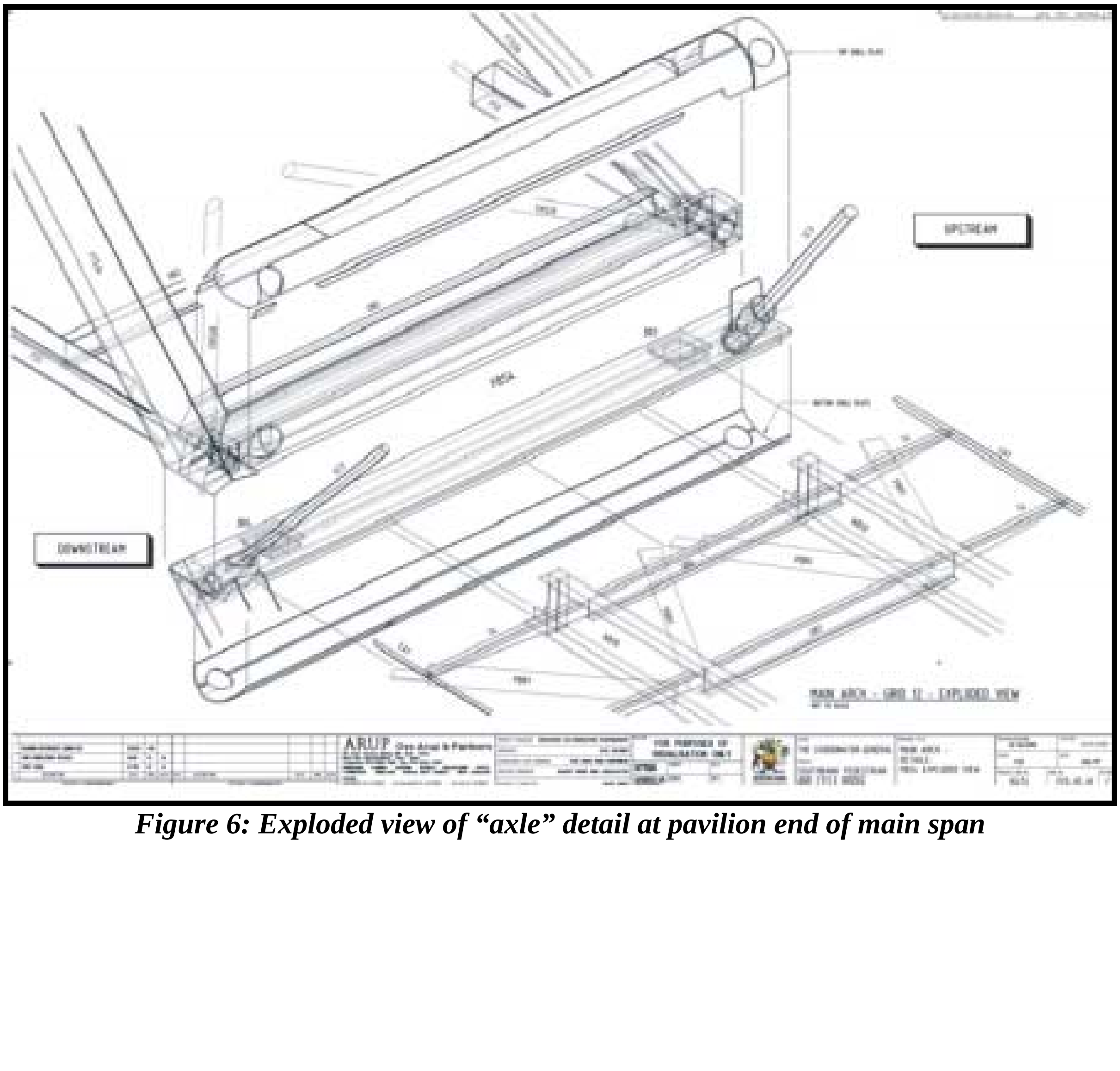

Figure 6: Exploded view of “axle” detail at pavilion end of main span

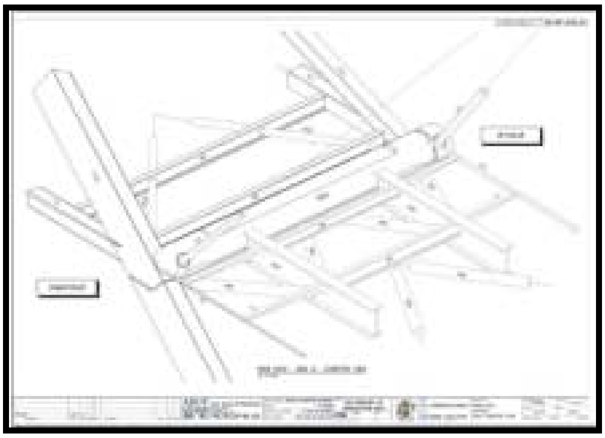

Figure 7: "Axle" arrangement drawing *Figure 8: "Axle" component during fabrication*

The form of this connection was of paramount importance to the architectural composition of the bridge. The solution that was jointly developed through workshops and use of computer and physical modelling accommodates the structurally required bearings, cable stay anchors and bracing elements in an absolutely unique manner. The complexity of the detail is not apparent in the completed structure, indicating that the enormous challenges posed by this detail were successfully overcome by a collaborative approach.

4.2 Design Engineer and Contractor

In recent years there have been instances where adversarial forms of contract have inhibited the close collaboration between designer and builder that is a key ingredient to successfully delivering complex projects. In the case of the Goodwill Bridge the client requested that Arup provide extensive assistance and guidance to the Contractor during development of temporary works procedures and designs.

Photo courtesy of John Holland

Figure 9: Main span on barge *Figure 10: Main span lift*

These procedures and designs included the development of temporary works systems to support the pavilion structure during erection (including progressive installation and monitoring of the mast and stay cable arrangement within demanding tolerances), and a strategy and detailed erection sequence to allow offsite prefabrication of the main span followed by transportation of the 300 tonne main span by barge and erection via heavy lift strand jacking.

A further example of the benefits of close collaboration between designer and builder was the way in which a very late client request for a full-scale load test of the main span was accommodated. In response to intense public interest in the unusual nature of the bridge, the client determined shortly before the scheduled opening of the bridge that a full-scale load test would provide a graphic and very public illustration of the quality of the bridge's design and construction. Load testing was not formally required for design or construction quality verification, however the clients request was duly addressed, with a full scale load test to 1.5 times design live load devised and carried out with minimal disruption to completion of the project. The remarkably close correlation between measured and calculated test results more than provided the graphic demonstration of design and construction quality that the client sought in requesting the test.

Figure 11: Load testing of main span via water tanks

5 CONCLUSIONS

The success of the Goodwill Bridge project is a testament to the combined efforts of a project team. The concept for the project was selected via an architectural design competition, and the Architect played a pivotal role in the project. This is a somewhat unusual arrangement for an infrastructure project, but it is clear from the Goodwill Bridge experience that this arrangement can add substantial value. The key to extracting value from a team with divergent skills and experience is close collaboration and respect for the skills that each brings to the project.

The popularity of the completed bridge and the number and diversity of users are indications that the tangible and non-tangible benefits targeted by the client have been delivered, with the Architect, Engineer and Contractor all playing critical roles. Benefits included:

- Enhanced pedestrian and cyclist networks, with corresponding reductions in vehicle movements and emissions.
- Rejuvenation of the southern end of South Bank and the Domain.
- Design and project delivery which maximised local industry participation.
- Successful delivery of a unique world class structure which demonstrated the capacity and technological prowess of Queensland designers and constructors.

Figure 12: Northern approach with main span in background

6 PROJECT PARTICIPANT ACKNOWLEDGEMENTS

Client: Department of State Development
Architect: Cox Rayner Architects
Structural, Civil, Traffic, Geotechnical and Environmental Engineering: Arup
Project Manager: Resource Co-ordination Partnership
Quantity Surveyor: Rider Hunt
Services Engineer: Barry Webb and Associates
Contractor: John Holland
Structural Steel Contractor: Rollpress Gurr
Superintendent: Queensland Department of Main Roads