KURILPA BRIDGE, BRISBANE

STRUCTURAL ENGINEERING AWARD 2010 (QLD)

ARUP

Design

The design for the 470m long pedestrian bridge utilises a unique tensegrity superstructure developed for the project. The bridge links the city centre to the new Millennium Arts Precinct including the Gallery of Modern Art (GoMA) and the State Library, providing workers from the rapidly developing West End and South Brisbane areas with a safe and convenient commute to the city centre; and provides easy access for residents and visitors to the cultural and tourist attractions of South Bank.

In developing the concept design, the design team considered a wide range of possible forms and materials. The potential forms were restricted by the geometrical limitations imposed by the specified landing points and the requirements for clearance over the river and the roads that the northern approach traverses, as well as the maximum permitted grades for disabled user access. These limitations dictated the minimum level of the underside of the bridge structure, and the maximum level of the bridge deck, effectively requiring that the overall depth of structure below top of deck level be limited to less than 1m.

Faced with the shortcomings of conventional forms for the particular characteristics of the site and client brief, Arup and Cox Rayner looked to devise a new form that incorporated the buildability and shallow structural deck of mast and cable structures without monumental mast structures. Drawing inspiration from Buckminster Fuller's tensegrity structures and the work of sculptor Kenneth Slessor, a viable and efficient structural form based around an innovative arrangement of masts and cables was developed.

This tensegrity design not only satisfied the need for a visually light, shallow and buildable form that would sit comfortably beside the Gallery of Modern Art, but the innovative and whimsical nature of the array of masts and cables also offered something that would be radically different to the norm.

In structural terms the bridge can be thought of as two interwoven structures: a modified version of a conventional cable-stayed bridge structure comprising a series of staggered masts and major cables that, in conjunction with the 6.5m clear width composite steel and concrete deck spans between the support piers; and a true tensegrity array of compression struts (spars) and secondary cables that laterally stabilise the masts, provide torsional rigidity to the bridge spans, and support the integrated canopy that provides shade for bridge users.

The overall bridge comprises three main sections each employing different structural systems. The 120m long Kurilpa Point approach is a reinforced concrete spiral ramp structure comprising seven spans up to 20m supported on reinforced concrete blade piers. The deck cross section tapers from a central 780mm deep spine to 280mm deep edges. The Kurilpa Point approach is separated from the tensegrity river spans and the Kurilpa Point landing abutment by expansion joints and bearings that allow the approach to expand and contract with minimal restraint from the adjoining sections.

The tensegrity bridge comprises three spans – a central span of 128m and side spans of 57m and 45m. The structure consists of a composite steel and concrete deck structure, a series of steel masts and cables, and an integrated tensegrity array of steel ties, flying struts (spars) and a steel framed tensegrity canopy.

Structurally this span composition is approximately balanced eliminating the need for massive abutments and allowing the tensegrity structure to be constructed via a balanced cantilever technique. Tie downs are provided at the outer ends of the side spans to counter the weight supported over the large river span. Support points flanking the navigational channel are more conventional with reinforced concrete twisted blade piers on pilecaps in the river. At each of these locations permanent rock anchors secure the concrete filled tubular steel piles to resist the design ship impact forces.

The 6.5m clear width deck structure comprises a reinforced concrete slab made from full depth precast panels joined by insitu concrete stitches which are supported by and act compositely with a series of structural steel cross beams. Purpose-designed precast deck panels are typically 4.9m long and 3.4m wide with panel depth varying between 200mm and 250mm. The panels incorporate cast-in fixings for balustrades, electrical and hydraulic services conduits and rebates for recessed light fittings. Cross beams are rolled steel I sections typically 530mm deep connected to the concrete deck by headed steel shear studs. The cross beams are supported by longitudinal edge beams which are suspended by a series of masts and cables. The edge beams are fabricated steel box sections typically 900mm deep and 450mm wide with top and bottom plates varying in thickness from 25 to 40mm, and side plates varying from 12mm to 16mm. A curved steel plate fairing is attached to the outside face of each edge beam to ensure aerodynamic stability of the bridge cross section under all service and ultimate design wind speeds.

Pairs of primary raking tubular steel masts spring from the tops of the main support piers on either side of the main span, on both sides of the bridge. These major masts set the location for a series of minor secondary masts which are approximately coplanar. The major and minor masts are offset from the perpendicular in both the longitudinal and transverse directions.

The tensegrity array of flying struts and cables that hovers above and beside the deck fulfils three critical functions:

- Tensegrity struts (steel circular hollow sections) and cables suspend the canopy, allowing it to float above the deck with no apparent means of support
- Tensegrity struts and cables laterally restrain the tops of the primary and secondary masts, preventing them from buckling sideways under the loads arising from the suspension of the deck and lateral wind and seismic loads
- Tensegrity struts and cables work in unison with the major and minor masts and cables to resist twisting forces and lateral forces arising from patch loads on the deck (for example crowds gathering on one side of the deck), wind loads and earthquake loads.

One of the unique aspects of bridges such as the Kurilpa Bridge that span over major river and road corridors is the need for the structure to support itself at each stage of the erection, without reliance upon temporary props and scaffolding. Working closely with contractor Baulderstone, the bridge was designed to be cantilevered out from each of the two major river piers, effectively using the permanent structure to construct itself. In May 2009 the two halves of the bridge met precisely as predicted by computer modelling, thus completing the deck structure.

Detailing for economy

The budget which the client set for the project in 2005 was based on a conventional ‘no frills’ structural form. The design and construction team were therefore faced with not only creating a completely new structural bridge form, but doing so within an extremely challenging cost framework.

The project was delivered on budget through:

- Using structural steel for the main span framing, with off-the-shelf sections used where possible
- Ensuring that the structural design was optimised to minimise materials through the development and use of sophisticated analysis and design tools
- Detailing all site connections to be bolted or pinned, avoiding site welding for all permanent connections, devising and designing connections in close consultation with fabricators and erectors to ensure that specified plate and sections were available, that weld types and sizes were optimised to avoid over-specification, that access for welding and testing was adequate, that member lengths could be readily adjusted by shimming prior to erection, and that components could be painted offsite
- Devising, designing and comprehensively testing a detailed erection sequence that would be fast, accurate and safe, and which would not require post-erection adjustments.

Practicality in fabrication and erection

Consideration of practical aspects of material procurement, fabrication and erection was a crucial part of the detailed structural design of the steelwork. Aspects of the structural design that demonstrate this attention to practicality include:

- Off the shelf section were utilised with simple cleat and end-plate connections. Where structural requirements dictated that fabricated box and tube sections be used, these were designed to be fabricated from available plate
- a detailed step by step erection sequence and methodology was developed in consultation with the fabricator and erector. The required preset cable lengths and mast and edge beam lengths were determined to ensure that when all members were erected at the correct length (with tolerance allowance considered) and in the specified sequence, the main spans would end up at completion in the correct position with all cables prestressed by the self weight of the bridge. This approach avoided the need for the ‘on-the-fly’ adjustments that are usually required by conventional erection methodologies
- Arup designed all temporary props required to stabilise the bridge during the initial erection stages while it was constructed in a balanced cantilever style from both sides. This design including specifying the stages in the erection sequence when the loads in the temporary props would drop to zero to allow these to be readily and safely removed without the need for jacking or similar.

As a result of the intense collaboration between engineer, contractor, fabricator and erector and the importance afforded to practical aspects of safe and rapid fabrication and erection, the steel superstructure of the bridge was erected in a short six month period, with nil rework or errors.

Innovation

The unique design was completely new and untested, with no precedents to draw on. The world-first nature of the design required every detail and facet of the construction to be developed from first principles, within the budget and time constraints. The task not only required innovation in technical design, but also the development of new approaches, processes and tools, outlined below.

Tensegrity superstructure structural form and analysis – prior to the Kurilpa Bridge, the use of tensegrity structures (arrays of tension and compression members where individual struts are connected only to tension members) had been limited to small scale sculptures and experimental strucures due to their inherent flexibility. Arup's superstructure design utilises a modified mast and cable arrangement for the primary support of vertical loads where high levels of stiffness and unpropped construction were required. The flexible tensegrity system of flying spars and cables above deck level was able to be designed to efficiently brace mast tops, carry lateral wind loads to deck level and support the floating shade awning. The highly non-linear nature of the cables substantially complicated the task of analysing and proving the design (including provision of redundancy), and required the development of new analytical techniques and software.

Construction stage modelling and design – working closely with the contractor, Arup developed a superstructure erection methodology based on balanced cantilever erection from each of the two river piers, using accurate length components (checked and adjusted if necessary before installation) erected in a sequence that ensured that upon completion all parts of the bridge would be in the theoretically correct position with all cables prestressed by the weight of the structure. This innovative approach removed the need to make any post-installation adjustments to any structural components, but did require that the construction stage analysis be exceptionally accurate and thorough. Once again purpose-written software was developed to allow thousands of separate construction stage analyses to be run and checked. The accuracy of this modelling was demonstrated by the two halves of the bridge meeting precisely at mid span in May 2009, with the deck at completion within 25mm of the theoretical profile.

Wind modelling and amelioration – With a completely new and untried form, there was little or no available code guidance on susceptibility of the bridge to aero-elastic excitation. A 12 month program of wind tunnel testing was commenced during the initial stages of the design, and used to test and select the optimum profile of edge fairings which ensure that the bridge will not suffer from galloping or flutter. In addition, detailed investigations were carried out into the risks of vortex shedding vibration of superstructure components (masts, spars and cables), and innovative low-cost damping systems were designed and installed where required.

SLE modelling and amelioration – Since the discovery in 2000 of the hitherto unknown phenomenon of Synchronous Lateral Excitation (SLE) (the tendency of some light, long span bridges to develop uncomfortable lateral vibrations when crossed by very moving large crowds of pedestrians), the design of long-span pedestrian bridges has required designers to carry out dynamic analysis to test for susceptibility to SLE. In the case of Kurilpa Bridge, these analyses indicated a small but non-zero potential for SLE in the initial concept design. The conventional approach to these findings would have been to make the structure more massive, but this would have negatively impacted the desired appearance of the bridge, and exceeded the project budget. Arup took the alternative approach of designing an innovative system of relatively inexpensive tuned mass dampers mounted under the deck to ensure that the bridge will comfortably and safely accommodate even the largest crowds.

Solar power and LED lighting – The bridge is lit with an innovative arrangement of LED luminaires, creating one of the world's largest bridge LED lighting installations. The lighting is programmed to produce an array of different lighting effects, with displays for special events and festivals. The bridge is also one of the first large-scale solar powered pedestrian bridges in the world, with 84 photovoltaic panels powering the LED lighting. Depending on its configuration, the solar panels supply between 75% - 100% of the power required to operate the lighting, with surplus electricity fed into the grid.

Efficient design of structure to suit application/process

With an unprecedented structural form, every aspect of the design and erection process had to be developed, refined and optimised, and then comprehensively analysed and tested. In addition to conventional structural engineering, the structural design process included rigorous testing which ensured that the carefully designed set of thousands of prefabricated precast concrete, steel and cable components would fit together, with every part of the completed structure in the correct theoretical position, and every cable correctly pretensioned by the weight of the structure.

Steel provided the lightness required to address the aesthetic appeal and construction issues. The aesthetic issues revolved around producing a lightweight and slimline structure that appeared to float. The tensegrity form of the bridge specifically required that efficient compression members appear as though they are floating in thin air held simply by thin strands of spiralstrand cable. Steel also provided the slimline effect in the deck required to achieve the many physical constraints in the original brief such as spanning the Riverside expressway, North Quay and the Brisbane River and maintaining the minimum vehicle and maritime traffic envelopes required without obstruction.At the same time the bridge had to comply with a specified apmaximum 1 in 20 grade and land at the prescribed access/ egress areas such as Tank Street on the North Quay side and Kurilpa Park on the South Bank side of the river. The accuracy and efficiency of the structural engineering design was a major contributor to the success of the project, including the structural engineer the accuracy and efficiency of the structural design.

Attention to corrosion protection

The nature of the bridge as an important piece of long-life public infrastructure and its proximity to the Brisbane River demanded that the bridge and all of its components be designed for durability. For the steel components of the bridge, measures included:

- steel box sections were either sealed, or reliably drained with inspection hatches to allow regular inspection
- all exposed connections were configured to drain under gravity, with drainholes, snipes and shedder plates incorporated to prevent corrosion traps
- components were designed to be built and painted offsite
- bird roosting was discouraged by minimising potential locations through appropriate member configuration and shape selection, and the use of proprietary spikes
- a high performance three coat polysiloxane paint system was applied to all steelwork that could be readily maintained and repainted during the life of the structure
- low or no maintenance materials were used for those elements that could not be readily recoated (eg. stainless steel cables, fittings and elements, hot dip galvanised cleats for main cable connections and metalcoat zinc epoxy flake protected HDG spiral wound cables for main cables)
- the bridge superstructure and mast/cable system is designed to provide redundancy in the event that individual cables are damaged or need to be replaced.

Sustainability

The bridge is designed in accordance with best practice sustainability and life cycle principles, as well as aiming for ‘delightful efficiency’ – where quality of design and the amenity that this brings encourages the community to use these facilities, resulting in public health benefits and reducing emissions from resultant reductions in vehicle usage.

A key initiative was to assist the State Government to deliver on the ‘Toward Q2: Tomorrow’s Queensland plan to reduce Queensland’s carbon footprint’. Kurilpa Bridge has met this need through solar panels which provide 75% of the power in most lighting configurations, with any surplus power returned to the main grid. This will amount to savings of around 40 tonnes of carbon emissions each year.

Socially, the demand for improved pedestrian and cycle pathways continues to grow. More than 30,000 cyclists and pedestrians are using the bridge each week to walk to work, to visit the cultural precinct or to simply enjoy the Brisbane River.

Summary

Kurilpa Bridge is an example of an innovative and creative use of steel to provide a connection between the Brisbane city centre and the arts precinct which relates to its context and, through rigorous testing and experimentation, economically achieves the structural and budget requirements of the project.

Project team

Architect:	Cox Rayner Architects
Structural engineer:	Arup
Head building contractor:	Baulderstone Pty Ltd
Steel distributor:	Beenleigh Steel Fabrications Metal Centre
Steel fabricator:	Beenleigh Steel Fabrications Pty Ltd
Steel detailer:	Online Drafting Services (Qld) Pty Ltd
Coatings supplier:	International Paints