Griffith University Cable Stayed Pedestrian Bridge

John Steele BE (Hons 1) M Eng SC, Associate SKM Sydney
Laura Chong BE (Hons) Project Engineer SKM Sydney
Eugene Newman BE (Civil) Project Manager Abigroup Contractors Pty Ltd

Synopsis
The Griffith University Gold Coast Campus is situated on the northern side of the Smith Street Motorway, approximately 3 kilometres to the west of Southport. A pedestrian link was required to a new student accommodation centre and planned expansion of the University on the Southern side of the Motorway. The University wanted the link to be an iconic bridge structure to promote the University to passing traffic. A 96m long cable stayed bridge was completed in January 2007 to meet the Universities needs.

1 Introduction
The Griffith University Gold Coast Campus is situated on the northern side of the Smith Street Motorway, approximately 3 kilometres to the west of Southport. As part of the planned expansion to the campus, development commenced on land previously purchased by the University on the southern side of the Motorway. This development included additional University buildings and a new student accommodation centre. As such it was essential have a pedestrian link across the busy Motorway. The University was also keen to have an iconic structure to promote the University to the passing traffic.

The transport planning for the Gold Coast includes expanding the Motorway from 2 to 3 lanes in each direction, providing bus lanes with bus set downs areas at the University and a light rail linking the main Gold Coast rail line at Nerang with Southport and Surfers Paradise. The overall length of the bridge required to accommodate all these future initiatives was 96 metres.

In March 2006 Abigroup Contractors Pty Ltd entered into an agreement with the University to design and construct the pedestrian bridge for the commencement of the University year and opening of the accommodation centre in February 2007. Working in partnership with the University, Abigroup and their engineers SKM and urban designers EDAW developed seven different engineering configurations for evaluation. These options included a basic 4 span concrete plank option, steel truss and arch options and cable stayed options with a single and dual towers.

The University selected the most iconic of these options that was a single tower cable stayed steel structure. The option comprising a 63 metre main span over the motorway and future light rail and 33 metre back span over the southern bus set down area. The deck width was set at 4 metres width between hand rails and the bridge had to be designed to support emergency and university security vehicles up to 5 tonnes.
An A-frame tower geometry was selected with a 1:10 slope towards the southern abutment. The tower has an overall height of 40 metres and 5 sets of anchors to support the bridge deck with back stay anchors to the southern abutment to control deflections in the tower.

**Figure 1: Bridge Elevation**

2. Design

Detailed design commenced in May 2006 and the fabricators, Beenleigh Steel Fabrication were brought onto the project at this stage and were involved in many of the design decisions. Two of the early decisions made on the project were to use a full twin cell steel box section for the deck rather than the more common steel trough with composite concrete deck and to use bolted splices for the deck segments rather than welded connections. Both of these decisions were made to minimise construction adjacent to and above the busy Motorway.

The Urban Designers EDAW worked closely with SKM and Abigroup and in consultation with the University and Gold Coast City Council in the development of the box girder design and cladding, tower geometry, stay layout, balustrades and lighting and coating systems and colours.

Detailed descriptions of the design of the structural elements are given below.

2.1 Deck

The steel box has an overall depth of 800mm and width of 2700mm. The top flange of the box was fabricated out of 16mm plate with longitudinal stiffening with 12mm steel plates 500mm centres and transversely with 127x75x8 angles at 3m centres. The webs are 12mm plate with 10mm plate stiffeners at 3m centres and bottom flange varies in thickness from 16mm to 25mm plate.
The box was fabricated upside down with the bottom flange plate cut into sections and welded between the webs and transverse stiffeners to complete the box. The welding to the top flange was relatively light with hit/miss welds used for the stiffeners. Butt welds were used to attach the bottom flange plates to the box. The number and size of the welds to the bottom flange were such that hogs of up to 100mm were induced in the segments from the imbalance in residual weld stresses between flanges. There was sufficient flexibility in the deck that the hogging between segments was easily removed during the installation but it is something that designers need to be aware of and not simply rely on a note on the drawing to place the responsibility onto the fabricator to allow for the distortion in the fabrication.

The 96m long bridge was fabricated in 5 segments with lengths varying from 16.5m to 21.5 metres. The segment lengths were set to suit the stay locations, transport and handling requirements and site constraints on the positioning of temporary supports.

2.2 Segment Splice Design
The bolted splices consisted of flange plates to transfer the bending and end plate connections between angle web stiffeners to transfer the shear. The bottom flange plate and web connections were relatively straight forward but the top flange had to be cranked down clear of the deck surface level and an opening had to be provided between the flanges to access the bottom flange. The top splice plate therefore had to be designed to span 700mm between the bolts groups on each segment.

The top flange plates also closed off the box so there was no access to hold the bolts into position for tightening. Tack welding the nuts was considered but was ruled out because of concerns that the heat of the weld would weaken the Grade
8.8 bolts. The nuts were instead held in a cage to prevent rotation. The top of the top flange plate was detailed with seating strips for a 6mm deck cover plate that was installed over splice.

![Figure 3: Deck Splice Detail](image)

### 2.3 Outrigger Design
The stays had ultimate design loadings of up to 990kN and the outriggers had to cantilever out 1175mm beyond the external web of the box girder to the end of the stay anchorage. The objectives with the outrigger design were to keep the fabrication simple and to keep the size of the outriggers as compact as possible. We considered the use of solid round or square steel sections and the fabricator sourced 300mm diameter steel billets from China but the steel did not satisfy the ductility requirements of Australian steel codes so we searched further and they were able to source 356mm diameter tube sections with a 27.6mm wall thickness from Japan. Local stiffening was detailed at the ends of the pipes for the stay anchorage with the remainder of the tubes filled with grout to prevent crushing at the web connections. For the heavier loaded stays 200mm by 20mm plates were rolled to the 356mm diameter and welded to the tubes to strengthen them locally at the external web. Horizontal and vertical stiffeners were installed within the box to minimise the stress concentrations in the webs.

### 2.4 Deck Restraint System
The difference in the span lengths creates an imbalance in the axial forces applied to the superstructure from the stays. This load imbalance creates a thrust towards the southern abutment. 350x480x73mm laminated elastomeric bearings have been placed end of the deck and the abutment back wall to resists this thrust. This thrust makes the southern abutment effectively a fixed restraint with all the expansion and contraction occurring at the northern abutment. A steel
cover plate has been used between the deck and the abutment to accommodate the movement at the joint.

The bridge is seated on 350x170x57mm and 350x280x153mm laminated elastomeric bearing at the southern and northern abutments respectively. There is potential for a small uplift at the southern abutment when the live loads are concentrated at the northern end of the bridge. A hold down system incorporated into the lateral system has been used to restrain the uplift.

The Lateral loads are resisted by steel brackets on either side of the box girder bolted to both abutments and welded to the cross beam of the tower.

2.5 Tower
The A frame tower was chosen for aesthetic and constructability reasons. The legs are a box section made out of 28mm plates using partial penetration butt welds on the corners to form the box. The size varied from 600x400mm at the top to 1050x600mm at the base. The tower was sized to control deflections in the tower and the effects these deflections have on the deck. Pairs of back stays were used from the tower to the southern abutment to help control the tower deflections. The tower design was also checked to ensure it was capable of being free standing after installation to avoid the need for temporary propping until the stays were installed.

Cross beams were provided under the deck, mid height and at the top of the tower to provide lateral stiffness and control buckling. The stays are anchored to 55mm plates welded into the box sections. The tower legs have a 50mm base plate and are anchored to the pile cap with 28 No. 8.8 Grade M30 bolts.

A shade structure has been included on the tower. It is made of rectangular hollow sections and was bolted to the tower after it was erected.

2.6 Stays
60mm and 75mm VSL MT600 bars were used for the bridge stays and back stays respectively. The stays use standard VSL clevis and pin arrangement at the tower and anchorage plates and nuts at the outriggers. The stays were supplied in 12m lengths and connected with couplers to provide the required stay lengths. Bars were selected over cable stays for their ease of inspection and maintenance. The selection of the stay sizes was governed by their stiffness and their effect on the deflections in the tower and deck rather than their strength.

2.7 Substructure
The ground profile at the site consists of residual clay overlying argillite at 6 to 8 metres depth below ground level. Bored cast in place piles socketed into rock were used for both the abutments and pier.
The sloped tower legs apply a lateral load onto the pier footings. The deflections due to this loading are controlled using pairs of 1200mm diameter piles at 3600mm centres parallel to the bridge span under each tower leg.

The southern abutment has to anchor the back stays for the tower and resist a horizontal thrust from the deck as well as support the vertical loads from the deck. The abutment has 6 No. 750mm diameter piles in two rows of 3 supporting a 7150mm wide by 3250mm long by 600mm slab. 300mm thick walls and have been built along the front and sides of the slab to form the abutment and wing walls. 1800mm long by 1045mm wide pits have been incorporated into the corners between the abutment and wing walls to provide access to the back stay anchorages. Buttress walls have also been incorporated into the front wall to distribute the thrust loads from the deck. The piles act in frame action with the base slab to resist the overturning and horizontal loadings in the abutment.

The northern abutment had to be constructed in such a way as allow for the future construction of the light rail without the need for temporary shoring or concern for movement of the abutment. A similar piled retaining wall to the southern abutment was also adopted for the northern abutment.

3. Analysis
The concept design for the bridge was developed using simple 2-dimensional models in the stiffness analysis program Microstran. A 3-dimensional model was then produced so that load cases such as wind load, earthquake load, train impact and loss of a stay could be analysed. The initial dynamic modelling of the deck was also undertaken using these models and the first mode of flexural frequency was established at 2.2 Hz. Although this is not ideal the structure is very stiff so it was not expected to be a problem but it needed to be confirmed with detailed dynamic analysis. After the sizing of the deck, tower and stays were completed more detailed analyses were undertaken to confirm the initial analysis and design results.

A series of transient dynamic analyses were undertaken in Strand7 in accordance with recommendations in AS5100.2 to ascertain the bridge response towards pedestrian excitation in the vertical and lateral direction. Limits set out in AS5100.2 for dynamic deflection in the vertical direction were adjusted for consistency with recommendations by Wheeler (1) and was also adopted for the lateral mode. Out of interest, a transient dynamic analysis was also run for a torsional mode to simulate a person walking at the edge of the deck. Dynamic deflection values obtained from the model were within acceptable limits and typically in the order of 2mm. The structure demonstrated satisfactory stiffness to rule out pedestrian excitation as an issue.

Recognising the special importance of several details on the bridge, namely the stiffener arrangement in the vicinity of the thrust bearing, the connection between the outrigger to the box and the splice between box segments, finite element
Modelling on Strand7 was employed to investigate local failures of the steel elements in these areas. The connections were modelled using plate elements with refined meshing around the critical areas and a combination of linear, non-linear and buckling analyses were undertaken to ascertain and optimise stiffener arrangements and plate sizes. The FEM offered a faster and more comprehensive analysis of plate yielding and buckling in comparison with the procedure recommended in AS5100.6 which are onerous for such a complex structure.

4. Durability
The following paint systems were used on the steelwork. The box girder and balustrade frames have a three coat paint system with inorganic zinc rich primer and two coats of MIO epoxy. The tower has a three coat paint system using a zinc rich primer and general purpose epoxy second coat and polyurethane top coat in red to match the University’s corporate colour. There was some concern about the red fading and the benefits of using a polysiloxane to hold colour for longer but the polyurethane was adopted because it could be recoated with minimal preparation.

The deck was initially coated with the same three coat system as the remainder of the box with metal filings placed in the second coat to achieve the required slip resistance. The slip resistance is dependent on the application of the filings and in some areas failed the slip resistance test and was replaced with a proprietary steel floor coating system.

Although the bridge is owned by the University it is constructed over a state road and forms an integral part of future transit initiatives so the Queensland Department of Main Roads QDMR were involved in the review and approval of the design and supervision of the fabrication of the bridge. The focus of the reviews was on durability of the steelwork. The box girder and tower legs should be sealed but there is no way to remove moisture during fabrication and monitor the condition of the steel within the boxes. There will be moisture trapped within the box, there will be condensation and there will be some corrosion and QDMR required a system to be in place to control the corrosion and suggested the Corroless corrosion inhibiting system be used.

Corroless is a powder that is injected into a confined space and absorbs the moisture within the space to prevent corrosion. Two threaded holed were installed into each void in the boxes and tower legs then filled with the powder. Bolts with a polished uncoated end were installed in the holes. These bolts will be removed and inspected every 5 years as part of the maintenance program for the bridge. If the steel in the bolt is found to be corroding the treatment will be reapplied.

Additional measures were taken with the design included bird proofing the tower to prevent bird droppings damaging the paint work.
5. Construction Staging

The construction staging was planned to minimise work around the busy Motorway. The Motorway was firstly isolated from the construction area with temporary precast concrete barriers.

The area around the bridge was then cleared and the earthworks under the bridge and on the approaches completed. The piles were installed shortly after followed by the pier pile cap and abutments. Temporary support towers using crane tower units were placed on either side of the Motorway behind the traffic barriers and between the tower and the southern abutment.

The deck and tower segments were transported from the fabrication shop to the painters and then to site. The tower legs were brought to site in two segments that were site welded together then the legs were joined using the cross beam sections. All the welds were tested and painted then the tower was lifted into position.

The service ducts, cladding and balustrades were attached to the deck segments on the ground prior to lifting the segments into position starting with the first then second segments. The third and fourth segments were bolted together on the ground and lifted into position in one lift to span the Motorway during a night road closure. The fifth segment was lifted into position the following morning.

Hydraulic jacks were fitted to the temporary supports so that the levels of the deck could be adjusted and the loads on the supports could be monitored during the stressing of the stays. The cambers in the segments were removed by adjusting the levels on the jacks after the segments had been bolted together.

*Figure 4: Installation of the first deck segment*
The cable stays were installed using a night road possession. The stays were stressed two nights later. After the stressing, the deck was surveyed and the loads in the jacks were checked and found to be within 5mm of the design levels. The deck had lifted off most of the supports and the load in the others jacks were found to be negligible so they were lowered without any need to adjust the loading in any of the stays.

The bridge was opened to the students within two weeks of lifting the first of the steelwork into position.

![Completed Bridge](image)

**Figure 5: Completed Bridge**

6. **Conclusions**

The design and fabrication of the steel work was critical in meeting the very tight program of moving from the selection of the cable stayed bridge to completion in 7 months. The collaboration between Abigroup and SKM and the involvement of Beenleigh Steel Fabricators early in the design ensured that the right design decisions were made so that the bridge could be installed on site in a very short period of time and with minimal impact on the Motorway.
The use of a full box sections, bolted splices, using the grout filled tubes for the outriggers, the selection of segment lengths and temporary support locations, designing to tower to be free standing without propping and the detailing of the cladding and balustrades were all decisions that benefitted the program objectives.

The bridge was opened on time and has since received tremendous accolades from the University and other local stakeholders.

Acknowledgements
The authors would like to acknowledge Griffith University for their vision to pursue this iconic bridge structure. We would also like to acknowledge the cooperation and input received from the Queensland Department of Main Roads. The designers would like to acknowledge the input of William Soong who reviewed the steelwork design and analysis for this bridge and whose guidance on the detailing of steelwork was always greatly appreciated. Sadly, William passed away late last year and the designers dedicate this paper to William’s memory.

References