Design of the Ross River Bridge, Townsville Port Access Road

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Abstract The Ross River Bridge will be located at the mouth of the Ross River in Townsville. This paper discusses the options which were examined during the Preliminary Design phase and the Detailed Design of the Bridge. Challenges which had to be overcome included: geometric and environmental constraints, difficult geotechnical conditions, possible ship impact, and durability in a hostile environment.

Introduction

The Townsville Port Access Road will connect Stuart Drive and the Bruce Highway to the Port of Townsville. The project has been designed by AECOM and is being delivered by the Abigroupp-Seymour Whyte Joint Venture for Transport and Main Roads through an Early Contractor Involvement contract. At its most eastern end the Townsville Port Access Road crosses the Ross River before finishing at the Port. The road crosses Ross River at its mouth and hence is in an exposed location. The location of the bridge is shown in Figure 1

Ross River is used by many maritime industries including the Australian Defence Force (ADF). A number of these industries will have to move to a new marina facility immediately downstream of the proposed bridge location as the height clearance for the new bridge has been set at 6.0 m. Some industries, including the ADF, will remain upstream of the new bridge and hence the bridge has to be designed for possible vessel collision.
The carriageway of the proposed bridge is shown in Figure 2 and will consist of two traffic lanes each 3.5 m wide, two shoulders and a shared pathway on the western side of the bridge to cater for pedestrians and cyclists. Including allowances for two concrete barriers and a pedestrian barrier, the total width of the bridge will be 15 m approximately.
Constraints

The project faced a number of constraints including budgetary but the key technical constraints are discussed in the following sub-sections.
**Geotechnical Profile**

The site is generally low lying and the approaches are generally at RL 2.0 m AHD. The southern section of the bridge site traverses tidal flats which are generally at RL 0.5 m to -0.5 m AHD. The bed of the main channel is generally at RL -4.4m to -7.0 m AHD.

At the southern end of the bridge site there are medium dense sands and soft clays to a depth between 7 and 13 m. This is underlain by a hard layer of dense to very dense sand and clayey sand and very stiff to hard clay and sandy clay. Over the tidal flats there are 6 m to 12 m of very loose to medium sand and soft clay. The hard layer noted above is present below this level. Soft to firm clays and loose to medium dense sands are present under the main channel to a level of RL -17.0 m AHD; below which is the hard layer. At the northern end of the bridge site there is a 4 m thick layer of loose to medium dense sand overlying approximately 4 m of soft to firm clay. The hard layer is found below this softer material.

Extremely to highly weathered rock was encountered at RL -49 m AHD. The rock becomes moderately weathered with depth and slightly weathered (SW) fractured rock (granite) was encountered at RL -58 m AHD.

As part of the geotechnical investigation, the following additional tests were performed:

- Acid Sulphate Soil/Potential Acid Sulphate Soil
- pH
- Chloride concentration
- Redox potential
- Resistivity
- Sulphate Reducing Bacteria (SRB)

The results of the tests conducted on borehole samples from the Ross River indicate that the site is generally moderately to severely corrosive for steel. Resistivities less than 100 ohm-cm and chloride levels greater than 4,000 mg/kg were observed down to RL -40 AHD, indicating that conditions are conducive to severe corrosion. However, oxygen is at very low concentrations at depth and therefore steel corrosion by oxidation is limited. Concentrations of SRB >1,600 counts per gram have been observed down to RL -20m.

**Geometrical Constraints**

A new marina facility is to be constructed downstream of the proposed bridge and many marine industries will relocate to this facility. The Harbour Master advised
that a navigable width of 22.4 m is required for shipping after the relocation of marine businesses. This clearance is to be maintained to any structure including fenders. The minimum height clearance shall accommodate a 6 m high vessel. To provide this, the soffit of any bridge structure is set 7 m above HAT (Highest Astronomical Tide) level. The additional 1 m allowance is for wave height and clearances.

The longitudinal grade of the shared path is limited to 5% [1]. The vertical and horizontal alignments for the bridge are constrained by the requirements for the intersection with Boundary Street (Refer Figure 1) and this, coupled with the navigational clearances, limits the available structural depth of the bridge.

**Environmental Constraints**

A number of environmental assessments were undertaken. The key findings were:

1. Runoff and spill containment – A drainage system is required on the bridge to carry the 10 year ARI runoff or 90 m3 spills to spill containment basins on both sides of the Ross River
2. Migratory birds – Avoid vegetation clearing and intrusive piling activities from October to February when the marine and migratory species are most abundant
3. Dugong – A dugong protection area extends from the mouth of the Ross River to Cleveland Bay. However there is little seagrass in the vicinity of the bridge so they are not expected to be an issue for bridge construction
4. Snub-fin Dolphin - Pile driving should be restricted to low flow periods to minimise acoustic impact on the Snub-fin Dolphin. Use of acoustic curtains and/or trained observers may be required to minimise impact on the dolphins
5. Marine habitat – The construction of the Ross River Bridge will impact permanently on the habitat areas including inter-tidal flats
6. Potential Acid Sulphate Soils are present and appropriate remedial measures will be needed for disturbed areas

**Local Availability of Materials and Skills**

It was desirable that the project contribute to local employment in North Queensland (NQ). This placed constraints on the choice of materials and skills required for the construction of the bridge including:

- The precasting facilities in NQ have capacity to cast Teeroff girders only up to a maximum depth of 1500 mm.
Slag is not available for use in concrete mix design to address durability and heat of hydration issues.

While small to medium span bridges including deck unit and Teeroff girder bridges are common place in NQ, long span bridges are not.

**Preliminary Design Phase**

Key challenges that were addressed in the preliminary design phase included, pile type selection and bridge form

**Pile Type Selection**

The selection of pile type was very difficult due to the geotechnical profile that has been discussed previously and requirements for ship impact.

Piled options were considered to be the most viable and three types of piles were considered as follows:

1. Precast, prestressed piles
2. Cast-in-place piles (no skin friction on steel liners)
3. Pipe piles (skin friction on steel liners considered)

Driven precast piles were discounted due to the large number required to resist the vessel impact forces. Splicing the piles from floating plant is also likely to be problematic.

Cast-in-place piles would have to found at RL -72 m AHD. The presence of the hard clay layer makes it doubtful whether steel liners could be driven to sufficient depth to enable safe and reliable construction of the socket. Cast-in place piles were not considered further.

Pipe piles have steel liners which are driven to refusal allowing for cleanout of the cores during driving if necessary. The steel tubes have shear keys to allow the maximum expected skin friction to be transmitted to the concrete core. The lengths of steel tubes (pipes) having shear keys can be restricted to the sections transferring skin friction, provided there is sufficient confidence regarding founding levels. The cores are cleaned out thoroughly to the depth of the pipes as far as safety allows. The core is filled with concrete, which is reinforced to full depth.
Pipe piles (1500 mm diameter) were selected for the river piers and driven, precast 550 mm octagonal piles were selected for the land piers and the abutments.

**Bridge Form**

During the Business Case phase of the project a Bascule Bridge was examined as an option to relocating the marine businesses upstream of the proposed bridge site. This was rejected due to the capital cost and ongoing maintenance costs. It was also seen to have operational drawbacks. The fixed span options were divided into two categories; short and long span.

The geotechnical profile of the Ross River would normally favour a longer span bridge. Box girder bridges would normally be favoured for this site. The vertical alignment of the road is constrained by the height clearance required for vessel navigation and the gradients required to access the Port facilities. The larger structural depth for the box girder options makes it difficult to achieve a satisfactory vertical alignment and hence these were not considered further.

Cable Stayed bridges are usually more suited to spans over 300 m. However the need for a thin superstructure and the poor geotechnical profile suit a cable stayed option. This option was rejected due to cost.

Short span options consisting of 1,500 mm deep Teeroff girders were considered. Girders were constrained to this depth due to the local precasting facilities and transportation costs from other facilities. The base option had six spans with each being 32 m long. Piers with hammer heads were considered but this option did not reduce the number of expensive river piers.

The six span Teeroff girder option was selected for detailed design as it best suited the local conditions and was consistent with community expectations.

**Detailed Design Phase**

The typical cross-section for the bridge is shown in Figure 2 and the elevation is shown in Figure 3
Ship Impact

Marine activities including the Water Police, ADF, fishing fleet, barge operators, marinas and private pleasure craft are located immediately upstream of the proposed bridge site. The Harbour Master for the Port of Townsville advised that a height clearance of 6 m would be appropriate for the bridge and vessels over that height would have to relocate downstream to the proposed marina at the Port. The Harbour Master also advised that a speed restriction of 4 knots would apply to vessels travelling in the vicinity of the bridge.

Clause 11.4 of AS5100.1 [2], requires that possible collision from shipping be considered. This clause addresses ship impact on bridge piers only. The Standard requires that piers be protected by auxiliary structures designed to absorb the collision impact energy or designed to resist the collision. The Standard does not give any guidance as to the size and speed of the design ship but leaves it up to the relevant authority to determine. It does indicate that the ship should be of a type typically used on the waterway travelling at normal navigable speeds.

The possibility of installing buffer systems or frangible piers was examined. However, these options were not accepted due to cost implications. The adopted philosophy was to design the bridge to resist ship impact and sustain minimal damage due to the impact.

The Australian Standard does not give any indication as to how a bridge is to be designed for ship impact. In view of this lack of guidance, reference was made to the AASHTO LRFD Bridge Design Specifications [3]. The AASHTO Specifications are most applicable to steel hulled vessels travelling on inland waterways and hence were deemed suitable for assessment of ship impact at the Ross River.
AASHTO adopts a probabilistic approach to determining the design vessel for ship impact using the formula below:

\[ AF = (N) (PA) (PG) (PC) \]

Where

\[ AF \quad = \quad \text{Annual frequency of bridge component collapse due to ship collision} \]
N = Annual number of ships classified by type, size and loading condition using the waterway (number of transits under the bridge)

PA = Probability of ship aberrancy

PG = Geometric probability of a collision between an aberrant ship and bridge component

PC = Probability of bridge collapse due to a collision with an aberrant ship

The DWT (Dead Weight Tonnage) and speed of the design ship are used to determine an Equivalent Static Ship Impact Force (ESSIF) for the design of a bridge pier or superstructure as shown in the formula below.

\[ PS = 8.15 \sqrt{V(DWT)} \]

Where

\[ PS \] = Equivalent Static Ship Impact Force (ESSIF) in kips
\[ V \] = Ship speed in feet per second
\[ DWT \] = Dead Weight Tonnage of a ship in tonnes

Formulæ are provided in AASHTO to calculate PA, PG and PC using factors such as the river geometry, water flow, bridge geometry, and profile of vessels using the waterway. The method proceeds by assuming a vessel size and speed for the design of the bridge and calculating AF. The design vessel and speed are adjusted until AF equals 0.0005 corresponding to a 1 in 2,000 year event. AASHTO nominates a target of 1 in 1,000 years but 1 in 2,000 years was adopted to be consistent with AS5100.

A profile of vessels using the waterway was formed using observed vessel trips and interviews with business owners and vessel operators. Information about 103 vessels, including length, beam, DWT, normal operating speed, and trip patterns was collected. It was determined by hydraulic analysis and observation that the mean tidal velocity of the Ross River is 1.4 knots. It was assumed that vessels travelling downstream would travel 1.4 knots faster than their operating speeds and that vessels travelling upstream would travel 1.4 knots slower than their operating speeds. It was observed that this assumption gave a slightly more conservative result than not making the adjustment.

AASHTO does not make any allowances for change in vessel characteristics and frequencies over the life of the bridge. Data from Maritime Safety Queensland was reviewed and it was found that the recreational fleet grew 5% pa from 2001 to 2007. This was mainly due to increased ownership rather than population growth. The same data indicated that the annual growth rate for commercial vessels was 0.6% and that fishing vessels actually declined in numbers. Growth was mainly
due to smaller vessels. An annual growth rate of 0.6% pa was assumed resulting in a growth in vessel traffic of 82% over the life of the bridge.

Vessels which will be relocated to the new marina were removed from the calculation. It was found that the calculation was dominated by the ADF’s LCM-8 landing craft. The LCM-8 has an unladen mass of 70 t and is 120 t when fully laden and it normally travels at 10 knots. The ADF advised that the LCM8s operate unladen 50% of the time and consequently, an average mass of 95 t was assumed.

In order to determine an appropriate ship impact force, a number of scenarios were considered as shown in Table I.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Mass (t)</th>
<th>Speed (knots)</th>
<th>Energy (kN.m)</th>
<th>ESSIF (MN)</th>
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<tr>
<td>1</td>
<td>LCM-8</td>
<td>95</td>
<td>5.4</td>
<td>372</td>
</tr>
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</tr>
<tr>
<td>7</td>
<td>POTL Advice</td>
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<td>1.4</td>
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</tr>
<tr>
<td>8</td>
<td>Vessel Berthing</td>
<td>100,000</td>
<td>1</td>
<td>837</td>
</tr>
</tbody>
</table>

Scenario 7 was prepared based on advice from the Port of Townsville that the new marina would cater for vessels up to a DWT of 5,000t. Although a vessel of this size would not travel upstream of the marina, the possibility that it could drift upstream at the mean tidal velocity was considered. A review of all scenarios indicated that an ESSIF of around 6 MN would provide protection against a number of possible scenarios and represented a robust solution. In line with AASHTO recommendations, a lateral ESSIF of 3 MN and a superstructure ESSIF of 1.2 MN were chosen.

AASHTO refers to ship impact as an extreme load case but leaves it to the relevant authority to determine whether the bridge is allowed to respond plasticly or elastically to the load. TMR indicated that the bridge should respond elastically but could suffer minor, non-structural damage. This was defined to mean that strain in the steel reinforcement was limited to 0.0025 for Grade N500 steel and to 0.0011 for Grade 50 concrete. A check was also made against the ultimate capacity as this may result in a lower capacity in the case of purely axially loaded columns for example. The ship impact force was taken to act simultaneously with permanent ultimate loads and 0.4 times the SM1600 Live Load with appropriate Load and Dynamic Factors.
The three river piers consist of a headstock supported by two rectangular columns. The columns are supported by a combined pile cap which is in turn supported by five pipe piles. The pile caps for the river piers are designed to resist the ship impact forces. The three river piers are fixed laterally and longitudinally to the deck with shear blocks and cast-in pins. The deck is in turn fixed to Piers 1 and 5 in the same manner. Consequently, all five piers participate in resisting the ship impact forces. All TeeRoff girders are supported on laminated elastomeric bearings.

The bottom of the pile cap was set 1 m above Mean Low Water Spring Tide and the top was set at 1 m above Mean High Water Summer Tide based on the deck of the impacting ship being 1 m above the water level. The impact faces of the pile caps were "protected" by a layer of stainless steel reinforcing bars and cover to the black steel was measured from the inside of the stainless steel layer. This strategy allows the pile caps to suffer chips and scrapes without compromising the 100 year design life of the pile cap.

Spans 2, 3 and 4 are over navigable water and hence the superstructure in these spans is subject to possible ship impact. This issue was addressed by designing impact beams to protect the relatively thin walls of the Teeoff girders from possible damage. The internal diaphragms of the outer two girders were thickened and strengthened and external diaphragms cast between them. The steel ship impact beams were supported at the diaphragms. The ship impact beams have been designed to transfer loads to the diaphragms and hence into the stiff deck. The deck then distributes loads to the piers.

Durability Plan

The location of the bridge at the mouth of the Ross River raised concerns regarding durability of the bridge. It was decided to prepare a durability plan for the bridge which examined each element of the bridge and assessed its durability as determined by its microclimate, in order to achieve a 100 year design life.

Possible deterioration mechanisms for concrete reinforcement investigated included:

1. Chloride ingress
2. Carbonation
3. Sulphate Attack
4. Alkali-aggregate reaction (AAR)
5. Acid sulphate soil degradation
6. Delayed Ettringite Formation (DEF)
7. Concrete cracking due to concrete heat of hydration

Chloride ingress was modelled using Fick’s Second Law of Diffusion and a probabilistic model assuming various concrete mixes and chloride concentrations at the surface of the concrete. Based on this modelling, a ternary mix with 25% fly ash and 8% silica fume was selected for elements exposed to significant concentrations of chlorides.

Carbonation of concrete was also examined using deterministic and probabilistic models. It was determined that B2 cover and concrete mix requirements as per AS5100.5 were more than sufficient for addressing carbonation rates. Concrete with 65% slag was not recommended due to its inadequate carbonation resistance.

Concrete in submerged and buried environments may be subject to sulphate attack. Type SR cement was considered but rejected due to its reduced chloride binding capacity. Consequently, it was proposed to use a ternary mix with 25% fly ash and 8% silica fume and to specify that the cement demonstrate sulphate resistance in accordance with AS3972. AS3972 requires that sulphate resistant cement exhibit expansion less than 900 microstrain at 16 weeks when tested in accordance with AS2350.14.

The potential for alkali-aggregate reaction is to be minimised by using 25% fly ash in the concrete mixes and using aggregates which are non-reactive.

SO4 concentrations are less than 1,500 mg/l and therefore the concrete mix and cover requirements to address chloride concentrations were considered adequate. DEF and concrete cracking due to the heat of hydration are discussed in detail in the next section.

The durability of the steel pipes in the pipe piles is discussed in more detail in Ref [4]. The main concern was that SRB corrosion of the steel pipe could occur at depth. A literature research was undertaken and is reported in Ref [5]. It was concluded that corrosion at depth would proceed very slowly and hence skin friction on the pile would be maintained. Concrete covers for the concrete core assumed the steel liner was absent.

The balustrades and cycle rails are proposed to be fabricated using a 6061 aluminium alloy with a T6 temper and protected by a clear anodising coating in accordance with AS1231. Fittings for the balustrade, rails, drainage pipe, ship impact beams and lights are to be Grade 316L stainless steel. The drainage pipe and ship impact beams are protected by hot dip galvanizing. These items are designed to be easily replaceable. The ship impact beams have safety chains to prevent them falling off the bridge in the event of a collision and to enable their easy replacement.
Thermal Modelling of Concrete Heat of Hydration

The river piers feature significant concrete pours. The pile caps are 2.3 m high by 7.2 m wide by 18.5 m long and the columns they support are 3 m wide by 1.1 m thick. The headstocks are 1.5 m high by 3.7 m wide by 14.3 m long. Pile caps for the land piers are 1.4 m high by 2.65 m wide by 4.3 m long. There are three main causes for concern due to the heat of hydration of the large concrete elements.

Firstly temperatures above 80 °C in concrete with more than 20% flyash could lead to a significant decrease in the ultimate strength of the concrete. The second concern is that Delayed Ettringite Formation (DEF) will take place if peak temperatures during hydration reach 80 °C, affecting the durability of the concrete. Cracking due to DEF can cause structures to deteriorate within 20 years. The third concern is that temperature differentials such as that between the core of a concrete element and its surface can lead to excessive cracking. Temperature differentials should be kept below 20 °C.

Concrete elements were modelled using the CIRIA C660 software suite which requires inputs such as the dimensions, reinforcement details, concrete mix design, expected temperatures of concrete mix elements, formwork details, and expected ambient temperatures.

As a result of modelling, it was determined that mix water for concrete should be chilled to 8 °C and that ice should be substituted for water at the rate of 80 kg/m3. The surfaces perpendicular to the cooling sides (largest area) of concrete elements should be insulated using polystyrene 100 mm thick. The cooling faces should typically be formed using 18 mm thick plywood and 10 mm thick polystyrene. Concrete should be poured during winter months so that concrete placement and ambient temperatures are below 25 °C. The most critical elements are the columns which are restrained by the pile cap when poured, leading to vertical cracking in the columns. This was addressed by adding stainless steel ligatures for a distance of 1 m above the pile cap and specifying that the columns had to be poured within 28 days of the pile cap being cast.

It is a further requirement that the concrete elements be monitored using thermal couples. A test concrete pour was carried out by the contractor to confirm the mix design, placement temperatures and the maximum and differential temperatures reached. Results confirmed model predictions.
Conclusions

The design of the Ross River Bridge had to overcome a number of challenges due to the nature of the site. By working closely with the client and the contractor, the designer was able to meet the needs of the client for a durable and robust bridge while addressing ease of construction.

The design approaches for ship impact, durability and mass concrete pours adopted for the Ross River Bridge are suitable for other challenging bridge sites.

The Australian Standard for bridge design, AS5100, does not provide guidance as to how a designer should approach design of bridges to resist ship impact. It is concluded that the AASHTO approach provides a suitable basis. However, its applicability to Australian conditions should be assessed.

References