Construction Engineering for Brisbane’s Kangaroo Point Bridge

Yann Martin, Design Manager, BESIX Watpac

Tim Deere, Project Director, BESIX Watpac

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| **Abstract**  The construction of The Kangaroo Point Bridge required extensive collaboration and coordination among constructors, fabricators, suppliers, and design teams for both permanent and temporary works. Rising more than 90 meters above the river, the bridge’s steel mast supports a sleek 183-meter cable-supported main span, earning its title as the longest pedestrian bridge span in Australia.  This paper provides an overview of the site constraints and construction challenges from delivering a complex project in a dense urban setting, over the Brisbane River during difficult market conditions.  To tackle these challenges, a key factor was to maximise the off-site assembly and use the Brisbane River to deliver most of the structural elements. Due to the unique shape and large scale of the bridge, these elements could be assembled in a logistical yard prior to being delivered to site by barges in much larger elements than allowed by road.  An overview of the temporary works required to construct the bridge is provided. This includes the precast pile cap system and temporary supports, falsework systems and formwork for the piers and temporary works for the steel mast erection, deck erection, welding platforms, and procedures for the stay cable assembly.  The construction staging considerations for the main span is also discussed. It covers the approach taken by the designer for design deflection control, and the requirements for cable stay stressing, level preset, and precamber to achieve the target deck levels. An overview of the process used to monitor levels at each stage is included demonstrating the successful collaboration between design and construction teams.  The digital engineering is also outlined, highlighting the use of digital models for coordinating steel fabrication, as well as the integration of bridge and building services, which are an integral part of the bridge design and construction.  **Keywords:** Temporary works, Cable-Stay, Logistics, Survey, Collaboration |

# Introduction

The Kangaroo Point Bridge, Brisbane's latest iconic river crossing, is strategically situated at the heart of the city, this landmark bridge seamlessly connects the central business district of Brisbane to the picturesque peninsula suburb of Kangaroo Point.

The 460m long bridge has a main span of 183m and back span of 90m, with approach spans on either side of the river. The main pylon reaches a height of 95m above the river highest astronomical tide (HAT) level and provides anchorage for 16 pairs of stay cable’s supporting the main bridge spans.

The architecturally striking structure features thoughtfully designed pedestrian rest areas at various points across the bridge, a spacious canopy structure, and a restaurant on the City Side approach span. This blend of functional urban spaces enhances public use while serving as a vital addition to Brisbane’s infrastructure.

# Structure Description

## Bridge Form

The Kangaroo Point Bridge presented a unique design challenge: to create a visually stunning structure with sleek supports whilst also being robust enough to perform and withstand the engineering required for the structure. To achieve this vision, the design philosophy centred around the use of steel box girders, paired with permanent concrete precast planks. These planks served as permanent formwork, allowing the deck to be cast in-situ and create a seamless, streamlined appearance that complements the bridge's slender concrete supports.

Figure 1 Main Span bridge girder 3D view

A close-up of a bridge

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The main pylon element above the deck is a steel structure supporting the 16 pairs of stay cables, optimised to a spacing of approximately 16.5m along the deck.

Both the pylon and the deck were designed with future maintenance and access in mind, incorporating ample space within the box girder, pylon legs, cruciform, and mast head to facilitate these provisions.

The innovative bridge design was optimised for offsite manufacturing, allowing for the efficient prefabrication of not only the deck elements, but also the pile caps and the main pylon. This approach enabled the use of large-capacity cranes on site to rapidly erect these structural components. Meanwhile, the piers were constructed in-situ due to their complex geometries and large scale, and a cast-in-place concrete topping was applied over the precast planks to complete the deck structure.

## Architectural Features

The stay cable bridge showcases a sleek and slender design, with the central pylon serving as a striking architectural focal point. The innovative four-legged pyramidical structure, situated both above and below the deck, reinforces the bridge's sense of lightness and symmetry.

Several distinctive architectural features contribute to the bridge's undeniably unique character:

* The pier design, shaped like a stylised "Y", adds a touch of elegance to the structure.
* An architectural canopy along the pedestrian side of the bridge offers shelter, improving comfort and protection for pedestrians while also elevating the bridge's aesthetic appeal and overall user experience.
* The mast pylon's cladding, paired with thematic lighting, creates an impressive visual effect, particularly at night whilst also providing added safety and security after dark.
* The seamless integration of the restaurant onto the bridge adds a new dimension to the user experience, offering stunning views and a unique dining atmosphere, encouraging more of a precinct feel.
* Strategically planted vegetation along the bridge reinforces the sub-tropical ambiance of the surrounding region, creating a harmonious blend of nature and architecture to create a blended urban space minimising any potential industrial feel to the infrastructure.

Figure 2: Image of the completed bridge and landscaping area, Kangaroo Point side

A view of a bridge from a walkway

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Figure 3: Pause point at Main Pylon

A high angle view of a bridge

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Figure 4 View of Main Span from Kangaroo Point

A bridge over water with city in the background

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# Site Constraints and Construction Challenges

The Kangaroo Point Bridge faced the following site access constraints:

* City Botanic Garden (southwest side) within the City Centre: Access through Brisbane CBD around the corner of Edward and Alice Street.
* Kangaroo Point Area: Access from Scott Street, a residential two way street, leading to steep embankment into the Brisbane River.
* Hamilton Street and C.T. White Park: Hamilton Street, a cul-de-sac, provided limited access options. Additionally, through access along the riverfront pathway in C.T. White Park needed to be maintained for pedestrians and cyclists throughout construction.

Figure 5: Kangaroo Point Bridge – Map plan view

A metal bar on a grey surface

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Due to the constraints at the two landings, traditional land-based delivery methods for large bridge components were not feasible. Instead, the project team utilised the innovative solution of using marine barges to transport pre-assembles bridge elements to the site. The isolated exceptions to this methodology were at the approach spans where Span 1 (city landing side) and Span 7 and 8 (Kangaroo point side) were delivered by road as the proximity of the river embankments prevented the delivery and unloading of these elements from the river.

To ensure the deck and pylon pre-assembled elements could be erected safely on site, two primary cranes were used: a 400T crawler crane on a marine barge was used to erect all over water structures except the main pier (pier 4) which was serviced by the highest capacity tower crane in the world a FAVCO M2480 tower crane.

The barges were loaded-out from a dedicated downstream logistics facility located at the Port of Brisbane, ensuring efficient and reliable delivery of critical project components.

## Navigation Channel Open to Public Vessels at all times

During construction of the Kangaroo Point Bridge, a navigational channel had to be maintained to allow daily marine traffic to continue to use the river. The navigational channel is situated beneath Span 5 of the bridge, primarily serving recreational and public transport vessels, which are part of the regular marine traffic in the area. During deck erection, temporary portals were placed at intervals of approximately 25-30 meters. The installation and stressing of the stay cables allowed the bridge deck to lift off the last two temporary portals, which were then removed to switch the temporary navigational channel beneath the cantilevered deck. Notably, the temporary channel only required one switch during the entire construction process, ensuring minimal disruption to the usual marine traffic.

Figure 6: Navigational channel sequence

A drawing of a bridge

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Figure 7: Navigational channel with vessel impact protection system being installed



## Dense Urban Setting

The Botanical Garden in Brisbane CBD is located at the tip of the peninsula; the streets do not allow delivery of large bridge elements. However, the first span of the bridge could not be delivered by barge, due to the area being restricted by shallow water, plus an existing river walk structure, which prevented a barge from being positioned close to Span 1.

Therefore, to deliver the two steel modules for Span 1, through Brisbane CBD, trucks had to reverse under police escort at night from Adelaide Street to Alice Street (approximatively 650 metres). Allowing the modules to be lifted within the crane slewing radius, located as close as possible to the Abutment.

The two steel modules each weighing 45T, and measuring in length of 26 metres, were lifted with a 500T Mobile Crane from the delivery truck directly into position onto Pier 1, the operation took 16hours and was conducted in January 2023.

Figure 8: Span 1 bridge girders being transported to site during night road closure

A street with cars and buildings at night

Description automatically generated

Similarly on the Kangaroo Point side, the last two spans consisting of 6 steel modules were delivered by land using road transport. The length of the modules was reduced to 16 metres to allow for road freight and temporary portals were included to permit splicing in-situ.

A temporary Jetty was built on the Kangaroo Point embankment to permit the lifts of substructure and superstructure elements for Span 6 and Span 7. All lifts were modelled on NavisWorks3D to ensure a clash free sequence.

## Market Conditions

The Kangaroo Point Bridge was built between September 2021 and November 2024. South East Queensland was experiencing a high demand for infrastructure construction during that period with other major projects also underway across Brisbane City, such as Cross Rivel Rail, Queen’s Wharf or Brisbane Metro, creating a skills and labour shortage in the workforce.

During this period, BESIX Watpac actively worked to train and upskill the workforce to deliver the project with more than 60 apprentices and trainees taking part in the project across a range of subcontractor, suppliers and BESIX Watpac internally.

# Maximising Off-Site Manufacturing and Pre-Assembly Methods

One of the key objectives of the project delivery was to maximise off-site pre-assembly to mitigate the risk of working over water and at heights. This necessitated a 10,000 m2 logistics yard where all the main structural elements could be pre-assembled if required and loaded onto the barge and delivered via the Brisbane River.

The logistics facility was located on Fisherman’s Island at the Port of Brisbane (PoB) managing inbound deliveries by road and outbound deliveries by barge for superstructure elements as listed below:

* Steel modules
* Precast concrete deck planks
* Reinforcement cages
* Temporary works items

Due to limitations on dimensions and weight for the transport of steel elements, the PoB Logistics Facility was also used as a location for site-based splicing of steel elements, with smaller sub-modules being assembled into completed modules at this facility, and pre-assembly of major temporary works to identify any issue prior to be loaded on the water. The logistics yard area allowed ample space for storage, assembly and loading of all elements required for the project.

Figure 9: Bridge and logistics facility locations (approx. 3 hours travel distance)

A map of a city with a river

Description automatically generatedA map of a site

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Site layout’s and staging plans of the logistics yard were produced on a weekly basis to ensure all activities were being coordinated and accounted for to ensure optimisation of productivity in relation to time and maximisation of the available space.

## Substructure Assembly

The following key substructure elements were delivered and pre-assembled in the logistics yard prior to being transported to site:

* Steel Liners for Marine Piles
* Pile cap precast shells
* Reinforcement cages (pile and piers)
* Piers formwork

The logistics yard provided the project team the opportunity to pre-assemble all critical elements, conduct the necessary QA and engineering inspections, allowing time for any rectification prior to delivery and installation on site. For instance, the pre-assembly of the reinforcement cages for the piers allowed inspection, rectification and surveying prior to being transported to site.

A similar process was adopted for the steel pier formwork which was assembled and surveyed prior to being dismantled and transported to site This approach prevented any fitment issues on site ensuring an efficient erection process.

The main pier, Pier 4, was the most complex to construct due to its cruciform shape. The large pile cap required a tie-in connection to the 45-degree angled arms referred to as the stems. A specialised reinforcement jig was developed to pre-install all starter bars, facilitating the connection of the Pier arms into the pile cap. This methodology ensured the precise installation of the reinforcement starters, which had to be arranged in a specific sequence and orientation. Achieving this level of accurately on site would have been extremely challenging if an in-situ method was adopted.

Figure 10: Pier 4 preassembled reinforcement and jig being lifted into position

A picture containing sky, outdoor, crane

Description automatically generatedA picture containing sky, outdoor, crane, tall

Description automatically generated

A large frame was required to sit on top of the pile cap to permit assembly of the 45-degree arms. The full assembly was constructed at the logistics yard, tested and surveyed prior to being dismantled into smaller components and loaded onto the barge for transport.

Figure 11: Pier 4 Formwork pre-assembly

A blue and yellow stairs

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Although this may seem like an unnecessary activity, several minor issues were identified such as missing connectors, missing access grillage, handrails etc - which were corrected without having any impacts to the critical path. This approach worked to maximise the use of the site crane and other on-site resources.

## Superstructure

The superstructure assembly was delivered and assembled in the logistics yard following the below sequence:

* Steel Deck Modules and Precast planks
* Pylon steel modules (legs, cruciform and mast head)
* Restaurant steel structure

Similar to the substructure, the superstructure elements were delivered as smaller components and assembled into larger modules within the site crane’s capacity and delivered to site.

All permanent and temporary elements of the steel superstructures could be roughed in and pre-fitted prior to site delivery such as:

* Service conduits
* Precast planks (within weight limits)
* Reinforcement inside box girders (at diaphragm location)
* Architectural Cladding
* Permanent Internal access platform
* Temporary Access Platform

Consequently, the deck modules of up to 60 metres were delivered and lifted by marine barges from the logistics yard:

Figure 12: Span 5, 1 of the 60m long deck modules being craned onto barge

A crane lifting a bridge

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The largest steel module requiring assembly was the mast head, which measured 35 metres high and weighed 180 Tonnes. The top section of the pylon, was assembled from three main pieces (the central core and the two wings) in the logitics yard.

Figure 13: Masthead pre-assembly

A large white object on a scaffolding

Description automatically generated

All elements were assembled and moved closer to the barge with a SPMT (self propelled modular transporter), before being rotated vertically into position and lifted onto the barge in readiness for transport.

Figure 14: Masthead rotation in progress

A crane lifting a bridge

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The masthead had complex fabrication, assembly, transporting, temporary support, and lifting requirements required close collaboration of construction engineering, permanent works and temporary works design.

# Construction of Marine Piers

The construction of the marine piers had the below challenges:

* Pile caps were in most cases below the median sea level
* The concrete piers all had different and complex shapes

Intensive temporary engineering works were undertaken to ensure the safe and efficient construction of the piers.

## Pile Caps

The marine pile caps were built using precast shells to be fitted through the marine piles. The precast shells were limited to a weight of 60 tons for lifting purposes. This led to some pile cap shells being split into three sections (pier 3, 4 and 5). All other pile caps were fabricated in one element.

To support the precast shells over the marine piles, the original intent was to use corbels around the side of the pile temporary linings. However, this required additional diving crews and underwater welding to ensure a durable seal was achieved. Furthermore, there were engineering concerns regarding the even distribution of load on the corbels.

As a result, a hanging system was chosen and was supported by the plunge columns which were cast into the permanent piles. The hanging system had cast in connections into the side of the precast shell walls, in order to connect the hanging beams. The hanging beams were pre-installed onto the precast shell and used as lifting beams before being supported by the plunge columns. Keeper plates were included in both directions to prevent any dislocation, and packers were positioned to correct any vertical misalignment. This system allowed a safer and more efficient placement of the precast shells.

Figure 15: Image of pile cap precast shell during construction



Once the precast shells were positioned, a 400mm thick concrete layer was poured at the base of the shell to strengthen the base of the shell for the subsequent wet concrete pour. This process also facilitated the removal of the hanging system and allowed for the placement of the upper reinforcement layer inside the pile cap.

Following placement of the first concrete layer, all upper pile cap reinforcement and pier starter bars were positioned prior to the second concreting stage.

The concreting of the larger pile caps (pier 4 and 5) required 250m3 of concrete to be poured in a layered sequence of 850mm height (three lifts in total) as defined by the concrete flow rate. This approach was necessary to prevent the formation of cold joints and to maintain the nominated design pressures on the precast shell walls. Extensive controls to manage concrete placement temperatures were necessary, to avoid the effects of delayed ettringite formation. Which included; use of up to 60Kg of ice per m3 of concrete, chilled water, and night pours.

## Piers

The construction of piers involved prefabricating the pile cages in the logistics yard. Due to the unique shape and size of Pier 4, the construction staging for this specific element was as follows, once the pile cap work was completed:

1. Connect tower crane grillage bracing to pile cap
2. Place falsework frame onto pile cap
3. Install formwork arm supporting frames, including stairs and access platform
4. Position the flower arm formwork
5. Position each arm reinforcement cage
6. Install tie-in reinforcement at arms intersection (cradle)
7. Close top arm formwork

Figure 16: Pier 4 installation of falsework and formwork image

A construction site on the water

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To ensure precise formwork placement, point cloud laser scans were conducted to verify that the forms were positioned within the required tolerances. These scans were integrated into the federated BIM model, allowing for accurate comparison with the design and helping to anticipate potential issues. Reinforcement for each arm was lifted into position using the tower crane, then slid between the starter bars of the stem, with stitch reinforcement placed in-situ. The pour for the Pier 4 arms was completed in one night over a duration of 10hours using 33 trucks. Hatches have been provided at the surface of the form to allow internal vibration of the concrete along with external vibrators.

Other piers could be installed as a fully prefabricated cage or spliced at mid height. An example of Pier 6 reinforcement cage, from the base of the pile cap to the underside of the bridge deck, being transported onto the barge is shown below.

Figure 17: Pier 6 pre-assembled reinforcement cage at logistics facility

A construction site with cranes and a large metal structure

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# Construction of steel pylon

The main pier of the bridge was built in steel above the deck level to ease constructability and was broken into the below elements:

1. Pylon Stubs – transferring load from the steel pylon into the concrete diaphragm
2. Lower Pylon Legs – Quantity: 4, each with a length of 25 metres
3. Cruciform – connects the 4 lower and upper legs
4. Upper legs – Quantity: 4, each with a length of 25 metres
5. Masthead – A one-piece structural element that connects the upper legs and provides anchorages for the stay cable system.

All elements were erected on-site using the FAVCO M2480 crane and connected with temporary bolted connection points prior to being fully welded. The pylon legs have been designed to be self-supporting during installation, eliminating the need for additional falsework.

As the pylon legs were erected on a slight angle, deflection adjustment was required, and a push-pull system was developed to allow for horizontal refinement of the pylon legs on site prior to erection of the cruciform and the mast head.

Access platforms were installed around each leg both prior to and after erection to provide safe access for welding and painting at each splice point. Each platform was reached via a hoist, which was bolted down through the concrete diaphragm.

Figure 18: Masthead construction access hoist & working platforms

A structure with blue text

Description automatically generatedA construction site on a dock

Description automatically generated with medium confidence

Once all legs were erected, the mast head was delivered to site in a vertical position on the barge, lifted by the tower crane and fixed into its final position. The tower crane operated at 90% of its capacity, while lifting and placing the mast head at a 23-meter radius.

Figure 19: Pylon masthead transport via barge and installation

A tall tower with cranes in the background

Description automatically generated with medium confidenceA boat with a tower on it

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# Construction of Steel Box Girder Bridge Deck

The steel deck modules for the main bridge varied in weight from 72.8 tonnes to 175 tonnes, with all modules lifted into place by either the FAVCO M2480 or the 400-tonne crawler crane from a marine barge. The deck modules were initially fabricated in 15-metre lengths, welded together on land at the Port of Brisbane, and then loaded onto marine barges for transportation to the site. The largest modules for the main span were delivered in 60-metre long elements, which were then lifted directly from the barge onto the temporary portals.

Figure 20: Main bridge deck module segmentation (elevation)

A diagram of a bridge

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Figure 21: Transportation of a main span deck module

A boat on a river

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The construction of the bridge deck followed a well-defined construction sequence, developed in collaboration with our design partners to ensure the steel deck modules could be fabricated with the relevant pre-camber and vertical pre-set on the temporary portals.

The construction preset positions of the deck modules and deck module pre-camber is illustrated in the following figure.

Figure 22: deck module pre-camber values

A diagram of a bridge

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For the main span, the steel modules installation was following the below construction sequence:

1. Position the steel deck modules on the temporary support
2. Position the precast deck panels and reinforcement
3. Cast the deck topping slab
4. Install and stress cables

At each stage, the deflections of the deck modules were surveyed and compared to the theoretical values, with a tolerance of +/-5mm for module and precast placement. During construction, it was confirmed that the deflections at each stage were accurate.

The process outlined above was repeated three times for the main span, once per each 60m long module providing the design team with sufficient time to re-assess the actual values and recommend any adjustments to the stressing forces for the subsequent stage.

# Cable Stay System Installation and testing and commissioning

The installation of the cable stay system for the main bridge was composed of six pairs of cables on the back span, including two pairs of 43-strand cables and four pairs of 15- and 12-strand cables while the main span featured a combination of 12- and 15- strand cables.

During construction, the back span deck modules were erected, welded and cast to allow for the installation of the first cable stay system. To save time during subsequent stages, all backstays were installed after the completion of the Stage 1 stressing campaign, with a minimum locking-off load applied to prevent dislocation of the wedges.

The installation of the forestay cables was carried out in three stages, with each stage corresponding to the placement of deck modules. The number of stages was determined by the length of the modules, which were divided into three sections:

Figure 23: Main span – installation and testing stages

A diagram of a bridge

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The designer provided the expected displacement at each cable stay anchor, not only for the cable being stressed but also for all cable anchorages along the bridge. Displacement of the pylon was also provided at each stage at cruciform, base of mast head and top of mast head.

The project team was able to monitor the actual displacement at each stage, comparing it to the theoretical values and adjust as required during the stressing operations. The stressing was carried out in stages of 50%, 80% and 100% of the expected cable force, with the cables stressed in pairs simultaneously using a mono-strand jack (iso-tension system) operated by hand and stressed from the deck anchorages.

Displacement, rather than cable stay forces, was the key factor in achieving the desired design grade. This is due to the criticality of the design grade, which was set at the maximum allowable limit of 5 per cent. Governed by AS1428 standard for equitable access.

Therefore. the final force was adjusted based on readings taken at 50% and 80% of the expected force, which was defined by the actual stiffness ratio of the girders. This ratio was then used to estimate the final cable force needed to reach the final desired displacement. This iterative process enabled precise site adjustment to achieve the target levels during each stage of the cable stressing.

Additionally, the design team was given all records during and after the completion of each stage, allowing for re-analysis of the cable forces for the subsequent stage. This provided an opportunity to refine the theoretical values and update the cable forces for the next stressing campaign.

Some minor variances of the actual versus design displacement are explained due to a combination of the below effects:

* Temperature effects on the pylon: +/-30mm movement along the bridge direction (25deg range)
* Deck curvature sensitive to subsequent cable stressing – when end cables are being stressed the curve “flattened”
* Slightly Stiffer Pylon (with backstays in place): Pylon movement during stage 2 and 3 stressing were slightly less than expected

The final loads were “balanced” between forestays and backstays with an overall difference of 0.5% between the design calculations and the as-built values, confirming the accuracy of the models.

Following the completion of the stressing campaign, all grades were less than the required 5% maximum grade for DDA compliance, and the clearance to the navigational channel was also achieved, meaning no further stressing adjustments were required.

At the end of the third stressing campaign, the last steel module was positioned to join both ends of the bridge.

Figure 24: Installation of closing segment

A bridge being built on a river

Description automatically generated

Close collaboration between the construction and design teams played a pivotal role in successfully advancing this critical stage of the project. A key factor in this success was the extensive use of the 3D model, which served as a central tool for coordination and decision-making throughout the process. The 3D model allowed for real-time visualisation and simulation of the construction elements, enabling the teams to identify potential issues, optimize processes, and ensure that every component was accurately aligned with the design intent. This level of coordination and communication between the teams was not only seamless but also essential in ensuring the project's smooth progression.

# Conclusion

The Kangaroo Point Bridge project presented a unique set of challenges due to its distinctive design and challenging construction site location. Despite these hurdles, the project team achieved remarkable success through innovative solutions. The off-site manufacturing and pre-assembly approach, which maximized element sizes, proved highly effective. Especially in terms of minimising the number of man hours worked at height and over water.

Additionally, the collaborative and iterative process employed during cable stressing, combined with strong partnerships with design partners and Brisbane City Council, ensured the successful erection of the main span. The Key to this success was by implementing the below process:

* Thorough staging analysis during the design phase to define displacement at each stage.
* Comparison of estimated tonnages with actual values prior to commencing the stressing campaign.
* Accurate estimation of Construction Loads to be accounted for.
* Allowing for stressing adjustments to achieve the target levels during each stage.
* Re-running staging analysis at the end of the stressing campaign with the actual values (off critical path).

The project's temporary works design was particularly extensive, however the use of the logistics yard allowed for thorough testing and refinement of elements before on-site assembly along with comprehensive quality assurance controls and a direct benefit to program. This proactive approach significantly mitigated the risk of costly rework and delays, ultimately contributing to the project's success.

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