Abstract
Construction is well underway for a second Gateway Bridge across the Brisbane River in Brisbane, Queensland. The bridge approaches either side of the main river span consist of precast concrete box segments constructed using a match casting process to ensure a very closely fitting joint. The segments are jointed together with epoxy paste and structurally joined by post-tensioning. The match casting method was found to be more efficient and cost effective than the cast-in-situ joints used on the previous bridge.

Introduction
The existing Gateway Bridge was constructed by Transfield (Qld) and was officially opened on 11 January 1986. Since then, steady traffic growth has meant that the bridge has progressively reached full capacity. The Gateway Upgrade Project was announced in February 2005, which included duplicating the Gateway Bridge and upgrading and constructing a total of 18km of road works (1). Excluding the new Gateway Bridge there are a total of 28 bridge structures in the upgrade project.

After a six month tender evaluation process (2), the successful tenderer, the Leighton Abigroup Joint Venture, was announced on 18 September 2006.

The duplicate Gateway Bridge is positioned approximately 50m downstream from the existing structure. The external side view profiles of the duplicate bridge and columns are similar to the existing bridge. When completed there will be obvious differences in the plan view as the downstream side of the new bridge has an additional 4.5m width lane dedicated for use by pedestrian and bicycle traffic. At strategic locations on the bridge structure, a number of viewing platforms will be provided for pedestrians. There are load capacity and construction detail differences, both in the superstructure, substructure and foundations (3).

The similar side profile of the bridges belies the differences in construction techniques and methods used to accommodate thermal expansion. This article will focus solely on the approach spans to the main span and the match casting techniques used to cast the reinforced concrete box segments. The construction of the main span will be covered in a future article.

The approach spans each side of the main bridge comprise approximately 730m on the northern bank and 375m on the southern bank. These consist of typically 71m spans with 60m end spans adjacent to the abutments. The deck structure is constructed from post-tensioned precast concrete segmental twin box girders, erected as balanced cantilevers.

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Approach span design criteria

Existing Gateway Bridge
The design concept and construction methodology between the old and new Gateway Bridge approach spans differ. The precast segments for the first Gateway Bridge were a single, two cell box segment.

The previous design has piers with bearings fitted at the top and base of the columns, which creates a 'pin joint' (Figure 1). A close examination of the top and bottom of these piers will show the steel cover plates, which cover the bearings. The expansion and contraction of the approach spans are accommodated at two expansion joints located on either side of the main river span adjacent to piers 5 and 8.

Figure 1. Design concept for old Gateway Bridge approaches

During erection of the first bridge, the individual segments were suspended in place with the aid of an erection truss. The 400mm wide reinforced wet joints between the segments were cast followed by post-tensioning. A span-by-span erection methodology was used.

New Gateway Bridge
As the new Gateway Bridge is wider to accommodate an extra lane, the approaches are formed by joining together, two individual single cell box segments. After the segments on a span are in place, the longitudinal joint between the two halves are stitch cast together.

The piers have 'built-in' ends at both the top and bottom in lieu of 'pin joints' (Figure 3). The piers are relatively slender which permit a limited amount of flexure. However, to limit deflection of the piers the design incorporates an expansion joint in every four to five spans. The segments at the halving joints are of special design with additional reinforcing steel and stressing bars to accommodate the transfer of vertical and horizontal forces. At the expansion joint/halving joint, a short cantilever past one pier provides a simple support for the longer remaining span. Longitudinal movement at the expansion joints are accommodated by bearings.

There are four bearings per expansion joint, with each bearing capable of carrying a maximum vertical load of 1600t and horizontal movements up to 650mm (Figure 4). Each bearing incorporates a pot bearing to cater for angular misalignment and a sliding bearing element comprised of a stainless steel sliding plate and PTFE² slipper. Only one of the four bearings provides lateral restraint at the expansion joint.

Figure 2. Original Gateway Bridge approaches under construction by Transfield (Qld)

2 PTFE is short for polytetrafluoroethylene. It is also commonly known as Teflon™ which is a trademark of DuPont. PTFE is known for its extremely low coefficient of friction, however it has poor strength properties. The strength of PTFE is enhanced by adding various fillers.
The construction method utilised match casting of the concrete segments at the on-site casting facility. Each segment is match cast against its adjacent segment to form a precision fit. The joint width between the installed segments is very small and any gaps are taken up with epoxy paste.

A 150mm wide wet joint is used on either side of the piers as it is not possible to match cast this joint as the pierhead is cast in place atop of the pier. The closure pours at mid span between the span cantilevers are 200mm wide cast in situ unreinforced concrete stitches. A detailed description of the construction methodology is outlined below.

**Concrete segment construction using match casting**

A match casting technique was employed for the bridge approaches as it provided for faster more efficient erection of the box segments as well as providing a more accurate location method.

Manufacture of the balanced cantilever precast segments are accomplished using the "short line" horizontal casting method, where segments are produced in a step-by-step procedure (production cycle) with the casting moulds maintained in a fixed position.

One of the benefits of the short line casting method is the ability to accurately survey and adjust each segment for vertical and/or horizontal curves by building in rotation in the horizontal and vertical planes.

The second benefit of the short line casting method is the ability to find geometry errors immediately following casting of a segment and then to make corrective geometry adjustments in the casting of the next segment. The actual values for the match cast segment geometry are compared to the design values for the segment. Corrections for any errors are calculated and if possible incorporated into the set-up for the wet cast segment.

The "short line" casting method requires all typical segments in a cantilever (casting run) to be cast in the same mould, using stationary moulds and against the previously cast segment (called the match cast segment) in order to obtain a match cast joint. The initial segment within a casting run is cast within the mould between a fixed and removable bulkhead.

The jointing face of the segments has a number of raised keys in the shape of a rectangular prism with tapered sides to provide a mechanical interlock for accurate location and shear resistance. When casting a segment, the jointing face is match cast against its previously cast mating segment so that this segment acts as a former.

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2Bearings are manufactured by FIP Industriale, Italy
Figure 5. Match casting process

Figure 6. Recently cast segment slid longitudinally for the next match casting
The construction process is illustrated in Figure 5 and is described as follows:

1. The reinforced concrete segments are individually cast to the appropriate dimensions in accurate steel moulds. Each segment is accurately surveyed before casting. (Note: the segments are membrane cured not steam cured.)

2. After concrete strength reaches 12MPa and before full release from the mould, the transverse tendons across the top of segment "A" are stressed to 20% of their target value. Segment "A" is resurveyed so that any dimensional inaccuracy in casting can be corrected during the casting of the next segment "B".

3. The segment "A" is then fully released from its mould and slid longitudinally so that the vertical jointing face or match cast face becomes the formwork for the next segment concrete pour (Figure 6). The face on segment "A" in contact with the next segment "B" to be constructed is treated with a release agent.

4. The reinforcing steel, conduit, transverse tensioning strands and voids for scuppers, safety railing and conical anchor voids are installed. The dead end of the post-tensioning strand terminates by splaying the individual wires of the stressing strand (termed onion anchor) and casting directly into the concrete. Figure 7 shows segment “B” prior to casting - note segment “A” upper right, covered with wet carpet to be match cast with segment “B”. The wet carpet provides the initial curing at the top of the segments.

5. Segment “A” is moved clear of the casting process and the top of the segment wet cured for 36 hours and all other exposed surfaces sprayed with a curing compound.

6. After segment “B” reaches a minimum of 12MPa and before the release of support from the mould, the transverse tendons across the top are stressed to 20% of their target value. Segment “B” is resurveyed so that any dimensional inaccuracy in casting can be corrected during the casting of the next segment “C”.

7. Segment “B” is fully released from its mould and slid longitudinally so that the jointing vertical face becomes the formwork for the next segment “C” and the process repeats itself (Figure 6).
Figure 8. 150t straddle carrier moves a finished segment

Figure 9. Completed segments
8. After segment "C" is cast, segment "A" has sufficient strength to be removed from its original casting platform and placed on support beams so that underneath the segment can be treated with curing compound. Any release agent on both vertical-jointing faces is removed and any concrete flash or surface imperfections are removed/repaid. Particular attention is paid to the vertical match-cast faces, as minor protrusions will prevent the segments from matching closely. After this operation the finished segment is moved to the storage yard for air curing and final tensioning (Figures 8 & 9).

9. While in the storage yard and after concrete strength reaches a minimum of 27MPa the transverse strands are tensioned to 100%. The strands are then grouted and the segments are then ready for erection.

**Approach pier construction**

1. The approach piers are of hollow two cell reinforced concrete construction. The columns are constructed using a lift form technique. The construction platform is periodically raised by cranes.

2. The pier head is solid reinforced concrete with no cells or voids. Two longitudinal openings are provided to allow for the passage of personnel across the pier head for post tensioning and maintenance activities. The construction platform for the pier head construction is supported by four large needle beams, which are inserted into the square holes in the piers. The square openings in the pier may be seen in the background in Figures 8 & 9 - these holes are later covered by stainless steel cover plates.

3. Once the pier head is cast, it is transversely post tensioned through the solid segment section below the deck wings. Figure 10 shows the post-tensioning of the pier head. Each strand is initially tensioned to a small nominal load and finally the entire tendon is tensioned with a 1000t multi-strand tensioning jack.

4. The platform used to construct the pier head is also used to support the first segment section either side of the pier. As the mating face of the pier was not match cast with the segment sections, this joint is a 150mm wide wet cast joint.

5. Once the first four segment sections are joined to the pier head and tensioned the match casting technique then comes into effect.

**Deck construction using match cast segments**

The bridge deck is comprised of a pair of balanced cantilevers incrementally constructed on either side of the pier and parallel to each other. The length of the segments is nominally 2.8m and there are generally 12 segments per cantilever spine on either side of a pier. Each span is comprised of two parallel spines of 24 segments each giving a total of 48 segments per completed span.

1. The segments are transferred from the storage yard to the erection site by low loader. A crane lifts the segment from the low loader and suspends it off the ground while it is set to the correct angle of inclination (Figure 11). This procedure ensures that the segment is aligned correctly with the previously installed segment. A special lifting jig has a three-legged sling attached - one leg is fixed while the two other legs are hydraulically adjustable. These adjustable legs may be lengthened or shortened remotely using hydraulic rams to align the segment at any angle.

During the later part of the project, it is planned to use an erection truss to hoist and position the segments. The truss is required to cater for the increased height of piers and for poor ground conditions. Significant costly ground improvements would be required to cater for very large capacity cranes.
2. Epoxy paste is to be liberally applied (3mm thick) by gloved hand ensuring that the whole face of the segment is covered.

3. The segment is then lifted into position and aligned with the segment against which it had been match cast. Inside each segment are cast concrete blisters (anchor blocks) for the specific purpose of temporarily tying the segments together. Figure 9 shows a pair of two bar blisters at ceiling level while at floor level is a single three bar blister. Figure 7 shows the conical voids in the upper large wing section of the segment, which are used to accommodate shear cones for two tensioning bars installed on top of the long segment wing at roadway level. Hence a total of nine bars tie the new segment to the previously erected segment. Figure 14 shows the tensioning of two bars located on top of the long segment wing. The bars are tensioned with a hydraulic jack and the nuts are tightened manually. The application of epoxy and tightening must be performed within approximately 45 minutes. Excess epoxy exuding from the joint on the inside and top surface of the segment is trowelled smooth. The remaining external jointed surfaces are dressed smooth during the final cleanup of the finished span.
4. After a pair of segments are installed to form a balanced cantilever, four conduits on top of the segment are utilised for longitudinal post tensioning. (As the cantilever advances the number of tensioned conduits is reduced to three.) These incrementally tensioned conduits are generally symmetrical about the segment webs (Figure 9). At this stage of construction, post tensioning is only required at the top of the segments as the spans are acting as cantilevers.

To facilitate the threading of stressing strand from one duct to another, a tensioning platform with a threading jig is mounted on each end of the cantilever tip. Four blue coloured threading jigs may be seen in Figure 15. The pushing and tensioning of the strand is performed from only one cantilever end. The strand is threaded through the bent tubes where it is manually directed into the appropriate ducts. Once a strand is installed, it is cut to length and the next strand pushed through. The post-tensioning ducts are grouted within six weeks of tendons being placed and tensioned.

5. Following this post tensioning operation, the temporary tensioning bars in the upper part of the segment are removed. The bars at floor level of the segments are progressively removed as the cantilever develops.

6. During the erection process, the finished positions of the erected segments are surveyed to ensure correct alignment. If realignment is necessary, small shims are placed in the match cast joint between the segments to allow incremental fine tuning of the cantilever tips. On continuous spans (no halving joint), the erection process is continued until each balanced cantilever meets at the mid-point.
7. Every four to five spans an expansion joint is installed. The expansion joint span consists of two sections. The longer section forms part of a continuous beam with a simple support at the expansion joint; the other section is a short cantilever with a concentrated end load at the expansion joint. This supporting cantilever is relatively short as it is located on the fourth segment from the pier head.

8. Once the centre span closure joint is cast, the completed span is fully post-tensioned and grouted to form a continuous beam. The majority of tensioning in the top of the segments has already occurred during construction to support the cantilever and finally to provide bending strength over the piers. The tendons in the bottom of the segments provide for the bending stresses in the bottom flange after continuity is achieved.

9. The remaining major operation is to stitch the two inner wing tips together to form one continuous deck. This remaining 900mm longitudinal gap (Figure 18) is formed and stitch cast together.

10. A preformed groove at each segment joint is filled with epoxy paste to ensure a seal is formed to prevent moisture entry from the deck.
11. The remaining operations are the installation of parapets, railing, lighting and finally the deck wearing surface is applied. A primary strip of high quality waterproof membrane is applied to each of the segment’s epoxy joints and at the stitch joints. The total deck is then covered with a standard waterproof membrane prior to the laying of the final deck wearing course.

**Summary**
The match casting technique has proven to be an efficient and effective technique. This process has aided the Leighton Abigroup Joint Venture in meeting the construction deadline for the Gateway Bridge duplication.

**References**

**Acknowledgements**
I wish to acknowledge the Leighton Abigroup Joint Venture for permission to reproduce information about the construction techniques used in the construction of the Gateway Bridge approach spans.

![Figure 19. Progressive construction](image-url)