Abstract
Construction has commenced on the duplication of the Gateway Bridge which crosses the Brisbane River in Brisbane, Queensland. To verify the capacity of the piles which support the main span piers, two test piles were constructed on the banks of the Brisbane River adjacent to the site of the new bridge. A load of 88MN was applied to the test piles using an Osterberg Cell. The tests indicated that the test piles met the factor of safety requirements set by the bridge design and confirmed various design parameters.

Introduction
The existing Gateway Bridge was officially opened on 11 January 1986. Since then, steady growth in south-east Queensland’s population and the development of the Australia TradeCoast in Brisbane has caused a significant increase in vehicles using the bridge. In anticipation of the Gateway Bridge and Motorway reaching capacity, investigations began in 2001, for a second Brisbane River crossing east of Brisbane’s CBD.

In February 2005, the Queensland Government announced that the Gateway Upgrade Project (GUP) would proceed. Currently, the $1.88 billion GUP is the largest road and bridge infrastructure project in Queensland’s history. The project involves duplication of the Gateway Bridge and upgrades to 20km of the Gateway Motorway, including the construction of a new 7km motorway deviation at the northern end.
Following the announcement of the GUP, Queensland Motorways Limited sought ‘Registrations of Interest’ from suitably qualified companies worldwide. Five international and national consortia registered an interest with three consortia invited to tender for the project. Tenders were received on 28 March 2006. The evaluation of the tenders took six months, with the successful tenderer, the Leighton Abigroup Joint Venture, announced on 18 September 2006. The project is now well into the construction phase.

The duplicate Gateway Bridge will be positioned approximately 50m downstream from the existing structure. The external side profiles of the duplicate bridge spans and the columns will be similar to the existing bridge. There will be an obvious difference in the plan as the downstream side of the new bridge has an additional 4.5m width dedicated to pedestrian and cycle traffic. There will be some construction detail differences, both in the superstructure and foundations. As an example, the main span box girder is a twin cell, compared to the single cell in the original bridge.

A comparison of the main pier foundation loads for the two bridges is as follows:

<table>
<thead>
<tr>
<th>Main Pier Loads</th>
<th>Total vertical load</th>
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<tbody>
<tr>
<td>Original structure</td>
<td>340,000 kN</td>
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<tr>
<td>Duplicate bridge</td>
<td>395,000 kN</td>
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</tbody>
</table>

Although the loads on the new bridge are higher than the current bridge because of the additional width and girder web, it is of interest to compare the foundations for the two structures. The current bridge’s northern main pier had 48 - 1.5m diameter bored piles which varied in length from 40 to 50m and were socketed into rock up to 8m (1). All piles are raked, varying from 1:10 to 1:6.

In comparison the duplicate bridge’s northern main pier will have 24 - 1.8m diameter bored piles. These will vary in length from 46m to 50m and will socket up to 6m into siltstone.

All piles are vertical. A significant difference in construction techniques will be that the pile sockets at founding level will not be directly inspected by personnel descending into the pile liners. The construction technique will typically entail driving 1.8m diameter steel liners to refusal into the weaker mudstone/siltstone layers. Due to the long lengths of piles, liners are driven in sections, with the additional sections joined by onsite butt welding. The material will be excavated from the liner utilising rotary drilling rigs. After excavation the liners will typically be full or partially full of water. The piles will be socketed into rock and, once founding level is reached, all loose material will be removed. Removal of the loose material is achieved by using purpose-designed cleaning buckets, air lifts, de-sanders and settlement tanks.

A visual inspection will be made with the aid of a SID (socket inspection device) and closed circuit video. The SID operates on the same principle as a diving bell — the environment inside the SID is pressurised air. The inspection process involves lowering the SID to the base of the rock socket and inspecting nine locations at the base and video-taping all inspections. The pile toe is deemed suitably clean if, over a minimum of 80% of pile base, less than 10mm of debris is present and can be flushed away by SID’s water jets. Additional base cleaning will be undertaken until the desired conditions are met.
To be assured that the 1.8m diameter piles have sufficient load capacity (including safety factor), it was proposed that two test piles be installed and a static load applied to verify their capacity.

The traditional method for applying a load on a test pile entails either a dead weight load or driving two additional tie-down piles, one either side of the test pile. In this second case, a large beam is mounted between the tie-down piles against which the compression load is applied to the test pile with a large hydraulic jack(s)(2).

Because of the extremely large test forces (88MN or 88,000kN), cost and the need for a variety of test data, an Osterberg Cell test was the test method selected to determine the test pile capacity and socket friction characteristics.

What is a Osterberg Cell?
The Osterberg Cell, gets its name from the inventor, Dr Jorj O Osterberg, Professor Emeritus of Civil and Environmental Engineering at Northwestern University, USA. He invented and developed a deep foundation load testing device to meet the construction industry’s need for an innovative effective method for testing high capacity drilled shafts and piles. Osterberg’s invention, the Osterberg Cell, commonly called the O-cell®, has changed the way foundation load tests are designed, performed and interpreted. The O-cell is a hydraulically driven, high capacity, sacrificial jacking device installed within the test pile’s foundations. Working in two directions, upward against side-shear and downward against end-bearing, the O-cell simultaneously separates the resistance data.

By virtue of its installation near the founding level of the pile, the O-cell load test is not restricted by the limits of overhead structural beams and tie-down piles. Instead, the O-cell derives all reaction from the soil and/or rock system. End bearing provides reaction for the side shear portion of the O-cell load test, and side shear provides reaction for the end bearing portion of the test (Figures 1,2).

Load testing with the O-cell continues until one of three things occurs:

1. ultimate side shear capacity is reached
2. ultimate end bearing capacity is reached, or
3. the maximum O-cell capacity is reached

Load testing using the O-cell requires precision monitoring of numerous test parameters. These include concrete strain using strain gauges, compression using telltale rods, shaft movement using displacement transducers, and applied load, by way of hydraulic pump pressure. Outputs from the instruments are collected and stored using a data logger. Figure 3 shows a reference beam, the top of the pile and data logging equipment.

Figure 1. Layout of an O-cell Test Pipe
Test piles

One test pile is located on the northern bank and the other is located on the southern bank of the river. The test piles are located on the river bank and not over water as it was deemed that the test pile positions were sufficiently close to the final pile location, hence the founding material would be of similar properties. It should be noted that the individual main pier piles have all been test drilled to determine the geotechnical condition at each location. The test pile locations have also been drilled to determine the optimum location of the O-cell. Adjustments will be made to the final pile levels, based on results of the test piles and geotechnical condition in each pile. Assembly and monitoring of the complex O-cell was made much easier by installing the test piles on land. The installation of the O-cell, - Leighton Abigroup Joint Venture.

The test piles are both 1500mm in diameter. This diameter was chosen based on the maximum capacity of the available load cells. On the south bank, the test pile is 28.7m long with a 10.5m long steel liner. On the north bank, the test pile is 54m long with a 37m long steel liner. Upon completion of testing, the test piles will play no further role as they will not to be included in the bridge’s foundations.

Four - 540mm diameter single acting hydraulic jacks/rams are installed in the base of the pile, each with a capacity of 11MN. The four jacks combine to form the O-cell assembly, which effectively tests to 88MN i.e. 44MN in each direction. The high pressure jacks have a working pressure of up to 700bar which is a similar pressure to jacks used in the bridge industry. The jacks are fed high pressure water through rubber hoses from a hydraulic power pack on the surface. The jacks are mounted to two 50mm thick steel plates, one on either side of the jacks. Figure 4 shows the four jacks in the process of being assembled, while Figure 5 shows the finished O-cell assembly with instrumentation.
The jacks are arranged so that the base reaction pushes downward against the pile foundations while the piston end pushes upward, resisted by skin friction plus the dead weight of the pile.

Mounted on the underside of the hydraulic jacks is a short length of pile section 2 to 3m long. Short lengths of steel angle are welded between the upper and lower steel plates to maintain accurate alignment while the reinforcing cage is assembled and lowered into the excavated pile. The steel plates have large cut-out holes including a larger hole in their centres to allow a tremie to pass through it to the pile founding level.

The test pile is fully instrumented (see next section) with displacement transducers, strain gauges and tell-tail steel rods. Once all the equipment is in place, the cage is lowered into the water-filled pile casing and the concrete is placed via the tremie. The concrete is required to achieve strength of 45MPa prior to the application of test load.

Concrete completely surrounds the jacks and instrumentation. During the initial stages of the test when the jacks first exert a force on the pile, the welds on the steel angles shear and the unreinforced concrete surrounding jacks easily fail in tension.

During a test it is possible to exert an upward force of 44MN (4 jacks @ 11MN each) and the same force downward. Hence if a pile safely passes a test, it has effectively withstood an 88MN load, as a pile’s capacity is made up of the combined resistances of skin friction and end bearing. The force of 88MN is the equivalent of three times the maximum working load of a 1800mm pile, scaled down to suit the 1500mm pile.

Figure 6 shows a plan view of the upper bearing plate. The reinforcing bars form a cone to guide the tremie to the base of the pile. Figure 7 shows the finished reinforcing cage complete with O-cell and instrumentation attached, in the process of being lowered into the bored liner.
Pile instrumentation

The pile is instrumented with displacement transducers, strain gauges and tell-tail steel rods. The outputs are recorded with a data logger.

Displacement transducers (Geokon Model 4450²)
- The displacement transducers are placed to measure movement across the O-cell. The displacement is measured using linear vibrating wire displacement transducers (LVWDT).

The operating principle of the LVWDT is the frequency of a vibrating wire is dependent on the wire’s mass per unit length, length and tension. Given that the mass of the wire and its length within the transducer is constant, the change in vibrating frequency is dependent on the change in tension. The wire is pre-tensioned with a spring, with the required spring constant; hence a change in length of the transducer translates into a change in wire tension. The reason for using a spring is because of the large displacements involved. Without the spring, the wire would be over-strained and fail in tension. (A common analogy of the principle is the adjustment and tuning of a piano or guitar strings.) The wire is plucked by an electro magnet activated by a signal sent from the surface. The vibration is detected with an electronic pickup and the frequency of vibration recorded. The frequency change between the unloaded and loaded state can be calibrated back to a displacement. An advantage of this vibrating wire system is that the output signals can travel over long distances without loss of accuracy.

Strain gauges (Geokon Model 4911-4) - the strain gauges have deformed reinforcing steel attached to either end to facilitate bonding to the concrete. These gauges also work on the same LVWDT principle. Figure 8 shows a section through the strain gauge. Although not expressly indicated in the figure, the vibrating wire may be seen in the centre of the sensor. Because the strains in the concrete are small, no pre-tensioning spring is necessary. On the southern test pile, 24 strain gauges were installed at varying elevations while 32 strain gauges were installed on the northern pile (Figure 9).

2 Displacement transducers and strain gauges are manufactured by Geokon Incorporated, USA
Figure 8. Strain gauge section

Figure 9. Strain gauge

Figure 10. Telltale rods

Figure 11. Telltale end anchor

Telltale steel rods — the tell-tails are purely mechanical devices. An inner solid stainless steel rod is fastened to the end where displacement is being monitored. The rod then sits loosely with a thin walled pipe which encases and protects the rod from the concrete until it emerges from the top of the pile. As the end of the rod is attached to the area of interest, movement at the top of the rod is simply a reflection of the movement of the bottom of the rod. The displacement of the rod end is measured with respect to the protective tube or to a reference beam which spans across the top of the test pile and remotely supported from the test pile (Figure 3). Two of the tell-tails are attached to both the top and bottom 50mm steel plates as well as at founding level (Figures 10,11). The telltales are installed in diagonal pairs to counteract any inaccuracies that may result by pile bending.
Test procedures and results

Initially the hydraulic jacks in the O-cell are pressurised in order to break the tack welds that hold the bearing plates closed and to form the fracture plane in the concrete surrounding the base of the O-cells. After the concrete surrounding the jacks and between the bearing plates fractures, the pressure is typically released and then the loading procedure begins. The O-cell is pressurised in stages to assess the combined resistances of end bearing and lower side shear below the O-cell and the side shear above the O-cell. The final test attempts to further mobilise skin and base resistance. In this test, the applied load exceeded the rated capacity of the hydraulic system by around 20%. Lastly, the O-cell is incrementally depressurised and the test concluded.

Test results are summarised for the southern test pile as follows:

Upper side shear resistance — the maximum sustained upward net load resisted by upper side shear was 51.81MN, with a corresponding upward movement of the upper load bearing plate of 9mm.

Combined end bearing and lower side shear — the maximum sustained downward load resisted by the combination of end bearing and lower side shear was 56.62MN, with a corresponding downward movement of lower bearing plate of 19mm. The movement measured at the base of the test pile was 17.7mm.

For a main support pile with an applied working load of 28MN, the corresponding factor of safety is approximately 3.7. Results also indicate that the application of the working load at the top of pile would result in a settlement of 10.7mm, of which 9.8mm is estimated to be the elastic compression of the pile itself.

Similar test results were obtained for the test pile on the northern bank.

Conclusion

The installation and loading of two test piles with an O-cell successfully proved that an acceptable load safety factor could be attained. The load tests gave an assurance as to the chosen design’s geotechnical parameters and confirmed the deflection characteristics of the piles. As part of the load tests, a remote inspection procedure not previously used by Main Roads was successfully used for the inspection of the pile foundations.

References


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