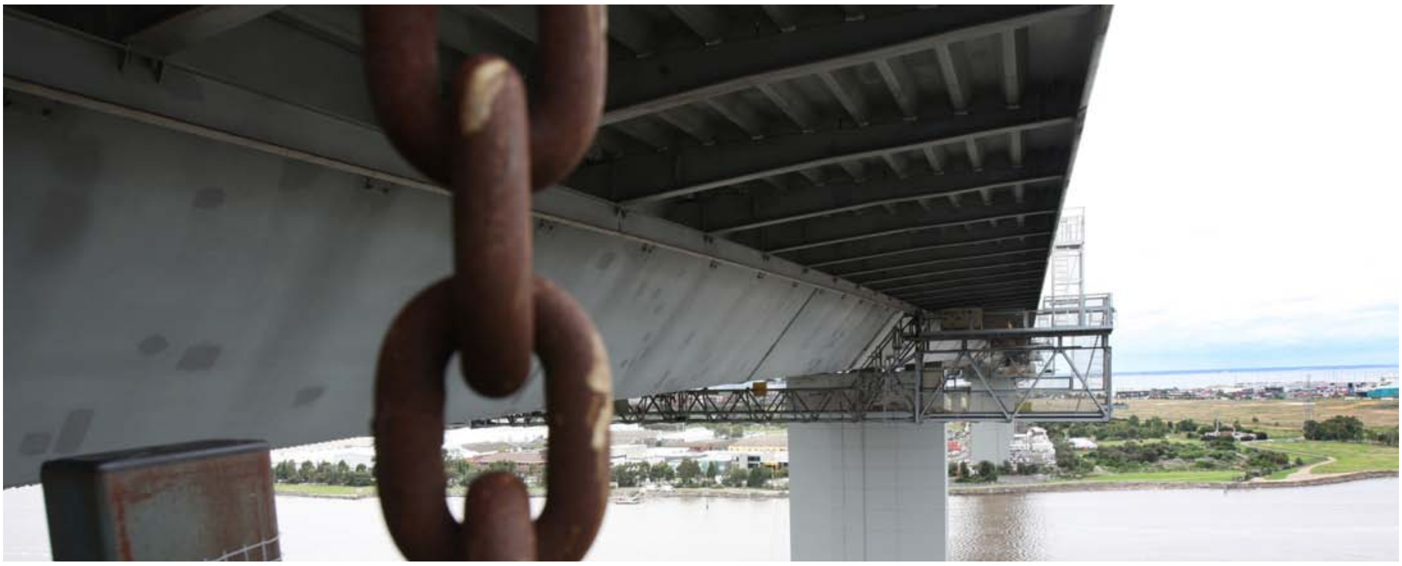
WEST GATE BRIDGE STRENGTHENING

STEEL AWARDS 2012
WINNER CASE STUDY

AUSTRALIAN STEEL INSTITUTE

ENGINEERING PROJECTS
NATIONAL WINNER 2012



DESIGN MERIT

The iconic West Gate Bridge is one of Australia's most important links in the national transportation network. Officially opened in 1978, the 2.6km bridge now carries 160,000 vehicles each day, including 24,000 trucks and heavy vehicles.

The West Gate Bridge includes a highly unique and complex 850m long cable stayed steel box girder central portion over the Yarra River and segmental prestressed concrete box girder approach viaducts of 670m and 870m long on the western and eastern sides respectively.

The West Gate Bridge strengthening project's objectives included:

· Strengthening the West Gate Bridge so that it continues to cater for current and future demands of commuter and freight traffic in compliance with modern day bridge design standards

· Reduce congestion on the bridge by increasing the traffic capacity from four lanes to five lanes in the peak direction and implementing a freeway management system

· Improve public safety by installing suicide prevention barriers and upgrading traffic barriers

The sheer volume and complexity of the analysis modelling for the West Gate Bridge Strengthening (WGBS) Project would exceed that of any previous similar bridge project. The global models for the steel bridge were developed in the London office of Flint and Neill and modelling of some localised elements was undertaken by the Alliance's design team in Melbourne and by Swinburne University. That such extensive analysis models were required is the result of a number of factors:

· Specialist techniques, expertise and knowledge are required for checking thin stiffened steel plates, a major factor behind the bridge collapses that occurred in the late 1960s and early 1970s. Clearly, the software and hardware tools available today are substantially more powerful than those which were available even in the recent past.

> Specialist techniques, expertise and knowledge were required to establish the degree of structural conservatism required for the existing structure, which had already been substantially modified after the bridge collapses in the 1960s and 70s.

· Following the collapse, the bridge was redesigned and this led to modifications to the steelwork that had already been fabricated and erected, adding a substantial level of complexity to the finished structure.

· Less sophisticated approaches would have resulted in substantially more strengthening without necessarily providing added margins of safety.

As has always been the case, codes of practice are written primarily for the design of new structures rather than assessment of existing structures.

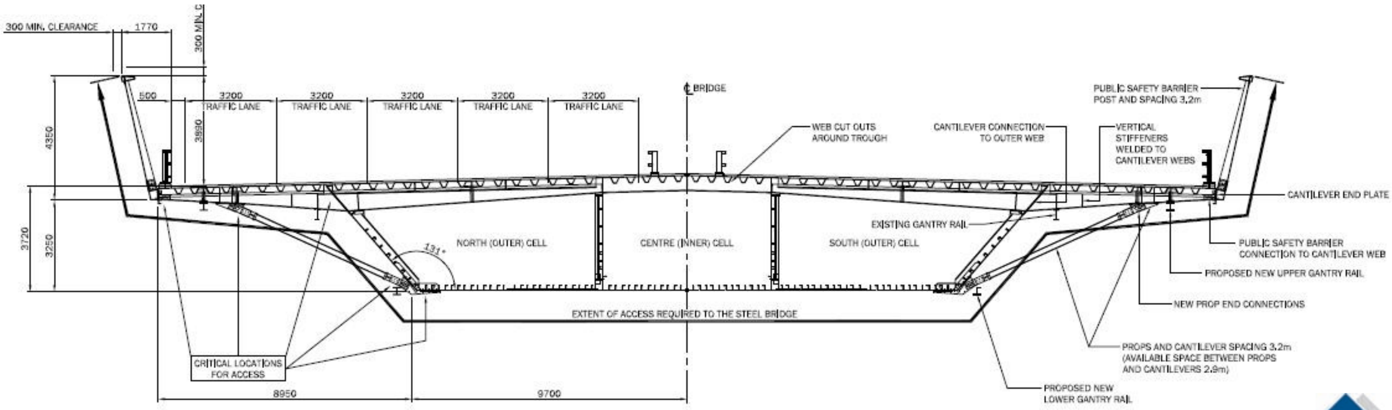
For a new structure, the conservatism typically inherent in the simplifications that lead to a more workable set of design rules

for general use results in only a small cost penalty. However, for an existing structure, such conservatism can lead to substantial additional cost or a conclusion that a structure is unserviceable which, by using more sophisticated methods, can be shown to be adequate.

> Many instances were encountered on site where the existing detailing did not comply with the design requirements in current codes.

A project specific set of assessment and design criteria was developed for the bridge that generally made use of current codes but supplemented them with additional guidelines. A key element of these criteria was a Bridge Specific Assessment Live Load. This load was developed from a probabilistic analysis of the current traffic loads on the bridge measured using Weigh-in-Motion equipment installed in the bridge deck. There were design teams in both London and Melbourne, although the majority of the design and drafting was done in London, which created a substantial challenge because of time differences and geographic separation. The effective level of cooperation between the two offices and with the construction team at all stages of the work reflects the attention paid to good communication and document management. There was continual need to adapt the designed detailing to accommodate conditions encountered on site and, for obvious practical reasons, much of the design advice for this process was provided by the Melbourne team, referring back to the design office in London where required.

Many instances were encountered on site where the existing detailing did not comply with the design requirements in current codes. The bolted connections in particular existing cases included a variety of faying surface preparations, slotted and oversize holes and deficient bolt hole edge distance. An extensive programme was established to determine the effect of these details and verify that they would perform satisfactorily.



In addition, although BS5400 (British standard for the design and construction of bridges) was generally used for the design work on the steel bridge, reference was made to the more comprehensive provisions of the Eurocode where the technology has clearly moved on from the original clauses in BS5400. This approach is a common means of delivering economies for clients with bridge assessment projects by those still using the BD56 (i.e. BS5400 approach) until the Eurocode bodies produce new codes for assessment as well as design.

> Due to the high cost of removing existing lead paint, a new type of stiffened panel strengthening was developed which would not require the lead paint to be removed.

The first step in the assessment and design process was the development of a set of as-built drawings. These drawings drew together five sets of documentation including the original Freeman Fox design drawings the modifications arising from the 1970s re-design and shop drawings and construction drawings from each stage of the bridge's history. The single set of draw ings provided at the end of the project included the recent strengthening and will provide an important legacy for the asset owner.

INNOVATION IN THE USE OF STEEL

The high cost of removing existing red lead paint wherever new steel was to be added required development of entirely new types of stiffened panel strengthening, made possible through advanced non-linear finite element analysis and the development of special custom built tools on site. For the majority of bolted connections for new steelwork, red lead was not removed from the interfaces within the bolted connections.

Dealing with the array of steelwork and congestion that had resulted from the bridge's history required a high level of sophistication with the design detailing. It was a requirement of the design that the detailing of fabricated elements were small and light enough that they could be lifted into the bridge through the manholes and transported along the inside of the bridge by hand.

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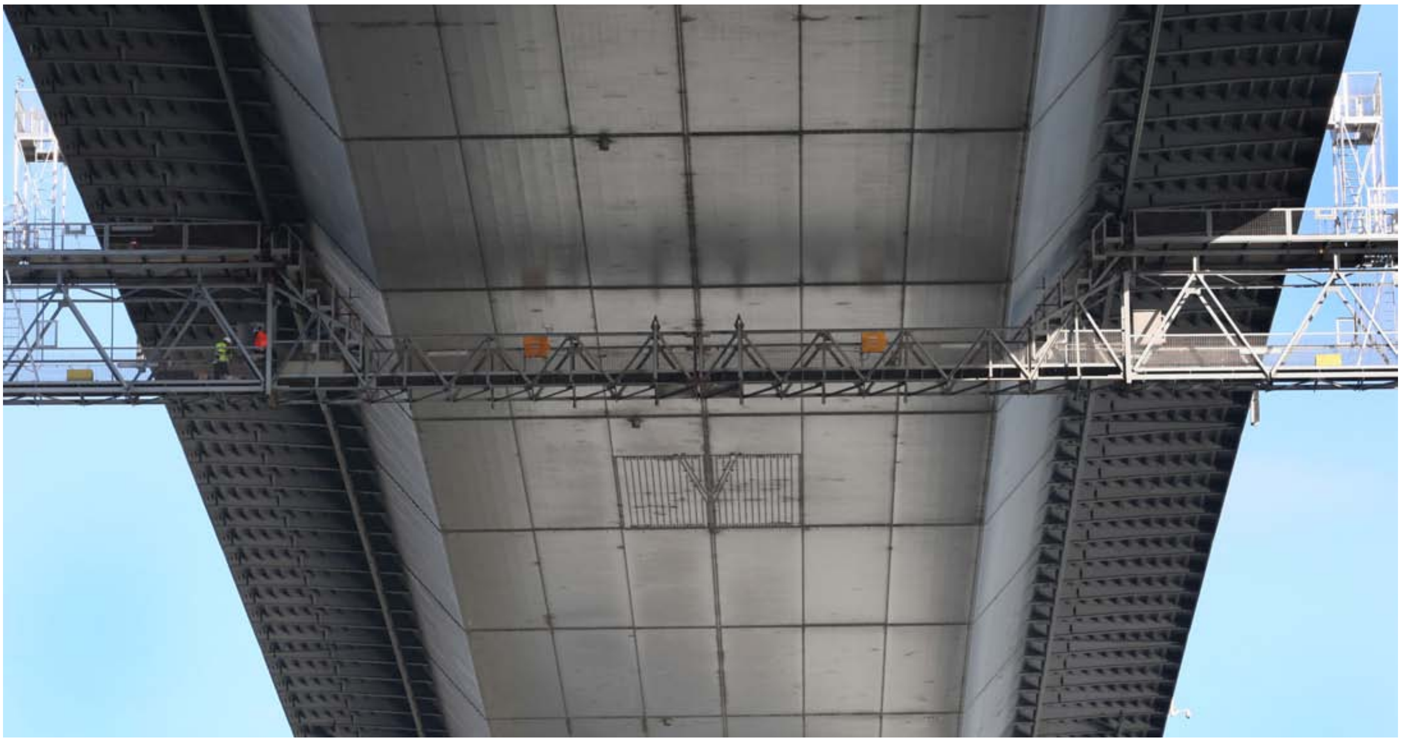
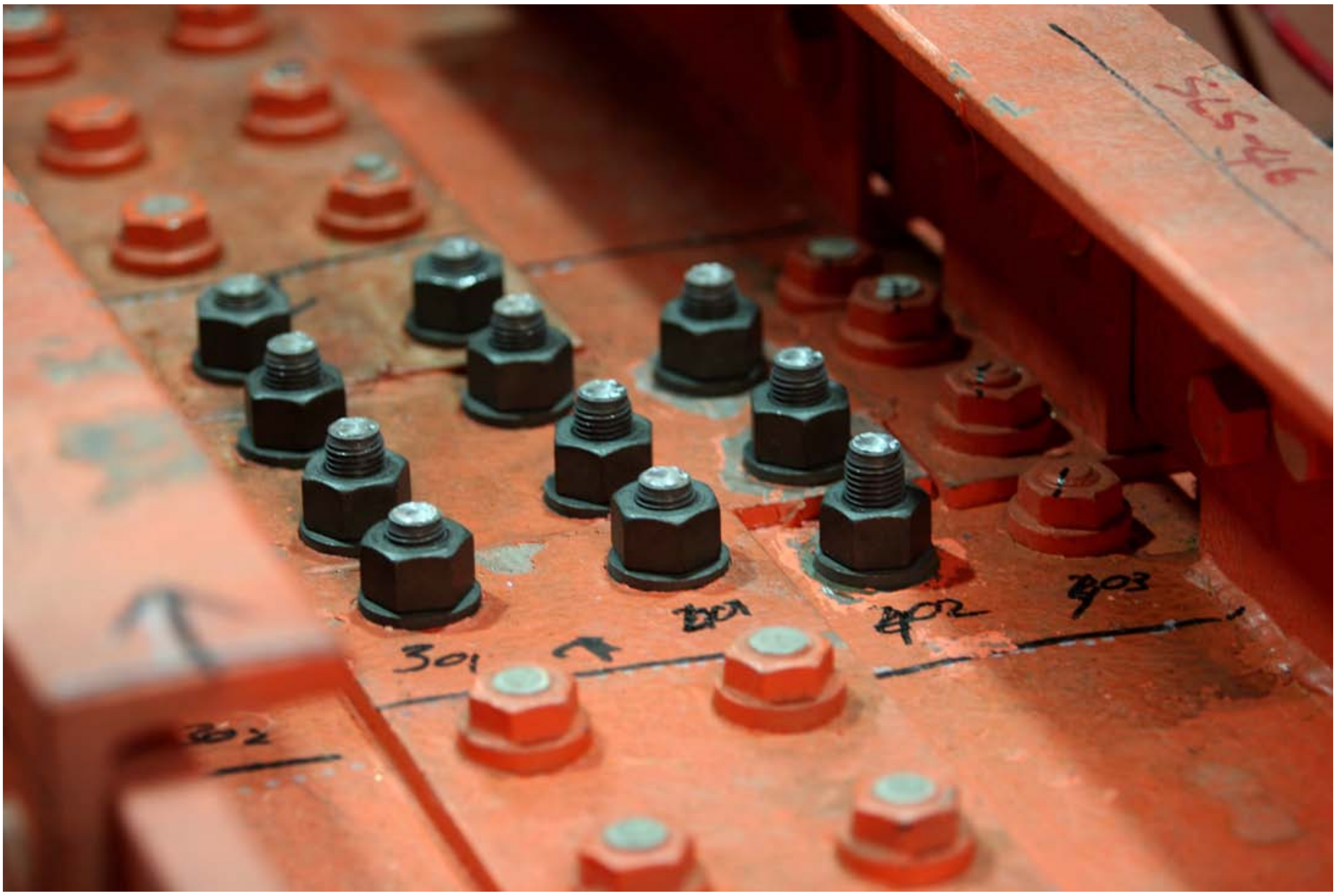
Improved access was provided to the inside of the box girder for future maintenance, included new manholes cut in the soffit of the bridge and enlarged holes through diaphragms and inner webs.

The genesis of the strengthening project was the limited capacity of the existing bridge for current traffic. However, many of the bolted splices first required the removal of bolts and splice plates to enable the installation of the strengthened detail.





Innovative techniques were devised for the strengthening details and construction staging to deal with this issue and yet maintain the integrity of the bridge and keep the four lanes of the bridge open for peak hour traffic at all stages throughout the strengthening project.

> The lines of the bridge are unchanged and the rhythm of the props, the only externally visible sign of the strengthening, is in harmony with that of the cantilevers that form part of the original construction.

Platforms were suspended from the bridge to provide access for installation of the props to provide additional support for the cantilevers along each side of the bridge. These platforms applied additional loads to the bridge. The platforms were designed to keep their weight to a minimum. In addition, their disposition and movements had to be carefully managed to avoid overloading the bridge and a practical sequence had to be developed for the order in which sections of the bridge were strengthened and the movement of the platforms. This appraisal process had to be continually revisited as portions of the work progressed either more or less speedily than had been assumed as the basis of the original programme.

The end result with the finished bridge has not in any way detracted from its appearance. In general, the lines of the bridge are unchanged and the rhythm of the props, the only externally visible sign of the strengthening, is in harmony with that of the cantilevers that form part of the original construction for the adjacent concrete viaduct cantilevers, which are seen by many as an embellishment.

1600 tonnes of steel was used to strengthen the West Gate Bridge which was cut into 100,000 different sized strengthening plates. Some 400,000 steel bolts were used to replace existing bolts or used to attach the new strengthening elements. Every strengthening element had 100% traceability from furnace to fit-up.

The initial design phase for strengthening the cable stayed steel box girder involved not designing new strengthening elements but rather, squeezing every last reserve of strength out of the existing elements. By returning to the principles that form the basis of current design standards, the Alliance was able to take advantage of measured imperfections in the installed steel work, rather than using more conservative assumed values written into the design standards.

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The strengthening elements of the steel box predominantly used a combination of angle sections and bent plates to tie weaker bulb flats to adjacent angles as well as strengthening the angles themselves in critical locations. The use of bent plates to brace weaker bulb flat sections was a design solution beyond current design codes and was the subject of intensive finite element investigation to ensure the sections would behave as required. The final solution eliminated the requirement for welding or removal of red lead paint in many areas, making the site safer to work in.

EFFICIENT USE OF STEEL

The central portion of the existing West Gate Bridge is a five span cable stayed steel box girder bridge spanning the Yarra River. The bridge is supported on six concrete piers at the underside of the steel box girder and the bridge steel towers sit on the two central piers.

All the strengthening work required was within the steel deck or towers; steel was therefore the obvious material choice for the strengthening members. Steel was also the preferred material for the strengthening because the components could be prefabricated and receive corrosion protection off site. As a result the cost of the strengthening components was reduced and the required quality was easily achieved in the controlled conditions of offsite fabricators and corrosion protection applicators.

A major advantage of strengthening the bridge using steel is that it allows for future maintenance and inspection. The existing structure is not concealed by the new strengthening therefore the existing structure is accessible for inspection and maintenance. If, say, a concrete strengthening solution had been adopted, the existing structure may have needed to be concealed or buried, thereby constraining future works. Also if a concrete solution had been adopted, a curing period would be required prior to the strengthening taking effect whereas steel is "instant". In addition, using steel for the strengthening limited the additional dead load.

The external strengthening to the cantilever of the bridge deck took the form of steel props installed to every cantilever beam location. To gain access to these locations, a modular platform system was supplied from APS Limited who worked with the Alliance to provide all external access systems. The platforms consisted of a modular steel space-frame platform which was suspended from the existing structure. The modular system steel components were designed to be easily carried by a single person and could be arranged into any shape of platform required.

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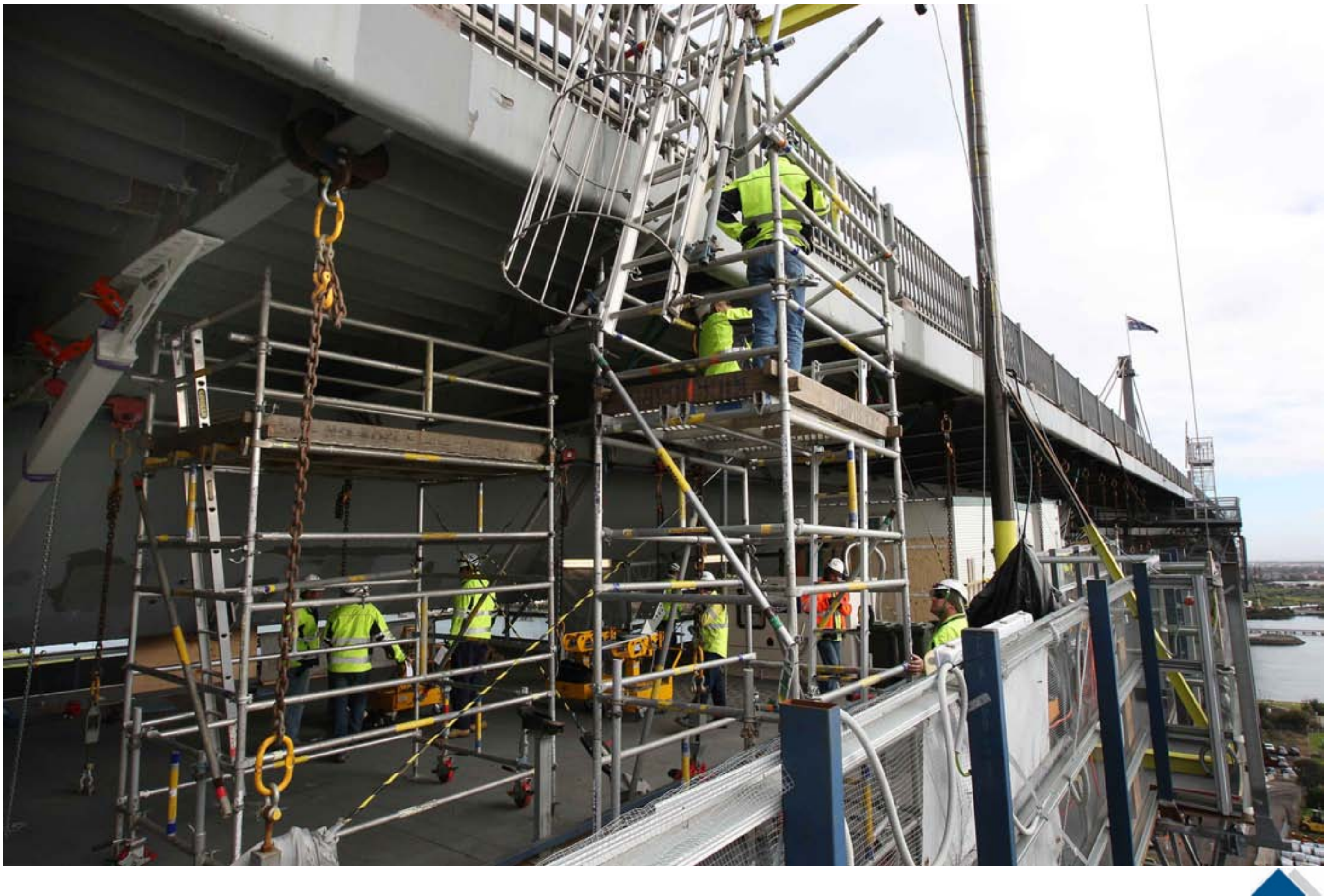
Although the components were fabricated specifically for the project, they were fabricated and galvanized to allow them to be used on other projects. APS have subsequently reapplied the system on other projects where the same steel components are being re-used.

ENVIRONMENTAL PERFORMANCE

Making use of an existing structure to enhance its capacity and increase its design life is, in itself, an environmentally sustainable solution. Strengthening existing structures uses a fraction of the materials that would be required for an entirely new structure.

Delays to the travelling public have significant impact on the environment, especially on the West Gate Bridge where approximately 160,000 vehicles cross per day. Being acutely aware of this, the Alliance minimised the impact of the strengthening



works by limiting the lane closures required, for the works, to off peak periods only even though this carried significant cost implications due to inefficient working shifts.

The steel materials in the bridge were designed to minimise the usage of raw materials. The major steel materials were all sourced in Australia to endeavour to limit transport costs and for similar reasons, the majority of fabricators used were based within 100km of the site. One of the key suppliers, Stilcon Pty Ltd is an ASI Environmental Sustainability Charter Member.

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Recycling options were reviewed for every material removed from the bridge. All steel and aluminium removed was recycled and other materials (road profilings / water / paper) were recycled or reused. Other redundant construction items are planned to be used in a skateboard park where an "industrial" theme is to be implemented.

To minimise the use of generators, mains power was installed throughout the site and potable water mains were installed to minimise the use of single use water containers. Both of these systems are to be retained as permanent systems for future maintenance and inspection works.

BUILDABILITY

Even with the improved access throughout the bridge, the delivery of components into the bridge remained as a logistical challenge. With a limited quantity of hatchways to make deliveries, each component was designed not only to fulfil its purpose but also to ensure that it could be delivered to the installation location. Where possible, components were such that they could be carried by a person however some components were up to four metres long and weighed over quarter of a tonne but were still designed to be able to be easily delivered to the installation location.

The design and the detailing of components was standardised where possible in order to capture fabrication efficiencies. The nature of the existing structure was that most installation locations were unique so the standard large components were used and they were locally shimmed at the connections to ensure an accurate fit. Throughout the construction period, there was a substantial design team on site as part of the project team. The design team on site was able to address issues that arose on site and speedily provide guidance on what was required to ensure the design intent was met.

Welding at the fabricators was kept to a minimum by maximising the use of rolled sections or steel forming (bending). On site the welding was also minimised by using bolted connections where possible. The minimising of welding improves delivery/installation times and reduces potential quality issues.

After considerable research, the team chose to use Tension Control Bolts (TCB) which negates the need for the "part turn" or "torque control" method of tightening the bolts. Using TCBs eliminates the potential quality issues that arise from other tightening methods and also has the advantage of tightening from one side only. The TCB also facilitates achievement of consistency with the load in the bolt when the spline has sheared and gives a visible indicator that the bolt has been tightened correctly.

One location where small components were not used was the installation of four Freeway Management System gantries which span the both carriageways. To install the gantries, the entire bridge needed to be closed and the installation time needed to be short and certain. The components were designed for installation in one night closure per gantry.

> The need for welding was minimised by using rolled sections and bolted connections.

Once the gantry was fabricated by Stilcon Holdings Pty Ltd, a trial assembly was undertaken and adjustments made to ensure that the gantries would be installed without a hitch. Even though this was the first time the bridge had ever had a planned closure, the confidence level was so high that the Alliance chose to install two gantries per night which proceeded without a problem. The four planned bridge closures were reduced to two, fully justifying the diligence of the Alliance and Stilcon in the preparatory works.

PROJECT TEAM

Structural Engineer:	Sinclair Knight Merz, Flint + Neill
Head Building Contractor:	John Holland
Steel Fabricators:	Agfab, Alfasi, Geelong Fabrications, Kiewa Valley Engineering, Materials Fabrication, Stilcon Holdings
Steel Manufacturers:	BlueScope, OneSteel, Orrcon Steel
Steel Distributors:	BlueScope Distribution, OneSteel Steel + Tube, Orrcon Steel, Surdex Steel
Coatings Supplier:	International Protective Coatings