Western Distributor Viaduct Modifications for the Cross City Tunnel Project – Sydney

P.T Sheasby, BSc(Hons), MIEAust, CPEng
Senior Project Engineer, CW-DC Pty Ltd, Sydney, Australia

J Steele, BE(Hons), MEngSc, MIEAust, CPEng
Project Engineer, CW-DC Pty Ltd, Sydney, Australia

I Cox, BE(Hons), MEngSc, MIEAust, CPEng
Senior Associate, CW-DC Pty Ltd, Sydney, Australia

C.J Marwick , BE, MIEAust, CPEng
Technical Associate, CW-DC Pty Ltd, Sydney, Australia

SYNOPSIS

The Cross City Tunnel Project in Sydney has provided many challenges for Engineers of all disciplines as the design of this new Motorway lies within areas of the City containing existing infrastructure including roadways, structures and utilities.

This paper outlines the key features of the structural design for the substantial superstructure and substructure modifications necessary to the existing Western Distributor Viaducts in Darling Harbour. These modifications were required to incorporate additional traffic lanes on the viaducts for merging traffic to and from the new Motorway, and included;

- Widening of the Market Street Viaduct
- Relocation of an existing Market Street Viaduct pier
- Cutting back of a Druitt Street Viaduct pier
- Incorporation of a bus cross over structure between the existing Bathurst Street and Druitt Street Viaducts

Complex structural assessment, analysis and documentation was required for all of these modifications to ensure that the integrity of the existing structures is maintained and the new structural works were readily constructible within the significant constraints of the site.

1 BACKGROUND

The $680 million Cross City Tunnel Project is currently under construction by Cross City Motorway Consortium (CCM) under a build, own, operate and transfer (BOOT) contract with the Roads and Traffic Authority (RTA). The project is due for opening in 2005.

Construction is being undertaken for CCM by Baulderstone Hornibrook and Bilfinger Berger (BHBB) under a Design and Construct Contract. The design of the civil works is being

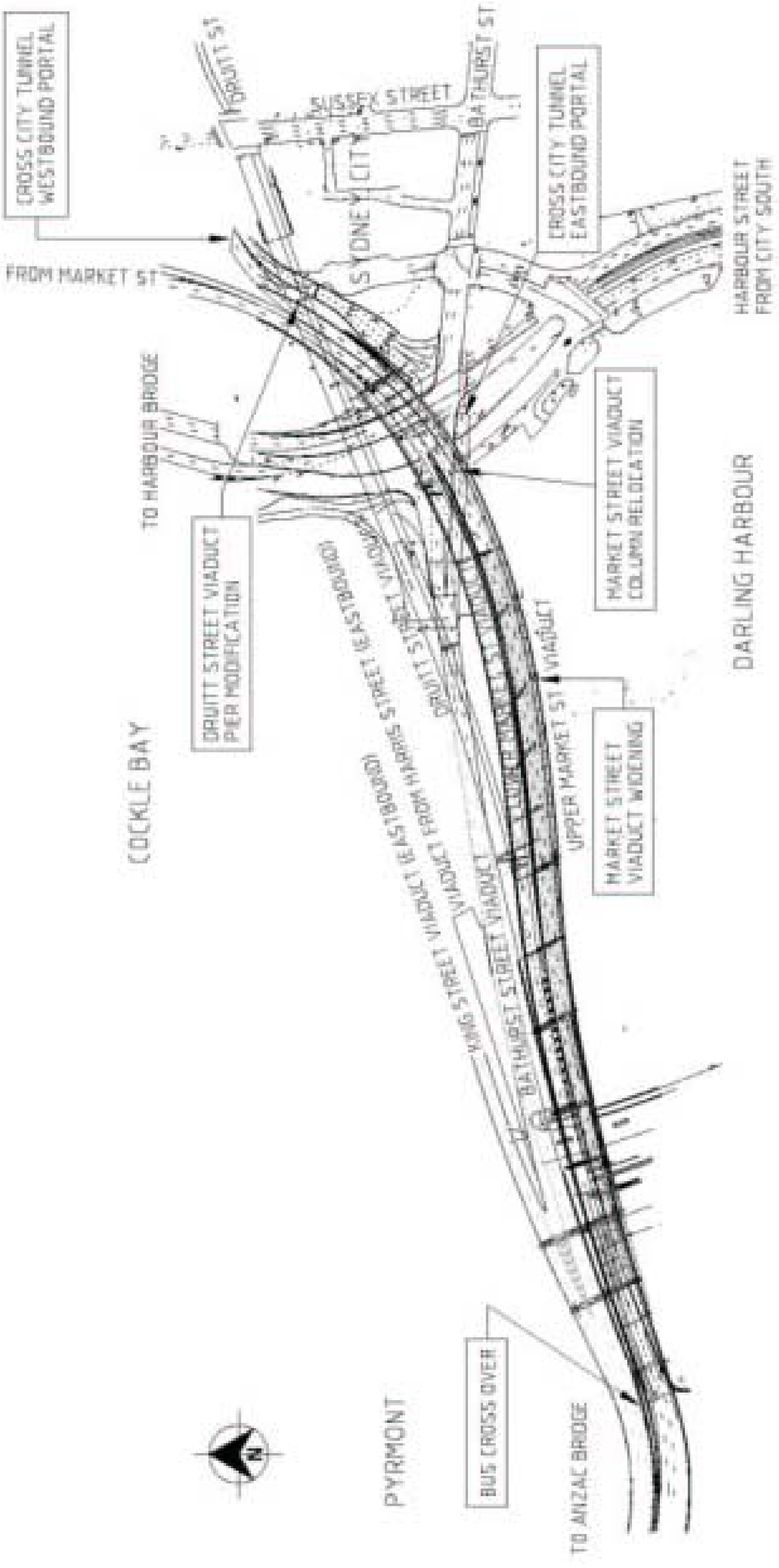

Figure 1. General Arrangement Plan – Western Distributor Viaducts

carried out by CW-DC, a wholly owned subsidiary of Connell Wagner, for BHBB.

The primary objective of the project is to remove east-west through traffic from Sydney's city streets by constructing two road tunnels each approximately 2.1 km long between Darling Harbour and Kings Cross. The project will require major modifications to the existing Western Distributor Viaducts at Darling Harbour. The required modifications are listed below and are noted in Figure 1.

- Widening of the existing Western Distributor Market St Viaduct from 2 traffic lanes to 4 lanes over a length of approximately 250 m
- Relocation of the Market Street Viaduct pier including a new steel portal frame to replace the pier and support the existing viaduct deck.
- Modification of the Druitt Street Viaduct pier including cutting back of the existing 5.4 m wide reinforced concrete pier by approximately half, requiring large steel support framing.
- Provision of a bus crossover between the Bathurst St and Druitt Street Viaducts included major new steel beams between the existing concrete box girders and concrete transition barriers.

These modifications presented significant design and construction challenges to both the builder and designers. The fast track nature of the project, the difficulties of working in a very busy urban environment, and the technical complexities in assessing and linking into major existing infrastructure which was constructed some 30 years ago, all added to the complexity of the project.

Innovative technical solutions designed to minimise strengthening work to the existing structures with associated cost benefit, and simplifying construction activities together with reducing the construction program for BHBB, were all key considerations in the engineering solutions considered.

2. MARKET STREET VIADUCT WIDENING

The existing Market Street Viaduct consists of three continuous, post tensioned, concrete box girder spans of approximately 30, 30 and 45 metres and eight simply supported steel girder spans with a composite concrete deck, with span lengths varying between 25 and 42 metres. The unusual span configuration was due to the original viaduct being designed to be built over existing railway lines that were located within the goods yard that previously occupied the current Darling Harbour site.

There are a number of variations in the substructure for the viaduct. The piers at each end of are founded on cast in-situ concrete pad footings, whilst the piers in the middle of the viaduct are founded on groups of three bored cast in-situ concrete piles up to 22 metres long. The piers at each end of the viaduct consist of pairs of cast in-situ columns, whilst the piers in the middle of the viaduct consist of single columns that were constructed using rectangular precast concrete hollow units that are post tensioned together with stress bars. The headstocks are typically post tensioned cast in-situ concrete, however there are two conventionally reinforced concrete headstocks.

This Section of the paper describes some of the interesting aspects of the new design and the design work that was carried out to prove the existing structure could support the additional eccentric loading with some strengthening where necessary from the widened superstructure.

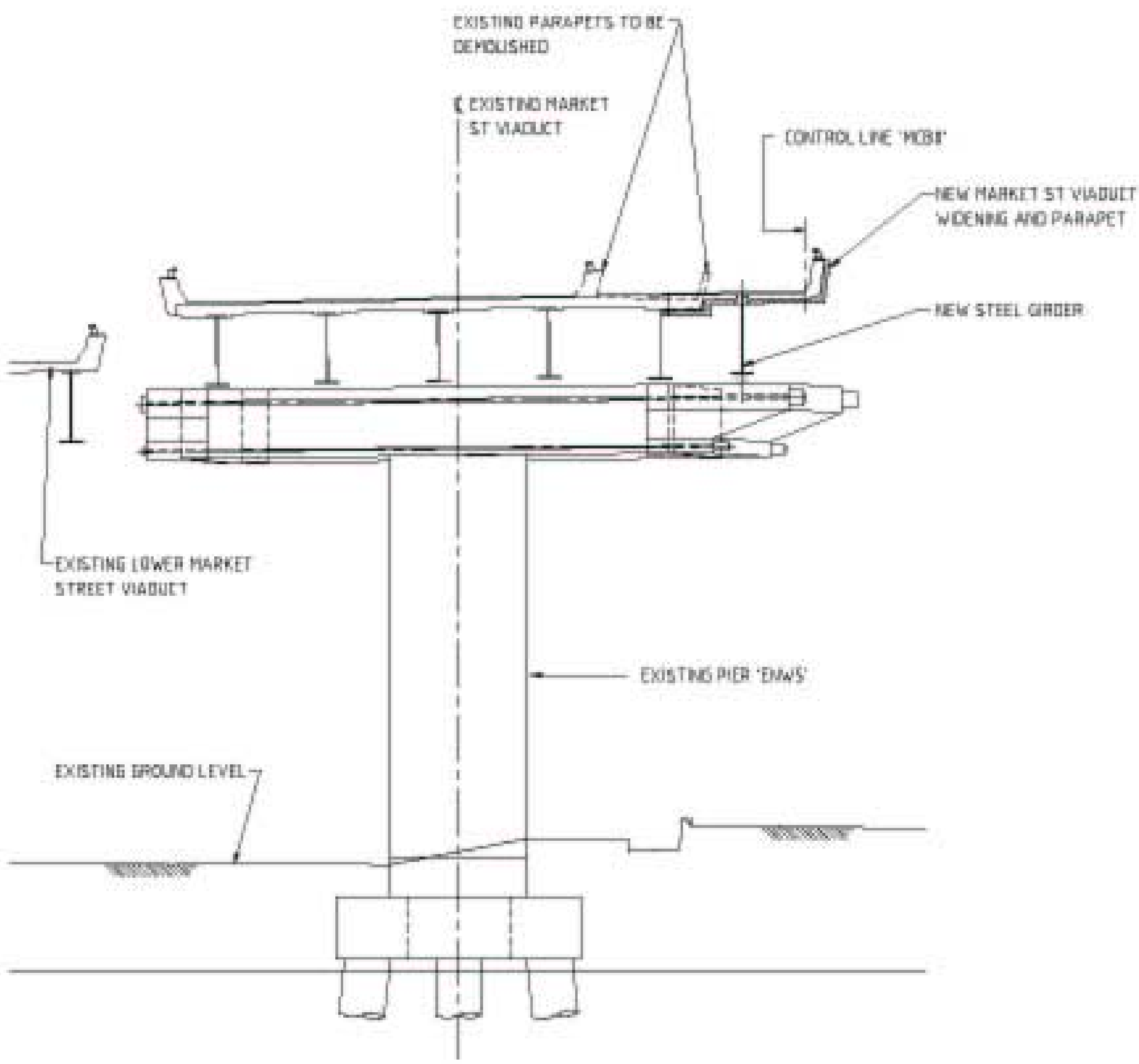

Figure 2:Elevation of Market Street Viaduct Widening at Steel Girder Spans

2.1 Market Street Viaduct Pile Caps

The existing pile caps, some of which are located approximately 6m below existing ground level, were initially analysed using a simple strut and tie method as would have been the approach in the original design. The additional loads on the pile caps from the eccentric deck widening were found to generate loads in excess of the pile cap section capacity, using this conservative method of analysis.

A more detailed three dimensional frame analysis method was subsequently undertaken. This method took into account the geometry of the large pier column section that is supported on the pile cap and by so doing reduces the assumed strut angles. This method indicated that the existing reinforcement in the pile cap could accommodate the new structural loading.

To confirm this anticipated outcome, an advanced non-linear finite element analysis method was then adopted. This method adopted state of the art practice in modelled the characteristics of reinforced concrete by accounting for the cracking of concrete under low tension stresses. The advanced finite element software package ANSYS using brick elements with defined reinforcement content was used.

The analysis confirmed that the existing pile cap reinforcement is adequate to safely carry the additional actions the pile caps will be subjected to, and that pile cap strengthening is not required.

This outcome has substantial benefits for the project in that considerable costs associated with exposing the five affected pile caps within a heavily used public precinct below ground level in water charged silts and sands, and then carrying out strengthening works, is not necessary.

2.2 Market Street Viaduct Headstock Strengthening and Extension.

The existing pier headstocks cantilever each side of a single column pier. The additional loads from the new girder required for supporting the roadway widening increase substantially the actions to be carried by the headstocks, requiring them to be strengthened. The six headstocks affected all differ in both shape and structural form with two headstocks being of reinforced concrete and the remainder of post-tensioned concrete. The main feature of these headstock members is that their ends are skewed by as much as 48°, complicating the addition of any form of extension. Existing bearings supporting the main girders are located on the headstock end corners, making it impossible to cut back these ends to achieve a square configuration. In addition, removal of large volumes of concrete was undesirable in this location under high pedestrian traffic.

Various strengthening options were considered, with the selected option requiring the installation of external post-tensioned cables combined with very large steel box units placed on the headstock ends for anchorage, refer to Figures 2 and 3. The steel extension unit located on the side to be widened was extended so that it could provide support to the new girder. These dual purpose steel units, although ideal in principle, still had to be designed to transfer the large post-tension forces to the headstock and in particular, be stable on the very skew headstock ends. The design had to take into consideration the following peculiarities:

- The skew angle of contact between the steel box unit and concrete contact faces
- The friction restraint between the steel box units and concrete contact face
- The limitation of allowable concrete stresses in the contact zone
- Gap formation between steel and concrete as the entire steel unit would not necessarily be in contact with the concrete face once stressed onto the headstock
- Global stability
- Limitation on stresses that could be generated within the steel elements of the extension units
- Fabrication and buildability constraints
- Aesthetics

The advanced capabilities of the finite element software package ANSYS were again used in the analysis. The analysis results confirmed that certain areas required special attention with regard to stiffening and plate thickening to reduce stress concentrations to within acceptable limits. Friction in the vertical direction between the steel unit and concrete, which is relied on for supporting the deck girder, was confirmed as being sufficient.

The large variation in the span lengths on the viaducts results in a significant load imbalance on some of the piers. This load imbalance and the torsion moments they induce are both increased by the widening of the viaduct. In addition to the externally applied post-tensioning required for increasing bending capacity, some of the existing headstocks were found to require strengthening to increase the section torsion capacity under ultimate loads.

Two options were considered for strengthening the headstocks for these torsion forces. These included external bonded carbon fibre reinforcement to increase the flexural and torsional strength of the headstock, or steel struts placed between the underside of the headstock and the column to resist the torsion forces exceeding the capacity of the existing headstock. The second option was adopted for overall life cycle cost and certainty of long term durability reasons.

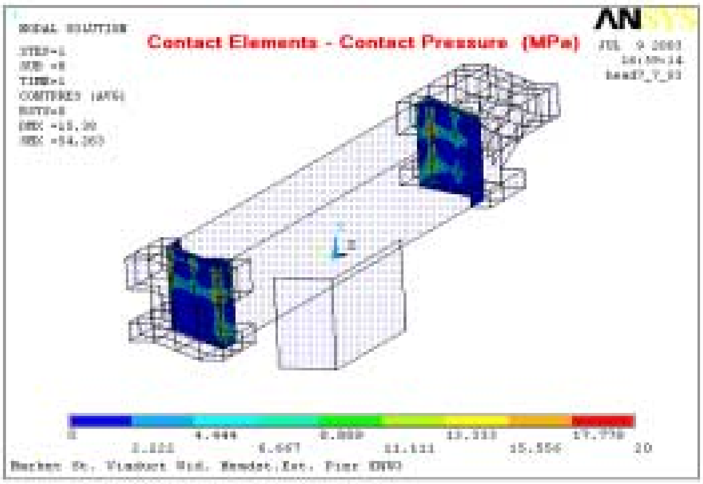

Figure 3: Graphics Plot of ANSYS analysis on Pier Headstock

2.3 Market Street Viaduct Deck Slab Widening

The steel girder spans over Darling Harbour vary from approximately 12 to 20 metres above ground level and are located over public space. BHBB identified very early in the design development that it was essential for them to create a safe working platform for the widening construction as early as possible in the construction sequence in order to minimise the risk to construction workers and to the public below. This platform will be achieved by using permanent, precast concrete formwork panels for the deck construction.

The complex geometry of the widening, the weight restrictions required to keep the loading within limits of the existing support elements and the level of relative movement that will occur between the new steel girders and the existing deck structure during construction, all presented special challenges to the design. There will be 140 formwork panels each 2.4 metres wide manufactured for the deck widening, and no two panels will be the same.

There are two types of deck units. For seven spans, the deck widening is formed with precast units that are supported on steel girders spanning between the headstock extensions as described in Section 2.2, refer to Figure 2. The second type of deck unit is used for three spans at the eastern end of the viaduct, where the widening is formed with precast units that are supported on raking steel strut members extending to the existing concrete box girder superstructure, refer to Figure 4.

3. MARKET STREET VIADUCT PIER RELOCATION

The southern column for the second pier group for the three span post tensioned concrete box girder spans of the Market Street Viaduct is to be demolished to make way for the Cross City Tunnel Eastbound Carriageway Tunnel approach, refer to Figure 4.

A concrete blade wall supported on piles founded on rock will be constructed on either side of the tunnel approach with steel girders spanning between the blade walls on either side of the existing 1830 mm square concrete pier to support the loading from the viaduct.

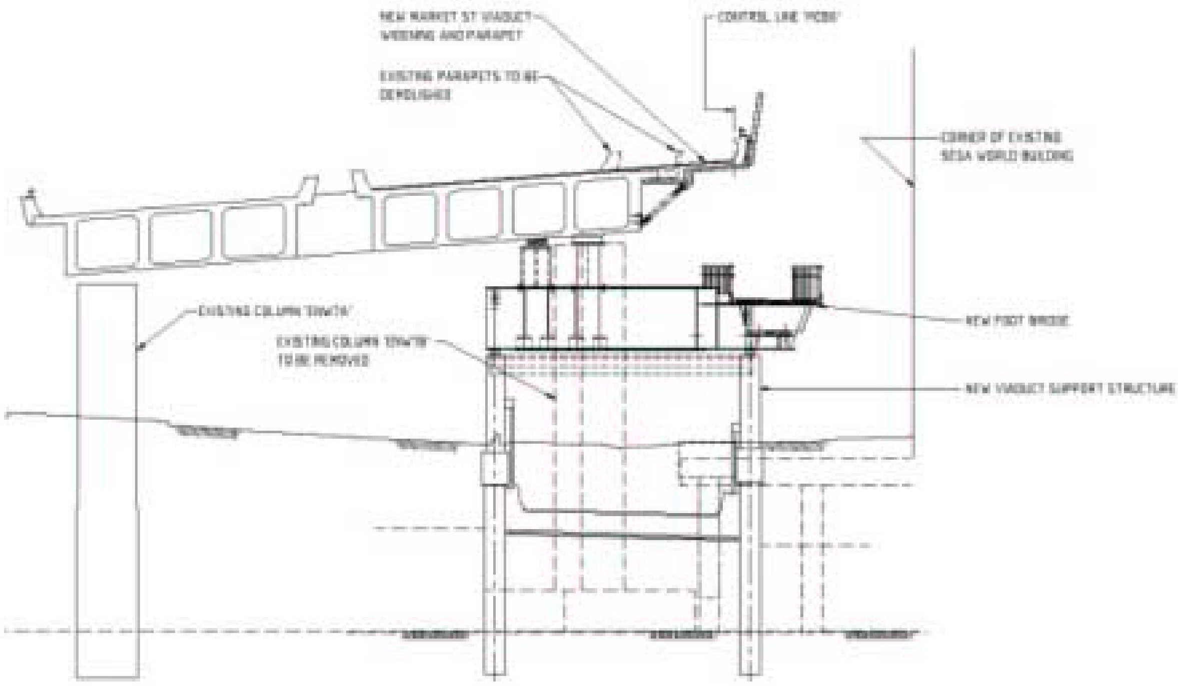

Figure 4: Elevation of Market Street Widening at Concrete Box Girder Span and Column Relocation

The challenge for the designers was to transfer the significant viaduct loading from the existing column to the new more flexible steel girder support whilst avoiding settlement of the viaduct superstructure and the potential to overstress the superstructure with the associated redistribution of loading. The following procedure will be used to transfer the loading onto the new steel girders.

- Steel cross beams will be site welded between the main girders adjacent to the existing southern column.
- Two 400 tonne jacks and two 200 tonne jacks will be placed on the pedestals fitted to the main girders and cross beams and then the superstructure will be lifted off the existing southern bearing.
- The existing column will be demolished
- Steel cross beams will be site welded between the main girders under the position of the existing bearing.
- A support pedestal will be fitted to the cross beams and a new bearing will be fitted to the existing bearing top attachment plate.
- A 1000 tonne flat jack will be fitted under the new bearing so that the load transfer into the new bearing can be controlled.
- The load will be transferred from the temporary jacks to the new bearing in a carefully staged process of loading the flat jack and de-loading the temporary jacks in increments and monitoring the level of the viaduct superstructure so that viaduct is supported at its current level.
- Once the load transfer has been completed the oil within the flat jack will be removed and replaced with a 60 MPa resin that will provide the permanent support for the bearing.

The structural system chosen for this modification is simple in its form and construction and provides a means of transferring the load of the superstructure from the existing column to a new support in the same location as the column with minimal effect on the forces within the superstructure.

4. DRUITT STREET VIADUCT PIER MODIFICATION (Figure 5)

The first pier on the Druitt Street Viaduct to the west of the abutment is located between Day Street and the Market Street Viaduct approach. In order to provide the required sight distance for a 65 km/hr vehicle speed for traffic that exits the westbound Cross City Tunnel and joins the Market Street Viaduct, the 5486 mm wide x 1219 mm thick pier had to be substantially cut back.

The pier supports a 32 metre and 45 metre span of a 15.4 metre wide, continuous post-tensioned concrete box girder superstructure. The pier modification will require the removal of the northern bearing of the pair of bearings that support the superstructure at the pier.

The northern support for the superstructure will be supported on a pair of steel frames placed on either side of the concrete column of the existing bearing location. As with the column relocation on the Market Street Viaduct it is necessary to transfer the loading across to the new steel frame without significant change in the force distribution within the superstructure. This will be achieved by:

- Installing the frames
- Placing jacks on the frames and lifting the superstructure off the concrete column
- Partially demolishing and making good the existing column
- Installing new steel support members and bearing at the existing northern bearing location, and a new bearing at the southern bearing location

- Lowering the superstructure onto the new bearings. Flat jacks will be incorporated in the bearing assemblies so that the loading between the two bearings can be adjusted to achieve the required balance

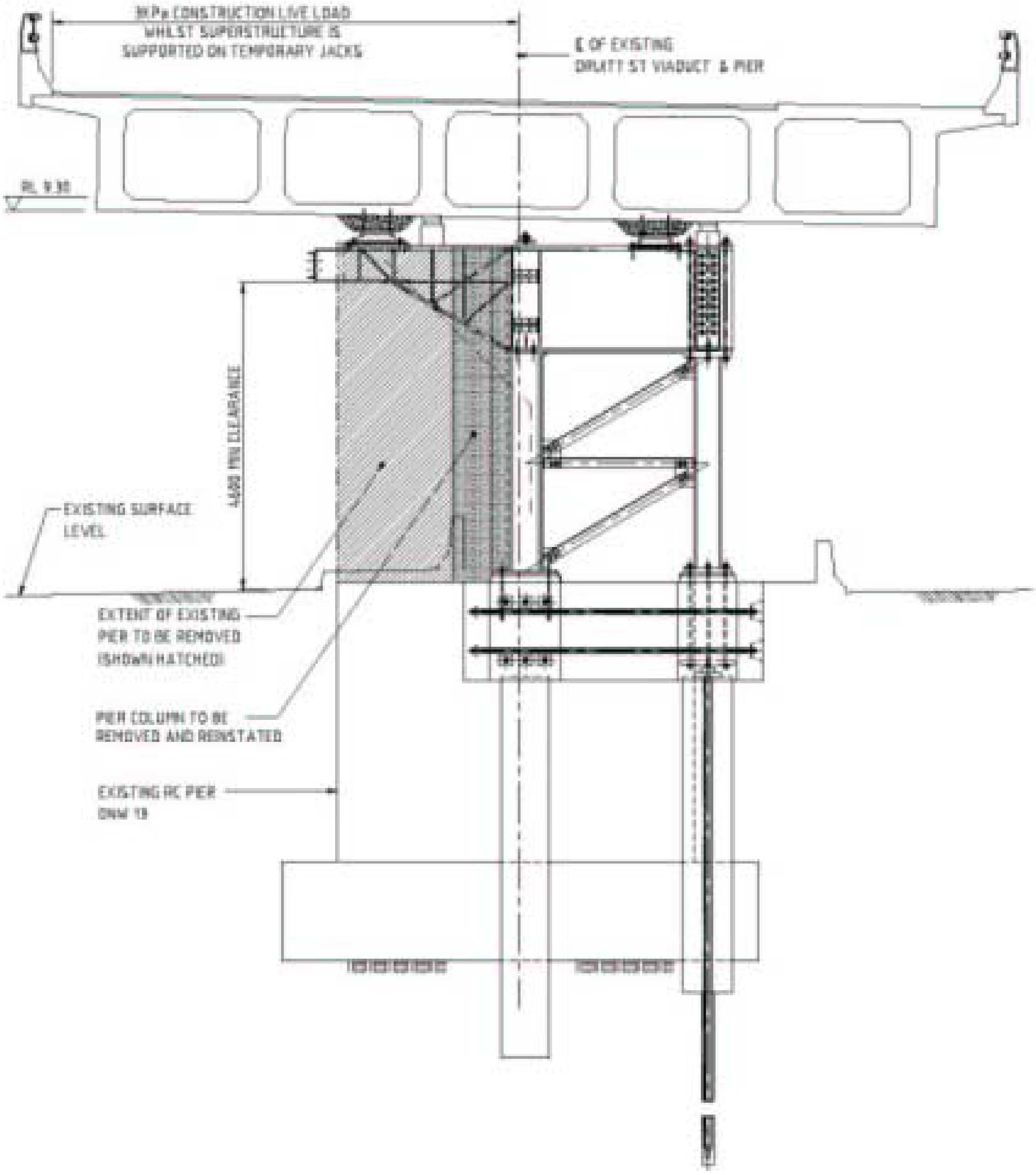

Figure 5: Elevation of Druitt Street Pier Modification

Due to the height restrictions under the Druitt Street Viaduct at the Pier modification, the structural system chosen for this modification is more complex in form and construction than the column relocation described above for the Market Street Viaduct Pier relocation. The depth of the girders vary in order to provide sufficient strength and stiffness whilst maintaining a minimum 4.6 metre clearance over the roadway. The clearances between the existing concrete column and the new steel framing also had to be limited to 20 mm in order to limit the span and hence depth on cross beams supporting the bearing. The tight clearances posed a number of issues with the detailing of the steelwork to ensure it could be installed and maintained.

5. BUS CROSS OVER (Figure 6)

The bus-cross over involves a 145 metre long infill between the existing eastbound King Street/Bathurst Street Viaduct and the westbound Druitt Street/Market Street Viaduct to allow for eastbound buses to cross over to a designated bus lane on the Druitt Street Viaduct.

The eastern 75 metres of the cross-over occurs in a section of viaduct with the same steel girder and composite cast in-situ concrete deck construction as was described in Section 2 for the Market Street Viaduct widening. The new design allows for an additional girder to be braced off the existing edge girder with short steel cross girders, allowing the deck to be cast in two stages on sacrificial concrete that is supported off the cross girders. The first stage pour stabilises and completes the new girder structure. The existing edge parapet is then demolished, with the demolition rubble caught and contained by the permanent formwork before casting the final strip of new deck. In this way no false work is required, which is a big advantage as these spans are high above busy streets.

The western half of the cross over consists of an infill deck between two curved post-tensioned box girder viaducts. The deck is required to span between these structures to deflect with them so that the joint is unaffected by a step in level. In addition, it had to be relatively light so as to not overload the existing structures, but at the same time be stiff enough to avoid problems with deflection at the deck joints, and to allow the two existing bridges to deflect freely. Finally, construction had to be suited to the difficult site access available, with the deck being between two arterial road bridges and above a busy intersection.

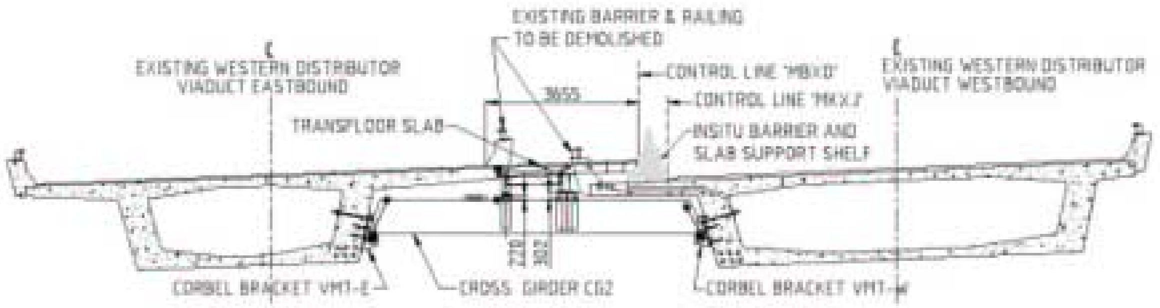

Figure 6: Typical Cross Section at Bus Cross Over

The final adopted solution was a steel grillage structure with a composite concrete deck that is cast on permanent concrete formwork with precast traffic barriers. The grillage is made of primary steel cross girders that span between the existing bridges, with continuous longitudinal beams.

The primary steel cross girders are supported off steel brackets that are stressed and bolted to the sides of the existing bridge girders. After these brackets have been erected, the rest of the steelwork grillage and permanent precast concrete formwork panels and precast concrete traffic barriers are installed. A cast in-situ deck is then poured to tie all the components together to form the final structure.

Articulation of the new deck is a critical aspect of design to achieve a road surface that allows the two existing bridges to remain independent in flexure, but without having longitudinal joints that are affected by excessive differential displacement. This is achieved with a carefully detailed arrangement of flexible deck joints and sliding bearings.

6. CONCLUSION

The modifications to the Western Distributor Viaducts posed many difficult challenges for the bridge design engineers. With careful and detailed analyses of these existing viaduct structures a full understanding of their behaviour was gained. With this knowledge and a close working relationship with the BHBB Construction teams, innovative solutions were developed to overcome these challenges that significantly benefited the Project.