DESIGN OF THE ORMISTON ROAD CABLE STAYED BRIDGE, NEW ZEALAND

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SYNOPSIS

This project consists of designing New Zealand’s first modern cable stayed road bridge. The bridge site is located in Manukau, New Zealand.

Manukau City Council created a design competition requesting design services to provide an iconic gateway bridge crossing a scenic park and leading into a new township. Beca in collaboration with Craig Craig Moller Architects won the competition with a cable stayed bridge.

The bridge is 70m long with a main span of 49m. The carriageway consists of two lanes, a cycle lane and a footpath in each direction. The deck has a 3.5m void between the eastbound and westbound carriageway to allow light to reach the park walkways passing beneath. The overall width is 27m including the void.

The architect and client both wanted a streamlined and sleek bridge. A key feature involves sloping the cable stay tower pylons in both longitudinal and transverse direction. The pylon diameter and box girder depth were kept to minimum dimensions, which resulted in detailing challenges for the steel box girder and the tower at the cable stay anchorage locations.

1.0 INTRODUCTION

The project involves a major gateway bridge over the new Barry Curtis Park and upgrading a 400m length of Ormiston Road to Regional Arterial Road standards. The project is part of the infrastructure necessary for the development of the Flat Bush area in East Tamaki. Flat Bush is a greenfields urban development within Manukau City, that is planned to be developed over the next 20 years to accommodate 40,000 new residents, making it New Zealand’s largest new town.

2.0 BACKGROUND

Beca Infrastructure Limited (Beca) in conjunction with Craig Craig Moller (CCM) Architects submitted a Stage 1 Tender in July 2004 in response to a Request for Tender - Ormiston Road Bridge Design Professional Services issued by Manukau City Council (MCC).

Beca-CCM was shortlisted and invited to submit a Stage 2 Tender. The tender evaluation process was a quality based system (Brook’s Law) where tenderers are required to submit their methodology and fee in two separate envelopes for undertaking the design and construction phases of the project. The Stage 2 tender incorporated a design competition where part of the evaluation marking is based on concept designs developed by the tenderers. Award of the project was based on company attributes and the submitted concept design. The fee was then negotiated.
After considering a wide range of options the three bridge forms that Beca selected as the most appropriate for this project were:

- Cable Stayed Bridge.
- Box Girder Bridge.
- Multiple Steel Arch Bridge.

Of the above three options, the Client considered that the Cable Stayed Bridge achieved the gateway and iconic status in an outstanding way, and was the preferred option. This cost of this bridge is the highest of the three.

The bridge needed structure elements above deck level for visual impact and a gateway appearance. Cable stayed, truss or arch structures were the only bridge forms in this category. The box girder bridge option was provided for a base option cost estimate for option evaluation.

The concept for the design was to ‘touch the ground lightly’ and seemingly soar across the 70m space, with a slim profile bridge supported on asymmetrical placed tower pylons using cable stays to the outer sides.

These pylons are angled in two directions in relation to the engineering design solution, and it gives a dynamic, iconic element to the landscape and a clear and uncluttered transition for the park to flow through.

The twin carriageways are separated by a 3.5m wide void, thus allowing light and sun to penetrate to the park below and provide separate elements rather than a full width traffic deck. The footpaths are located on the outer edges.

The bridge will incorporate spectacular lighting effects using similar techniques to the lighting of Auckland’s Sky Tower. This will consist of feature lighting of the pylons, cables and decks together with the top section of the pylons, which will have a stainless steel tapered cage with glass infill panels, all of which are illuminated from within to resemble ephemeral beacons, which will be visible for some distance.

Thus the bridge will provide an iconic and elegant element in the landscape both during night and day, and allow the free flow of the park beneath.

3.0 STRUCTURE DESCRIPTION

Cable stayed construction is an efficient structural form for medium to long span bridges. Although it is more usually adopted for longer spans than those being considered here, the form has been used very effectively for spectacular shorter span structures and was considered appropriate to meet Council’s objectives of a “Gateway” and a “Landmark Feature”.

The layout has a cast in place concrete deck on steel framing spanning onto slender longitudinal steel box section beams at each side of the bridge. The footpath is on precast concrete slabs supported on cantilever beams each side of the deck. The footpath barrier consists of stainless steel wires to enhance the visual lightness of the
structure. The overall width of the bridge is 27m including the interior void. Refer to figure 1 to figure 3 for the bridge plan, elevation and cross section.

The main longitudinal members are supported by the stay cables, which transfer loads to the tall reinforced concrete pylons located asymmetrically in elevation. The pylons are inclined to the vertical to give a distinctive appearance, which does not detract from the structural function of transmitting the stay cable forces to the foundations. Cables are anchored to steelwork boxes mounted at the top of the concrete pylons by large clevice and pin connections. Each box is clad externally with a curved steel shell shaped and painted to match the concrete. A high level cross frame connects the two pylons and decorative conical extensions are mounted above the structure.

The stay cables are high strength steel wire with proprietary anchorages and high quality corrosion protection system (designed for a 100 year life). The bridge design and the cable system allow replacement of cables in the event of accidental damage; all details are designed for durability and simple maintenance.

Foundations are reinforced concrete bored piles supporting the pile caps and abutment beams.

4.0 DESIGN CRITERIA

The bridge is detailed to have a design life of 100 years. The principal design criteria for this bridge were:

- HN_HO_72 live loading in accordance with the Transit New Zealand Bridge Manual
- Wind loading derived from AS/NZS 1170
- Seismic loading in accordance with AS/NZS 1170 for an elastically responding structure
- Cable design in accordance with Post Tensioning Institute (PTI) Guide “Recommendations for Stay Cable Design, Testing, and Installation”
- Fatigue in accordance with AS 5100
- Deck vibration in accordance with Canadian Highway Bridge Design Code. AS 5100 did not provide acceptable vibration limits for cable stayed bridges

5.0 GEOTECHNICAL CONDITIONS

Subsurface materials comprise of Puketoka Formation Alluvium overlying East Coast Bays Formation Waitemata Group Rock. The alluvium comprises firm clays and loose sand layers with most SPT values in the range of 6 to 8 blows per 300mm. The depth to bedrock varies with almost 10m difference in rock levels between the two abutments, being approximately 23m and 14m below existing ground respectively.

6.0 SUBSTRUCTURE
6.1 Abutments

The abutments and pylons are supported by bored piles socketed into competent Waitemata group sandstone. The piles are grooved within the rock socket to develop the required axial resistance by skin friction.

The western abutment piles are post tensioned due to the uplift forces generated by the asymmetrical nature of the bridge. The post tensioning is designed to maintain the pile internally in compression under all serviceability limit state loads. The pile stiffness affected the structure deflection and hence it was beneficial for the pile stiffness to remain uncracked under all serviceability load conditions.

The abutments are live load continuous with the superstructure. This assists with vibration and removes the need for deck joints. The abutments are constructed in stages so the dead load of the superstructure does not induce significant moments into the piles.

6.2 Pylons

The raking of the tower pylons in the longitudinal direction requires a tension tie beam between the pylon pilecap and the western abutment to transfer the horizontal axial component of the pylon. This was preferred to the pylon piles resisting the horizontal load in flexure, which would generate additional creep moments into the piles as the resisting soil crept over time. The tie beam was also post tensioned to remain in compression under all load conditions at the serviceability limit state condition for the same reason as the western abutment piles.

The pylons are reinforced concrete tapering from 1800mm diameter at the pylon base to 1200mm at the interface with the cable stay steel anchorage box. A stainless steel lattice frame in the form of a cone completes the top of the pylon. The lattice frame has glass mounted inside and will be utilised as part of the bridge feature lighting. The lattice frame provided a visual effect of the tower tapering to a point, which was a key aesthetic feature for the architect.

The cable stay anchorage consists of a fabricated steel box stressed onto the concrete pylon. The anchorage box is inclined with the pylon and requires vertical steel plates projecting out for providing the anchorage to the clevis and pin connection of the cable stay.

The pylons incline transversely inwards over the carriageway. A horizontal portal beam is required to carry the horizontal axial load component generated from the cable stays.

7.0 SEISMIC DESIGN

The bridge is designed as a “locked in” structure in the longitudinal direction and as an elastically responding structure in the transverse direction. Vertical acceleration was assessed as the third seismic case. The seismic demands are from 100%X + 30%Y and 30%X + 100%Y where X and Y are the longitudinal and transverse directions respectively. Seismic was not a critical load case for the bridge design.
8.0 SUPERSTRUCTURE

The deck carriageway consists of two 3.2m lanes, a 1.4m cycle lane and a footpath travelling in each direction. The carriageway is separated in each direction by a 3.5m void running down the centre of the bridge. The void provides natural light underneath the bridge during the day.

The superstructure consists of slender box girders supported by the cable stays at 7m intervals. The box girders in turn, support transverse cross beams which support intermediate stringers. This system was chosen rather than the option of only transverse cross beams so the deck thickness could be minimise and reduce the overall dead load onto the cable stays.

A number of corrosion protection options were investigated for the steel components. Weathering steel was a favoured option in terms of aesthetics, but the concern of possible staining of the piers eventually ruled it out. Zinc metal spray with a finish paint coat was the agreed solution.

The in situ concrete deck consists of a minimum thickness of 170mm and is designed to carry a proportion of the horizontal axial compression load generated from the cable stays.

9.0 CABLE STAYS

The size of the bridge created challenges for detailing. The effective tributary load area for the cables was of similar magnitude to a much larger cable stay bridge because of the large deck width and resulted in similar size cable stays. The challenge was to fit the cable stay anchorages in a small confined steel box girder 1m deep and also to anchor the cable to the top of the pylon. This resulted in the use of two back stay cables of smaller size rather than one large back stay.

Stay cables are galvanised parallel wires protected by a petroleum based product in a HDPE sheath with BBR DINA anchorages at the live end and proprietary clevis anchorages at the pylon anchorage location. The parallel wire system was preferred to the parallel strand system based on the vibration performance and fatigue characteristics. The cables are protected by the road barrier and a robust steel sleeve projecting from the deck.

The design of the cables is limited to 0.45fpu of the cable capacity at the serviceability limit state. Fatigue assessment of the cables was in accordance with the PTI Guide based on a single design truck occupying a single lane.

The constant axial load on the concrete pylons and concrete deck causes the concrete to creep over time resulting in a decrease in cable prestress for the long-term scenario. The short-term cable prestress load is assessed to ensure the cable stress limit is not exceeded when the bridge is first opened to traffic.

Two load combinations consisting of the loss of a cable was considered. The first situation is the replacement of a cable under controlled conditions. This would require the closure of two lanes closest to the cable being replaced. The remaining
two lanes would be contraflowed with one lane for each direction of traffic. This load combination is treated as an overload combination.

The second situation is the failure of a cable due to vehicle impact or fatigue, with reduced traffic loading on the bridge. This situation is assessed to prevent progressive collapse of the bridge. Inelastic behaviour of all elements is acceptable provided that collapse is prevented. This is an extreme event and a reduced live load factor is applied similar to the reduced live load factor for live load combined with ship impact load combination in the AASHTO LRFD Bridge Design Specifications.

The stability of the bridge was also assessed for the loss of one crossbeam so no lateral restraint to the box girder is provided at this location. The critical element assessed was the box girder with a reduced concrete deck area for carrying the deck compression load.

10.0 CONSTRUCTION STAGING

The proposed construction methodology is to fully support the superstructure on falsework through to the placement of the deck and then lift the superstructure off the falsework with the cables.

Temporary vertical supports in the main span and one in the back span are required to support the superstructure until the cables are stressed. The temporary supports are not in the same location as the cables. When the cables are stressed the deck profile should not change appreciably, only the reactions from the temporary supports are transferred to the cables.

The bridge construction staging will be:

- Construct substructure elements including stressing of abutment piles and tie beam,
- Erecting of the steelwork on falsework,
- Pouring the concrete deck and kerb, poured making the abutments integral with the steel boxes at the same time,
- Erection and stressing of the cables,
- The footpath, surfacing and barriers are then added. These items are added after the cables to reduce the load on the temporary supports,
- A final cable stressing stage is required to achieve the final alignment.

11.0 SUMMARY

Ormiston Road Bridge achieved the Client’s desire of an iconic structure that would provide a “Gateway” and a “Landmark Feature”. The cable stay bridge was the winning option for a design competition created by Manukau City Council. Other options considered were; a multiple steel arch bridge, and a box girder bridge. The resulting cable stay bridge design has achieved an outstanding outcome with the Clients expectations exceeded in all aspects.

12.0 ACKNOWLEDGEMENTS

Consent of the Client, Manukau City Council, to publish this paper is gratefully acknowledged.
Figure 3

Figure 4