Bridges on the Northern Gateway Motorway

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Synopsis

The challenge on this project was to develop 7.5km of new motorway through difficult and environmentally sensitive terrain. Northern Gateway Alliance set the vision to create a visual showcase of environmental and engineering excellence. To help achieve the vision the bridges were not only designed to be constructable and durable but also visually attractive. This paper describes all six bridges along the route and the key considerations that featured in their design.
1. Introduction

The Northern Gateway motorway is a 4 lane, 7.5 kilometre long, green fields motorway development. This section of motorway runs from Orewa through to Puhoi, north of Auckland.

New Zealand Transport Agency (NZTA), formerly Transit, awarded the project to the Northern Gateway Alliance in 2004. It was a technically challenging project which, at conception, had significant risks. The engineering risks were generally associated with the scale of the project, which at $365 million is the largest roading project undertaken by NZTA, and the steep and difficult terrain. The motorway alignment generally runs north-south through a series of ridge lines that run east-west. This is evident in the long section shown in Figure 1. This necessitated large earthworks operations and many bridges and tunnels. There were also risks with constructing the motorway through an environmentally sensitive area as well unresolved regulatory planning issues.

This section of motorway is the first automatically tolled road in New Zealand; as such it was important to offer a high amenity value to the motorway user. To achieve this emphasis was placed on creating an attractive stretch of motorway that fitted into the environment; it was to have the flattest gradients possible and very good ride quality. These aspects were embodied in the mission statement for the project which was “To create a visual showcase of environmental and engineering excellence”. The mission statement provided a touchstone that guided many design decisions including selection of the form of the bridges.

There are 6 bridges on the Northern Gateway Motorway; these are listed in Table 1. The following sections of this paper summarise each bridge, the reasons for selection of that type of bridge and the key technical issues faced in the design.
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Table 1. Northern Gateway bridge statistics

2. Orewa Interchange Bridge

Photo 1 shows the completed Orewa Interchange Bridge. The bridge is in the middle of a full diamond intersection situated at the start of the tolled section of motorway. The bridge carries two lanes of traffic and one footpath over the motorway. A typical cross section of the bridge is shown in Figure 2 and the long section in Figure 3.

Photo 1  Orewa Interchange Bridge
This is a fairly conventional bridge by New Zealand standards with double hollow core units forming the superstructure. Cast in situ concrete is used for the central pier and abutments. The whole bridge is founded on bored piles socketed into sandstone.

Since this bridge is very visible to the motorist, careful attention was given to the appearance of the bridge. The 25m span length is significantly larger than needed for the 10.6m wide motorway to pass beneath; however it was desirable to have a larger span for aesthetic and economic reasons. The actual span length was determined by the maximum practical span that a 900mm deep beam unit could achieve when simply supported. The beams are designed as fully prestressed sections using 60MPa concrete. The outer beams have 50 prestressing strands while the inner beams have 42.
By pushing the spans out to 25m, the abutment fills are minimised and clearance underneath the bridge opens up a wide field of vision for the motorway user. The generous lateral clearances also avoid the need for edge barriers at the abutments since the abutments are positioned sufficiently far enough away from the motorway lanes so as not to create a hazard. The long spans also give a more aesthetically pleasing span/height ratio than would have been achieved if the minimum span length had been used. Attention to aesthetic detailing can be seen with the curved outer deck beam and the corrugated finish on the concrete edge barriers, refer Photo 2. This feature also occurs on Hillcrest Bridge; providing a sense of consistency between two very different bridges.

3. Nukumea Viaduct

Nukumea Viaduct takes the motorway across an ecological corridor centred on the Nukumea stream. The viaduct surface is barely distinguishable from the motorway leading to it and the viaduct is likely to go unnoticed by the motorist.

![Photo 3. Nukumea Viaduct](image)

The Viaduct is 180m long and comprises 6 spans of 30m. A typical cross section of the Viaduct is shown in Figure 4. The cross section comprises eight 1500mm deep tee-roff beams with an in situ concrete deck. The deck was designed to carry 100 tonne earthworks vehicles during construction and as a consequence is more heavily reinforced than needed for legal traffic loads.

The design and construction of this Viaduct was very similar to Otanerua Viaduct. The only difference being Nukumea has deck joints at both ends of the bridge while Otanerua has one deck joint at mid-length.
4. **Hillcrest Bridge**

Hillcrest Bridge is a 115m long structure that carries a single lane of traffic and a footpath over the new motorway. The structure is very visible to the Northern Gateway motorist being located above a 27m deep cutting and therefore the structural form was chosen to carefully fit the site. Significant attention was given to architectural detailing. Photo 4 shows the completed bridge.

![Photo 4](Hillcrest_Bridge.jpg) **Photo 4**  
**Hillcrest Bridge.**
The geotechnical conditions at the site comprise a weathered profile of Waitamata series sand/silt stone. Slopes for the cutting were excavated at 2:1 in the weathered soils and 1:1 in the less weathered sandstone. The transition between the two slopes provided the springing point for the piers. The change in slope can be seen clearly on the left hand pier in Photo 4. The right hand pier is similar but is obscured by the slope in the foreground.

The bridge superstructure is a continuous reinforced concrete tee-beam, as shown in Figure 5. The underside of the superstructure follows the original ridge line. This allowed the superstructure to be poured on formwork at the original ground level and the bridge to be built with a top-down construction methodology.

The 756mm diameter inclined steel tube columns supporting the bridge are structurally logical but they did not suit top-down construction. To overcome this problem four temporary bored piles were constructed near where the steel columns connect to the superstructure (refer Photo 5 & 6). The ground beneath the bridge was then excavated to top of sandstone level where the permanent foundations could be constructed. At this point the inclined steel columns were installed and the temporary piles were removed. Photo 5 shows the all of the steel columns installed with the temporary piles still in place. The connection of the steel tube to the bridge deck was accomplished with a concrete stitch, as shown in Figure 5. Load was transferred from the temporary piles to the permanent steel columns with the use of sand jacks on top of each temporary pile.

Photo 5. Hillcrest Bridge during construction

Photo 6. Column connection and sand jack.
5. Otanerua Viaduct

Otanerua Viaduct is a 256m long bridge that crosses the Otanerua Valley and provides an ecological corridor between two areas of regionally significant bush land that the new motorway would otherwise bisect.

The Viaduct superstructure comprises 8 x 32m spans each with 10 tee-roff beams. Like Nukumea Viaduct the beams are 1500mm deep and are designed as partially prestressed. A typical cross section of the bridge is shown in Figure 6. The completed bridge is shown in Photo 7. In elevation the Viaduct is barely visible to the public. Being 32m high it provides the motorist with fleeting glimpses of the coast above stands of regenerating Manuka and Podocarp forest.

Otanerua Viaduct is discussed in greater detail in a paper titled “Evolution, design and construction of Otanerua Eco-viaduct” published in the Austroads 2006 Bridge Conference Proceedings.

Photo 7. Otanerua Viaduct – Aerial View
6. Waiwera Viaducts

Waiwera Viaducts are two separate bridges each 518m long spanning across the Waiwera Valley. Photo 8 shows the viaducts at a stage when they are nearly complete. The viaducts are generally parallel with each other, with 2.5m clear gap between them for most of their length except at the northern end where the gap widens out to approximately 11m to provide the correct alignment for entry into the twin tunnels through Johnstone’s Hill.

Figure 6. Otanerua Viaduct – Typical cross section.

Description
A brief description of the physical attributes of the Viaducts is given below.

Piles 4 No. 1800mm diameter bored piles per pier. Piles found in Pakiri formation sandstone. Pile capacity was based on combined side friction and end bearing. Pile capacity proven by load test.

Pilecaps 9600mm x 9100mm x 2500mm deep reinforced concrete.
Columns 5400mm x 2400mm (varies with taper) rectangular hollow section.
Superstructure Precast segmental box girder constructed by the balanced cantilever method.

Design
Both viaducts have been designed for HN-HO-72 New Zealand bridge loads. Gravity loads, environmental loads and load combinations were as specified in the Bridge Manual. The design standards used are predominantly the Concrete Structures Standard, NZS 3101 and AASHTO Guide Specification for Segmental Bridges, 1999.
Figure 7. Waiwera Viaduct – Typical cross section.

The box girder is continuous throughout its length with deck joints at both ends. Piers C, D & E (those between Waiwera River and Weranui Road, refer Photo 8) were constructed monolithically with the superstructure. Pier B & F support the superstructure on fixed pot bearings while the remainder of the piers and abutments support the superstructure on sliding-guided bearings.

Design actions on the piers that are cast monolithically with the superstructure were dominated, in the longitudinal direction, by shortening effects caused by temperature, creep and shrinkage. Transversely seismic forces dominate. Wind forces on the partly constructed bridge, when the gantry is in operation (refer Photo 9), were of a similar magnitude.

The box girder superstructure has been designed, for longitudinal actions, as a fully prestressed section that does not go into tension under any serviceability limit state load combination. Prestressing is provided by post-tensioned tendons made from 15.2mm diameter EHT strand. A combination of 12 strand and 19 strand tendons were used. The post-tensioning was all internal, no external tendons were used.

The launching gantry used to construct the superstructure (refer Photo 9) was selected early in the design phase and consequently the design of the viaduct could be optimised to suit the capability and loads imposed by the gantry. This was assisted greatly by the construction team also being engaged during the detailed design phase so the design detail could be tailored to the constructor’s preferences.

Each precast segment of the box girders was 2.9m long, they varied in weight from 50 to 90 tonnes. In all there were 356 segments. The segments were match-cast using the short line casting method. During erection the match-cast faces were covered in wet epoxy and pulled together with temporary prestress. When the permanent prestress was installed the temporary prestress was removed.
Transversely the box girder is conventionally reinforced. Edge barriers were required to be performance level 4 (concrete F shape barrier). However, it was decided to reinforce the barriers and the deck slab for performance level 5 as a means of future proofing the design.

**Aesthetics**
The viaducts are a dominant feature in the Waiwera Valley and as such were afforded significant attention to their appearance.

Span lengths were dictated to some extent by the obstacles on the ground that the piers had to avoid, these included an ecological corridor on the side of Johnstones Hill, the Waiwera River, Weranui Road and an archaeological site. Within these constraints a maximum span length of 76m was selected. Near the southern abutment where the structure gets closer to the ground span lengths were reduced to avoid the obstacles mentioned and within the constraints imposed by the balanced cantilever construction method. Figure 8 shows the final span arrangement. This variable span arrangement gives a more uniform span to depth ratio for each span along the bridge leading to a more balanced appearance, when viewed in long section, than compared to the alternative of uniform pier spacing.

The variation in box girder depth has been created by linearly varying the depth over the first 6 segments and thereafter using a constant depth segment. The different span lengths are achieved by varying the number of segments with constant depth.

*Photo 9. Waiwera Viaducts under construction.*
Figure 8. Waiwera Viaduct long section

Pier columns have been given a slight taper (1 in 75) in elevation, reducing in width at the top. Refer Figure 8 and Photo 12. No taper is provided in the other direction. Although very subtle, the taper accentuates the height of the viaducts, it also emphasises the logical flow of structural forces, that is the columns are visually (and actually) stronger at their base. The tapered piers compliment the linear lines on the viaduct bottom flange. The clean lines of the viaduct are assisted by the design decision to fully bury the pile caps.

A top rail on the edge barriers has been provided for extra protection to prevent a person falling from the viaduct. To maximise the views from the viaduct a slim-line aerofoil top rail was selected to provide the least disruption to the motorist’s views. The aluminium aerofoil railing is shown in Photos 11 and 12.

Photo 11. Edge barrier detail

Photo 12. View along the Viaducts

Durability
The proximity to the coast is evident in Photos 8 and 9 and hence the viaduct is frequently exposed to wind blown chlorides. Durability design was based on the provisions in the Concrete Structures Standard, NZS 3101:2006. All piers were considered as Exposure Category C and the superstructure was considered to be Exposure Category B2.

To meet the requirements for Exposure Category C, all pile caps and piers were constructed with fly ash concrete containing a minimum cement content of 350kg/m$^3$ and maximum water/cement ratio of 0.40. Generally 100mm of
cover was provided to the reinforcement in all substructure elements. This is substantially more than the minimum requirement. Curing, which is also very important for durability, was undertaken in accordance with NZS3101.

Predicted cracks widths in the substructure and superstructure were controlled by reinforcement to ensure they did not exceed the relevant limits, 0.3mm and 0.4mm for Exposure Category C and B2 respectively.

Tendons are protected from corrosion by concrete cover, galvanised steel duct and durable grout. Joints between precast segments were sealed with epoxy.

Photo 12. Waiwera Viaducts under construction.

7. Titfords Bridge Widening

Titfords bridge is an existing 12m span reinforced concrete structure at the northern end of the project. The existing bridge needed to be widened to satisfy the safe geometric requirements for the motorway termination. The original bridge was built in 1937 and was designed for traction engine loads (which are less than current design loads). Despite the bridge being 70 years old and spanning over a tidal river it was in very good condition. Carbonation and chloride ingress were measured these indicated the bridge still had at least another 30 years life remaining. The decision was made to widen it rather than replace it.

Widening was achieved with new reinforced concrete beams matching the dimensions and spacing of the original beams. The widened section of bridge
was completed then the two bridges were stitched together with a closure pour. Figure 9 shows a cross section of the new widened structure.

![Figure 9. Titfords Bridge cross section](image)

To bring the portion of original bridge up to modern bridge strength (despite the fact that it had performed perfectly well for the last 70 years) the beams were strengthened with external post tensioned tendons each side of each beam. The tendons are 40mm diameter VSL Stressbar tendons, these are protected from corrosion with a polythene sheath filled with cement grout.

Edge barriers on the original deck were upgraded to performance level 4. This required carbon fibre strips to reinforce the deck at the post locations.

8. Conclusion

The bridges structures on the Northern Gateway Motorway are a major and very visible part of the motorway project. The designers had to select bridge structures that suited the site constraints and balance the sometimes conflicting requirements of designing an efficient and readily constructable bridge with the desire to create a visually attractive structure. Time will tell if the balance attained was right.

The Motorway was opened on the 26th January 2009. It was completed three months ahead of schedule and under budget.

Acknowledgements

Taking a major infrastructure project to a successful conclusion is a team effort involving many designers and constructors. I wish to thank everyone at Northern Gateway Alliance, their sub-consultants and sub-contractors who contributed to this successful project. I would also like to thank NZTA for permission to publish.