THE MANY DESIGNS OF OTANERUA ECO-VIADUCT

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INTRODUCTION

The Otanerua Eco-Viaduct is an integral component of the new State Highway 1 Northern Motorway Extension (ALPURT B2), connecting Auckland to the far north. The Viaduct is part of this last sector of the Albany to Puhoi highway.

The Otanerua Valley has an undeveloped catchment, vegetated with native bush, that provides for a diverse range of native flora and fauna. The 256m long Otanerua Viaduct crosses over the northern tributary of the Otanerua Stream, about 1.5km inland from the coast at Hatfield’s Beach. The primary purpose of the Viaduct is to maintain an ecological corridor between two areas of regionally significant bush that the new motorway would otherwise bisect.

This paper describes the background to the Viaduct, the various designs that have been undertaken for it, from concrete to steel and back to concrete again and the construction progress up to the time of writing.

Figure 1. Schematic map of the route for the Northern Motorway Extension

1 Structures Design Manager, Northern Gateway Alliance.
EVOLUTION

The first sectors of the ALPURT motorway were started in 1997 long before the details of the last sector, B2, were finalised. This was possible since the early stages of ALPURT offered benefits in their own right and were therefore able to be completed well ahead of the final Sector.

Sector B2 is by far the most challenging of the ALPURT route - challenging from a technical point of view and also environmentally, economically and socially.

Generally speaking, the technical challenges stem from the difficult topography of the area. The proposed motorway alignment runs north-south through a series of steep ridge-lines running east-west. The flat gradients required of a modern motorway have necessitated large cuts through the ridgelines and large fills or bridges in the valleys. The deepest cut on the project is approximately 50 m deep (at Chin Hill immediately north of Otanerua Viaduct) and the deepest fill is approximately 30 m deep. In all there are 3.2 million cubic metres of earthworks, 7 bridges and two tunnels on this 7.5km stretch of motorway.

The environmental challenges predominantly centre on an area of native bush-land known as RAP-21. (Regional Area for Protection number 21, as listed in the Department of Conservation Management Strategy), through which the motorway is required to pass. This is an area of Podocarp forest interspersed with Manuka gum-land. The acidic, nutrient deficient, podzolised soils are sensitive to disturbance and are typical of North Auckland soils with mature Podocarp forests. In geotechnical terms the soils are weathered Waitamata Series sandstone/siltstone of the Pakiri formation.

RAP-21 provides native habitat to many rare species including the endangered semi-flightless fernbird, the North Island Robin, the green gecko, the forest gecko and at least 7 species of native fish present in the waterways of the Otanerua Stream. The motorway has the potential to bisect RAP-21 – splitting the ecological communities in two, making them less sustainable than the original whole.

The solution to this environmental issue culminated in August 1996, with the signing of a Heads of Agreement between Transit New Zealand, the Department of Conservation and the Auckland Conservation Board. The Agreement was to provide a Viaduct over the northern tributary of the Otanerua Stream to create an ecological corridor beneath the Viaduct that is suitable for the passage of aquatic, terrestrial and arboreal fauna. This was the genesis of the Otanerua Eco-Viaduct.

In March 1999 Transit New Zealand competitively tendered the professional services contract for the design of ALPURT Sector B2. In June of that year the contract was awarded and a detailed design of the motorway was undertaken. The appointed consultants undertook the design within the limits of their brief and budgetary constraints at the time. Of these constraints the primary financial hurdle was to achieve a benefit-cost ratio greater than 4, which was only marginally achieved. As part of this professional services contract a Specimen Design was produced for the Otanerua Eco-Viaduct, this comprised twin incrementally launched prestressed concrete box girder bridges. The cross section of the box girders is shown in Figure 2 below. With spans of 45 m, this structural form and inherent method of construction offered minimal damage to the environment since access into the steep sided valley was needed only for construction of the piers. Construction of the superstructure did not require any further machine access to the valley floor since the superstructure was to be built behind the southern abutment and incrementally launched over the piers.

Figure 2. Specimen Design – Twin prestressed concrete box girders.
The large quantities of earth that required shifting to enable formation of the motorway required movement of significant quantities of material along the partly formed motorway route. It was recognised that, with the planned earthworks sequence, some 250,000 cubic metres of earth had to be transported across the Otanerua Valley. As a result the Otanerua Eco-Viaduct was needed early in the programme, to be part of the earthworks haulage route. It was therefore planned to release Otanerua Eco-Viaduct as a design-build, advanced work package.

Design-build tenders were called for the Viaduct in November 1999. The 45 m span incrementally launched concrete box girder option for the Viaduct was given as the Specimen Design (Figure 2). In May of 2000, three valid tenders were received, two similar to the Specimen Design, a post tensioned concrete box girder, and a third, the preferred tender, a 40 m span, steel girder bridge with a composite concrete deck. This bridge had a sub-structure very similar to the box girder option. The superstructure was envisaged to be constructed by the incremental launching method. The typical cross section is shown below.

![Figure 3. Preferred Tender Design – Steel-concrete composite girders.](image)

Despite being the preferred tender, the steel - concrete composite bridge never eventuated. As events transpired, Environment Court delays, land ownership issues and changed criteria for funding delayed the project. All tenders to build the Otanerua Eco-Viaduct lapsed - the whole project was delayed.

The project was resurrected again by Transit in November 2003 in response to the changing legislative environment resulting from the introduction of the Land Transport Management Act (LTMA) and pressure from the Environment Court to reduce traffic volumes at the current termination of the motorway on the outskirts of Orewa.

With the introduction of the LTMA in 2003, consideration of social, environmental and economic implications for all transport projects became a legal requirement. This necessitated a triple bottom line evaluation of every new transportation project undertaken and this provided particularly appropriate criteria for assessment of ALPURt Sector B2. ALPURt B2 was brought back to life again when Transit, through a competitive tendering process, awarded the design, construction and management of the project to the Northern Gateway Alliance.

**DESIGN**

The Northern Gateway Alliance established a vision for the project "To create a visual showcase of environmental and engineering excellence", this vision fitted well with the original thinking behind the Otanerua Eco-Viaduct.

The pursuit of engineering excellence for the motorway alignment required full compliance with State Highway Geometric Design Manual (draft) for a 100kph design speed. Compared to the original designs for the Viaduct, this required flatter gradients, larger radii curves and shoulder widening to provide safe stopping site distance around the curves. The combined effect of these refinements resulted in the Otanerua Viaduct becoming 256m long by 25m wide, an increase in deck area of 57% over the original designs. Figure 7 at the end of this paper shows the plan and longitudinal section of the revised design for the Viaduct.

Under the Alliance framework the project essentially started from scratch again, the only constraints being the existing Resource Consents and the Motorway Designation. Hence the choice of bridge type, span arrangement and construction methods and materials was open to all options. The optimum choice would be one that was economic, meets with the stated vision for engineering and environmental excellence and satisfies the sustainability requirements of the LTMA.

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2 Northern Gateway Alliance comprises Transit New Zealand, Leighton Contractors, Fulton Hogan, URS New Zealand, Tonkin & Taylor and Boffa Miskell.
Course screening of a long list of potential candidates for bridge type yielded two designs worthy of closer consideration, these were:

- Steel I-girder with composite concrete deck, refer Figure 4 and
- Precast super-tee beams with an insitu concrete deck, refer Figure 5.

Both bridge types had similar foundation systems, these comprised twin reinforced concrete cylindrical columns connected at their top with a pier head, creating a portal frame in the transverse direction. The columns are founded on single bored piles. This type of foundation offered the least long-term footprint on the landscape, thereby maximising the space available for the ecological corridor beneath the Viaduct.

The steel composite structure was designed with main spans of 46 m and end spans of 36 m. This span length is in the economical range for composite girders. Alternative span lengths were considered with trial designs but the one proposed was the most economical for the site. The superstructure construction method involved incrementally launching the superstructure from the southern abutment. It was planned to launch the superstructure in two halves - the northbound bridge followed by the southbound bridge, followed by a closing pour between the two decks. The four steel I girders were 2050 mm deep and had varying section properties, the pier section weighed 726 kg/m and the mid-span section weighted 675 kg/m.

The corrosion protection system was thermal sprayed zinc to 150 microns thickness. This coating system was considered to have a life to first maintenance of 40 years, which is arguably conservative but deemed prudent since microclimatic conditions under the bridge, caused by vegetation growth, would have a detrimental effect on the steel and coating durability.

The precast concrete super-tee option comprised eight spans of 32 m each. A cast insitu topping would form the deck of the bridge. Each precast, pretensioned, open top super-tee beam was 1500mm deep and was designed using a partially prestressed approach. The beams were reinforced with a combination of prestressed and mild steel reinforcement. The inclusion of mild steel reinforcement was primarily to control camber growth. Each of the 10 beams in the cross section weights approximately 55 tonnes. Erection of beams was by the beam launching method using an overhead truss. This minimises the effects on the vegetation in the valley in a similar way to incremental launching. The beam launching technique means that one span of the bridge needs to be constructed before the next spans beams can be placed, this suited simply supported spans. Each end of the simply supported beam is seated on an elastomeric bearing. The cast insitu deck slab is continuous over the piers. This minimizes the number of deck joints, reducing maintenance and improving ride comfort. An interesting feature of the precast concrete design was the single expansion joint at mid-length of the Viaduct with each half of the Viaduct anchored back to a deadman behind each abutment. This system proved to be more economical than the more conventional system of an expansion joint at each abutment because, without the joint at midspan, the short piers near the abutments attracted large strains from creep and shrinkage shortening effects on the superstructure.
Both preliminary designs for the steel composite bridge and the precast concrete bridge were developed to an advanced stage of detailed design. The advanced design was needed because there was no clear difference in estimated price between the two options. The estimated cost of the precast concrete bridge was $9.15 million. This is the 2005 cost excluding preliminary and general items and goods and services tax. The estimated cost of the steel girder option was 2% more.

At the time of estimating (late 2004), the recent cost of international steel had been rising sharply, more so than the unit price of concrete, as shown in Figure 6 below. But when these relative costs are compared to those that would have been current at the time of the first design-build tender (early 2000) the situation is surprisingly reversed. That is, over the last 5 years concrete has been losing its competitive advantage to imported steel. This is primarily because the exchange rate and relatively high value of the New Zealand Dollar has offset price increases for international steel plate.

**Figure 6. Relative cost of concrete and steel normalised to year 2000 cost.**

Replacement of the corrosion protection system is a significant cost that would be incurred some 40 years in the future with the steel option, but when this cost was discounted to a net present value, the value was small and not a significant differentiator.

It was clear that little distinction between the two structural systems could be made on economic grounds.

As discussed earlier, since 2003, the LTMA requires more than just consideration of economics of the structural types, less tangible effects such as environmental and social sustainability also need to be considered. A number of different aspects of sustainability were considered prior to making a decision.

The underside appearance of the steel option was considered inferior to the precast concrete option. This was a relatively minor issue considering the opportunities to view the Viaduct from underneath are limited.

The full life cycle of the materials used in construction is a consideration. The ability to economically recycle steel favoured the steel option. However, it is also possible to recycle concrete, though with current technology this is seldom economically viable. The economics did not influence the decision since the cost of recycling, 100 years from now, when discounted to present day values is incredibly small.

Local supply versus international supply was a significant sustainability consideration. Steel plate for the steel bridge would have to be imported since the size of plate required is not readily manufactured in New Zealand. It was also probable that the beams would have been fabricated overseas and imported as fully fabricated elements. This required a longer lead time and generated potential programme issues. This was compared to the concrete option where the components are made locally, from locally manufactured cement, aggregate and reinforcing steel. This was a clear sustainability and programme advantage for the concrete option.

**CONCLUSION**

Otanerua Eco-Viaduct has been through six serious redesigns over the past 5 years starting in 1999 as a post-tensioned concrete box girder, prepared as the Specimen Design for a design-build tender. That tender process yielded three viable designs, the preferred option being a steel-concrete composite bridge. However project delays meant this tender was not accepted and this option was not constructed. When the project was restarted in 2004 with the Northern Gateway Alliance, all options for the Viaduct were reinvestigated. The merits of a redesigned steel-concrete composite bridge were weighed against a precast concrete supertee bridge. The precast option was the preferred option though the decision was marginal.

At the time of writing this paper (July 05) the preferred option has been fully developed and is currently under construction.

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3 Concrete price sourced from Rawlinson’s Construction Estimating Handbook. Steel price sourced from Steel Business Briefing website adjusted for $NZ/$US exchange rate.
It is interesting to question what are the factors that led to the preferred design material for the bridge superstructure being concrete rather than steel?

These factors are;

- The span length has been brought back to an economical range for precast concrete beams
- The precast concrete option met the sustainability criteria better than the steel option. In particular, the aesthetics were considered superior and the beams and concrete were locally sourced.
- The steel option presented potential programme delays.

The cost of both options was estimated to be essentially the same.

In the Author’s opinion, aspects that are currently eroding concrete’s historically competitive advantage in the bridge industry are;

- The high value of the New Zealand dollar makes importation of steel financially attractive.
- The steel industry has an active engineering support and lobby group promoting the wider use of steel.

Figure 7 – Plan and Longsection of Otanerua Eco-Viaduct