Composite Steel-Concrete Bridge Solutions for the East Taupo Arterial

Dr Rob Presland, Project Director, Holmes Consulting Group
Michael Chan, Design Engineer, Holmes Consulting Group
Richard Jackson, Design Engineer, Sinclair Knight Merz
Raed El Sarraf, Structural Engineer, Heavy Engineering Research Association

Synopsis
Steel-concrete composite bridge structure solutions have not been widely used on typical large bridging projects in New Zealand. Commonly held mis-conceptions around the costs and maintenance requirements of these forms of bridge structure have overshadowed the advantages this form of construction can bring to a project. This paper describes these mis-conceptions and outlines two major bridge structures using steel-concrete composite construction on the East Taupo Arterial project.

Introduction
The East Taupo Arterial (ETA) project is a new rural roading project currently under construction just outside Taupo in the central North Island. The project consists of approximately 16 km of new road alignment forming a new highway bypass around the town of Taupo. The project includes five new intersections including two grade separated intersections, major new bridge structures crossing the Waikato River and the Contact Energy geothermal power plant and numerous crossing structures for associated geothermal steam pipes. Parts of the route are also constructed over geothermally active ground.

This paper looks at the steel-concrete composite bridge structure solutions adopted for the two major bridge structures on the ETA project and the reasons for adopting these bridge structure forms. Commonly held perceptions regarding steel bridge structures are highlighted and the measures taken to address these perceptions in regard to the ETA project are provided.

Perceptions of Steel Bridging Solutions
Most bridges in New Zealand, particularly short span applications in the order of 30 m length, are constructed in concrete, typically precast concrete beams and reinforced concrete decks. The principal reasons given for this are that concrete is generally considered to be more cost effective in the short span range, especially with the use of precast beam or deck units (Super T or double hollowcore beams), compared to steel and it is generally considered that the construction programme for concrete bridges is just as fast with the use of precast beams and that steel supply and fabrication programming issues are seen as a reason not to adopt steel structures.

Many of New Zealand's major bridge contractors also possess in-house precasting capability as part of their basic operations, none having large scale steel fabrication capabilities. With in-house precasting capabilities contractors can exert greater control over materials and programming than they can with steel fabrication.

Another major perception is that concrete is considered “maintenance free” and that once constructed, the bridge provide a 100 year design life with negligible
maintenance of the structural elements. The reality is that concrete bridges still require regular inspections and maintenance work over their design life. Ongoing reinforcing bar corrosion requiring remedial repairs, cracking and spalling of concrete and structures experiencing alkali-silica (ASR) reactions are examples of the types of maintenance concrete bridges may require during their design life.

Structural steel beams require a protective coating system for durability and ongoing maintenance of the coating system is considered to be costly and inconvenient in comparison with concrete structures. Historically, the difficulty of assessing site specific corrosivity, and the short times to first maintenance for available coating systems in severe environments, has led to structural steel bridging being viewed as inherently less durable and more costly to maintain than concrete bridges. Up until early 2008, new steel bridges proposed on the State Highway system were faced with a financial penalty, based on that perception, which lead to structural steel options being considered as uncompetitive, particularly in a competitive design-build situation.

The availability of better guidance on assessing site specific corrosivity and the advances in coating systems for severe environments has addressed these perceived disadvantages and the durability performance of a well designed and competently coated steel bridge can now be determined with the same certainty as a well designed and constructed concrete bridge.

**Addressing the Perceptions**

The perceptions of structural steel for short to medium span applications noted above have been addressed [1] and recent successful applications of steel-composite structures have shown that these are competitive against concrete bridges [2,3].

Key to the competitive aspects of steel-composite bridge structures is the consideration of the steel bridge structure solution as a whole rather than just as an alternative superstructure element. Consideration of superstructure type and options for the construction of the concrete deck have a significant influence on the costs associated with these bridges [1]. The lighter nature of steel-composite superstructures offers the advantage of being able to rationalise the substructure, often leading to smaller foundations and associated cost savings.

Construction equipment and resources, particularly the size of craneage required to erect steel girders will be smaller than required for erecting corresponding concrete girders. The high strength to weight ratio of steel girders also allows span lengths to be increased offering the potential to reduce the extent of the foundations required, particularly for multi-span structures.

Careful attention to the design and sizing of main structural steel members offers the potential to optimise section and plate sizes to match the availability of common plate widths and thicknesses and reducing off-cut wastage. Development of fabrication details with input from the steelwork fabricator offers the advantage of being able to adapt the design detailing to provide easy to fabricate details and use less material/labour intensive fabrication details, for example weld preparation and welding details.

Work done by the Heavy Engineering Research Association of New Zealand (HERA) to develop and publish the New Zealand Steelwork Corrosion Coatings Guide (HERA Report R4-133) [4] now provides structural engineers with good guidance for
assessing site specific corrosivity and selection of suitable corrosion coatings systems. This guide, used in conjunction with the joint standard AS/NZS 2312 [5], provides designers with guidance to determine the corrosion rate and specify a cost effective corrosion coatings system and specify it in a generic manner. Important factors to consider in regards to a coatings performance and guidance on inspecting, maintenance and re-coating of systems is also given.

Associated with the use of the Coatings Guide is the use of life cycle costing assessments for different coatings systems [6]. Initial capital costs, required time to first maintenance, touch-up repairs, inspection and access costs and re-coating costs are considered. The net present value for a coatings system can be calculated and compared between systems over the design life of the structure to determine the maintenance costs throughout the design life of the structure.

Durability statements for structural steelwork are available from HERA and are valuable particularly for new designs. These statements cover the determination of site specific corrosivity category, recommended coatings systems, life cycle costings of the systems and guidance on general site and maintenance requirements.

The East Taupo Arterial Project

The current State Highway 1 route takes traffic from the SH1/SH5 intersection at Wairakei, through the central business area of Taupo and along the lake foreshore to Taupo Airport. The proposed route of the ETA will form a bypass around the town taking through traffic, which comprises a considerable number of heavy vehicles, away from the lake foreshore and central business area. The project is being constructed for the Taupo District Council, as a local road bypass. Upon completion the road will be designated State Highway 1 and become the responsibility of the New Zealand Transport Agency.

The proposed ETA alignment takes traffic from the SH1/SH5 intersection southbound over the Contact Energy Wairakei geothermal power plant site, crossing the Waikato River and then passing to the east of the Taupo urban area (refer Figure 1). The route is linked to local roads via grade separated interchanges at Centennial Drive and Broadlands Road, roundabout intersections at SH 5 and Lake Terrace near the Taupo Airport, forming the southern end of the project.

The road alignment passes through areas of active geothermal ground and several scenic reserves which places limitations on permitted excavations for the new route through these areas.

Major bridge structures required for this project include the Contact Energy Bridge, the Waikato River Bridge and interchange bridges at Centennial Drive and Broadlands Road. This paper will discuss the bridge structure solutions developed for the Contact Energy Bridge and the Waikato River Bridge crossing. The interchange bridges at Centennial Drive and Broadlands Road are single span precast Super T and double hollowcore bridge decks respectively and are not considered further in this paper.

The ETA project has been procured through a design-build tender process for the Taupo District Council. Fulton Hogan Ltd were successful in their design-build tender bid with lead consultants Sinclair Knight Merz (SKM) undertaking roading, geotechnical and drainage design. Holmes Consulting Group (HCG), as sub-consultants, are responsible for the design of the Waikato River and Broadlands
Figure 1 East Taupo Arterial route
Road Bridges, with SKM undertaking design of the Contact Energy Bridge, Centennial Drive Bridge and the steam pipe crossing structures.

**ETA Tender Design Development**

A key philosophy adopted in the development of the overall ETA tender design scheme was to reduce materials required in construction of the project, from earthworks to structures. The philosophy was aimed at reducing environmental impacts of the project construction as well as a means to focus on developing a cost effective design solution. Multiple road alignment options were investigated to minimise earthworks volumes involving consideration of multiple vertical and horizontal alignment options and interchange arrangements. Bridge structure solutions investigated included alternative structure arrangements to minimise materials required in construction and reduce the resources required to construct them. Key to the development of the bridge structure options was the decision to adopt structural steel-composite solutions for the two major bridge structures on the project.

**Contact Energy Bridge**

The specimen design solution for the structures over the Contact Energy site, south of the SH1/SH5 roundabout included five separate structures linked with a series of short embankments. The form of structures included various forms of concrete solutions including Super T’s, double hollowcore beams and flat slabs. The footprint over the Contact Energy site, in particular from the high embankments, had impacts on the programming of works having to coincide with scheduled plant shutdown periods to allow steam pipes to be relocated.

Construction of the embankments in and around the geothermal power plant infrastructure would have created potential issues with access and working room for the heavy machinery required. The use of Super T beam units for the bridge superstructures would require sizeable craneage to lift these elements into position, creating safety issues when lifting heavy elements over and around the steam pipes. Bored or driven pile options, offered in the specimen design, would have posed issues for sensitive Contact Energy generating plant within the site with the creation of dust and vibration during the construction phase.

The tender designs looked at combining structures into longer bridges in order to eliminate the short embankments called for in the specimen design and the associated earthworks in and around the power plant. Eliminating the earth embankments would reduce the impact of the proposed ETA project on Contact Energy infrastructure within the power plant site and issues for equipment working in a tight site. This encouraged further investigation into utilising a single bridge option across the full Contact Energy site.

Development of the tender design considered the use of concrete bridge structure solutions but quickly identified the advantages that steel-composite construction would offer. A single steel-composite ladder bridge structure was investigated to span the entire Contact Energy site, commencing from the northern side of the Contact Energy Access Road terminating south of the access road to the Prawn Farm (refer Figure 2). The choice of a single elevated structure and the road alignment through the area allowed the embankment construction beyond the bridge to avoid an existing, operational, steam pipe. This meant that construction could...
Figure 2  Contact Energy Bridge General Arrangement
proceed independent of the plant shut down periods allowing construction to be completed a year ahead of schedule. This aspect alone provided a significant advantage to the tender proposal for this project.

The Contact Energy Bridge is 444 m long using continuous spans between 28 to 36 metres long, with piers arranged to fit between steam pipes and other services across the Contact Energy site. Expansion joints are provided at each abutment and approximately halfway along the bridge.

A ladder bridge comprises two deep steel girders located on either side of the bridge with a series of smaller transoms at closer centres spanning between them, forming the “rungs” of the ladder [7]. A concrete deck slab spans between the transoms, composite with the transoms and main longitudinal girders (refer Figure 3).

The steel-composite structure provides a comparatively lightweight superstructure compared to a similar structure constructed from concrete beams. In using a steel-composite bridge it also made it possible to provide longer spans over the various steam pipe crossings and the Wairakei Stream, compared to that achievable by the most commonly available Super T beam.

As the bridge utilises lighter structural elements, this reduces the size of cranes required to erect the superstructure. Potential risks to Contact Energy steam pipes beneath the structure are reduced as lighter loads are involved and fewer elements

Figure 3  Contact Energy Bridge Cross Section
need to be lifted over the pipes. The decreased dead load prompted the investigation into pad foundations beneath each column location eliminating the need to construct bored or driven pile foundations across the site.

The use of pad foundations and elimination of the embankments also reduces excavation and the potential to create dust or vibration during construction and any potentially detrimental effects on Contact Energy generation plant.

Location of the bridge over a geothermal plant requires a high specification coating system to the structural steelwork. Structural steel bridge structures on a State Highway are required to have a coating system that will provide a time to first maintenance of 40 years. Using the HERA Coatings Guide [4] and AS/NZS 2312 [5] a thermal aluminium spray plus sealer coat system is required in this environment.

**Waikato River Bridge**

The structure proposed for the Waikato River Bridge is 148 m long, three spans with a 100 m central arch span (refer Figure 4). The central arch span is a network arch - a form of tied arch structure where the hangers supporting the lower tie are inclined and arranged such that the hangers cross one another at least twice [8]. The lower tie forms the deck supporting the roadway including a footpath.

The inclined hangers, with multiple intersections, distribute forces in such a way that bending moments and shear forces are distributed to the upper (arch) and lower (tie) chord, just like in a truss. This provides increased structural efficiency, bending and shear actions in the chords are significantly reduced compared to a traditional tied arch with vertical hangers, allowing smaller sections to be used.

This form of structure was developed in Norway during the 1950’s by Dr Per Tviet with the first network arch structure constructed at Steinkjer, Norway in 1963 [8]. Network arch bridges have not been adopted widely around the world since they were first developed – the potential advantages offered by this structural form apparently being overlooked in favour of a more traditional vertical hanger arrangement. This is being changed now with a number of network arches under design or construction over recent years across Europe, the United States and now in New Zealand.

The Waikato River Bridge, upon completion, will be only the second and the longest network arch bridge in New Zealand. The first network arch bridge in New Zealand [3], an 85 m span single lane road bridge, was completed shortly before the Waikato River Bridge design commenced.

The span length adopted for the Waikato River Bridge arch is governed by the positioning of the piers outside the waterway. Project resource consents require the piers to be located so that normal river water flow does not pass behind the piers, in response to iwi cultural considerations. The span length adopted also minimises environmental impacts by avoiding working within the waterway.

The network arch structure uses a fabricated steel box section top chord, concrete filled to provide additional flexural capacity. The design requirements for this bridge included design scenarios to consider the loss of hangers through fatigue or accident. These load combinations proved to govern the size of the arch members because of large bending moments developed in the arch top and bottom chords where the hangers had been removed. The bottom chord member is fabricated as a
Figure 4  Waikato River Bridge
steel box element and includes post-tensioning tendons to provide further flexural capacity. The post-tensioning tendons also ensure that the concrete deck slab remains in compression, minimising stress fluctuations in the deck due to live loading on the bridge. The roadway is supported via a ladder deck arrangement between the two bottom chords. The plate girder transom beams support a concrete deck slab consisting of precast concrete panels and an insitu topping. Medium tensile (Grade 460) solid bar elements make up the hangers to the bridge. The end spans are a ladder deck arrangement, similar in form to the Contact Energy Bridge.

The arch span is supported on single reinforced concrete columns directly beneath the arch springing points. The columns are supported in turn on single large diameter bored piles. The abutments are supported on shallow pad footings on the approach embankments.

The project required two steam pipes be located on the bridge crossing the river. The addition of two large diameter pipes had the potential to dominate the aesthetics of the bridge structure resulting in a decision to locate these at roadway level (refer Figure 5). This location also provides easier access to the pipes for inspection and maintenance, compared to locating these pipes beneath the bridge superstructure.

While the bridge structure is located in the vicinity of geothermal activity, little

![Figure 5 Waikato River Bridge Cross Section](image-url)
guidance was available as to how far this influence extended and what impact this would have on the coating system required for this bridge. Technical advice was sought by the design team from HERA and a durability statement prepared for the bridge. An assessment of the site determined the corrosivity at the bridge site to be less aggressive than originally thought. The durability statement identified several coating systems that would achieve the 40 year time to first maintenance including a single coat inorganic zinc silicate paint system to be adopted on the bridge.

The network arch span provided a lightweight structural system – the central span utilises approximately 300 tonnes of structural steel (150 kg/m\(^2\) on deck area). Network arch bridges are suitable for road, rail and footbridge applications with road bridges up to 250 m span having been designed and constructed recently. The network arch arrangement greatly reduces live load deflections and arch chord bending moments compared to traditional tied arch bridges with vertical hangers [8].

The resulting savings in materials makes them very competitive and they provide a distinctive structural form that can form local landmark structures.

**Conclusions**

The use of steel-concrete composite bridge structures for the major bridges structures on the East Taupo Arterial project proved to be winning solutions. The cost effective and efficient bridge structure solutions utilised lighter structural elements, reducing the size of cranes required to erect the superstructure. Risks to Contact Energy steam pipes beneath the structure were reduced as lighter loads are involved.

The ladder deck bridge across the Contact Energy site provided the opportunity to utilise shallow foundations on this bridge, reducing materials involved in excavation and substructure construction. Dust and vibration during construction (and potential detrimental effects on the Contact Energy generating plant) are reduced through eliminating embankments and any pile construction. By avoiding existing steam pipes within the power plant site this eliminated any need to relocate them, shortening the construction period.

The network arch bridge over the Waikato River allowed the span length to be maximised, reducing the environmental impacts of working within a waterway. Avoiding piles in the waterway, addressing iwi cultural concerns around structures in the river, was viewed favourably as part of the tender assessment. This bridge also provides a distinctive structural form of bridge that will form a local landmark for the Taupo township.

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References


