REPLACEMENT OF AKATARAWA BRIDGES

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ABSTRACT

Upper Hutt City Council (UHCC) has replaced the existing Akatarawa Bridges B 1/4, B 1/5 and B 1/6 with new Bridges. The terrain and geology of the site presented a lot of challenges to the design and construction team. The difficult site access, limited site space, construction of sub-structures close to a water way and a tight construction program presented major challenges. These challenges are discussed in the paper and include both the design and construction aspects of the bridges.

INTRODUCTION

Project Background

The existing bridges, believed to have been constructed in the 1920's, posed route security and maintenance concerns to the bridge owners and road users due to their deteriorated condition. The bridges were single lane timber truss bridges, with a 10 km/h maximum speed limit for Bridge B 1/5, and 30 km/h maximum speed limit for Bridge B 1/4 and B 1/6.They required significant on-going maintenance and were located on Akatarawa Road which is the only road that directly links Upper Hutt and Waikanae on the Kapiti Coast.

The timber was severely deteriorated and required increasing maintenance to keep the bridges in operation. While a considerable amount of structural repair work had been undertaken on the bridges all three had reached the end of their economic life and needed to be replaced. Upper Hutt City Council (UHCC) decided to replace the Akatarawa Bridges B 1/4, B 1/5 and B 1/6 with new bridges to provide two traffic lanes and a suitable additional carriageway width to allow for occasional pedestrian and cycle use. Upper Hutt City Council engaged Beca to provide engineering design services for the Design and Construction Monitoring of the new bridges work and subsequently Brian Perry Civil Ltd for the Construction.

Location of the Bridges

The bridges are located in the upper Akatarawa Valley, an area predominantly characterised by rural land and native forest. Bridges B 1/4 and B 1/5 carry Akatarawa Road over the Akatarawa River, whilst Bridge B 1/6 carries Akatarawa Road over Bull Creek.

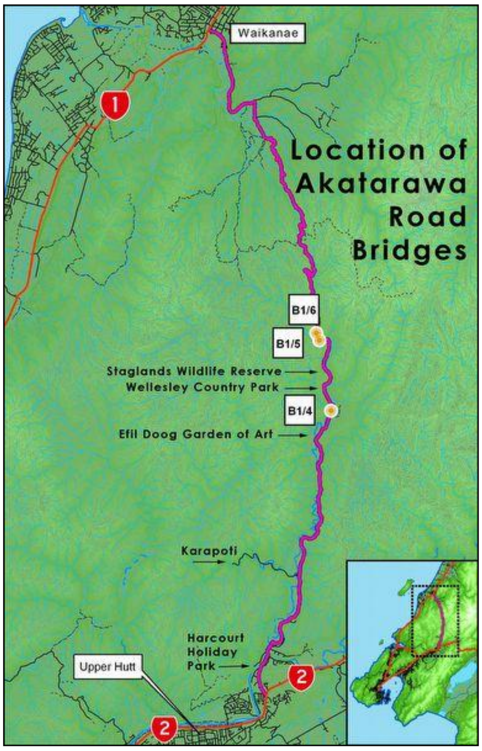

Figure 1: Location of Akatarawa Road Bridges

Bridge B 1/4 is approximately 13.3 km from State Highway 2 in Upper Hutt, Bridge B 1/5 is located approximately 3.4 km north of Bridge B 1/4 and Bridge B 1/6 is located 580 m north of Bridge B 1/5, as illustrated by Figure 1, above.

TECHNICAL DESCRIPTION OF BRIDGES

The decks of the new bridges consist of 25m simply supported single spans which carry a two-lane rural highway with shoulders. The overall bridge deck width is 9.25m and comprises of 2 x 3.2m traffic lanes, 1.25m and 0.6m shoulders and 2x 0.5m edge barriers. The superstructure comprises eight 900mm deep prestressed single hollowcore beam units. The bridge deck is skewed 15^0 for bridge B 1/5 to ensure that the bridge foundations are supported on sound rock. Bridges B 1/4 and B 1/6 are square spans.

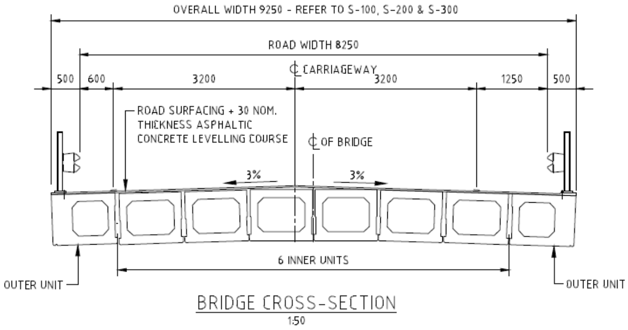

Figure 2: Typical Bridge Deck Cross Section

Flexible steel barriers are provided at the edges of the bridge decks. A barrier performance level 3 (TL3) was considered to be appropriate for these bridges, as it will provide appropriate containment of cars, heavy utilities and light to medium mass commercial vehicles in accordance with the Transit New Zealand Bridge Manual.

The bridge substructure consists of 1200mm thick (widening down to 1500mm thickness) cast-in-situ reinforced concrete abutment walls. The sub-structure is laterally restrained in the longitudinal direction by the bridge deck with a pin connection between the abutment and deck. The bridge structure is designed for a 1000 year seismic event in accordance with the Transit Bridge Manual.

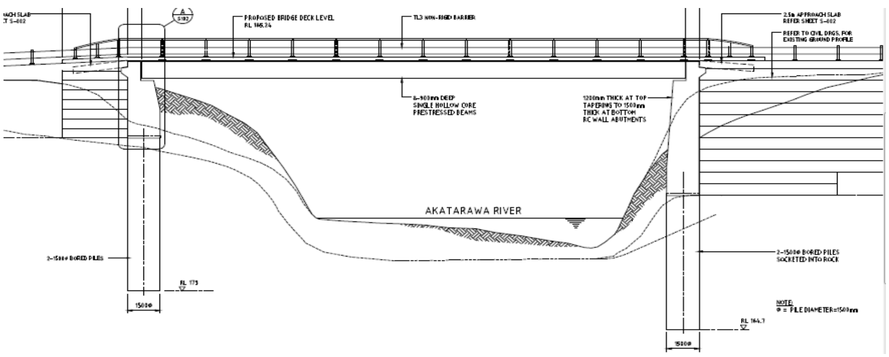

Figure 3: Typical Long Section of Bridge

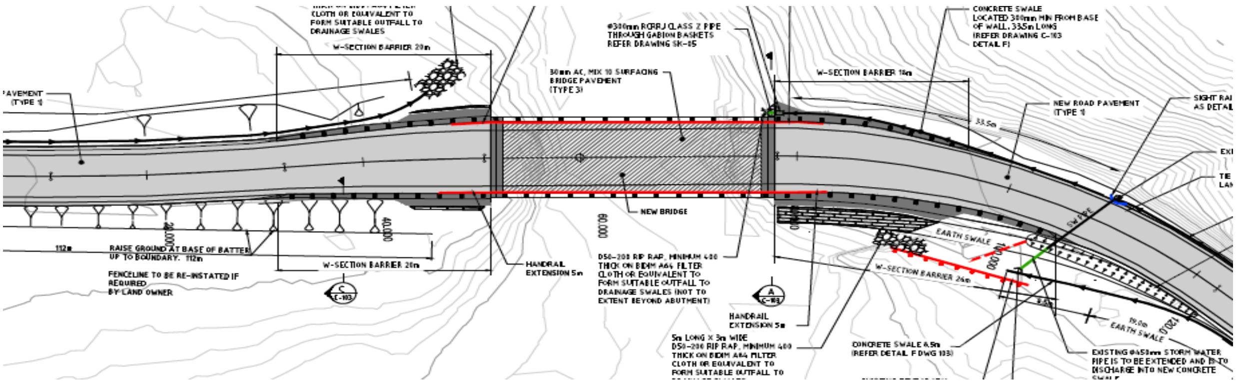

Figure 4: Typical Plan of Bridge

WHY WAS CONCRETE SELECTED FOR THE PROJECT?

Concrete is one of the most cost effective, durable and aesthetic construction materials and can provide advantages over other construction materials. The key driving factors in selecting an appropriate structural material for these bridges were:

- Durability, ease of maintenance and ongoing cost of maintenance in a remote location.
- Access to the site, limited site space and construction time
- The road conditions which limited the access of heavy vehicles to the site (the only access being from SH2 during construction via 14m of Akatarawa road which is narrow, windy and has some steep grades).

The durability, ease of maintenance and minimum ongoing cost of maintenance led to the selection of concrete for this project. The reinforced/prestressed concrete members with appropriate concrete covers as specified in the code could meet the required 100 year design life of the bridges.

The cast-in-situ concrete bored piles provided a suitable foundation solution in a soil profile of alluvium overlying in situ Greywacke rock, the level of which was highly variable. They are also very efficient in handling the unbalanced lateral forces due to differences in the abutment heights at both ends.

The standard pre-cast hollow core bridge beams provide a suitable and cost effective solution for these bridge decks. The standard 900mm deep pre-cast Single Hollow Core beams were successfully used on the job without any modification or amendments from the NZTA's Standard Pre-cast Bridge Beams (NZTA Research Report 364).

The cast-in-situ concrete abutments supported on cast-in-situ bored piles provide a robust solution for the lateral unbalanced loads. The piles and abutments also had the advantage that any variation in rock level or topography could be accommodated, which minimised design changes.

DESIGN CHALLENGES

Geology of the Area

The Akatarawa valley runs through steep sided Greywacke hills with a relatively flat lying valley floor of up to around 500m width.

According to the published geological map, the Akatarawa valley lies within basement Greywacke rock, the valley filled to an unknown depth by floodplain gravels. Site inspections of available outcrops surrounding the bridges generally confirmed the mapped geology.

The alignment of the Akatarawa River channel appears to be controlled by geological faulting. The valley runs in an N-S orientation for much of its length, deviating from this trend to a SW-NE orientation in places, parallel to the general structural trend and fault orientations in the area.

Several active faults pass through the Akatarawa Valley area. Bridge B 1/4 is located near the junction of the Akatarawa, Moonshine and Otaki Forks faults (refer Figure 5, Fault Location Plan), and bridges B 1/5 and B 1/6 are some 3km offset from the Otaki Forks fault. Due to constraints on the location of bridge B 1/4 the fault rupture zone could not be avoided. However, as the return period for movement on these active faults is significantly greater than the specified return period for the design (1000 year) seismic event, fault rupture did not govern foundation design.

<u>Bridge B 1/4</u>

Bridge B 1/4 is located at a bend in the Akatarawa River. There is a depth of alluvium overlying in-situ Greywacke rock on the south side of the bridge, and Greywacke rock partially overlain by alluvium/ colluvium on the slope outcropping on the north side of the bridge. The rock profiles at the south and north abutments varied, with the top of rock differing by around 4m. This resulted in an unequal height of abutments, and the foundations were subjected to unbalanced earth and seismic forces.

<u>Bridge B 1/5</u>

Bridge B1/5 is located at a bend in the Akatarawa River, and crosses a deep, steep sided gorge in Greywacke rock. The old existing bridge abutments were founded on in-situ Greywacke rock on both sides.

Again the rock profiles at the south and north abutments varied, the top of rock level differing by about 4m from one end of the bridge to the other. This resulted in an unequal height of the north and south abutments, and foundations subjected to unbalanced earth and seismic forces. Furthermore, the bridge deck for Bridge B 1/5 is skewed about 15º to ensure that the foundation is supported on sound rock.

<u>Bridge B 1/6</u>

Akatarawa Bridge B1/6 crosses a tributary of the Akatarawa River, known as Bull Stream. Bridge B1/6 is located at a bend in the stream, the south side of the bridge is founded on a steep Greywacke slope (on the outside bend) and the north side founded on an alluvial point bar on the inside of the bend.

The top of the rock at the north end of the bridge was below the river bed. This provided an additional challenge for the design and construction of MSE approach walls in this area.

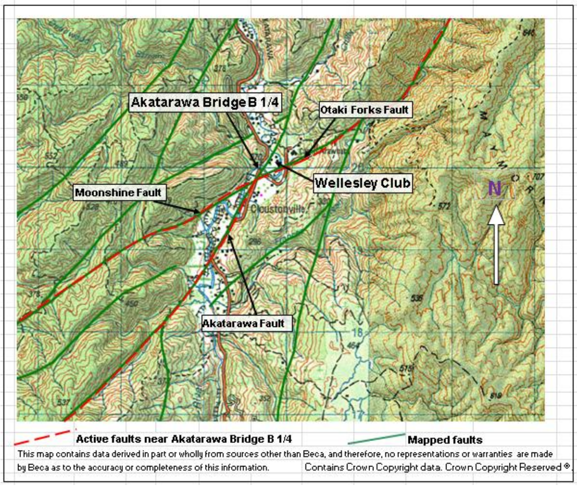

Figure 5: Fault Location Plan

Overall, the geology of the bridge sites presented significant challenges to the design and construction team due to the steeply inclined and variable bedding of the rock with a number of changes required during construction once rock levels had been confirmed.

Access to Local Residents during the Construction

There are a number of businesses, particularly tourism related, within the Akatarawa valley, including a café, blueberry farms, book binding, farming, a conference centre, equestrian, sawmilling, gardens, chicken farms, strawberries, logging, fish farm, art studio and Staglands Wildlife Reserve. Staglands is situated in the Akatarawa Valley, 16km from the SH2 junction. Staglands is a nature reserve in addition to being open to the public, and is also involved in the conservation of threatened native species and rare breeds of animals. One of the Principal's requirements for the project was to maintain the road open at Bridge B 1/4 to the public traffic during the construction period and minimise the delay to motorists, so the access to Staglands and local residents could be maintained at all times.

Figure 6: Bailey Bridge at B 1/4 Location

It was also required to provide access across to the river to pedestrians and cyclists at bridges B 1/5 and B 1/6 during the construction of these bridges, but road access was not required.

Hence, a temporary Bailey Bridge was provided at Bridge B 1/4 during construction, and temporary pedestrian Bridges were provided at Bridges B 1/5 and B 1/6. The Akatarawa Road was closed for a period of 23 weeks at bridge B 1/5 and B 1/6 while the bridges were constructed.

Figure 7: Temporary Pedestrian Bridges

Hydrology of the Area

Greater Wellington Regional Council (GWRC) Flood Protection Department required the bridges to be constructed above the 100 year Annual Probability of Exceedance (APE) flood level. There was no historic data available for 100 year flood events, so hydraulic modelling was needed to establish the 100 year APE flood level at the bridge locations. The bridge site was modelled using HEC-RAS software. The model for Bridge B 1/4 extended for a total of 810m; this being 510m downstream and 300m upstream of the existing bridge site.

Table 1: Peak water and discharge levels

Design Event	Peak Water Level (m RL)	Peak Discharge (m^3/s)
Onset of spill	-	150
50yr (present climate)	183.62	140
50yr (2090 climate)	183.87	137
100yr (present climate)	183.81	138
100yr (2090 climate)	184.08	131

Using design flows based on the Akatarawa flow gauge, and assuming the river was allowed to overflow across the south bank and the 100 year level of service was enforced, the bridge needed to be designed for a flood level of 184.08m RL, and the soffit level located above the 100 year APE flood level. It would also need to be designed to withstand debris loads that could be expected during a large flood event. This would give a minimum bridge soffit level of 184.08m with no freeboard provided.

Since Bridges B 1/5 and B 1/6 are very close to each other, a single hydraulic model covering both bridge sites was developed in HEC-RAS software. The model extended for a total of 1275m, including 280m of Bull Creek upstream of bridge B1/6 and 995m of the Akatarawa River. The downstream extent of the model is 415m downstream of Bridge B1/5. Bridge B1/5 crosses the Akatarawa River at a deep, narrow constriction. With an existing road level of 234.0mRL there is over 5m of freeboard to the 100 year APE flood level for all climate change scenarios, so the existing road level did not need to be raised. Because the catchments are forested there is a likelihood of debris being washed down during large flood events. Referring to the Transit Bridge Manual a freeboard allowance of 1.20m should be provided.

This freeboard is easily exceeded at Bridge B1/5 but required Bridge B1/6 to be raised by up to 2.10m, depending on the depth of the existing bridge structure.

Rather than designing Bridge B1/6 with freeboard it was considered more appropriate to keep the new bridge soffit just above the 100 years APE flood level and design the structure to withstand debris loads, and allow overflow around the bridge on the true right bank. This overflow is expected to occur when water levels exceed 235.0m, which corresponds approximately to the existing bridge deck level.

Seismic Design Philosophy

Seismic loads have been derived in accordance with the Transit Bridge Manual and AS/NZS1170.5:2008 Structural Design Actions. The longitudinal and transverse earthquake loads have been applied parallel with and perpendicular to (respectively) the centreline of the bridge. Analysis was carried out using the Equivalent Static Force Analysis approach of the Bridge Manual.

The seismic weight includes the superstructure, surfacing, barriers and half the weight of the abutment wall. The pile vertical reactions are calculated by conservatively assuming the design vertical load, V', is equal to 0.8 or 1.3 times the dead load reaction at the abutments. This requirement comes from Table 3.2 of the Transit Bridge Manual where a 0.8 or 1.3 factor accounts for vertical acceleration.

<u>Transverse Seismic Design</u>

Lateral restraint under transverse seismic loading is provided by the cast-in-situ bored piles and the sliding resistance of the abutments is ignored.

The inertia load of the superstructure is transferred to the abutments via galvanised linkage bars between the joints of the precast Single Hollow Core beams and the shear blocks on each side of the deck. The bridge foundation piles are designed to resist the design transverse earthquake.

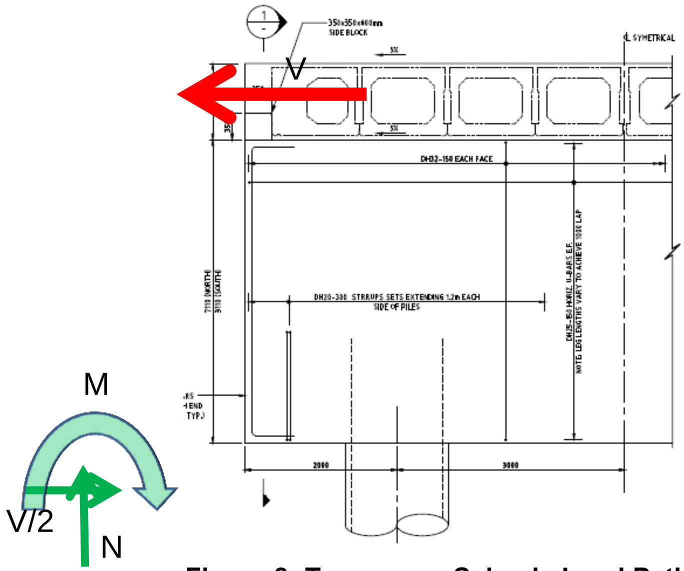

Figure 8: Transverse Seismic Load Path

Therefore, in the transverse direction, the structure becomes as a frame structure and the structure is designed in accordance with Transit Bridge Manual, with seismic loads derived to suit the period. A ductility factor of 1.25 (nominally elastic) has been adopted as appropriate for the transverse seismic loading in accordance with the recommendations in the Transit New Zealand Bridge Manual.

As with the bridge abutments, the approach roads are be protected by MSE embankments extending to rock level, so no further erosion protection is required for the approach roads.

<u>Longitudinal Seismic Demands and Restraint</u>

In the longitudinal direction, the bridge deck is connected to the abutment walls through linkage bars and will be locked into the abutment wall against the lateral earth pressure due to the approach backfill at the back of the abutment walls. This detail makes the abutment semi-integral. A ‘locked-in’ approach was then adopted for the design in accordance with the Bridge Manual. Longitudinal seismic loads are resisted by passive soil resistance behind the abutments ($\square_{pp}P_p$) plus pile lateral resistance. A ductility factor of 1.0 is adopted and the structure is designed as elastic.

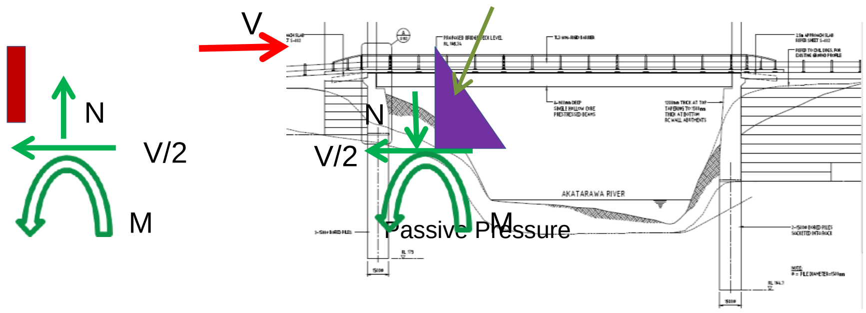

Figure 9: Longitudinal Seismic Load Path

Vibration

There is limited pedestrian traffic on these bridges, therefore the bridge only needs to comply with the vibration criteria of the Transit Bridge Manual where economically justifiable. However a check of the vertical velocity of the bridge with the highest span/depth ratio was carried out and the results compared to the limit set in the Transit Bridge Manual of 0.055m/s. The “Highway Bridge Design Brief 1978” was used to calculate the bridge vertical velocity with vertical displacement under HN axles and bridge frequency as inputs.

Protection of the Local Environment & Habitat

The bridges are located in an area predominantly characterised by rural land and native forest. Greater Wellington Regional Council has identified this section of the Akatarawa River as a water body with important trout habitat. Therefore, Greater Wellington Regional Council required that additional care be taken in the works around the River during the times of spawning between 31 May to 31 August. No works were allowed to take place within the active river channel during this period.

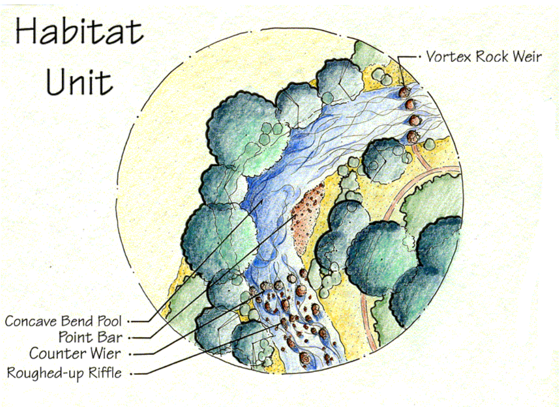

Figure 10: Habitat Unit

Figure 11: Trout Habitat

In the design, reinforced earth embankments, with green Terramesh were adopted for the approach widening behind the abutments, where the faces of the embankment can be planted with grass, to reduced the visual impact on the surroundings.

Figure 12: Green Terramesh Embankments

CONSTRUCTION CHALLENGES

Soft Crushed Sand Layer Encountered during Piling

Proof drilling was carried out at each pile location to a depth of five times the pile diameter below the anticipated pile toe level, to establish the level of competent rock and to confirm the final pile toe level.

For Bridge B 1/4 north abutment piles the top of the competent rock level was confirmed at 177m and the pile toe level was established at 164.7m by proof bore drilling. The north east pile was drilled through the competent rock to a 175.5m and a temporary steel casing was installed. The drilling of the pile was continued through the competent rock from 175.5m to 173m where an unexpected layer of crushed sandy material was found, which collapsed in the hole. The layer appeared to be about 1.2m thick. The drilling was stopped and a number of options were discussed. One option was to stabilise the sand layer by drilling the pile using a support fluid. During a review of the proposed pile construction technique, it was noted that hydraulic connection between the river and the pile posed unacceptable risks to the environment. This resulted in the method being discarded.

An alternate approach was adopted to overcome the issue, in which the construction team tried to create a bell within this crushed sand layer and then fill the hole with low strength concrete. Once the concrete set drilling of the pile was carried out through the concrete and the drilling of the pile continued into the rock to 164.7m. The pile was then cast using the tremie technique.

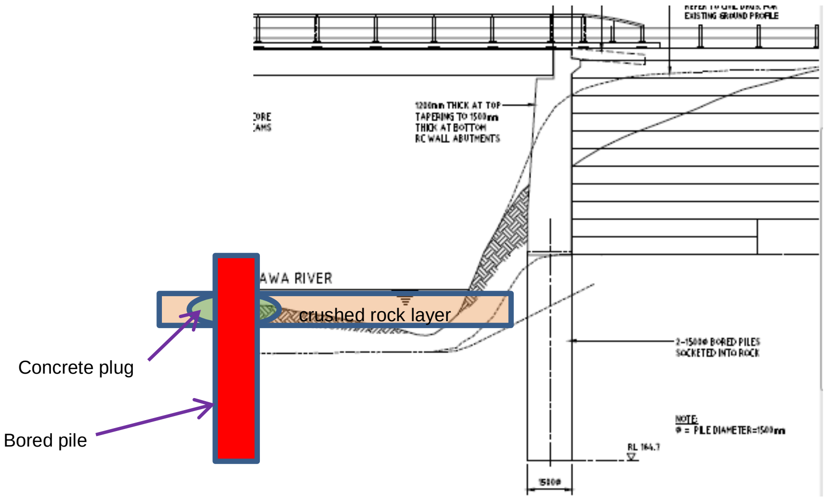

Figure 13: Drilling pile through a soft crushed layer within the rock

Cold Weather Concreting

The concrete specifications restrict the free water content to a maximum of 170 kg/m3 for pump concrete. The concrete mix design adopted to meet this requirement contained fly ash, which slowed down the setting of concrete and reduced the heat of hydration. During the 2011 winter, when there was snow in Wellington, there were concerns of frost when pouring the concrete as Akatarawa valley is generally about 5 degrees colder compared to the Hutt Valley. After consultation with the designer and concrete suppler the following methodology was adopted:

- The mix design was revised and the free water content limit relaxed to 190 kg/m3 and super plasticiser Adva 142 super was added to the mix design:
- Concrete was placed in accordance with the requirements of NZS 3019 “Cold weather Concreting”:

- The Contractor monitored the placement of concrete to ensure that no segregation occurred during the placement of the concrete:
- After stripping the formwork the contractor inspected the abutment for signs of honeycombing, segregation and other defects:
- Concrete cubes were cast in accordance with NZS 3112 at the site just before the pour and sent for testing in accordance with NZS 3112 to confirm that the concrete met the specified design strength.

Large Concrete Pours

The project included a number of large concrete pours. The first large concrete pour was for the Bridge B 1/4 north abutment. The seven metre deep abutment required 90 cubic metres (20 truckloads) of concrete and was poured in a single continuous pour. The pour began at 3:30am in the morning and was finished at 5:00pm.

Figure 14: Bridge B 1/4 North Abutment

The next large concrete pour was for the north abutment of bridge B 1/5. The nine metre abutment including the reinforced concrete wing walls was the biggest concrete element of the project and required two concrete pours. The first concrete pour was for the lower eight metres of the abutment and was the single biggest concrete pour of the project. The limiting factor was the ability of the formwork to contain the pressure resulting from the eight metres of wet concrete. Once again the concrete supplier and construction team met the challenge. The pour began at 4am in the morning and required 160 cubic metres (32 truckloads) of concrete.

Figure 15: Bridge B 1/5 South Abutment

Temporary Propping of the Abutments

Due to the topography of the site the abutments were of different heights and back filling of the abutments was not allowed until the abutments were propped by the bridge deck. However, the installation of the bridge deck was not possible until backfill was in place to form a platform for the crane. Therefore, for Bridge B 1/4 and Bridge B 1/5 temporary steel props were installed at the top of the abutments. The backfill was carried out simultaneously from both sides in such a way that the difference in the backfilled was never more than 1m. The temporary props were removed after installing a number of the bridge beams.

Figure 16: Temporary Props

For Bridge B 1/6 the construction sequence was revised to catch up delays and the north MSE wall was modified to be a self-supporting wall with a physical gap between the MSE wall and the abutment. The MSE wall was built-up to form the platform for the crane and the bridge beams were launched from the north end. The physical gap was filled with drainage metal as the back-filling on the back of south abutment progressed and corners were sealed with the concrete.

Figure 17: Bridge B 1/6 Revised Methodology

Transportation of Bridge Beams

The alignment conditions on Akatarawa Road imposed challenges in the transportation of large span pre-cast beams. The transport company identified a number of sharp horizontal bends along the road which required some trimming to transport the 25m long pre-cast beams. The pre-cast beams were cast in Otaki and delivered to Upper Hutt during the night. A time slot between 10am to 1pm was reserved for the delivery of the beams from Upper Hutt to the bridge location, as at this time the Akatarawa road is less busy. The local residents were notified of this.

Figure 18: Beam Transportation

Delivery of the new bridge beams, 25 meters long and weighing 43 tonnes each, was a logistical challenge for the drivers. On tight corners, a second driver was needed to steer the rear axle of the truck independently. The combination of bad weather and the need for the drivers to determine the best method to negotiate each corner meant that the first trip from the Akatarawa Cemetery up to the bridge site took 3 hours and 20 minutes, whereas subsequent deliveries took one and half hours.

USER'S SATISFACTION

Upper Hutt City Council

The bridges have proved to be a success both in their design and operation. The client, Upper Hutt City Council, is satisfied with the final outcomes of the project and is proud of its new assets. In the following text we include the statements from Mayor Wayne Guppy and Roading Manager, Horace Parker of Upper Hutt City Council.

Upper Hutt Leader reported on 19 October 2011: *Mayor Wayne Guppy said the completion of the 34-week project was significant. "It will be great to again link directly with our Waikanae neighbours," he says*.

A statement from Horace Parker, Roading Manager - Asset Management and Operations of Upper Hutt City Council: *"Council was pleased when this project was completed. It has provided three quality bridges that form an integral part of the City's network and also provides a good level of service along a section of Akatarawa Road that will accommodate for future development of this essential access route between the Kapiti Coast and Upper Hutt City. The project would not have been possible without the funding subsidy from NZTA and the co-operation and hard work of Council staff, Beca Consultants and Brian Perry Civil."*

Local Business

Upper Hutt Leader reported on 19 October 2011: *The owners of the Staglands Wildlife Reserve are looking forward to again linking to the north. "The bridges will improve our visitors' journey to Staglands," John Simister says. "I'm delighted that the road is re-opening in time for Labour Weekend."*

CONCLUSION

The new bridges provide two traffic lanes and a suitable additional carriageway width to allow for occasional pedestrian and cycle use. The new bridges are designed as single span bridges with mechanically stabilised earth retaining systems for the approaches. The new bridge structures are designed for a 1000 year seismic event in accordance with the Transit New Zealand Bridge Manual, but the approaches are designed to move under this event and will need to be repaired.

The bridges were designed for the waterways to pass a100 years APE flood event. The deck for bridge B 1/5 is at the existing road level, as there will be about 5m freeboard below the bridge. The bridge decks for Bridges B 1/4 and B 1/6 have been raised about 1m to allow the soffit of the bridge to be above the 100 year APE flood level.

Concrete was adopted as the most cost effective, durable and aesthetic construction material for the project. The variation in the soil profile of the bridge sites presented significant challenges for the design and construction of foundations and sub-structures. The adopted cast-in-situ concrete bored piles provided a suitable foundation solution in a soil profile of alluvium overlying in-situ Greywacke rock. The cast-in-situ concrete abutments supported on cast-in-situ bored piles provide a robust solution for the lateral unbalanced loads. The standard 900mm deep pre-cast Single Hollow Core bridge beams were successfully used on the job without any modification or amendments from the NZTA's Standard Pre-cast Bridge Beams (NZTA Research Report 364).

The impact of construction on the local business and residents were minimised by providing a temporary Bailey Bridge at B 1/4 and temporary pedestrian Bridges at B 1/5 and B 1/6 during the construction. The Akatarawa Road was closed for 23 weeks at Bridge B 1/5 and Bridge B 1/6 during their construction.

The local environment was protected by controlling all construction activities within the road reserve. No work was allowed within the active water channel of the river and the visual impact of the bridge was minimised by using green Terramesh reinforced earth embankments.

The construction team successfully handled the challenges of cold weather concreting, large concrete pours, delivery of construction plant and pre-cast beams to the site and changed the construction sequences to catch-up delays to the programme.

ACKNOWLEDGMENT

The authors wish to acknowledge the foresight of Upper Hutt City Council in promoting these bridges to be built, New Zealand Transport Authority for their funding contribution, local business and residents for their kind co-operation and the skills of the design and construction teams which enabled these bridges to be brought to reality.