

RAISING THE “TANGIWAI” BRIDGE

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INTRODUCTION

The existing bridge carrying SH49 traffic over the Whangaehu River at Tangiwai was recently raised by 2m to allow freeboard for anticipated lahar flows down the river valley.

Raising the bridge involved several issues of interest, ranging from the concept to detail to construction.

BACKGROUND

Tangiwai is well-named. The name itself means “weeping waters” [1], which according to AW Reed reflects the death of a Maori chief many years ago when caught by sudden floods.

More recently Tangiwai was the site of one of New Zealand’s worst disasters on Christmas Eve 1953, when a lahar took out the rail bridge crossing the Whangaehu River shortly before the Auckland – Wellington express arrived. 151 of the 286 people on board lost their lives. The Ministry of Culture and Heritage website <http://www.nzhistory.net.nz> [2] includes the two images shown on this page, but also gives a broader appreciation of the significance both of the physical damage sustained and the impact the event had both within New Zealand and internationally.



Photos following 1953 Railway disaster

The road and rail bridges built since 1953 have allowed increased freeboard, which has proven adequate for subsequent lahar flows. However the latest round of Ruapehu eruptions during 1995 and 1996 changed the characteristics of the catchment. In particular they deposited a tephra dam some 7.5m high over the historic outlet in the rock rim of the crater lake.

The unconsolidated airfall materials which make up the tephra are not robust, but they are sufficiently strong to increase crater lake level beyond levels which have launched recent lahars. The tephra dam also provides an additional and immediate source of flow solids when the lake breaks through the new dam. In consequence significantly greater lahar flows are predicted (in the order of 2-3 times that of the 1953 event) for the next lahar. The date of this next lahar is contingent on weather patterns, but lake levels are being monitored with appropriate care.



Photo of Tephra dam – Crater Lake

Transit New Zealand has opted to raise the existing road bridge over the Whangaehu River to cater for the lahar discharge now anticipated, as one of the measures to minimise the risks posed by the lahar to vehicle traffic.

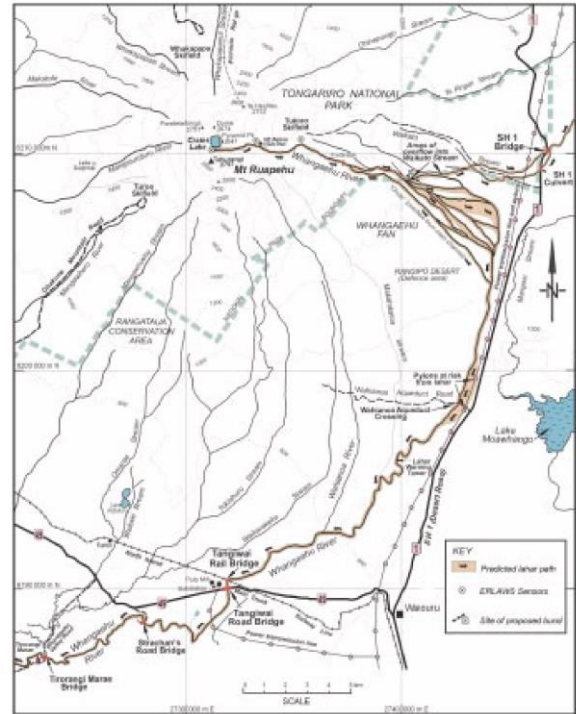
It is worth noting in passing that raising the bridge is only one of the measures taken by Transit New Zealand. In conjunction with other authorities they have also installed early warning systems to alert

¹ Bloxam Burnett & Olliver Ltd

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approaching traffic well in advance of a lahar reaching the SH49 bridge; automatic gates triggered by the early stages of lahar movement on the mountain will prevent access to the Whangaehu River flood plain as well as the bridge at Tangiwai when a lahar is on its way; and increased personnel will be available on the ground in the interest of the safety of those who evade or overlook the measures provided for their security. The predicted time taken for the lahar to travel from the crater lake to the road and rail bridges at Tangiwai is 90 minutes.

The map adjacent indicates the path that the lahar will follow from the crater to Tangiwai.

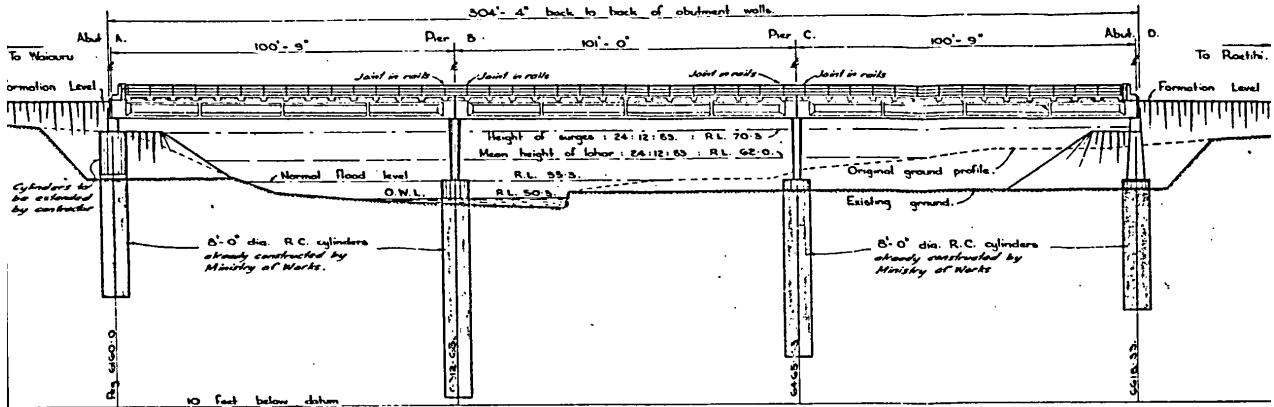


Map: G. Hancox, GNS

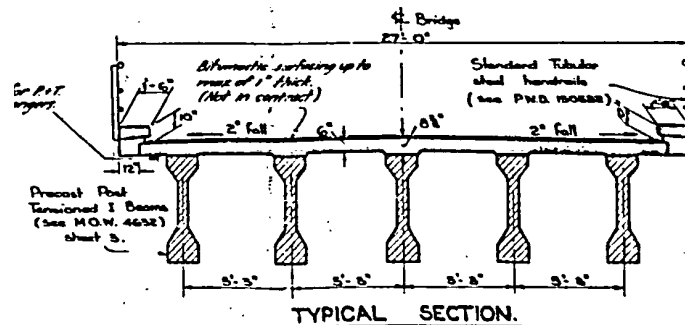
BRIDGE STRUCTURE

The general arrangement of the existing bridge remains unchanged. Three equal 31m spans of simply-supported pretensioned concrete I-beams support a composite in situ concrete slab, and are linked by in situ concrete diaphragms.

One abutment has relatively slender reinforced concrete posts springing from large-diameter (2.44m Ø) cased bored piles. The other abutment is supported directly off the bored piles. Reinforced concrete wall piers similarly spring from large diameter cased bored piles



ELEVATION OF BRIDGE & LONGITUDINAL SECTION OF SITE.

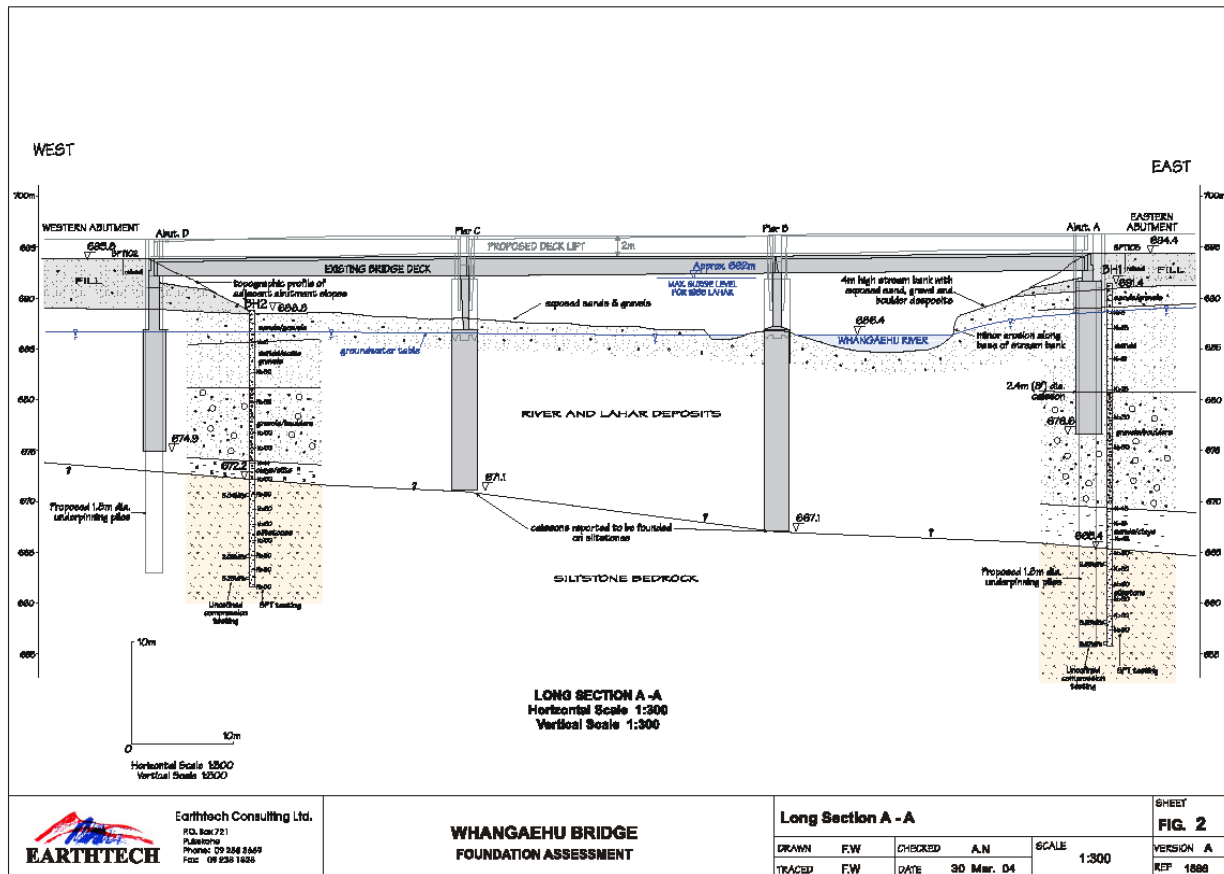


TYPICAL SECTION.

FOUNDATION CONDITIONS

Anticipated geotechnical conditions [3] comprise of dense bouldery gravels to some 16 to 20m below bed level, with “papa” bedrock below.

Abutment piles penetrate into but not through the bouldery gravels. Pier piles reach the papa but effectively sit on it rather than being socketed any significant depth into it.



LAHAR

The characteristics of the anticipated lahar are interesting from an engineering perspective:

- ◆ Density is expected to be closer to concrete than to water – sediment concentration at between 50 to 60%
- ◆ Flow velocities are expected to be of the order of 6m/s at the bridge location,
- ◆ Substantial boulders are expected to be included in the flow – the larger boulders uncovered in the river bed during the project were greater than 1.0m in diameter
- ◆ Peak discharge of 1160 cumec is predicted at the road bridge. This is in the order of twice the flow of the 1953 event.

These base characteristics conspire to impose significant demands on both natural and built environment.

Dr Grant Webby of Opus Wellington was engaged to produce a micro hydraulic model of the immediate river surrounding the road and rail bridges. Dr Webby had previously been involved in the macro modeling of the river from the crater lake to about 10km below the SH road bridge.

This initial modeling had been undertaken for DoC and the Ministry of Civil Defence and Emergency Management to provide likely flood depths and resulting damage scenarios at key locations along the river course. Due to the inherent coarseness of the macro model, it was decided a more refined model of the State Highway bridge location was necessary to provide an increased confidence level of likely lahar flood depths, flow direction and velocities. A two dimensional MIKE21 model was created based upon a detailed digital terrain model surveyed specifically for the purpose of the hydraulic model. The most probable lahar flow, designated D1x4 was passed through the model to determine flow depths, flow direction and velocity at the bridge and likely inundation of surrounding landscape. The model was checked against both the 1953 and 1975 lahar events and found to give reasonable results when compared to known flood depths from these two events. The model graphically showed both the significant scale of the anticipated event and its limited duration. The final height the bridge superstructure was to be lifted was based on the predicted lahar flood

height plus an additional allowance for the bow wave over the general flood depth with an additional clearance then being applied to ensure the bow wave did not strike the beams under the design event.

DESIGN ISSUES

Continuity of traffic

SH49 needed to remain in service throughout bridge works as the route provides the detour for SH 1 traffic when the Desert Road is closed due to snow and ice. This occurred a number of times during the project. Continuity of the network at Tangiwai was achieved using a 2 span Bailey Bridge from Transit's emergency stock, located just downstream of the existing bridge, and operating on a one-way basis under traffic-light control. The Bailey bridge height was set at a nominal 2.5m lower than the soffit of the existing bridge which provided adequate clearance for expected 'normal flood' events and minimized the earthworks necessary on the approaches. The road approaches were sealed to provide a high level of service for the road user.

Scour

There are many documented instances of scour-induced bridge collapse. This is reflected by the wide range of design guidance available for avoiding adverse scour effects under traditional hydraulic conditions.

Equivalent design guidance for scour due to dense flows such as the anticipated lahar could politely be described as scanty, but potential scour depths of up to 12m are predicted. This exceeds the embedment of the original abutment piles. Hence the abutment piles have been underpinned, using permanently cased reinforced concrete bored piles of 1.8m diameter coupled to substantial crosshead beams. The existing caissons were left in place as was the existing crosshead beam which was incorporated into the final structure. The new piles were steel cased to 1.0m into the underlying papa and then unlined for a further 6.0m of penetration into the papa material. Pile length below the crosshead beam varied from 24m to 33m as the papa level varied between the pile locations.

Pile diameters of this order were useful structurally but were also practical as the bed materials comprise substantial boulders in a gravel matrix. Penetration rates for relatively small piles were expected to be low.

Attack of angle

The angle of attack of the flow on abutments and pier walls is expected to vary due to the flooding effect of the lahar as it spills out of the river channel inundating the low lying area surrounding the memorial and then has to pass beneath the

bridge to continue its journey. Angle of attack up to 22 degrees on the pier blade walls is expected. A sensitivity analysis was used to determine the implications. The bridge structure was designed to cater for envelope actions.

In terms of gross longitudinal loads, seismic and lahar loadings were of comparable magnitude. However the base connection of the pier walls were not adequate to carry face loadings imposed by the anticipated lahar, so the original substantial bored piles were effectively extended up the full height of the pier walls.

Overturning

Exposure of the bridge girders to peak lahar flows gives overturning demands far in excess of the bridge's ability to resist particularly in a scoured bed environment. Hence raising of the superstructure needed to be sufficient to keep the bridge girders above expected flows. A rise of 2m was adopted to maintain freeboard under expected flows, recognising that incremental cost for increased lift height was small.

Structural continuity

Factors of safety against pier overturning remained small, so an element of longitudinal continuity under transverse load was instigated using external post-tensioning. Four post-tensioned tendons were positioned immediately below deck level anchored in the new crosshead beams. The tendons are designed to transfer transverse horizontal load out of the pier stems back to the abutments to be resisted by the new well founded substantial anchor piles at the abutments. The original simply supported behaviour of the beams under vertical loading was maintained by introducing elastomeric bearings between the ends of abutting girders prior to post-tensioning.

Lifting bridge spans

Lifting the bridge was accomplished on a span-by-span basis. Each span weighs about 350 Tonne. The end diaphragms are brittle, and relatively feeble compared to loads of this magnitude. The horizontal linkage bolts passing between spans and the vertical holding down bolts in the pier diaphragms had to be removed or cut prior to lifting.

For this reason the conceptual design opted not to push the bridge span from below. Instead the concept was based on pulling the bridge up using prestress jacks supported by steel frames springing from the abutments and piers, passing through the deck slab. Prestress tendons passed through the deck to temporary steel bearers sitting under the precast concrete girders. The proximity of the steel frames to the deck concrete was capable of providing some stability in the event of construction-stage earthquake.

We took the precaution of checking the concept with industry sources, verifying in particular that hardware of adequate duty was available in sufficient quantity for the task.

Smithbridge departed from our proposals in detail but not concept, and this mode of lifting individual spans proved effective.

Bearings

Inserting vertical elastomeric bearings between the ends of abutting precast concrete I-beam girders was an important part of enabling the structure to behave in the intended manner. This was not a simple task, and we appreciate SmithBridge's commitment to installing the bearings as proposed.

Drawings on the following 2 pages show sections through abutment D and piers prior to lifting, during the lift, and at completion of the process.

Waterway optimisation

Raising the superstructure of the bridge has been supplemented by works to the river bed to improve its contribution to performance under lahar conditions. These were limited to common sense provisions including removal of aggraded deposits and protection of vulnerable features. The waterway beneath the bridge was returned to a similar profile to what was constructed when the bridge was originally built in 1968 and this profile was extended upstream by approximately 100m to the corner below the toilet block. As part of this waterway work a large number of boulders in the range of 300-600mm in diameter considered too large for incorporation into the approach fill were put through a rock crusher set up in the river bed with the resulting product then incorporated into the fill. This was a cheaper option than removal of the boulders for disposal off site. Larger boulders uncovered that could not be crushed have been repositioned downstream of the bridge to eliminate any damage these may cause to the piers during the lahar event. The bulk of the recovered material was suitable for use as structural fill on the raised approach embankments.

Programme

The interval available for design and construction was minimal. Close collaboration of all involved parties was instrumental in expediting the design process including a series of meetings to ensure the Resource Consents necessary to undertake the work were issued in a timely manner. One aspect which was in the favour of an expedited resource consent process is that the Whangaehu River has acidic water flowing in it and as such is a dead river as far as aquatic life is concerned making Fish and Game and DoC signoff on the project straightforward.

Bloxam Burnett & Olliver Ltd were instructed in late September 2003 to provide a report on options available to mitigate the risk to the travelling public at the Whangaehu Bridge on SH 49 at Tangiwai by mid November for inclusion into the Transit Board meeting set for the beginning December 2003. This report covered a number of options including the construction of a new bridge, providing additional waterway remote from the bridge in the form of an overflow channel, lengthening the bridge without raising the level and the option finally adopted of lifting the bridge and approaches.

Instruction to proceed with the raising of the superstructure was given in the first week of December 2003. At this stage the predicted earliest tephra dam failure at the crater lake was January/February 2005 and completion date was set for Christmas 2004.

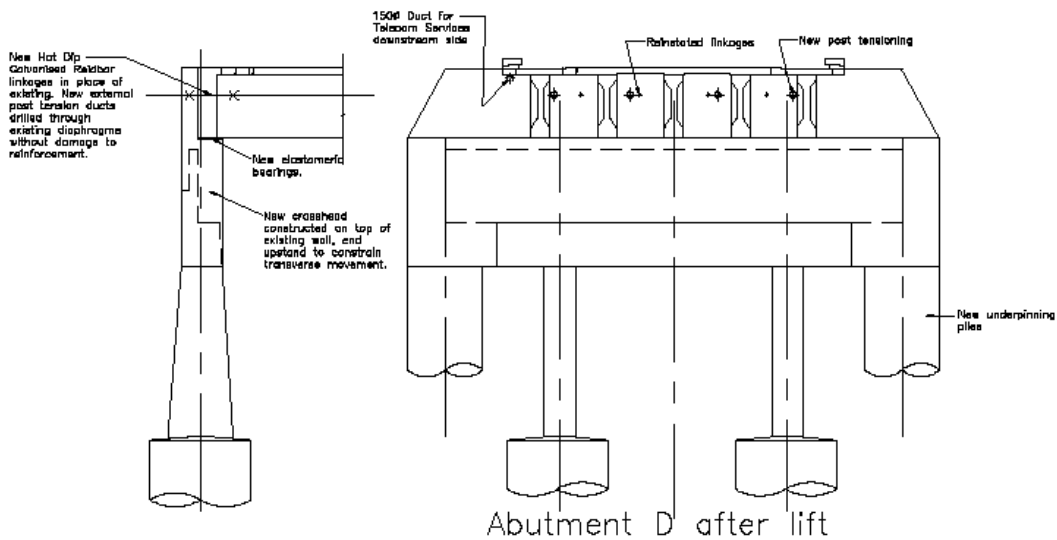
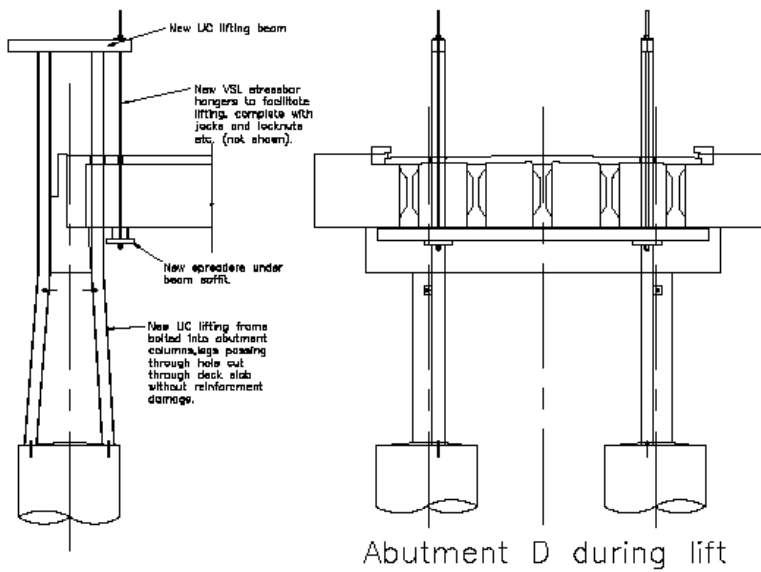
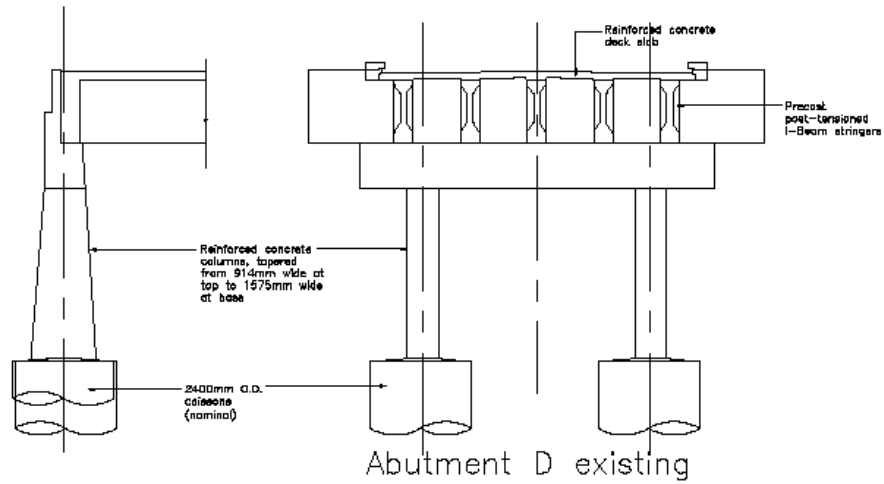
To expedite the construction process two separate contracts were let, the first covering the installation of the bailey bridge and formation of the temporary bypass road and the second for the main bridge lift, formation of the raised approaches and waterway modifications.

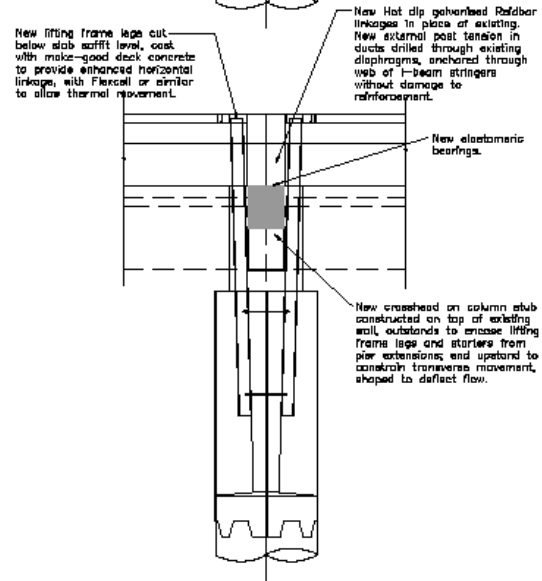
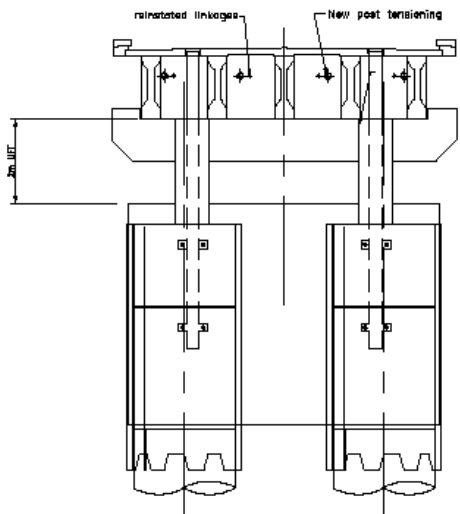
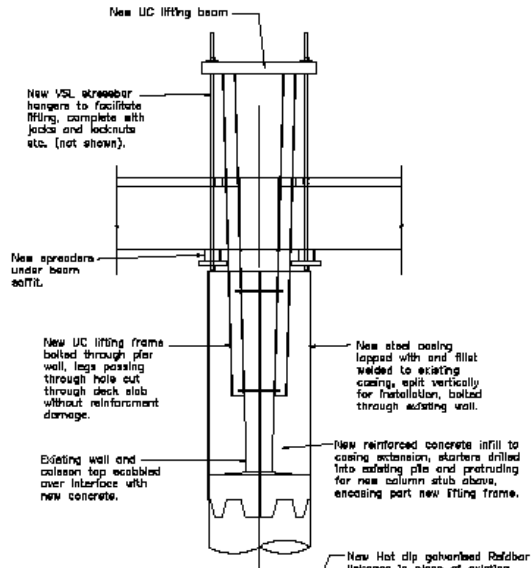
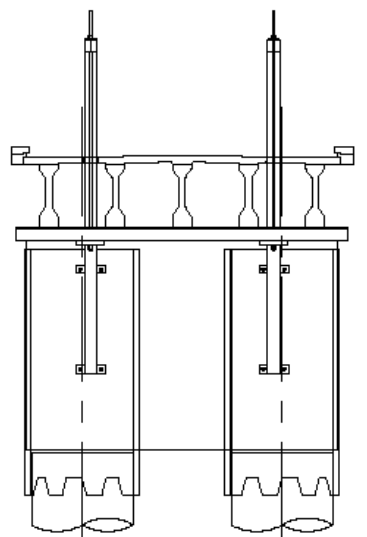
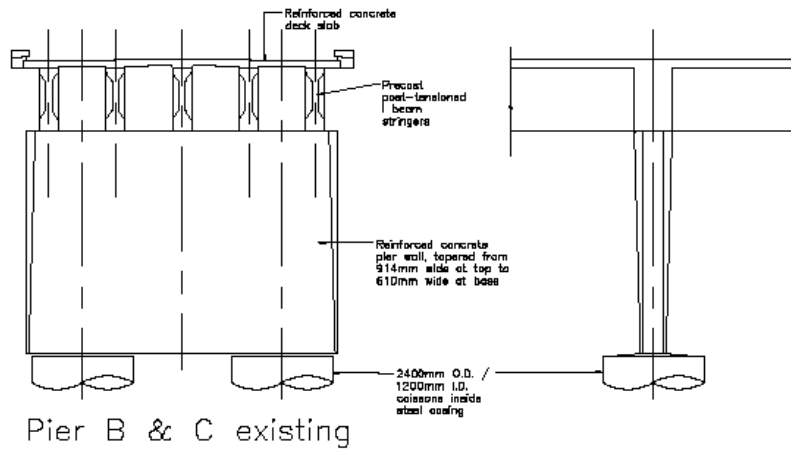
The contract for the temporary alignment and bailey bridge was let to Smithbridge Ltd on 14 April 2005 with a 5 week contract period. Concurrent with this process Transit as the Principal procured the majority of the steel necessary for the project including the abutment pile casings, the casings for the pier caisson extensions and the universal columns to be used in the lifting frame. This was done due to a predicted worldwide shortage of steel, rapidly rising steel prices and the time savings gained in the main contract with the contractor not needing to procure the steel supply.

The main contract was awarded to Smithbridge Ltd on 21 May 2004 with a contract period of 20 weeks making a completion date of 19 December 2004. This completion date was extended out to the end of January with time extensions granted for delay in relocation of the fibre optic cable onto the temporary bailey bridge crossing and unforeseen ground conditions encountered in one of the abutment piles which delayed the project by 9 working days plus the Christmas period shutdown. It should be noted that no extension of time was granted for inclement weather although there were 7 days when snow and/or sleet prevented work on the critical path from proceeding. All inclement weather time fell within the weather allowance in the tender documents. The bridge was reopened to unrestricted traffic on 2 February 2005.

During the contract period the crater lake level remained below the hard rock level ie no surcharge on the tephra dam material until mid way through January 2005 peaking at the beginning of February at a height of 0.5m above

the hard rock rim level. Since that time the lake level has receded to a level some 1.6m (as at 30/6/05) below the rock rim. The earliest likely time for a lahar event is now predicated to be February 2006.





CONSTRUCTION ISSUES

Smithbridge Ltd were awarded both the temporary alignment contract and the main lifting contract following competitive bidding under Transit CPP requirements.

Careful programme management was required due to the necessary short contract periods imposed by the predicted earliest lahar occurrence of January/February 2005.

Construction was trying, working through the winter in a sub-alpine environment where snow and sleet closed the site on several occasions including one day when access was not even possible to the site due to the amount of snow that had fallen overnight. River levels did not pose a problem with only minor freshes passing through the site and never being high enough to impede progress.

Pile penetration / excavation

The most difficult aspect of the construction phase of the main contract was the sinking of the 1.80m diameter abutment piles. Due to the bouldery nature of the subsoils. Smithbridge had elected to pre-drill the piles on the line of the casing with a small diameter (0.2m) downhole rotary hammer drill to cut through any boulders that may have been in the path of the casing. On the first pile a limited number of cores were made in the interior zone of the pile, this was later found to be inadequate and the entire pile cross section was cored on the remaining three piles. The small diameter holes were backfilled with gravel, to prevent collapse, upon withdrawal of the down hole hammer.



Pre-drilling

Fulton Hogan was subcontracted to auger out the broken up material and to bore the socket into the

underlying papa material. There were problems with the auger heads skipping on buried boulders not completely broken up by the pre-drilling and more traditional methods of chiselling and clam bucketing were necessary at times to progress the piling.



Clearing out casing

There was a collapse of the wall of the papa socket in the third pile which allowed flowing sands to enter the pile socket and casing. To overcome this problem the casing was progressed a further three metres into the papa material and the socket extended by a further three metres to compensate for this layer of unsound papa. Once sealed removing the ingress material was relatively straight forward if slow. This delay added 9 days to the programme being on the critical path.

Concrete strength for the piles was called up at 25 MPa while all other structural concrete was specified at 40 MPa. Byfords Readimix supplied the concrete either out of their Waiouru or Taihape plant. A standard mix design was used which allowed for pumping and tremie placement of the concrete.

Bearings

To ensure simply supported action was maintained in the bridge spans following the addition of post-tensioning over the full length under normal dead and live loadings, the beams were re-seated on new solid rubber bearings as per the original design requirements but also had a set of vertical bearings placed between the beam ends prior to tensioning the external tendons. The intention is to allow for rotations to occur at the beam ends without binding of the concrete faces which would have occurred if no separation of the opposing faces was made prior to post tensioning.

Installation of these bearings proved to be a difficult task. Smithbridge elected to place the bearings after re-positioning the spans back onto their supports. Due to the uneven nature of the cast faces on the diaphragms simply slipping the

bearing pad into place was not possible and a series of slots had to be formed from above deck in the gap between the two spans to allow the bearing to be positioned correctly.

Weight of lift

Smithbridge elected to follow in principle the concept methodology for lifting as set out in the tender documentation. The final design was prepared by Ocel Consultants of Christchurch. The design utilised 4 – 36mm diameter dywidag bars in each corner as the hanger rods to a 610 UB underslung beam which supported the bridge beams during the lift. Initially a single 100 tonne capacity hydraulic jack was used on each corner but this arrangement was found to only just handle the span weight and the number of jacks was doubled for subsequent lifts to 2x100 tonne jacks on each corner which easily handled the applied loads. The spans were lifted to 2.5m above their initial position to allow for working space beneath the beams. Once in their lifted position, the dywidag bars were locked off and the jacks removed to the next span to be lifted. In the lifted state the lifting frame over the piers was braced back via props to the adjacent deck span which was still in its original position. Further longitudinal bracing was provided in the form of anchored stressing tendon from the new piles or pier extension passing through an anchorage in the midspan diaphragm. Lateral stability relied on portal frame action of the lifting frame.



Abutment lifting arrangement

A maximum of two spans were lifted at any one time with the abutment lifting frame needing to be shifted from one abutment to the other before the opposite end span could be lifted.



Central span in lifted position



Bridge deck at 3 Different levels

CONCLUSION / ACKNOWLEDGEMENTS

Acknowledgements are the conventional termination of technical papers, but in this case are far more than nominal.

The cooperation of those involved was essential to satisfying unusual technical demands and demanding programme constraints. We like working in a team environment, and believe that this project shows what can be achieved by a positive and focussed collaboration.

We met with contractors who had expressed their interest at a relatively early stage, and presented and discussed the approach proposed.

Specialist resources within the design and construction communities contributed their respective expertise:

- ◆ Aidan Nelson and Phil Kelsey of Earthtech for geotechnical inputs;
- ◆ Grant Webby of Opus for hydraulics;
- ◆ Rob Robinson of ConTech for heavy lift aspects.
- ◆ Harry Keys of DoC, Turangi for keeping everybody informed on the status of the crater lake levels (ongoing).

A range of authorities have all been fundamentally involved:

- ◆ Maurice Mildenhall and Errol Christiansen from Transit New Zealand, who were faced with a demanding task and limited options;
- ◆ Peter Davies and Sarah Gardner from Horizons;
- ◆ Margaret Hawthorne and Campbell Larking of Ruapehu District Council.

Finally a range of parties have agreed to the information gleaned from this project to be shared in this way:

- ◆ Notably Transit New Zealand;
- ◆ Again Grant Webby from Opus;
- ◆ Ministry of Culture and Heritage.

We express our appreciation to all these individuals and their parent bodies.

REFERENCES

- [1] AW Reed, 1961, *A Dictionary of Maori Place Names*, AH & AW Reed
- [2] Ministry of Culture and Heritage website
- [3] Earthtech Consulting Limited, March 2004, *Whangaehu River Bridge Foundations assessment – Geotechnical Investigation Report*