Replacement of single lane bridges in Northland

Oliver de Lautour, Associate, Aurecon

ABSTRACT

The New Zealand Transport Agency has a bridge replacement programme in the Northland region of New Zealand to replace existing single lane bridges on the State Highway network with two lane structures.

Taipa and Matakohe bridges are the first to be replaced in the programme and this paper presents the design and construction of these three structures. Taipa bridge consists of a 4-span structure constructed across the Oruru River with precast hollowcore units and a length of 107m. Matakohe Bridges consist of two structures constructed with precast super-tee units over tidal estuaries. The bridges have span arrangements of 2 and 6 spans and lengths of 55m and 191m respectively. All three bridges have spill through abutments and are supported on bored piles into component bedrock.

This paper provides an overview of the bridge forms, detailed design considerations including Safety in Design and Urban Design and use of digital engineering.

1 INTRODUCTION

The New Zealand Transport Agency has a bridge replacement programme in the Northland region of New Zealand to replace ten single lane bridges on the Northland State Highway network with two lane structures. Figure 1 shows the location of the proposed bridge replacements. These structures are located on key freight and tourist routes and provide important connections to support the Northland economy.

The initial replacement programme has included the detailed design and construction of three bridge structures. These are two bridges at the Makakohe site and one bridge at the Taipa site. These bridges were procured using a competitive Early Contractor Involvement (ECI) model. The bridges are currently near completion and formal opening of the structures is programmed for mid 2019.

Figure 1 – Northland Bridges replacement programme (Source : NZTA website)

2 BRIDGE FORMS

The proposed bridge forms were developed during the competitive tender phase in collaboration with the contractor to meet the Principal's Requirements PR's whilst providing a low-cost design focusing on constructability. All bridges provide a 10.0m road carriageway consisting of two 3.5m lanes and two 1.5m wide shoulders. In addition, the Taipa Bridge provides a 2.5m Shared Use Path (SUP) that widens to 4.5m over the central span.

1.1 BR01 Matakohe – Parerau Creek Bridge

The Parerau Creek bridge crosses Parerau Creek near Matakohe, see Figure 2. The bridge is constructed off-line to the existing bridge crossing. The bridge consists of a two span structure with equal span lengths of 27.4m and spill through abutments with a 1V:2H batter. The bridge deck is 10.8m wide and skewed at 15 degrees. It is construction from four 1225mm deep precast prestressed Super-tee girders with an in-situ reinforced concrete (RC) topping of 180mm minimum thickness. The bridge deck is construction as integral at the central pier support and simply supported at the abutments. At the abutments, the bridge deck is supported on elastomeric bearings and has strip seal type deck expansion joint. The bridge is supported by 1050mm and 1500mm bored RC pile foundations at the abutment and pier locations respectively. TL5 precast concrete barriers with an HT top rail are provided as bridge deck edge protection.

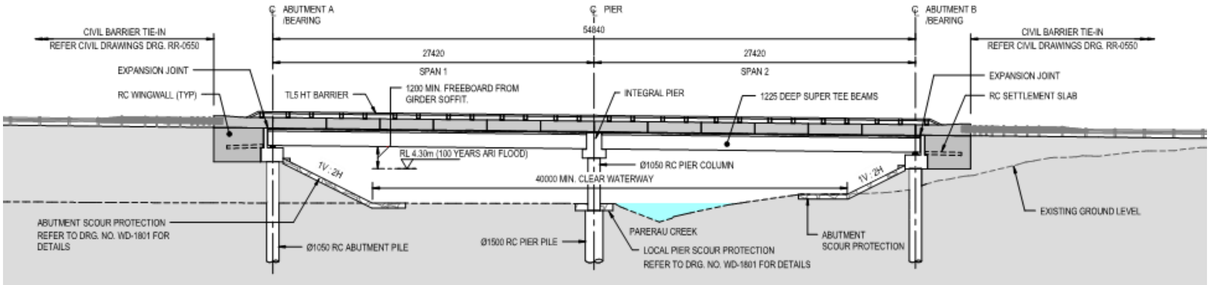

Figure 2 – Parerau Creek Bridge

1.2 BR02 Matakohe – Matakohe River Bridge

The Matakohe River Bridge crosses the Matakohe River near Matakohe and is constructed on an offline alignment. The bridge consists of a six span structure with main spans of 32.5m and back spans of 30.5m. The bridge approaches consist of earthworks and the bridge has spill through abutments. The bridge deck is 10.8m wide and is constructed from five 1225m deep precast prestressed Super-tee girders and an in-situ RC topping of 180mm minimum thickness. The bridge deck is constructed as integral at the internal piers supports and simply supported at the abutments. At the abutments, the bridge deck is supported on elastomeric bearings and has a saw tooth type deck expansion joint. The bridge is supported by 1200mm and 1350mm bored RC pile foundations at the abutment and pier locations respectively. The design level of the bridge is approximately 15m above the ground level at its highest. TL5 precast concrete barriers with an HT top rail are provided as bridge deck edge protection.

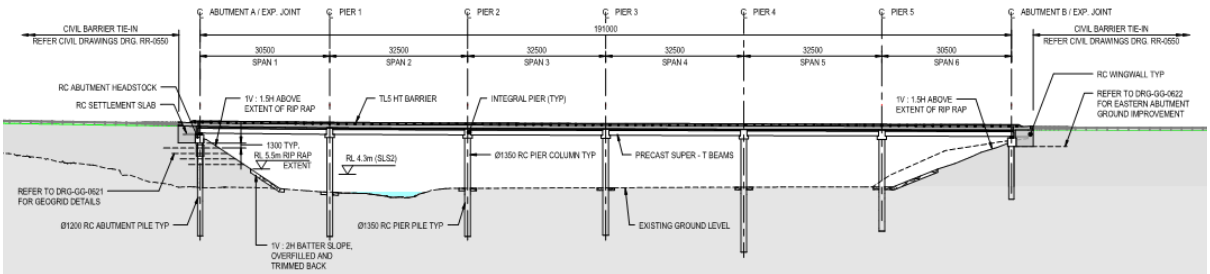

Figure 3 – Matakohe River Bridge

1.3 Taipa Bridge

Taipa Bridge crosses the Oruru River and is constructed offline adjacent to the existing bridge. The bridge consists of a four span structure with 27.1m central spans and 26.4m back spans. The bridge approaches consist of a widened earthworks embankment on the Eastern approach. The bridge abutments are spill through type with 1V:2H spill batters. The bridge deck is constructed using nine 900mm deep and two 200mm deep precast prestressed Hollowcore units to form the roadway and SUP respsectively. The 900mm deep Hollowcores are transversely post-tensioned together while the 700mm deep Hollowcores have a 200mm in-situ RC topping. The RC topping forms an in-situ cantilever to widen out the SUP over spans three and four. The bridge is constructed as semi-integral at the piers and abutments and is supported by elastomeric bearing strips. The bridge is supported by 1050mm and 1200mm diameter RC bored piles at the abutment and pier locations respectively. TL4 VGAN barriers provide bridge deck edge protection and a 1200mm high handrail provides safety form falling on the SUP.

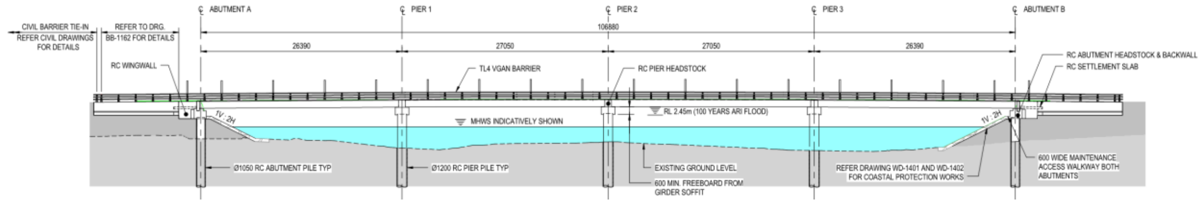

Figure 4 – Taipa Bridge

3 DETAILED DESIGN

The bridges were designed in accordance with the NZ Transport Agency Bridge Manual 3rd Edition, 2nd Amendment as modified by the project PR's.

The structures were designed as Importance Level 3 structures with a design life of 100 years for HN-HO-72 live loading. Precast prestressed concrete bridge forms were used due to economics, industry preference and superior durability. The design considered whole-of-life costs and there was a preference to use integral or semi-integral construction for areas that would be difficult to access in the future for inspection and maintenance e.g. pier supports within the waterways.

1.4 Prestressed design

The precast prestressed Super-tee and Hollowcore bridge beams were used for construction of the bridge decks. All girders were designed as 'Class C' partially prestressed for sagging moment at the Service Limit State (SLS). This limits the increment in stress from live loading to 150MPa at SLS. At the Ultimate Limit State (ULS), sagging moment capacity was checked for strength using the strain-compatibility method for determining the increment in prestress stress post cracking.

Where the girders were constructed integral with the supports, the girder was designed as an RC section for hogging moments at both the SLS and ULS states.

Design of the girders considered redistribution of permanent loading due to restrained creep and shrinkage movements and differential shrinkage effects as per guidance within AS5100.5.

1.5 Foundation design

The bridges were all supported by 1050-1500mm diameter RC bored pile foundations into competent rock. The piles were permanently cased above the rock socket with a steel casing. Due to the weaker rock in the Northland region, long rock sockets were typically required. At BR01 Matakohe, up to 21 pile diameters were required where founding into Northland Allochthon Melange Mudstone.

1.6 Seismic design

The bridges were all designed for a 1 / 2500 Annual Exceedance Probability (AEP) ULS seismic event. Northland region is one of the lowest regions for seismicity in New Zealand. The bridge sites at

Matakohe and Taipa had a zone factor Z (as defined in NZS 1170.5) of 0.07 and 0.06 respectively. This is smaller than Auckland at 0.10, New Zealand's most populated city and Wellington at 0.40, sitting directly on the Wellington fault line.

The Transport Agency Bridge Manual requires the following performance criteria in seismic events;

- SLS – Minor earthquake (1/4 x design level earthquake) - minor damage is accepted, however, must be usable for traffic immediately after event,
- ULS – Design level earthquake – damage allowed, must be feasible to reinstate to carry traffic, useable for emergency traffic immediately after event,
- CLS – Major earthquake (1.5 x design level) – collapse avoidance, extensive damage allowed

The seismic design philosophy for the bridges was to design the structures as dynamically responding in the transverse direction due to the flexibility of the intermediate pier supports. In the longitudinal direction, the Matakohe bridges were released at the abutments with deck expansion joints and therefore designed as elastically responding also. Tapia bridge was designed as 'locked-in' longitudinally due to the semi-integral construction.

Ductility factors used in the design for the ULS design level event were between 1.0 and 1.25 (nominally ductile) for inertia loading. This means the structure is effectively responding elastically to the ULS seismic event, without plastic hinging/inelastic deformation occurring. High ductility factors were not required in the design due to the low level of seismicity. Adopting a ductility factor of between 1.0-1.25 also allowed standard design procedures to be used, and specific seismic reinforcement detailing or capacity design principles need not be applied.

In addition to seismic inertia loading, two bridges were subject to additional demands from seismic induced abutment slope movements. These were;

- BR01 Matakohe – Parerau Creek landslide induced movements at one abutment of up to 140mm and 320mm in the ULS and CLS cases respectively,
- Taipa Bridge – Lateral spreading movements at both abutments of up to 150mm at CLS. Minor movement, less than 25mm is expected at ULS,

The analysis and design approach to applied soil movements acting on the structures was adopted from the guidance and analysis methods within the Transport Agency Research Report 553. The analysis method uses a non-linear push over analysis to analyse the combined loading effects of inertia and soil movements on the structure. A stiff frame element is used to represent the movement of the soil block to the depth of failure plane. Nonlinear pile springs are used to represent the soil stiffness and lateral capacity. Where provided, a 'gap element' is used to model the expansion joint and the subsequent propping action within the deck once this is closed. Plastic hinges are used to model the moment curvature response of the piles. The Bridge Manual does not specify the requirements for combining inertial and soil displacement loading. The philosophy proposed in the design considered that peak inertia and soil displacement are not a concurrent loading case, as several cycles would be required to fully mobilise the soil and induced movement. Instead the peak cases are considered independently and considered sufficient to cover potential loading cases with concurrent loading, however, not at peak values. The Bridge Manual requires the effects of two ULS seismic events to be allowed for the in design. The design philosophy was that the second ULS event would be treated using collapse avoidance criteria. Material strains in the plastic hinges were used to demonstrate compliance with the Bridge Manual seismic performance criteria. Strain limits for the ULS and collapse avoidance criteria were adopted from the draft Section 5 of the Bridge Manual. The analysis showed BR01 Matakohe reached approximately 50% of the ULS strain limit under soil movements.

1.7 Tsunami design

Design requirements for Tsunami loading were incorporated into the second amendment of the Transport Agency Bridge Manual third edition. Tsunamis are bore waves that are generated by the displacement of a large volume of water from landslides, seismic activity and other phenomena. The bores can travel from distant sources, e.g. coastline of South America to remote locations including New Zealand. The effects of tsunamis can be very destructive however, are localised to exposed coastal areas. Guidance within the Bridge Manual notes the understanding of tsunami effects on structures is in its infancy.

The Bridge Manual states the ULS design event shall have the same AEP as required for seismic design, i.e. 1 / 2500 AEP event for an Importance level 3 structure and 100 year design life. The tsunami bore height is determined from a series of maps prepared by Geological and Nuclear Sciences (GNS) New Zealand. The Taipa site is located on an exposed section of Eastern coastline facing the Pacific Ocean. Estimated bore height for a 1 / 2500 AEP event is 12m. This is estimated to generate vertical (uplift) and lateral pressures of 190kPa and 290kPa respectively. These pressures are unable to be accommodated in conventional bridge structures.

The PR’s for the project modified the Bridge Manual requirements to not require a specific design for tsunami. Instead the PR’s required an assessment of what resilience is provided in the conventional design proposed. The Taipa Bridge, designed for all other actions, was assessed to be capable of withstanding the uplift pressure from a 2.0m bore, approximately 30kPa. This uplift pressure would cause hogging failure in the Hollowcore girders. In the most unfavorable tidal state (high tide), this corresponded to approximately a 1 / 100 AEP event, significantly less resilience than achieved with the ULS 1 / 2500 AEP event. Hollowcore deck construction without an in-situ topping slab exhibits particularly poor performance due to the lack of hogging moment capacity. The form of construction was not changed, however, as it met the requirements of the PR’s and had advantages for construction over a sensitive estuary.

4 SAFETY IN DESIGN

Safety in Design (SiD) was a key project objective. The existing Tapia Bridge crosses a tidal estuary which has a channel that is sufficiently deep to allow the public to jump from the bridge railings into the water below near high tide. Jumping off the bridge is a popular activity for the local community, however, is a safety concern as a designer with a significant amount of injuries and fatalities reported in New Zealand.

The requirements for the replacement bridge stipulated in the PR’s that a diving platform should be provided that had no handrailing and was accessed by a lockable gate from the SUP.

The design team raised a number of SiD concerns with these PR’s;

- The lockable gate created an uncontrollable hazard that could be tampered with and/or left open causing a risk of falling/drowning,
- A designated area without handrails encouraged the potentially unsafe act of jumping. It also restricted the jumping to a small area, increasing the likelihood of collision with jumpers and potentially confined jumping to an area which could become unsafe over time (e.g. movement of the channel),
- The replacement bridge was wider than the existing bridge, reducing visibility of small vessels that also use the channel,
- The offline construction of the bridge increased the distance jumpers would need to swim to exit the estuary.

To explore the SiD concerns and present these to the client a virtual reality model was made, see below for further discussion. This model was presented at a SiD session held specifically for this issue. The consensus from the session as follows;

- Lockable gate and designated diving platform was to be removed from the design,
- Anti-jumping fencing e.g. 3m high fencing was not appropriate and there was no precedent to provide this,
- Handrail height shall be 1200mm typically and reduce to 1100mm where the SUP widens out to provide a zone outside the nominal SUP width corresponding to the deeper part of the

channel/estuary. This does not confine jumpers to a single location and gives them a choice from where to jump from,

- Handrail featured vertical fins to with a flat horizontal top. This reduced climbability of the handrail and avoided an impaling risk if climbed,
- Buoys to separate the small boats from accessing the jumping zone were to be provided,
- Warning signage to be provided,

5 URBAN DESIGN

Urban design with the incorporation of local Iwi art into the bridge design was a key objective at the Tapia site.

In collaboration with the project bridge architect ‘Waka’ ends and an architectural handrail were proposed for the bridge. Additional off-bridge urban design items such as landscaping, seats/storyboards and art are also proposed. Waka is the traditional Maori canoe which features distinctive carved elements at the Tau-Ihu (front) and Tau-Rapa (back). Figure 5 below shows a typical Waka profile and the Tau-Ihu and Tau-Rapa elements that were developed for the bridge ends. These elements are 4-5m high and constructed from precast RC panels and have a recess to fit feature carved timber inserts on both faces. The height of the elements was important to achieve the desired representation of a Waka from a distant perspective.

The bridge handrail was designed to have vertical fin infill panels supported by vertical fin posts to achieve a uniform transparent aesthetic where the handrail infill and posts were seamless. The handrail posts were setout to match the roadway TL4 VGAN barrier at approximately 2.2m centres and achieve a rhythm along the bridge. In between the handrail posts, every third post is a taller 3m post featuring a carved timber element on the top.

Figure 5 – Urban design at Taipa Bridge

6 DIGITAL ENGINEERING

Digital initiatives on the project include; full 3d modelling of all design elements, coordination of the design in 3d using clash detection software, visualisation and virtual reality models of the design for interaction with the clients and community

This was the first highways project for Aurecon in New Zealand that utilitised digital modelling, coordination and visualisation tools for digital delivery of a project. Digital tools were used throughout the design process and at meetings with the client. The use of 3D modelling enhanced client interaction and led to a deeper understanding of the design by all parties.

Design elements from every discipline were modelled accurately in terms of geometry and position in 3d. This included design elements such as road signs or light poles for which there is no current purpose-built software to model these. Instead, existing structural modelling software was used to model these items. This is understood to be the first Transport Agency highways project to use digital engineering to this extent. Typically, projects have been traditional designed in 2d with minimal 3d modelling. The advantages of adopting a 3d modelling approach to the design was the ability to coordinate the design in 3d using clash detection software. The design was coordinated in 3d using Navisworks to perform clash detection. This allowed clashes to be detected that may not have been understood or addressed using the traditional 2d approach. This provided the client confidence in the design and demonstrated the design team was committed to enhance the project by adding value using digital tools.

A 3d laser scan of the existing bridge was conducted to provide confidence with building adjacent to the existing structure. See Figure 6 below. Elements such as the existing timber railing and concrete kerb were difficult to understand spatially with a traditional survey. The 3d laser scan was able to provide an accurate 3d view of the existing structure so that potential clashes could be resolved in the design process. The clearance between the new bridge and existing was reduced to 200mm due to the confidence gained from the laser scan survey.

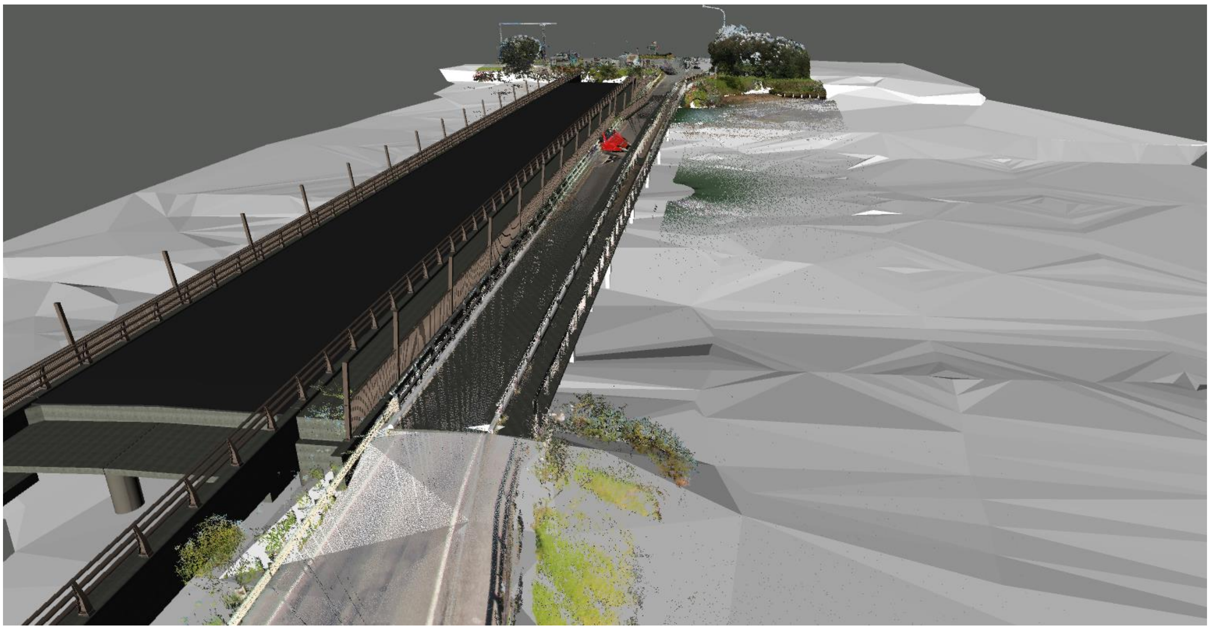

Figure 6 – Taipa Bridge 3d laser scan

A key SiD issue, as mentioned above, people jumping off the bridge into the estuary below, was explored in a 3d model. See Figure 7 below. The model was used in a SiD session with the client. This allowed the design team and stakeholders to understand sightlines and visibility of boats from a first-person perspective. This led to changes in the design with re-configuration of the bridge handrailing to ensure public safety.

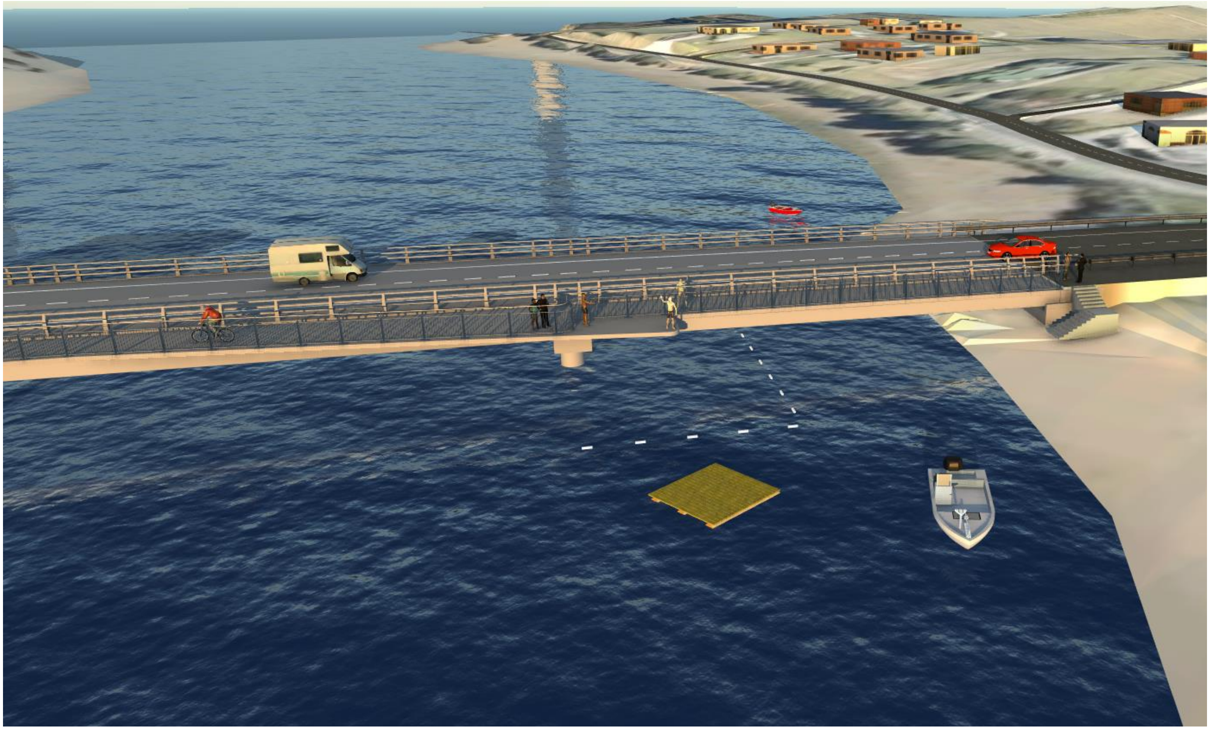

Figure 7 – Taipa Bridge SiD Infraworks model

A community project open day was held for the Taipa site in late 2017 prior to construction of the bridge commencing. The design team designed an experience for the open day with a futuristic display set-up. People were immersed in the virtual reality model of the bridge, watching cars and people travel on the bridge. See Figure 8 below. They also understood the design more easily from a 3d visual perspective than the traditional printed 2d long plots. Positive community engagement, feedback and support for the project was generated at the open day and it was deemed a success by the Transport Agency, our client.

Figure 8 – Taipa Bridge community open day virtual reality model

7 CONCLUSIONS

Three bridges have been successfully delivered for the Northland bridge replacement programme by Aurecon. Innovation has been achieved in the project through the application of digital engineering. Key examples are the development of a virtually reality models for the community open day and collaboration in 3d with a complete design model.

8 REFERENCES

- The NZ Transport Agency Bridge Manual Edition 3, Amendment 2, 2016,
- The NZ Transport Agency Bridge Research Report 553 *The development of design guidance for bridges in New Zealand for liquefaction and lateral spreading effects*, 2014,

9 ACKNOWLEDGEMENTS

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10 AUTHOR BIOGRAPHY

Dr Oliver de Lautour is an Associate at Aurecon, New Zealand with 14 years' experience in structural design and is a Chartered Professional Engineer. He has a PhD in Civil Engineering studying Structural Health Monitoring. His background is predominantly in the detailed design of bridge structures in the Australasian and South Pacific regions. His experience includes undertaking complex bridge analysis and design, working collaboratively in multi-disciplinary design teams and bridge aesthetics. He has previously presented at the Small Bridges Conference.