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NORTHLAND RAIL UPGRADE – FAST-TRACKED REPLACEMENT OF FIVE BRIDGES USING POST-TENSIONED SEGMENTAL CONSTRUCTION

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SUMMARY

Following a successful application for funding from the Provincial Growth Fund, the Northland Rail Upgrade (NRU) project team began the arduous task of upgrading the railway line between West Auckland and Whangarei. Starting in late 2019, the projects vision was to rejuvenate rail operations on the North Auckland Line (NAL) and improve the economy of Northland. In doing so, it has improved asset health and resilience on the line, reduced rail freight journey time by easing current speed restrictions and enabled Hi-cube container freight capability. This paper focuses on the successes and challenges related to the replacement of five existing timber piled bridges that formed part of the programme of works for the Northland Rail Upgrade project. These are Bridges 88, 89, 100, 126 and 168 on the NAL.

INTRODUCTION

New Zealand's railway has a long history, operating since the mid-nineteenth century. The railways were built to connect people and places and enable efficient movement of freight around the country. Inevitably, certain periods in the past were not all conducive for railway transportation due to various political pressures. This meant substantial rail infrastructure was either not adequately maintained for a long period or discontinued due to limited patronage. Resurgence of rail is nothing new and recently KiwiRail with support from New Zealand Government has made a concerted effort to rejuvenate some of these long-neglected railways.

Following successfully receiving funds from the government, KiwiRail began upgrading the North Auckland Line (NAL) in late 2019. There are thirteen tunnels and 88 bridges between Swanson and Whangarei on the NAL. All the tunnels required maintenance and repairs including lowering all of the tunnel floors to provide sufficient clearance for Hi-cube container freight. Of the 88 bridges, five of the timber piled bridges were identified for replacement, along with one bridge that required lowering to align with the adjacent lowered tunnel floor. Additionally, track renewal works involving the replacement of 50,000 sleepers, the placement of 50,000m^3 of ballast, improvements to drainage, and vegetation clearance were performed.

NORTHLAND RAIL
$94.8 MILLION PROVINCIAL GROWTH FUND INVESTMENT

Northland Line
(Swanson-Whangarei)

Track renewal
- 54km of the tracks either upgraded or replaced
- Approximately 50,000 sleepers replaced
- Approximately 50,000m^3 of ballast added

Bridge replacement
- 5 wooden/steel bridges are in poor condition and will be replaced with concrete structures.

Drainage improvements
- Drains alongside the 181km of track will be cleared
- A quarter of the 950 culverts are in poor condition will be remediated as required
- Effective drainage is crucial to manage flooding in weather events and ensure stability of the rail line.

Repairs to 13 tunnels
- Urgent structural repair work
- Investigating 'below ground' conditions in preparation for later work to lower the tunnels (to fit high-cube containers).

Slope stabilisation
- Stabilising slopes on 9 embankments, includes embankment widening and drainage improvements.
- Ongoing monitoring of embankments to determine if further civil engineering is needed.

Whangarei Rail Yard
- Review and make improvements to the Whangarei Rail Yard to improve safety and efficiency.

Vegetation control
- Significant amount of vegetation needs to be cleared from the sides of the track to protect track and rolling stock and improve worksite access.

Benefits
- Allow some speed restrictions to be lifted, reducing the rail freight journey time to Auckland.
- Make the network more resilient and rail services more reliable, reducing the number of line outages.
- Set the conditions for rail freight growth in Northland.
- Where possible, KiwiRail will be using Northland based contractors and sourcing materials from Northland.

Figure 1. Northland Rail Upgrade Overview

KIWIRAIL'S OBJECTIVES FOR THE PROJECT

With the vision of improving the economy of Northland and rejuvenating the North Auckland Line, KiwiRail had the following primary objectives for the NRU project:

- Enable existing speed restrictions to be lifted in areas being attended, reducing the rail freight journey time between Northland and Auckland.
- Make the network more resilient and reliable, reducing the number of outages.
- Provide conditions that will enable rail freight growth in Northland.
- As much as possible, utilise Northland based contractors and locally sourced materials for construction.

Another key criteria for the project was that most of the construction was to be completed within a five month of Block-of-Line (BoL) period to limit disruption to rail services to a confined block of time. This single criterion was critical to many design decisions.

THE EXISTING BRIDGES

KiwiRail identified five bridges on the NAL with low bridge health index scores that required replacement (Bridges 88, 89, 100, 126 & 168 NAL). These five bridges ranged in age from 80 to 100+yrs old and were a mix of steel and timber spans, predominately supported on timber piled piers. Bridge 89 NAL and Bridge 100 NAL prior to replacement are shown in Figure 2.

Primary reasons for these bridges requiring replacement included:

- Deteriorated condition of timber elements.
- Piles founded at shallow depths and at risk of scour.
- Timber piles in marine environment vulnerable to attack from Teredo worm (a form of marine borer).
- Low strength rating of timber and steel spans. Limiting train axle loading and line speed.

- Some steel spans having exceeded theoretical fatigue life.
- Improving safety for railway maintenance staff by providing across structure walkways.

Figure 2. Bridge 89 and Bridge 100 NAL before replacement

THE REPLACEMENT BRIDGES

From the onset of the project the design team faced the challenge of a very compressed design programme for the replacement bridges, to enable construction during the planned BoL. The concept development for replacement bridges took just over two weeks to investigate the plausible configuration (number of spans), superstructure types, and substructure details for all five bridges. With only preliminary investigations of geotechnical and hydraulics for each site available at this stage. From beginning concept design to practical completion of construction, 9 months had been allowed.

A series of key design drivers were considered when developing concepts for the replacement bridges. These included:

- Span configuration - single, two and three span bridges were considered suitable. Bridges with a greater number of spans were not considered as they would require more in-stream work (minimising in-stream work helped reduce complications with consenting) and shorter spans were not considered economical.
- Requirement to minimise or eliminate the need for any track raising to avoid disturbing existing embankments.
- Adopt tried and tested construction techniques used in New Zealand, to minimise potential for cost and programme over run.
- Standardisation and simplification. To reduce design and construction time.
- KiwiRail's preference for ballast deck structure to minimise on-going maintenance costs.

Following a series of concept development workshops including all the project team, a standardised design was selected for the five bridges. This consisted of three-span bridge structures for Bridge 88 & 89 NAL and two-span structures for Bridges 100, 126 & 168 NAL. For the bridge superstructures a post-tensioned concrete ballast tray form was adopted, which was designed using a segmental precast concrete approach. This form of construction had previously been implemented successfully on KiwiRail bridges during the NCTIR (North Canterbury Transport Infrastructure Recovery) project and lessons from that project were taken forward on the NRU project. A more conventional substructure form was adopted, typically consisting of twin bored piles and an insitu concrete capping beam.

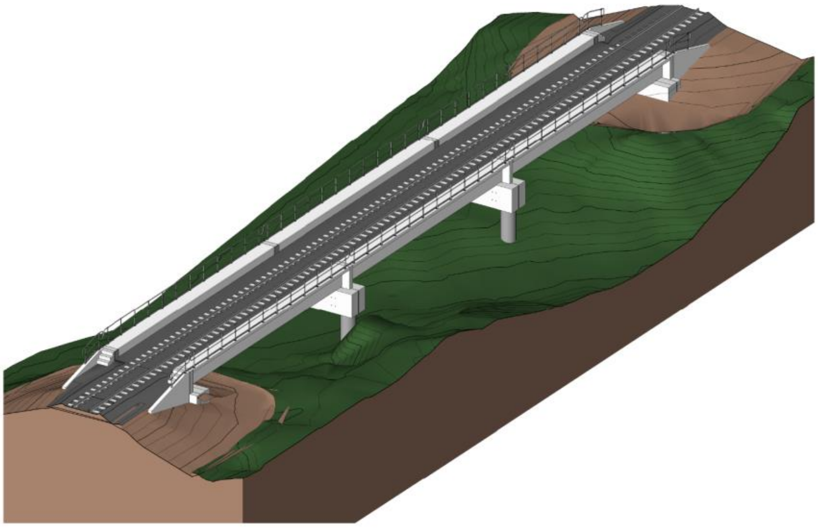

Figure 3. 3D image of Bridge 88 NAL .

Superstructure Form

The standardised superstructure form adopted for all five bridges was a segmental post-tensioned concrete ballast tray. The superstructure spans are simply supported on plain rubber elastomeric bearing pads, with a span length of 16m between bearing centrelines. The ballast trays have an overall depth of 1.35m, with the inside width of the tray being 4.1m and an overall width of 6.1m. On either side of the ballast tray, 1m wide outstands act as a structural elements, whilst also allowing maintenance walkways to be incorporated on each side of the bridge. A typical cross section of the superstructure is shown in Figure 4.

The post-tensioned ballast trays were designed and constructed using a match-cast segmental precast concrete approach. Each span consisted of six precast segments, with each segment being 2.75m in length and weighing approximately 22 tonnes. The units were transported individually and joined together on-site. Some of the key advantages of this approach included:

- Precast segments were fabricated and cured off-site in the controlled environment of a precast yard.
- Reduced on-site construction time to enable completion during BoL period.
- Match casting of one segment against the face of the previous segment ensured perfect fitment of segments.
- Segments could be made of a manageable size and weight for transportation and handling.

On-site the six segments that formed a span were placed on temporary works. Locator keys were incorporated into the match cast faces of the precast segments to help align adjacent segments. Epoxy was then applied to the joint faces before a temporary stressing force was applied whilst the epoxy cured. A specialised segmental bridge adhesive (epoxy) was specified, as they have been formulated to both lubricate the segments during fitment and provide the required shear transfer and durability across the joints once cured.

After the epoxy had cured the permanent post-tensioning strands were installed and stressed to complete the span. The BoL period allowed the spans to be constructed on the existing rail alignment, therefore once completed they only needed to be lowered down from the temporary works onto the new piers and bearings. Once lowered, the spans were secured in-place using a combination of reinforced concrete headwalls and stainless steel dowel bars. Refer Figure 5 and Figure 6 for examples of temporary works implemented.

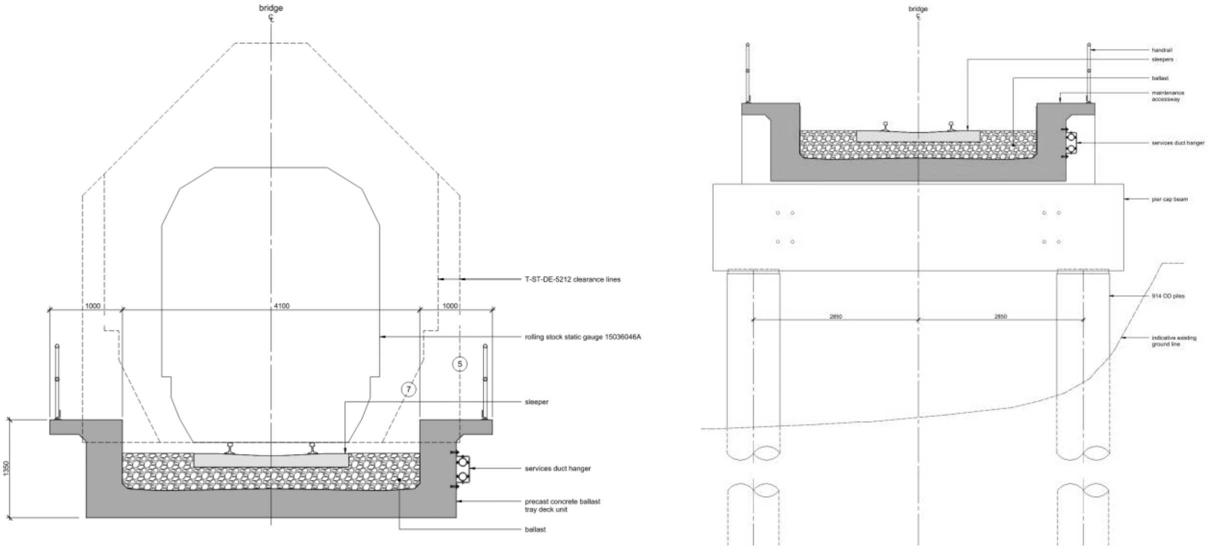

Figure 4. Typical superstructure cross-section and pier elevation

Figure 5. Precast segments supported on temporary works at Bridge 100 NAL

Figure 6. Trial fitment of segments at Bridge 126 NAL

Substructure Form

The piers and abutments consisted of two piles and a reinforced concrete cap beam. The piles were spaced at 5.7m centres to enable installation of the piles before the planned BoL if required. At Bridges 88, 89, 100 and 168 permanently cased bored piles that socketed into the founding rock layer were adopted. These were typically 900mm diameter, except at Bridge 168 where 1050mm diameter piles were required due to the increased depth of the founding rock layer. At Bridge 126 the Northland Allochthon founding rock layer was not considered suitable for bored pile construction, therefore driven steel tubes were specified. A typical pier elevation is shown in Figure 4.

The abutment and pier capping beams were typically 1.3m-1.4m wide x 1.5m deep and were designed to be constructed in-situ. As part of this project, localised improvements were performed on the embankments directly behind the abutments. These improvements were performed to reduce the likelihood and magnitude of static soil creep and seismic soil displacements, which cause large demands on the piles. At the abutments of each bridge, 4m long settlement slabs were provided, along with wingwalls to retain the embankment and ballast.

DESIGN CHALLENGES AND SUCCESSES

As with all projects of this size there were several challenges during the design and construction phase of these bridges which required solving. These challenges however lead too many successes that should be celebrated and shared by the parties involved. Further detail on how some of these more significant challenges were successfully navigated by the project team is provided in the following sections.

One Team Collaborative Approach:

The compressed design and construction programme required a cohesive project team to avoid the inherent time losses that come with a disjointed team.

The structural design was led by Holmes Consulting with three design offices being used to resource the bridge design and internal verification. An ECI (Early Contractor Involvement) process early in the design phase ensured that the bridge design suited Contractor’s experience, plant and the availability of materials to avoid delays associated with design/construction mismatch. Together with Geotechnical, Hydraulic and Geometric sub-consultants, work was often completed in parallel with each other to develop, design and detail solutions to meet programme milestones. While originally intending to work out of a project office, Covid-19 restrictions forced the project to go online early in the detailed design process.

The five bridges were constructed by three main contractors, with precast work being completed by a further two sub-contractors. During construction, a full-time design representative was required to monitor construction QA and attend site, with the five bridges progressing in parallel. Microsoft Teams was implemented across the project for both communications and document control.

Standardisation and Segmental Construction:

From concept design, it was identified that standardisation was a key driver to ensure the design and construction teams could successfully deliver the work in the required programme. This led to all five bridges having the same length span, with either two or three spans for each structure. Coupled with segmental bridge construction, each bridge span was broken into six equal length match-cast precast units. In total, the bridge superstructures incorporated 72 precast units.

Whilst a standardised approach was adopted where possible, unique constraints relating to the location of the site or ground conditions meant that each bridge had some unique challenges that required consideration during design and construction. A summary of the most significant unique features working against the standardisation philosophy are provided below:

- Bridges 88 & 89 – Located in a marine environment with limited freeboard.
- Bridge 100 – High approach embankments requiring mechanically stabilized retaining walls. Farm access track passing beneath bridge.
- Bridge 126 – Piles founded in sensitive Northland allochthon rock which is not suitable for bored pile construction, therefore driven piles were adopted instead. No-exit local road passing beneath bridge.
- Bridge 168 – Located in a marine environment with a curved track alignment. Spans skewed to accommodate curved track within the ballast tray with sufficient clearance. Increased depth to founding rock layer meant larger diameter piles required.

Limited freeboard

The existing bridges over the tidal waterways (Bridges 88 and 89 NAL) did not have adequate freeboard for the design flood event of 100-year ARI (Average Recurrence Interval), when considering the future sea level rise and climate change effects. Even without the consideration of future sea level rise, these two bridges had nil or substandard freeboard.

To satisfy future freeboard requirements, including possible future sea level rise and accounting for the effective depth of the new superstructure, the track would need to be raised 700 – 1,250mm. As this is only a possible future requirement it was agreed not to raise the soffit levels of these two bridges at this time but to design-in a method for the bridge superstructures to be lifted. By doing so, this work could be completed at a later date, and in parallel with adjacent line raising.

To allow for the potential future lifting of Bridges 88 and 89, recesses have been provided in the top of the abutment caps, which allow jacks to be installed to enable the superstructure to be raised. At the piers, horizontal ducts have been provided through the piers which will allow temporary jacking corbels to be attached using post-tensioning bars. The depth of the abutment and pier caps will then need to be increased to permanently support the superstructure at its new height through insitu concrete pours. The substructure was then designed considering increased seismic mass and an increase in the effective seismic inertia height.

Soil loads at the bridge abutments

A risk was identified that the existing embankments could impose creep and/or seismic soil displacements on the structure, as the approaches often sat anywhere from 3-6m proud of the surrounding ground. An optimisation exercise was carried out to balance approach embankment improvements with the structural capacity of the structure to sustain soil displacements.

Soil improvements were limited to localised replacement of material behind the abutments with geogrid improved gravel rafts. Additional oversized pile sleeves and approach setbacks were too provided to limit the improved material imposing large passive earth pressures on the structure should movement occur. Where only shallow sleeves were required, inexpensive and readily available precast concrete risers were used. Approach setback details typically used across the replacement bridges can be seen in Figure 7 (left). In the instance of Bridge 100

NAL which required a mechanically stabilized earth wall embankment, the entire approach was set back behind the piles as shown in Figure 7 (right). The settlement slabs then acted as land spans to bridge the gap between the approach embankment and the abutments.

Given the improvements noted, the bridge structures were then designed to accommodate any residual creep and seismic soil displacements. Estimated soil creep displacements ranged between 80 and 300mm whilst the seismic displacements ranged between 40 and 300mm. These displacements are predominantly expected to take place in the longitudinal direction of the bridge.

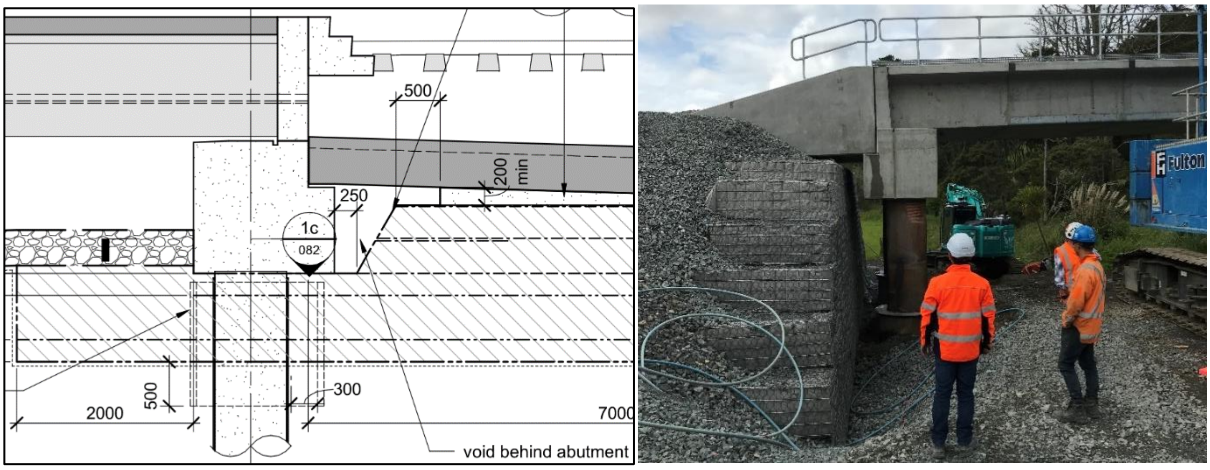

Figure 7. Approach setbacks, left – typical across bridges, right - Brigde 100 NAL

Early Procurement of Materials

Early procurement of pile casing was crucial to starting construction on time. For the case of the NRU programme, this meant confirming the pile size very early in the design process. Having sized the piles for vertical loads, seismic inertia checks were found to not be not critical given the bridges low seismic hazard zone. The piles were however very sensitive to both creep and seismic soil ground displacements. With limited geotechnical investigations and detailed embankment modeling still underway this was a challenge. An exercise was therefore undertaken to identify the outstanding risk at each bridge site and what mitigation measures could be implemented through design. The following were all considered:

- Form plastic hinges in the piles when subject to seismic soil movements.
- Pile casings considered as permanent structural elements to increase moment capacity in highly loaded areas.
- Increase extent of ground improvement behind the abutments to reduce expected movements.
- Increase the length of oversized sleeves provided.
- Construction of the embankments before the piles, to enable short term construction sequence related movements to take place prior to pile installation.
- Apply seismic philosophy to the design of creep soil movements, allowing plastic hinges to form in selected locations while insuring stability when subject to dead and live loads.
- Install monitoring equipment to track slope movements and implement a traffic light system to identify movements that may trigger slope stabilisation works being required.

SUMMARY

The completion of the Northland Rail Upgrade project has improved the conditions for rail freight growth between Northland and Auckland by providing a more resilient and reliable network, reducing journey times, and enabling High-cube container freight. This will help reduce road congestion by reducing road freight movements, which will also reduce overall transport emissions.

The replacement of five bridges has provided a more resilient and reliable network as they have been designed to current design standards which has enabled speed restrictions to be eased and axle load limitations that were in place for the existing bridges to be removed. The ballast tray form of the new bridges also requires less maintenance than the directly fastened track bridge structures that they replace. Safety for railway maintenance staff has also been improved by the provision of walkways with handrails, across either side of each new bridge.

The standardisation of the bridge forms, in particular that of the superstructure and the adoption of match-cast segmental construction proved to be key to the success of this project. As it significantly reduced the on-site construction time enabling the compressed programme to be met.

Another key objective of the project was to bring economic benefits to the Northland communities. This was achieved through the design team engaging local consultancies to participate in the design delivery and utilising locally sourced material and labour for construction, such as precast concrete. One of the three contractors engaged to build the bridges was also locally based in Northland, and they constructed both Bridges 126 and 168, located near Wellsford and Whangarei respectively. This enabled the upskilling of the local staff, in addition to bringing economic returns to the region. The ultimate prize for the Northland communities is the rejuvenated NAL, which enables improved and effective freight movement, additionally allowing for the connection to the future proposed Marsden Point Link.

The objectives the project setout to achieve were successfully completed on-time and on-budget and the Hi-Cube capable NAL re-opened for rail traffic on the 11th of January 2021.

Figure 8. New Bridge 88 NAL

Figure 9. Bridge 126 NAL near completion and Bridge 168 NAL

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