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Railway Bridge: Design and Detailing for Construction

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Abstract

Holmes Consulting Group have been involved in a number of railway bridge replacement projects with Tranz Rail Ltd. A major factor in these bridge replacement projects is the requirement to maintain normal day-to-day operation of the railway lines for the duration of the construction and complete the changeover within a short timeframe. Three recent projects undertaken have required close cooperation between the designers, contractors and Tranz Rail to ensure smooth completion of the railway bridge construction.

Bridge 177, North Auckland Line, Whangarei, included the replacement of the existing two span railway bridge with much longer spans to improve local traffic flow underneath the bridge. Precast, post-tensioned concrete "L" beams, each 27.5 metres long were lifted into position and connected with an in-situ concrete splice to form a "U" shaped bridge superstructure.

Bridge 2A, Newmarket Line included the construction of a three span, post-tensioned concrete superstructure, with a 48 metre central span, as part of the Grafton Gully motorway extension. The 2300 tonne superstructure was constructed on falsework alongside the existing rail embankment and pulled across, in one piece, 15 metres sideways into position.

The Otira Underpass project on State Highway 73 is related to highway alignment improvement works. Improvements to the existing road alignment are being combined with a new railway bridge to increase clearances for larger vehicles to use this route. The 3-span superstructure was successfully slid transversely into position during a series of 12 hour block-of-line periods on a busy section of railway line.

1.0 Introduction

Construction of railway bridge structures usually necessitates the continued operation of the railway lines, especially with the replacement of an existing structure.

The three projects featured in this paper required the construction of new or replacement bridge structures to allow modifications for road realignments underneath the existing railway bridges.

Due to the requirements to maintain normal railway operations for the duration of the project, the new bridge superstructures are installed during a short "block of line" period. The time set aside for the operation must allow for the removal of existing bridge or embankment structures, positioning of the new bridge superstructure and reinstatement of the rail tracks.

Bridge design and construction must take into account the proposed methods for installation within the limited time available for this critical phase of the operation. Engineering of the proposed designs, with inputs from the contractor regarding their proposed construction and installation methodology, has allowed the successful completion of all three projects featured.

Project 1: Bridge 177 NAL

Bridge 177, North Auckland Line is located in central Whangarei and was completed in January 2003. The original bridge, a 31 m long two span bridge, carried rail traffic through Whangarei between Westfield and Otiria. As part of the reconstruction of the intersection beneath the railway bridge, the Whangarei District Council requested that Tranz Rail extend the bridge by approximately 20 m in the southern direction.

As shown in Figures 1 and 2, the new Bridge 177 includes two 27.5 metre spans with a single track ballast deck. The superstructure is a 2.4 metre deep U-shaped post-tensioned girder.

Reinforced concrete piles, footings and columns were constructed with the existing bridge remaining in operation. Precast concrete abutment beams were placed during two short block of line periods prior to the main changeover operation. The central pier cap was placed after the existing bridge and embankments were removed during the main 48 hour changeover operation.

The superstructure was precast as two separate L-shaped sections per span. These

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L-beams were post-tensioned separately, lifted

**Figure 1** Bridge 177 NAL, Whangarei

**Figure 2** Bridge 177 NAL, Whangarei, view of completed railway tracks
into position and joined with a cast in-situ strip to form the U-shaped superstructure.

The original bridge design was developed by Tranz Rail. Fulton Hogan Civil was contracted to construct the new bridge and complete the other roading works associated with the project for the Whangarei District Council. Holmes Consulting Group and Fulton Hogan Civil were involved in the value re-engineering of the original design and developed a similar bridge design and structure incorporating the required detailing and constructability aspects.

Project 2: Otira Underpass Replacement

The Otira Underpass replacement was completed in July 2003. The project was initiated and funded by Transit NZ as part of the State Highway 73 upgrade. The main drivers for replacing the existing underpass structure were to improve the vehicular clearance through the structure, improve highway alignment and public safety.

The bridge, known to Tranz Rail as Bridge 51 Midland Line, is situated approximately 1 km from Otira township and 3 km west of the Otira Rail Tunnel. The new bridge is located on a straight but inclined section of rail track with the road running at an approximate skew angle of 50° to the railway. The existing underpass was located within metres of the new structure and was partially demolished and backfilled once the new bridge was fully operational.

The new three span bridge structure, shown in Figure 3, comprises reinforced concrete post-tensioned spans on twin pile bents. The single track ballast deck is supported by a flat concrete slab with 1 m high vertical upstands on each side, as can be seen in Figure 4.

Tranz Rail’s design requirements were such that the replacement structure provide equal (or less) maintenance than the existing structure. This was achieved through the use of monolithic detailing between pier caps, abutment caps and the main girder. Transit NZ’s roading consultant also required the distance between rail level and the bridge soffit be minimised to reduce volumes of earthworks and maximise the vertical clearance for the highway.

The project was designed by Holmes Consulting Group, for Tranz Rail Ltd as part of the Transit NZ funded state highway works. Fulton Hogan were awarded the contract to construct the new railway bridge.

Figure 3 Otira Underpass, before road construction. The existing underpass is located to the right of the new bridge.
Project 3:- Bridge 2A Newmarket Line

Bridge 2A Newmarket Line is a new bridge structure required as part of Auckland’s Grafton Gully motorway improvements, undertaken by Transit NZ. The bridge replaces a section of railway embankment which was removed to allow for a new road alignment. The new Stanley Street alignment passes under the railway line at the Beach Rd / Parnell Rise / Stanley Street intersection. Major changes to this intersection have been undertaken to improve access from the port to the motorways.

The new bridge, shown in Figures 5 and 6, includes a 3 span post-tensioned concrete superstructure, 68 metres in length with a 48 metre central span. The central span comprises a reinforced concrete bottom slab, transversely post-tensioned to carry a double track ballast railway. Tall upstand walls, longitudinally post-tensioned, on either side of the bridge carry loads back to the twin pile bent supports. End spans are a similar configuration without the transverse post-tensioning.

The section of railway over this bridge carries commuter suburban rail services between the new Britomart underground railway station, the adjacent Strand Station (the old Auckland Railway Station) and the Newmarket station. The Overlander/Northerner passenger service and freight services also utilise this section of line.

This bridge superstructure was constructed on temporary steel falsework constructed alongside the existing railway embankment. Weighing approximately 2300 tonnes, the 15 metre transverse slide to install the superstructure is believed to be the heaviest transverse bridge superstructure sliding operation undertaken in New Zealand. The bridge was launched into position late January 2003.

This bridge was designed by Tranz Rail and constructed by Fletcher Construction as part of the Freeflow Alliance, including Transit NZ, involved with the motorway improvements being undertaken in Grafton Gully. Holmes Consulting Group provided a construction monitoring role for Tranz Rail and value engineering services during the construction phase.
**Figure 5**  Bridge 2A Newmarket Line

**Figure 6**  Bridge 2A Newmarket Line, view through completed bridge superstructure
2.0 Maintenance Requirements

The three projects featured in this paper were required as part of roading projects, which affected the existing railway lines adjacent to the roadway. The railway bridges replaced were not due for renewal by Tranz Rail or subject to future planned railway alterations.

A significant consideration in the development of the new, replacement, bridges was to provide a structure with similar maintenance requirements as the existing structures being replaced.

Reinforced or post-tensioned concrete structures were selected for the advantages relating to reduced maintenance and inspection requirements for these structures, compared to steel superstructures. Concrete also provides improved resistance to accidental road vehicle impact and/or impact from de-railed railway wagons compared to steel superstructures. ‘Through’ type superstructures generally provide thinner rail to beam soffit dimensions when compared to conventional superstructures. Concrete superstructures also generally have thinner slabs compared to the floor beams required on a similar steel superstructure. As a result the clearance between the highway and bridge soffit can be optimised without impacting on highway geometrics. Hence a “U” shaped concrete span allows railway and highway levels to more closely approach one another than is possible with an underslung beam system. This permits more flexibility in simultaneously optimising road & railway levels.

Monolithic detailing is utilised where ever possible to minimise joints and bearings in the bridge and therefore reduce maintenance requirements.

Despite the heavier dead load, Tranz Rail has a preference for the bridge structures to have a ballast deck. Ballast deck bridges support the railway tracks and sleepers along with a layer of railway ballast rather than direct fixing of the railway track and sleepers to the bridge deck. Structures with a ballast deck have advantages over direct fixings with the maintenance and repair of the track in the event of damage from de-railed wagons. Also regrading or re-levelling of the railway tracks can be more easily completed with a ballast deck structure for maintenance or future re-alignments of the railway line.

3.0 Operational Requirements

The continued, uninterrupted, operation of the railway lines had to be largely maintained throughout the duration of the construction of the new bridges. Exceptions to this were co-ordinated with Tranz Rail through short block of line periods to complete any works which interrupt normal rail operations on the line.

Strict safety requirements, including operating clearances around live railway lines, have to be maintained throughout construction. The design of new piles and columns were positioned, wherever possible, outside the line of the track and main construction activities located away from the clearance envelope, to minimise the impact on rail operations.

The Otira Underpass is located on the Coal Route, just before the Otira Tunnel. Transport of coal from the West Coast, for export via the port at Lyttleton, forms a significant commercial operation for Tranz Rail. Rail traffic through this section of line is very busy, with up to two trains per hour. Five fully powered locomotives are required to haul a fully laden coal train up through the Otira Tunnel. Minimum speed limits must be maintained on the approach to the Otira Tunnel or trains have difficulty maintaining sufficient momentum to climb through the 8 km long tunnel. Typically three locomotives then return to the Otira side of the tunnel as they are not required to haul the train for the remainder of the journey through to Lyttleton.

Commuter rail operations from the main Auckland Railway Station (now located at Britomart) were maintained throughout the construction of Bridge 2A. Commuter rail services run as frequently as every 15 minutes during peak periods along this section of railway line, to and from the Britomart Station.

A series of weekend only block of lines, for Bridge 2A, were required to install the piles, columns and temporary cofferdams within the railway embankment. Temporary relieving beams were placed to carry the railway lines over the cofferdams and allowed the abutment and pierhead caps to be constructed insitu beneath the railway lines without further interrupting the rail traffic. The main construction activities took place away from the railway embankment which permitted uninterrupted railway operations through-out the construction phase.
4.0 Design and Detailing Considerations

All three bridges featured have been designed using simply supported spans. This design approach simplifies the detailing of the spans and permits an easy span by span construction methodology. For the Otira Underpass project, the each span was installed on a separate occasion and opened to rail traffic after each installation.

Twin pile bents with deep pile foundations, founded on driven plugs in gravels or socketed into underlying rock were used on each project. Bridge 177NAL also utilised a shallow footing for the central pier which offered construction savings compared to the piles as originally proposed. The simple foundation systems are designed to take vertical applied loads as well as resist lateral loadings from earth pressure at the abutments from the approach embankments and from seismic loadings. The twin pile bent configuration offers the advantage that the new foundations can be located to minimise impact on day-to-day rail operations during construction, where ever possible, by positioning them outside the rail clearance envelope.

The design of the bridge superstructure must consider any potential construction sequences and methodologies which may be viable for constructing the bridge. The original design and detailing may require modification or verification once inputs from the selected contractor are received as to their preferred construction methodology. Value engineering with the selected contractor may be used to match the design to their proposed construction sequence and/or equipment capacities. This may also help reduce any risks associated with a particular methodology if the contractor has suitable input or background into the structures design philosophy and detailing. Design modifications or checks can be made on the original structure design to verify the structure will not be overstressed as a consequence of the proposed construction methodology.

5.0 Construction Methodology

Due to the logistics of replacing an existing railway bridge structure or formation, which is to remain operational for the duration of the construction period, the methodology to construct the new bridge requires consideration at the beginning of the design phase. It is often impractical or impossible to divert rail traffic away from or around the construction site, as is often done with roading projects.

The three replacement bridge superstructures covered here were designed to be constructed adjacent to the final bridge position, or off-site in the case of Bridge 177NAL, and located into the final positions during 2 - 3 day block of line operations.

Construction of the superstructure elements for the Otira Underpass and Bridge 2A were carried out alongside the existing railway embankment. The superstructures were installed by sliding them laterally into position. The Bridge 177 NAL superstructure beams were precast and post-tensioned off site, trucked to location and craned into position.

The Otira Underpass spans were built on a formation constructed from locally sourced material, alongside the existing railway embankment. While the piles and columns were being installed, work was underway constructing the cap beams and deck. The abutment and pier caps were constructed on grade alongside the final bridge location. The main deck girders were constructed on temporary formwork and connected to the caps to form a monolithic structure.

The contractor’s construction methodology differed slightly from the designers intentions, as they proposed sliding the precast caps and girders into position rather than using large cranes to lift them into place. The availability of suitable craneage at the time of construction dictated this alteration to the construction methodology.

Construction of a temporary formation alongside the Bridge 2A site was not practical as the site is located in a busy urban area. Hence a temporary steel falsework structure was constructed alongside the existing embankment, supported on driven steel H piles. The bridge spans were constructed on the falsework which included large support beams that formed the support points for the launching operation.

Temporary cofferdams were constructed within the existing railway embankment. These were designed by the contractor to retain the sides of an excavation made through the embankment to construct the piles, abutment and pierhead beams. The cofferdams also supported the relieving beams which carried the railway tracks over the excavation within the cofferdams.

The original design for the Bridge 2A project included post-tensioning to the central span only. During construction the reinforced concrete end spans were re-designed to incorporate several of the post-tensioning tendons from the central span. The simply supported nature of the spans was maintained and several tendons were extended through the bottom slab of the span. This also had the
advantage of tying the structure together as one piece for the launching operation, eliminating the need for extensive brackets to link the three spans together.

6.0 Changeover Operation

Activities during the changeover operation require co-ordination of a number of different parties associated with completing the structural and track installation activities. Careful planning and co-ordination of the activities on the changeover day forms a vital part of the success of the operation.

In the three projects featured, demolition and excavation activities formed the first phase of the changeover operation. The existing bridge structures or railway embankments had to be removed in order to position the new bridges in place along the railway line.

Tranz Rail require a detailed methodology and programme for the changeover operation to be submitted by the contractor and approved prior to the block of line being approved. The methodology usually outlines considerations for the resources required (earthmoving equipment, craneage requirements, access and labour) along with co-ordination required with other rail related activities (block of line duration, track removal and reinstatement). Disruption to rail services and alternative services if required, traffic management for construction activities and public notification is generally included as part of the overall changeover operation.

While a contingency is built into the programme for the changeover operation, disruption to rail services beyond the planned duration of the block of line is not acceptable to Tranz Rail. The changeover operations for the three projects featured were all successfully completed within the allotted times for the block of line.

The Bridge 177NAL superstructure changeover operation was undertaken during a 48 hour block of line period. During this time the existing bridge spans were removed, the existing bridge abutment structures demolished and the railway embankment excavated to provide for the extended new bridge. Installation of the new precast concrete cap beam, post-tensioned concrete L-beams and casting of the in-situ infill strip completed the superstructure. By supporting the formwork for the in-situ infill strip off the precast L-beams temporary propping off the ground was avoided. There was originally a road closure allowed for one week but this let the contractor hand over the road to the District Council early. Other roadworks were subsequently undertaken beneath the new bridge as part of widening and placement of a roundabout around the central pier of the new bridge.

The Otira Underpass project changeover was completed with three 12 hour block of line operations to install a span at a time. These block of lines were scheduled to coincide with rail line closures for other Tranz Rail project work on the Coal Route (e.g. repair work to the Otira Tunnel). The block of line period had to include removal of the existing track, excavation of the embankment to a suitable level to allow the span to be pushed into position and reinstatement of the rail tracks. Further excavation to provide for the road re-alignment was completed outside these block of lines. One further block of line period was required to partially demolish and infill the existing underpass after the new road re-alignment was completed.

Bridge 2A in Newmarket was installed during a 72 hour block of line on Auckland’s Anniversary weekend. Activities commenced on the Friday evening after the last commuter train passed through. Bus services were put in place for the Saturday between the Newmarket and Auckland stations, while no rail services were scheduled for Sundays and public holidays. Embankment excavations took place through the night and the structure was located above its final position by Saturday evening. The structure was lowered and ready for handover on the Sunday. Transfield Services Ltd complete the track installation and laying of ballast and the line was re-opened to rail traffic late Monday night. Further excavation and road re-alignment took place after the bridge was installed and operational. The new road alignment has recently been opened to normal traffic.

The sideways launching operation of the 2300 tonne superstructure for Bridge 2A also required the ability for the superstructure to be lifted up at any stage of the launch operation. The contractor designed and cast a number of stainless steel “slipper pads” into the underside of the superstructure while it was resting on the falsework. These temporary bearings were used to slide the bridge along steel launching beams constructed as part of the falsework and onto the reinforced concrete pierhead beams of the final structure.

The concrete pierhead beams were checked to ensure that the superstructure could be lifted up, with a special jack arrangement, at any stage if any problems were encountered during the sliding operation. This jack arrangement was also used to lift the superstructure to remove the temporary bearings and lower the
bridge onto its permanent bearings. All aspects of the contractor's proposed launching operation were checked to verify that overstressing of the final bridge structure would not occur.

The Otira Underpass bridge utilised a similar sideways launching operation as used for Bridge 2A. The two end spans of the bridge were installed first during earlier block of line operations with the main central span installed last. The cap between the piles/columns was constructed integral with the end spans. High early strength concrete products were used in the pile/column connection to the cap to avoid having to pour and cure large quantities of concrete. The rapid hardening mortar also allowed the rail line to be re-opened to rail traffic soon after installation.

7.0 Conclusions

The three bridge projects featured in this paper have been successfully constructed and installed within the available timeframes allotted for their installation. This has required the careful planning of the construction and changeover operations along with close co-operation and co-ordination of a number of activities required on site for each project.

The need to maintain normal rail operations, uninterrupted as far as is practicable, during the construction phase, requires consideration at the earliest state of design. Design, planning and co-ordination, to achieve a successful changeover to the new bridge structure, during a relatively short timeframe, is also required to be considered throughout the design and construction phases.

The three recent projects undertaken, Bridge 177NAL, in Whangarei, Otira Underpass and Bridge 2A, Newmarket have shown close co-operation required between the designers, contractors and Tranz Rail which has provided a successful outcome and smooth completion of the new railway bridges constructed.

8.0 Acknowledgements

The successful completion of these three projects would not have been possible without the contributions and co-operation from Tranz Rail, Transit NZ, Fulton Hogan Civil, Fulton Hogan Civil (South Island) and the Freeflow Alliance.