BRIDGE 1 RAPAHOE: DESIGN AND DETAILING

R. A. Presland[1], A. Bell[2] and W.R. Rushbrook[3]

Abstract

The new Bridge 1 Rapahoe Line railway bridge crosses the Grey River, just outside Greymouth. This bridge carries trains transporting coal from mines to the north of Greymouth to be exported via the Port of Lyttleton. The new bridge is a replacement structure for the 110 year old original timber truss bridge, which was removed as part of this project.

This paper describes considerations in developing the design of the new railway bridge at this site and construction methodology innovations required to complete the project.

The post-tensioned concrete U beam superstructure was designed with provision to develop preferred construction methodologies alongside the successful contractor. The winning tenderer, Smithbridge Ltd, proposed using precast post-tensioned L beam units with a cast in-situ, post-tensioned bottom slab. The methodology provided a self supporting platform limiting the amount of work needed to be completed over the river's waterway.

The successful completion of this project was achieved through the Contractor developing a preferred construction methodology, confirmed through re-design by the structural designers and a client prepared to explore opportunities to develop project details.

1.0 Introduction

The original railway bridge constructed across the Grey River was a timber truss bridge designed for the Greymouth-Port Elizabeth Rail Company. Design commenced in 1896 and the bridge was completed in 1899. The bridge was built to provide rail access to the northern side of the river to extract coal from mines in the Rapahoe area.

The bridge has a total length of 265 metres consisting of nine 80 foot and two 40 foot timber Howe trusses and short timber rail beam spans at each end. The bridge was founded on driven timber pile, sheathed piers and formed an S-shape alignment in plan. This unique bridge was one of only two know remaining examples of this type of bridge in the world.

A review of the existing bridge, undertaken to determine the ability of the structure to carry heavier trains, showed that the bridge had effectively reached the end of its economic life.

Restrictions were also in place on the existing bridge limiting the axle weight of coal wagons crossing the bridge. Due to the bridge alignment, loaded coal trains coming from the Rapahoe Line had to enter the Greymouth depot and be shunted before continuing on to Lyttleton along the Midland Line. This often conflicted with the Tranz-Alpine passenger service which stops at Greymouth.

Recommendations were put forward to design and construct a replacement bridge structure whilst maintaining the existing bridge in a serviceable condition until the new bridge was completed.

2.0 Replacement Bridge Options

Several previous schemes had been developed over the years prior to the latest review of the existing bridge, examining options for bridge structural form and alignment. Geotechnical investigations had been completed for some options and the potential for design-build procurement options had also investigated.

Options reviewed included a replacement bridge on a straight alignment paralleling the existing bridge or a new bridge alignment. Options for steel and concrete superstructure were investigated for each of the alignment options.

Alignment 1 proposed a replacement bridge on a straight alignment roughly paralleling the existing bridge. This option would have impacted on current rail levels and require loaded coal trains to enter the Greymouth depot for shunting before heading to Lyttleton.

Alignment 3 was a horizontally curved alignment approximately 100 m upstream of the existing bridge. This alignment would require a longer length of bridge as well as a significant length of approach embankment on the southern side of the river.

The preferred alignment, Alignment 2, was

---

[1] Holmes Consulting Group, Wellington

[2] General Manager, Smithbridge Ltd

[3] Structures Manager, Ontrack

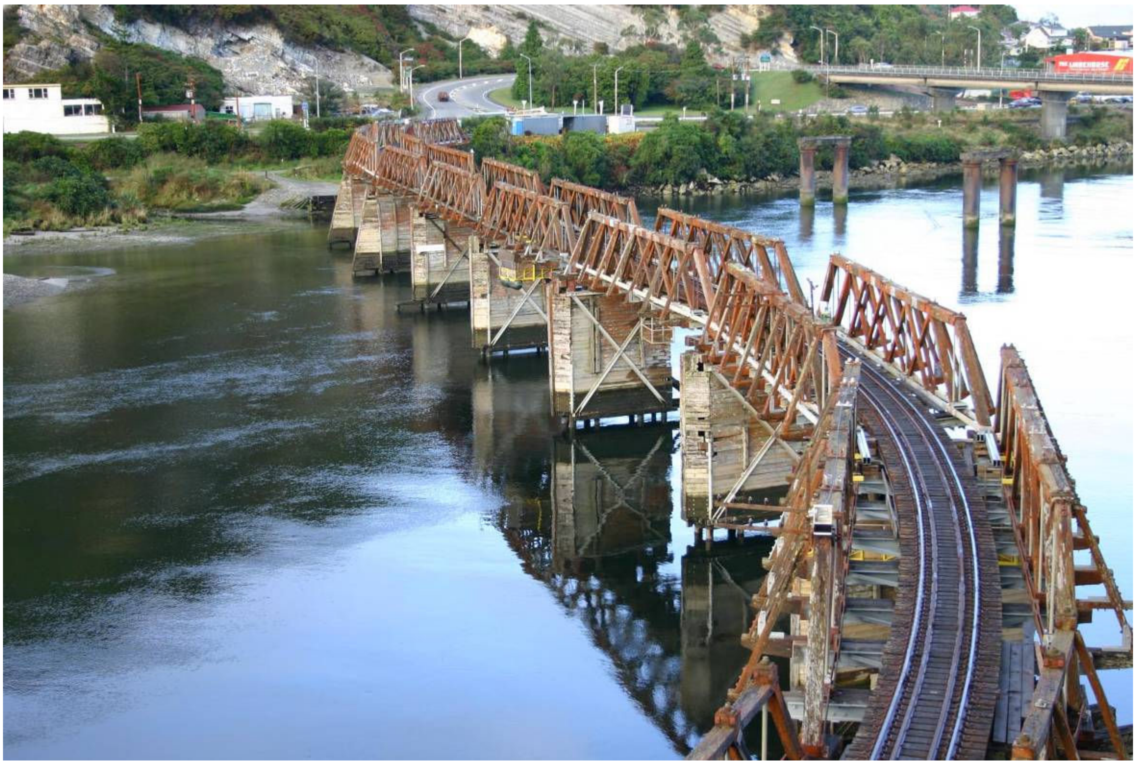

Figure 1 Existing Bridge 1 Rapahoe showing S-shaped alignment

intermediate between the above two options, located ~50 m upstream of the existing bridge. The bridge comprised two short 150 metre radius curves at each end of the bridge linked by a straight segment. A shorter approach embankment on the southern side of the river allowed the new alignment to link directly into the Midland Line and loaded coal trains to head directly to Lyttleton.

3.0 Design Considerations

The design of the new bridge was to allow for maximum axle weights on loaded wagons and to improve flood clearances beneath the new bridge.

The existing Rapahoe Line rail track alignment is constrained on a narrow rock ledge cut into a cliff face on the northern side of river, limiting options for re-aligning the track in this location. Any changes to the rail levels on the northern, Rapahoe Line, approach and the southern, Midland Line, approach were to be kept to a minimum. The low grades on the approaches would have required significant lengths of rail track re-alignment if rail levels were changed significantly.

The Grey River has one of the largest river catchments in New Zealand and is capable of passing significant floods. A minimum 1.2 metre freeboard over the 100 year flood was adopted for the new bridge design, requiring the new bridge rail alignment to be located higher than the existing rail bridge alignment. With the 100 year flood level estimated at RL 7.0 m, this required raising the rail alignment 0.3 m at the northern abutment and 1.5 m relative to the southern abutment of the existing bridge.

Single circular piers were selected for the new bridge as these would offer less resistance to river flows compared to a multi-column arrangement. As the new bridge is sited near a large bend in the river, the piers are also subject to variable angles of flood flow. Span lengths and pier locations were chosen to minimise the number of piers within the waterway to limit the impact on flood levels.

In order to provide the maximum freeboard clearance and limit any potential impact on existing rail levels, a through girder superstructure was selected (refer Figure 2) . This also allowed for a ballast bridge deck – where the railway track is supported on ballast. This type of bridge deck is preferred as there is no change of track construction and maintenance requirements between the approach embankments and the bridge deck.

Reinforced concrete single column piers and sub-structure were favoured for all bridge options considered as part of this project. Concrete was

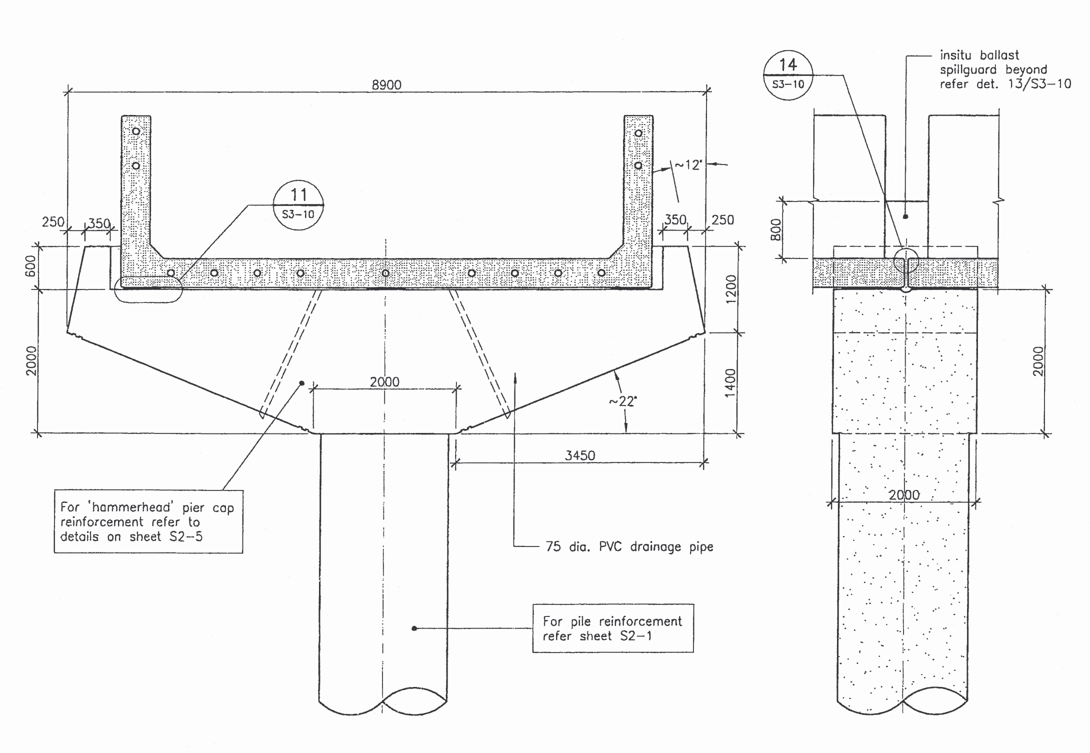

Figure 2 New bridge cross section

also the favoured construction material as it is considered superior for durable performance in this aggressive environment, which is close to the sea. Concrete superstructure options are also more robust at resisting possible train derailment effects.

The new bridge structure is 290 metres long, comprised of 10-27.5 metre spans and a shorter span at the northern end of the bridge. The “U” shaped through girder superstructure is 2.4 metres deep and 7.4 metres overall width, to allow for the curved rail track alignment and adequate clearances for locomotives and wagons.

The simply supported post-tensioned superstructure beams are supported on a reinforced concrete hammerhead beam on a 1.8 m reinforced concrete column. The column is supported on a 2.0 m diameter reinforced concrete pile founded into the river gravels or underlying limestone papa rock. The deepest pile extended 36 metres below the river level to found in gravels at depth.

The superstructure beams were cast from 60 MPa strength concrete, primarily to cater for strength requirements of the post-tensioning of the spans and high railway live loadings. The high strength concrete also offers good durability performance for this bridge which has a 100 year design life. For these reasons 45 MPa strength concrete was adopted for the hammerheads and other substructure concrete. As the river water levels at the bridge site are affected by tide levels, the columns were specified as a marine grade concrete (50 MPa with micro-silica) due to the potential for sea water migrating up the river channel. Piles were specified as conventional 50 MPa strength concrete, to match the columns above, as they are protected within a 20 mm thick permanent steel casing.

4.0 Resource Consent Considerations

The construction of a new bridge over a major river and the demolition of the existing historic bridge had the potential to raise numerous issues through the Resource Consent process. Considerations for minimising the effect of constructing a new bridge in the river and the effects on the ability of the river to pass flood flows was an important factor to resolve during the design stage.

Considerable modelling of flood flows was undertaken for this project to examine the changes in flood levels upstream, due to the construction of the new bridge piers. This modelling was extended to cover the construction period where the new bridge piers, existing bridge piers and piles for a temporary access bridge would be present in the river bed. In addition to piers and piles associated with this project, there are also piers to the old road bridge and existing road bridge downstream of the site.

This additional hydraulic modelling demonstrated that the effects on flood levels in the river would be minimal during the construction period. The project also required the removal of the existing bridge piers which is predicted to result in a decrease in flood levels upstream during flood conditions, compared to the situation with the original bridge.

Construction of the southern approach embankment involved the extraction of gravel from the river bed to provide source material. Existing gravel extraction consents were available for sourcing this material as local companies operate commercial gravel extraction operations from this site.

Options for constructing the bridge across the river were unlikely to allow for the use of a large gravel embankment being advanced across the river for access to construct piles at pier locations. This method was used for construction of the existing road bridge downstream and this temporary embankment was washed out a couple of times during construction, with consequent delays and costs. With the Resource Management Act, it would be unlikely that a temporary gravel embankment would have been granted consent so temporary access staging would have to be considered.

Due to the condition of the existing bridge, its removal from the river was considered necessary, for safety and flooding purposes. The removal of this listed, historic structure would result in the loss of heritage values for future generations. Local historic groups were interested in retaining a truss span from the old bridge for incorporating into a heritage park development at the old south abutment.

Consultation with affected parties including local iwi and the Historic Places Trust lead to the Resource Consent for this project being granted on a non-notified basis.

5.0 Construction and Detailing Considerations

The design phase of the project was set up as a conventional – design and document for tender process. The bridge superstructure was designed, detailed and tendered as a fully cast insitu structure. Considerations for the constructability and potential construction methodologies recognised that further value could be brought to the process by allowing contractors some level of input into the design and detailing.

With the knowledge that contractors would be likely to bring further ideas to the table, the Client was prepared to explore opportunities to incorporate these ideas into the design and/or construction to help minimise construction costs but also ensure that construction risks were controllable.

Contractors tendering for the project were encouraged to offer alternative designs within the general scope of the original design. In order to limit design costs associated with preparing alternative designs, a “Commercial in Confidence” opportunity was offered to each tenderer to put forward alternative design and/or construction options. Each tenderer’s options were assessed by the original designers for suitability and advanced in sufficient detail to enable the tenderers to provide a tender price. Full design and documentation of the successful tenderer’s concept would take place after award of the contract.

The successful tenderer, Smithbridge Ltd, proposed a part precast, part insitu construction detail for the superstructure U beams (refer

Figure **3**). This methodology offered the opportunity to complete much of the superstructure work over the river from a suspended, self supporting platform clear of any potential flood flows. This reduced risks of high river levels washing out any temporary falsework before a cast insitu span can be self supporting.

The size of the precast elements was limited by craneage requirements and limits on the temporary access staging. Two 150 tonne crawler cranes were to be used on site for constructing the temporary access bridge and permanent piles of the new bridge. These cranes would also be used to lift the new superstructure beams into place and heavier precast elements would require larger cranes and a heavier temporary access staging. The 85-90 tonne weight limit for the precast elements was at the limit of the cranes lifting capacity when placing the outer L-beam units off the temporary staging.

The precast L beam concept had been employed on similar previous railway bridge span construction but not with the incorporation of post-tensioning tendons within the insitu stitch. Typically the insitu bottom slab stitch was kept to a minimum width and only conventionally reinforced rather than constituting a majority of the bottom slab to the girder. Previous examples of this type of construction also did not have the limitations on craneage and access due to the use of temporary staging over the river, unique to this project.

The L-beams were precast off-site at a local precast and ready mix concrete facility about 20 minutes travel south of Greymouth. Each of the precast L-beams was cast in the yard and post-tensioned so that they could be lifted and transported to site. Once moved to the new bridge site, they were lifted into place between the

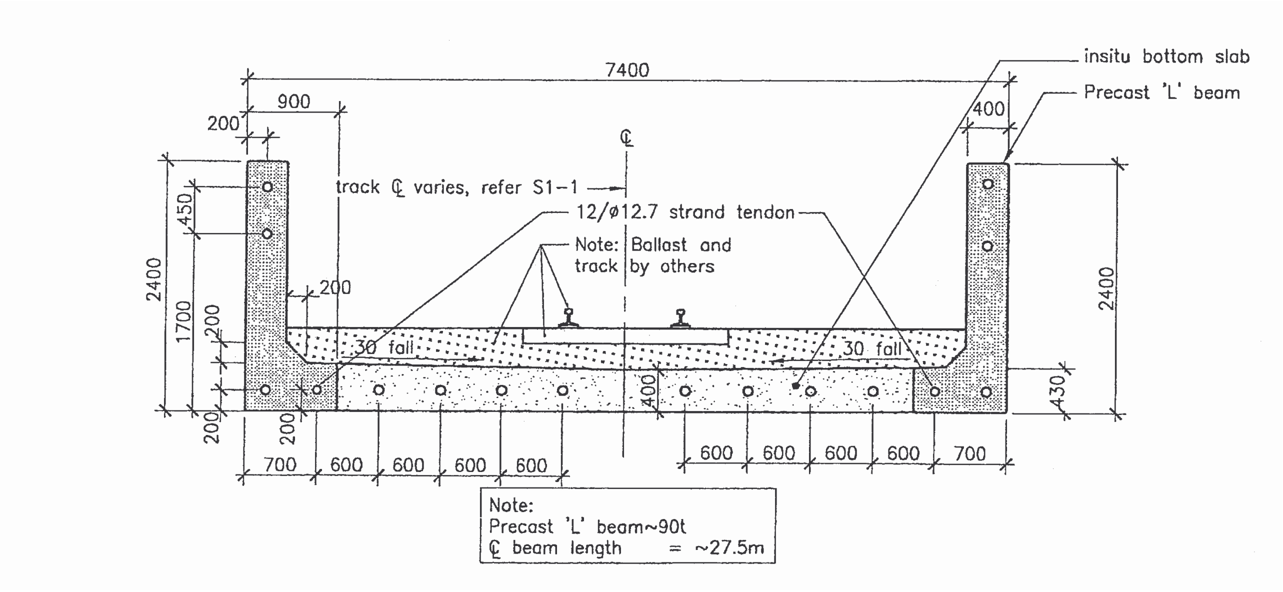

Figure 3 Superstructure girders showing typical precast L beams and insitu bottom slab stitch

Figure 4 Precast L-beams in place on piers

completed piers. Falsework was designed to be supported off the toe of the L-beams to provide a working platform to complete reinforcement and casting of the insitu bottom slab.

Detailed design of the contractors preferred methodology was required to consider the changes in the section properties, from the L-shape to the U-shaped beam and the effects of the staged post-tensioning once the insitu bottom slab tendons were stressed. Positioning of post-tensioning tendons within the L-beams had to balance stresses within the L-section during lifting and under construction loading before the bottom slab became composite with two L-beam units.

Once the bottom slab became composite with the L-beams, forming a U-shaped girder, additional stresses were introduced into the section due to the post-tensioning of the tendons in the bottom slab. Further stresses occur in the U-shaped girder with the addition of ballast, railway tracks and railway live loads.

The effects of differential shrinkage and creep between the precast and insitu sections were also included in design checks. This effect was an important consideration in ensuring that the proposed post-tension tendon layout within the L-beams and the final U-shaped girder would give long term stresses within the post-tensioned concrete beam that complied with design codes. A finite element model of the U-girder was developed to allow an examination of the development of stresses at key points within the section over time due to the development of the differential shrinkage strains. This showed that the final detailing of the post-tensioning tendons required a small increase in the tendon requirement over the original fully insitu beam design.

The north abutment area posed a challenge to construct an abutment and approach to the existing railway track alignment given the near vertical aspect of the rock cliff face . The rock cliff rises approximately 10 metres from river level and included significant overhangs at the proposed north abutment location.

The original proposal for the north abutment included the use of an abutment beam spanning from the existing rock ledge, extending beneath the existing track alignment, to a single pile constructed just outside the cliff face. A new retaining wall was to extend along the outside edge of the new railway track formation to provide sufficient width for the new track to meet with the existing track. This wall was to be stressed back into the rock cliff face using rock anchors.

The proposed location of the single pile to support one end of the north abutment beam was found to clash with an overhanging piece of the cliff face. Pushing the pile further out toward the river to avoid the overhanging rock would have resulted in a longer abutment beam and the pile encroaching into the river‘s flood flow. The solution was to form a concrete buttress stressed back against the existing rock cliff face to support the end of the north abutment beam.

Excavation and clearing of vegetation on the north abutment area showed soft clayey material had been pushed off the edge of the narrow rock ledge at the edge of the rail formation. It was believed that the rock ledge formed a roughly horizontal platform close to the base of the railway ballast layer.

Local excavation of the railway formation, in order to construct and place the last span of the bridge and the north abutment beam showed that the rock surface was deeper than expected and dropped quickly from the ledge down toward the river. Temporary steel beam spans were placed to carry the existing railway track over the excavated areas and maintain train operations while the last spans of the bridge were constructed. Excavation and placing of these spans allowed the rock surface to be exposed and founding of the north abutment retaining wall to be prepared and constructed similar in form to that envisaged in the initial design.

6.0 Changeover Operation

Throughout the construction period, trains continued operating across the existing bridge. In order to change over to the new bridge alignment, the existing track had to be cut so that the last span to the new bridge could be placed and the new bridge brought into operation.

A four day shutdown operation was scheduled for the Rapahoe Branch Line to coincide with a scheduled maintenance shutdown on the Midland Line, to facilitate the changeover to the new bridge and alignment.

A majority of the trackworks, sleepers and ballast were laid on the southern approach embankment and across the new bridge prior to the main shut down period. The last span to the new bridge was constructed as two precast L-beams to be craned into position. As this was a shorter span, the L-beams were made with a larger portion of the bottom slab within the 85 tonne weight limit. This allowed the precast sections to incorporate all the necessary post-tensioning tendons within the precast portion of the beams themselves, leaving only a short insitu, conventionally reinforced, connection between the beams. This stitch piece could be completed on one day of the changeover period once the last beam sections were lifted into position.

Figure 5 Completed new Bridge 1 Rapahoe before removal of the original bridge in the background

The remainder of the ballast and sleepers could then be completed and the railway tracks connected onto the existing alignment. Signals work was completed to re-configure the signalling for the new bridge alignment and the bridge carried it's first coal train on 2nd of June 2006.

7.0 Conclusions

Completion of the new Bridge 1 Rapahoe project marked the end of a major construction project for the West Coast, providing an improved link for rail transport of coal from the area, with the increased tonnage of coal capable of being carried across the new bridge.

The project was successfully completed on programme and budget with no delays despite the potential for difficulties with construction over a major waterway. The choice of construction methodology, proposed by the contractor and developed in conjunction with the designers, was a factor in reducing potential risks associated with working over a large river.