Refurbishment of Makatote Viaduct, New Zealand

G. Matthews¹, M. Keenan², D. Jansen²
¹TBS Group, New Zealand, ²Structures Engineering Services, KiwiRail, New Zealand

1. Introduction
The Makatote Viaduct is on the North Island Main Trunk (NIMT) Railway line, which is a 680km long railway that connects Auckland and Wellington, the two major cities in New Zealand (NZ). Due to both natural and man-made difficulties it took nearly 40 years to finally complete the whole route[1]. The railway passed through some of the most challenging terrain in the North Island and required engineering ingenuity to complete. Additionally, there was resistance from the local Iwis, who were against the settlement made between the tribal leaders and the Government.

The viaduct was one of the last pieces to be completed on the route, which was opened in 1908. At 78m above the stream it was the highest structure on NIMT until 1981. Its elegant tall and slender steel trestle piers with lightweight trusses rising through the gorge with the backdrop of National Park have made it an iconic structure (Figure 1). It has been one of the most photographed steel rail viaducts in New Zealand[2]. The Viaduct has been assessed for and found to possess aesthetic, historical, social and technologically significant values[3].

When the viaduct celebrated its centenary in 2008, it became apparent that the structure required refurbishment to extend its life and improve the resilience of the NIMT. To this end KiwiRail commissioned contractor TBS Farnsworth and design engineers Opus International Consultants (Opus) to undertake a detailed load assessment, strengthening and repairs to improve the load capacity and repainting of the entire viaduct. The physical works commenced in September 2014 and was completed in October 2016.

This paper presents the details of this work together with some critical challenges overcome on site.

2. Viaduct Description
The viaduct bridges the Makatote Gorge 12km south of National Park in Central North Island, NZ (Figure 1).

It is 262m long and 78m high. It comprises 5 No. 30m (100’) deck Pratt trusses and 10 No. 11m (36’) plate girder spans, five of which act as pier heads for the five cross braced steel towers (Figure 2).

The viaduct is a riveted structure with the girders on the piers and components of the trusses being built up using a large amount of small section lacing. The total area of coated steel is 15,400m².

3. Previous Work On Viaduct
1925 - Along with other bridges and viaducts on the NIMT, the Makatote had its truss spans strengthened to ensure it could bear the heavier class of locomotive that was being introduced[1].

1950(s) - Full abrasive blast and prime with lead based primer and two coats of a MIO alkyd build and finish coat.

1982 - Underpinning occurred on Pier 6 due to concern about scour risk of footing.

1982 - Reinforced caps and stressing cables were installed on Piers 3 & 9 for seismic resilience.

1986 - Strengthening and modifications for electrification.

1997 - Partial paint touch up of Piers 4 and 5 using a spot abrasive blast and full overcoat with moisture cured urethane.

2007 - The last significant addition to the Makatote Viaduct was the underpinning of Pier 7 due to concerns over scour.
4. Refurbishment Issues

4.1 Corrosion
One of the major concerns was the deteriorating paint system leading to significant corrosion and section loss of key elements on the viaduct. Although the existing coating has performed adequately since the last full blast and paint of the viaduct some 50 years ago, there was significant breakdown of the coating in many places and heavy corrosion very evident with some lacing elements having already been replaced (Figure 3). Like many in the world, the viaduct’s coating system was based on red lead primer (RLP) which was used extensively until the 1990’s due to its excellent performance characteristics and tolerance to poor surface preparation. It is unfortunately also harmful to the environment and humans and it is no longer in use in most parts of the world. There was an attempt to overcoat the existing lead based coatings in 1997 but poor application quality assurance and a lack of compliance to environmental based consent conditions caused the project to be cancelled when only partially complete.

A 2010 reassessment of the coating system found the adherence of the RLP to the steel substrate was now compromised meaning it would have to be removed and a new coating system installed. Removal of RLP requires a full enclosure surrounding the subject elements so that the RLP will not be discharged to the atmosphere.

4.2 Strength
The current allowable axle load is 18T on a 30m truss. The future axle load requirement has been set at 20T for locomotives and 22.5T for wagons respectively.

The normal rating of the structure is shown member by member in Figure 4 with the red line representing the required future load. Fifteen members of each truss are shown to be understrength. The towers were originally designed to resist hurricane force wind and this resulted in them having sufficient capacity for the future increased loads.

The execution of the work required significant temporary works in the form of access scaffolding and containment. The dead loads of the scaffold and the live wind loads of the containment could easily overload an already weakened structure and required close engineering management.

4.3 Environmental
The structure is in a pristine natural alpine environment with part of the structure in the Tongariro National Park. The Makatote River is a habitat of the threatened Blue Duck (Whio) and the river is a stunning clean mountain river with outstanding water quality (Figure 5). The previous attempt to paint the structure resulted in the contractor and owner being served with cessation notices by the statutory authority (Horizons Regional Council).

4.4 Weather
The viaduct is located on the southwestern slopes of Mount Ruapehu and is 700m above sea level. The closest weather stations have recorded an average of around 200 days of rain fall per annum. During the winter snow is not uncommon and frosts can be very severe.

5. Appointment of TBS Farnsworth
As a legacy of the previous painting attempt in 1997 there was reluctance from the stakeholders to give consent for the works when KiwiRail approached them again in the early 2000’s. KiwiRail needed to demonstrate exactly how they would protect the environment, because the traditional approach had been to get a specification, a resource consent, then engage a contractor to deliver the project. KiwiRail chose
to go to the market early to engage a contractor who would lead the system specification, the methodology and work with them to obtain the required resource consents. This resulted in three conforming bids with costs within 10% of each other. TBS Farnsworth (TBS) was selected as the preferred tenderer in February 2011.

Due to a funding shortfall the project was delayed for a year, then in early 2012 TBS was engaged in an early contractor involvement (ECI) agreement to carry out the following work.

- Select coatings system and prepare specification (Opus led by Willie Mandeno)
- Develop detailed methodologies for all works (TBS)
- Carry out detailed design of the strengthening of the trusses (method by TBS, detailed design by Opus)
- Obtain resource consent (by Opus)
- Design access and containment (TBS)
- Design a replacement inspection walkway (Opus & TBS)
- Assess loads on viaduct from access and determine sequencing of the works to manage the load. (Opus & TBS).

All of the strengthening work was valued and a lump sum contract was awarded to TBS in June 2014 for the full refurbishment, including strengthening and structural works to be completed by January 2017.

6. Coating System

Opus International Consultants were engaged to prepare a specification for the bridge. This involve generating a brief on the current condition of the structure, the environment and the coating design life of nominally 50 years until full replacement and then going to the market and obtaining proposals from coating manufacturers.

As a result of poor structural detailing of certain elements on a viaduct located in a harsh environment, there were many areas in which water pooled. Combined with a lack of maintenance, this resulted in significant corrosion damage. A coating system using an epoxy primer was selected to be compatible with this, and a urethane top coat was selected to provide the best weathering properties.

A supplier short list of International and Carboline was agreed upon. As the brush coating was such a large component of the work the final decision was made after reviewing cold weather curing performance and brushing trials. Altex Coatings Ltd was chosen as the preferred supplier to provide the Carboline coatings.

The initial specification called for a low pressure wash to remove vegetable matter and salts. The capture and disposal of the lead contaminated water was a major environmental obstacle so trials were carried out which demonstrated the wash was not required and all cleanliness standards were readily achieved by abrasive blasting with garnet. The heavy rainfall at this location proved to be an asset in this regard.

The initial coatings specification was:
- Dry abrasive blast to Sa2½ with a profile 40-75µm and salts<70mg/m²
- Primer Carbomastic 615MIO HBE, 150µm DFT
- Rustbond Penetrating Sealer into crevices
- Stripe with Carbomastic 615MIO HBE
- Build Carboguard 690 HBE (red tint), 150µm DFT
- Top Coat Carbothane 133, Polyurethane Venetian Red 75µm DFT

There were a number of modifications to the specification as the project developed;

1. The time taken to apply the 150µm primer severely reduced the time in a day to abrasive blast clean. This reduced production and residual dust would fall from rough sawn timber sleepers into the slow curing heavy coating with each train movement. Therefore a holding primer of Carboguard 504 at 50µm DFT was applied, then the stripe coat of 615MIO was applied on completion of all the priming in a containment and finally the build coat of 615MIO to achieve the full 150µm DFT of the prime coat.

2. The Rustbond was dispensed with as the crevice corrosion was not a significant problem and replaced with more stripe coats.

3. Both the intermediate and top coat required a full stripe coat of every rivet, crevice and edges in order to be able to guarantee the film builds. This was a finding on the painting of two previous riveted bridges and is a very significant additional cost.

There was a total of 15,300 L (one litre for every square metre) of paint used on the project with an average film build of about 430µm DFT. The client engaged Linetech as the third party independent coating inspector and this proved immensely valuable in ensuring the required standards were always achieved, providing significant confidence to KiwiRail.

7. Access

7.1 Span Access

The capacity of the trusses to accept transverse loads was very limited, so all wind loads had to be taken back to the top chord. This required bespoke engineered brackets to be fixed to each transom and a double truss with torsional capacity to be run between the brackets along both sides of the bridge and then double standards, also with good bending resistance, to support a twin level decked access. This provided an expensive access, but with no contact points other than at the brackets, this allowed structural repairs and coatings work to proceed without interruptions to modify scaffolding.

![Figure 7: Truss access scaffold cross section.](image-url)
All of the scaffolding was done using the Layher Ringlock system which proved to be very efficient, robust and strong.

7.2 Pier Access
The original proposal was to scaffold the two short 30m piers and use a bespoke swinging stage system to access the three taller piers. The stage system was abandoned as impractical after significant design investment and identifying that the piers had the capacity to withstand wind loads from significantly larger containments than initially advised.

The design process for the scaffolds was a significant project in itself. Each tower had bespoke footings, both concrete pads and steel beams. Beams were used when concrete foundation piers were well off the ground and where the dead weight of the scaffold needed to be transferred to the foundation to improve the resistance to over-turning of the structure in high winds.

The largest scaffold is pier six which is 76m high. It contains 270 tonnes of scaffold equipment and consumed 4,500 man-hours to build. It is fitted with a man-riding 500kg power hoist and internal access is by stairways. No ladders were used as they are unsafe especially for helmet clad abrasive blasters and inefficient when carrying materials and equipment.

8. Containment
One of the biggest challenges of the project was to provide a water tight rail deck between the four rails, that would withstand the expansion and contraction due to the temperature, vibration and movement of the rails with each train passing over the bridge (Figure 8). With the very regular rain this proved to be highly troublesome as the rain adversely affected the blast and painting operation, making recovery of wet spent garnet very difficult and necessitated use of a drier to recycle the garnet. It was decided to use already used garnet on wet days so if it got wet we would dump it.

The bottom level of the scaffold was lined with linoleum to produce an impervious tough deck that garnet could be swept and shovelled off.

The sides of the containment were clad in 200µm shrink wrap plastic film. Our initial risk strategy for extreme wind event assumed that the plastic film would fail and therefore not damage the viaduct. Wind tunnel testing was commissioned to establish the maximum thickness of film to get failure at 100km/hr on a standard 2m x1m panel and it was found the film would not fail even at 100µm thick, which was too thin to resist mechanical damage.

A weather monitoring and cut away intervention plan was adopted but fortunately not required to be implemented as cutting would have had to be done long before the wind speed limit was reached to ensure the safety of the cutting team.

During the winter months the underside of the sleepers were lined with plywood and a second skin of film was fixed on the inside of the span scaffold to provide “double glazing” and allowed us to heat the containments to 15°C when the ambient temperature was below zero using indirect fired heaters.

The heating of the piers is more difficult as a second skin could not be fitted and the hot air rose requiring the height of the heater spaces to be reduced so we completely sealed floors every 10m to contain the heat. This all made painting through the winter much slower and more costly.

9. Abrasive Blasting Systems
9.1 Blast Equipment Containment
To allow the project to proceed all year round an abrasive blast plant building was built on a 11m x15m concrete pad. The structure was constructed from scaffold and was 8m high to allow abrasive loading by telehandler and had a lifting 8m wide door that sealed. The space was connected to the 15m³/s dust collector to control any lead containing dust from the recovery/recycling plant (Figure 9).

9.2 Air Blast Equipment
Three air compressors supplied 1.0m³/s (2,100cfm) at up to 10Bar (150psi). Each had a separate aftercooler dryer and the air went to a 15m³ air receiver. Blast pots consisted of a four nozzle 8 tonne Megablaster which would be filled once per day and a twin nozzle large pot required two fills per day. Six blast lines were run in 50mm steel pipe along the bridge deck and 50mm hose reducing to 32mm at the operator. Most blasting was done using a No. 6 nozzle with angle nozzles used on a very limited basis.

Each of the blaster operators were fitted with radios with voice activated throat mikes and were in constant contact with the plant operator or their supervisor.
9.3 Dust Collectors
Two dust collectors were used on site; a larger 15m³/s (30,000cfm 100HP) at the top of the bridge and a 700mm diameter duct was run 260m along the western side of the bridge with “T’s” at each pier. A second 10m³/s (20,000cfm 65HP) dust collector was placed at the base of the larger piers as ducting runs from the larger unit were getting too long. Filtration standard has 99.95% retention of particles down to 0.5µm (Figure 10).

Dust collectors ensured that the containments were well ventilated and hazardous dust was readily controlled by the negative pressure in the containments. Management of the potential risks required a rigorous programme of visual observation. The resource consent requirements were exceeded and audit reports from Horizons Regional Council stated environmental management of the project exceeded their requirements.

Figure 10: Blast Equipment Building.

9.4 Abrasive Recovery
A stationery vacuum recovery unit was positioned in the abrasive blast plant building (Figure 10). This was powered by a 150HP blower with exhaust from the dust collector also achieving 99.95% retention of particles down to 0.5µm. A 150mm duct was run the entire length of the bridge. The plant was relocated to the base of pier 5 for the lower sections of the big piers.

Gravity chutes were also used to convey the recovered abrasive down the piers with the vacuum system being used to clean the containments. A high-quality containment cleaning process was necessary as there is significant mechanical work in the containment after the blast and prime is completed. It is also necessary to clean the scaffold to the highest practical standard to minimise the amount of lead contaminated material getting into the environment when stripping the scaffold.

9.5 Abrasive Recycling and Disposal
The recovered abrasive was loaded into the recycler that could progress 3T/hr. The recycler initially removes gross contaminants passing through a rotating drum with a 6mm screen and then passes over an air-wash that draws off the fines and finally onto a vibrating screen with a finer mesh. Over time the abrasive gets a higher fines loading and eventually the full batch is dumped. Blast pots were loaded with a blend of new material and recycled. On average we got around 2.5 cycles of the garnet but with wet wastage this was reduced to about 2 cycles.

The waste streams from the recycler has a proprietary leaching reduction additive manually blended into it and then when there is sufficient waste the bulk bags are emptied out into 15m³ hook-bins and fully blended using a small digger. The leachable lead is so low, the spent abrasive is then able to be dumped as non-hazardous waste at about 40% of the cost of lead containing hazardous material.

10. Lead Management
All of the systems developed for the project were significantly determined by the need to manage the risks associated with lead. All personnel on the project were given a baseline heath check including blood lead levels and all personnel were tested every month to monitor the effectiveness of the management systems and focus on individuals who clearly were not being rigorous in their personal hygiene. All staff were fit tested for their respirators and were issued clean overalls every day. They were required to wash their hands when leaving the bridge and smoking was banned on the work site with a controlled smoking area in the establishment area.

Abrasive blaster operators wore chest high waders and Nova blast helmets with full length sleeve blouse and gloves taped at the wrist. When it was not hot they also wore disposable Tyvek overalls with hoods over the normal overall. Decontamination was by dry air wash and wearing dust masks in the transition area. This process proved very successful. Given the cold and issues with water-pipes freezing, wet decontamination would have been very problematic.

Other trades were required to wear respirators and wear Tyvek overalls when working in the containments after blast and prime. Our greatest problems were with the mechanical team wearing the PPE, as the fitting of steel requires a lot of verbal communication with respirators being a significant impediment. Strict enforcement was instigated with the mechanical and scaffolding teams. TBS operate our own intervention blood-lead levels that are well below the statutory levels and only one person exceeded this level and was stood down. Since that event the levels on average have reduced.

11. Painting
Paint was applied by conventional air spray pots and guns. All surfaces were sprayed down to the smallest sections of steel. Whilst the steel plate girders have some bigger flat areas it was not sufficient to warrant using airless spray equipment.

About 60% of the painting man hours were consumed in brush application of stripe coats. As stated earlier, the stripe coating was carried out for each of the three main coats and this was essential to meet the quality standards set for the project.

Figure 11: Inspecting Rivets for Paint Film.
TECHNICAL REVIEW

12. Structural Strengthening and Repair

12.1 Truss Strut Strengthening
The existing lattice bars on the vertical struts were removed and replaced with new plates which had access holes included for installation, maintenance and inspection purposes. The holes also ensured that the lightweight appearance of the truss remained. These plates increased the compressive capacity of the struts.

12.2 Truss Bottom Chords
The tension bars were installed in the bottom chords which connected into washer plates at each joint. These were tensioned up to a specified percentage of the dead load only, so as not to put the existing plate chords into compression. These bars increased the tensile capacity of the bottom chords.

12.3 Truss Ties
The diagonal ties used rods in the same manner as the bottom chords except special connections had to be fitted for these to transfer into the joints.

12.4 Connections at Truss Nodes
The connections were strengthened by simply adding one or two bolts as required into the joint where additional strength was required.

12.5 Structural Repairs
A significant number of elements were replaced, both in the towers and the trusses. This was mostly as a result of pooling water due to poor structural detailing. In particular the diaphragm plates on the inside of the pier legs had insufficiently sized drainage holes that became clogged. There were also some channels with the flanges facing up which collected water. All of this water pooling led to significant corrosion of some members.

A significant number of lacing bars on the pier struts as well as batten plates on the tower legs were perforated and corroded (Figure 14). Careful structural analysis showed that there was some redundancy in the tower struts and legs, allowing many of the lattice bars and batten plates to be ground smooth and painted, rather than fully replaced. Many of the Huck bolts that were installed in 1980’s required replacement with HSFG bolts as they were not galvanized and had possibly not been adequately painted at the time of installation.

13. Construction Challenges
The area experiences over 200 rain days per year. Keeping the deck sealed to prevent water ingress was challenging particularly considering the trains were still running over the top and vibrating free any recent attempts at sealing. Eventually a train-proof system was arrived at.

Winter conditions forced a slowdown of work on site and sometimes closure of site due to heavy snow. The encapsulation was double wrapped to form an insulation system during winter. Diesel indirect fired heaters pumped air into this system and paint continued to cure on the bridge while snow was falling outside.

Due to the limits in allowable wind loading there was careful consideration of sequencing to ensure that the area encapsulated did not put the structure at risk of toppling over. A balance of efficiency and risk acceptance was combined with contingent plans to remove encapsulation in the event of very high wind forecast.

The intricate lattice work connected by hundreds of thousands of rivets made painting difficult. A spray application would normally be the most efficient way to apply paint but the low film build produced around edges and the back of rivets has historically led to premature failure. These all had to be stripe coated by hand, three times.

14. Environmental Protection
The environment is a pristine National Park and strict environmental protection measures are required to keep it this way. The water quality is also important to the Whio (blue duck), the white-water specialist, who lives all year around on the river and is on the nationally endangered list.

During the early stakeholder engagement there was difficulty in assessing whether the site works planned to be undertaken would have a detrimental effect on this endangered Whio. An activity that was known to have a positive effect was the trapping of known predators of Whio such as rats and stoats. A trapping programme, implemented by DOC and sponsored by KiwiRail was developed. During the life of the project, hundreds of rats, stoats and other invasive species harmful to the Whio have been trapped. A number of Whio have been observed in the vicinity of the viaduct throughout the project.

Discharge permits and land use consents were granted with the following process and monitoring programme.
Plan certifications by the regional council:
- Erosion and Sediment Control Plan
- Environmental Management Plan (EMP).
- Visible emissions assessment – Daily during blasting
- QMCI and sediment sampling for lead within river
  – Pre and post project
- Black disc monitoring of Makatote River during track
  maintenance – Weekly.

There have been no cases of non-compliance at the site and
it is the only site in the region to have obtained an "exceeds
compliance" result. This had had the positive effect of
enhancing the KiwiRail environmental image which will make
future interactions with stakeholders easier.

15. Safe Work and Sustainability
When the viaduct was originally constructed seven workers
fell to their deaths slipping on icy steel. The designer Peter
Hay got so wet and cold on one visit that he unfortunately
died of pneumonia on his return journey home. He never saw
the finished product.

The access standards today are vastly improved as is the
personal protective equipment. A total of 130,000 man hours
were consumed on the project without a single lost time
accident. The project was completed in November 2016 two
months ahead of programme. A detailed project management
plan was prepared for the project and has been a working
document. Safety is incorporated into every deliberate action
on site. Every day starts with a group tool box followed by
individual team job plans. Routines such as this are important.
All activities were planned with detailed written work methods
and job safety plans generated by the work teams to identify
hazards and how to manage them.

There has been a fulltime compliance officer on the project
with responsibilities including all QHSE requirements.

16. Conclusions
The Makatote Viaduct refurbishment project demonstrates
that an asset over 100 years old can still be relevant for a
modern railway business. This is testament to the original
designers and constructors. In addition strengthening and
painting a large steel structure in a cold, wet and at times
snowy environment is not impossible when innovation
and determination are employed. The adverse effect on the
environment of a project involving the removal of lead can be
controlled with simple but innovative methods, As a result an
environment can even be left enhanced at project completion.

Safety of staff on is achieved by a pursuit of excellence in all
aspects and constant vigilance. The safe return of staff home
every night is one of the targeted success factors of the project.

18. References
of Civil Engineers: Engineering History and Heritage.162 Issue
EH4. 207 – 219.


[3.] Astwood, K., 2009 Registration report for a historic place,
Makatote Viaduct.