Saving Money by Extending the life of New Zealand Heritage Bridges

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Abstract

New Zealand has many bridges that appear to be due for replacement. This paper shows how to extend their useful life while saving money.

Most asset owners assume that a bridge at the end of its 100-year design life is in need of replacement. The Detailed Condition and Structural Assessment combines the principles of corrosion management and structural engineering to determine the remaining structural capacity for current and future loads within a 30-year structure-specific plan.

This paper gives examples from around New Zealand where bridge asset life has been extended while maintaining or improving levels of service and resilience. Extending the useful life of bridges provides millions of dollars in savings through deferred works, and minimises disruption to users while preserving an important part of our heritage.

Keywords: Asset Management, Condition Assessment, Structural Assessment, Corrosion Management, Saving Money, Historic Bridges, Bridge Criticality, Bridge Risk Prioritisation.

Introduction

Ageing bridges is a major concern to all owners of infrastructure. From iconic and heavily used highway bridges to remote rural examples, the question of what to do with them at the end of their design life is a common dilemma. In most cases, owners assume that since a bridge has met its 100-year design life, it should be replaced.

The principles of Asset Management are commonly used to manage a roading network. Depending on the level of information available, this dictates the direction to be followed when developing network-wide asset management plans. In New Zealand this is based on the *International Infrastructure Management Manual* (NAMS Group 2006). Others advocate a bridge risk and criticality approach (Bush et al 2013), which in turn stipulates the level of information required. Alternatively, a condition rating system for each structure can be considered, that feeds into a software program to assess the overall health of the network (Tamakoshi and Kobayashi 2006).

Regardless of the what method or philosophy is used, the main requirement for all of them is data. A reliable set of information is required that outlines not only the bridge's actual condition, but also needs to consider the Owner's expectations and performance requirements for the given asset.

Corrosion Management

One set of data not typically considered in New Zealand when assessing bridges (possibly even in most countries), are those generated based on the principles of Corrosion Management.

Corrosion affects all structures regardless of the construction material. Whether it is rusty steel, carbonated concrete or decaying timber, when materials deteriorate they will compromise the structural capacity of the structure, and in turn its function over time.

Corrosion Management can be defined as managing the threats of corrosion throughout the asset's life. It is an integral part of asset management in the Oil and Gas Industry, where the risk and consequences of each component failure are identified in hazard and operability (HAZOP) studies. Failure due to corrosion can have a significant monetary and environmental cost but, in some unfortunate circumstances, human lives as well.

The NACE International IMPACT Study (impact.nace.org) provides a detailed outline on how the principles of Corrosion Management can be used in different industries and fields. Its main focus is optimising corrosion control actions and minimising life cycle corrosion costs, plus meeting safety and environmental goals. Goals that are applicable not only to pipelines but to steel structures like bridges as well.

Introducing the principles of Corrosion Management when assessing bridges will assist in improving the quality and reliability of the gathered data. This in turn will improve the overall forecasting and long-term planning of network-wide asset management plans, by minimising risks and failure criticality of the structures. As discussed by Omenzetter et al (2011) the availability of reliable data leads to immediate gains in terms of risk management.

Figure 1 outlines where Corrosion Management sits within the Asset Management field. The data generated is then used to develop asset management plans, strategy and policy. Whilst Figure 1 is given in relation to the Oil and Gas Industry, the principles are easily adapted to bridges and the roading network.

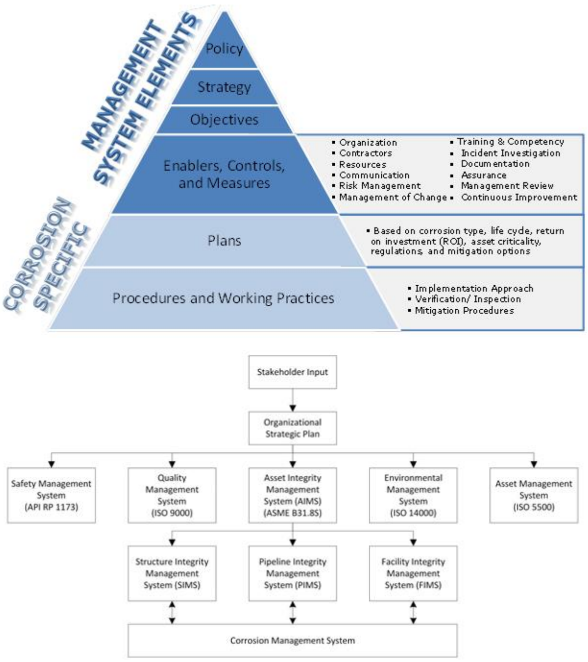

Figure 1: Corrosion Management in the Asset Management (images courtesy of NACE).

Detailed Condition and Structural Assessment

To maximise the benefits of the data generated by Corrosion Management practitioners, is to combine this information with Structural Engineering. As once the actual condition of a bridge's components is known, a Bridge Engineer can then assess the structure, in some cases using finite element analysis (FEA). This in turns provides a realistic representation of the stresses acting on the members to the required/given demands.

Combining these two disciplines provide another level of assurance to the data required when considering and comparing remediation options to the replacement of a bridge. This in turn will assist in the development of whole of life cost comparison between the different options and in turn the overall asset management plan for the given structure.

This process has been termed Detailed Condition and Structural Assessment.

To better understand the principles and benefits of Detailed Condition and Structural Assessments, the following case studies are given.

Bridge 223 NIMT: Waiteti Viaduct

KiwiRail's historic Waiteti Viaduct is a 128.6m multi-span, railway viaduct that has carried heavy rail traffic across the Waiteti Gorge (South East of Te Kuiti) since 1888. Throughout that time, and as the traffic became heavier and more frequent, the bridge underwent strengthening in the 1920's, 1950's and 1970's. The latest repair work was undertaken in 1983, which included the re-application of red lead primer as the main form of corrosion protection. Figure 2 provides an overview of the viaduct.

Figure 2: Waiteti Viaduct.

In 2016 KiwiRail was advised that the viaduct required selective strengthening work for a number of components, and should be considered for full replacement from 2020; for an estimated cost in the range of $12M to $15M.

A Detailed Condition and Structural Assessment was undertaken by the authors, which included a detailed inspection and assessment of the corrosion protection system itself. This included assessing the coating according to AS 4361 and AS/NZS 2312. Including measuring the total dry film thickness of the coating, assessing the adhesion of the coating to AS 3894.9 and steel corrosion to AS 1580.481.3. The inspection was undertaken by a NACE Coatings inspector – Level 2 Certified, with a rope access training (Figure 3).

Figure 3: A qualified coating inspector in action.

Overall the protective coating was found to be in satisfactory condition with coating delamination and/or complete breakdown estimated as up to 15-20% on some parts of the structure (see Figure 4 for an example).

Figure 4: Example of coating breakdown.

This was contrary to previous inspection records that indicated that the whole structure is covered in red rust, implying complete coating breakdown. What was previously thought to be red rust, was in fact found to be red lichen, with the coating underneath still in good condition.

A few areas of section loss were identified and measured, as well as structural defects. This information was then used as the basis of a FEA model, that considered not only the current axle load of 18t axle load at 60 kph, but also future projected loads of 20t axle load at 60 kph and an aspirational load of 22.5t axle loads at 100 kph. An example of the FEA model output is given in Figure 5.

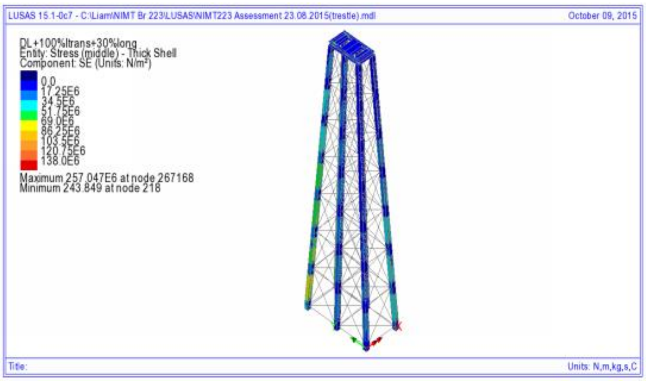

Figure 5: Example of FEA.

Based on the findings of the Detailed Condition and Structural Assessment, it was determined that the viaduct can continue to function beyond the previously advised 2020 replacement period.

To ensure its continued functionality and service, a number of remediation options were considered. These took into account the rail traffic loads in combination of different coating remediation strategies. These options were then costed and compared against each other and the replacement option; based on a whole of life net present value cost analysis.

The developed remediation options were:

- *Option 1: Do Minimum: Wash Only and Delayed Spot Repair*
  This option was considered for the 18t @ 60kph axle loading. It assumed that the viaduct underwent maintenance washing within the first 12 months, with subsequent maintenance washing very 5 years. Followed by spot repair of the coating in Year 5, with an expected time to first major maintenance of 10-15 years. No additional strengthening of the structure is required.

- *Option 2: Do Better: Wash and Spot Repair*
  Wash as before followed by spot repair of the coating within 12 months, followed by 5 yearly maintenance washing. This option was considered for the 18t @ 60kph axle loading. Expected time to first major maintenance is 10-15 years for spot repaired surfaces.

- *Option 3: Do Best: Wash, Spot and Overcoat*
  Wash as Option 1 followed by a spot repair and full overcoat of the coating within 12 months, followed by 5 yearly maintenance washing. This option was considered for the 22.5t @ 100kph axle loading. Expected time to first major maintenance is 25+ years. Strain gauges would also be added for live monitoring of identified "at risk" members, in addition to replacing select members.

- *Option 4: Full Replacement*
  Full replacement of the viaduct with a new structure, with an expected time to first major maintenance of 40 years; and 25t @ 100kph axle loading.

The above options underwent a net present value cost comparison at 6% discount rate over 30 years (NZTA 2013). The results were as follows:

Table 1: Waiteti Viaduct NPV Analysis.

Option	NPV Cost (6%)
1: Wash and Delayed Spot	$4.7M
2: Wash and Spot	$4.6M
3: Wash, Spot & Overcoat	$6.3M
4: Full Replacement	$12.5M

Based on the above, it was evident that the Waiteti Viaduct can be refurbished and continue its functionality and service into the foreseeable future, by undertaking certain actions during that period. Furthermore, by following any one of the proposed remediation work, KiwiRail may save up to 50% of the estimated replacement cost of a new structure.

New Plymouth Jack Arch Bridges

The New Plymouth District Council were advised to consider replacing 4 jack arch bridges that were erected in 1907, which were considered at the end of their economic life.

The bridges utilised a number of steel beams embedded in the concrete deck (i.e. only the bottom flange was exposed), with a hot dip galvanized corrugated iron arch used as permanent formwork. The beams had an embedded tie rod connecting them together. See Figure 6 for representative cross section of the bridge.

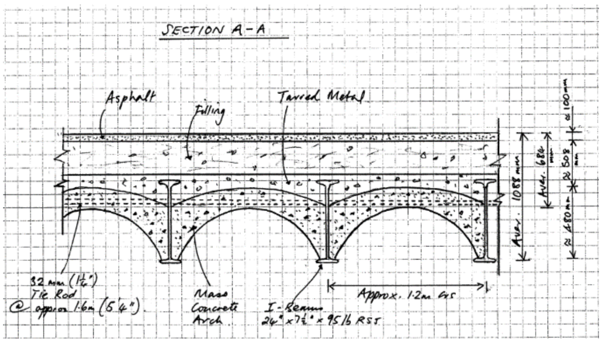

Figure 6: Cross section of the jack arch bridges.

The bridges are located over an active railway line. Their total replacement cost was estimated at $3.6M, to be undertaken by 2027.

All 4 bridges underwent a Detailed Condition and Structural Assessment that in addition to assessing the condition of the steel beams, the protective coating and measuring section loss, also included an in-depth assessment of the concrete deck and abutments as well. The concrete assessment included determining the level of carbonation and chloride ingress, as well as attempting to identify the size, type and location of the reinforcement.

The Condition Assessment findings included measuring the remaining steel thickness of the exposed bottom flange, which still had an average thickness of 20mm (originally 25mm). With the lowest readings located beneath water leaks through the deck (Figure 7) on all 4 bridges. This was identified as being one of the critical maintenance issues on these bridges.

Figure 7: Typical example of water leaks trough the deck.

Other findings included the lack of any reinforcement to be found either in the deck or abutment. It simply was mass concrete, which probably saved the structure, as chloride ingress levels were found to be high due to the use of beach aggregate. This would have resulted in spalling of the concrete, possibly within the first 50 years of the bridge's life. Figure 8 shows concrete testing on a representative concrete component.

Figure 8: Concrete testing.

Overall the protective coating was found to be in satisfactory condition, which was confirmed to include red lead primer. The coating maintenance history is not known.

The Details Structural Assessment confirmed that based on the average measured steel thickness of 20mm (Figure 9), the bridge was found to be at 150% capacity. It was also calculated that the critical minimum thickness of the steel flange was 12mm.

Hence one of the questions was how long can the steel beams function without reinstating the protective coating?

Figure 9: Typical section loss.

To determine the remaining life of the steel beams an assessment of the site atmospheric corrosivity category was undertaken. This determined the sites' micro-environments as being C5-M (Very High-Marine) to AS/NZS 2312.1. For which the steel corrosion rate was estimated as being 165µm/annum.

Based on this corrosion rate, the potential period for the steel section to reach 12mm was estimated to be >40years. However, due to the identified water leaks and the poor condition of the steel web and beam under those leaks, the leaks were deemed to be a high risk that require urgent attention.

Therefore, it was deemed that it was possible to save the 4 bridges by developing targeted remediation actions during the next 10 to 20 years; thereby ensuring their continued performance for the foreseeable future.

Note that due to the position and orientation of one bridge in relation to the prevailing wind; it was determined that this bridge will require a shorter time to major maintenance (estimated at 10 years) than the other 3 bridges (estimated at 20 years).

Based on the above, the following remediation options were considered:

Table 2: Whole of life net present value cost comparison of the different options.

Year	Option 1: Site Clean Up + Replace			Option 2: Clean + Patch Repair			Option 3: Clean + Full Seal			Option 4: Replace		
	Action	ROC Cost	NPV Cost	Action	ROC Cost	NPV Cost	Action	ROC Cost	NPV Cost	Action	ROC Cost	NPV Cost
2018/2019	Clean up	$20,000	$19,000	Clean up	$20,000	$19,000	Clean up	$20,000	$19,000	-	-	-
2019/2020	-	-	-	Patch Repair	$50,000	$36,000	Full Seal	$200,000	$107,000	-	-	-
2027/2028	-	-	-	Paint Bridge D	$75,000	$42,000	Paint Bridge D	$75,000	$42,000	Replace bridges	$3.5M	$1.95M
2037/2038	-	-	-	Paint remaining 3 bridges	$225,000	$70,000	Paint remaining 3 bridges	$225,000	$70,000	-	-	-
2047/2048	-	-	-	Reinstate Bridge D Paint	$75,000	$13,000	Reinstate Bridge D Paint	$75,000	$13,000	-	-	-
2057/2058	Replace Bridges	$3.5M	$340,000	Reinstate remaining 3 bridges	$225,000	$22,000	Reinstate remaining 3 bridges	$225,000	$22,000	-	-	-
Total Cost (rounded figures)		$3.57M	**$359,000**		$670,000	**$202,000**		$820,000	**$273,000**		$3.5M	**$1.95M**

- *Option 1: Site Clean Up + Full Replacement*
  Clean up the site within 12 months (to reduce the risk of a rubbish fire) and carry out no other maintenance apart from monitoring the steel section loss till it reaches the critical min thickness, then replace. This was estimated to be required in 40 years.

- *Option 2: Site Clean Up + Deck Leak Patch Repair*
  Following the clean-up, patch repair the deck leaks. Recoat the Bridge D in 2027, and the remaining bridges in 2037. Note that this option has a risk of the water leak reappearing elsewhere else in the deck.

- *Option 3: Site Clean Up + Deck Full Seal*
  Same as Option 2, but the deck undergoes a full seal to minimise the risk of the water leak occurring elsewhere in the deck.

- *Option 4: Full Replacement*
  Replace all 4 bridges in 2027.

The different options underwent a whole of life net present cost comparison, taking into account future maintenance cost; based on a 6% discount rate over 40 years. The results of the cost comparison are given in Table 2.

By comparing the different options, Option 3 provided the lowest risk and comparative cost. This, when compared with the whole of life net present value of full replacement by 2027, provided a net present value cost saving of ~$1.7M over the next 40 years.

Bridge Risk Prioritisation Tool

While the benefits of a Detailed Condition and Structural Assessment is demonstrated above, it is clear that these benefits are being realised for specific bridges. The main challenge that will be encountered when assessing an Asset Owner's bridge stock, is where to start?

Which bridge(s) warrant the full Detailed Condition and Structural Assessment treatment?

How can we assess and prioritise those structures, based on which information and how do we rate them?

To address this, the Bridge Risk Prioritisation Tool was developed.

This tool assists Asset Owners by evaluating and ranking the criticality of their bridges. The goal of this approach is to improve the safety and reliability of bridges by focussing effort where it is most needed, optimising the use of resources and available funding.

The prioritisation score system has been based on a core set of data (give in the left hand side of chart in Figure 10) which accounts for 80% of the total score and a more variable set of factors (right hand side of the chart) which accounts for the remaining 20%.

The core set of aspects are summarised below:

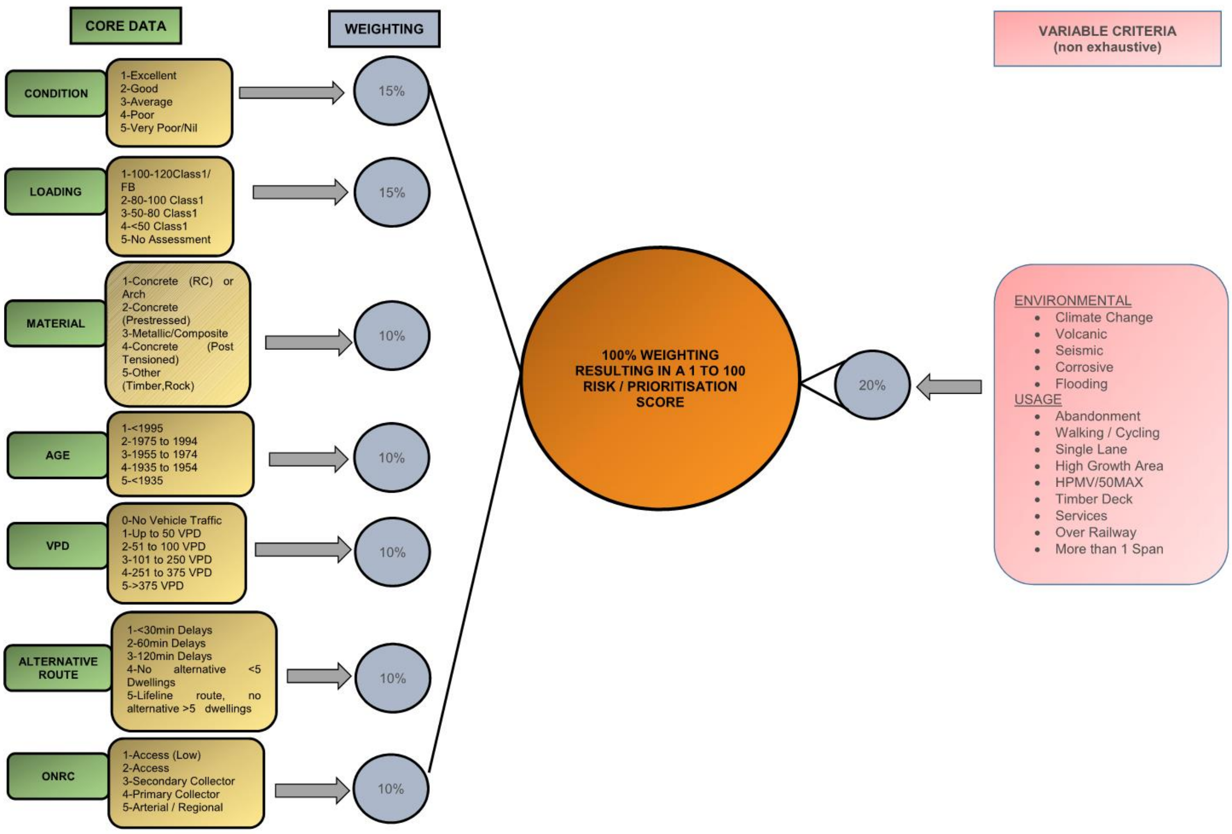

Figure 10: Risk Prioritisation Tool weighting system.

- *Condition:* it grades the condition of the structure ranging from excellent (as new) with a risk score of 1, to poor condition or not inspected with a risk score of 5. This is based on bridge inspection templates, such as NZTA S6 (NZTA 2017).

- *Loading*: it considers the live load capacity of the structure in relation to Class 1 loading (general mass). The score ranges from a risk score of 1 for bridges with live load capacity greater than Class 1 to a risk score of 5 for bridges with no live load assessment information.

- *Material:* it reflects the different durability of the bridge materials. The score ranges from a risk score of 1 for reinforced concrete to a risk score of 5 for timber bridges.

- *Age*: it considers how old the bridge is. As expected the older the bridge the higher the risk factor. The score ranges from a risk score of 1 for bridges built after 1995 to a risk score of 5 for bridges built before 1935.

- *VPD (Vehicles per Day):* It reflects how intensively the structure is used and how many vehicles per day it supports. The score ranges from a risk score of 0 for pedestrian bridges to a risk score of 5 for bridges with a VPD greater than a given value, as agreed with the Asset owners; based on their size and volume being experienced on their network. For example, for Taranaki this was 375 vehicles.

- *Alternative Route:* it considers the time delays for any alternative routes. The score ranges from a risk score of 1 for a bridge with an alternative route causing a delay of less than 30 minutes to a risk score of 5 for bridges where no alternative access exists, or lifeline bridges.

- *ONRC:* it reflects the importance of the bridge under the One Network Road Classification. The score ranges from a risk score of 1 for bridges located on access (low volume) roads to a risk score of 5 for bridges located on arterial or regional roads.

The last two factors are level of service requirements, while the other 5 factors are inherent physical characteristics of the bridges or a function of their location.

The weightings put more emphasis on the condition and loading factors at 15% each, while the rest of the factors have a weighting of 10%. These percentages are based on engineering judgement gained from extensive knowledge of bridge stock both in New Zealand and overseas, where condition and loading are considered to have a greater influence on bridge vulnerability.

The variable set of aspects were introduced to account for more specific client demands and can be adjusted on a case by case basis after discussions with the Asset Owner.

Factors such as HPMV/50MAX requirements, flooding, whether the bridge is in a high growth area, whether bridge carries services, etc are considered and given the appropriate weighting based on the importance to the asset owner.

The risk prioritisation is an indication tool "Barometer" on where to start looking/investigating and in turn helps focus the asset stock into a priority list based on a consistent set of criterial.

For example, in the case of New Plymouth District Council, it helped generate a high priority list of structures which will be used to carry out further investigations (such undertaking a load assessment, a General Inspections to the comprehensive Detailed Condition and Structural Assessment). This is done to reduce the unknowns and better understand the asset stock. It also serves to provide direction on which structures may need to have business cases developed in the coming years and eases the processing of funding applications due to the transparency of investment methodology. The list can be used to articulate the asset owners' priority and in turn this can be shared with internal and external stakeholders and it may impact and influence their decisions by allowing a more systematic approach to be taken.

Conclusion

Ensuring the availability of reliable information is critical to achieving the optimum outcome for any endeavour. This is as important for a Bridge Engineer designing a new bridge, as to an Asset Manager developing a network wide management plan.

To assist in improving the quality of information gathered, the principles of Corrosion Management can be used. When combined with Structural Engineering, these two disciplines have demonstrated that a comprehensive assessment of the bridge structure is possible; from which a realistic comparison between different options can be considered, from remediation to replacement.

In both cases given, this has resulted in significant cost savings (up to 50%), when compared against the replacement cost. It also demonstrated that historic structures can be saved, ensuring their continued performance and service for generations to come.

This process named the Detailed Condition and Structural Assessment has one drawback. This was how can we identify the at-risk structures that will benefit most from this assessment.

This was addressed by the development of the simple to use Bridge Risk Prioritisation Tool. Based on well-defined variables and known risks, the tool prioritises the bridge structures for assessment inspection.

The ultimate aim is to provide the Asset Owner with a realistic assessment of their structures and provide them with the information required to make an informed decision. Whether it is feasible and cost effective to simply replace the structure or refurbish and save it.

Finally, it is envisioned that once there is a better understanding by owners on the health of their bridges, a comprehensive and more reliable network wide asset management plan can be developed.

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