AUCKLAND HARBOUR BRIDGE PAINTING: DEVELOPMENT OF A FUTURE MAINTENANCE STRATEGY

Raed El Sarraf, Opus International Consultants Ltd, New Zealand

Willie Mandeno, Opus International Consultants Ltd, New Zealand

Alex Ingram, Auckland Harbour Bridge Alliance, New Zealand

ABSTRACT

The Auckland Harbour Bridge (AHB), built in 1959 and widened in 1969, has some 125,000 m^2 of external steel surfaces which have been maintained using a “patch and recoat” philosophy. This has been carried out since 1998 by Total Bridge Services (TBS) under a performance specified maintenance contract using moisture-cured urethane coatings. TBS is a joint venture between TBS Farnsworth, Opus International Consultants Ltd and Fulton Hogan. In 2012 a maintenance alliance was formed (AHB Alliance), between the NZ Transport Agency, TBS and Beca. The Alliance commissioned the authors to; develop a deterioration model for the existing coatings, review the existing maintenance regime and potential protective coating systems, investigate alternative maintenance strategies, and make recommendations towards developing an optimized strategy to provide corrosion protection within more restrictive environmental protection requirements.

This paper summarises the findings of the initial report and some subsequent investigations; including analysis of 15 years of audit adhesion testing, and the possible use of a high ratio calcium sulfonate alkyd overcoating system to avoid the need for abrasive blasting and so reduce the environmental impact of maintenance painting.

INTRODUCTION

The Auckland Harbour Bridge (AHB), is the most iconic and one of the busiest bridge structures in New Zealand. An average of 175,000 vehicles travel over the bridge each week day making it one of the most vital infrastructure links not only between the North Shore suburbs and the rest of Auckland, but also between Northland and the rest of New Zealand. Since its opening in 1959, and subsequent widening in 1969, the bridge has been maintained with a number of coatings systems using a “patch and recoat” philosophy.

Since 1998, the maintenance of the bridge has been undertaken by Total Bridge Services (TBS) using moisture-cured urethane coatings. TBS is a joint venture between TBS Farnsworth, Opus International Consultants Ltd and Fulton Hogan. Until 2012, works were undertaken under a performance specified maintenance contract (PSMC). In 2012 a maintenance alliance was formed, known as the AHB Alliance, between the NZ Transport Agency as the owner, TBS and Beca.

With the aim of improving the management and maintenance of the bridge, the AHB Alliance has taken a proactive approach in reviewing the current maintenance regime and identifying potential alternative protective coating systems. Covering a surface area of nearly 125,000 m^2, not only should the cost of maintenance be considered, but also minimising its environmental impact, and the health and safety risk both to the workers on the bridge and general public. From this review, a suitable maintenance strategy will be developed that will meet the more restrictive environmental protection requirements, that will commence on certain spans on the bridge from 30 August 2014.

This paper summarises the findings of the initial report and some of the subsequent investigations including analysis of 15 years of audit adhesion testing, and the possible use of a high ratio calcium sulfonate alkyd overcoating system to avoid the need for abrasive blasting; this reducing the environmental impact of maintenance painting.

BRIEF COATING HISTORY OF AHB

Coating Pre 1998

The initial maintenance painting specification utilised a brush-applied oil/phenolic zinc chromate primer after light abrasive blasting with a fine grade of quartz sand. This was followed by 2 patch coats of a phenolic zinc chromate patch primer. After patch priming, 2 complete cover coats of a phenolic finishing paint heavily pigmented with micaceous iron oxide (MIO) was applied by brush or spray. Repainting external surfaces (approximately 62,000 m^2 not including hand rails and lighting poles) with this system first commenced in 1963 and was completed in 1969 which was followed by a continuous and ongoing maintenance programme.

The “clip–on” extensions bridges external surfaces (approximately 63,000 m^2) were originally primed with either 65 microns of inorganic zinc silicate or 25 microns of zinc metal spray, sealed with PVB etch primer and then given two finishing coats of the MIO/phenolic top coats. These were completed in 1969 and by 1989 had been repainted twice. From 1989 a five coat alkyd system was applied up until 1994 when, for environmental and health reasons, the specification was amended to allow the use of a double coat of a proprietary high build chromate-free alkyd primer to replace the previous three primer paints.

Details of these systems and trials of alternative coatings considered for their eventual replacement are discussed in earlier technical papers by Mandeno (e.g.1991 & 2006).

Maintenance Regime 1998-2012

In 1998 Transit NZ introduced the system of Performance Specified Maintenance Contracts (PSMC). This was based on a long-term performance specification under which the Contractor is required to ensure that the overall condition and level of service of the asset is maintained to a pre-determined standard.

The PSMC coatings repair requirements were based on the coating’s age, alongside an intervention level of Rust Grade 7 (0.3% rust as defined in ASTM D610). This intervention level was later increased to Rust Grade 8 (0.1% rust). A patch and overcoat methodology was employed, using a 3 coat Wasser maintenance system approved by NEPCOAT, and based on moisture cure urethane (MCU) technology developed by Bayer. It was first utilised for bridge maintenance by the Oregon and Washington State Departments of Transportation in the USA who have similar climatic conditions to New Zealand. The coating system used on AHB involved the following steps;

- Wash surface with potable water at 4,000 – 4,500 psi at 21 litres/minute
- Spot dry abrasive blast rusting surfaces with C-Grade Super garnet to at least a Sa 2½ standard of visual cleanliness to give a 35 to 75 micron profile with < 75mg/m2 salt as determined with a Bresle patch and conductivity meter
- Treat crevices with a MCU penetrating sealer primer. Sweep blast sealed areas when cured
- Patch prime bare steel plus stripe coat rivets and edges with zinc-rich MCU at 75 microns dry film thickness (DFT)
- Apply a patch build and stripe coat of an aromatic MIO pigmented MCU at 75 microns DFT
- Apply an aromatic MIO pigmented MCU tie coat at 40-60 microns DFT to all surfaces
- Fill gaps with a flexible MCU sealant
- Apply an aliphatic MIO pigmented MCU stripe then a full finish coat to all surfaces.

Current Maintenance Regime (2012 to date)

The current maintenance regime uses the previously described Wasser MCU coating system but it has only been applied as patch coats, i.e. with no full cover coats. This was also the practice during repair of coating damaged by the welding of strengthening steel to the ‘clip-on’ extension bridges under the previous regime. It is intended that this will continue until a new maintenance strategy has been agreed.

DEVELOPMENT OF A DETERIORATION MODEL

Introduction

In order to develop an optimised maintenance strategy for AHB, the rate of the deterioration of the existing coating system is required. This is needed to determine if or when the failure of the coating, predicted to be wide-spread delamination of the aged coatings, is likely to occur so that it can be removed from high risk areas and replaced in a planned and proactive manner. This has required examination of historic painting and inspection records (including trend analysis of adhesion testing) for all the main bridge elements and their different microclimates. Some additional testing was required to extend the data to the present and this was carried out in March 2013 (Dalzell 2013).

It was not expected that this analysis would forecast future coating failure with any great accuracy due to multi-coat patch painting and over coating philosophy used over the years, but nevertheless this has been attempted.

Audit Inspection Reports

Periodic audit inspections were conducted on the AHB from the start of the PSMC maintenance regime in 1998 until 2011, of which the adhesion testing results from 18 separate locations were used in this study.

Adhesion Tests

Concern has been expressed at how long the overcoating strategy could be maintained before significant delamination occurred, due to embrittlement as the aging alkyd and phenolic binders continue to oxidise. In 2006, some areas of the bridge were first identified as having *“unacceptable levels of adhesion”* (between primer coats based on X-Cut knife testing to a modified Method B of AS 1580.408.2) (Dalzell 2006).

Discussion on the Pull-Off Adhesion Test Results

As noted in the most recent report (Dalzell 2013), 16 out of 18 tested sites (i.e. 88%) on the AHB have an acceptable rating based on a minimum average test result of 2.5 MPa as recommended in AS 4361.1, with only 2 being marginal and none being unacceptable. Even though the report states that the results may be limited due to localised influences such as paint sub-layer embrittlement and micro cracking, it continues by saying:

“*In most locations, regardless of dry film thickness (d.f.t) and age, the tensile strength indication was sufficient to allow for over coating of existing paintwork*”.

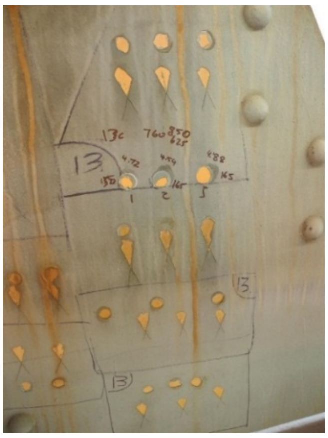

Figure 1: Example of adhesion failure between the primer and the layers above.

It should be noted that most of the adhesion failures were not between the primer and substrate but between the phenolic zinc chromate patch primer coloured orange and the layers above (Figure 1). There were also cases of adhesion failure between the dark and light grey phenolic finishing paints and the more recently applied moisture cured urethane.

To better assist in identifying the trends in the pull off adhesion results, plots were generated to provide a visual representation of the data, and an example of an "acceptable" site is given in Figure 2 and for an unacceptable site is given in Figure 3. The complete set of plots for all the sites is given in Appendix D (Mandeno and El Sarraf 2013).

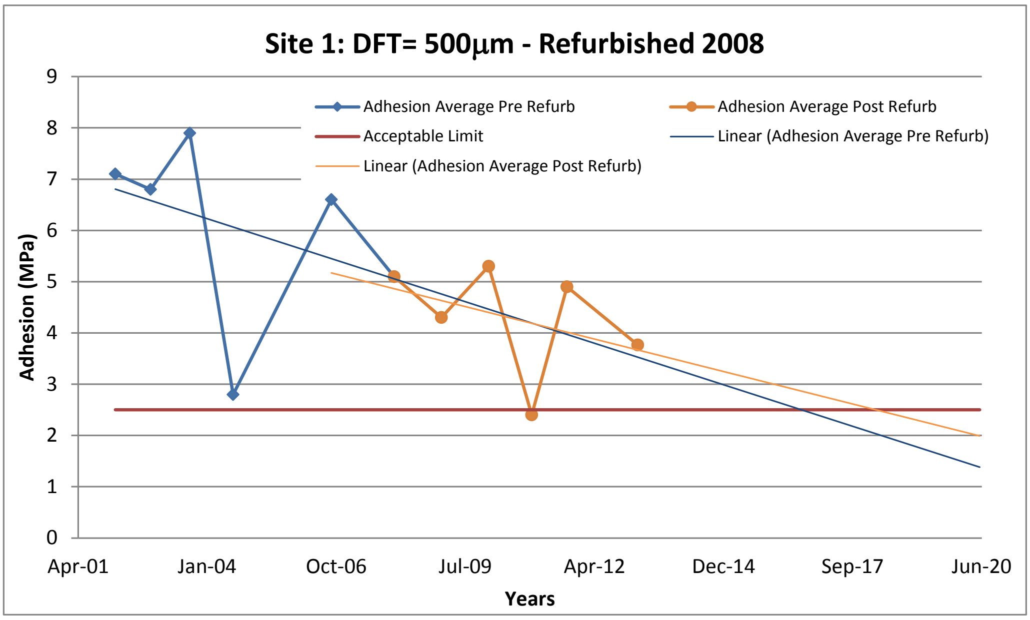

Figure 2: Pull –Off Adhesion Test Trend Plot for Site 1.

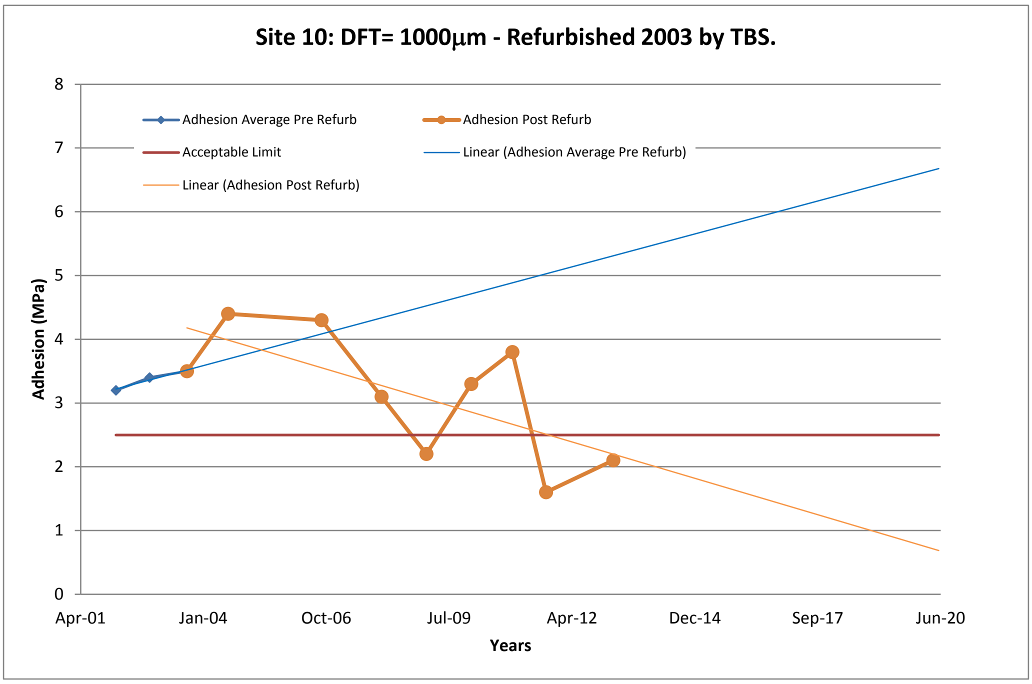

Figure 3: Pull –Off Adhesion Test Trend Plot for Site 10.

After reviewing the visual representation plots and the trend lines (as detailed in Appendix C of Mandeno and El Sarraf 2013), the time of refurbishment and the skew effects of anomalous values were taken into account when the rating based on trend line was considered, and such cases are noted. An example of 4 sites is given in Table 1 below.

Table 1: Example of coating condition.

Site	DFT	Average Adhesion (MPa) Post Refurb	KDA Rating for 2013	Rating based on Trend line		Comments
				For 2013	For 2015	
7	500	5.1	Acceptable	Acceptable	Acceptable	
8	1000	2.4				
9	1500	3.53		Unacceptable	Unacceptable	Jan 2010 reading skews the results.
11	500	5.96		Acceptable	Acceptable	

Deterioration Model Discussion and Conclusion

It should be noted that concerns were raised about the relatively limited number of adhesion test readings of 3 adhesion pull-off reading/site/reporting year, which are also affected by the refurbishment date of the site. This has resulted in highly skewed trend line, such as trend lines with only 2 readings before a refurbishment (as seen in Site 1) or due to a single widely scattered average (as seen in Site 9).

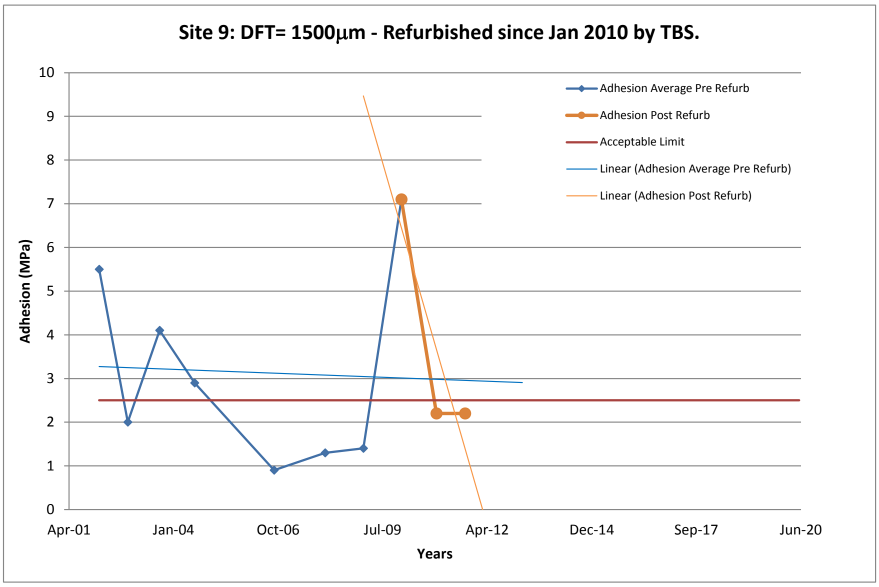

Figure 4: Pull –Off Adhesion Test Trend Plot for Site 9.

Other concerns are discrepancies noted between historic dry film thicknesses (DFT) and the 2013 set of readings (Dalzell 2013). Some of these discrepancies could be explained by the fact that some areas were refurbished through the years or sites were relocated due to an access issue, but the original DFT reading appears to have not been updated. Therefore, additional measurements of the DFT for all sites was recommended.

As such, even with all of the above concerns and discrepancies, the authors at this stage only have these data from which to develop the trend line plots deterioration model based on the adhesion pull off test results. Taking these concerns and limitation in consideration the following assumptions and conclusions were made in our initial report (Mandeno and El Sarraf 2013).

- The risk of delamination is considered to be low until 2015, except for Sites 10 and 17 that may require patch repair over this period, with Sites 9 and 13 to be monitored
- Additional investigation should be conducted over this period to assess and confirm the condition of the coating on specific areas of the truss bridge. This includes adhesion testing on the extension bridges that were not included in the coating condition surveys conducted between 2002 and 2013

- Due to the relatively limited quantity of data (only 3 adhesion pull off readings/site/reporting year) and discrepancies noted, the above additional investigation will assist in providing a better understanding of the condition of the non-conventional multi coat system currently on the Auckland Harbour Bridge. This includes the assessment and revision, as required, of the proposed post 2015 maintenance strategy.

RESOURCE CONSENT

Environmental concerns and Resource Consent requirements have a significant influence on which surface preparation methods and coating systems can be used. For example, the current resource consent prohibits the washing of the bridge without containment, and requires collection and treatment of run off. This means the potential benefits of regular surface washing to remove the build-up of wind-borne marine salts, which in turn assists in extending the life of the existing coating, could not be obtained.

Under the current consent, containment is now required overland, whether for maintenance patch painting, or full removal and recoating. This requirement will be extended to Spans 1, 6 and 7 by September 2014 and the rest of the structure by 2021. Containment on the extension bridges could be achieved through modification of existing access gantries, without the need for any significant bridge strengthening. Containment over the original truss bridge would be far more difficult. Even with restrictions on the size of the containment system, the bridge would need to be strengthened to resist the additional weight and wind loading.

This in turn has greatly affected the choice of coating selection, as any system with a reduced and minimal containment requirement would equate to significant cost savings. Therefore, in addition to cost and environmental impact, minimising the containment requirements is one of the main criteria when selecting a maintenance strategy.

In parallel with these studies, the AHB Alliance has chosen to apply for a new Resource Consent that will allow more flexibility in meeting environmental objectives through an adaptive management process. This may mean that full containment can be deferred if more environmentally friendly methodologies and products are implemented; offering the owner considerable cost savings without compromising the environment.

COATING SYSTEM REVIEW

A review of traditional and alternative coating systems was undertaken, that included the pros and cons of each system. The main restriction considered was minimising dust generation from abrasive blasting with the aim of reducing the containment requirements, particularly for discharge to air and water. Traditional coatings, such as thermal metal spray and three coat systems, that require a “near-white metal” level of cleanliness were therefore not considered as maintenance coating systems, but are an option when or if full removal and recoat is required in the future.

As a result, alternative coating systems that are relatively new to New Zealand were considered. These maintenance coatings can encapsulate the existing coating system where it has sufficient adhesion, and can also protect bare steel where coating has failed. Their main advantage is that they only require a water pressure wash to remove loosely adherent material and salt contamination, thereby providing the opportunity to meet the Resource Consent requirements, with a reduced level of containment.

The two potential systems considered were a high-build elastomeric acrylic (HBEA), and high ratio calcium sulfonate alkyd (HRCSA). Of the two systems, HRCSA was chosen for further consideration and testing as HBEA requires the relative humidity (RH) to be less than 80%. An analysis of Auckland’s weather from 2009 to 2012 identified that it could have only been applied on approximately half the available painting days so making it impractical for use as a viable all year round option.

In comparison HRCSA offered the follow advantages:

- Well proven track record in North America on bridges and penstocks for nearly 25 years

- Can be applied in cold (>2°C) weather, with the steel temperature above 5°C and 2°C above the dew point limit
- Suitable for riveted structures with crevices
- Promoted as being an environmentally friendly material that, according to the Product Data Sheet “PDS”, “does not adversely affect marine life”, and is approved in Canada for use on bridges over salmon spawning streams.
- Surface preparation requirement for encapsulation is hot water wash at 6000 psi
- Lower containment requirements with the collection of debris loosened by water rather than abrasive debris.

Its disadvantages are:

- May take several weeks to harden enough to walk on and even when fully cured has low abrasion resistance
- As it is relatively flexible, it is not suitable on steel sections being monitored for fatigue cracking.

MAINTENANCE STRATEGY

With the requirements for full containment stipulated by the new Resource Consent, which will require some strengthening of the original truss bridge, the following maintenance strategies are proposed in order of preference based on their level of containment and expected cost.

Option 1: Single Maintenance Coat System not to AS/NZS 2312

This proposes that the existing coating is patch painted and encapsulated using a medium term performance coating, and HRCSA on the truss that will provide an expected time to first maintenance of 10-15 years based on FHWA testing (FHWA 2011).

The benefits of this option are:

- Surface preparation only requires a hot water high pressure water jetting
- No airborne dust generated hence lower level of containment is possible
- Single pack material that can be piped to work areas
- No waiting time between coats
- Easy removal of overspray
- Environment and applicator friendly
- Easy to apply on/around crevices, bolts and rivets.

Disadvantages are:

- Slow to harden
- Poor resistance to abrasion (e.g. unsuitable for walkway surfaces and handrails)
- Limited use to date in NZ
- Proprietary systems from single overseas supplier
- Unsuitable on sections being visually monitored for fatigue cracking, especially on the extension bridges
- Restricted weather conditions for application of HBEA
- Overspray containment requirement.

Option 2: Single Maintenance Coating System to AS/NZS 2312

This proposes that the patch repair and full recoat of the original truss bridge and both extension bridges, using a long term performance coating, such as moisture cured urethane that will provide an expected time to first maintenance of 10 to 15 years based on Table 6.3 of AS/NZS 2312: 2002.

The benefits of this option are:

- This coating is well suited for overcoating moderately adherent existing coating due to its low curing stresses and flexibility
- A proven track record on the AHB, since it has been used since the start of the current PSMC, i.e. for the past 14 years
- Coating applicators are experienced in using this coating option on the AHB
- Costs and stress on existing coating could be reduced by not full coating surfaces that are not easily seen by the public.

Disadvantages are:

- Proprietary system from overseas supplier, although local manufacture could be arranged
- Environmental/ Operational Safety and Health (OSH) hazards greater than Option 1
- Full containment is likely to be required.

Option 3: Zone Coating

This option utilises the use of different coatings, with different containment levels, Rust Grade levels and aesthetics required for the different parts of the bridge:

- Extension Bridges: Full coating removal and recoat with an extra-long life performance coating such as a sealed “85/15” zinc/aluminium metal spray that if 200 microns thick (i.e. TSZ200S) will provide an expected time to first maintenance of 25+ years according to Table 6.3 of AS/NZS 2312
- Truss Bridge minus the Overarch and Wearing Surfaces: Encapsulate with a long term suitable maintenance coating, such as HRCSA, that will provide an expected time to first maintenance of 10 to 15 years based on FHWA testing (FHWA 2011)
- Truss Bridge Arches and Wearing Surfaces. Full coating removal and recoat with a long life and abrasion resistant coating such as moisture cured urethane that should provide an expected time to first maintenance of 8 to 15 years based on experience to date. TSZ200S could be used on surfaces accessible for spray application.

The benefits of this proposal are:

- The different expected time to first maintenance may provide long term cost savings, since the maintenance of each system will be spread over a longer period
- Possible cost savings due to the different levels of containment required. All coating removal will require full containment due to the required control of dust generated from the dry abrasive blasting, while the encapsulation option requires the collection of debris and water runoff only
- Different Rust Grade Levels could be specified on each part, such as the under walkway sections could have a lower Rust Grade level than the more visible extension bridges and the truss arch, allowing for potential cost savings
- The maintenance coating options (HRCSA and MCU) are well suited for the complex riveted truss bridge where brush application is required to coat some surfaces
- MCU has a proven 14 year track record on the AHB.

Possible disadvantages are:

- The different coating systems used throughout the bridge may cause confusion, allowing for the incorrect system being applied in the wrong place
- Higher risk of incorrect surface preparation and application of the other non-MCU coatings
- Additional surface preparation and applicator training and equipment will be required
- Difficult to successfully coat compound members (e.g. back-to-back angles) and lattice sections onsite with TSZ200S, hence the different coating systems for each structure type
- Partial containment would be required, depending on the coating system being use.

LIFE CYCLE COSTING

There are different life cycle costing models that can be used, of which the most common method in New Zealand is the Net Present Value (NPV) method. This model takes into account the initial construction cost followed by the expected maintenance cost throughout the design life of the bridge. This incorporates a discount rate which modifies the future maintenance cost, into "today's dollars" taking inflation as being 0%. The equation for the net present value is:

$$NPV = IC + \sum_{t}^{T} \frac{OC}{(1+DR)^t} \quad (1)$$

Where:

NPV = Net present value

IC = Initial construction cost

T = Design life in years (usually 100 years for bridges)

t = Operation time in years

OC = Operating maintenance cost

DR = Discount rate.

Section 10 of HERA Report R4-133 (El Sarraf and Clifton 2011) provides detailed guidance on the use of the net present value model.

Model Assumptions

Since Option 1 was preferred, the life cycle costing of using this option was then considered. This did include a comparison between different levels of containment, to determine the cost difference between them. The life cycle modelling was based on the following assumptions:

- Cost is based on per square metre rate
- Discount rate is taken as 6% for a 40 years period (NZ Transport Agency 2013)
- HRCSA is taken to have a 15 year expected time to first maintenance in an atmospheric corrosivity category E-M (Very High, Marine)
- Total cost estimate includes access, surface preparation, coating material cost and application cost
- Estimated total cost without containment is NZ$300/m2
- Estimated total cost with containment is NZ$450/m2
- Note, that the estimated total cost are indicative and are used herein for comparative purposes only.

A simplified example of the life cycle costing model using the net present value method is given in Figure 5.

The model was based on different scenarios that consider the percentage area of painting being undertaken on a given year, and the period when large painting commences and for how long. This is shown in the model as three work periods over a specific number of years. The current patch paint programme is estimated to be undertaken to only 1% of the total bridge surface area, this equates to only 1250m^2 of the estimated 125,000 m^2. This is the minimum percentage area considered in the model.

Once the total net present value cost is determined, this can then be multiplied to the total area of the bridge which will provide the total cost over 40 years to maintain the Auckland Harbour Bridge. A total of 15 scenarios were considered which some are given in Table 2 below.

Scenario 7

Period	Year (1)	%Area Maintained	Current Cost (2) $/total m^2	NPV (3) for DR (4) 6% $/total m^2
1	0	1.0%	3.00	3.00
	1	1.0%	3.00	2.83
	2	1.0%	3.00	2.67
	3	1.0%	3.00	2.52
	4	1.0%	3.00	2.38
	5	1.0%	3.00	2.24
2	6	10.0%	30.00	21.15
	7	10.0%	30.00	19.95
	8	10.0%	30.00	18.82
	9	10.0%	30.00	17.76
	10	10.0%	30.00	16.75
	11	10.0%	30.00	15.80
	12	10.0%	30.00	14.91
	13	10.0%	30.00	14.07
	14	10.0%	30.00	13.27
	15	10.0%	30.00	12.52
3	21	1.0%	3.00	0.88
	22	1.0%	3.00	0.83
	23	1.0%	3.00	0.79
	24	1.0%	3.00	0.74
	25	1.0%	3.00	0.70
	26	1.0%	3.00	0.66
	27	1.0%	3.00	0.62
	28	1.0%	3.00	0.59
	29	1.0%	3.00	0.55
	30	1.0%	3.00	0.52
	31	1.0%	3.00	0.49
	32	1.0%	3.00	0.46
	33	1.0%	3.00	0.44
	34	1.0%	3.00	0.41
	35	1.0%	3.00	0.39
	36	1.0%	3.00	0.37
	37	1.0%	3.00	0.35
	38	1.0%	3.00	0.33
	39	1.0%	3.00	0.31
	40	1.0%	3.00	0.29
	41	Either full removal and recoat or continue with mainteance coating		
			Total NPV Cost $	187.52 /m^2

Total Cost (surface preparation, coating material cost, access and application cost) $300 /m^2
Containment Cost $0 /m^2

Notes:
1. Year(s) after commissioning bridge.
2. Current Cost/total m^2 = % Area Maintained x System Cost $/m^2
3. NPV Net Present Value: NPV = Operating Cost/(1+DR)^{Year}
4. Recommended discount rate for Transit NZ is 6% for 40 years. (NZTA 2013)

DISCLAIMER: The above costings are approximate and should be confirmed with a coating supplier and applicator.

Figure 5: Example of a Life Cycle Costing using Net Present value.

Table 2: Life Cycle Costing Scenarios.

Scenario	Period (%area/number of years)			Containment required	NPV Cost ($/m2)	Cost over 40 years NPV x total area ($million)
	1	2	3			
1	20%/5	0%/10	1%/25	Yes in period 1	$415	$51.88
8	1%/5	6.7%/15	1%/20	No	$175	$21.88
13	1%/40			No	$45	$6.75
14	1%/5	12.5%/8	1%/20	No	$200	$25
15	1%-5%/5	12.5%/8	1%/20	No	$220	$27.5

Note: [1] This scenario assumes that work will be increased from 1% to 5% in the first 5 years.

Model Discussion

Under the net present value method, the longer time that major work can be delayed or prolonged, the lower the overall cost will be which was consistent with the model findings. Table 2 shows a number of scenario, which can be summarised as follows:

- Scenario 1: is the most expensive option, which assumes that major maintenance work commences in 2015, where the whole bridge is recoated in a 5 year period. Such large scale work will require full containment, and does not take into account the additional structural strengthening cost discussed in the Resource Consent section above. Thereby the actual cost is higher by an additional amount which is required to be spent to set up the containment before the actual maintenance is undertaken
- Scenario 8: Assumes that current maintenance work is continued as is, for the first 5 years followed by a 15 year period of recoating the bridge. This option does have a relatively low overall cost, with no containment being required

  The only concern of this option is that over a 15 year period, the risk of the existing coating delaminating due to embrittlement is high. If that occurs, then the cost will suddenly increase, to that similar to Scenario 1. Hence, while this option is favourable from a cost point of view, the risk of delamination disqualifies this option

- Scenario 13: Assumes that current maintenance work is continued, as is, indefinitely. While, this option provides the most cost effective method, it is unrealistic as the existing coating will fail at some point in the future, as discussed earlier in the report. Hence, while the above numbers show that it is cost effective, other factors must be considered when conducting NPV modelling that the assessor needs to consider when managing risks and client expectations

- Scenario 14: Assumes that current maintenance work is continued as is, for the first 5 years followed by an 8 year period of recoating the bridge. This option does have a relatively low overall cost, with no containment being required

  This option does provide a realistic expectation on the performance of the existing coating with medium risk of premature failure near the end of the 8 year recoating period. If the coating failed during that period, then it may only affect a reduced surface area with an expected increase of less 50% of Scenario 1

- Scenario 15: Assumes that current maintenance work is increased over the first 5 years to 5% surface area of the bridge. Followed by an 8 year period of recoating the bridge. This option does have a relatively low overall cost, with no containment being required. In the authors' view, this is the preferred option

  Increasing the surface areas of the bridge being maintained over the first 5 years, will allow for identified weak areas being recoated earlier. This will minimise the risk of the coating in those areas delaminating at the end of the 8 year period, highlighted in Scenario 14. It will also provide the benefit of training the workforce on the surface preparation and application of the specified coating system, and managing the logistics of rehabilitating a larger surface area than that currently being undertaken. Therefore, while it is slightly more than other lower cost scenarios, the extra cost during the first 5 year period will allow for the mitigation of the expected long term risk potentially providing a lower overall cost in the long term.

CONCLUSIONS & RECOMMENDATIONS

Based on the findings of our report, the following conclusions were reached:

- Extrapolation of adhesion and DFT tests carried out over the past 15 years indicates that the risk of significant delamination is low and that the current practice of patch repair can be safely continued until mid-2015
- The current maintenance regime using moisture cured urethane appears to have been successful in retarding the embrittlement of the ageing alkyd layer, hence reducing the risk of significant delamination

- Significant savings could be made, while minimising the environmental impact, if full containment requirements can be reduced through the use of encapsulation coatings that do not require preparation by abrasive blasting
- A number of maintenance strategies were proposed, of which encapsulation with a maintenance coating provides the most advantages
- A number of coating systems were considered, with high ratio calcium sulfonate alkyd (HRCSA) being identified as best meeting the performance and logistical criteria on the truss portion of the Auckland Harbour Bridge
- A number of scenarios were developed to determine the most cost effective option using the net present value model. From these, a scenario was identified (i.e. overcoating with HRCSA) that provided an affordable option while minimising potential risk of the existing coating delaminating and associated cost increases.

In addition the following recommendations were made:

- Due to the limited amount of data available and its high variability, additional investigations should be conducted to assess and confirm the condition of the coating on the bridge. This includes monitoring of sites where coating thickness and adhesive strength trends indicate early full removal may be required, plus an adhesion survey of coatings on the Extension Bridges
- Full scale trial applications should be carried out to confirm both the feasibility and possible limitations of applying a high ratio calcium sulfonate alkyd system to the Truss Bridge using high pressure water cleaning as preparation. This includes investigation of its possible environmental impact to determine the level of (if any) containment it may require
- The maintenance options should be re-evaluated based on the above findings, and the long term maintenance strategy is further refined after input from all stakeholders.

ACKNOWLEDGEMENT

The author acknowledges the New Zealand Transport Agency and the other Alliance partners (Total Bridge Services, a TBS Farnsworth, Opus International Consultants Ltd and Fulton Hogan joint venture, and Beca Ltd) for the opportunity to write and present this paper.

REFERENCES

AS 1580.408.2:2004 ‘Paints and related materials – Methods of test method 408.2: Adhesion – Knife Test – Method B’. Standards Australia. 2004

AS 4361.1:1995. ‘Guide to lead paint management – Industrial applications’. Standards Australia. 1995

AS/NZS 2312:2002. Guide to the protection of structural steel against atmospheric corrosion by the use of protective coatings. Standards NZ. 2002

ASTM D610-08(2012). Standard Practice for Evaluating Degree of Rusting on Painted Steel Surfaces.

ASTM D4541-09. ‘Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers’.

Dalzell, K., ‘Auckland Harbour Bridge – Adhesion Testing’, Kerry Dalzell and Associates. Ref: 06/1500. 2006 (Internal report to TBS).

Dalzell, K., ‘Auckland Harbour Bridge – Adhesion Testing’, Kerry Dalzell and Associates. Ref: 13/1500. 19 March 2013 (Internal report to TBS).

El Sarraf, R. and Clifton, G.C., ‘New Zealand Steelwork and Corrosion Coatings Guide’, HERA Report R4-133, NZ Heavy Engineering Research Association. Auckland, New Zealand. 2011

FHWA-HRT-11-046. ‘Performance Evaluation of One-Coat Systems for New Steel Bridges. Federal Highway Agency’. June, 2011.

Mandeno W.L., 'Painting State Highway Bridges - Past, Present and Future', NZ Road Research Unit Bulletin 84 Vol. 5. Republished by Journal of Protective Coatings & Linings Vol.8, No.1, pgs. 44 to 51 (1991).

Mandeno W.L. and El Sarraf, R., 'Coatings Maintenance Strategy for the Auckland Harbour Bridge'. Auckland Harbour Bridge Alliance. Auckland, New Zealand. 2013.

Mandeno W.L., 'Performance Specified Maintenance Painting on the Auckland Harbour Bridge – A Review', paper presented to Austroads 6th Bridge Conference, Perth, Australia. (2006).

NZ Transport Agency, 'Economic Evaluation Manual (Vol. 1)', Wellington, New Zealand. 2013

AUTHOR BIOGRAPHIES

Raed El Sarraf, BSc(Civil Engineering)from Baghdad University (1999), MEngSt & ME(Civil(Hons) Auckland University 2008. He was a Structural Engineer at NZ Heavy Engineering Research Assoc(HERA)2003-2010, Holmes Consulting Group(2010-2012) and Materials Engineer at Opus since Oct 2012. He is co-author of several HERA & NZTA Bridge Design Guides.

Willie Mandeno, BE(Civil)from Auckland University. Willie was a Design/Construction Engineer with Mandeno Chitty & Bell (1970-73), Chartered Engineer with Harris & Sutherland in London (1974-75), Investigation/Construction/Design Engineer MWD Power Div in Wellington for Huntly & Ohaaki Power Project (1976-83). He is a Materials Engineer with MWD Civil Div,WORKS Consultancy/OPUS (1984 to date) including 37week secondment as Corrosion Engineer to Shell Todd Services in New Plymouth. Made Fellow of IPENZ in 1999. President of Australasian Corrosion Association in 2000 and awarded their Corrosion Medal in 2008. Certified as a Corrosion Specialist by NACE International in 2010.

Alex Ingram is a graduate of the University of Auckland, Alex has over ten years' experience in the design, construction and maintenance of bridges and civil structures in New Zealand and the UK. Recent roles include: Bridge Engineer for the London 2012 Olympics, Senior Structures Engineer on Transport for London's Road Network, and Project Manager for the construction of the Auckland Harbour Bridge Cable Support Structure and Bridge Strengthening project. He is currently the Asset Manager for the Auckland Harbour Bridge Alliance.