Protective coatings for steel bridges

A guide for bridge and maintenance engineers

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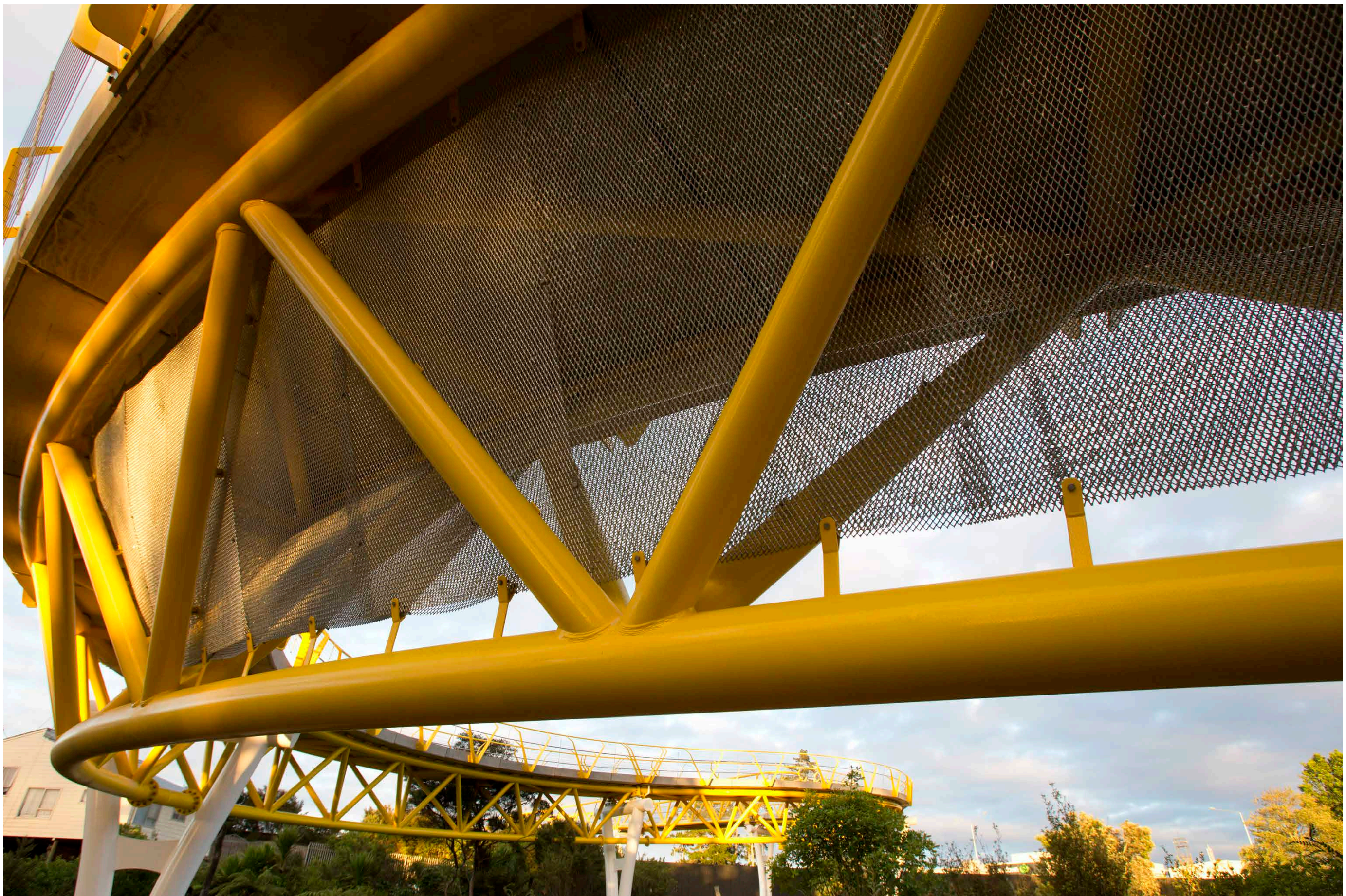

NZ TRANSPORT AGENCY
WAKA KOTAHI

New Zealand Government

Protective coatings for steel bridges

A guide for bridge and maintenance engineers

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Opus International Consultants Ltd

www.nzta.govt.nz

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Document management plan

1) Purpose

This management plan outlines the updating procedures and contact points for the document.

2) Document information

Document name	*Protective coatings for steel bridges*
Document number	-
Document availability	This document is located in electronic form on the NZ Transport Agency's website at www.nzta.govt.nz.
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3) Amendments and review strategy

All corrective action/improvement requests (CAIRs) suggesting changes will be acknowledged by the document owner.

	Comments	Frequency
Amendments (minor revisions)	Updates to be notified to users by publication of a technical memorandum placed on the NZ Transport Agency's website.	As required.
Review (major revisions)	Periodic updates will be undertaken where amendments fundamentally changing the content or structure of the guide or new technology resulting from research or ongoing refinement have been identified.	As required.
Notification	All users that have registered their interest by email to info@nzta.govt.nz will be advised by email of amendments and updates.	Immediately.

4) Distribution of this management plan

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Record of amendments

This document is subject to review and amendment from time to time. Amendments will be recorded in the table below.

Changes since the previous amendment are indicated by a vertical line in the margin. The date of issue or amendment of a page appears in the header on each page. This page will be updated each time a new amendment is released.

Amendment number	Description of change	Effective date	Updated by
0	*Protective coatings for steel bridges* 1st edition published.	February 2014	Nigel Lloyd
1	Revised to suit AS/NZS 2312 published November 2014.	April 2017	Nigel Lloyd

Foreword

Steel bridges comprise approximately 20% of New Zealand state highway bridges and, with the inclusion of the Auckland Harbour Bridge, represent an asset replacement value of over $2 billion.

Protective coatings are often less than one third of a millimetre in thickness and are required to protect highly stressed steel from corrosion in often aggressive marine environments.

Historically the full potential life of these coatings has not been achieved due to less than optimum coating selection, specification, application or maintenance.

The ultimate objective of this guide is to optimise the long term capital and maintenance costs of steel structures through the implementation of best practice in the selection, application and maintenance of protective coatings on steel structures.

Protective coatings for steel bridges generally provides an overview of the key processes and considerations with references to other key standards and documents. It is provided to inform and assist the wider industry in achieving best practice. However, it is also strongly recommended that specialists with skills and experience in protective coatings are used to ensure the accurate interpretation and application of this guide and various reference documents on individual projects.

Barry Wright
National Structures Manager
NZ Transport Agency

Contents

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1.0 Introduction

The use of structural steel in bridges has been increasing since 2007, resulting in a number of new steel bridges located in different corrosive environments around New Zealand. Depending on the environment, different corrosion protection systems have been used. In most cases, the use of a sprayed-on coating system was typically specified.

This document provides a summary of available information that can assist the bridge designer with the specification of a cost effective performance based corrosion protection system, taking into account future maintenance requirements, by using the net present value life cycle costing model. Guidance is also provided for the maintenance painting of existing steel bridges.

This document complements existing guidance documents on the specification of protective coating systems for new and existing steel road bridges by either referencing them or reproducing relevant sections as required. These documents are:

- AS/NZS 2312 *Guide to the protection of structural steel against atmospheric corrosion by the use of protective coatings*(1)
  Part 1 Paint coatings
  Part 2 Hot dip galvanizing
  Part 3 Thermally sprayed metallic coatings (In prep.)
- NZS 3404.1 *Steel structures standard* part 1 Materials, fabrication, and construction(2)
- HERA Report R4-133 *New Zealand steelwork corrosion and coatings guide*(3).

Whilst this document has been developed by the NZ Transport Agency for use on bridges on state highways, it may also be used on other state highway structures, where appropriate. The use by other road controlling authorities, of the guidance and any specific requirements detailed in this document, may also be considered appropriate.

2.0 Corrosion basics

Corrosion of metal is essentially an electrochemical reaction. It is the same process that is involved in a battery where stored chemical energy is released as electrical current as materials change their form. Iron and steel are made from iron ore in a reduction process, which uses a lot of energy (approx. 3 tonne of coal is used to make 2 tonne of iron). This process is reversed by natural oxidation that can occur just by the contact of ferrous metals with air and water, and the reaction is powered by the energy released from the conversion of iron back to its natural form as iron ore or rust.

Water provides a path (or electrolyte) for ion transfer between anodes (areas where metal is lost to corrosion); and cathodes (the other surface areas) where released electrons are used to form oxides and hydroxides, and corrosion does not occur. In other words corrosion occurs at the anodic sites while there is no metal loss at cathodic surfaces. The wetter the environment, the faster the reaction rate and as it is an electrochemical reaction, the higher the temperature the faster the reaction rate, except when the corrosion rate is reduced by drying surfaces.

2.0 continued

Air is also required to provide oxygen to allow oxides to form at the cathodes, so corrosion is very slow if steel is deeply buried or submerged. If the conductivity of water at the metal surface is increased by dissolved salts, especially chlorides, the current flow and hence the corrosion rate is increased. When iron and steel is kept dry, or free from oxygen, corrosion will cease. Conversely, surfaces that are shaded by vegetation or in contact with soil, and stay damp for longer periods, will corrode at a faster rate than those that dry more quickly.

There are three types of protection mechanisms used in coatings systems, these are sacrificial, passivating, and barrier.

Sacrificial systems act by cathodic protection, through the use of a material that is more reactive to oxygen than steel. When both are in electrical contact and are exposed to oxygen and moisture, the more anodic material oxidises and protects the steel, as it has been made cathodic.

The most common sacrificial material used in coatings is metallic zinc, deposited on the surface as thermal zinc metal spray, galvanizing, or as a “zinc-rich” priming paint. In thermal metal sprays, zinc may be combined with, or replaced by other anodic metals (eg aluminium and magnesium) and their alloys, as required for greater durability.

Passivating systems use chemicals such as zinc phosphate, and previously zinc chromate and red lead, as a passivating pigment in the primer coat. This combines with any moisture that penetrates the coating system such that when it reaches the steel, it is inhibited and slows the formation of anodes.

Barrier coats work both by sealing the steel surface from air and water, and electrically isolating the anodic and cathodic surfaces, thus preventing the electrochemical reaction from operating. When a barrier coat is breached back to the metal substrate, there is nothing to prevent rusting of exposed steel. As the rust layer forms, it occupies at least 3 times the volume of the steel being lost, leading to swelling around the damaged region and progressive undercutting of the barrier coat. This problem is reduced if there is a sacrificial layer between the steel and the paint, either through galvanizing, or the use of a zinc-rich primer. However the area of zinc available is less than with an uncoated galvanized or inorganic zinc single coat sacrificial layer, so pitting may still occur.

These different protection mechanisms are illustrated in section 1 of HERA Report R4-133(3).

3.0 Durability design and detailing considerations

3.1 General

Any steel structure exposed to a corrosive environment must be designed to provide optimum long term performance with a minimal level of normal maintenance. Durability design will require either the use of self-protecting stainless or weathering steel or conventional carbon steel with a corrosion protection system utilising a protective coating. When conducting a durability design, the bridge designer is recommended to determine the optimum solution, ie one that will achieve the lowest net cost based on the structure's performance and aesthetic requirements, maintenance frequency, design life, and location. The optimally designed structure for sustainability, whether coated or uncoated, will minimise the initial material and energy inputs, provide cost savings from reduced future maintenance, provide health and safety benefits, and for coated structures, less on-site debris to be contained and disposed of.

All durability design and detailing requirements should be to section 3 of AS/NZS 2312.1(1) and section 7 of AS/NZS 2312.2(1), with additional guidance given by HERA Report R4-133(3).

Typical bridge related design and detailing requirements are given below, with references to the relevant AS/NZS 2312.1(1) clauses:

- Eliminate crevices to prevent crevice corrosion and pack rust, clause 3.3.4.2.
- Seal hollow tubular or box members to minimise/prevent internal corrosion of the hollow section, clause 3.3.4.3.
- Eliminate water ponding to minimise accelerated corrosion, clause 3.3.4.4.
- Design to both allow and facilitate site painting for repairs and future maintenance, clause 3.3.4.6.
- Separate all dissimilar metals or steel from other materials to prevent galvanic corrosion and accelerated corrosion respectively, clauses 3.3.3.2 and 3.3.4.15.
- Treat faying surfaces for high friction-type bolted joints as given in clause 3.3.4.12.

Figures 3.1 and 3.2 of AS/NZS 2312.1(1) also provide typical design and fabrication problems and their solutions, such as:

- Poor weld finish could affect the surface coating, allowing for dirt to accumulate or water to pond. In this case, smoothing the weld surface thereby lowering its profile is suggested (figure 3.2(a)). For butt welds, grinding the weld flush is recommended.

Insufficient edge preparation (ie sharp edge) prior to painting, will cause the paint to fail at that point since the coating thickness will be significantly less than the specified dry film thickness. It is recommended that edges be chamfered or rounded prior to painting (figure 3.2(b)).

3.2 Topics of interest

The following topics should be considered when conducting a durability design.

- Zone coating: This concept proposes modifying the coating system to suit different microclimates within the structure. This could be by specifying different dry film thickness of the coating system, or the use of different coatings in separate zones throughout the bridge. For example; in hard to reach areas of the bridge a thicker coating could be applied or a higher performance coating be specified, in comparison to easy to reach areas that are easier to maintain, where it may be more economical to use a shorter life coating with more frequent recoats in this area. Alternatively components in a more severe microclimate, such as below deck joints, could receive an additional intermediate coat.
- Surface treatment: The performance of any coating is dependent on the level of surface treatment and preparation undertaken prior to its application. Most long term protection coatings require a surface preparation visual cleanliness standard of Sa2½ to AS 1627.4 *Metal finishing – Preparation and pre-treatment of surfaces* part 4 Abrasive blast cleaning of steel(4). Wet abrasive blasting or water jetting may be also be used especially to aid in the removal of nonvisible but soluble contaminants such as marine salts. Further guidance is given in section 4 of AS/NZS 2312.1(1) and appendix B of this guide.
- Stripe coating: Allow for stripe coating of all edges and welds, ie an additional layer of the specified coating is brush applied before the spray application of the coating. Thereby a thicker layer will be deposited on vulnerable locations, minimising their likelihood of premature failure.
- Additional protection of hot-dip galvanized fasteners: The zinc coating on bolts, nuts and washers typically range between 40 to 60 microns (AS/NZS 1214 *Hot-dip galvanized coatings on threaded fasteners (ISO metric coarse thread series)*(5)). However, in corrosive marine environments, these will have lower durability than typically used high performance coatings such as thermal metal spray, or inorganic zinc silicate. In this case, additional protection is recommended, which could be in the form of:
  - stripe coating, followed by the application of the same finish coating as specified for the components that they are joining
  - application of an additional barrier coat
  - use of the UV stable plastic Radolid® Caps.
- Rust grades: Are based on ASTM D 610 Standard practice for evaluating degree of rusting on painted steel surfaces(6) and SSPC-VIS 2 Standard method of evaluating degree of rusting on painted steel surfaces(7), where rust is assigned a numerical grade from 1 to 10 using a logarithmic scale on the basis of percentage of surface area rusted. Rust grade 10 means there is 0% rust, while rust grade 1 means there is 100% rust. These should be called up in a performance warranty to define the acceptable level of degradation at the end of a guarantee period. They may also been used in setting a key performance indicator in a long term maintenance contract.

3.3 Curing issues with water borne inorganic zinc silicate

It should be noted that there is a significant risk in using water borne inorganic zinc silicate. As stated in section 8.3.5 of HERA Report R4-133[3] it requires low humidity and relatively high temperature for it to cure. Therefore, areas such as Hawke's Bay and Canterbury in summer are better suited for its application. Alternatively, additional steps may be required such as fans to increase air flow and or painting the steel in a dehumidified painting booth. Failure to provide optimum drying conditions may result in the premature failure of the water borne inorganic zinc silicate from improper curing of the coating (see *Water based inorganic zincs – performance vs practicability*[8]), and an expensive onsite repair of the coating after a relatively short time frame.

These curing requirements may add additional cost, so that if solvent borne inorganic zinc cannot be used, other protective coating options will need to be considered. Alternatives, such as thermal metal spray or traditional three coat systems could be used.

3.4 Durability issues with duplex thermal sprayed metal systems

Thermal sprayed metal (TSM) systems using zinc and/or aluminium have a proven long term durability when applied correctly to NACE No.12/AWS C2.23M/SSPC – CS 23.00 *Specification for the application of thermal spray coatings (metallizing) of aluminum, zinc, and their alloys and composites for the corrosion protection of steel*[9]. Their potential performance can be compromised when overpainted with organic top coats for aesthetic reasons, especially when sealing of the porous TSM has not been effective. It is critical that the sealer has sufficiently low viscosity to penetrate into the TSM and seal the interconnected surface porosity, and if to be top coated, that the sealer is applied before the TSM is exposed to dewpoint conditions or windborne contaminants. Note that most international specifications require the temperature of the item being coated to remain at least 3°C above dewpoint temperature from the start of metal spraying until absorption of the sealer is complete.

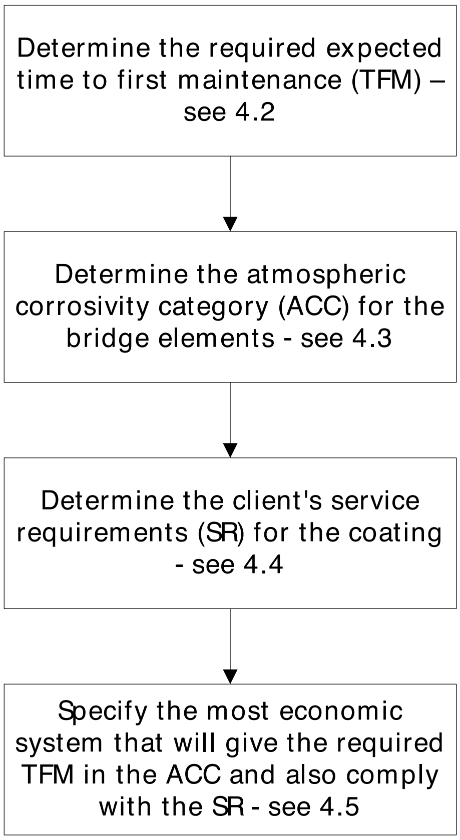
Note also that the addition of organic topcoats to create a 'duplex' system may reduce potential life if they are of excessive thickness (>200 microns) as discussed in section 5.2 of AS/NZS 2312:2002 *Guide to the protection of structural steel against atmospheric corrosion by the use of protective coatings*[10]. Further, the migration of corrosion products through the topcoats on sheltered surfaces on coastal structures can affect appearance, especially if the top coat colour is other than a light grey. Duplex aluminium systems must not be used where subject to marine immersion (eg bridge piles).

It should also be noted that the life expectancies for TSM systems given in AS/NZS 2312:2002[10] are for unsealed and sealed metal spray and may not apply to Duplex systems. It is therefore recommended that where a colour other than a light or silver grey is required, that an alternative long life system based on a zinc-rich primer/MIO epoxy build coat and a polyurethane or polysiloxane topcoat, similar to the systems designated PUR5 or PSL2 in table 6.3 of AS/NZS 2312.1[1] be specified.

4.0 Coating selection for new bridges

One of the benefits of coating new steel bridges is that if the appropriate coating system is selected for the given environment, and is applied correctly, with independent inspection to certify that, then corrosion should be prevented until the expected time to first maintenance. The following sections outline the methodology and guidance on how to select a coating system for new bridge elements.

4.1 Design flow charts



4.2 Current NZ Transport Agency requirements, expected time to first maintenance

The NZ Transport Agency *Bridge manual*[11], section 4.3.6 requires that:

> Primary structural members and elements not easily accessed or replaced (eg bearing plates, deck joint components) in steel shall be corrosion protected with a system capable of achieving a time to first maintenance of at least 40 years unless agreed otherwise with the road controlling authority. Secondary steelwork elements (eg barriers, handrails) shall be corrosion protected with a system capable of achieving a time to first maintenance of at least 25 years.

4.2 continued

To summarise the above, the expected time to first maintenance for:

- primary structural members and elements not easily accessed or replaced: 40 years
- secondary steelwork elements: 25 years.

There is also the following qualification to the "at least 40 years" requirement:

> Where the corrosivity of the environment is such that achieving the above levels of performance is impractical or not economically viable, a lower level of performance may be proposed and justified within the structure design statement.

The expected time to first maintenance is discussed in clause 1.6 of AS/NZS 2312.1(1) and clause 5.1.2 of NZS 3404.1(2).

4.3 Determine atmospheric corrosivity category

The determination of the atmospheric corrosivity category (ACC) is outlined in both section 2.3 of AS/NZS 2312.1(1) and section 5 of HERA Report R4-133(3). It should be noted that the categories given in AS/NZS 2312 parts 1 and 2(1) are based on the macroclimate conditions of washed surfaces. However the guidance given in HERA Report R4-133(3) includes a methodology to determine both the macro- and microclimate conditions. Bridge designers should always assess both conditions to provide a realistic estimate of the most severe atmospheric corrosivity category that the bridge elements are exposed to.

Another reference is given in table 14 of NZS 3404.1(2), and is included in table 4.1, which is based on both AS/NZS 2312.1(1) and HERA Report R4-133(3). This table has been developed for steelwork in external and internal conditions and can be used for all steel structures. For most bridges the given corrosivity categories in external conditions are sufficient. However, the corrosivity categories for internal conditions may be used for the inside of steel box girders or piers. For bridges located in the Volcanic Zone the guidance has been revised to reflect the corrosivity in an internal and geothermal environment.

Table 4.1: Atmospheric corrosivity categories from table 14 of NZS 3404.1(2)

Corrosion map zones	Macroclimate corrosion category	Typically	Location	Characterised by	Surface specific corrosion category				
					External			Internal	
NZS 3404.1(2)	AS/NZS 2312.1(1)				Exposed	Sheltered	Wet	Dry	Damp
Seaspray	C5M	Within 200 m from the breaking surf on the West Coast of the South Island. Within 100 m from breaking surf on West Coast of the North Island. Within 50m from breaking surf of all other coasts. This environment may be extended inland by prevailing winds and local conditions.	All coasts	Heavy salt deposits. Almost constant smell of salt spray in the air	C5M*	C5M	C5M	C1	C3
	C5M	200m up to 500m or more inland from breaking surf. In the immediate vicinity of calm salt water such as harbour foreshores. This environment may be extended inland by prevailing winds and local conditions.	West Coast of the South Island		C5M*	C5M	C5M	C1	C3
	C4	50m up to 500m or more inland from breaking surf. In the immediate vicinity of calm salt water such as harbour foreshores. This environment may be extended inland by prevailing winds and local	All coasts except West Coast of the South Island	Medium salt deposits. Frequent smell of salt in the air	C4*	C5M	C5M	C1	C2
	C4	500m to 1km from breaking surf. In the immediate vicinity of calm salt water such as estuaries.	West Coast of the South Island	Little salt deposits. Occasional smell of salt in the air	C4*	C5M	C5M	C1	C2
Zone 1	C3		East Coast of both Islands, South Coast of the North Island and all harbours		C3*	C5M	C5M	C1	C2
		More than 1km to 20km from salt water.	West and South Coast of the South Island	Minor salt deposits. No smell of salt in the air	C3*	C5M	C5M	C1	C2
		More than 1km to 5km from salt water.	East Coast of both Islands, West Coast of North Island, South Coast of North Island and all harbours		C3*	C4	C5M	C1	C2
Zone 2	C2	More than 20km to 50km from salt water.	West and South Coasts of South Island	No marine influences	C2*	C3	C4	C1	C2
		More than 5km to 50km from salt water.	East Coasts of both Islands, West and South Coast of North Island, and all harbours		C2*	C3	C4	C1	C2
Zone 3	C2	Inland, more than 50km from salt water.	North and South Islands		C2*	C2	C3	C1	C2
Zone 4	C5I	Close to the geothermal source <500m.	Volcanic Zone	Major geothermal influence	C5I*	C5I	C5I	C1	C4
	C2	Not closer than 500m to geothermal source.		Mild geothermal influence with no marine influences	C4*	C4	C4	C1	C3

Notes to table 4.1:

External	Exposed to the weather
Internal	Protected from the weather by being located inside the structure (ie inside of a box girder)
Exposed	Exposed to airborne salts, is washed by the rain and can dry quickly after wetting
Sheltered	Exposed to airborne salts but unwashed, such as the underside of a steel bridge
Wet	Often wet for extended periods of time, such as crevices, or in low points pockets and other surfaces that are not adequately drained
Dry	Dry internal environment, such as in sealed box girders or sealed tubular and hollow sections
Damp	Damp and poorly ventilated internal environment where condensation may often occur, such as in vented box girders

4.4 Client service requirements for the coating

Service requirements need to be separated from durability requirements as these can involve additional initial and maintenance costs. These are generally related to the aesthetic requirements that may be required to meet a resource consent or maintain a minimum standard of appearance to prevent complaints from adjacent landowners, neighbours or the public. Some of these issues are discussed below:

- Aesthetics: To be considered in accordance to the client service requirements and the provisions given in section 2.6 of the *Bridge manual*(11), PSG/12 *Urban design professional services guide*(12) and *Urban and landscape design frameworks – highways and network operations guideline*(13). Matters such as colour, colour retention and gloss levels shall be considered, as described below.
- Colour: The Transport Agency's *Bridging the gap*(14) states:

  > Colour provides opportunities to give consistency to a family of bridges and to reinforce the landmark quality of a standalone structure. When used to highlight particular elements it should form part of a coherent composition. Colour must be used carefully as it draws the eye, especially in a rural setting.

  Examples of colour used as part of the bridge design include the white on the Te Rewa Rewa Footbridge, pale yellow on the Newlands Bridge and the blue on the SH20 Beachcroft Bridge.

Figure 4.1: Example of coloured top coats on the international award winning Te Rewa Rewa foot bridge which was over 70% funded by the NZ Transport Agency

4.4 continued

- Fade resistance: When the colour is something other than white, a topcoat with UV resistant stable resins and pigments similar to that used in automotive coatings, needs to be selected for elements that are exposed to sunlight, and the allowable gloss and colour shift over time needs to be specified and also be covered by a performance guarantee. These requirements could be specified by referencing a performance standard such as AAMA 2604 *Voluntary specification, Performance requirements and test procedures for high performance organic coatings on aluminum extrusions and panels*(15), used for coated aluminium panels on buildings, or specifying a colour fade rating to ASTM D2244 *Standard practice for calculation of color tolerances and color differences from instrumentally measured color coordinates*(16) or a limit on chalking when measured to ASTM D4214 *Standard test methods for evaluating the degree of chalking of exterior paint films*(17). Consistent appearance over at least a ten year period would be considered as a reasonable requirement.
- Gloss levels: Similarly restrictions on levels of gloss may be imposed to reduce reflectivity which can be hazardous to night-time drivers, or to reduce visual impact of the structure. Low gloss coatings help disguise variations in profile but are less easily cleaned by rain or maintenance washing. Some softer coatings may have issues with dirt accumulation or biogenic contamination. Some coatings like epoxy are vulnerable to chalking so where gloss stability appearance is important a UV resistant and pigmented top coat should be used. Note a clear polyurethane should not be used over an epoxy where exposed to sunlight as the epoxy will still chalk from the UV and the clear coat will then delaminate.
- Corrosion: The acceptable level of corrosion needs to be identified when planning maintenance as this may require repainting before it is necessary from an asset protection perspective. As an example, Auckland and Sydney Harbour Bridges have been repainted at rust grade 8 (<0.1%) instead of allowing deterioration to reach rust grade 6 (<1%) or rust grade 5 (<3%). The higher rust level is closer to the most economic time for repainting but its appearance may not be acceptable to some stakeholders.
- Graffiti: In most bridge locations there is the risk of defacement by graffiti. In urban areas and other locations of high public visibility, steel components that are accessible should be protected with an anti-graffiti topcoat (see clause 4.12.9 of the *Bridge manual*(11)). These are usually a solvent resistant coating, such as a two-pack polyurethane, which will allow removal of the graffiti without damaging the corrosion protection system. In some areas a "sacrificial" coating may be used which is removed along with the graffiti and then needs to be replaced. This latter type is more commonly used on softer or porous substrates like concrete that could be damaged by water jetting. A list of approved products for use on state highways is provided on the Auckland Motorways website(18).

4.5 Suggested coatings in different environments

The suggested coatings given in tables 4.2 to 4.5, are expected to provide between 25 and 40 years' time to first maintenance in the given environments. Other coating systems that are available are given in AS/NZS 2312.1(1).

4.5 continued

While the provisions given in AS/NZS 2312.1(1) only provide the expected time to first maintenance of "25+" years, the guidance given in section 9.1 of HERA Report R4-133(3) has been used to extend the time to first maintenance for the suggested coatings. Tables 4.2 to 4.5 are based on those given in NZS 3404.1(2), which also only provides coating options for 15 and 25+ years.

Note that some single coat systems that provide 40 years time to first maintenance may still be cost effective when only 25 years is required. The bridge designer should contact their coating supplier's technical manager or a coatings consultant for additional guidance and assistance on specifying coating systems, especially when 40 years expected time to first maintenance is required.

Additional information on coating systems and their typical use, including their advantages and disadvantages, is given in appendix A, while information on the different surface preparation methods is given in appendix B. A relative costing comparison between the different coatings is given in table 8.2 of HERA Report R4-133(3).

Note that AS/NZS 2312 parts 1(1) and 2(1) are a guide and not a standard specification so care is required as to how it is referenced in contract documents. The only paint coating specification published by Standards Australia is AS 4848.1 *Application specifications for coating systems – Single coat inorganic (ethyl) zinc silicate – Solvent-borne*(19) for a 100 micron coating of solvent borne zinc silicate which is not included in AS/NZS 2312.1(1). However there are some errors in AS 4848.1(19) (see *New standard on single coat inorganic zinc silicate coatings*(20)) that should have been rectified at the public review stage. In section 10(d), the dry film thickness is listed in millimetres and not microns, and the minimum dry film thickness for point readings is listed at 75 microns in section 8 and 80 microns in section 10(d).

Table 4.2: Coatings for atmospheric corrosivity category C2

<table>
<tr><th>Years</th><th>System designation</th><th>Surface preparation</th><th>Number of coats</th><th>Hardness</th><th>Typical colour</th><th>Initial gloss</th><th>Colour and gloss retention on weathering</th></tr>
<tr><td rowspan="3">25</td><td>EVH2</td><td rowspan="6">Sa2½</td><td>1</td><td rowspan="5">Excellent</td><td rowspan="2">Limited range</td><td>Flat to semi-gloss</td><td>Fair</td></tr>
<tr><td>MCU2</td><td rowspan="2">3</td><td>Semi-gloss</td><td>Very good</td></tr>
<tr><td>PUR3</td><td>Wide range</td><td>Semi-gloss to full gloss</td><td>Excellent</td></tr>
<tr><td rowspan="5">40</td><td>IZS4</td><td>1</td><td>Mostly grey</td><td>Flat</td><td>Fine</td></tr>
<tr><td>PUR5</td><td>3</td><td>Wide range</td><td rowspan="2">Semi-gloss</td><td rowspan="2">Excellent</td></tr>
<tr><td>ACE1[1]</td><td>2</td><td>Good</td><td>Limited range</td></tr>
<tr><td>HDG600</td><td>See AS/NZS 4680</td><td>1</td><td rowspan="2">Excellent</td><td rowspan="2">Grey[2]</td><td>Gloss</td><td rowspan="2">Fair</td></tr>
<tr><td>TSZ100[3]</td><td>Sa2½</td><td>1</td><td>Flat</td></tr>
</table>

Notes:

1. Acrylic elastomeric
2. Wide range when colour sealer/top coat is used
3. May be cheaper than HDG for heavy girders

Table 4.3: Coatings for atmospheric corrosivity category C3

Years	System designation	Surface preparation	Number of coats	Hardness	Typical colour	Initial gloss	Colour and gloss retention on weathering
25	PUR5	Sa2½	3	Excellent	Limited range	Semi-gloss	Excellent
	ACE1[1]		2				
40	IZS4		1		Mostly grey	Flat	Fair
	TSZ100[3]				Grey[2]		
	HDG600	See AS/NZS 4680	1				
	HDG600P7	Sweep abrasive blast	2		Wide range	Semi-gloss to full gloss	Excellent

Notes:

1. Acrylic elastomeric
2. Wide range when colour sealer/top coat is used
3. May be cheaper than HDG for heavy girders

Table 4.4: Coatings for atmospheric corrosivity category C4

Years	System designation	Surface preparation	Number of coats	Hardness	Typical colour	Initial gloss	Colour and gloss retention on weathering
25	IZS4	Sa2½	1	Excellent	Mostly grey	Flat	Fine
	HDG900				Grey[1]		
	HDG600P7	Sweep abrasive blast	2		Wide range	Semi-gloss to full gloss	Excellent
40	TSZ150S	Sa2½			Grey[1]	Flat	Fine

Notes:

1. Wide range when colour sealer/top coat is used

Table 4.5: Coatings for atmospheric corrosivity category C5M

Years	System designation	Surface preparation	Number of coats	Hardness	Typical colour	Initial gloss	Colour and gloss retention on weathering
25	TSZ200S	Sa2½	2	Excellent	Grey[1]	Flat	Fine
40	TSZ300S						
	TSA225S[2]	Sa3					

Notes:

1. Wide range when colour sealer/top coat is used
2. TSA225S is also suitable for atmospheric corrosivity category C5I, eg a mild geothermal environment.

5.0 Maintenance coating selection for existing bridges

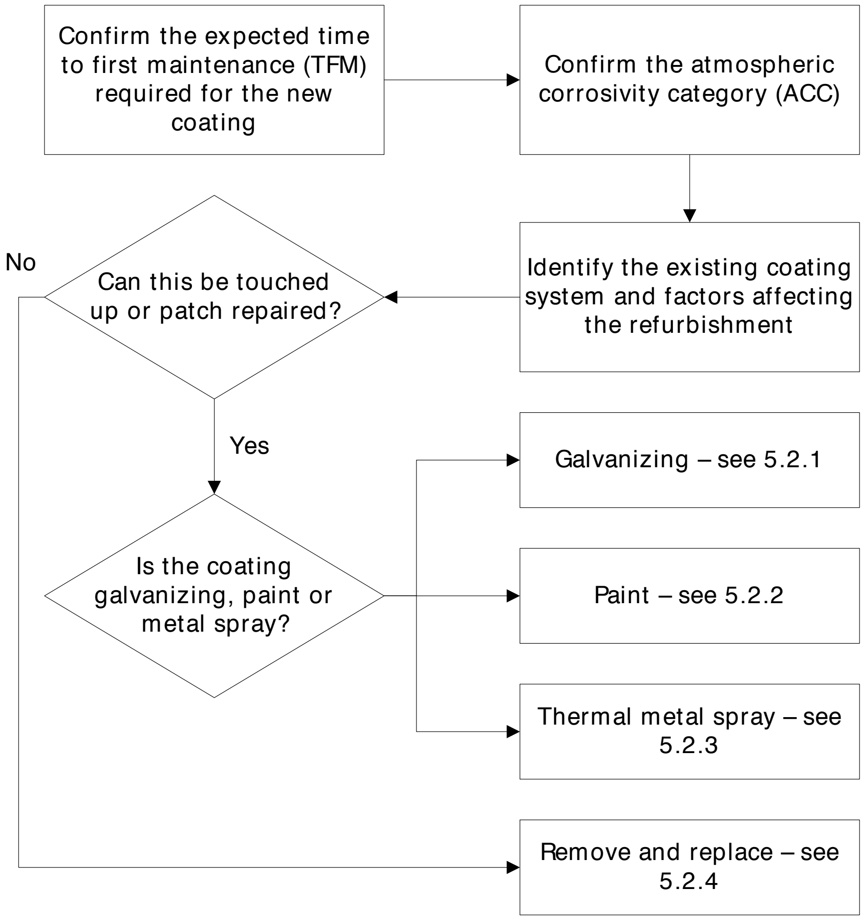
All coatings will require some form of maintenance over the design life of a bridge. This could range from simple touch up after erection to repair transportation damage, to a full recoat/replacement of the coating system when a patch repair is no longer an economic option.

The selection of a maintenance coating is dependent on number of factors, such as the ability of the original finish coat to be recoated with itself, the required time to first maintenance of the repair coating system, level of surface preparation that can be achieved, accessibility and any time constraints due to traffic management, whether containment is required, and weather conditions (humidity levels and temperature) expected during the contract period. All these factors need to be considered when specifying the maintenance coating system. Hence, the selection of a suitable maintenance coating can potentially be complex, in comparison to the more straightforward selection process of protective coatings for new structures.

Additional guidance on the maintenance of coatings is given in section 8 of AS/NZS 2312.1[(1)] and section 14 of HERA Report R4-133[(3)].

The following sections outline the methodology and guidance on how to select a maintenance coating system for existing bridge elements.

5.1 Maintenance design flow charts



5.2 Coating maintenance procedures

5.2.1 Galvanizing

The recommended specification for repair of galvanized coatings damaged by transportation, erection or subsequent welding is given in section 8 of AS/NZS 4680 *Hot-dip galvanized (zinc) coatings on fabricated ferrous articles*[21]. This is repeated below:

Extent of damage requiring repair

For new steelwork galvanized to AS/NZS 4680[21] after fabrication, the sum total of damaged or uncoated areas is required to be less than 0.5% of the total surface area or 250cm^2, whichever is the lesser, and no individual damaged or uncoated area greater than 40cm^2. NOTE: ISO 1461 *Hot dip galvanized coatings on fabricated iron and steel articles – Specifications and test methods*[22] allows a maximum uncoated area of only 10cm^2 and it is recommended that this lower limit be incorporated into bridge specifications. This means that most areas where welding has been undertaken after galvanizing will require repair.

New galvanized steel work that has not been stored correctly (by ensuring good drainage and ventilation) can develop "white rusting" which is a soft coating of zinc oxide and hydroxide. This should be removed by scrubbing with a weak acid (eg acetic or citric acid) and rinsed before putting into service, after ensuring the zinc thickness still exceeds the minimum specified in the standard.

For aged steelwork that has been galvanized and exposed to extended periods of dampness due to water runoff, the characteristic grey will change to a dark brown colour as the zinc/iron alloy layer is exposed after the pure zinc is removed by weathering processes. This is variously termed as "coffee staining" or "bronzing" and, because the protective coating thickness on heavy sections will still often be >85 microns, these areas do not need maintenance painting until specks of red rust appear, or its variable appearance is unacceptable.

Where galvanizing has been exposed to marine salts that are not regularly removed by washing, a tenacious crust of zinc oxychloride can form, which needs to be removed by wet abrasive blasting before a maintenance coating is applied.

Methods of repair

Three methods are specified by clause 8.2 of AS/NZS 4680[21] for the repair of damaged or uncoated surfaces. These are as follows:

1. Organic zinc-rich primer. Apply two coats, each having a minimum dry film thickness of 50 microns to the affected areas. (NOTE: This will not be achieved using zinc-rich from aerosol spray).
2. Inorganic zinc silicate paint to at least 30 microns greater than the local zinc coating thickness. For HDG600, this requires 125 microns of paint – ie IZS3 or IZS4.
3. Zinc metal spray to at least 30 microns greater than the local zinc coating thickness. For HDG600, this requires TSZ150 and for HDG900, it requires TSZ200.

Note that for options (2) and (3) the steel surface of these areas to be repaired must be prepared to surface preparation standard Sa2½ to AS 1627.4[4]. This will require abrasive blast cleaning using a small diameter nozzle, while option (1) requires a minimum surface preparation standard SSPC-SP 11 *Power tool cleaning to bare metal*[23]. For further information on systems referred to by acronyms see appendix A or clause 4.2 of AS/NZS 2312.1[1].

5.2.2 Paint (inorganic or organic)

The first step is to identify the generic type of the existing coating to ensure compatibility with the new coating system (by then using the information in table 5.1). Identification can be made by an experienced coatings inspector testing the aged coating's solvent sensitivity (eg acrylics can be dissolved by rubbing with a cloth soaked in methylated spirits; while chlorinated rubber and vinyls can be softened using xylol and alkyds by methyl-ethyl ketone). However bridges painted by the previous Ministry of Works and Development should have their previous repainting details stencilled onto a girder or the abutment (see figure 5.1).

Figure 5.1: Example of stencilled repaint details on the Clive Bridge

The presence of lead can be confirmed by the application of sodium sulphide solution onto a freshly cut surface which will instantly turn black as sodium plumbate is formed. Also red lead-based primer is often indicated by its distinctive red-orange colour.

The next step is to check the adhesion of the existing coating to ensure it is capable of resisting curing stresses of the new coating system or increased thermal movement if colour is changed to a darker colour. Adhesion can be assessed using various tests (eg AS 3894.9 *Site testing of protective coatings* part 9 Determination of adhesion(24)) with a minimum level of 2.5MPa being required to overcoat with epoxy, and 1.5MPa for more flexible systems like moisture cured urethane or the very flexible systems using acrylic elastomeric, HRCSA or other wax based coatings. If poorly adherent material is not removed by scraping, or "search blasting" with dry abrasive or a water jet, it will eventually delaminate taking the new coating with it. Similarly all surface contaminants that could affect adhesion such as mill scale, chalking, algae, oils, and soluble salts, must also be removed to the level recommended by the coating manufacturer.

Inorganic zinc silicates have recently been confirmed (see *Repair of single coat inorganic zinc silicate coatings*(25)) as being able to be refurbished by application of a further coat of either water borne or solvent borne zinc silicate, provided all iron and zinc oxides have been removed allowing the silicate to chemically bond with freshly exposed zinc or abrasive blast cleaned steel. However adhesive strength is slow to develop (may take weeks), and if a colour topcoat is required then a faster curing organic zinc-rich should be used. Note that this needs to be compatible with the topcoat so if a chemically cured epoxy or polyurethane is being used, the primer needs to be an epoxy zinc-rich. However if the topcoat is a single pack, a compatible single pack zinc-rich can also be used which may be advantageous in cold weather.

5.2.2 continued

Coatings which dry by solvent evaporation, such as chlorinated rubber and acrylics are termed “non-convertible” and are best maintained by using the same generic system. Chlorinated rubber has the ability to “solvent weld” the new coating onto the existing system and develops good adhesion to a washed surface. Epoxies and polyurethanes on the other hand, require sweep blasting or hand sanding to roughen the aged surface prior to recoating and sometimes a special tie-coat may be required to ensure good adhesion.

5.2.3 Thermal metal spray

Unsealed thermal sprayed zinc can be repaired using the same methods given above for galvanizing. Where a seal coat has been used this must be removed from the edges of the repair area to allow the repair material to overlap and bond onto freshly abrasive blast cleaned zinc. The seal coat can then be reinstated as a patch coat. If required, the whole surface can be overcoated, but the new system will require use of a tie-coat that is compatible with the original seal coat.

Thermal sprayed aluminium (TSA) as used on bridge piling in tidal locations should be repaired by abrasive blast cleaning of rusted areas, to surface preparation standard Sa3, to restore a 75 micron plus surface profile, the aluminium reapplied using flame or arc spray and an aluminium pigmented seal coat reapplied. TSA should not be overcoated or patch repaired with a thick organic topcoat (see *Thermal metal spray: success, failures and lessons learned*[26]).

Figure 5.2: Failure of epoxy repair on TZA on Ahuriri Bypass bridge piling

5.2.4 Remove and replace

The total replacement of the original coating is often the preferred option when maintaining steel bridges where the coating is in poor condition. For all long term performance coatings, a surface preparation standard Sa2½ is required before the application of the coating.

When the coating has performed as required, the original specification may be reapplied. However, if the previous coating suffered a premature failure which was not due to incorrect application but was unsuitable for the general site environment or a particular micro environment, the specification and application of a higher performance coating will be required.

5.3 Alternative maintenance coating systems

In addition to the repair coatings mentioned above, there are other options that can be used that are currently not included in AS/NZS 2312 parts 1 or 2[1]. These are systems based on surface tolerant coatings, specifically designed to be applied over existing coatings after removal of contaminants and are not normally top coated with other than themselves. These systems are:

1. Direct to metal (DTM) acrylic elastomerics (ACE) at a minimum of 350 microns applied in two coats over a surface preparation standard St2 and/or high-pressure water cleaning with a rotary head at a minimum of 5,000 psi depending on surface condition.
2. High ratio co-polymer calcium sulfonate alkyd (HRCSA) coating system applied in two coats "wet on wet "at a minimum of 250 microns requiring a high-pressure water cleaning at 8000 psi or a 5000 psi hot water wash to remove salts. Crevices are pre-treated with a HRCSA penetrating primer and then caulked with an additional stripe coat of the finish coat.

The latter coating system is relatively new to New Zealand but both have performed well in recent FHWA trials (see *Performance evaluation of one-coat systems for new steel bridges*[27]), and are available in a wide range of colours. Contact the coating suppliers for more information on these coatings and whether they are suitable for the application under consideration.

5.4 Factors affecting maintenance coating selection

5.4.1 Patch paint vs full replacement

The choice between patch painting or the full replacement of a coating system is dependent on the level and nature of deterioration of the coating. Other than the initial touch up after erection, patch paint during the life of the bridge is the common method of repair for relatively small or localised areas of damaged or deteriorated coatings.

Examples of patch paint suitability could be the reinstatement of the coating system after buckling of steel arches from seismic forces, such as that seen in the Colombo Street Bridge (figure 5.3), or when a limited area of coating has failed due to delamination, such as the Auckland Harbour Bridge (figure 5.4). In these cases, a patch repair of the affected area only will provide a cost effective option instead of the full recoat of the bridge. Full replacement is usually undertaken when there is a severe and widespread breakdown of the coating, which ideally occurs at the expected time to first major maintenance, and may follow several cycles of patch painting.

Clause 8.3 of AS/NZS 2312.1[1] outlines the criteria for deciding when to paint or repair coatings.

The selection of the coating for patch repair is dependent on the standard of surface preparation that can be achieved. While most coatings require a surface preparation standard Sa2½, this could be difficult and/or costly to achieve depending on the required level of containment, ease of site access and environmental conditions (eg humidity and temperature) at the time when work needs to be carried out. In some cases, the use of "surface tolerant" coatings over a lesser degree of surface preparation (with a consequential reduced life) may be required, or aesthetics of the surface finish may be a governing factor. All these factors should be considered when selecting the appropriate coating when undertaking a patch repair.

5.4.1 continued

Figure 5.3: Example of damaged coatings – Colombo St Bridge

Figure 5.4: Example of damaged coatings – Auckland Harbour Bridge

5.4.2 Containment levels

Containment utilising planking and reinforced plastic screens is often used to collect debris and reduce dust emissions during surface preparation. This also reduces overspray when water jetting or spray painting, and can reduce contamination of clean surfaces or freshly applied paint by wind borne debris or give weather protection.

A more substantial containment structure will be required when removing lead-based paint so that a negative pressure can be maintained to prevent emission of hazardous dust (see figure 5.5). In this case the environment can be controlled with heating or dehumidification allowing a wider range of coatings to be utilised. The containment level is usually dictated by the environmental resource consent for the project and its design may require use of the bridge by traffic or pedestrians to be maintained.

The level of containment required should be clarified in the early design stages to assist in the selection of the most appropriate coating system.

5.4.2 continued

Figure 5.5: Full containment for repainting the Patea Rail Bridge
(Supplied by TBS-Farnsworth)

5.4.3 Environmental conditions

5.4.3.1 Preparation and application requirements

Unlike the application of coating of new steelwork which is usually done in relatively controlled conditions off site, onsite application requires suitable environmental conditions unless these can be modified using containment as discussed above.

The most important factors are steel temperature and the relative humidity as these affect the cure of the coating. Coatings should not be applied when the steel temperature is less than 3°C above the “dew point” (temperature when condensation will form on the steel). If the steel temperature is too low, some chemically cured coatings (eg epoxies) will not harden and if the temperature is too high the coating film may blister and/or have poor adhesion. Waterborne coatings (eg acrylics) require low humidity whereas moisture cured coatings (eg solvent borne zinc silicates) require high humidity to cure. In addition most wet applied coatings need adequate ventilation to remove solvents at the boundary layer and so allow the film to dry.

Maintenance painting should ideally be programmed to occur between October and May when warmer drier conditions are more likely to occur. Use of low temperature cure epoxies in containment and moisture cure urethanes can allow repainting to be carried out at other times of the year, but these materials are more expensive and reduced daylight hours will lower productivity. Designers should therefore be aware of when the repair work is required to be undertaken, to assist in selecting the appropriate coating for the expected environmental conditions, and also to determine whether some form of containment and temperature/humidity modification equipment is required.

5.4.3.2 Dealing with effects of preparation and application

The Transport Agency is committed to environmental and social responsibility and must meet its statutory responsibilities in accordance with the Resource Management Act 1991. The Transport Agency is also required to deliver value for money, and seeks to use effective and efficient methods to deliver desired outcomes.

Maintenance and coating work including washing, surface preparation and spray application can all result in potential discharges to air, soil or water which are managed under the Resource Management Act 1991.

5.4.3 continued

The Transport Agency's Z19 *State highway environmental & social responsibility standard*(28) explains how and where to implement the Transport Agency's environmental and social requirements for any state highway work including the requirement to prepare an environmental and social management plan for state highway contracts (including bridge maintenance).

The Transport Agency's *Guideline for preparing an environmental and social management plan*(29) contains guidance on preparing a plan to manage environmental risks and opportunities and to meet the Transport Agency's responsibilities and legal obligations. Additional guidance for bridge maintenance contracts is contained in *A methodology for identifying environmental risks for bridge maintenance*(30) and an *Example of an environmental and social management plan for structure maintenance contracts*(31) and this template can be used to create the plan. As noted in these guidance documents the plan should be appropriately scaled to the size, type and location of the bridge.

5.5 Lead based paint encapsulation

In some circumstances, such as when the remaining existing coating is still generally adherent, a significantly cheaper maintenance option where lead-based primers are still present is to simply overcoat them. This technique is discussed in the Transport Agency research report 115 *Guidelines for the management of lead based paint on roading structures*(32) and TNZ C26 NOTES *Notes for the cleaning and recoating of steelwork coated with lead based paint*(33) which are based on AS 4361.1 *Guide to lead paint management* part 1 Industrial applications(34). According to NCHRP Synthesis 251 *Lead-based paint removal for steel highway bridges*(35), moisture cured urethane (MCU) coating systems were the most preferred by roading authorities in the United States of America. However flexible coating systems such as some acrylic elastomerics and HRCSA are also suitable to encapsulate lead and chromate primers. Otherwise their removal will require full containment to prevent release of hazardous materials into the environment. Encapsulation also allows these extremely efficient corrosion inhibiting chemicals to continue their intended function of protecting the structure by reinstating a weather resistant topcoat.

5.6 Compatible coatings table

Table 5.1 outlines the compatibility of the existing coating with the maintenance top coat that could be used, when undertaking patch repair of the deteriorated or damaged coating. This table is an updated version of table 14.1 of HERA Report R4-133(3).

In using the table, the legend has the following meaning:

- C means the surfaces are compatible. If the existing coating is sound use low-pressure water washing to clause 4.2.5(a) of AS/NZS 2312.1(1), with detergents as required for degreasing and salt removal. If the existing coating is not sound, use high-pressure water washing to clause 4.2.5(b) with detergents as required for degreasing.
- CA means the surfaces are compatible with special precautions required. This will typically mean washing/degreasing followed by abrasive sweep blasting, possibly to a specified surface roughness or, for the sacrificial systems, to expose unweathered zinc.

5.6 continued

- NC means the surfaces are not compatible. The existing coating must be removed by abrasive blast cleaning to the standard of surface preparation required for the new coatings system. See section 15.3 of HERA Report R4-133[3] for some guidance on how to achieve this.

Note, for the application of sealer and paint finishes to metal sprayed surfaces refer to sections 5.2.4 and 5.2.5 of AS/NZS 2312:2002[10].

For the maintenance of chlorinated rubber coating system, see appendix A.

Table 5.1: Compatibility between maintenance and existing coatings systems

Existing topcoat	Maintenance topcoat											
	Alkyd, phenolic alkyd, silicone alkyd, urethane alkyd	Epoxy two-pack	Epoxy mastic	Polyurethane		Inorganic zinc silicate	Acrylic		Acrylic elastomeric	Thermal spray, zinc	Thermal spray, aluminium	High ratio co-polymer calcium sulfonate alkyd
				Moisture-cured	Two-pack		Two-pack	Latex				
Alkyd, phenolic alkyd, silicone alkyd, urethane alkyd	C	NC	CA	C	CA	NC	CA	C	C	NC	NC	C
Epoxy												
• two-pack	CA	CA	CA	CA	CA	NC	CA	C	CA	NC	NC	C
• coal tar	NC	CA	CA	CA	NC	NC	NC	CA	CA	NC	NC	C
• ester	C	NC	CA	CA	NC	NC	CA	C	CA	NC	NC	C
• mastic	CA	CA	C	CA	C	NC	CA	CA	CA	NC	NC	C
Vinyl												
• unmodified	CA	NC	CA	CA	NC	NC	NC	C	C	NC	NC	C
• acrylic	C	NC	NC	CA	NC	NC	NC	C	C	NC	NC	C
Zinc-rich												
• inorganic	NC	C	C	C	CA	CA	CA	CA	CA	NC	NC	C
• organic, two-pack	NC	C	C	C	CA	NC	CA	CA	CA	NC	NC	C
Polyurethane												
• two-pack	CA	CA	CA	CA	CA	NC	CA	C	C	NC	NC	C
Acrylic (solvent type)	C	NC	NC	C	NC	NC	NC	C	C	NC	NC	C
Acrylic latex	CA	NC	NC	NC	NC	NC	NC	C	C	NC	NC	C
Acrylic – two-pack	CA	CA	CA	CA	CA	NC	CA	C	C	NC	NC	C
Acrylic elastomeric	NC	NC	NC	NC	CA	NC	NC	C	C	NC	NC	C
Thermal spray zinc	NC	CA	CA	CA	CA	CA	CA	CA	CA	CA	CA	C
Thermal spray aluminium	NC	CA	CA	CA	CA	NC	CA	CA	CA	CA	CA	C
Galvanizing	NC	CA	CA	CA	CA	CA	CA	CA	CA	CA	NC	C
HR co-polymer calcium sulfonate alkyd	CA	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	C

Legend:
C = Compatible, washing/degreasing required, as described in Section 14.1
CA = Compatible, but special precautions required on surface preparation and/or application (refer to the manufacturer of the proposed maintenance topcoat)
NC = Non-compatible

6.0 Life cycle costing using net present value

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 of 6% for 40 years (see *Economic evaluation manual*[36]), which modifies the future maintenance cost, into "today's dollars" taking inflation as being 0%. The equation for the net present value is:

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

Where:

NPV = Net present value

IC = Initial construction cost (material, fabrication, erection, etc)

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[3] provides detailed guidance on the use of the net present value model, which includes proposed costing that could be used for certain operating maintenance factors like onsite application depending on site access difficulty. A worked example is also provided in appendix D.4 of HERA Report R4-133[3], with additional updated examples given in 6.1.

It is strongly recommended that the relevant current unit rates are used when calculating the NPV life cycle cost. Bridge designers should contact their coating supplier, and/or applicator to obtain these rates.

6.1 Level of service vs asset protection

In most cases, bridges are expected to be fully recoated when the expected time to first maintenance is reached. However, in some cases aesthetics is the governing factor, especially for "iconic" bridges, thereby requiring the top coat to be regularly repainted well before the expected time to first maintenance for corrosion protection. In this case, it is expected that the base coats will rarely be repaired or replaced as the top coat is being continuously reapplied, hence protecting the original primer which should have been applied under optimum conditions that are difficult to achieve for steelwork in situ.

To demonstrate the difference in the net present value of both options, the following examples are given. Both examples are based on the bridge being located in an atmospheric corrosivity category C5M requiring a high performance coating that provides 40 years expected time to first maintenance, while the second uses the same coating but the top coat is recoated every 10 years.

As seen in these examples the net present value of a coating recoated every 10 years (at $137.63/m^2) is greater than that with a longer 40 years expected time to first maintenance (at $84.47/m^2). Even though the shorter recoating period results in a higher net present value, the upkeep of the top coat to meet the principal's requirements and expectations, may be the overriding factor if aesthetics is the main concern.

6.1 continued

Note that the rates used in these examples are provided to illustrate the method of calculation, and current rates should be obtained from an experienced bridge painting contractor.

Example 1: Recoat coating at expected time to first maintenance

Operation Number	Year (1)	System Designation	%Area Maintained	Current Cost (2) $/total m^2	NPV (3) for DR (4) 6% $/total m^2
0	0	A1+A2+F	100%	69.00	69.00
1	0	B+F	1%	1.74	1.74
2	3	C+F	1%	1.74	1.46
3	30	E	100%	covered	client
4	30	C+F	1%	1.74	0.30
5	40	E	100%	covered	client
6	40	D+F	100%	110.50	10.74
7	43	C+F	1%	1.74	0.14
8	70	E	100%	covered	client
9	70	C+F	1%	1.74	0.03
10	80	E	100%	covered	client
11	80	D+F	100%	110.50	1.04
				Total $	84.47

Coating System Specification:
Based on 200 micron TSZ200S with sealer coat
Expected time to first mainteance 40
System Designation:

A1 Washdown	High pressure washdown to remove fabrication oil etc prior to blast cleaning
A2 Initial Coat:	Shop: Grit Blast to Sa 2 1/2; 200 micron nominal DFT TSZ200S
B 2% Erection Touch-up:	Field: Follow Clause 5.2.7 of (AS/NZS 2312)
C 1% or 5% Touch-up Repair:	Field: Follow Clause 5.2.7 of (AS/NZS 2312)
D 100% Recoat:	Field: sweep blast of whole area to manufacturer specification; replace TSZ200S sealer coat only
E Inspection of surface to determine condition [9]:	Field: Independent inspection of existing surface to determine extent of maintenance required at 75%, 100% tfm. Cost covered by NZTA general bridge inspection regime and not part of specific steel coating cost
F Independent inspection of coating [10]:	Field: Independent inspection of applied coating for designations A2, B, C and D

Base costings used are as follows (these are for shop application of large areas, with small area and site access factors included for the onsite work as described below)

Operation	Cost $/m^2$ steel surface
Initial washdown in shop	5.00
Blast clean and apply TSZ and sealer (labour cost)	43.50
Shop inspection of surface or coating	1.50
Site inspection of surface or coating	2.00

Paint/Inspection System Designation	Base Rate Paint $/m^2$	Base Rate Labour $/m^2$	Area Factor Labour(5) $/m^2$	Initial Rate(6) $/m^2$	Site Access Rate(7) $/m^2$	Current Cost(8) $/m^2$
A1	0.00	5.00	1.00	5.00	0.00	5.00
A2+F	19.00	45.00	1.00	64.00	0.00	64.00
B+F	20.00	45.50	2.40	129.20	45.00	174.20
C+F	20.00	45.50	2.40	129.20	45.00	174.20
D+F	20.00	45.50	1.00	65.50	45.00	110.50
E	0.00	2.00	1.00	2.00	45.00	47.00

Summary:

Initial Cost/total m^2		72.20	This covers operations 0, 1 and 2 above which are part of the construction contract
NPV Maintenance Cost 100yr/total m^2	$	12.26	This covers operations 3 to 11
Full life cycle NPV cost 100 year/total m^2	$	84.47	

Notes:
1. Year after commissioning bridge.
2. Current Cost/total m^2 (% Area Maintained x System Cost $/m^2$)
3. NPV Net Present Value: NPV = Cost/$(1+DR/100)^{Year}$
4. Recommended discount rate for NZTA is 6% for 40 years. (Economic Evaluation Manual 2016)
5. Area factor for labour is obtained from Section 10.5 of HERA Report R4-133. It allows for higher setup and wastage costs due to the small areas involved.
6. The initial rate is the materials + labour including area factor.
7. The Site access rate is taken from Section 10.5 of HERA Report R4-133, using *moderate* for touch-up, small area maintenance and for recoat. This reflects the remoteness of the site.
8. The current cost/m^2 is the initial rate plus the site access rate.
9. Inspection costs for the weathered surface cover independent inspection of the surface near the end of its rated life to determine the need for and extent of recoating required. This is carried out on 100% of the surface
10. Inspection costs for the painted surface cover independent inspection of the area that has been painted.

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

Example 2: Recoat top coat every 10 years

Operation Number	Year (1)	System Designation	%Area Maintained	Current Cost (2) $/total m²	NPV (3) for DR (4) 6% $/total m²
0	0	A1+A2+F	100%	69.00	69.00
1	0	B+F	1%	0.47	0.47
2	10	E	100%	covered	client
3	10	D+F	100%	57.00	31.83
4	20	E	100%	covered	client
5	20	D+F	100%	57.00	17.77
6	30	E	100%	covered	client
7	30	D+F	100%	57.00	9.92
8	40	E	100%	covered	client
9	40	D+F	100%	57.00	5.54
10	50	E	100%	covered	client
11	50	D+F	100%	57.00	3.09
12	60	E	100%	covered	client
13	60	D+F	100%	57.00	1.73
14	70	E	100%	covered	client
15	70	D+F	100%	57.00	0.96
16	80	E	100%	covered	client
17	80	D+F	100%	57.00	0.54
18	90	E	100%	covered	client
19	90	D+F	100%	57.00	0.30
				Total $	137.63

Coating System Specification:
Based on 200 micron TSZ200S with sealer coat
Expected Time to first maintenance 10
System Designation:

A1 Washdown	High pressure washdown to remove fabrication oil etc prior to blast cleaning
A2 Initial Coat:	Shop: Grit Blast to Sa 2 1/2; 200 micron nominal DFT TSZ200S
B 2% Erection Touch-up:	Field: Follow Clause 5.2.7 of (AS/NZS 2312)
C 1% or 5% Touch-up Repair:	Field: Follow Clause 5.2.7 of (AS/NZS 2312)
D 100% Recoat:	Field: sweep blast of whole area to manufacturer specification; replace TSZ200S sealer coat only
E Inspection of surface to determine condition 9:	Field: Independent inspection of existing surface to determine extent of maintenance required at 75%, 100% tfm. Cost covered by NZTA general bridge inspection regime and not part of specific steel coating cost
F Independent inspection of coating 10:	Field: Independent inspection of applied coating for designations A2, B, C and D

Base costings used are as follows (these are for shop application of large areas, with small area and site access factors included for the onsite work as described below)

Operation	Cost $/m² steel surface
Initial washdown in shop	5.00
Blast clean and apply TSZ and sealer (labour cost)	43.50
Sweep blast and apply sealer (labour cost)	4.50
Shop inspection of surface or coating	1.50
Site inspection of surface or coating	2.00

Paint/Inspection System Designation	Base Rate Paint $/m²	Base Rate Labour $/m²	Area Factor Labour(5) $/m²	Initial Rate(6) $/m²	Site Access Rate(7) $/m²	Current Cost(8) $/m²
A1	0.00	5.00	1.00	5.00	0.00	5.00
A2+F	19.00	45.00	1.00	64.00	0.00	64.00
D+F	5.50	6.50	1.00	12.00	45.00	57.00
E	0.00	2.00	1.00	2.00	45.00	47.00

Summary:

Initial Cost/total m²	$ 69.47	This covers operations 0, 1 and 2 above which are part of the construction contract
NPV Maintenance Cost 100yr/total m²	$ 68.16	This covers operations 3 to 11
Full life cycle NPV cost 100 year/total m²	$ 137.63	

Notes:
1. Year after commissioning bridge.
2. Current Cost/total m² (% Area Maintained x System Cost $/m²)
3. NPV Net Present Value: NPV = Cost/(1+DR/100)^{Year}
4. Recommended discount rate for NZTA is 6% for 40 years. (Economic Evaluation Manual 2016)
5. Area factor for labour is obtained from Section 10.5 of HERA Report R4-133. It allows for higher setup and wastage costs due to the small areas involved.
6. The initial rate is the materials + labour including area factor.
7. The Site access rate is taken from Section 10.5 of HERA Report R4-133, using *moderate* for touch-up, small area maintenance and for recoat. This reflects the remoteness of the site.
8. The current cost/m² is the initial rate plus the site access rate.
9. Inspection costs for the weathered surface cover independent inspection of the surface near the end of its rated life to determine the need for and extent of recoating required. This is carried out on 100% of the surface
10. Inspection costs for the painted surface cover independent inspection of the area that has been painted.

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

7.0 Guidance on extending the maintenance period of coating systems

7.1 Management practices

There are different methods that can be used to extend the maintenance period of coating systems, some of which are discussed in AS/NZS 2312.1[1] and earlier in this document. The Federal Highway Administration has issued the *Bridge preservation guide*[37], which outlines the different methodologies for extending the design life of the bridge structure. The definition of bridge preservation is given as:

> Actions or strategies that prevent, delay or reduce deterioration of bridges or bridge elements, restore the function of existing bridges, keep bridges in good condition and extend their life. Preservation actions may be preventive or condition-driven.

The *Bridge preservation guide*[37] provides guidance for all the components of the bridge, from coatings, the concrete deck, bearings and so forth. The main guidance regarding coatings is:

- bridge washing and/or cleaning
- painting steel.

The *Bridge preservation guide*[37] is based on the available maintenance budget allocated for the bridge. The most cost effective preventative measure recommended is to wash and/or clean the bridge. This is then followed by other measures (eg repair deck joints and bearings) which increase in cost accordingly. In theory the design life of a well maintained bridge can be increased beyond the usual 100 year design life in a cost effective and planned manner.

Bridge washing and/or cleaning

The guidance on washing states that the bridge structure should be washed a minimum of once or if possible twice a year when de-icing salts are used. The main benefit of that is the removal of contaminants such as salt build up and bird droppings, which in turn assist in extending the design life of the coating. Additional guidance on the washing frequency is provided in section 14.4 of HERA Report R4-133[3].

While the HERA Report R4-133[3] states that for locations approximately 1km from the sea sheltered surfaces of steel structures should be washed once a month, this is not practical for bridges which usually have a more durable coating system than commercial buildings, which usually have easier access for maintenance. In this case the following guidance should be followed for the given microclimate atmospheric corrosivity category (ACC):

- for ACC C5: once per year
- for ACC C4: once every 2 years
- for ACC C3: once every 4 years
- for ACC C2: once every 8 years.

It should be noted that the washing should be by low pressure water cleaning to clause 4.2.5(a) of AS/NZS 2312.1[1], using a biodegradable surfactant and water pressure at 3000 to 5000 psi only. Higher pressures may damage some paint coatings that are otherwise sound.

7.1 continued

Painting steel

The other recommended maintenance option is the periodic painting of steel, either as patch paint or recoat, including the use of zone painting. Both of these topics are discussed in earlier sections of this document.

Other preventative measures

Other measures discussed in the *Bridge preservation guide*[37] are (but not limited to):

- sealing deck joints
- facilitating drainage
- sealing concrete
- remove channel debris
- protecting against scour
- lubricating bearings.

The *Bridge preservation guide*[37] provides good guidance on the preservation of bridges and it is recommended that bridge designers consider how these measures can be implemented when considering design options. Note that the *Bridge preservation guide*[37] is not only relevant for steel bridges but for concrete bridges as well.

8.0 Quality assurance

8.1 General

It has been variously reported (see *Who pays when the paint fails?*[38]) that 70-80% of premature failures of protective coatings can be attributed to poor quality of surface preparation and coating application. Areas of potential concern include:

- standard of visual cleanliness
- allowable level of non-visual contamination and its method of measurement
- substrate profile height
- correct mixing of multi-pack materials and heavily pigmented paint (eg zinc-rich)
- thickness of total film and individual layers, eg how it is measured and is specified – is thickness an "absolute minimum" or a "minimum average"
- continuity of coating, eg free from pinholes and thinning on sharp edges
- delamination of coating due to intercoat contamination, exceeding the recoat window or overcoating weakly adherent or incompatible existing coatings
- lack of training and experience or poor attitude of blaster/painter
- suitable equipment, access and weather conditions.

8.2 Minimum standards

In order to ensure that an appropriate coating system is specified and the potential life of that coating system is achieved, the Transport Agency requires the following provisions for bridges on state highways:

8.2 continued

- Qualified coating specifiers shall be used to prepare or peer review the coating system specification to confirm it meets the durability requirements given in the *Bridge manual*[11], and review of the construction drawings to ensure that detailing is in accordance with recommended details in figure 3.1 of AS/NZS 2312.1[1]. The required qualification shall be one of the following:
  - NACE Protective Coating Specialist
  - Australasian Corrosion Association (ACA) Technician or Technologist with successful completion of the ACA's Coating Selection and Specification Course and/or certified to NACE Coating Inspection Program (CIP) Level 2.
- Chartered Professional Engineers who sign a producer statement (PS1 or PS2) confirming the requirements of the B2 (durability) clause of the *Building code*[39] have been met, should also confirm that the above specifying and detailing requirements have been met.
- Tenders will only be accepted from coating application contractors with an effective quality assurance system and who employ trained and experienced blaster/painters and supervisor/inspectors, and have well maintained plant and facilities. This will be achieved by only using contractors who are accredited under the Australian Paint Contractors Certification Program (PCCP). (Note that from 1 July 2015 this has been a mandatory requirement.)
- Only coatings approved by an independent body such as APAS, NEPCOAT or NORSOK shall be used.
- The Transport Agency, or its agent, shall employ a qualified and experienced independent coatings inspector to audit the quality of the work. As a minimum, the inspector shall be qualified to NACE Coating Inspector Program Level 2 or a Protective Coatings Inspector with a current Competence Certificate issued by the Certification Board for Inspection Personnel NZ (CBIP). It is important that for the inspector independence from the physical works and coatings contractors is maintained.
- An inspection test plan (ITP), that covers all the relevant matters associated with surface preparation and coating application listed in clause 9.6 of AS/NZS 2312.1[1], and a completed NZ coatings industry checklist (given in appendix D) list shall be submitted with the tender.
- A "pre-job conference", as described in clause 9.4 of AS/NZS 2312.1[1], shall be arranged with all affected and involved parties before work starts, to eliminate any potential misunderstandings regarding such things as the specifications requirements and constraints, access, work schedule, inspection methods, transportation and erection matters, and repair methods.

8.3 Quality monitoring

Allowance shall be made for the installation of two sets of test coupons on new bridges, and existing bridges when recoated, on the primary structural members. For coated steelwork, the coupons should be prepared, coated and inspected during the application of the protective coating system, while for weathering steel the coupons will only require the same level of surface preparation as the structure.

These coupons will be used as part of the bridge inspection monitoring in order to optimise maintenance of its protective coating system (ie paint or patina). Consult with the Transport Agency National Structures Manager on what quality monitoring should be applied to the structure.

8.3 continued

For example, this could require that a total of 30 coupons (150 x 100 x 5mm carbon steel or WS panels) be installed per bridge, of which 15 are installed in three locations on the outer girder, that is exposed to the prevailing weather, and 15 on three locations on an inward facing girder surface, that is sheltered from the sun and rain washing. A set of three coupons per side could then be removed and tested on years 6, 12, 18, 24 and 30, to confirm the condition and monitor the rate of breakdown of the coating.

9.0 Other corrosion resistant options

The application of a protective paint system to steel components is not the only method of providing durable metal components in bridges. There are other options via the use of other corrosion resistant materials, details of which follow.

9.1 Stainless steel

Stainless steel is commonly viewed as an expensive material, rarely being used in bridges other than as an aesthetic component to highlight features on a bridge, as low maintenance hand railing, or in hard to replace, long life structurally critical components such as bearings. However, international examples in the past 10 years have demonstrated the many benefits of stainless steel, ranging from stainless steel reinforcement in marine bridge decks and substructures, through to complete stainless steel bridges.

Bridge designers considering the use of stainless steel should undertake a comprehensive life cycle costing to demonstrate its feasibility. A review on the use of stainless steel in bridges is given in *Stainless steel in bridges – a discussion*(40) while the design of stainless steel from cold formed sections should be to AS/NZS 4673 *Cold-formed stainless steel structures*(41) and welding to AS/NZS 1554.6 *Structural steel welding* part 6 Welding stainless steels for structural purposes(42).

Figure 9.1: Wellington Harbour Culvert stainless steel reinforcement cage

9.2 Weathering steel

Weathering steel, or "structural steel with improved atmospheric corrosion resistance", is a high strength low alloy steel that in suitable environments may be left unpainted as it forms an adherent protective rust "patina" that greatly minimises the corrosion rate of the steel.

KiwiRail has built around 10 replacement bridges in weathering steel since 2012. The Transport Agency has built around 5 weathering steel bridges. The first of these, SH1 Mercer to Longswamp off-ramp (built in 2006) is shown in figures 9.2 and 9.3.

Section 4.3.6(b) of the *Bridge manual*[11] states that:

> Weathering steel shall only be used in locations and environments for which they are suitable for use as defined by the HERA Report R4-97 *New Zealand weathering steel guide for bridges*[43] and only with the prior approval of the road controlling authority. The design and detailing guidance provided by HERA Report R4-97[43] shall be complied with.

Therefore, the use of structural weathering steel in the appropriate location and environment, mainly up to a microclimate no more severe than atmospheric corrosivity category C3, should be considered. When undertaking a life cycle costing, the cost of building with the weathering steel material should be directly compared to the cost of building and maintaining coated mild steel over its lifetime.

Note that the HERA *Design guide for bridges in Australia: Weathering steel*[44], has additional updated information on the environmental limitations on where weathering steel can be used, surface preparation and welding of weathering steel to what is given in HERA Report R4-97[43].

Figure 9.2: Mercer Bridge upon completion in 2006

9.2 continued

Figure 9.3: Mercer Bridge after four years weathering

9.3 Aluminium

Aluminium has been used successfully for highway bridge hand railing and can be cost effective in marine climates as it is a low maintenance material. Aluminium structures should be designed using AS/NZS 1664.1 *Aluminium structures* part 1 Limit state design[(45)] or AS/NZS 1664.2 *Aluminium structures* part 2 Allowable stress design[(46)] and welded using AS/NZS 1665 *Welding of aluminium structures*[(47)] or connected using hot-dip galvanized fasteners. Stainless steel fasteners can also be used but these require the fitting of non-absorbent and non-conductive separating spacer washers to prevent galvanic corrosion. Since the coefficient of thermal expansion for aluminium (0.023mm/m/°C) is approximately double that for steel (0.011mm/m/°C) due allowance needs to be made when detailing for thermal expansion.

9.4 Hot-dip galvanizing

Due to the relatively smaller bath sizes in New Zealand and the typical long span of bridge beams they are not commonly hot-dip galvanized in comparison to bridges in Australia and North America. A rare local example of a fully galvanized structure (a private rail overbridge) is shown in figure 9.4. However, a recently installed galvanizing bath is now available that can cater for up to 18m long beams via double dipping or up to 13m as a single dip. The local galvanizer should be contacted for confirmation of their bath sizes and capabilities.

The advantage of this process is that hollow sections and areas of complex steel work that are difficult to clean and coat, can be readily and reliably protected with a tough iron-zinc alloy layer and outer coating of pure zinc. Disadvantages include the risk of distortion, especially of non-symmetrical and or heavily welded or cold worked components, and the risk of a brittle coating on some silicon killed steels.

9.4 continued

Figure 9.4: Example of a galvanized bridge

For simple heavy sections like plate girders, the use of arc sprayed zinc or sprayed zinc silicate paint is usually more cost effective. For light weight bridge components subject to abrasion like steel handrails and grating, the hot-dip galvanizing process is ideal.

The durability of galvanized structural steel is discussed in AS 2309 *Durability of galvanized and electrogalvanized zinc coatings for the protection of steel in structural applications – Atmospheric*(48) and AS/NZS 2312.2(1). NOTE: This process should not be confused with "continuous" or "inline galvanizing" to AS/NZS 4791 *Hot-dip galvanized (zinc) coatings on ferrous open sections, applied by an in-line process*(49) and AS/NZS 4792 *Hot-dip galvanized (zinc) coatings on ferrous hollow sections, applied by a continuous or specialized process*(50) which gives a much thinner zinc coating without the tough iron/zinc alloy layer. Products coated by "electrogalvanizing", which is better known as zinc electroplating, can have a zinc thickness <10 microns. Neither material should be used on bridges without additional protection.

Figure 9.5: Inline galvanized purlin section used as handrail in marine environment

9.4 continued

Figure 9.6: Unpainted galvanized base plate of handrail on coastal bridge

10.0 References

(1) Standards Australia and Standards New Zealand jointly AS/NZS 2312: ________ *Guide to the protection of structural steel against atmospheric corrosion by the use of protective coatings*
    Part 1:2014 Paint coatings
    Part 2:2014 Hot dip galvanizing
    Part 3 Thermally sprayed metallic coatings (In prep.)

(2) Standards New Zealand NZS 3404.1:2009 *Steel structures standard*. Part 1:2009 Materials, fabrication and construction.

(3) New Zealand Heavy Engineering Research Association (2011) *New Zealand steelwork corrosion and coatings guide.* Report R4-133, Manukau City.

(4) Standards Australia AS 1627.4-2005 *Metal finishing – Preparation and pretreatment of surfaces*. Part 4 Abrasive blast cleaning of steel.

(5) Standards Australia and Standards New Zealand jointly AS/NZS 1214:2016 *Hot-dip galvanized coatings on threaded fasteners (ISO metric coarse thread series)*.

(6) ASTM International (2012) ASTM D610-08 *Standard practice for evaluating degree of rusting on painted steel surfaces*. West Conshohocken, PA, USA.

(7) The Society for Protective Coatings (2000) SSPC-VIS 2 *Standard method of evaluating degree of rusting on painted steel surfaces*. Pittsburgh, PA, USA.

(8) Hemmings E and Demirdjian N (2001) *Water based inorganic zincs – performance vs practicability*. Australasian Corrosion Association (ACA) Corrosion & Prevention 2001 Conference proceedings. Republished in Inorganic Zinc Coatings (2nd ed.) by ACA in 2013, Melbourne, Australia.

(9) NACE International, American Welding Society and The Society for Protective Coatings jointly (2016) NACE No.12/AWS C2.23M/SSPC – CS 23.00 *Specification for the application of thermal spray coatings (metallizing) of aluminum, zinc, and their alloys and composites for the corrosion protection of steel*.

(10) Standards Australia and Standards New Zealand jointly AS/NZS 2312:2002 *Guide to the protection of structural steel against atmospheric corrosion by the use of protective coatings*. Superseded.

(11) NZ Transport Agency (2013) SP/M/022 *Bridge manual*. Wellington.

(12) NZ Transport Agency (2011) PSG/12 *Urban design professional services guide*. Wellington.

(13) NZ Transport Agency (2009) *Urban and landscape design frameworks – highways and network operations guideline*. Wellington.

(14) NZ Transport Agency (2013) *Bridging the gap: NZTA Urban design guidelines*. Wellington.

(15) American Architectural Manufacturers Association (2013) AAMA 2604, *Voluntary specification, Performance requirements and test procedures for high performance organic coatings on aluminum extrusions and panels*. Schaumberg, IL, USA.

(16) ASTM International (2016) ASTM D2244-16 *Standard practice for calculation of color tolerances and color differences from instrumentally measured color coordinates*. West Conshohocken, PA, USA.

(17) ASTM International (2015) ASTM D4214-07 *Standard test methods for evaluating the degree of chalking of exterior paint films*. West Conshohocken, PA, USA.

(18) Auckland Motorways *What anti-graffiti products are approved for use on the Auckland motorways?* Last accessed 13 April 2017. <www.aucklandmotorways.com/SitePages/FAQ%20-%20What%20Anti-Graffiti%20products%20are%20approved%20for%20use%20on%20the%20Auckland%20Motorways.aspx>

(19) Standards Australia AS 4848.1-2006 *Application specifications for coating systems – Single coat inorganic (ethyl) zinc silicate – Solvent-borne*.

(20) Francis R (2006) *New standard on single coat inorganic zinc silicate coatings*. Published in *Corrosion and materials* Vol.31, No.4, Australasian Corrosion Association, August 2006.

(21) Standards Australia and Standards New Zealand jointly AS/NZS 4680:2006 *Hot-dip galvanized (zinc) coatings on fabricated ferrous articles*.

(22) International Organization for Standardization ISO 1461:2009 *Hot dip galvanized coatings on fabricated iron and steel articles – Specifications and test methods.*

(23) The Society for Protective Coatings (2000) SSPC-SP 11 *Power tool cleaning to bare metal*. Pittsburgh, PA, USA.

(24) Standards Australia AS 3894.9-2003 *Site testing of protective coatings*. Part 9 Determination of adhesion.

(25) Francis RA, Ellis D, & Walker AL (2007) *Repair of single coat inorganic zinc silicate coatings*. Proceedings of Australasian Corrosion Association Corrosion & Prevention Conference 2007, Sydney, Australia.

(26) Mandeno W (2012) *Thermal metal spray: success, failures and lessons learned*. Proceedings of Australasian Corrosion Association Corrosion & Prevention Conference 2012, Melbourne, Australia.

(27) Federal Highway Administration (2011) FHWA-HRT-11-046 *Performance evaluation of one-coat systems for new steel bridges*. US Department of Transportation, Washington DC, USA.

(28) NZ Transport Agency (2016) Z19 *State highway environmental & social responsibility standard*. Wellington.

(29) NZ Transport Agency (2014) *Guideline for preparing an environmental and social management plan*. Wellington.

(30) NZ Transport Agency (2014) *A methodology for identifying environmental risks for bridge maintenance*. Wellington.

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(32) NZ Transport Agency (1998) *Guidelines for the management of lead based paint on roading structures*. Research report 115, Wellington.

(33) NZ Transport Agency (2003) TNZ C26 NOTES *Notes for the cleaning and recoating of steelwork coated with lead based paint*. Wellington.

(34) Standards Australia AS 4361.1-1995 *Guide to lead paint management*. Part 1 Industrial applications.

(35) Transportation Research Board (1997) NCHRP Synthesis 251 *Lead-based paint removal for steel highway bridges*. The National Academies, Washington DC, USA.

(36) NZ Transport Agency (2016) *Economic evaluation manual*. Wellington.

(37) Federal Highway Administration (2011) FHWA-HIF-11-042. *Bridge preservation guide – Maintaining a state of good repair using cost effective investment strategies*. US Department of Transportation, Washington DC, USA.

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(42) Standards Australia and Standards New Zealand jointly AS/NZS 1554.6:2012 *Structural steel welding*. Part 6 Welding stainless steels for structural purposes.

(43) New Zealand Heavy Engineering Research Association (2005) *New Zealand weathering steel guide for bridges*. HERA Report R4-97, Manukau City.

(44) New Zealand Heavy Engineering Research Association (2017) HERA *Design guide for bridges in Australia: Weathering steel*. Manukau City.

(45) Standards Australia and Standards New Zealand jointly AS/NZS 1664.1:1997 *Aluminium structures*. Part 1 Limit state design.

(46) Standards Australia and Standards New Zealand jointly AS/NZS 1664.2:1997 *Aluminium structures*. Part 2 Allowable stress design.

(47) Standards Australia and Standards New Zealand jointly AS/NZS 1665:2004 *Welding of aluminium structures*.

(48) Standards Australia AS 2309-2008 *Durability of galvanized and electrogalvanized zinc coatings for the protection of steel in structural applications – Atmospheric*.

(49) Standards Australia and Standards New Zealand jointly AS/NZS 4791:2006 *Hot-dip galvanized (zinc) coatings on ferrous open sections, applied by an in-line process*.

(50) Standards Australia and Standards New Zealand jointly AS/NZS 4792:2006 *Hot-dip galvanized (zinc) coatings on ferrous hollow sections, applied by a continuous or specialized process*.

Appendix A Brief introduction to coating systems

The following coating systems are typically used in new and existing bridges, most of which are given in AS/NZS 2312.1[(1)]. Alternative coatings currently not given in AS/NZS 2312 parts 1 and 2[(1)], that should be considered, are also given below. Note that additional guidance is available in section 8 of HERA Report R4-133[(3)], while table 6.3 of AS/NZS 2312.1[(1)] and table 7.1of AS/NZS 2312.2 provide guidance on the different coating systems, with table D1 of AS/NZS 2312.1[(1)] providing detailed descriptions of each component of those systems. Guidance on thermal metal spray systems is given in table 5.1 of AS/NZS 2312:2002[(10)].

Table A1: Summary of typical bridge coating systems

	Coating	System designation	Description	Typical use	Reference
New and existing bridges	Inorganic zinc silicate (IZS)	IZS	Comprises of powdered metallic zinc dispersed in a self-curing inorganic silicate medium. This is available as a solvent borne (SB), water borne (WB) and water borne high ratio	As a single coat provides a durable coating, with high abrasion and damage resistance. Note can only be used in non-acidic environments (within pH 6 to 10 range). Also used as a primer for epoxy and polyurethane coatings systems	AS/NZS 3750.15[(A1)] • Solvent borne type 4 • Water borne type 3 • Water borne, high ratio type 6
	Thermal metal spray	TSZ TSA	Comprises of a single coat metallic coating, available as pure zinc, aluminium or an "85/15" zinc/aluminium formulation. A "sealer" top coat is usually applied	Provides a hard, durable coating with excellent long term protection, especially in marine environments and for aluminium metal spray in industrial and geothermal environments. Has high abrasion and damage resistance	ISO 2063[(A2)]
	Polyurethane	PUR	Comprises of a multi coat system, with a base primer (either an epoxy or zinc-rich), usually with an intermediate coat (high build epoxy) and topped with a polyurethane top coat	The total system provides a very hard, durable coating, with a high gloss finish, excellent colour retention and is chalking and UV resistant	AS/NZS 3750.6[(A3)]
	High build epoxy	EHB	For bridges usually comprises of a multi coat system, with a base primer (either an epoxy or zinc-rich), topped with a high build epoxy only, or with two coats of epoxy micaceous iron oxide (MIO)	May be used as a finish coat, with good chemical and abrasion resistance. However, usually used topped with a polyurethane, as it is prone to chalking	AS/NZS 3750.14[(A4)]
Existing bridges	Moisture cured urethane	MCU	Usually applied as a multi coat system	Provides a surface tolerant low to medium gloss, UV stable coating from mild to severe environments. It has excellent colour and gloss retention and can be applied in high humidity and low temperature conditions	AS 3750.18[(A5)]
	Acrylic elastomeric	ACE	Applied as a two coat system	Surface tolerant, direct to metal self-priming coating, providing a flexible, durable, thick rubbery film that can be used as an encapsulating system	-
	High ratio co-polymer calcium sulfonate alkyd	HRCSA	Comprises of a HRCSA penetrant sealer and two HRCSA top coat applied wet on wet	Very surface tolerant, direct to metal and/or sound existing coating, providing a durable, soft thick film that can be used as an encapsulating system after water cleaning (8000 psi) also abrasive blasting if required	-

Appendix A
continued

Additional notes on other coatings for existing bridges:

- Chlorinated rubber (CLR): Existing bridges coated with this system can be patch painted with another chlorinated rubber primer and top coat. High-pressure water cleaning at 8000 psi is sufficient to prepare the surface.
- High build epoxy (EHB3): this variation of the high build epoxy systems is another suitable patch repair option. The variation is the use of an epoxy mastic intermediate coat instead of a high build epoxy as given in table 6.3 of AS/NZS 2312.1[(1)].

A1 References

(A1) Standards Australia and Standards New Zealand jointly AS/NZS 3750.15:1998 *Paints for steel structures*. Part 15 Inorganic zinc silicate paint.

(A2) International Organization for Standardization ISO 2063:2005 *Thermal spraying – Metallic and other inorganic coatings – Zinc, aluminium and their alloys*.

(A3) Standards Australia and Standards New Zealand jointly AS/NZS 3750.6:2009 *Paint for steel structures*. Part 6 Full gloss polyurethane (two-pack).

(A4) Standards Australia and Standards New Zealand jointly AS/NZS 3750.14:1997 *Paint for steel structures*. Part 14 High-build epoxy (two-pack).

(A5) Standards Australia AS 3750.18-2002 (R2013) *Paint for steel structures*. Part 18 Moisture cure urethane (single-pack) systems.

Appendix B Surface preparation

B1 General

Clause 4.2 of AS/NZS 2312.1[(1)] outlines the different surface preparation treatments. Details of the common treatments used for bridges follow.

B1.1 Abrasive blast cleaning to AS 1627.4[(4)]

- Sa2½: the most common surface treatment for nearly all coatings, especially for those with long term performance. The steel is subjected to "very thorough blast cleaning" removing millscale, rust, and foreign particulars to the extent that only traces remain in the form of spots or stripes, and the cleaned surface shows varying shades of grey.
- Sa3: Typically used for coating subject to immersion and aluminium metal spray coatings, the steel is blasted to "visually clean steel" where millscale, rust and foreign particles are entirely removed and the cleaned surface has a uniform metallic colour but may show varying shades of grey when viewed from different angles.

Note that the cleanliness standards given by AS 1627.9 *Metal finishing – Preparation and pretreatment of surfaces* part 9 Pictorial surface preparation standards for painting steel surfaces[(B1)] (that is based on ISO 8501-1 *Preparation of steel substrates before application of paints and related products – Visual assessment of surface cleanliness* part 1 Rust grades and preparation grades on uncoated steel substrates and of steel substrates after overall removal of previous coatings[(B2)]) and those given by NACE – SSPC surface preparation standards are similar but not identical. Caution is advised when substituting either standard.

B1.2 Power tool cleaning to AS 1627.2[(B3)] and SSPC-SP11 [(23)]

- St2: is typically used where abrasive blasting is not permitted or practicable. Where power disc sanding is not possible, surfaces may be cleaned by needle guns, by power wire brushing or manual wire brushing and a surface tolerant primer should be used. Where priming with zinc-rich, the use of power disc sanders or "bristle blasters" should be used to remove all contamination back to clean bright steel. Bright steel is defined in SSPC-SP11[(23)], which is summarised as steel that has a shiny surface free from rust, scale or other harmful imperfections and 25 microns profile. Sharp edges shall be rounded to a minimum radius of 2mm and surface defects made smooth.

B1.3 Pressure cleaning to clause 4.2.5 of AS/NZS 2312.1[(1)]

- Low-pressure water cleaning (LPWC < 5,000 psi): used to remove loose millscale, rust, paint chalking and soluble salts.
- High-pressure water cleaning (HPWC = 5,000 psi to 10,000 psi): used to remove light to moderate rust scale, concrete splashes, severe marine fouling and loose coatings.
- High-pressure water jetting (HPWJ = 10,000 psi to 30,000 psi): used to remove rust, intact paints, contaminants and some weathered millscale.
- Ultra-high pressure water jetting (UHPWJ = >30,000 psi): used to remove rust, coatings and all most all millscale, to prepare steel to a "Very thorough cleaning" standard ("WJ-2").

B1.3 continued

Notes:

1. The term "water blasting" should not be used without defining the nozzle (not pump) pressure, but is a non-preferred term as is used in North America to describe wet abrasive blasting where abrasive media is entrained as a slurry or mixed with water at the nozzle.
2. In addition to nominating the water pressure range required for cleaning, the minimum levels of cleanliness, non-visual contaminates and flash rusting should be specified using the relevant replacement standard for the now withdrawn SSPC-SP12/NACE No. 5 *Joint surface preparation standard: Surface preparation and cleaning of metals by waterjetting prior to recoating*(B4) standard, ie
   - SSPC-SP WJ-1/NACE WJ-1 *Waterjet cleaning of metals – Clean to bare substrate*(B5)
   - SSPC-SP WJ-2/NACE WJ-2 *Waterjet cleaning of metals – Very thorough cleaning*(B6)
   - SSPC-SP WJ-3/NACE WJ-3 *Waterjet cleaning of metals – Thorough cleaning*(B7)
   - SSPC-SP WJ-4/NACE WJ-4 *Waterjet cleaning of metals – Light cleaning*(B8).

   The associated visual reference guide is SSPC-VIS 4/NACE VIS 7 *Guide and reference photographs for steel surfaces prepared by waterjetting*(B9).

In order to remove all intact mill scale by UHPWJ to achieve a WJ-1, "Clean to bare substrate" standard, a nozzle pressure of >35,000 psi is required. This is unlikely to be economic on new steel where abrasive blasting will usually be more cost effective.

B2 References

(B1) Standards Australia AS 1627.9-2002 *Metal finishing – Preparation and pretreatment of surfaces*. Part 9 Pictorial surface preparation standards for painting steel surfaces.

(B2) International Organization for Standardization ISO 8501-1:2007 *Preparation of steel substrates before application of paints and related products – Visual assessment of surface cleanliness*. Part 1 Rust grades and preparation grades on uncoated steel substrates and of steel substrates after overall removal of previous coatings.

(B3) Standards Australia AS 1627.2-2002 *Metal finishing – Preparation and pretreatment of surfaces*. Part 2 Power tool cleaning.

(B4) The Society for Protective Coatings and NACE International jointly (2002) SSPC-SP 12/NACE No. 5 *Joint surface preparation standard: Surface preparation and cleaning of metals by waterjetting prior to recoating*. Pittsburgh, PA, USA. Withdrawn.

(B5) The Society for Protective Coatings and NACE International jointly (2012) SSPC-SP WJ-1/NACE WJ-1 *Waterjet cleaning of metals – Clean to bare substrate*. Pittsburgh, PA, USA.

(B6) The Society for Protective Coatings and NACE International jointly (2012) SSPC-SP WJ-2/NACE WJ-2 *Waterjet cleaning of metals – Very thorough cleaning*. Pittsburgh, PA, USA.

(B7) The Society for Protective Coatings and NACE International jointly (2012) SSPC-SP WJ-3/NACE WJ-3 *Waterjet cleaning of metals – Thorough cleaning*. Pittsburgh, PA, USA.

(B8) The Society for Protective Coatings and NACE International jointly (2012) SSPC-SP WJ-4/NACE WJ-4 *Waterjet cleaning of metals – Light cleaning*. Pittsburgh, PA, USA.

(B9) The Society for Protective Coatings and NACE International jointly (1998) SSPC-VIS 4/NACE VIS 7 *Guide and reference photographs for steel surfaces prepared by waterjetting*. Pittsburgh, PA, USA.

Appendix C Paint marking for steel bridges

A standard identification system shall be used to record details of the coating system.

Information should be recorded by neatly painting in contrasting colour (and with compatible paint) onto the web of the outer girders in 50mm high letters so it is easily visible. If possible this should be done near the abutment on the left-hand side when looking with route distance, and in a position difficult to deface with graffiti. The information should include:

a. Contractor's initials and date of completion of paint application, eg

NSB/ FEB 2014

b. Surface preparation, eg

S/W	Scrape and wire-brush
HPWJ	High pressure water jet
SA2½	Abrasive blast to near white metal

c. Priming coat(s) and dry film thickness (DFT) specified eg

IZS	Inorganic zinc silicate
MCUZR	Moisture cure urethane zinc-rich
EZR	Epoxy zinc-rich
ZPA	Zinc phosphate alkyd

d. Cover and finish coats with DFT, eg

CR	Chlorinated rubber
HBE	High build epoxy
EM	Epoxy mastic
MIO	Micaceous iron oxide
PU	Polyurethane

Examples:

i. System PUR5 with two build coats would be shown as:

SA2½	
EZR	1/75
HBE	2/100
PU	1/75
NSB	

ii. System ALK6 with patch painting:

S/W SPOT	
ZPA	1/40 SPOT
MIOA	1/40 SPOT
MIOA	1/50

Appendix D NZ coating industry checklist

HERA
Innovation in Metals
Structural Systems

17-19 Gladding Place
P O Box 76 134, Manukau City
Auckland, New Zealand

STEEL BRIDGE DEVELOPMENT GROUP
Tel: +64-9-262 4756
Fax: +64-9-262 2856
Email: structural@hera.org.nz
Web-site: www.hera.org.nz

New Zealand Coating Industry Checklist

Item	Details	Reference	Tick Box
1	**Scope of Work:** *Outline scope of the project and work involved.*	Client/designer	
1a	Special Requirements: *Outline any special requirements.*		
1b	State the required performance criteria: *E.g. performance warranty, aesthetic, corrosion protection, etc.*		
1c	Design Life of Structure: *State the structure's design life.*	Clause 5.1.1 of NZS 3404.1:2009	
1d	Substrate: *State the substrate the coating is being applied onto.*	Designer	
1e	Atmospheric Corrosivity Category: *Specify this taking into account both the Macroclimate and Microclimate conditions.*	Clause 2.2 & 2.3 of AS/NZS 2312.1:2014	
1f	Time to First Maintenance: *Specify the expected time to first maintenance.*	Clause 5.1.2 of NZS 3404.1:2009	
2	**Design Detailing and Fabricator Considerations**		
2a	Eliminate typical design problems: *Ensure typical design problems are considered and eliminated before fabrication begins. It is recommended that the fabricator and coatings applicator are included when developing the drawings to assist in addressing typical design problems. Such problems include allowing suitable access to allow for surface preparation for all coated areas and for their future maintenance.*	Clause 3.3.4 & Figure 3.1 of AS/NZS 2312.1:2014	
2b	Post fabrication: *Clean to ensure all contaminants, weld splatter, etc, are removed.*	Clause 4.1 of AS/NZS 2312.1:2014	
2c	Consider whether there is sufficient lead time for work commencement and repairs.	Designer	
3	**Coating System:** *State coating thickness(es) including dry film thickness (DFT).*	Section 10 of AS/NZS 2312.1. Designer/Coating Supplier	
3a	Coating Specification: *This document is a job specific document that states the surface preparation, coating system details, its application and other required details, such as a finish reference plate and hold points for client or independent third party inspector (TPI) inspection. Review by supplier and coating specialist or TPI.*		
3b	Specification Reference and Date of Issue: *Record and confirm current.*	Designer	
3c	Maintenance Manual: *This document outlines the maintenance requirements of the coating, after its application, including repair. It should also include the specification for refurbishment at the expected time of first maintenance.*	Coating Supplier/Designer/ Maintenance Engineer	
4	**Quality Control**		
4a	Coating Application: *Ensure that the equipment, coatings application and required environmental conditions are met. The application of the coating system should be applied by a qualified coating applicator with an NZQA National Certificate in Blaster Coating (preferably Level 3).*	Designer/Coating Applicator	
4b	Quality Control/health and safety to meet OSH and client requirements: *Ensure the appropriate on-site quality control and health and safety procedures are in place. This includes specifying the level of required Personal Protection Equipment (PPE).*	NZS 4801:2001 and/or OSHA18001	
5	**Inspection:** *Use of an independent third party inspector (TPI) qualified in coating inspection by CBIP, ACA or NACE. NACE CIP Level 2 is recommended for major structures.*	Use relevant parts of AS 3894:2002, AS/NZS 2312.1 or AS/NZS 4680:2002	
5a	Before Coating Application: *This is applicable to all coatings.*		
5b	During Coating Application: *This is not applicable to hot dip galvanized coatings.*		
5c	After Coating Application: *This is applicable to all coatings.*		
6	**Pre-commencement Meeting:** *Before the commencement of the work, a meeting shall be held between representatives of the Engineer, Contractor, Coating Manufacturer and any subcontractors to clarify and agree the specification, Contractor's proposed programme and methodology, and inspection procedures.*	Representative of all parties	
6a	Agree on required DFT: *Discuss and agree, whether the minimum average DFT (from AS3894.3) or absolute minimum DFT (from coating supplier) is needed. This is dependent on the environment and type of coating used. For hot dip galvanized coatings, refer to the minimum zinc coating requirements of AS/NZS 4680.*	AS 3894.3:2002/Coating Supplier/ AS/NZS 4680:2006	

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HERA Innovation in Metals

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NZ TRANSPORT AGENCY WAKA KOTAHI

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