Protective coatings for steel bridges

A guide for bridge and maintenance engineers

Published: February 2014
Amendment 2: August 2020

WAKA KOTAHI
NZ TRANSPORT AGENCY

New Zealand Government

Protective coatings for steel bridges

A guide for bridge and maintenance engineers

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www.nzta.govt.nz

First edition, Amendment 2

Effective from August 2020

ISBN 978-0-478-41922-1 (online)

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Published February 2014
ISBN 978-0-478-41922-1 (online)

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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.
Document owner	Nigel Lloyd, Principal Structures Engineer
Document sponsor	Barry Wright, Lead Advisor Structures
Prepared by	WSP

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

Copies of this document management plan are to be included in the NZ Transport Agency intranet.

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
2	Revisions based on user feedback, the publication of AS/NZS 5131 in December 2016 and SNZ TS 3404 in February 2018; and production of NZ Transport Agency specifications for coating bridge steelwork and anti-graffiti coatings.	August 2020	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
Lead Advisor Structures
NZ Transport Agency

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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.)
- SNZ TS 3404 *Durability requirements for steel structures and components*(2)
- AS/NZS 5131 *Structural steelwork – Fabrication and erection*(3)
- HERA Report R4-133 *New Zealand steelwork corrosion and coatings guide*(4)
- NZTA S9 *Specifications for coating steel highway structures*(5)
- NZTA S10 *Anti-graffiti coatings specification*(6).

Whilst this document has been developed by Waka Kotahi 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 (approximately 3 tonnes of coal are used to make 2 tonnes 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.

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[(4)].

3.0 Development of protective coatings for bridges in New Zealand

Before 1950, steel structures around the world were generally protected by a coating based on red lead pigment mixed with linseed oil, similar to that used on the Forth Bridge, Scotland in 1880. The ubiquitous PWD No.2 primer was an improved formulation that was specified by the Public Works Department (PWD). Its excellent wetting properties with good corrosion resistance over steel with little or no surface preparation, made PWD No.2 an almost fool-proof primer and it was still being used for bridge maintenance by NZ Railways until the early 1980s.

Rapid advances in polymer chemistry during the 1950s saw many new generic types of protective coatings appear and paint technology began to move from an art to a science The Ministry of Works (MOW) introduced its own specification for the US developed self-curing inorganic zinc silicate that replaced lead-based paints. This became the preferred primer for structural steelwork in power stations and bridges, usually overcoated with chlorinated rubber-based topcoats.

From 1963 until 1988, the Ministry of Works and Development (MWD) operated a 'periodic approval scheme' where paint samples from coating manufacturers were tested every 3 years by the Department of Scientific and Industrial Research (DSIR) Chemistry Division against MWD specification to confirm their suitability for use on public projects. This scheme was restructured as the NZ Paint Approval Scheme, modelled on the Australian Government Paint Committee program, and then combined to form the Australian Paint Approval Scheme (APAS) administered by CSIRO (Commonwealth Scientific & Industrial Research Organisation). The latter is still used for NZ Transport Agency projects, as well as other international equivalent certifications, that are referenced in this document.

The 1980s saw the introduction of surface tolerant epoxy mastics for use in maintenance painting and high-build epoxies to provide barrier protection using fewer paint layers than the oil or alkyd resin-based coatings they replaced. It also saw wider use of thermal zinc spray as an alternative to galvanizing following the development of computer-controlled arc spray technology.

An influential guide on the use of protective coatings for steel structures, AS/NZS 2312[(1)], was first published in 1984 and has been updated several times since as new coating systems have been developed. This is now complemented with the 2018 publication of SNZ TS 3404[(2)], which gives guidance on coatings systems to ensure compliance with the durability requirements of the *Building code*[(7)].

Changes in coating technology are reflected in changes to the coating systems used to maintain the Auckland Harbour Bridge. These have been specified by MWD since it took over responsibility for the bridge in 1984. The original structure was 'metallised' with flame-sprayed zinc before receiving five coats of alkyd paint with the first three coats being pigmented with zinc chromate. Then in 1994 it was changed to a four-coat system using chromate-free primers following trials of zinc phosphate pigmented metal primers commissioned. In 1999, it changed again to a three-coat system using moisture cured urethanes. This change was based on successful use of this coating system on highway bridges in the State of Washington, which are maintained in similar climatic conditions to New Zealand with relatively high humidity during their summer painting season.

Since 2008, the NZ Transport Agency has required, where economically feasible, that coatings on bridge beams should give 40 years protection against corrosion before requiring major maintenance. This has resulted in the use of high-build inorganic zinc silicate or thermal sprayed zinc alloys for coastal bridges.

4.0 Durability design and detailing considerations

4.1 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), which are summarised in SNZ TS 3404(2), with additional guidance given by HERA Report R4-133(4).

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)).

Additional requirements for surface treatment and corrosion protection of steel surfaces are specified in section 9 of AS/NZS 5131(3). Specifiers shall reference NZTA S9 *Specifications for coating steel highway structures*(5) for coating of new steelwork in their contract document.

Note that arc-sprayed zinc is often specified for coating of mild steel hollow structural sections (eg on highway gantries) as an alternative to hot dip galvanizing. Unless large enough to be internally coated, the following requirements should be considered:

- such elements need to be hermetically sealed to exclude entry of oxygen and so prevent internal corrosion

4.1 continued

- these sealed elements must then be detailed to eliminate the need for through-wall drilling to bolt on attachments or to allow the internal location of service pipes or cables.

Large tubular or box sections that are coated internally by galvanizing or paint should be provided with a hole at their lowest point after erection, to allow for the drainage of any internal condensation.

4.2 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[8]. 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. Further guidance is given in SSPC-PA Guide 11 *Protecting corners, edges, crevices, and irregular steel geometries by stripe coating*[9].
- 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)*[10]). However, in corrosive marine environments (ie C5-M), 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:
  - application of a site applied additional barrier coat compatible with the adjacent steel work corrosion protection
  - the use of pre-painted bolts with the additional barrier coat, with site touch up post installation
  - use of the UV stable plastic or metallic caps (on both ends).
- Rust grades: Are based on ASTM D 610 *Standard practice for evaluating degree of rusting on painted steel surfaces*[11] and SSPC-VIS 2 *Standard method of evaluating degree of rusting on painted steel surfaces*[12], 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.

4.2 continued

- Treatment of the top flange in a composite deck design: Masking of the centre strip is only necessary when stud welding on site. If shear studs are welded prior to blasting and painting, the top flange should be fully painted to minimise the risk of crevice corrosion and rust staining the concrete deck below joints.

4.3 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[4] 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*[13]), 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.

4.4 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*[14]. 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.

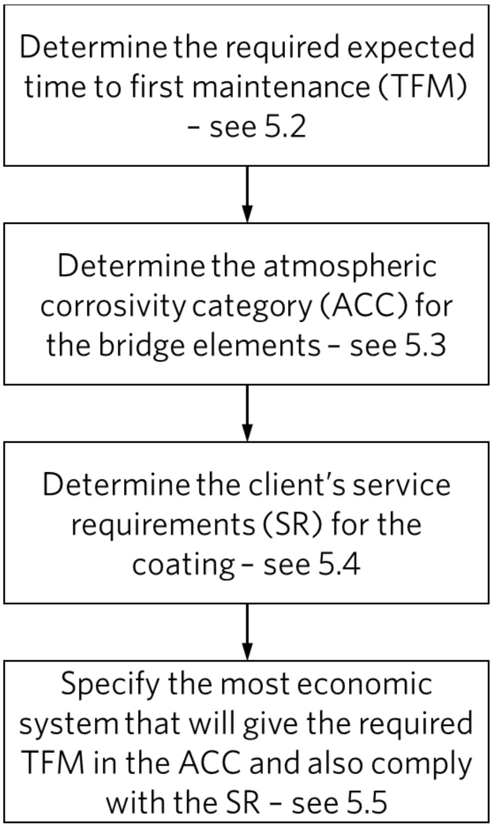
Note also that the addition of organic topcoats to create a 'duplex' system may reduce potential life if they are of excessive thickness (>200 microns) as discussed in section 5.2 of AS/NZS 2312:2002 *Guide to the protection of structural steel against atmospheric corrosion by the use of protective coatings*[15]. 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[15] 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.

5.0 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.

5.1 Design flow charts



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

The NZ Transport Agency *Bridge manual*[16], 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.

5.2 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 1.7 of SNZ TS 3404[2].

5.3 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[4]. 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[4] 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 2 of SNZ TS 3404[2], and is included in table 5.1, which is based on both AS/NZS 2312.1[1] and HERA Report R4-133[4]. 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 Geothermal zone the guidance has been revised to reflect the corrosivity in an internal and geothermal environment.

5.4 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*[16] and *Urban and landscape design frameworks – highways and network operations guideline*[17]. Matters such as colour, colour retention and gloss levels shall be considered, as described below.
- Colour: The Transport Agency's *Bridging the gap*[18] 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.

Table 5.1: Atmospheric corrosivity categories from table 2 of SNZ TS 3404[2]

Macroclimate corrosion category AS/NZS 2312.1[1]	Typically	Location	Characterised by	Surface specific corrosion category – External – Exposed	External – Sheltered	External – Wet	Internal – Dry	Internal – Damp
C5-M	Within 200m from breaking surf on the West and South Coasts of the South Island. Within 100m from breaking surf on the West and South Coasts 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	C5-M	C5-M	C1	C4
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 conditions.	All coasts	Medium salt deposits. Frequent smell of salt in the air	C4	C5-M	C5-M	C1	C3
C3	More than 1km to 20km from salt water.	West and South Coast of the South Island	Minor salt deposits. Occasional smell of salt in the air	C3	C5-M	C5-M	C1	C3
	Within 5km from salt water.	East Coast of both Islands, West and South Coasts of North Island, and all harbours.		C3	C4	C5-M	C1	C3
C2	More than 20km to 50km from salt water.	West and South Coasts of South Island	No marine influence	C2	C3	C4	C1	C3
	More than 5km to 50km from salt water.	East Coasts of both Islands, West and South Coasts of North Island, and all harbours		C2	C3	C4	C1	C3
	Inland, more than 50km from salt water.	North and South Islands		C2	C2	C3	C1	C3
C5I	Close to the geothermal source <500m.	Geothermal zone	Constant smell of hydrogen sulphide (H_2S)	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 5.1:

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
Geothermal zone	Refer to note 3 given in table 2 of SNZ TS 3404(2)

5.4 continued

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, blue on the SH20 Beachcroft Bridge and red and blue on the Tirohanga Whānui Footbridge.

Figure 5.1: 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

- Fade resistance: When the colour is something other than white, a topcoat with both 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*(19), 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*(20) or a limit on chalking when measured to ASTM D4214 *Standard test methods for evaluating the degree of chalking of exterior paint films*(21). Consistent appearance over at least a ten-year period would be considered as a reasonable requirement. For a longer aesthetic performance, consider the use of fluoropolymer urethanes which can meet the more stringent 15-year requirements of AAMA 2605 *Voluntary specification, performance requirements and test procedures for superior performing organic coatings on aluminum extrusions and panels*(22). Note that the usual organic pigments to give non-toxic red and blue colours have poor long-term fade resistance when exposed to direct sunlight.

5.4 continued

- 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*(16)). 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.

  The requirements for the supply and application of anti-graffiti (AG) coatings are given in NZTA S10 *Anti-graffiti coatings specification*(6). This uses Austroads Technical Specification ATS 5820 *Anti-graffiti coatings*(23) as its principal means of compliance and covers both permanent and sacrificial anti-graffiti coatings for application to both metallic and non-metallic substrates.

  Specifiers need to specify whether the anti-graffiti system to be applied is:

  - permanent or sacrificial
  - level of gloss required (semi-gloss or matt)
  - clear or coloured (eg galvanizing or concrete grey, ie standard colour N11 to AS 2700 *Colour standards for general purposes*(24)).

  Before application, APAS accredited coating manufacturers must supply evidence that the performance of their proposed anti-graffiti coating system has demonstrated compliance with one of the several specified test methods.

  In addition to the use of anti-graffiti coatings, specifiers should also consider installation of fencing to restrict access to 'taggers' in high risk areas and the incorporation of anti-climb devices at the ends of girders, as shown in figures 5.2 and 5.3.

5.4 continued

Figure 5.2: Example of anti-climb plates on bridge girder bottom flanges

Figure 5.3: Example of flared stiffener on bridge girder to discourage climbing
(image courtesy Eastbridge Ltd)

5.5 Suggested coatings in different atmospheric environments

The suggested coatings given in tables 5.2 to 5.5, 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) and SNZ TS 3404(2).

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(4) has been used to extend the time to first maintenance for the suggested coatings.

Tables 5.2 to 5.5, are based on those given in SNZ TS 3404(2), which also only provides coating options for 15, 25 and 40 years.

5.5 continued

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[4].

Note that AS/NZS 2312 parts 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*[25]. AS 4848.1-2006[26] specified a 100 micron coating of solvent borne zinc silicate which is not included in AS/NZS 2312.1[1]. However AS 4848.1:2019[25] now covers designated systems IZS1 and ISZ4.

NZTA S9 *Specifications for coating steel highway structures*[5] currently include inorganic zinc silicates, moisture cured urethane, epoxy/polyurethane, epoxy/polysiloxane, hot-dip galvanizing and thermal metal spray.

Table 5.2: Coatings for atmospheric corrosivity category C2

Years	System designation	Surface preparation	Number of coats	Hardness	Typical colour	Initial gloss	Colour and gloss retention on weathering
25	IZS1	Sa2½	1	Very good	Mostly grey	Flat	Fair
	MCU2		3		Limited range	Semi-gloss	Very good
	PUR3				Wide range	Semi-gloss to full gloss	Excellent
40	IZS4		1	Excellent	Mostly grey	Flat	Fine
	PUR5		3	Very good	Wide range	Semi-gloss	Excellent
	ACE1[1]		2	Good	Limited range		
	HDG390	See AS/NZS 4680[27]	1	Excellent	Grey[2]	Gloss	Fair
	TSZ100[3]	Sa2½	1			Flat	

Notes:

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

5.5 continued

Table 5.3: 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	Very good	Wide range	Semi-gloss to full gloss	Excellent
	ACE1[1]		2	Good	Limited range	Semi-gloss	
40	IZS4		1	Excellent	Mostly grey	Flat	Fair
	TSZ100[3]				Grey[2]		
	HDG600	See AS/NZS 4680[(27)]	1				
	HDG6005D	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 5.4: 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	PUR5 or PSL2	Sa2½	3	Very good	Wide range	Semi-gloss to full gloss	Excellent
	IZS4		1	Excellent	Mostly grey	Flat	Fine
	HDG900				Grey[1]		
	HDG6005D	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

5.5 continued

Table 5.5: Coatings for atmospheric corrosivity category C5-M

Years	System designation	Surface preparation	Number of coats	Hardness	Typical colour	Initial gloss	Colour and gloss retention on weathering
25	TSZ200S[1]	Sa2½	2	Excellent	Grey[4]	Flat	Fine
40	TSZ300S[1]						
	TSA225S[2,3]	Sa3					

Notes:

1. Only zinc/aluminium alloy (85% zinc, 15% aluminium) to be used in C5-M environment.
2. TSA225S is also suitable for atmospheric corrosivity category C5I, eg a mild geothermal environment.
3. Thermal aluminium spray is mostly used for structures within 100m from the sea due to the high corrosivity category and abrasiveness of the environment, while thermal (pure) zinc spray is used in the less corrosive C3 and C4 categories
4. Wide range when colour sealer/top coat is used.

5.6 Suggested coatings for non-atmospheric environments

Bridge piles and other buried or immersed steel components should be coated as recommended in AS/NZS 2312.1[(1)] appendix C2 and SNZ TS 3404[(2)] section 3. Note that the corrosion rate is usually relatively slow from about 2m below ground or bed level due to limited oxygen access.

Consideration should be given to the risk of damage to coatings during installation or abrasion in service where exposed to movement of bedload during flooding or scour conditions. In some situations, it may be sufficient to provide a sacrificial thickness of steel which may already be present in driven piles. A method of predicting the rate of metal loss for zinc and steel is given in SNZ TS 3404[(2)]. Alternatively, sprayed gunite or a protective precast concrete collar could be placed around the pile where abrasion is severe. In very corrosive soils additional life may be achieved with a cathodic protection system. Further guidance, and options, are given in clause 3.3 of SNZ TS 3404[(2)].

Examples of suitable systems are given in table 5.6.

Table 5.6: Coatings for non-atmospheric environments

Years	System designation	Surface preparation	Number of coats	Hardness	Typical colour	Initial gloss	Colour and gloss retention on weathering
20+	EVH2	Sa2½	1	Very good	Grey[1]	Flat	Fair
	EVH3		2	Excellent			
	PES1		1				

Notes:

1. Abrasion resistance of epoxy may be enhanced by the addition of glass flake pigment.

6.0 Maintenance coating selection for existing bridges

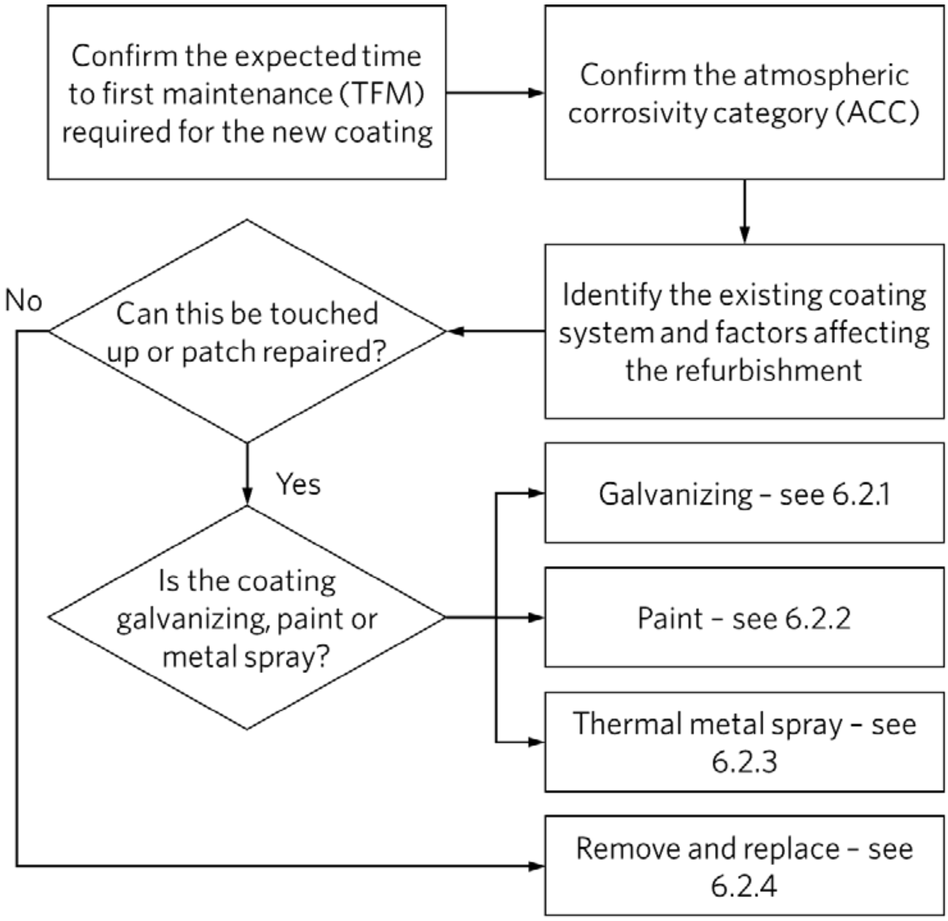
All coatings will require some form of maintenance over the design life of a bridge. This could range from simple touch up after erection to repair transportation damage, to a full recoat/replacement of the coating system when a patch repair is no longer an economic option.

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[4].

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

6.1 Maintenance design flow charts



6.2 Coating maintenance procedures

6.2.1 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*(27). This is repeated below:

Extent of damage requiring repair

For new steelwork galvanized to AS/NZS 4680(27) 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*(28) 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(27) 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(8). 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*(29). For further information on systems referred to by acronyms see appendix A or clause 4.2 of AS/NZS 2312.1(1).

6.2.2 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 6.1). 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 6.1).

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. If the disturbance of lead or chromate pigments during maintenance is expected, refer also to 6.5.

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[30]) 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.

Figure 6.1: Example of stencilled repaint details on the Clive Bridge

Inorganic zinc silicates have been confirmed (see *Repair of single coat inorganic zinc silicate coatings*[31]) 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.

6.2.2 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.

6.2.3 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 figure 6.2 and *Thermal metal spray: success, failures and lessons learned*[(32)]).

Figure 6.2: Failure of epoxy repair on TSA on Ahuriri Bypass bridge piling

6.2.4 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.

6.3 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 where abrasive blasting is not permitted and 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 elastomeric (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), a slow drying visco-elastic coating system applied in two coats "wet on wet "at a minimum of 350 microns DFT requiring a high-pressure water cleaning at 8000 psi or a 5000 psi hot water wash to remove salts. Black rust remaining after water cleaning should be removed and the surface rewashed. Crevices are pre-treated with a HRCSA penetrating primer and then caulked with an additional stripe coat of the finish coat.

These proprietary systems have not been widely used on New Zealand bridges but both have performed well in FHWA trials (see *Performance evaluation of one-coat systems for new steel bridges*[33]), 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.

6.4 Factors affecting maintenance coating selection

6.4.1 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 6.3), or when a limited area of coating has failed due to delamination, such as the Auckland Harbour Bridge (figure 6.4). 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.

6.4.1 continued

Figure 6.3: Example of damaged coatings – Colombo St Bridge

Figure 6.4: Example of damaged coatings – Auckland Harbour Bridge

6.4.2 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 6.5). 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.

6.4.2 continued

Figure 6.5: Full containment for repainting the Patea Rail Bridge (image courtesy SRG Global)

6.4.3 Environmental conditions

6.4.3.1 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.

6.4.3.2 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.

The Transport Agency's Z19 *State highway environmental & social responsibility standard*(34) 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).

6.4.3 continued

The Transport Agency's *Guideline for preparing an environmental and social management plan*(35) 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*(36) and an *Example of an environmental and social management plan for structure maintenance contracts*(37) 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.

6.5 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*(38) and NZTA C26 NOTES *Notes for the cleaning and recoating of steelwork coated with hazardous paint*(39) which are based on AS/NZS 4361.1 *Guide to hazardous paint management* part 1 Lead and other hazardous metallic pigments in industrial applications(40). According to NCHRP Synthesis 251 *Lead-based paint removal for steel highway bridges*(41), 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 elastomeric 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.

6.6 Compatible coatings table

Table 6.1 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(4).

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.
- 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(4) 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(15).

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

Table 6.1: 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

7.0 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*[42]), 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[4] 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[4], with additional updated examples given in 7.1.

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.

7.1 Level of service vs asset protection

In most cases, it is assumed that bridges are required to be fully recoated when the expected time to first major maintenance is reached. However, in some cases aesthetics is the governing factor, especially for "iconic" bridges, thereby requiring the top coat to be refurbished well before the need for 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.

7.1.1 NPV cost analysis example

To demonstrate the difference in the net present value of both options, the following example is given. In this example the bridge is located in an atmospheric corrosivity category C4 (high), over a location with difficult access. In this case, three options are considered, namely a protective coating that can provide the 40 years expected time to first maintenance, whilst the other two options consider a coloured option that needs recoating every 15 or 25 years.

A summary of each corrosion protection system is given below:

7.1.1 continued

- Thermal metal spray (TMS): This is the typical coating used on a number of Transport Agency steel bridges, to meet the required 40 years' time to first major maintenance in a C4 (high) and C5-M (very high – marine) on primary members. In this case, TSZ150S was specified.
- Conventional polyurethane (PUR5): This is a commonly used three-coat long-life protective coating system typically used on bridges, when a colour finish is required. However, the re-coatable polyurethane top coat has an expected life of 10-15 years, after which the colour will have faded, and the gloss levels been reduced. At that point in time, assuming that there were no premature coating breakdown and/or signs of corrosion (ie red rust), the refurbishment of this system is to wash the surface and apply a new polyurethane finish. Abrasion of the original polyurethane top coat may also be required on areas that are faded but still glossy.

  For the purpose of this example a 15-year period before 'refreshing' is assumed.
- Fluoropolymer polyurethane: This is the most durable type of polyurethane, which was developed in Japan, where it is used extensively on monumental architectural structures. It has a proven track record of excellent long-term resistance against both colour fade and loss of gloss and meets the AAMA 2605(22) specification. To date, it has limited used in New Zealand, due to its high cost (3x) when compared against conventional polyurethane. The zinc rich primer and epoxy build coat are the same as the conventional PUR5 system.

  However, there is evidence that this system may achieve 20 to 30 years' time to first maintenance of the top coat, before it requires any refurbishment, using the same methodology outlined above.

  For the purpose of this exercise a 25-year maintenance free period is assumed.

7.1.2 NPV cost analysis

To keep the cost model simple, the above options are based on:

- the cost of the steel tonnage/metre length, for an unpainted mild steel 1200WB455 beam, the total steel surface area is taken as 4.4m²/m.
- the material and application cost of the coating, for the initial coating application
- the material and application cost of the coating, at the time to first maintenance; for the refurbished exposed and accessible portions of the girder (ie surface area is taken as being 3.9m²). For the polyurethane, a full refurbishment of the top coat was assumed, while for the TMS, a full recoat was assumed. In both cases, to keep it simple, it is taken that containment is required in both cases
- access and other associated costs for working under the bridge, was also taken as being the same.

A breakdown of the costings is given below.

Item	Cost
Mild steel	$205/m @ $1500/tonne
Conventional 3-coat polyurethane (on new steelwork)	$90/m²
Conventional polyurethane (at refurbishment)	$38/m²
Fluoropolymer 3-coat polyurethane (on new steelwork)	$106/m²
Fluoropolymer 3-coat polyurethane (at refurbishment)	$54/m²
Thermal zinc spray sealed (on new steelwork)	$80/m²
Thermal zinc spray sealed (at refurbishment)	$100/m²

7.1.3 Cost model results

A summary of the cost from the net present value cost analysis for each option is given below. This is based on a 6% discount rate, over a 40-year period, as per the *Economic evaluation manual*(42). This takes into account the maintenance cost over the 40-year period.

Years	Conventional PUR5	Fluoropolymer Polyurethane	Thermal Metal Spray
0 (when new)	$581	$652	$537
15	$1,100	-	-
25	-	$632	-
30	$459	-	-
40	-	-	$286
Total ($/m)	$2,140	$1,284	$823
Total ($/m²)	$486	$291	$187

7.1.4 Discussion

As seen in the above example, the net present value of a coating refreshed every 15 years (at $486/m²) is greater than the longer life 25 years system (at $291/m²). Thus, when aesthetics is the main driver, the use of a higher performance top coat should be considered.

However, when the main driver is achieving the required durability regardless of aesthetics, then the 40 years expected time to first maintenance coating system (ie TMS) provides the lowest NPV cost at $187/m².

In conclusion, the objective should be to specify the system with lowest NPV cost to meet the project requirements; even though this is likely to result in a higher initial cost.

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 by specifiers wishing to confirm that their proposed system has the lowest whole of life cost.

8.0 Guidance on extending the maintenance period of coating systems

8.1 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*[43], 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*[43] 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*[43] 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[4].

While the HERA Report R4-133[4] 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 3 years
- for ACC C3: once every 6 to 12 years, depending on accumulation of corrosive organic matter, eg wet leaves or bird guano
- for ACC C2: once every 12 to 20 years, depending on accumulation of corrosive organic matter.

8.1 continued

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 2500 to 5000 psi only, with a 40° nozzle at a minimum distance of 300mm. Higher pressures or closer stand-off distances may damage some paint coatings that are otherwise sound.

In addition, growth of adjacent vegetation may need to be periodically controlled with herbicide where this could result in abrasion during high winds, or delay drying of coated surfaces due to shading or accumulation of leaf material.

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*[43] are (but not limited to):

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

The *Bridge preservation guide*[43] 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*[43] is not only relevant for steel bridges but for concrete bridges as well.

9.0 Quality assurance

9.1 General

It has been variously reported (see *Who pays when the paint fails?*[44]) 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.

9.2 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:

- Qualified coating specifiers must be used to prepare or peer review the coating system specification to confirm it meets the durability requirements given in the *Bridge manual*(16), 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 who has successfully completed the ACA's Coating Selection and Specification Course or is currently 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*(7) have been met, shall 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. Coating systems that demonstrate compliance with ISO 12944 *Paints and varnishes – Corrosion protection of steel structures by protective paint systems* (whether in part 5 Protective paint systems(45) or part 9 Protective paint systems and laboratory performance test methods for offshore and related structures(46)) may also be approved. However, coating systems that do not have certified real-life performance data and are solely based on salt spray test results to ISO 9227 *Corrosion tests in artificial atmospheres — Salt spray tests*(47) or ASTM B117 *Standard practice for operating salt spray (fog) apparatus*(48) shall not be accepted.
- The Transport Agency, or its agent, must 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 clauses 13.8.1 and 13.8.2 of AS/NZS 5131(3), and a completed NZ coatings industry checklist (given in appendix D) list shall be submitted with the tender. Model ITPs are given in appendix A of each part of NZTA S9 *Specifications for coating steel highway structures*(5).
- A "pre-job conference", as described in clause 9.4 of AS/NZS 2312.1(1), must 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.

9.3 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. A model test coupons drawing is given in appendix E.

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's Lead Advisor Structures on what quality monitoring should be applied to the structure.

For example, this could require that a total of 10 coupons (150 x 100 x 5mm carbon steel or WS panels) be installed per bridge, of which 5 are installed on a location on the outer girder, that is exposed to the prevailing weather, and 5 on another location on an inward facing girder surface, that is sheltered from the sun and rain washing. One coupon 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. Five additional coupons of hot-dip galvanized steel could be added where it is desirable to determine corrosivity of the local microclimate, as loss of zinc thickness is easily measured for comparison with loss rates given in AS/NZS 2312.2[1].

The required levels of quality documentation are given in AS/NZS 5131[3]. Coatings for steel in corrosivity categories C1 and C2 need to comply with the requirements for coating quality level PC1. In more severe environments, the more stringent requirements of level PC2 should be met with additional requirements where steel (eg for architectural features) is designated as "architecturally exposed structural steel".

The inspection requirements for level PC2 paint coatings are given in NZTA S9 part 1 *Specification for coating steel highway structures with inorganic or organic coatings*[5]. This was based on sections 13.9 and 13.10 of AS/NZS 5131[3] for paint coatings and galvanized coatings respectively.

10.0 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.

10.1 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*[49] while the design of stainless steel from cold formed sections should be to AS/NZS 4673 *Cold-formed stainless steel structures*[50] and welding to AS/NZS 1554.6 *Structural steel welding* part 6 Welding stainless steels for structural purposes[51].

Figure 10.1: Wellington Harbour Culvert stainless steel reinforcement cage

10.2 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.

10.2 continued

KiwiRail has built around 15 replacement bridges in weathering steel since 2012. The Transport Agency has built around 10 weathering steel bridges to date (see figures 10.2 and 10.3). Design and detailing requirements are given in section 4.3.6(b) of the *Bridge manual*(16), as well as HERA Report R4-97 *New Zealand weathering steel guide for bridges*(52).

Furthermore, the selection of suitable locations and environments for using weathering steel, whether conventional or nickel added coastal weathering steel grades (that can be used in C4 and C5-M environments), as well as guidance on surface preparation, welding, inspection and other matters is given in HERA Report R4-97.

Removal of graffiti from weathering steel is more difficult than from concrete or painted steel, due to likely damage to the protective patina resulting in a change to the surface appearance. Trials carried out for Network Rail in the UK (*Weathering steel graffiti removal trials*(53)) found that the most suitable cleaning method was use of an alkaline poultice (eg Peel Away®) to dissolve the paint followed by steam cleaning. After rinsing, this resulted in only relatively minor residual 'shadowing' remaining on the surface.

Figure 10.2: SH6 Kawarau Falls Bridge during launching in 2017

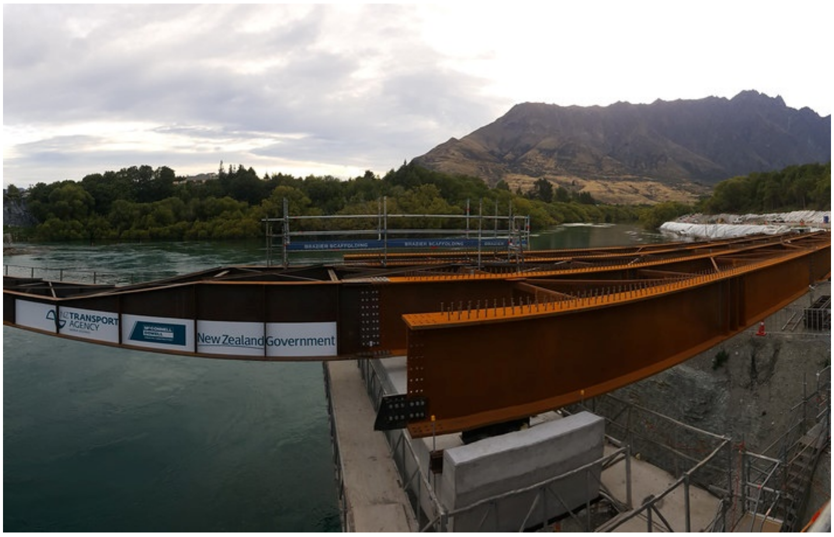


Figure 10.3: SH1 Mercer Bridge after four years weathering in 2010

10.3 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[54] or AS/NZS 1664.2 *Aluminium structures* part 2 Allowable stress design[55] and welded using AS/NZS 1665 *Welding of aluminium structures*[56] 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.

10.4 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 10.4. 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.

Figure 10.4: Example of a galvanized bridge

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.

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.

10.4 continued

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*(57) 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*(58) and AS/NZS 4792 *Hot-dip galvanized (zinc) coatings on ferrous hollow sections, applied by a continuous or specialized process*(59) 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.

Where galvanizing is in contact with damp cementitious material, such as under crash barrier base plates or bearing plates, it should first be coated with a non-conductive epoxy as detailed in figure 12.1 of HERA Report R4-133(4), and as specified in NZTA S9 part 2 *Specification for galvanizing steel highway structures*(5), to prevent crevice corrosion and rust staining as shown in figure 10.6.

Figure 10.5: Inline galvanized purlin section used as handrail in marine environment

Figure 10.6: Unpainted galvanized base plate of handrail on coastal bridge

10.4 continued

Also, flowable grout should be used rather than dry pack mortar under baseplates to minimise the risk of trapping moisture. Slotted holes in baseplates should be plugged or filled with flowable grout for the same reason. This includes site drilled holes in base or bearing plates, to provide protection to the exposed steelwork. Figures 10.7 and 10.8 illustrate what can happen.

Figure 10.7: Staining under unpainted baseplate over dry pack mortar after 9 months in rural environment

Figure 10.8: Example of the condition of the underside of the baseplate

11.0 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 (redesignated AS 2312.1 by amendment 1:2017)
  Part 2:2014 Hot dip galvanizing
  Part 3 Thermally sprayed metallic coatings (In prep.)

(2) Standards New Zealand SNZ TS 3404:2018 *Durability requirements for steel structures and components*.

(3) Standards Australia and Standards New Zealand jointly AS/NZS 5131:2016 *Structural steelwork – Fabrication and erection*.

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

(5) NZ Transport Agency (2020) NZTA S9 *Specifications for coating steel highway structures*. Wellington. In prep.
  Part 1: Specification for coating steel highway structures with inorganic or organic coatings
  Part 2: Specification for galvanizing steel highway structures
  Part 3: Specification for coating steel highway structures with thermal metal spray.

(6) NZ Transport Agency (2020) NZTA S10 *Anti-graffiti coatings specification*. Wellington. In prep.

(7) Parliamentary Counsel Office (1992) Building Regulations 1992. Schedule 1 *The building code*. Wellington.

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(15) 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.

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

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

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(20) 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.

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

(22) American Architectural Manufacturers Association (2020) AAMA 2605 *Voluntary specification, performance requirements and test procedures for superior performing organic coatings on aluminum extrusions and panels*. Schaumberg, IL, USA.

(23) Austroads (2020) Technical Specification ATS 5820-20 *Anti-graffiti coatings*. Sydney, NSW, Australia.

(24) Standards Australia AS 2700-2011 *Colour standards for general purposes*.

(25) Standards Australia AS 4848.1:2019 *Application specifications for coating systems – Single coat inorganic (ethyl) zinc silicate – Solvent-borne*.

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

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(47) International Organization for Standardization ISO 9227:2017 *Corrosion tests in artificial atmospheres – Salt spray tests*.

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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 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[4], while table 6.3 of AS 2312.1[1] and table 7.1 of AS/NZS 2312.2 provide guidance on the different coating systems, with table D1 of AS 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[15].

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[A 1] • 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 2063-1[A 2]
	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[A 3]
	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[A 4]
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[A 5]
	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 5000 to 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 (R2013) *Paints for steel structures*. Part 15 Inorganic zinc silicate paint.

(A2) International Organization for Standardization ISO 2063-1:2019 *Thermal spraying – Zinc, aluminium and their alloys*. Part 1 Design considerations and quality requirements for corrosion protection systems.
(Identical to BS EN ISO 2063-1:2019)

(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 (R2013) *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 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[8]

- 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 for dry abrasive blasting. Caution is advised when substituting either standard.

Wet abrasive blast (WAB) cleaning methods may be preferred when cleaning steel that is contaminated by water soluble salts (eg chlorides, sulphates and nitrates). Vapour blasting is a recently developed technique that minimises the amount of water required. NACE-SSPC have a suite of surface preparation standards that can be referenced, eg NACE WAB-2/SSPC-SP 10 (WAB) *Near-white metal wet abrasive blast cleaning*[B3].

Sweep blasting is used to prepare galvanizing for painting and may also be used to remove adherent surface salts from aged inorganic zinc silicate or thermal sprayed metal systems or provide a key to aged epoxy or polyurethane by removing chalk and/or residual gloss to achieve a fine matte finish before recoating. The procedure for sweep blasting is specified in clause 7.5.3.2 of AS/NZS 2312.2[1] and care should be taken to minimise the removal of any sound residual protective coating

B1.2 Power tool cleaning to AS 1627.2[B4] and SSPC-SP11[29]

- 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[29], 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").

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 standard below:
   - 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 (R2017) *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) NACE International and The Society for Protective Coatings jointly (2015) NACE WAB-2/SSPC-SP 10 (WAB) *Near-white metal wet abrasive blast cleaning*. Houston, TX, USA.

(B4) Standards Australia AS 1627.2-2002 (R2017) *Metal finishing – Preparation and pretreatment of surfaces*. Part 2 Power tool cleaning.

(B5) The Society for Protective Coatings and NACE International jointly (2017) 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 (2017) 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 (2017) 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.

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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 2020

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

ii. System ALK6 with patch painting:

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

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Appendix D NZ coating industry checklist

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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.*	As defined in SNZ TS 3404:2018	
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 of SNZ TS 3404:2018	
1f	Time to First Maintenance: *Specify the expected time to first maintenance.*	Clause 1.7 of SNZ TS 3404:2018	
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 2312.1:2014; and Section 9 of AS/NZS 5131:2016.	
2b	Post fabrication: *Clean to ensure all contaminants, weld splatter, etc, are removed.*	Clause 4.1 of AS 2312.1:2014; and Section 9 of AS/NZS 5131:2016.	
2c	Consider w hether there is sufficient lead time for w ork commencement and repairs.	Designer	
3	**Coating System:** *State coating thickness(es) including dry film thickness (DFT).*	Section 10 of AS 2312.1. or Clause 2.3 of SNZ TS 3404:2018; and Section 9 of AS/NZS 5131:2016. 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 OSHA 18001	
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 2312.1 or AS/NZS 4680:2006; and Section 13 of AS/NZS 5131:2016.	
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.*	Clause 9.4 of AS 2312.1:2014	
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	
7	**Architecturally Exposed Structural Steel**: Define the required category level and associated specification, fabrication and erection requirements.	Section 10 of AS/NZS 5131:2016.	

Version: 3.3
Published: August 2020

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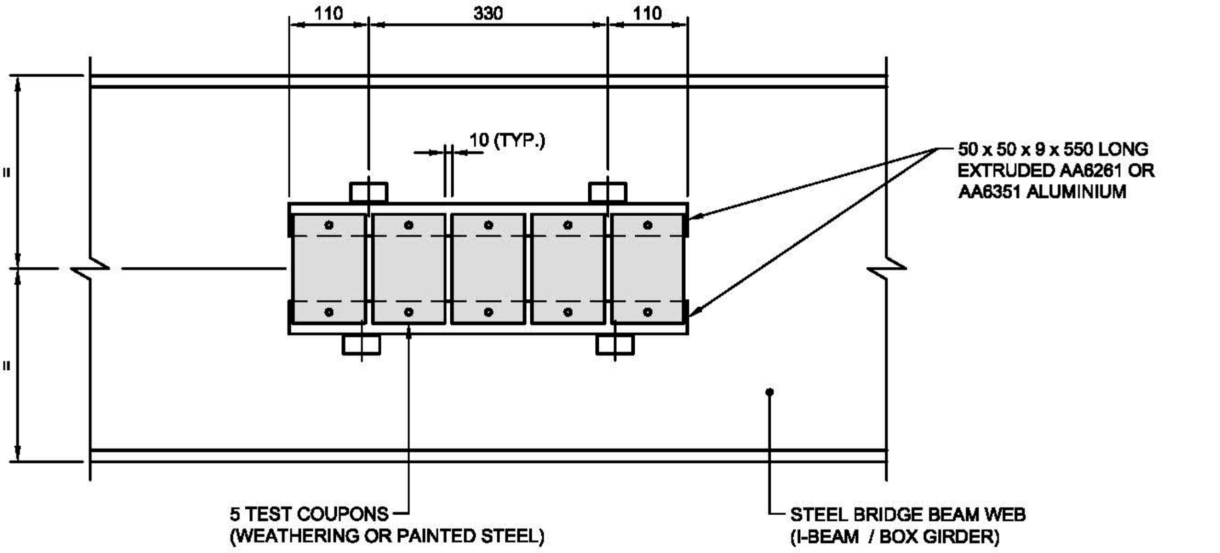
Appendix E Test Coupon Drawings



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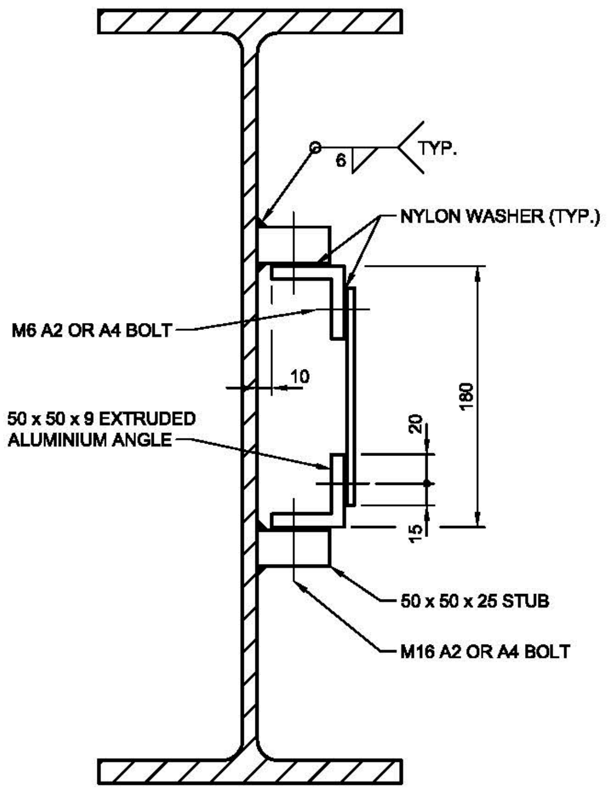
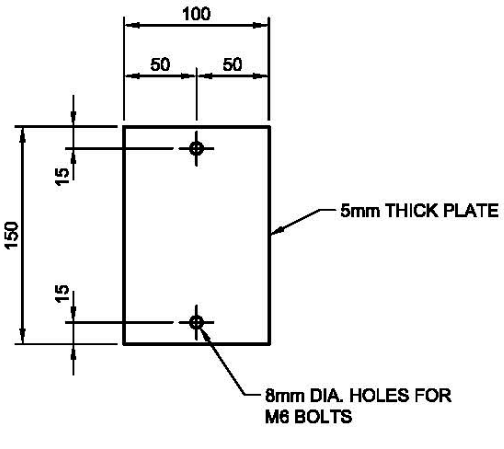


TYPICAL SECTION



TEST COUPON