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Managing the Technical Risk with Uncoated Weathering Steel Bridges

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Abstract

Weathering or weather resistant steel has been used on overseas bridges since the mid-twentieth century. There are only a limited number of weathering steel (WS) bridges in Australia and most of them are of a relatively new construction. It is envisaged that use of WS in Australian bridges will increase significantly in future due to its inherent characteristic of the formation of a protective patina on the atmospherically exposed surfaces in a suitable environment, enabling it to be used uncoated and, thus, avoiding the need for protective painting, consequently supporting sustainability and reducing maintenance costs. Due to a greater impetus on sustainability globally, WS is emerging as the preferred material for future steel bridges. However, as with any other material, WS also has limitations and unless these are considered in the early stage of project development, the material performance may be undermined due to non-formation of the protective patina, resulting in the need for protective paint application to mitigate the risk of corrosion. Failure of the protective patina formation has led to the underperformance of several WS bridges overseas and, at least in one instance, a complete collapse of the bridge has been reported. This could have been prevented by monitoring of patina formation and if need be, application of protective coating.

This paper describes the evolution of weathering steel, its corrosive behaviour, provisions in the design standards for corrosion allowance, the technical risk associated with its use and the management of technical risk by taking necessary mitigating actions. It is envisaged that the paper will provide guidance to the engineers, specifiers, designers and asset owners in developing a proper understanding of behaviour of this material enabling them to use it judiciously and successfully, thus managing the associated technical risk.

Keywords: bridge, weathering steel, patina, sustainability, technical risk.

1. Introduction

Managing technical risk with uncoated weathering steel (UWS) bridges requires a thorough understanding of the technical risk associated with the material's corrosive behaviour and adopting appropriate measures to manage it.

Weather resistant (WR) steel, commonly known as weathering steel (WS), has been in use for construction of bridges for more than half a century, albeit predominantly overseas. Although its uncoated use has been mostly successful due to formation of protective patina, failure of patina formation has been reported on several overseas bridges (NCHRPR[1], 1984 and KTCRR[2], 2016), leading to a significant maintenance burden and importing considerable technical risk, thus compromising the very purpose of its use. The following sections of the paper describe the evolution of WS, its corrosive behaviour, provisions in the design standards for corrosion allowance, the technical risk associated with its use and management of technical risk by taking necessary mitigating actions.

2. **Weathering Steel**

Evolution

Weathering steel is a low alloy steel that has evolved from copper-bearing steel (Fletcher[3] 2005, Murata[4] 2011). The widely known 'COR-TEN', the first generation of WS, was developed by 'United States Steel' in 1933 containing higher levels of copper (Cu), silicon (Si) and phosphorus (P) compared to carbon steel (CS). This composition was later modified to include chromium (Cr) and nickel (Ni). These five elements (Cu, Si, P, Cr and Ni) are reported as the key elements for enhanced corrosion resistance of WS (NCHRPR[1] 1984, KTCRR[2] 2016, Fletcher[3] 2005, Murata[4] 2011, Townsend[5] 2001, Townsend[6] 2002, Copson and Larrabee[7] 1959, Morcillo et al[8] 2013, Morcillo et al[9] 2019, Damgaard et al[10] 2010, Shastry et al[11] 1988, Tripathi and Fatemi[12] 2024). When COR-TEN was produced, although its strength of 345 MPa was considered high, modern WS used in bridge construction today commonly exhibits strengths up to 450 MPa. Weathering steel has been in use in Japan since the 1960s. Nippon Steel Corporation developed a version of the WS with higher percentage of nickel, up to 3%, for use in coastal areas (NSTR[13], 2003).

A review of the published literature indicates that the first Australian version of WS was produced by BlueScope Steel Ltd (formerly Broken Hills Proprietary or BHP Steel) in the late 1960's (TB-26[14], 2004). A fifteen-year study on the performance of UWS was initiated by the BHP Steel in 1968 (Mandeno et al[15], 2024, Badger and Wallace[16], 1988) to determine the suitability of its product in different exposure environments. The current version of BlueScope WS, REDCOR, is a modified version of Aus-Ten 50 of the 1960's and 70's (TB-26[14], 2004). An example of Aus-Ten 50's use is the 6.8 m diameter central column of Sydney Centre Point Tower which consists of 56 universal columns rolled from this material (Technology in Australia 1788-1988[17], 2000).

The addition of the alloying elements, primarily copper, chromium, nickel, silicon and phosphorous, leads to formation of a dense and tightly adherent layer of corrosion products on an uncoated surface. This layer, known as the 'protective patina' or simply 'patina', retards further corrosion of the metal. This enables WS to be used uncoated, eliminating the need for protective paint and thus supporting sustainability. Further details on the evolution of WS has been published by Fletcher[3] (2005), Murata[4] (2011), Tripathi and Fatemi[12] (2024).

Corrosion Behaviour

Although the atmospheric corrosion of WS and CS is essentially electrochemical in nature, the corrosion behaviour of WS under suitable atmospheric exposure is something that differentiates it from CS. The corrosion behaviours of both materials are similar when immersed in water or buried under soil or embedded in concrete (TB-26[14], 2004).

Under atmospheric exposure, bare CS corrodes. The resulting corrosion product, being porous and loosely adherent to the substrate, is ineffective in protecting the corrosion front from oxygen and moisture. As a result, corrosion of the material continues until fully consumed. Therefore, CS structures require some form of protection to achieve the designed durability.

In contrast, when uncoated WS corrodes under suitable atmospheric exposure, the corrosion product has at least two distinct layers. The one on the top is relatively porous, similar to CS, but the underlying layer is denser and tightly adherent, consisting primarily of nanophase goethite [α- FeO(OH)], preventing moisture and oxygen penetrating the corrosion front and thus protecting the substrate from further corrosion (Fletcher[3] 2005, Morcillo et al[9] 2019, Tripathi and Fatemi[12] 2024). This dense and tightly adherent inner layer of corrosion product is the protective patina. Although some other metals also form protective patina e.g. copper, the patina formed on WS has its unique colour, texture and elemental characteristics. Figures 1 and 2 show the copper and WS patinas, respectively, with different colour and texture.

Fig. 1. Copper patina on the roof of the Minneapolis City Hall.

(CDA/CCBDA[18], 2025)

Fig. 2. Weathering Steel patina on Berry to Bomaderry Bridge in NSW.

This patina on WS forms only in the instance of a suitable exposure environment and, if that is not present, the patina formation may not occur. Failure of patina formation on several overseas bridges has been reported in several reports (NCHRPR[1] 1984, KTCRR[2] 2016) and will be discussed in detail in the following sections of this paper.

The product standard for CS and WS (AS/NZS 3678[19], 2016), includes five key elements in the chemical composition and specifies higher amounts of Cu, Cr, Ni, Si and P (for plate thicknesses less than 20 mm) for WS compared to CS. However, when the chemical compositions of the two materials are examined using actual material certificates, it is evident that the actual amounts of the first four elements are very high in WS compared to CS. The amount of phosphorous specified in the product standard for WS is much less for plate thicknesses greater than 20 mm. The actual amount of phosphorous found in the material certificates for the two materials is even lower, as excessive phosphorous, despite enhancing the corrosion resistance, negatively impacts toughness and welding properties. A detailed discussion on the effect of alloying elements on the corrosion behaviour of WS is presented by Copson and Larrabee[7] (1959), Townsend[5] (2001) and Tripathi and Fatemi[12] (2024).

The volume of alloying elements in WS is much less compared to other types of steel with very high percentages of the alloying elements e.g. stainless steel wherein for grade 316, the amount of Cr and Ni is typically in excess of 17 and 10 percent, respectively (Outokumpu[20], 2013). For this reason, it is known as low alloy steel.

Corrosion Allowance

When WS is used uncoated and a protective patina is formed on atmospherically exposed surfaces, the thickness of the material slightly reduces due to this patina formation, typically a few microns in the first few years of patina formation to a few hundred microns after several decades. To account for this, standards and codes of practices include provisions for corrosion allowance of WS. Various national standards specify different corrosion allowances based on the observed material behaviour of the particular WS produced in that nation with specific chemical composition.

The Australian Standard for steel and composite bridge design, AS/NZS 5100.6[21] (2017), contains design provisions for WS including corrosion allowances. It permits WS use in corrosivity categories C1, C2 and C3 with specified corrosion allowances for each of the atmospherically exposed surfaces of 1, 1, and 1.5 mm, respectively, for a design life of 100 years. The corrosivity categories are described in AS/NZS 4312[22] (2019) and ISO 9223[23] (2012). The specified corrosion allowance in the design standard for interior surfaces of box sections is 0.5 mm. Comparisons with some of the overseas standards (European design guide[24] 2021, Tripathi and Fatemi[12] 2024), indicate the Australian design corrosion allowance values are significantly higher.

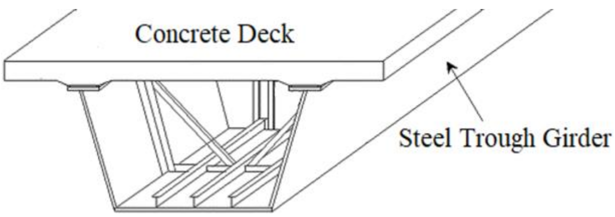
While this conservative approach enhances structural safety, it may not lead to the optimum use of WS or accurately reflect the behaviour of Australian WS, REDCOR. Tripathi and Fatemi[12] (2024) indicated that it is not clear if the provision in the bridge design Standard (AS/NZS 5100.6[21], 2017) for corrosion loss of 0.5 mm for internal surfaces of box sections is applicable to fully welded and completely closed (sealed by welding) box sections or the same section with an access hatch in the bottom flange with an airtight cover or a WS trough section with a composite concrete deck on the top (Figure 3). The WS trough section with a composite concrete deck is likely to have a higher risk of corrosion due to the potential for water ingress in the long term should the concrete deck develop cracks. Using the same corrosion allowance for all the above exposure conditions for the internal surfaces does not appear to be a rational approach and the users of the Standard may need further guidance to deal with different situations within a box or a trough section (Tripathi and Fatemi[12], 2024).

The bridge design standard AS/NZS 5100.6[21] (2017) advises that caution should be exercised in using WS in corrosivity category C3 with high levels of chlorides, sulfur dioxide and any other type of contaminants but there is no guidance in the standard on the limiting values of the contaminants. This can result in different Australian transport agencies using diverse approaches for the use of same product, REDCOR, nationally. The standard also advises that the durability of protective coatings is the same irrespective of the substrate being CS or WS, which is contrary to some of the published literature on this aspect (Murata[4] 2011, Krivy[25] 2011, TB-26[14] 2004). Therefore, it appears that there is a need for improvement and update in the bridge design standard.

The HERA design guide[26] (2014) has similar provisions to AS/NZS 5100.6[21] (2017), however, some notes are provided for further clarification, including for internal surfaces of box and tub (trough) sections.

Extensive work has been done overseas on estimating corrosion loss in different environments (Krivy 2011[25], Wilson and Raff[27], 2012). A detailed discussion on the specified corrosion losses in different standards is published by Krivy[25] (2011), Krivy[28] et al (2015), The European design guide[24] (2021) and Tripathi and Fatemi[12] (2024).

Fig. 3. Trough girder with concrete deck.



(Ryu and Chang[29], 2005)

Fig. 4. Non-formation of patina.

(Krivy et al[28], 2015)

3. **The Technical Risk**

As previously mentioned, there have been reported cases of non-formation of protective patina and continued corrosion of some of the UWS bridges overseas (Fig. 4) The first UWS bridges were commissioned in the mid-1960s in the United States (US). An inspection in 1982 of 49 UWS bridges in the US indicated that 30% were in overall good condition, 58% had moderate corrosion and 12% had heavy corrosion in some areas (NCHRPR[1], 1984). This led to a moratorium on the use of UWS in the US, significantly reducing the number of UWS bridges constructed between the mid-1980s and 1993, to only 300 in comparison to the 2000 UWS bridges constructed before the mid-1980s. A Federally commissioned task force investigated this issue and produced a technical guidance note, FHWA T5140.22 (FHWA[30], 1989) which helped restore confidence in UWS. By 2016, there were reportedly 10,000 UWS bridges in the US (KTCRR[2], 2016).

Similarly, the Kentucky Transportation Centre (KTC) inspected 21 UWS bridges throughout Kentucky during 2003 and 2015 and found that six bridges (28%) had progressive corrosion or poorly formed patina, mainly due to microclimatic effects such as water ponding and debris buildup. Additionally, eight bridges in Ohio and one in Louisiana had to be treated through remedial painting in 1983. Many others in Alaska, California, Iowa, and Michigan were recommended for painting (KTCRR[2], 2016).

In 1979, the West German Department of Transport (DoT) effectively banned the use of UWS for bridges on the federal system due to performance concerns (NCHRPR[1], 1984).

On January 28th, 2022, an UWS bridge over Fern Hollow in Pittsburgh, Pennsylvania, collapsed due to structural failure resulting from progressive corrosion of the WS elements (Fig. 5 and 6). This progressive corrosion of WS occurred due to the non-formation of the protective patina, which was caused by prolonged wetness due to accumulated debris (NTSB[31], 2023). No fatalities were reported.

Fig. 5. Collapsed Fern Hollow Bridge.

(NTSB[31], 2023)

Fig. 6. Corroded elements of Fern Hollow Bridge.

(NTSB[31], 2023)

As previously detailed, UWS develops a protective patina only when subjected to suitable atmospheric conditions. For example, in urban or coastal environments with low atmospheric pollutants (e.g. sulphur and chlorides), the development of a protective patina is highly likely. However, even under suitable atmospheric conditions, poor detailing or construction can result in water ponding or debris collection on WS surfaces, preventing patina formation. If inadequate deck drainage leads to persistent wetting of the adjoining surfaces, the patina is unlikely to form. Additionally, vegetation growth that keeps the WS surfaces wet for prolonged periods my act to hinder patina formation.

From the discussion above, it is evident that the key technical risk in using UWS is the non-formation of the protective patina. This can occur due to various reasons and if not managed, may lead to progressive corrosion, compromising structural integrity and public safety.

4. Managing the Technical Risk

The primary objective of using UWS is to eliminate the need for protective treatment, as UWS elements are intended to self-protect through patina formation. However, since the risk of non-formation is now understood, effective risk management is necessary.

The following section considers strategies for managing technical risk associated with UWS elements across a bridge's lifecycle, based on existing literature, international standards, and industry best practices. This is not an endorsed approach from TfNSW but rather a consolidation of recommendations from the referenced sources.

Design

During the design phase, an initial assessment of the service environment should determine if UWS is a feasible option. Studies indicate that patina formation on UWS is likely to be hindered if the time of wetness is more than 60% (FHWA[30] 1989, Wilson and Raff[27] 2012). The time of wetness is defined as the duration when humidity exceeds 80% (ISO 9223[23], 2012). If the environment is classified as C4 or C5 (AS 4312[22] 2019, ISO 9223[23] 2012), the use of UWS is precluded as per the Australian and New Zealand bridge design standard 5100.6[21] (2017) and the HERA design guide[26] (2014). If WS must be used in these corrosivity categories, an appropriate type of protective treatment is recommended.

For environments classified as C1 to C3 (AS 4312[22] 2019, ISO[23] 9223 2012), UWS can be used in accordance with AS/NZS 5100.6[19], 2017. However, for C3 environments, additional caution is recommended when atmospheric contaminants such as chloride and sulphur levels are high.

Although no specific contaminant thresholds are provided in AS/NZS 5100.6[21] (2017), contaminant levels could be measured and compared against values in overseas standards and published literature, such as the European Design Guide[24] (2021). Additionally, material suppliers (e.g. BlueScope for

REDCOR in Australia) could provide written confirmation regarding the suitability of UWS in the proposed service environment. Tunnel-like conditions should be avoided for UWS applications, FHWA[30] (1989).

To validate UWS performance, an adequate number of UWS samples could be placed at the proposed bridge site early in the project as per ISO 8565[32] (2011) with two or three collected after the first year and the initial corrosion rate calculated using weight loss measurements as per ISO 8407[33] (2021). Based on this data, long-term corrosion predictions could be made using ASTM G101-04[34] (2020).

This standard provides two methods for predicting long-term corrosion loss. The first method predicts long term corrosion based on short term corrosion loss using the following equation:

$$\mathrm{C} = \mathrm{A}\mathrm{T}^{\mathrm{B}} \qquad 1$$

Where C is corrosion loss in microns, T is time in years, and A and B are constants. In the above equation, A represents the corrosion loss at T=1 year and B is the slope of log C vs log T plot. This method could be used to validate that the predicted corrosion does not exceed the corrosion allowance specified in the design. This exercise does not necessarily need to be completed before construction commences. However, if feasible, it can provide benefits, particularly if the predicted corrosion exceeds the adopted corrosion allowance, in which case remedial measures, such as protective treatment, can be implemented.

The second method is based on the chemical composition of WS and uses a corrosion resistance index (CRI) or simply corrosion index (CI), to assess WS suitability. The CI equation in ASTM[34] (2020) is a modified version of the ‘Legault-Leckie’ corrosion index equation (Townsend 2002[6], Legault and Leckie[35] 1974) which is derived from statistical analysis of field exposure data collected by Larrabee and Coburn[36] (1962) for 270 samples for 15.5 years (Krivy et al[28], 2015). The modified CI in ASTM[34] (2020) is:

$$\mathrm{CI} = 26.01\mathrm{Cu} + 3.88\mathrm{Ni} + 1.2\mathrm{Cr} + 1.49\mathrm{Si} + 17.28\mathrm{P} - 7.29\mathrm{Cu} \times \mathrm{Ni} - 9.1\mathrm{Ni} \times \mathrm{P} - 33.39\mathrm{Cu}^2 \qquad 2$$

Townsend[5] (2001) presented equations for predicting corrosion loss based on the exposure of 750 samples over 16 years, which allows for CI calculation. This method incorporates the effects of additional elements on WS corrosion resistance, including sulfur, carbon, manganese, arsenic, molybdenum, tin, vanadium, tungsten, aluminium and cobalt. Although this approach is more exhaustive than the ‘Legault-Leckie’ method (Equation 2), it provides a more comprehensive analysis. The ASTM website[37] (2025) offers CI calculators based on the methods of Legault and Leckie[35] (1974) and Townsend[5] (2001).

The corrosion rate could be determined at planned intervals using weight loss measurements from the remaining samples left on site. It is recommended that this assessment continues even after bridge construction for a total period of 10-15 years to validate that the long-term corrosion rate, based on actual field observations, aligns with the designed corrosion loss. Samples can also be visually examined for the patina colour, texture and tested for the patina chemistry to confirm that the elemental phases and percentages meet expectations. Guidance for visual examination and patina testing is available in published literature (European Design Guide[24] 2021, Krivy et al[38], 2017, Shuichi Hara et al[39] 2006). Additionally, where chloride contamination is expected to be higher, it is recommended that its measurement be carried out using an industry-accepted method (Krivy et al[38], 2017).

As part of good design practice, elements can be detailed to support patina formation (European design guide[24], 2021). For example, a welded box or trough girder with external flat surfaces prevents debris and water accumulation on the webs and flanges, whereas an I-section does not, as it allows for accumulation at the top of the bottom flange, particularly if stiffeners are welded to it.

Similarly, a jointless bridge (FHWA[30] 1989, Wilson and Raff[27] 2012) or one with joints only at the ends of a bridge – equipped with an underside trough to collect water - minimises the risk of prolonged wetness on exposed surfaces.

Welded joints in the UWS bridge elements are recommended as they avoid crevice formation. Welding consumables with the same or superior chemical composition as the parent metal ensures uniform corrosion resistance and colour on the exposed uncoated surfaces. If consumables matching the parent metal's composition are unavailable, those with higher nickel content could be used ensuring that all passes in a multi-pass weld contain a chemistry conducive to patina formation (TS01744[40], 2024).

Where bolted joints are necessary, WS bolts with an equal or superior chemical composition are recommended with appropriate protective treatments for all contact surfaces in the bolted joints. It is recommended that all crevices formed by these joints are caulked using appropriate sealant that is maintained throughout the life of the bridge. The sealant should be applied in a way that, in case of premature failure, water does not accumulate within the crevice but instead drains out. This can be achieved by omitting sealant at the lowest point of the crevice. If the bolted joint requires a friction type connection, a protective coating that provides the required friction is recommended rather than bare contact surfaces, even if abrasive blast cleaned for friction.

All surfaces expected to be in contact with concrete, water or buried, are recommended to have an appropriate protective treatment specified. The protective treatment requirements of WS are the same as for CS, including surface preparation requirements and paint coating systems. (TS01746[41], 2024). It is recommended that the protective treatment extends beyond the edge of the contact area and over the atmospherically exposed surface by at least 20 mm, ensuring visibility and maintainability. For example, if a concrete deck rests on the top flange of an I-section, it is recommended that the entire top flange receives protective treatment, extending to cover the top flange thickness. The crevice formed between the two surfaces is recommended to be caulked (TS01746[41], 2024). However, when the joints are specified to be caulked, water ingress through the concrete deck should be avoided, as trapped moisture can cause greater damage in a caulked joint due to the absence of water egress.

Construction

This phase includes material procurement, fabrication (including welding), surface preparation, transportation to the site and installation. In all of these activities, it is recommended to exercise care to minimise the technical risk.

Once the appropriate type of WS is selected and specified during the design stage, it is advisable to ensure that the specified WS is procured and used in fabrication. To support this, material certificates and all relevant procurement requirements in the technical specification for steel work fabrication, such as manufacturer certification and material traceability, can be reviewed and validated by competent personnel. During fabrication, it is beneficial to take precautions to avoid hindering patina formation, following the material manufacturer's guidelines and the project's technical specification. The use of the correct consumables during welding is also important to achieve a matching colour on the welds with the parent metal, as well as to maintain the same corrosion rate for both the welds and the parent metal.

Post fabrication, it is suggested that atmospherically exposed surfaces undergo abrasive blast cleaning to the grade of cleanliness specified in the project or agency-specific specification. Wetting and drying cycles, as outlined in the specifications, can help expedite patina formation (European Design Guide[24] 2021). Areas with potential hydrocarbon contamination may benefit from cleaning with an appropriate solution, followed by washing, as dry abrasive blast cleaning alone may not be sufficient. For surfaces near coastal areas, washing with high-pressure water can help mitigate chloride contamination. It is recommended that water used for cleaning and wetting the surface is free from any contamination.

Before transporting to the site, abrasive blast cleaning to Sa 2½ class of finish (TS01744[40] 2024, TS01746[37] 2024) to AS 1627.4[42] (2005) is generally recommended, although some specifications may require only Sa 2 class of finish. It is recommended that surfaces be washed with potable water prior to transport and rewashed after arrival on site if there is any potential for chloride contamination during transport, (e.g. a long stretch of travel along the coastline). During handling, protecting the surface from scratches and damage is recommended to avoid delays in patina formation. Good ventilation and minimising contact points during site storage can further support patina development. It is also helpful to keep surfaces free from contaminants like oil and chalk marks that might interfere with patina formation (TB-26[14], 2004). During and post installation, preventing surface damage and promptly cleaning any splashes can help maintain surface integrity.

Operation

Once the UWS bridge is commissioned and becomes operational, actions that facilitate patina growth are recommended. Ensuring that joints do not leak onto exposed UWS surfaces is particularly important as water ingress has been found to be the most common reason for patina formation failure (KTCRR[2], 2016, European design guide[24] 2021). If there is any potential for leaks or water splashing onto the WS surface, painting beyond the area of impact may enhance long-term performance.

Visual inspections of the patina are suggested as part of planned inspection activities for UWS bridges. Training bridge inspectors to differentiate between a protective patina and a patina that is unlikely to be protective or requires further investigation can enhance the inspection process. Since visual examination of the patina is not always reliable, it can be helpful to supplement them with analytical techniques such as Scanning Electron Microscopy (SEM), Energy Dispersive Spectra (EDS), or X-Ray Diffraction (XRD) to identify the different phases, percentages and distribution.

The visual appearance of patina can vary significantly, displaying different colours and textures depending on the environment and duration of exposure (European Design Guide[24] 2021). Colour, in particular, can be deceptive under different lighting conditions. Figure 7 below shows actual samples of WS plates, placed in environments with different corrosivities, aged between 13-18 months.

Fig. 7 – UWS plates in different environments after 13-18 months.

Maintenance

Maintenance specific activities to minimise the technical risk during this phase include regular cleaning and washing as per the maintenance regime to prevent debris build up. In general, the presence of de-icing salt is not a predominant issue in Australia. However, areas with high atmospheric pollutants may require more frequent washing, particularly in the presence of chloride, such as bridges located near the coastline. Managing vegetation growth around the structure and addressing leaks or dampness sources such as downpipes, drainage troughs and joints can further protect the UWS surfaces (FHWA[30], 1989).

If inspections reveal potential patina formation issues such as coarse, flaky, or delaminating corrosion products then investigating and addressing root causes is recommended. For example, levelling surfaces or adding drainage holes could help prevent unintended water accumulation prior to application of protective coating.

Monitoring steel corrosion rates through ultrasonic thickness measurements at specific locations can inform maintenance decisions. If it is established that the patina is not forming and the actual corrosion rate exceeds the designed corrosion rate, appropriate remedial measures should be adopted. Locally affected areas can be painted similar to carbon steel. Tests on paints have demonstrated that those suitable for carbon steel are also suitable for weathering steel (KTCRR[2], 2016). It has been observed that a zinc rich epoxy primer followed by epoxy and polyurethane provides effective protection. It is recommended that this coating system be applied to a surface prepared to an Sa 2½ class of finish.

For pitted surfaces that cannot be prepared to this class of finish, epoxy mastic followed by epoxy and polyurethane can be used. It is recommended that pitted areas be washed with high-pressure potable water to remove chloride contamination as dry abrasive blast cleaning or hand, and power tool cleaning do not typically remove chloride effectively.

5. Conclusion

It is now well understood that the formation of an effective protective patina on the surface of a UWS structure is the most critical factor for its successful use. Patina formation is not only influenced by the corrosivity of the service environment but also by activities carried out throughout the design, fabrication, construction, commissioning and in service maintenance phases. Based on the discussion presented in this paper, the following conclusions can be drawn:

- Uncoated weathering steel bridges provide a sustainable solution by eliminating the need for protective treatments.
- Formation of a protective patina is essential to achieve the intended benefits of uncoated weathering steel.
- Patina formation is not only dependent on the service environment but also on various factors e.g. material procurement, fabrication, transportation, installation, operation and maintenance.
- The key technical risk in using UWS is the non-formation of a protective patina. This risk can be managed through appropriate risk management measures applied during design, construction, operation and maintenance of the bridge.

This document presents a summary of best practices from existing standards, research, and international guidelines. It is intended as a reference tool and not as a TfNSW-endorsed methodology. For project-specific decisions, practitioners should refer directly to the relevant standards and seek expert advice where necessary.

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