ABSTRACT

Steel is one of the most sustainable materials on Earth. It is 100% reusable, recyclable, easy to use and maintain. To complement the numerous benefits of steel and extend its life, suitable protective measures must be taken to ensure structural performance is not reduced over its design life. Corrosion protection systems have been used for decades, but recent advancements in coatings; use of weathering steel, and improved durability design guidelines and quality control, can extend the time to first maintenance and improve the sustainability of steel structures.

This paper looks at the various methodologies to improve sustainability by outlining the guidance available for sustainable durability design and provides a brief introduction to those systems.

1. Introduction

Steel is one of the most sustainable materials on Earth. It is 100% reusable, recyclable, easy to use and maintain. To complement the numerous benefits of steel and extend its life, suitable protective measures must be taken to ensure structural performance over its design life. This is especially the case for the wide range of New Zealand corrosion environments.

New Zealand is a long, thin mountainous country lying in the prevailing westerly wind belt of the Southern Hemisphere. Although surrounded by sea, its nearest continental land masses are the world’s hottest continent, Australia, and the world’s coldest, Antarctica. All these conditions give New Zealand a diverse climate and very wide range of corrosion conditions, which if not designed for properly, will prohibit steel from reaching its full sustainability potential.

Structural engineers need to have a basic understanding of the durability issues involved in structural steelwork to enhance the sustainability benefits of steel. The New Zealand Heavy Engineering Research Association (HERA) have addressed this issue by publishing two documents that provide the necessary guidance for engineers to be able to understand and design for those durability issues.

The first is HERA Report R4-133 “New Zealand Steelwork Corrosion Coatings Guide” [1], used in conjunction with the joint Australian/New Zealand Standard AS/NZS 2312 “Guide to the Protection of Structural Steel Against Atmospheric Corrosion by the Use of Protective Coatings” [2]. These provide guidance to allow an appropriate and cost-effective coatings system for structural steelwork to be selected and then specified in a generic manner. They cover the different types of protective coatings available, the calculation of design corrosion rates for any steel surface, interior or exterior, above or below ground, as well as coating inspection and maintenance, among other topics. The calculation method is a world first and necessary if coatings are to be appropriately specified for the specific range of environments to be encountered.
Weathering steel provides an alternative to the use of protective coatings especially for bridges. HERA Report R4-97 “New Zealand Weathering Steel Guide for Bridges” [3] provides the necessary guidance to ensure that dependable performance is realised for applications of weathering steel for New Zealand bridges. It covers the limitations on the use of weathering steel, design issues such as Standards and detailing, construction issues such as bolting, welding and handling, as well as what to look for when inspecting and maintaining a weathering steel bridge.

These publications give improved information to design engineers on different durability issues and their solutions. So by specifying a coated protective system or utilising the benefits of weathering steel a more sustainable solution can be found.

2. Sustainability of Steel

There are a number of articles and papers written about the sustainability of steel, such as “Sustainable Steel Construction” by Corus [4]. This section provides an overview of the sustainability benefits of steel.

2.1 Supply

Iron, the basic raw material, is a plentiful natural resource which can be mined and converted into steel in most countries.

2.2 Recycling and Reuse

An important sustainability strength of steel is its ability to be repeatedly re-used or recycled without any degradation in the quality of the material. Other materials are often recycled only once before downgrading, which means that, they eventually find their way to landfill.

Steel never loses its value and has a sustainable economic life cycle that is unrivalled by most other construction materials. All used steel has a value, whether it is being re-used or recycled. This recycling property was already being utilised before sustainability became an issue. There was never any need to legislate for it to be recycled, as steel has an intrinsic value as a scrap material and is always in demand for the production of new steel.

2.3 Waste Minimisation

Little waste material is generated during the manufacture of steel components, and most of this is recovered and recycled. On construction sites, which can generate large volumes of waste, off-site fabrication ensures that no steel is wasted, as only what is needed ever comes to site. Almost all of the waste generated in the fabrication shop is recovered for re-use or recycling.

2.4 Off site manufacture

Off-site manufacture has always been a key feature of steel construction. All steel construction involves off-site manufacture, which means that steel scores highly on many sustainability criteria.

More accurate workmanship can be achieved with steel being manufactured and fabricated off-site. Waste is minimised and a high quality, defect free product is possible. In the modern fabrication workshop, where state of the art numerically controlled machinery is fully integrated with CAD software, steel can be easily standardised, tested and certified. Corrosion and fire protection coatings can be applied at the fabrication stage, reducing the overall site construction programme.

Local communities benefit from offsite manufacture as there is much less traffic to sites and far smaller on-site workforces adding to local traffic congestion. Other benefits for local people are that steel construction is dry and dust free and relatively quiet. At the end of its working life a steel building is easily taken down without the noise and dust associated with demolishing masonry or concrete structures, and all the steel is recycled.

Off-site manufactured steel leads to more predictable construction programmes. Site managers benefit from just-in-time delivery, being able to hold fabricated steelwork at depots or at the steelwork contractors’ workshop until it is needed, saving space and reducing the possibility of damage from on-site storage. Once delivered to site, pre-engineered steelwork sections are speedily and safely erected. Steelwork is inherently safer, requiring fewer people to install who are generally well trained. The site activities are predictable and well practiced.
3. Achieving Improved Sustainability

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 an applied coating. However, a sustainable design approach is recommended to determine the optimum solution, i.e. one that will achieve the most economic time to first maintenance based on the structure’s performance and aesthetics requirements, design life, and location. The optimally designed structure, 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 onsite debris to be contained and disposed of.

To specify the optimum corrosion protection system the following publications and guidance should be used.


3.1.1 Introduction and scope
This document (“the Guide”) was originally planned to cover the coating selection for steel bridges but this was changed to include guidance for all types of steelwork. Its overall objective is to provide the necessary process to allow an appropriate and cost-effective coatings system for structural steelwork to be selected and then specified in a generic manner.

To achieve this objective, the Guide covers the following:
- the general types of protective coatings available
- an overview of the Standard AS/NZS 2312, covering the key aspects of that Standard and how it is used with the Guide
- design corrosion rates for any steel surface, interior or exterior, above or below ground
- the general steps required to select an appropriate coating system, together with the required details to implement each of these steps
- important factors to consider in regard to a coating’s performance
- guidance on inspection, maintenance and refurbishment of coating systems
- guidance on the protection of steel in commonly encountered non-atmospheric environments

Since its introduction, the Guide has been use extensively by engineers to estimate the corrosion rate and specify a coating system with known present and future costs. This has helped reduce costs and uncertainties associated with specifying the wrong product, and as well as improving engineers’ general knowledge of coating systems, has ensured their proper use and application to achieve a cost effective protection system for their steelwork.

3.1.2 General steps to determining an appropriate coatings system using AS/NZS 2312
The procedure for use of the Guide and the Standard to determine an appropriate coatings system is as follows:

1) Determine the design service life of the element being coated
2) Determine the site-specific corrosivity category, which is derived from the first year steel corrosion rate. This rate is determined from the combination of:
   - macroclimate, plus microclimate
3) Determine the time to first (major) maintenance required for the coatings system
4) Select an appropriate corrosion protection system to meet the environmental requirements of 2 and 3 stated above based on cost, performance and any owner-specified factors such as colour and appearance.

The design service life for structures is readily determined from [7], being typically 50 years for buildings from the NZ Building Code [7] and 100 years for bridges from Transit New Zealand Bridge Manual [8]. Note that the design life of the structure is not usually the same as its durability rating- i.e. the years to first major maintenance. This point is made in AS/NZS 2312 Clause 1.6, where it is noted that the protection offered by the coatings systems is usually shorter than the design service life of the structure, which means due consideration must be given to its maintenance or renewal requirements at the planning and design stage. It is only when components of the structure are not accessible for maintenance after assembly that the corrosion protection system must remain effective for the design service life of the structure. This important distinction is not always recognised by designers and specifiers.
- The process of selecting an appropriate coatings system is always site-specific, and will typically be surface specific where microclimate effects are important and different surfaces have different exposures.
3.1.3 Determining the first year corrosion rate

- Macroclimate

An important part of the Guide are the maps of first year carbon steel corrosion rate in New Zealand. These maps are based on equations developed by Hyland and Enzensberger [5], using BRANZ corrosion data published by Duncan and Cordner [6], and climate data from the National Institute of Water and Atmospheric Research Ltd. The equations were determined as a function of the following variables which are needed to determine the macroclimate:

- distance from seacoast (0.5, 5, ≥ 20 km)
- average annual daily temperature
- 9 am time of wetness (RH ≥ 80 %)
- annual rainfall
- upper bound results used

These equations were used to produce the macroclimate corrosion rate maps which greatly simplified the process of determining the atmospheric corrosivity category, as seen in Figure 1, which provides the North Island first year corrosion rates. The corrosion maps have recently been updated and simplified. They will be included in the revised version of NZS3404 Part 1 [9] and the updated version of the Guide, with both documents aimed to be published by the middle of 2009.

- Microclimate

The other factor that is needed to determine the corrosion rate are the microclimate effects on the steel surface. These depend on whether the steel surface is shaded, in a wet location, and whether the steel is in contact with timber or concrete. The most significant microclimate effect is if the steel surface is sheltered from rain washing but exposed to the wind blown marine salts as this greatly influences the corrosion rate, depending on the distance from the sea and its position in relation to the prevailing wind.

Each one of these factors will affect the corrosion rate by multiplying or adding to the macroclimate corrosion rate determined above. The example given in Section 3.3 demonstrates the effects of the microclimate on determining the atmospheric corrosivity category.

![Figure 1: Detailed (left) and simplified (right) North Island first year carbon steel macroclimate corrosion rates](image-url)
3.2 HERA Report R4-97:2005 “New Zealand Weathering Steel Guide for Bridges”

Weathering steel, or to use its technical title of “structural steel with improved atmospheric corrosion resistance”, is a high strength low alloy steel that, in suitable environments, may be left uncoated because it forms an adherent protective rust “patina” that greatly reduces the corrosion rate of the steel. Weathering steel in structural applications is a recent introduction in New Zealand and HERA Report R4-97 [3] provides the necessary guidance to ensure that dependable performance is realised for applications of this material in New Zealand bridges, such as the SH1 Mercer to Longswamp Off-ramp, New Zealand’s first weathering steel bridge, as shown in Figure 2.

![Figure 2: SH1 Mercer to Longswamp Off-ramp, New Zealand first weathering steel bridge.](image)

This guide covers aspects for design, construction, inspection, maintenance and even rehabilitation of weathering steel, should corrosion rates exceed those anticipated at the design stage, as well as the limitations on the use of weathering steel. Cost savings from the elimination of the protective paint system may outweigh the additional material costs. Since there is no need for the disposal of blast cleaning debris, there are also major environmental benefits. The minimal future maintenance requirements of weathering steel bridges mean there will also be savings on direct maintenance costs as well as on indirect costs arising from road and rail traffic delays.

3.3 Durability Design versus Sustainable Durability Design

The following example is given to demonstrate the process of determining the life cycle costing methodology and the differences between a standard durability design and a sustainable durability design. A steel bridge is to be built for Transit NZ (now New Zealand Transport Agency) and located on the Waikato River in Hamilton, 40km from the sea. Section 3.3.1 starts with the methodology of determining the actual atmospheric corrosion category that will be used to specify a coating system and calculate the corrosion rate of weathering steel.

3.3.1 Determine the Atmospheric Corrosion Category

- **Determine the design service life of the element being coated:**

  The bridge is to have a design life of 100 years as stated in the TNZ Bridge Manual [8].

- **Determine the site-specific corrosivity category, which is derived from the first year steel corrosion rate:**

  This rate is determined from the combination of the macroclimate and microclimate effects.

  **Site macroclimate effect:**

  The site macroclimate effect is determined from the North Island first year carbon steel macroclimate corrosion rate found in Appendix A.1 of the Coatings Guide, as 20 µm/year.
Site microclimate effect:
Shaded location: microclimate effect of a shaded location is 5 µm/y which is added to the macroclimate effect, from section 4.3.1 of the Guide. Therefore, the design corrosion rate is now 25 µm/y.

Unwashed effects: taking into account the unwashed area $C_{uw}$ multiplier from section 4.3.2, the multiplier is:

\[ C_{uw} = 1.2 \text{ for sites greater than 5 km from the seacoast. (Option 5 of Section 4.3.2)} \]

Therefore, the first year corrosion rate is $25 \times 1.2 = 30 \mu m/y$.

- **Corrosivity category for the site, including microclimate effects**

This is obtained by using the first year corrosion rate calculated above as 30 µm/y, in Table 1.

From Table 1, the corrosivity category C20%D applies; this designation means that the determined atmospheric corrosivity category is within C and 20% of the way towards category D.

<table>
<thead>
<tr>
<th>Corrosion rate for steel µm/year</th>
<th>AS/NZS 2312</th>
<th>ISO 9223</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;1.3</td>
<td>A: Very Low</td>
<td>C1</td>
</tr>
<tr>
<td>1.3 to 25</td>
<td>B: Low</td>
<td>C2</td>
</tr>
<tr>
<td>25 to 50</td>
<td>C: Medium</td>
<td>C3</td>
</tr>
<tr>
<td>50 to 80</td>
<td>D: High</td>
<td>C4</td>
</tr>
<tr>
<td>80 to &gt; 200</td>
<td>E: Very High</td>
<td>C5</td>
</tr>
</tbody>
</table>

Note to Table 1: This is based on [2] Table B1.

- **Determine the time to first (major) maintenance required for the coatings system**

For a more sustainable durability design option a time to first maintenance of 35 years or longer time is sought, while a time to first maintenance of 25 years is considered for the ‘standard’ durability design.

3.3.2 **Select an Appropriate Corrosion Protection System**

A single coat inorganic zinc silicate (IZS) solvent-borne (SB), IZS3-SB which has 125µm dry film thickness (DFT) will meet the 35 years requirement. Based on the Coatings Guide and AS/NZS 2312, for the determined corrosivity category of C20%D, the time to first maintenance for the IZS3-SB system is 37 years.

Note that inorganic zinc silicate coatings are available in either solvent-borne (SB) or water-borne (WB) form. AS/NZS2312 gives lower performance levels for the solvent-borne (SB) coatings than for the water-borne (WB) coatings. However, this is misleading for the SB systems for the reasons given in section 7.3.5 of the Coatings Guide. The sacrificial protection offered by both products is similar; hence the only difference in design life is due to the slightly increased quantity of active ingredient (powdered metallic zinc) in the WB systems.

For the 25 years time to first maintenance, a polyurethane (PUR3) 3 coat thickness with a total 250µm DFT is chosen.

3.3.3 **Determination of Life Cycle Cost of IZS3-SB and PUR3**

This section gives the life cycle cost estimate for the IZS3-SB and PUR3 coating systems over the proposed 100 year life determined above. The information is presented in Figures 3 and 4, which was developed by Raed El Sarraf and Charles Clifton in 2005 and finalised in February 2006. The estimated time to next maintenance is determined in accordance with Section 3.2.2 above. The coating and labour rates are provided from the coating supplier, International Protective Coatings. The labour costs are based on shop application of large areas, with adjustments made for site conditions as specified in Note 6 in Figure 3 and 4. The net present value and net forward value are both calculated to provide a more realistic associated cost.

- **Estimated time to next maintenance**

The estimated time to next maintenance is assessed in accordance with [2] and Reina et. al., [10] as follows:

After each painting (initial coat and maintenance recoats), 2% of the area is assumed to require touch-up after 3 years and another 5% of the area is assumed to require touch-up at 75% of the time for which the next full coating is required.
The time to first full coating is taken as 35 years in Figure 3 and 25 years in Figure 4. The time to subsequent touch-up repair is taken as 75% of 35 years (26 years) and 75% of 25 years (18 years).

The two touch-up coats between full recoats are in accordance with the recommendations for bridge coatings, based on experience. In practice, one or both may not be necessary. It is assumed that both coatings thickness loss will be reasonably consistent over the exposed surface area so that all areas will require reinstatement when the durability-time to first maintenance is reached. For that reason, a full recoat is specified when that time is reached. In practice, using the criteria for assessing when to paint or repair from Clause 10.2(a) of [2], a longer interval between recoats than that used in Figures 3 and 4 might be obtained.

<table>
<thead>
<tr>
<th>Operation Number</th>
<th>System Designation</th>
<th>% Area Maintained</th>
<th>Current Cost ($/total m²)</th>
<th>NPV (10% for DR) ($/total m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>A1+W+F</td>
<td>100%</td>
<td>1.65</td>
<td>1.65</td>
</tr>
<tr>
<td>1</td>
<td>B+F</td>
<td>2%</td>
<td>1.65</td>
<td>1.65</td>
</tr>
<tr>
<td>2</td>
<td>C+F</td>
<td>2%</td>
<td>1.65</td>
<td>1.65</td>
</tr>
<tr>
<td>3</td>
<td>E</td>
<td>100%</td>
<td>4.14</td>
<td>4.14</td>
</tr>
<tr>
<td>4</td>
<td>E</td>
<td>100%</td>
<td>50.50</td>
<td>50.50</td>
</tr>
<tr>
<td>5</td>
<td>D+F</td>
<td>100%</td>
<td>35.50</td>
<td>35.50</td>
</tr>
<tr>
<td>6</td>
<td>C+F</td>
<td>2%</td>
<td>1.65</td>
<td>1.65</td>
</tr>
<tr>
<td>7</td>
<td>E</td>
<td>100%</td>
<td>50.50</td>
<td>50.50</td>
</tr>
<tr>
<td>8</td>
<td>F</td>
<td>5%</td>
<td>4.14</td>
<td>4.14</td>
</tr>
<tr>
<td>9</td>
<td>E</td>
<td>100%</td>
<td>50.50</td>
<td>50.50</td>
</tr>
<tr>
<td>10</td>
<td>E</td>
<td>100%</td>
<td>50.50</td>
<td>50.50</td>
</tr>
<tr>
<td>11</td>
<td>D+F</td>
<td>100%</td>
<td>50.50</td>
<td>50.50</td>
</tr>
</tbody>
</table>

Coating System Specification:
Based on 125 micron IZS3-SB, paint reference number CO1a from [2].

Time to first maintenance (35, 40, 50 years)  35

System Designation:
A1 Washdown: High pressure washdown to remove fabrication oil etc prior to blast cleaning
A2 Initial Coat: Shop: Grit Blast to Class 2.5; 125 micron nominal DFT IZS3-SB
B 2% Erection Touch-up: Field: Abrasive blast of damaged area to Class 2.5; 125 micron nominal DFT IZS3-SB
C 2% or 5% Touch-up Repair: Field: Abrasive blast of degraded area to Class 2.5; 125 micron nominal DFT IZS3-SB
D 100% Recoat: Field: Abrasive blast of whole area to Class 2.5; 125-150 micron nominal DFT IZS3-SB
E Inspection of surface to determine condition (10): Field: Independent inspection of existing surface to determine extent of maintenance required at 75%, 100% film coverage
F Independent inspection of coating (11): Field: Independent inspection of applied coating for designations A2, B, C and D

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

<table>
<thead>
<tr>
<th>System Designation</th>
<th>Initial washdown at shop</th>
<th>Blast clean and apply single coat (labour cost)</th>
<th>Shop inspection of surface or coating</th>
<th>Site inspection of surface or coating</th>
<th>Current Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>4.00</td>
<td>18.00</td>
<td>4.00</td>
<td>5.00</td>
<td>27.50</td>
</tr>
<tr>
<td>A2+F</td>
<td>11.50</td>
<td>22.00</td>
<td>1.00</td>
<td>6.70</td>
<td>40.20</td>
</tr>
<tr>
<td>B+F</td>
<td>12.50</td>
<td>23.00</td>
<td>2.40</td>
<td>67.70</td>
<td>94.60</td>
</tr>
<tr>
<td>C+F</td>
<td>12.50</td>
<td>23.00</td>
<td>2.40</td>
<td>67.70</td>
<td>94.60</td>
</tr>
<tr>
<td>D+F</td>
<td>12.50</td>
<td>23.00</td>
<td>2.40</td>
<td>67.70</td>
<td>94.60</td>
</tr>
<tr>
<td>E</td>
<td>0.00</td>
<td>5.00</td>
<td>1.00</td>
<td>5.00</td>
<td>15.00</td>
</tr>
</tbody>
</table>

Summary:
Initial Cost/total m²  $ 40.40 This covers operations 0, 1 and 2 above which are part of the construction contract
NPV Maintenance Cost 100y/total m²  $ 2.26 This covers operations 3 to 11
Full life cycle NPV cost 100 year/total m²  $ 42.66

Notes:
1. Year after commissioning bridge.
2. Current Cost/total m² (% Area Maintained x System Cost $/m²)
3. NFV Net Future Value: Current cost with inflation included. i.e. expected actual inflated dollar cost at time of maintenance.
4. Inflation Rate (I): Recommended discount rate for Transit NZ is 10% for 25 years. Cl. 2.9.3 of [11]
5. NPV Net Present Value: NPV = NFV/(1+DR/100)^t
6. Area for labour is obtained from section 7.6 of [1]. It allows for higher setup and wastage costs due to the small areas involved.
7. The initial rate is the materials + labour including area factor.
8. The Site access rate is taken from [12], using easy for touch-up, small area and site access.
9. The current cost/m² is the initial rate plus the site access rate.
10. Inspection costs for the weathered surface cover independent inspection of the surface near the end of its rated life to determine the need for and extent of recoating required. This is carried out on 100% of the surface.
11. Inspection costs for the painted surface cover independent inspection of the area that has been painted.

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

Figure 3: Life cycle cost estimate for IZS3-SB including inspection.
### Coating System Specification:

Based on a 3 coat total DFT of 250 micron PUR3, paint reference number C06+C13+C26 from [2]

#### System Designation:

**A1** Washdown: High pressure washdown to remove fabrication oil etc prior to blast cleaning

**A2** Initial Coat: Shop: Grit Blast to Class 2.5; 250 micron nominal DFT PUR3

**B** 2% Erection Touch-up: Field: Abrasive blast of damaged area to Class 2.5; 250 micron nominal DFT PUR3

**C** 2% or 5% Touch-up Repair: Field: Abrasive blast of degraded area to Class 2.5; 250 micron nominal DFT PUR3

**D** 100% Recoat: Field: Abrasive blast of whole area to Class 2.5; 250 micron nominal DFT PUR3

**E** Inspection of surface to determine condition 10:

Field: Independent inspection of existing surface to determine extent of maintenance required at 75%, 100% tfm.

Cost covered by Client general bridge inspection regime and not part of specific steel coating cost

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#### Paint/Inspection System

<table>
<thead>
<tr>
<th>Operation Number</th>
<th>System Designation</th>
<th>%Area Maintained</th>
<th>Current Cost $/total m²</th>
<th>NPV $ for 10%</th>
<th>NPV $ for DR</th>
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<tr>
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<td>2.46</td>
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<tr>
<td>3</td>
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<td></td>
</tr>
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<td>4</td>
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<td>6.15</td>
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<td>by client</td>
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<td>2.46</td>
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<td>5%</td>
<td>6.15</td>
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<td>0.01</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>D+F</td>
<td>100%</td>
<td>65.00</td>
<td>6.00</td>
<td>0.05</td>
</tr>
</tbody>
</table>

**Total** $ 280.73  69.76

---

#### Summary:

1. **Initial Cost/total m²** $ 61.76
2. **NPV Maintenance Cost 100yr/total m²** $ 8.01
3. **Full life cycle NPV cost 100 year/total m²** $ 69.76

---

#### Notes:

1. Year after commissioning bridge.
2. Current Cost/total m² (% Area Maintained x System Cost $/m²)
3. NPV Net Future Value: Current cost with inflation included. i.e. expected actual inflated dollar cost at time of maintenance.
4. NPV Net Present Value: NPV = NPV(1+I/100)
5. Recommended discount rate for Transit NZ is 10% for 25 years. Cl. 2.9.3 of [11]
6. Area factor for labour is obtained from section 7.6 of [1].
7. The current cost is the initial rate plus the site access rate.
8. Inspection costs for the painted surface cover independent inspection of the surface near the end of its rated life to determine the need for and extent of recoating required. This is carried out on 100% of the surface.

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

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### Figure 4: Life cycle cost estimate for PUR3 including inspection

#### 3.3.4 Determining the Corrosion Rate of Weathering Steel for a 100 Year Design Life

The calculation below will estimate the corrosion rate of the weathering steel based on [1], [3], and ISO 9224 [13]. Using the corrosion rate of mild steel determined in Section 3.3.1 herein and Table 1 of ISO 9224 to interpolate the corrosion rate of weathering steel in comparison to mild steel. Therefore, the corrosion rate of weathering steel is:

- Determine the corrosion rate of weathering steel for the first 10 years of the 100 year design life from ISO 9224:

  \[ r_{av} = 3.2 \mu m/y \]
- Determine the corrosion rate of weathering steel for the remaining 90 years of the 100 year design life from ISO 9224:

\[ r_{\text{fin}} = 1.8 \, \mu\text{m/y} \]

Therefore, the 100 year design life total corrosion per exposed face is:

\[ 3.2(10) + 1.8(90) = 194 \, \mu\text{m/exposed face or 0.2mm/exposed face} \]

A factor of 2 is recommended to be applied to allow for localised increased rates of corrosion. Therefore, when designing the main girders, a loss of 0.4mm/exposed face should be taken into account when determining the section capacity of the girder.

- Notes on Using Weathering Steel

The calculated corrosion rate stated above is based on the protective patina layer forming, if this does not form properly then continuous corrosion of the steel will occur which will be higher than the estimated corrosion rate above. Weathering steel will start out as a rusty red colour but with time weathering steel will turn to a darker earthy tone (to nearly black) but only if the conditions are favourable (eg. not subject to salt contamination and low ‘times of wetness’). For the bridge in this example, the proposed site is an ideal location for the protective patina layer to form.

- Costs of Using Weathering Steel

On average the cost of weathering steel is $300/tonne more than that of mild steel. Therefore, the current cost (as of October, 2008) of uncoated mild steel plate is $2200/tonne, this equates to an average cost of $2500/tonne for weathering steel. Depending on the weight and type of girders chosen for the steel bridge in this example, the cost per square meter of the premium of using weathering steel equates to $14.27/m² to $31.2/m² for beams ranging from a 800WB122 to 1200WB455 respectively.

Once the patina forms on the weathering steel, the greatly reduced corrosion rate will allow the steel to meet the required performance requirements with negligible, if any, maintenance. These figures are applicable for both the net present and net forward values minus the inspection cost, as they equate to the initial cost of a protective corrosion system. Even though, weathering steel has this cost premium in comparison to uncoated mild steel, the future cost savings for maintenance related activities makes this option cost competitive.

3.3.5 Results Discussion

A summary of the results is given in Table 2. By comparing both coating systems net present value and net forward value, the use of a single coat coating with a longer time to first maintenance provides the most cost effective solution. This solution also has less onsite wastage with the fact that only 1 coating layer is needed to be reinstated while the multi coat option requires up to 3 coats. Also, with a longer time to first maintenance the IZS3 option required only 2 recoats in comparison with the 3 recoats for the PUR3, this equates to a reduced possibilities of accidents and other health and safety issues from occurring.

However, when comparing the costs between the inorganic zinc silicate single coat system with the weathering steel option, the results showed that the latter provides a more economical solution. Also, with the negligible maintenance, onsite wastage is further reduced to a minimum, while the health and safety benefits have been greatly improved due to that negligible maintenance.

<table>
<thead>
<tr>
<th>Corrosion Protection System</th>
<th>Cost ($/m²) for a 100 year design life</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>IZS3</td>
<td>$42.66 Net Present Value</td>
<td>$151.73 Net Forward Value</td>
</tr>
<tr>
<td>PUR3</td>
<td>$69.76 Net Present Value</td>
<td>$280.73 Net Forward Value</td>
</tr>
<tr>
<td>Weathering Steel</td>
<td>$31.2 Net Present Value</td>
<td>$31.2 Net Forward Value</td>
</tr>
</tbody>
</table>

3.3.6 Sustainable Durability Design Example Conclusion

Even though, weathering steel produced the most economic solution, other factors must be considered by the designers when specifying the optimum sustainable durability option. As mentioned in the beginning of Section 3, the designer must not only consider achieving the most economic time to first maintenance option, but must also consider the required structure’s performance, aesthetics, design life, and location which
includes future maintenance accessibility. These factors may govern the design and a more expensive option may be chosen to meet those requirements.

Weathering steel starts as a rust colour layered which gets darker with age which aesthetically may not be desirable in high profile projects. While inorganic zinc silicate provides a single colour option of grey, while the polyurethane option provides a wide range of colours and graffiti protection. The aesthetic factor is one of many factors that are considered when carrying out a sustainable durability design. All these factors govern the chosen corrosion protection system based on the requirement ultimately stated by the client. Whether it is a major highway bridge project, a landmark building or a residential home, each structure has its challenges and requirements which the designer must consider to produce the optimum solution for that structure.

3.4 Durability Statement

One of the services that HERA provides is durability statements for structural steelwork, especially for new bridges. This statement covers the following topics:

- determination of site-specific atmospheric corrosivity category
- recommended coating system or systems.
- determination of life cycle cost of three coating systems
- feasibility of using weathering steel
- general site and maintenance requirements.

The coatings evaluation is undertaken in accordance with [2] and the process is based on [1], [3] and [13]. This statement has proven to be useful for designers, especially in the early design stage as it provides an accurate cost estimate for a coating system by including maintenance and inspection throughout the bridge design life, which in turn provides a better overall cost estimate for the project during the tender process.

4. Coating Application

One of the main problems with coating systems is the lack of quality control and improper application of the system onto the steel. This is a major issue with most coatings, as improper application will affect the performance of the system and may result in premature failure, which will then require early repair or replacement of the system. A number of articles [14] and publications [15] discuss and address this issue. In New Zealand, the International Accreditation New Zealand (IANZ) used to run a coating accreditation scheme for NZ manufacturers which, in the mid 1990’s, was absorbed into the Australian Paint Approval Scheme. However, this scheme applies to accreditation of coating system performance and not their application.

The other issue with this problem is that coating suppliers are currently not providing a guarantee on their product’s performance due to this lack of quality control during the application process. This affects the choosing of steel as a structural material due to the misconception that it will require expensive repair at regular short intervals. The current practice is that an independent and qualified coatings inspector (eg. certified by the NZ Certification Board for Inspection Personnel CBIP)) approves the application of the coating system before the supplier will provide a guarantee. However, if the inspector finds that the coating had been not applied properly, this will require rework which may impact on the work programme.

After discussing this matter with the industry and clients, especially NZ Transport Agency and Ontrack, the authors propose to reintroduce a coatings application accreditation scheme to address these issues. This is to be done via a three stage process, which is:

- **Stage 1:**

  Coatings are to be applied by qualified coating applicators that are trained by a recognised training provider, such as Extraction Industry Training Organisation (EXITO) based in Christchurch, and who are employed by companies who meet minimum criteria of accredited in-house Health & Safety, and QC/QA Management Systems. The specified coatings systems must be supplied by a reputable coating suppliers with an accredited QA system and coatings that meet the required performance and/or composition standards requirements such as given in [2] and ISO 12944 [16]. Finally, an independent CBIP or NACE certified inspector inspects the coating. This will allow the suppliers the confidence to provide a guarantee on their products and the clients the assurance that the potential performance of the designed and specified coating protection system is met.
- Stage 2:

In parallel with Stage 1 outlined above, a study will be conducted by HERA and/or the Australasian Corrosion Association, on the establishment of the accreditation scheme in New Zealand. Australia already has a scheme called the Painting Contractor Certification Program for coating applicators and an Australian Paint Approval Scheme for coating systems. Both are currently hosted and managed by the Commonwealth Scientific & Industrial Research Organisation (CSIRO) and governed by a board made up of industry representatives. The study will show whether New Zealand should join the Australian scheme or re-establish a New Zealand scheme that could be over seen by International Accreditation of New Zealand (IANZ).

- Stage 3:

The commencement of the scheme based on outcomes of the study published in Stage 2. This should be done over an agreed period of time to give the coating industry sufficient time to reach the required accreditation approved level.

5. Maintenance Management

Another important topic is the maintenance management of coating systems and structures. All structures require regular maintenance to guarantee their performance over the design life of the structure, as specified in the NZ Building Code [7] and the TNZ Bridge Manual [8]. However, there is a general lack of understanding from designers and clients on this matter which is usually neglected and not considered in the design stage. Considerations for maintenance must be conducted as part of the design process; this includes accessibility for future maintenance and the establishment of a maintenance regime as required for all of the components during the life of the structure, from reinstatement of the coating system to the regular cleaning of the steelwork of chemical and biogenic contamination.

6. Conclusion

1. The authors believe that the wider use of steel as a sustainable construction material has been handicapped by the lack of information available to designers which has now been largely overcome by the publication of a number of design resources referenced in this paper.
2. The remaining major handicap is the lack of confidence that a specified protective coating system will achieve its potential design life. This is supported by the difficulty in obtaining a credible warranty for many systems due to the lack of a quality assured applicators scheme.
3. Use of correctly detailed weathering steel in appropriate locations is an alternative sustainable design option that should be considered by structural designers.

7. References

[9] NZS 3404 Part 1; Steel Structure Standard, incorporating Amendment No. 1 (June, 2001) and No. 2 (October, 2007), Standards New Zealand, Wellington. 1997

