PERFORMANCE OF HOT DIP GALVANIZING IN COASTAL ENVIRONMENTS: A REVIEW

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SUMMARY: The performance of hot dip galvanizing in coastal environments continues to be questioned by some people in industry, including engineers, architects, specifiers and builders. Six years ago, a study was conducted along the South West coast of Victoria, Australia, as a direct response to some comments by corrosion professionals as to the poor performance of hot dip galvanized steel in coastal applications. This study returned to Victoria's South West to review the performance of the hot dip galvanized steel along a stretch of approximately 400kms of the coastline.

The specific sites in the study conducted six years ago were revisited for this review. The sites consisted of iconic buildings, water treatment infrastructure and some more common structures, such as bridge rails and safety barriers along the Great Ocean Road. The water treatment infrastructure and buildings are generally over 10 years old, with some items being 15 years or older.

The coating thickness of various hot dip galvanized steel articles was measured at each site, along with climatic conditions such as relative humidity. The results of this review of the performance of hot dip galvanizing along Australia's south east coastline support that with proper design and consideration of the location's corrosivity, hot dip galvanized steel structures can provide robust and maintenance free options for the prolonged protection of steel in coastal environments.

Keywords: Hot dip galvanizing, Coast, Coating thickness, Time of wetness, Design, Case studies.

1. BACKGROUND

In mid-2007, a study was conducted on the performance of a number of structures, with varying ages, along approximately 400km of Victoria's south west coast due to a growing negative perception and communication regarding hot dip galvanized steel and its performance in coastal areas[1]. Three case studies were looked at where (batch) hot dip galvanized steel was used in structures located only short distances from the coastline along with a survey of galvanized bridge rails on the coast's Great Ocean Road.

The study noted how interpretation of literature, standards and accelerated testing had supported industry belief of hot dip galvanizing's poor performance in coastal locations, yet the empirical evidence collected from the study showed little to no sign of deficient performance (in the form of highly corroded or rusted surfaces) of the hot dip galvanizing in these areas. Instead, it demonstrated that with proper design, hot dip galvanizing provided a robust and maintenance free option for the durable use of steel in coastal environments [1].

This paper aims to build on the aforementioned study by presenting further evidence of hot dip galvanizing's true performance in coastal environments around Australia.

2. INTRODUCTION

The hot dip galvanizing process and coating has a long history with few major changes to the basic process in over 150 years. During this time, there has been much research and empirical data collected and published about the durability of galvanized steel. Some notable sources include Porter's 'Corrosive Resistance of Zinc and Zinc Alloys' and Slunder and Boyd's 'Zinc and its Corrosion Resistance'. Standards, such as ISO 9223 and AS/NZS 2312, have taken advantage of the vast amounts of data available and established guidelines for industry on the durability of corrosion protection systems, one of which is hot dip galvanized steel.

Hot dip galvanizing has been used in numerous coastal environments to wide practical success throughout its history. Yet, in recent times, there has been a movement towards the use of theory, with the extrapolation of practical data and testing over short periods, for the prediction of a coating's durability. Due to the broad range of information from various locations and environments around the world, unsuitable data and theories can easily be used when determining potential durability if there is a lack of understanding of the different influencing factors on such predictions; for example, the use of widely differing micro-environments and material specifications.

The corrosivity categories from ISO 9223, by which general environments are broadly defined, are often used to help determine corrosion rates and therefore durability of various materials in specific applications. These are a great tool when the general environment is correctly identified. The categories take into account four major influencing factors of corrosivity in a general environment:

1. The amount of sulphur dioxide (SO_2) in the atmosphere
2. The amount of airborne salinity in the atmosphere
3. Relative humidity (RH) }
4. Temperature } To provide an estimated time of wetness

How these four major factors apply to the Australian climate and its different coastlines affects the application of the corrosivity categories given in ISO 9223. Climate conditions in Australia can be unique when compared to America and Europe, so even though the location may be similar in terms of distance from the coast and salinity, the degree of corrosivity may vary considerably. For example, the level of SO_2 in Australia's atmosphere, for the most part, has not been a significant factor and generally only needs to be considered in specific industries or applications [2].

Australia's major cities are built on widely varying coastlines leading to variations in the amount of salt spray that occurs and how far inland that airborne salt travels. However, it is likely the differences in the Australian relative humidity and temperature (i.e. estimated time of wetness), when compared to the European and North American countries, allows hot dip galvanizing to be successful along Australia's coastal regions. ISO 9223 defines time of wetness as the 'period when a metallic surface is covered by adsorptive and/or liquid films of electrolyte to be capable of causing atmospheric corrosion' [3]. In Annex B of the Standard, it goes on to state the length of time during which the relative humidity is greater than 80 % (at temperatures > 0 °C) is used to estimate the calculated time of wetness [3]. As they are next to large bodies of water, there may be a general expectation that coastal environments would have more time in which the RH of the environment is 80% or greater, hence they would have a greater estimated time of wetness. However, due to other climatic factors and topography, the amount of time at which RH is 80% or greater will vary in different coastal locations.

The other factor in the corrosion of hot dip galvanizing, which is often not considered, is that the corrosion rate slows down significantly over time. This is shown in the values of maximum corrosion attack given for extended exposures in Annex A of ISO 9224 [4]. Zinc corrosion products (Table 1 [5]) on the surface of the hot dip galvanized coating are believed to be responsible for the reduction in the corrosion rate, due to the formation of a insoluble barrier (patina) between the atmosphere and the underlying coating. This patina prevents the continual corrosion of the galvanizing and effectively reduces the corrosion rate. However, the patina is formed over an extended period of time; over many natural wet-dry cycles. The time and environment it takes for the patina to form are two reasons why accelerated corrosion testing techniques are not able to achieve an accurate correlation between their results and real life performance [6] of the hot dip galvanized coating.

Table 1. Zinc Corrosion Reactions in Different Atmospheres[5]

Type of atmosphere	Attacking substance†	Corrosion products composition	Relative solubility in water	Corrosion rate
Rural	$O_2 + H_2O$ +	$ZnO \rightarrow Zn(OH)_2$	Very Low	Very Low
	CO_2	$\rightarrow 2ZnCO_3 \cdot 3Zn(OH)_2$		
Marine	$O_2 + H_2O$ +	$ZnO \rightarrow Zn(OH)_2$	Moderate	Low
	CO_2 +	$\rightarrow 2ZnCO_3 \cdot 3Zn(OH)_2 \rightarrow$		
	Cl	{ $ZnCl_2 \cdot 4Zn(OH)_2$ + { Zn_3OCl_4 { $ZnCl_2 \cdot 6Zn(OH)_2$ + { Zn_4OCl_6		
Urban and	$O_2 + H_2O$ +	$ZnO \rightarrow Zn(OH)_2$	Good	High

industrial	CO_2 +	→ $2ZnCO_3 \cdot 3Zn(OH)_2$ →		
	SO_2	→ ZnS → $ZnSO_3$ + $ZnSO_4$		

†CO_2 has been included as an attacking substance because it participates in the formation of the corrosion products. However, CO_2 is also necessary in order for stable films to form.

The performance of the hot dip galvanized steel structures shown in the updates of the case studies to follow will highlight that hot dip galvanizing should not be overlooked as a corrosion protection system for steel in a coastal environment.

3. CLIMATE OF VICTORIA'S SOUTH WEST COAST

The location for this study on the performance of hot dip galvanizing spanned along Victoria's south west coast from Geelong to Portland. According to Australia's Bureau of Meteorology (BOM), this coastal region has a temperate climate, with a wet winter and low summer rainfall. The average daily RH at 9 o'clock in the morning generally ranges from between 70% to 80% in the summer months to above 80% in the winter months. However, at 3 o'clock in the afternoon the average daily RH is generally between 70 to 80% in winter, 60 to 70% in spring and autumn and 50 to 60% in summer [7]. The decrease in RH during the daylight hours would suggest a short time of wetness (as described by ISO 9223) generally limited to non-daylight hours and rainfall frequency in the environment.

The annual average number of daily sunshine hours in this region is between 5 and 6. In the winter months (May to September) the average number daily sunshine hours are between 3 and 5, while in the summer months (October to April) there are between 6 and 7 hours of sunshine a day [7]. Refer to the Appendix for more detailed climate data.

This information is significant when looking at the wet-dry cycle of the environment. When the RH decreases during the day and over the summer months there is a shorter time of wetness, hence an increase to the dry period of the wet-dry cycle. In the case of hot dip galvanized steel, the extended dry period of the wet-dry cycle is more beneficial for the development and retention of its natural patina which, in turn, decreases the coating's corrosion rate and increases the durability of the corrosion protection system. The average temperatures and average monthly rainfall of the areas along Victoria's south west coast are displayed in Figure 1 and Figure 2 respectively.

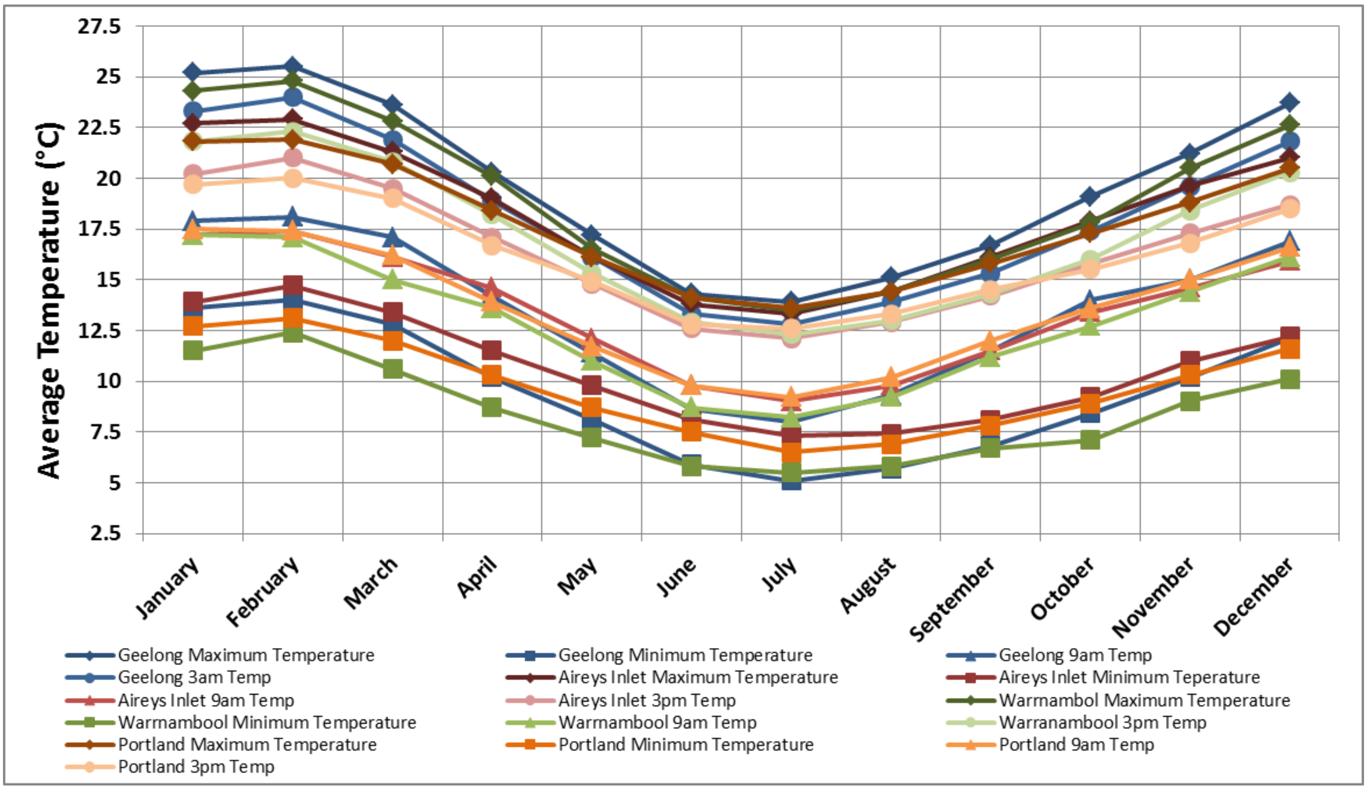


Figure 1 Average temperatures each month in places along Victoria's south west coast [7]

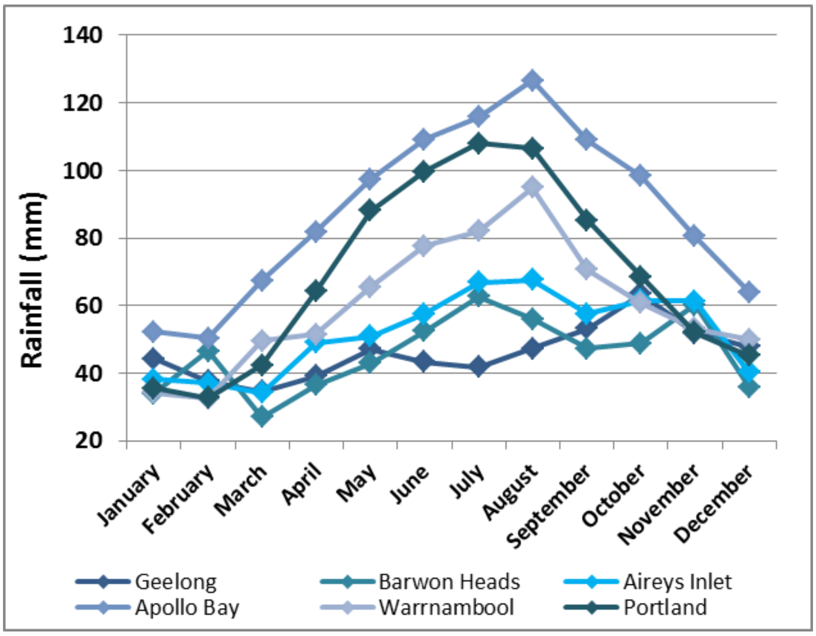


Figure 2 Average rainfall each month in places along Victoria's south west coast [7]

During the inspection of the galvanizing from mid-January to early February 2013 at each location, the RH, the air temperature and the surface temperatures of the steel were measured using an Elcometer 319 Dewpoint Meter. The minimum, maximum and averages of the RH and the difference between surface and dew point temperatures for each case study are displayed in Figure 3 and Figure 4 respectively.

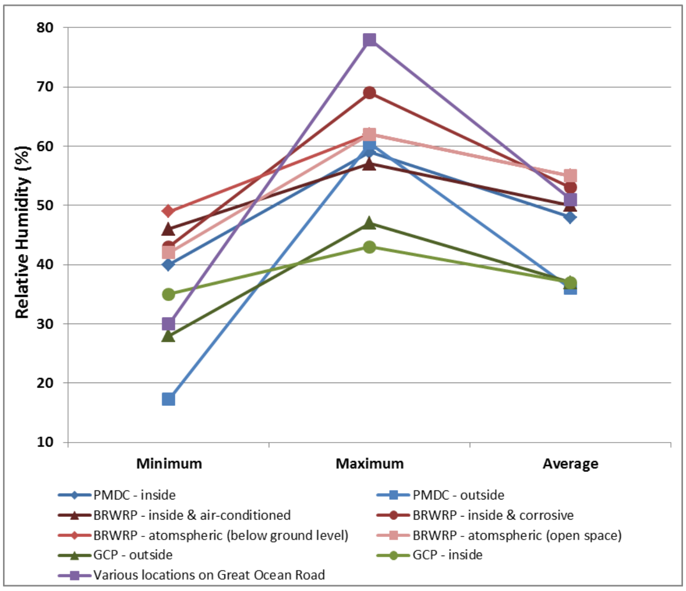


Figure 3 The measured minimum, average and maximum relative humidity at the case study sites during time visited

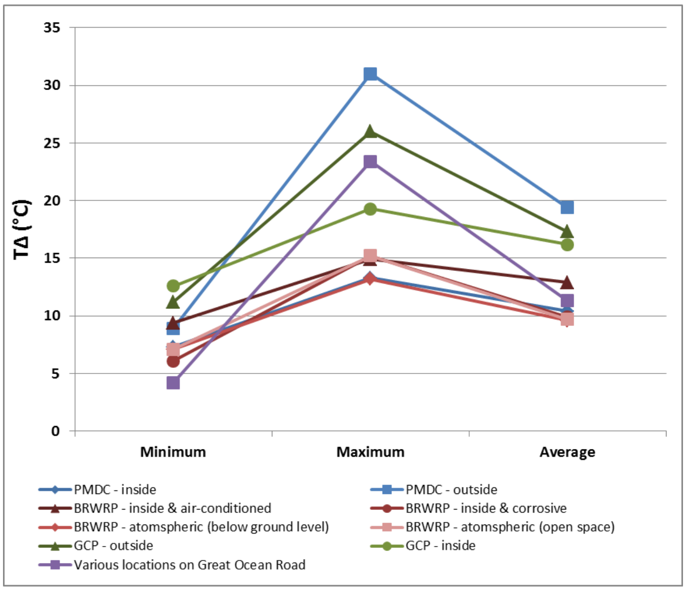


Figure 4The minimum, average and maximum difference between surface and dew point temperatures at the case study sites during time visited

4. STANDARD MINIMUM VERSUS PRACTICAL AVERAGE COATING THICKNESS OF (BATCH) HOT DIP GALVANIZING

Coating thickness is an important parameter where durability and the service life of a corrosion protection system are concerned. AS/NZS 4680 Hot-dip galvanized (zinc) coatings on fabricated ferrous articles states the minimum coating thickness requirements of hot dip galvanizing for steels of varying thicknesses. The stated minimums are based on the general minimum coating thickness which will be achieved on most steels of certain thicknesses when put through the batch hot dip galvanizing process.

The actual coating thicknesses achieved via the galvanizing process usually comfortably exceed the minimums in the Standard for structural sections. This can be due to various factors including steel thickness, steel mass and/or the chemical composition. Table 2 shows the difference between the minimum and typical practical coating thicknesses for various steel thicknesses.

Table 2. Standard minimum and practical hot dip galvanizing coating thicknesses

Steel Thickness (mm)	Average minimum coating thickness as per AS/NZS 4680 (µm)[8]	Practical (approx.) coating thickness (µm)[9]
> 2 ≤ 3	55	80
> 3 ≤ 6	70	100
> 6 ≤ 8	85	120
> 8 ≤ 15	85	150
> 15	85	170

Considering actual coating thicknesses are generally greater than the minimums stated in the Standard, there will be a longer durability predicted for an actual hot dip galvanized coating based on corrosion rates.

5. A REVIEW OF THE HOT DIP GALVANIZING PERFORMANCE

5.1 Case Study 1: Portland Maritime Discovery Centre

This Maritime Discovery Centre (Figure 5) was constructed and opened in 1997 in the birthplace of Victoria, Portland. It functions as both a visitor's information centre and a museum, which displays many aspects of the city's rich maritime history. This facility is located a stone's throw away from the water of the port of Portland, which is formed by two man-made breakwaters with a north facing entrance channel[10]. The entire building is located within approximately 50m from the shoreline and is shaped like a ship's anchor, with a frame structure made up of universal beams and columns. All the structural steel is hot dip galvanized and much of it is exposed to the atmosphere.

In the original case study, the galvanized steel was 9 years old and was said to have performed well with no maintenance [1]. Now it is a little over 15 years old with no maintenance, some of the galvanizing still looks barely weathered with the original spangle or bright shiny finish still evident on the surface (Figure 6 and Figure 10), while other areas show an even weathering, sporting an overall dull grey appearance (Figure 7, Figure 8, Figure 9 and Figure 11). There are good design aspects to the Discovery Centre as well, with structural beams mounted on concrete bases with sloped sides to assist drainage (Figure 6 and Figure 7). The stainless steel wire, used as a safety barrier on the outside decking, passes through the hot dip galvanized stanchions with insulating rings separating the different metals to prevent bimetallic corrosion (Figure 8 and Figure 9).

Figure 5 Portland Maritime Discovery Centre

Figure 6 Discovery Centre Plant room, under main floor

Figure 7 Structural beam exposed to the bay

Figure 8 Decking of the Portland Maritime Discovery Centre

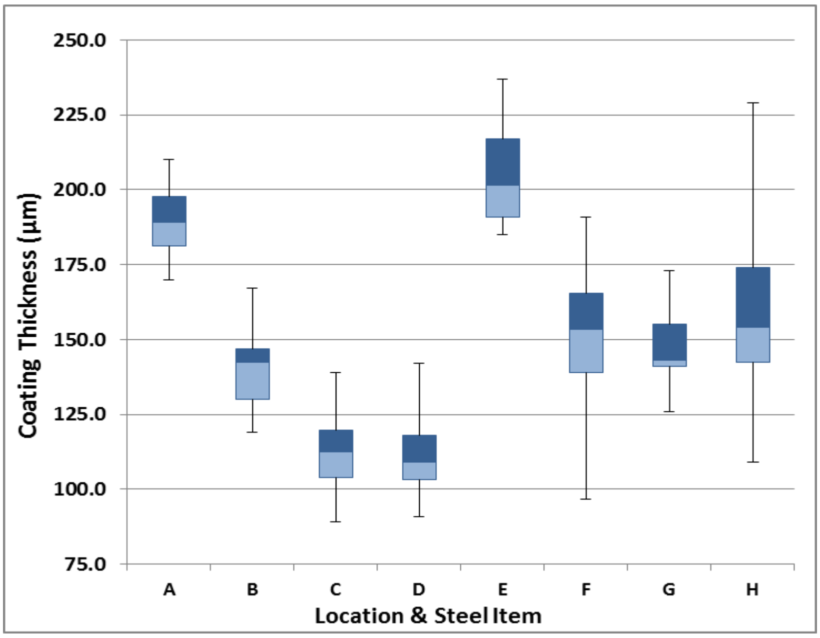
Figure 9 Stainless steel wire and hot dip galvanized stanchions make up decking guard rail

Figure 10 Galvanized beam supporting inside decking of the Maritime Discovery Centre

Figure 11 Hot dip galvanized beams hold up the entrance to the Centre

The average coating thickness of the structural steel from the first study was stated as 2 to 3 times (160-220µm) the required level of AS/NZS 4680[1]. During this visit, the galvanizing thickness was measured in various locations around the Discovery Centre, both inside and out. Average coating thicknesses ranged from 111µm to 206µm on various galvanized items (See the Appendix for details). The spread of coating thickness measurements on the various steel items can be seen in Figure 12. The coating thicknesses of the galvanizing were still well above the required minimums in AS/NZS 4680 for the different steel thicknesses present in the structure.

Based on this data, the existing coating thickness will protect the steel from corrosion for approximately a further 15 to 30 years prior to the need for maintenance, affording an estimated total of 30 to 50 years of protection for the main structure.



A = Plant Room & I-beam (flange)

B = Plant Room & I-beam (web)

C = Outside – Bayside & I-beam (flange)

D = Outside – Bayside & I-beam (web)

E = Outside – Bayside & Stanchion

F = Inside – Deck (support) & I-beam

G = Outside – Entrance & I-beam (flange)

H = Outside – Entrance & I-beam (web)

Figure 12 Coating thickness measurements of the hot dip galvanized items at Portland Maritime Discovery Centre

5.2 Case Study 2: Black Rock Water Reclamation Plant

Water treatment and reclamation plants are important to society in terms of sustainability as they produce, through the treatment of sewage (Figure 13 and Figure 14), recycled water and biosolids which become valuable products with a number of uses in industry, agriculture and the general community. The Black Rock Water Reclamation Plant has been operational since 1989 and was upgraded in 1995. The Black Rock plant is the largest of Barwon Water's water reclamation plants and treats sewage from the greater Geelong region [11].

Figure 13 Black Rock Water Reclamation Plant primary settling tank

Figure 14 Black Rock aeration tank with the ocean below the horizon

Due to the location approximately 200m from the coast, the corrosive nature of the effluent being treated and the need for continuous performance with minimal maintenance, a mixture of hot dip galvanizing, stainless steel, aluminium and concrete have been used for various purposes throughout the plant. Hot dip galvanized steel is used for the pipes that deliver heated air to the aeration tanks. It is also used for much of the structural steel and other steel furniture, e.g. stairs, handrails, gratings.

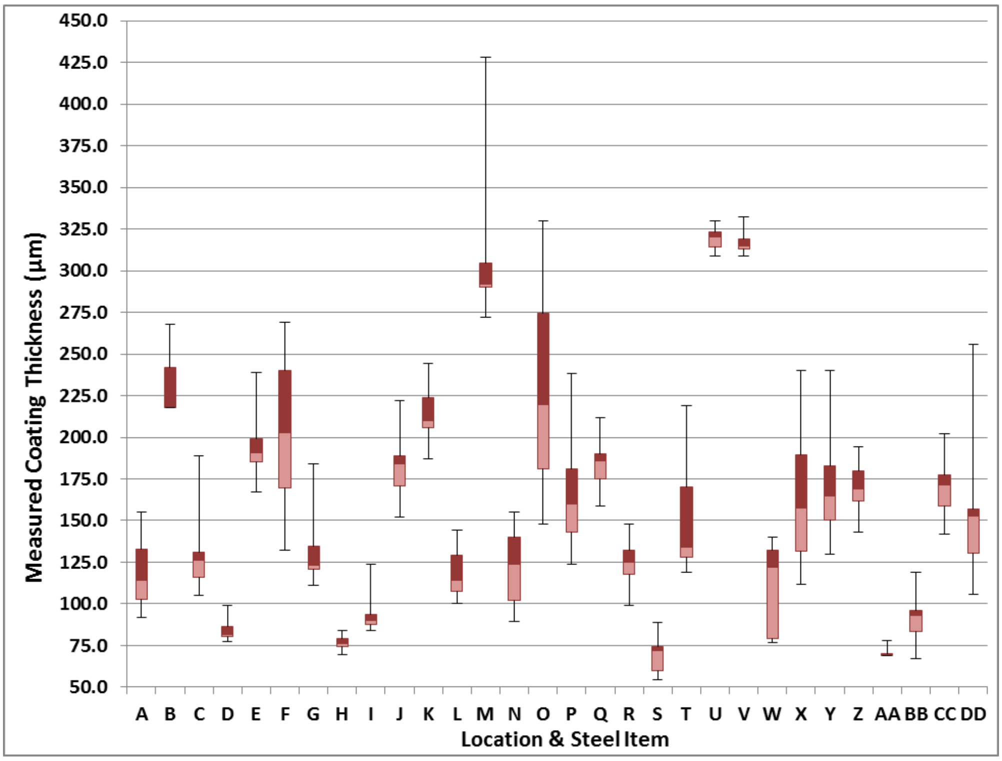
At the time of the previous case study most of the steelwork had been installed for around 10 to 15 years and was stated to be performing above expectations in a H_2S and chloride environment [1], but no thickness measurements were published. On the return visit to the reclamation plant, numerous coating thickness measurements were taken around the plant. Items measured included the pipes carrying air beside the tanks (Figure 14) and a section underground (Figure 16), stairs (some duplex, some bare galvanizing) (Figure 17), machine cages and other, more recently installed, structural members. The spread of coating thickness measurements on the various hot dip galvanized items are shown in Figure 18. The average coating thicknesses ranged from 70μm to 185μm with many over 150μm. For a table of the average coating thicknesses on the items see the Appendix.

Figure 15 Neoprene sleeves separating hot dip galvanized pipe from immersed stainless steel pipe

Figure 16 Heated air in hot dip galvanized pipes below ground

Figure 17 Fine screening building with duplex coated stairs and handrails

In addition to the remaining large coating thicknesses measured on the galvanized steel, in most areas there were little to no signs of corrosion. This can be attributed in part to good material selection and design. The pipes delivering air into the aeration tanks use both hot dip galvanizing and stainless steel for the exposed and immersed sections respectively. In order to prevent bimetallic corrosion, a neoprene sleeve is used to electrically isolate the two metals and provide a connection between them (Figure 15). In the locations closer to the relatively raw sewage and H_2S sources, such as the filtration area and the primary settling tanks (Figure 13), there was more evidence of corrosion, with some lightly rusted areas. On the whole, after nearly 20 years or more in service, the hot dip galvanized coatings have performed fittingly and will continue to perform their purpose in this environment for many years to come.



A = Aeration tanks – west side Pipe

B = Aeration tanks – west side Pipe

C = Aeration tanks – west side Pipe

D = Below ground –Stairs RHS

E = Below ground –Stairs RHS

F = Below ground Pipe

G = Settling tanks Pipe

H = Settling tanks Pipe

I = Biosolids dewatering facility Machine cage

J = Biosolids dewatering facility Machine cage

K = Biosolids dewatering facility Kick Plate

L = Biosolids dewatering facility Side of grating

M = Oxygen dissolver – Stairs Channel

N = Oxygen dissolver – Stairs Grating

O = Oxygen dissolver – Stairs Channel

P = Beside aeration tanks – west side Gantry (I-beams)

Q = Support for overhead pipe & cables Column

R = Support for overhead pipe & cables I-beam

S = Support for overhead pipe & cables Bolts

T = Between biosolids drying facility & aeration tanks I - beam

U = Between biosolids drying facility & aeration tanks I - beam

V = Fine screening building – stairs Channel (duplex coated)

W = Fine screening building – stairs Channel

X = Fine screening building – stairs Channel

Y = Stairs – below ground, far east side Channel

Z = Aeration tanks – east side Pipe

AA = Aeration tanks – east side Bolts

BB = Aeration tanks – east side Pipe

CC = Aeration tanks – east side Pipe

DD = Aeration tanks – east side Pipe

Figure 18 Coating thickness measurements of the hot dip galvanized items at Black Rock Water Reclamation Plant

5.3 Case Study 3: Geelong Carousel Pavilion

The Geelong Carousel Pavilion houses an extremely rare and exquisite Armitage Herschell hand-carved wooden Carousel (Figure 19) that was constructed around 1892. The carousel was purchased by the Steampacket Place Development Board in 1996[12] and took two years to restore. Although originally powered by a steam engine, it is now powered by electricity [13]. A restored 1898 Gavioli band organ also accompanies the carousel [12].

Figure 19 Restored Armitage Herschell hand-carved wooden Carousel

Figure 20 Geelong Carousel Pavilion on Geelong Waterfront

The Pavilion is located on the Geelong Waterfront (Figure 20) and its structural design (Figure 21) needed to take into account the offshore wind loading. The design consciously considered potential corrosion issues with the use of bolting and other detailing (Figure 22). The expanded metal roofing, designed to reduce wind loading [1], has the added benefit of allowing rain to have a washing effect on the external steelwork (Figure 22 and Figure 23).

Figure 21 Corner of Pavilion showing hot dip galvanized column and mullions

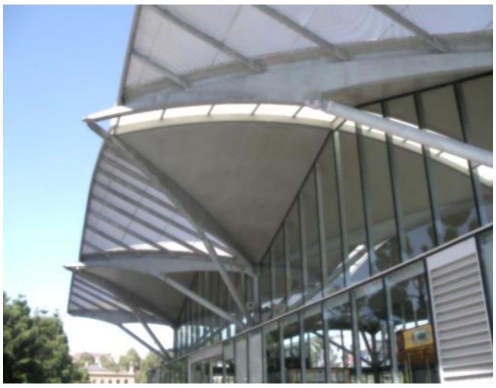


Figure 22 Curved roof of Pavilion with bolted joints

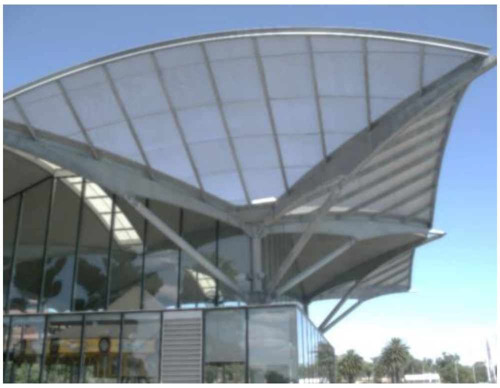
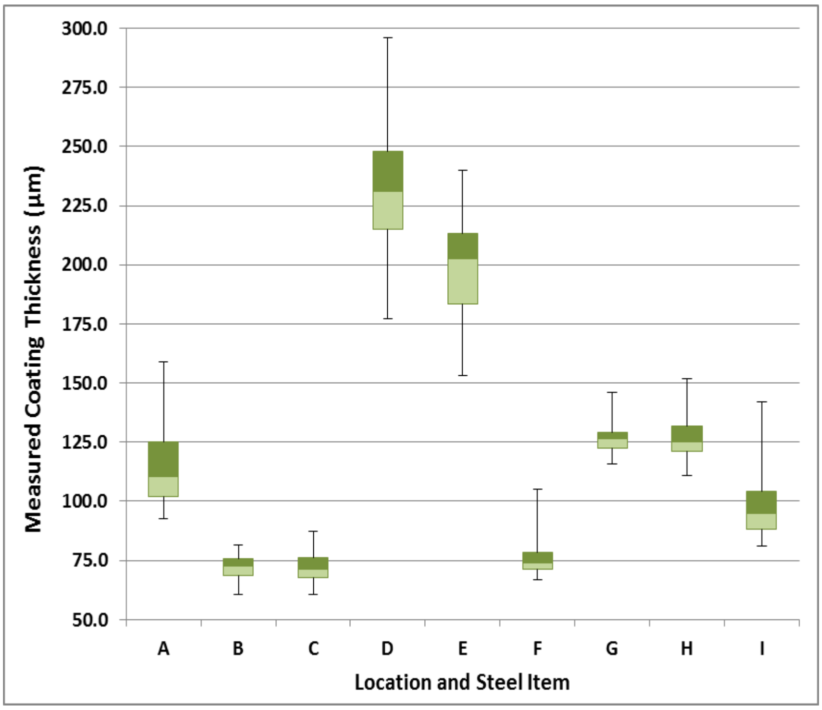


Figure 23 Curved roof to decrease wind loading and allow rain washing

The Carousel Pavilion had been open for 6 years when the last case study was performed and the steelwork was said to be in excellent condition, with all of the galvanizing being 2 to 3 times in excess of the levels required by AS/NZS 4680 [1]. A further 6 years, 12 years in total, and the hot dip galvanized coating, although weathered to a dull grey and accumulating dirt in some of the higher areas of the structure, is still performing with no signs of coating degradation. The average coating thicknesses measured were between 72µm and 233µm on steel items of varying thicknesses. (Refer to Appendix for details.) This indicates a life to first maintenance of 25 – 50 years for the structural elements of the Pavilion. The spread of coating thickness measurements on the various steel items can be seen in Figure 24.



A = Inside - side wall Mullions

B = Inside - side wall Mullions

C = Inside - back wall Mullions

D = Inside - back wall Plate

E = Inside – corner Column

F = Outside – door Channel

G = Outside – corner T-section

H = Outside – corner T-section

I = Outside – door RHS

Figure 24 Coating thickness measurements of the hot dip galvanized items at Geelong Carousel Pavilion

5.4 Case Study 4: Great Ocean Road Bridge Rails

There are a number of bridges along the Great Ocean Road, which winds its way along Victoria's south-west coast. In both the previous case study and this study, 12 of the bridge rails and safety barriers located on or next to the bridges along the Great Ocean Road were examined. It is standard for these rails to be hot dip galvanized and some are also duplex coated for aesthetic reasons.

The average measured coating thickness on the bridge rails were mostly still well above the required minimum average coating thickness stated in AS/NZS 4680. The average coating thickness on the bare galvanized rails ranged from 83µm to 224µm, with base plate thicknesses from 126µm to 333µm and the thickness of duplex painted rails were between 184µm to 348µm. See the Appendix for details on average coating thicknesses. Figure 28 shows the spread of coating thickness measurements for the bare galvanizing items and Figure 29 shows the spread of measurements for the duplex coated items.

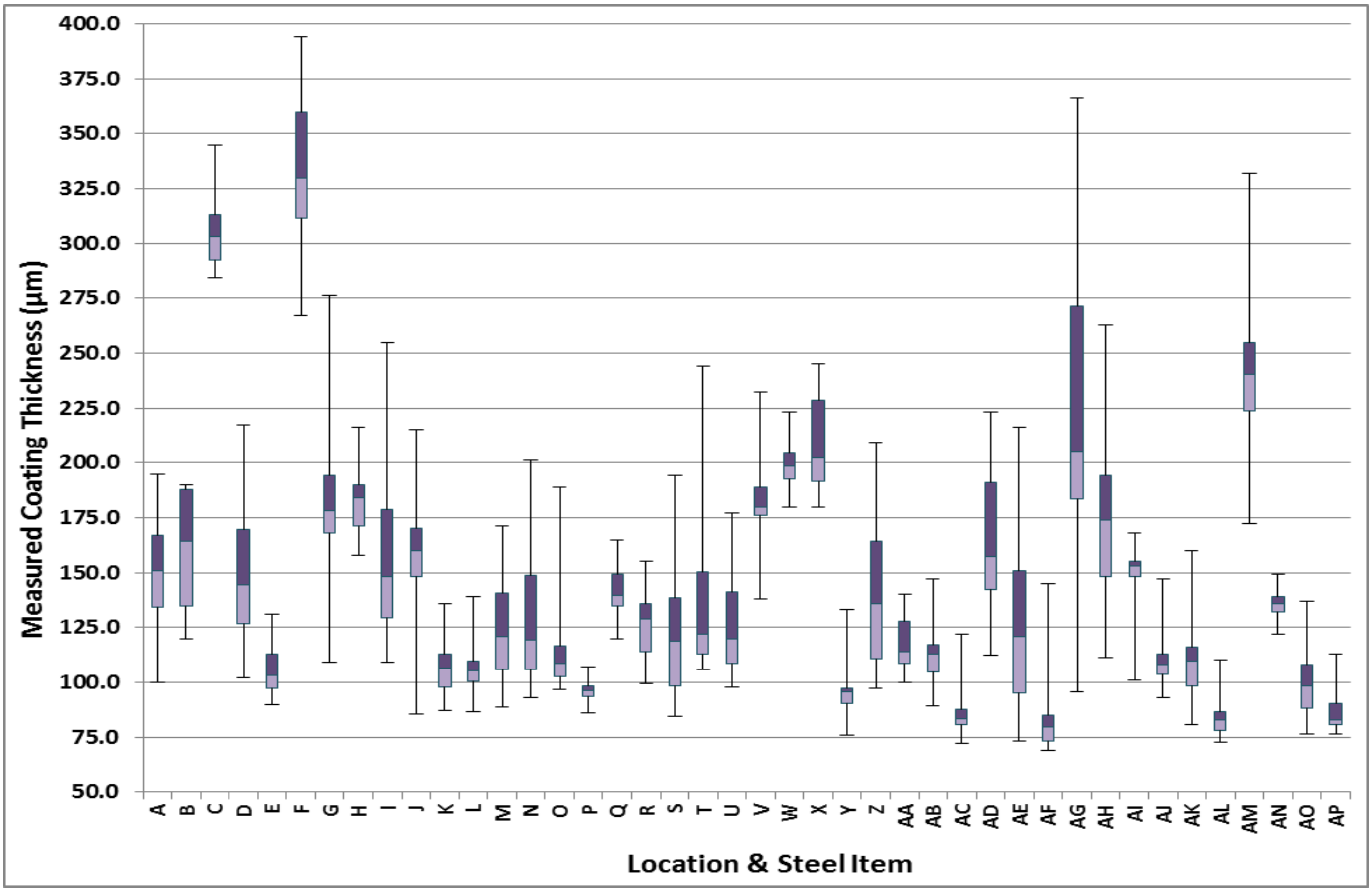
The rails examined were generally located approximately 100m to 1km from the breaking surf on the coastline and many were over estuarine waters. Due to their close proximity to the ocean, many of the rails were encrusted in salt deposits or had developed a rough patina (Figure 33). Some of the rails had been cut or welded after galvanizing and subsequently repaired with a zinc rich paint. Some of the repairs were performing with no rust visible, some looked to have been re-coated (Figure 27) and others showed visible signs of rust. Where the rails had been designed without the need for welding or cutting after galvanizing, such as when bolted connections were used (Figure 32), there were little to no signs of rusting.

The local road authority has a general life expectancy for rails of 20 years with minimal maintenance [1]. Some of the rails inspected are 15 or more years old and most are still in a reasonable condition, indicating they will achieve their expected life and more than likely surpass it by many more years.

Figure 25 Painkalac Creek bridge rails

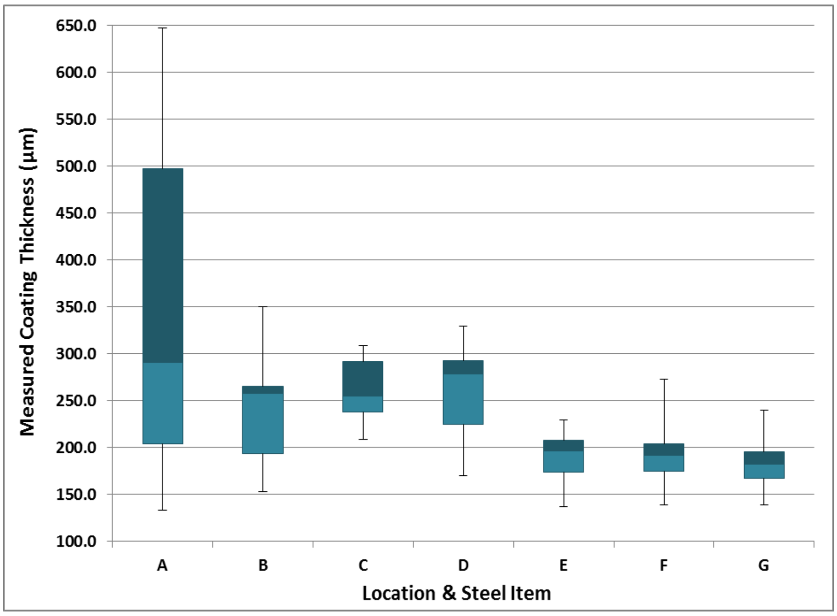
Figure 26 Reedy Creek bridge rails and road safety barriers

Figure 27 Repaired weld on bridge rail at Jamison River



A =	Painkalac Creek Rail	**O =**	Reedy Creek Rail	**AC =**	Kennett River Post
B =	Painkalac Creek Post	**P =**	Reedy Creek Post	**AD =**	Symthe Creek Rail
C =	Painkalac Creek Base plate	**Q =**	Jamison Creek Rail	**AE =**	Symthe Creek Rail
D =	Painkalac Creek Rail	**R =**	Jamison Creek Barrier end plate	**AF =**	Symthe Creek Rail
E =	Painkalac Creek Post	**S =**	Jamison Creek Rail	**AG =**	Skenes Creek Rails
F =	Painkalac Creek Base	**T =**	Jamison Creek Rail	**AH =**	Gellibrand River Barrier Post
G =	Painkalac Creek Rail	**U =**	Jamison Creek Post	**AI =**	Gellibrand River Barrier
H =	Painkalac Creek Rail	**V =**	Wye River Rail	**AJ =**	Sherbooke River Rail
I =	Painkalac Creek Rail	**W =**	Wye River Rail	**AK =**	Sherbooke River Rail
J =	Painkalac Creek Post	**X =**	Wye River Rail	**AL =**	Sherbooke River Post
K =	Grassy Creek Rail	**Y =**	Wye River Post	**AM =**	Curdie's River Barrier
L =	Grassy Creek Rail	**Z =**	Kennett River Rail	**AN =**	Curdie's River Post
M =	Reedy Creek Rail	**AA =**	Kennett River Rail	**AO =**	Hopkins River Beam
N =	Reedy Creek Rail	**AB =**	Kennett River Rail	**AP =**	Hopkins River Beam

Figure 28 Coating thickness measurements of the hot dip galvanized items at various locations along the Great Ocean Road



A = Painkalac Creek Weld repair

B = Reedy Creek Rail

C = Jamison Creek Rail

D = Jamison Creek Weld repair

E = Hopkins River Rail

F = Hopkins River Rail

G = Hopkins River Rail

Figure 29. Coating thickness measurements of the duplex coated items at various locations along the Great Ocean Road

Figure 30 Wye River bridge rails and post with bolted base plate

Figure 31 Kennett River bridge rails & safety barrier

Figure 32 Bolted joints & welding before galvanizing in bridge rail

Figure 33 Symthe Creek bridge rail with salt encrusted galvanized coating

Figure 34 Symthe Creek bridge rails - 15 years old

Figure 35 Curdie's River bridge rail with 27 year old galvanized light pole

Figure 36 Painted bottom of lightly rusted, salt encrusted galvanized light pole

Figure 37 Sherbrooke River bridge rails, posts and base plates

Figure 38 Hopkins River hot dip galvanized structural

Figure 39 Duplex coated bridge rails at Hopkins River supports for footbridge

6. CONCLUSIONS

There are a number of factors involved in determining the corrosivity of an environment and how a corrosion protection system is going to perform. Some factors can be more influential than others and for durability design it is important to understand what they are for each environment or location in order to achieve the desired results.

In these case studies, the consideration of the corrosivity of the location of each article in the design has allowed the hot dip galvanized steel to achieve the desired durability. The examples of good design solutions include the separation of different metals to prevent bimetallic corrosion and the use of bolted connections. The designed use of perforated metal in the Carousel Pavilion's roof was a solution for both wind loading and elimination of unwashed areas. Also, the overall design for minimal use of on-site modifications reduced the need for repair of hot dip galvanized articles. All of these specific design solutions helped to reduce the effects of micro-environments experienced by the hot dip galvanized steel articles in a coastal environment.

The four case studies in this paper all show that hot dip galvanizing can be an effective corrosion protection system in a coastal environment as well as in other more severe conditions when the relevant factors are taken into account.

7. ACKNOWLEDGMENTS

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8. REFERENCES

1. Pimentel, E. The Performance of Galvanized Steel in Coastal Environments. In: The 7th Asia Pacific General Galvanizing Conference; Sept. 14-17, 2007; Beijing, China 2007. p48-56.

2. The Department of Sustainability, Environment, Water, Population and Communities. State of the Air in Australia. Canberra: Australian Government Publishing Service; 2011. 202 p.

3. International Organization for Standardization. Corrosion of metals and alloys - Corrosivity of atmospheres - Classification, determination and estimation. 2012; ISO 9223:2012; Available from: International Organization for Standardization Online.

4. International Organization for Standardization. Corrosion of metals and alloys - Corrosivity of atmospheres – Guiding values for the corrosivity categories. 2012; ISO 9224:2012; Available from: International Organization for Standardization Online.

5. Porter, F C. Corrosion Resistance of Zinc and Zinc Alloys. New York: Marcel Dekker, Inc.; 1994. Table 2.16, Zinc Corrosion Reactions in Different Atmospheres; p. 140.

6. Uhlig, H H., Blum, W., Waldron, L J. The Corrosion Handbook. New York: John Wiley & Sons, Inc.; 1961.

7. Australia's official weather forecasts & weather radar - Bureau of Meteorology; Climate and past weather; http://www.bom.gov.au/climate/. Last accessed 18 June 2013.

8. Standards Australia. Hot-dip galvanized (zinc) coatings on fabricated ferrous articles. 2006; AS/NZS 4680:2006; Available from: Standards Australia Online.

9. Industrieverband Feuerverzinken, Korrosionsverhalten Von Zinküberzügen An Der Atmosphäre; http://www.feuerverzinken.com/wissen/arbeitshilfen/arbeitsblaetter/arbeitsblatt-54/; Last accessed 27 June 2013.

10. Portland Tourist Association. Portland & The Discovery Coast - Official Visitor Guide. Glenelg Shire Council; 2011.

11. Barwon Water, Water recycling and sewage; http://www.barwonwater.vic.gov.au/learning/recycling; Last accessed 18 June 2013.

12. Geelong Australia - City of Greater Geelong, Carousel; http://www.geelongaustralia.com.au/ct/service/article/item/8cb648bed8b5a72.aspx; Last accessed 18 June 2013

13. Intown Geelong - online entertainment, leisure, tourist & city guide, Geelong Waterfront Carousel; http://www.intown.com.au/locals/geelong/attractions/carousel.htm; Last accessed 18 June 2013.

9. AUTHOR DETAILS

Ann is the Corrosion and Sustainability Officer at the Galvanizers Association of Australia (GAA). She was employed by the GAA at the start of 2009 and working part-time while completing her Bachelor of Applied Chemistry, which she obtained in 2010. With the support of the association, she obtained First Class Honours in Applied Science from RMIT University in 2012, with her thesis entitled 'Characterisation and Quantification of Chromate Coating on Galvanized Steel'. Ann is also a NACE Certified Level 2 Coating Inspector. Ann started working full-time at the GAA in early 2012.

APPENDIX

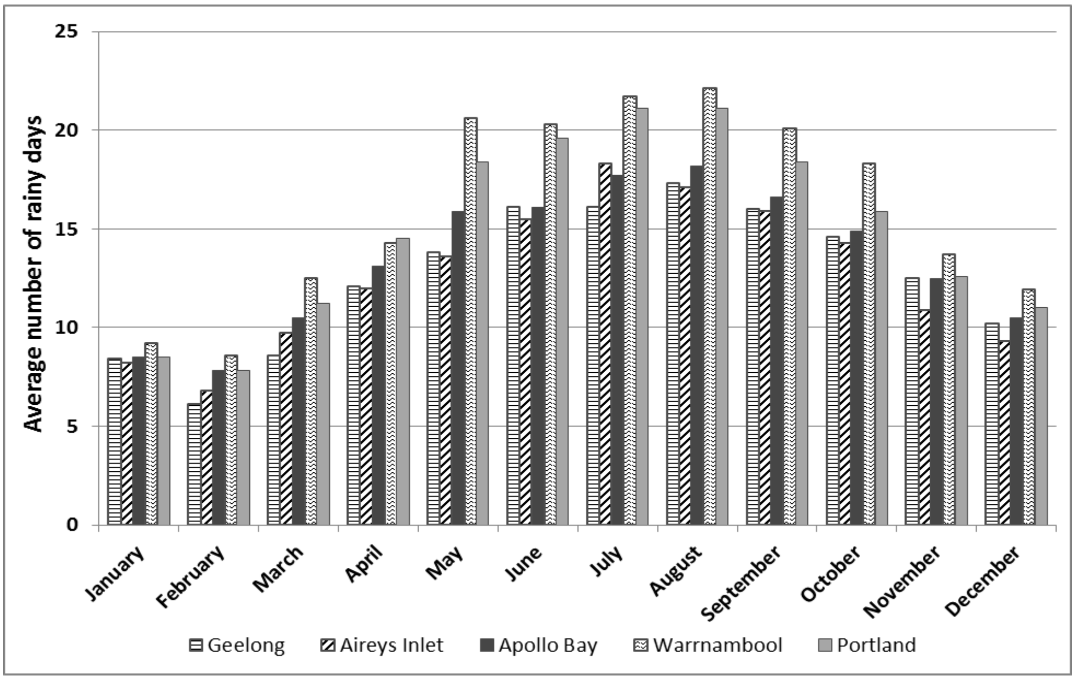

Figure a. Average number of rainy days per month along Victoria's south west coast [7]

Table A. Mean daily solar exposure (MJ/m^2) for years 1990 to 2013 [7]

Location	Autumn	Winter	Spring	Summer	Annual
Geelong (Norlane)	11.8	7.7	18.1	23.4	15.3
Barwon Heads (Golf Club)	12.5	8.0	18.7	24.3	15.9
Aireys Inlet	11.6	7.5	18.2	23.4	15.2
Apollo Bay	10.9	7.0	17.3	22.0	14.3
Warrnambool (Airport NDB)	11.7	7.4	18.0	23.7	15.2
Portland	11.8	7.5	18.6	23.5	15.4

Table B. Hot dip galvanizing coating thickness measurements at the Portland Maritime Discovery Centre

Location	Steel Item	Average Coating Thickness (µm)
Plant Room	I-beam (flange)	189
Plant Room	I-beam (web)	140
Outside - Bayside	I-beam (flange)	112
Outside - Bayside	I-beam (web)	111
Outside - Bayside	Stanchion	205
Inside – Deck (support)	I-beam	149
Outside - Entrance	I-beam (flange)	147
Outside - Entrance	I-beam (web)	160

Table C. Hot dip galvanizing coating thickness measurements at the Black Rock Water Reclamation Plant

Location	Steel Item	Average Coating Thickness (μm)
Aeration tanks – west side	Pipe	118
Aeration tanks – west side	Pipe	233
Aeration tanks – west side	Pipe	131
Below ground -Stairs	RHS	84
Below ground -Stairs	RHS	194
Below ground	Pipe	203
Settling tanks	Pipe	129
Settling tanks	Pipe	77
Biosolids dewatering facility	Machine cage	94
Biosolids dewatering facility	Machine cage	185
Biosolids dewatering facility	Kick Plate	215
Biosolids dewatering facility	Side of grating	118
Oxygen dissolver - Stairs	Channel	291
Oxygen dissolver - Stairs	Grating	121
Oxygen dissolver - Stairs	Channel	228
Beside aeration tanks – west side	Gantry (I-beams)	162
Support for overhead pipe & cables	Column	182
Support for overhead pipe & cables	I-beam	126
Support for overhead pipe & cables	Bolts	70
Between biosolids drying facility & aeration tanks	I - beam	159
Between biosolids drying facility & aeration tanks	I - beam	319
Fine screening building – stairs	Channel (duplex coated)	317
Fine screening building - stairs	Channel	110
Fine screening building - stairs	Channel	162
Stairs – below ground, far east side	Channel	168
Aeration tanks – east side	Pipe	170
Aeration tanks – east side	Bolts	71
Aeration tanks – east side	Pipe	91
Aeration tanks – east side	Pipe	171
Aeration tanks – east side	Pipe	150

Table D. Hot dip galvanizing coating thickness measurements at the Geelong Carousel Pavilion

Location	Steel Item	Average Coating Thickness (μm)
Inside - side wall	Mullions	115
Inside - side wall	Mullions	72
Inside - back wall	Mullions	72
Inside - back wall	Plate	233
Inside - corner	Column	201
Outside – door	Channel	77
Outside – corner	T-section	126
Outside – corner	T-section	127
Outside – door	RHS	97

Table E Hot dip galvanizing coating thickness measurements of the Great Ocean Road bridge rails and safety barriers (Note: the rail and posts were generally made from RHS sections)

Location	Steel Item	Average Coating Thickness (μm)
Painkalac Creek	Rail	164
	Post	160
	Base plate	306
	Paint repair	348
	Rail	148
	Post	105
	Base	333
	Rail	181
	Rail	182
	Rail	157
	Post	153
Grassy Creek	Rail	108
	Rail	106
Reedy Creek	Rail	125
	Rail	128
	Rail	117
	Post	96
	Paint	239
Jamison Creek	Rail	141
	Barrier end plate	126
	Painted rail	260
	rail	123
	Rail	135
	Post	126

	Paint	261
Wye River	Rail	181
	Rail	199
	Rail	209
	Post	97
Kennett River	Rail	141
	Rail	118
	Rail	112
	Post	85
Symthe Creek	Rail	164
	Rail	126
	Rail	83
Skenes Creek	Rails	224
Gellibrand River	Barrier Post	172
	Barrier	150
Sherbooke River	Rail	111
	Rail	111
	Post	84
Curdie’s River	Barrier	239
	Post	136
Hopkins River	Beam	99
	Beam	88
	Rail (duplex)	191
	Rail (duplex)	195
	Rail (duplex)	184