Sustainable Construction

- A Guide on Corrosion Protection for Steel Structures

BCA Sustainable Construction Series - 5

Building and Construction Authority

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CONTENT

FOREWORD

Structural steel is well recognised as an excellent construction material. In an era where more emphasis is placed on the reusability and recyclability of materials, steel certainly fit the bill. Steel can be recycled repeatedly without any degradation in performance or properties. Amongst all construction material, steel has one of the highest strength to weight ratio. Steel can span long distances offering larger open space and greater design flexibility. It is fast to construct and highly buildable and this minimizes any possible impact to the surroundings during construction.

To ensure that steel structures offer optimal performance during their life span, careful consideration on corrosion protection and fire protection are important. Earlier this year, BCA published A Guide on Fire Protection and Performance-based Fire Engineering. This Guide, fifth in the Sustainable Construction series, is developed to address concerns on corrosion protection. It provides useful information on the application of different corrosion protection methods, the inspection and maintenance aspects of protected steel structures and detailing on how to minimize corrosion.

This Guide is the product of a close partnership between public sector agencies, private sector organisations and institutions of higher learning. I would like to put on record my appreciation to the Working Committee for contributing towards this Guide. I am confident that the industry will find this Guide useful.

Dr John Keung
Chief Executive Officer
Building and Construction Authority

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BCA is grateful to the members of the Working Committee for their assistance and inputs for this Guide.

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Introduction

Definitions and Abbreviations

The following terms and definitions are used in this guidebook:

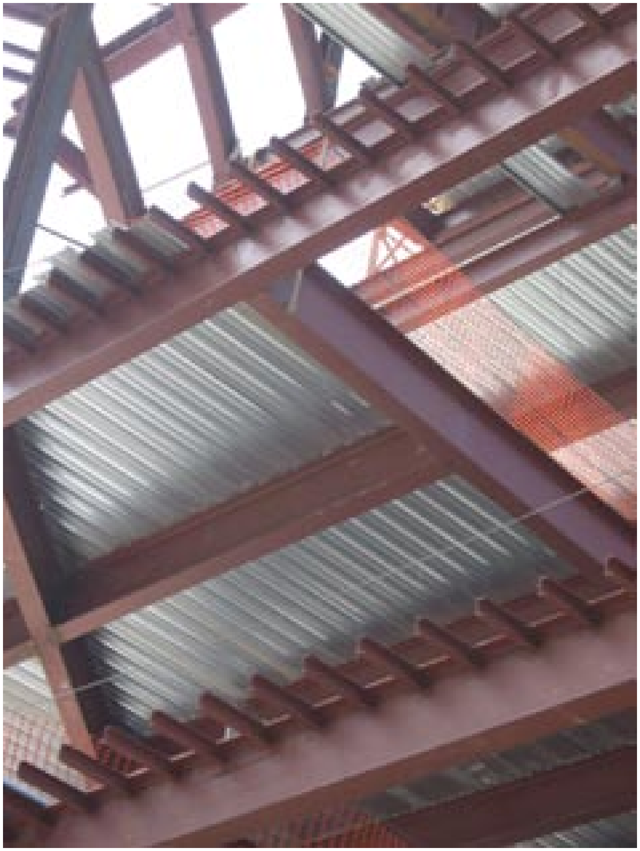
Dry film thickness (DFT)	The measured thickness of the final dried film applied to the substrate
Wet film thickness (WFT)	The initial thickness of the wet coating applied to the substrate
Volatile organic content (VOC)	Volatile organic content (VOC) is the weight of organic solvent per litre of paint. Legislative requirements differ from country to country and from region to region.

Applications of Steel

Steel sections are rolled or formed into a variety of cross-sections, such as universal beams, universal columns, rectangular hollow sections and angles. The majority of these cross-sections are obtained by hot rolling of steel billets in a rolling mill, while a minority, sometimes involving complex shapes, are cold formed from steel sheets.

Hollow sections are obtained by extrusion or by bending plates to the required cross section, and seaming (welding) them to form tubes. The sections are usually produced in a variety of grades of steel having different strengths and other properties.

The metallurgical process of **Hot rolling**, used mainly to produce sheet metal or simple cross sections from billets, describes the method when industrial metal is passed or deformed between a set of work rolls and the temperature of the metal is generally above its recrystallization temperature (i.e. half the melting point), as opposed to cold rolling, which takes place below this temperature. Hot rolling permits large deformations of the metal to be achieved with a low number of rolling cycles.



Building constructed using hot rolled sections

Because the metal is worked before crystal structures have formed, hot-rolling does not affect the the metal's microstructural properties. Hot rolling is primarily concerned with manipulating material shape and geometry rather than mechanical properties. This is achieved by heating a component or material to its upper critical temperature and then applying controlled load which forms the material to a desired specification or size.

Hot-rolled steel members are usually used for structural load-bearing members, such as columns, beams and other forms of load-bearing elements such as trusses and frames.

Cold formed hollow sections used at Changi Airport Terminal 3 roof structures

Cold formed square hollow sections

Cold-formed (sometimes known as cold rolling) is a metal working process in which metal is deformed by passing it through rollers at a temperature below its recrystallization temperature. Cold rolling increases the yield strength and hardness of a metal by introducing defects into the metal's crystal structure. These defects prevent further slip and can reduce the grain size of the metal, resulting in Hall-Petch hardening.

Cold rolling is most often used to decrease the thickness of plate and sheet metal. While cold rolling increases the hardness and strength of a metal, it also results in a large decrease in ductility. Thus metals strengthened by cold rolling are more sensitive to the presence of

Light gauge steel frame used in the construction of landed houses

cracks and are prone to brittle fracture. In contrary, hot rolled steel is created without the hardening effect. It may be less hard, but is much more pliable and resistant to fracture.

A metal that has been hardened by cold rolling can be softened by annealing. Annealing will relieve stresses, allow grain growth, and restore the original properties of the alloy. Ductility is also restored by annealing. Thus, after annealing, the metal may be further cold rolled without fracturing.

Cold-formed steel can be found in secondary building components such as purlins, roof trusses, channels and minor structures such as walkways.

In recent years **light gauge steel frame system** has increasingly been used in landed residential houses. This light gauge steel frame is developed through a cold-formed process without the use of heat. This process enables steel manufacturers to produce light-weight but high tensile steel sheets. The sheet surface is coated with a zinc alloy or zinc and aluminium alloy that completely covers the steel surface and seals it from the corrosive action of its environment.

The light gauge steel frame systems are lightweight and consequently easy to assemble and install. Prefabrication and modern fixing techniques further speed up its construction, and enhances on site productivity.

Stainless Steel

Stainless steel is the most corrosion resistant steel used in construction. Stainless steel is a solid material and not a special coating applied to ordinary steel to give it “stainless” properties. Stainless steel contains a minimum of 11% chromium that produces a thin protective oxide film on the surface that protects the material from corrosion. If damaged, this protective layer simply re-forms.

While the original form of stainless steel (iron with minimum 11% chromium) is still in widespread use, designers now have a wide choice of different types (grades) of stainless steel. In all, there are more than 100 different grades but these are usually sub-classified into distinct metallurgical “families” such as austenitic, ferritic, martensitic and duplex families.

Stainless steel is rarely used as structural steel in an entire building but is used in some specific structural products such as suspension rods, tie-backs, lintels and masonry support systems. Stainless steel is more commonly used in architectural components such as claddings, escalators, doors, railings, etc.

The most commonly used stainless steel for architectural applications are Type 304 and 316. The 300-series stainless steel, such as Type 304 and 316, are iron-chromium-nickel alloys. They have austenitic microstructure, which combines strength and ductility, and are non-magnetic. The low carbon grades, Type 304L and Type 316L, improve weld corrosion resistance when the section thicknesses are greater than 6mm. The general corrosion resistance of Type 304 is equivalent to Type 304L, and Type 316 is equivalent to Type 316L.

Type 430 is less corrosion-resistant and less frequently used in exterior applications. The 400-series stainless steel, such as Type 430, are iron-chromium alloys, have a ferrritic microstructure and are magnetic.

Highly alloyed stainless steel is sometimes needed for aggressive environments as the corrosion resistance and mechanical properties of these grades span a broad range.

Stainless steel is rarely used for structural steel but used mostly for roofing, claddings and other internal applications. Photo of Kranji Racecourse taken by Chadwick Technology

Rural Sites

Locations categorized as "rural" are not exposed to industrial atmospheric discharges or coastal or deicing salts. Suburban areas with low population densities and light, non-polluting industry may also be categorized as rural.

Urban Sites

Urban sites include residential, commercial and light industrial locations with low to moderate pollution from vehicular traffic and similar sources.

Industrial Sites

Industrial sites are locations with moderate to heavy atmospheric pollution usually in the form of sulphur and nitrogen oxides from coal combustion and gases released from chemical and process industry plants.

Coastal and Marine Sites

Seawater contains a mixture of salts. It is typically 2.5 to 4% sodium chloride with smaller quantities of magnesium chloride, calcium chloride, and potassium chloride. Chlorides in airborne sea spray and dry salt particles may cause pitting and rusting of stainless steel unless high corrosion-resistant grade is chosen. Evaporation and infrequent rain increase salt concentrations on exterior surfaces and corrosion rates.

Stainless steel suspension rods

Table 1: Grade Selection Guidelines

Grade (Type)	Location											
	Rural/Suburb			Urban			Industrial			Marine/Deicing Salt		
	L	M	H	L	M	L	L	M	H	L	M	L
Highly Alloyed	■	■	■	■	■	■	■	■	▲	■	■	▲
316 316 L	■	■	■	■	▲	▲	▲	▲	(▲)	▲	▲	(▲)
304 304 L	▲	▲	▲	▲	▲	(▲)	(▲)	(▲)	╬	▲	(▲)	╬
430	▲	(▲)	(▲)	╬	╬	╬	╬	╬	╬	╬	╬	╬

L Least corrosive conditions within that category due to low humidity and low temperatures

M Fairly typical of category

H Corrosion is likely to be higher than typical for the category due to persistently high humidity, high ambient temperatures and/or particularly aggressive air pollution

■ Good service, but may be over-specified

▲ Most economical choice

╬ Corrosion likely

( ) Indicates that the grade may be suitable if a smooth surface finish is selected and it is washed regularly

Built-up Sections

Built-up sections are steel sections fabricated from plates. Built-up sections are usually used when the resulting bending moments are larger than the moment capacity of available rolled sections. Buildings with complex and complicated designs may need to resort to built-up sections, since conventional rolled sections will not have sufficient capacities.

One advantage of using built-up sections is the optimal use of materials as compared to rolled sections. The designer has greater freedom to vary the section to respond to a change in the applied forces, since the section is fabricated from plates. Not withstanding the advantages, built-up sections are heavier and can be more difficult to transport. The provision of openings for services in boxed-up sections is also more difficult.


An example of a built-up section

Corrosion Protection Methods

What is Corrosion?

Corrosion is the destruction of a metal by its reaction with the environment. This reaction is an electrochemical oxidation process that usally produces rust or other metal oxide. Therefore, the main purpose of protection is to provide a barrier between the metal and the environment that is necessary for corrosion to occur.

The protective treatment of bolts, nuts and other parts of the structural connections also require careful consideration. Ideally their protective treatment should be of a standard at least equal to that specified for the general surfaces.

Corroded steel sections

Where high performance paint systems are to be used, it is worth considering hot dip spun galvanised or stainless steel fasteners.

In all cases the coating must be free of pinholes or other discontinuities and of sufficient thickness to prevent the environment from reaching the metal.

Surface Preparation

The surface preparation of the steelwork has a major influence in determining the protective value of the coating system.

For galvanising and metal spraying, surface preparation is an integral part of the process and is included in national standards for these operations. With paint systems there is usually a choice of preparatory methods. Therefore the actual method chosen for a specific job must be specified as part of the protective coating treatment.

The choice between blast-cleaning and manual cleaning is partly determined by the nature of the coatings to be applied. Coatings applied to a degreased blast-cleaned surface always last longer than similar coatings applied to manually cleaned surfaces. However, some short-life coatings do not warrant the high cost of blast-cleaning

Manual blasting of steel sections

as required for long-life coatings. Details of methods for blast cleaning surfaces are given in ISO 8504.

In cases where solvents are used to remove the surface contaminants, the operators should refer to the "Guidelines on Solvent Degreasing" issued by the Ministry of Manpower (MOM).

Blast Cleaning

Abrasive particles are directed at high velocity against the metal surface. They may be carried by compressed air or high-pressure water, or thrown by centrifugal force from an impeller wheel. For some open blasting, high pressure water without abrasives may be used.

The choice of blast-cleaning method is determined by the following factors.

a. Shape and size of steelwork

Centrifugal methods are economic for plates and simple sections; they can also be used for large prefabricated sections, e.g. bridge sections, but only in specially designed plants. 'Misses' discovered by inspection can be cleaned with open-blast techniques. For large throughput of shaped items, e.g. pipes, both open and vacuum blasting techniques can be used in continuous and automatic plants.

b. Effect of the stage at which cleaning is carried out

For blast-cleaning on site, open or vacuum-blasting methods have to be used on large fabricated sections. It is usually impractical to use centrifugal methods.

c. Throughput

Centrifugal plants are economic for a high throughput, but even with a low throughput the method may still be preferable to large-scale open cleaning.

d. Environmental conditions

Despite its relatively high cost, vacuum blasting may be necessary to avoid contamination of the immediate area with abrasive. It should be ensured that the blast-cleaning process does not affect adjacent materials.

e. Types of surface deposit to be removed

Wet-blasting methods, with abrasives, are particularly suitable for removing entrapped salts in rust and for abrading old, hard painted surfaces, e.g. two-pack epoxies, before recoating.

For new structures, blast cleaning can be carried out before or after fabrication. When it is before fabrication, a "blast" or "holding" primer is applied to prevent corrosion during fabrication. Areas damaged during fabrication, e.g. by welding, require re-preparing and priming as soon as possible.

Blast Cleaning Standard

ISO 8501-1 1988 is a visual standard which shows different degrees of blast cleaning on four levels of rusting. The reference prints are in colour and the standard is based on the widely used Swedish Standard SIS055900. It is used to specify and control the standard of abrasive blast cleaning required.

Corrosion Protection Methods

The level and choice of the type of corrosion protection method to be adopted depends on the building usage, environments and corrosion risks (See Table 2).

Table 2: Atmospheric Corrosivity Categories and Examples of Typical Environments (ISO 12944 Part 2)

Corrosivity category and risk	Mass loss per unit surface/ thickness loss (see Note 1)	Examples of typical environments in a temperate climate (informative only)	
	Low carbon steel thickness loss µm	Exterior	Interior
C1 Very low	≤ 1.3	--	Heated buildings with clean atmospheres. E.g. offices, shops, schools, hotels
C2 Low	> 1.3 – 25	Atmospheres with low level of pollution. Mostly rural areas	Unheated buildings where condensation may occur, e.g. depots, sports halls
C3 Medium	> 25 - 60	Urban and industrial atmospheres, moderate sulphur dioxide pollution. Coastal area with low salinity	Production rooms with high humidity and some air pollution, e.g. food-processing plants, laundries, breweries, dairies
C4 High	> 50 - 80	Industrial areas with high humidity and moderate salinity	Chemical plants, swimming pools, coastal, ship and boatyards
C5-I Very high (industrial)	> 80 - 200	Industrial areas with high humidity and aggressive atmosphere	Buildings or areas with almost permanent condensation and high pollution
C5-M Very high (marine)	> 80 - 200	Coastal and offshore areas with high salinity	Buildings or areas with almost permanent condensation and high pollution

Table is extracted from Page 1308 of The Steel Designers' Manual, 6th Edition. Permission granted by The Steel Construction Institute and Blackwell Publishing

1. *The thickness loss values are after the first year of exposure. Losses may reduce over subsequent years.*
2. *The loss values used for the corrosivity categories are identical to those given in ISO 9223*
3. *In coastal areas in hot, humid zones, the thickness losses can exceed the limits of categories C5-M. Special precautions must therefore be taken when selecting protective paint systems for structures in such areas.*
   1 µm = 0.001 mm

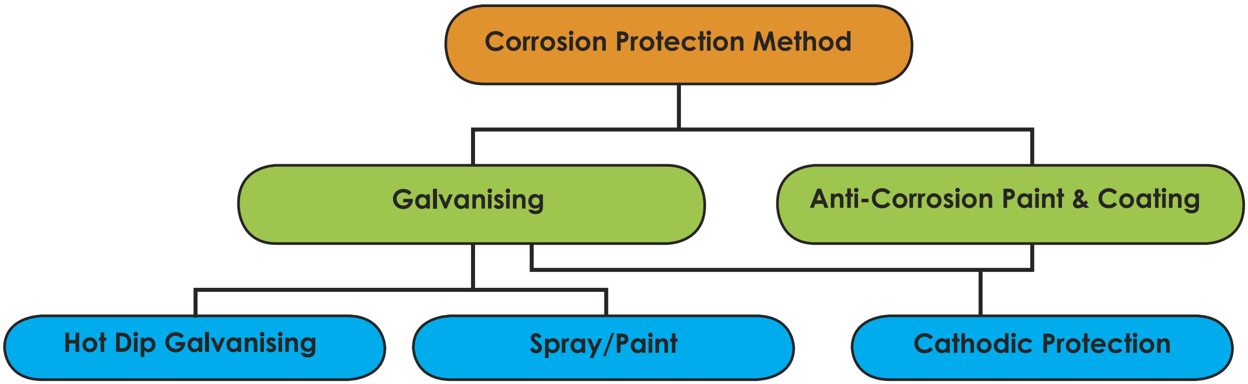
The required corrosion protective system (typically paint coating, galvanising or both) at various locations of the building should be indicated clearly in the drawings.

For paint coatings, the recommended thickness for protective coating systems for various environments are given in Annex A of EN ISO 12944-5. For galvanised protective system, while the recommended thickness for various environments are given in Table 2 of BS EN ISO 14713, one should also account for the rate of corrosion as indicated in Table 1 of BS EN ISO 14713.

As metals are constantly exposed to a corrosive environment which includes marine, chemicals and other pollutants, an effective barrier is imperative over the metal surface to maintain the structure and prolong its life.

In Singapore, the most commonly used corrosion protection systems are galvanising or anti-corrosion paint system. The galvanising methods can be further categorised into hot dip galvanising with/without spray/paint.

For smaller fixtures such as bolts and door handles, electroplating can be used to provide corrosion protection but its performance will be lower.



Hot Dip Galvanising

Hot dip galvanising is considered one of the most common and cost effective metallic coating used to protect steel construction. Very simply, the process involves coating the surface of the steel with a corrosion-resistant metal, usually zinc or an aluminium/zinc alloy.

The molten zinc of the galvanising bath covers corners, seals edges, seams and penetrates recesses to give complete protection to potential corrosion spots.

Surface Preparation

Rust, scale, oil and other surface contaminants are carefully removed from steelworks by pickling in dilute sulfuric acid.

Fluxing

The prepared steel is lowered into the bath of molten zinc through a floating layer of flux (which is ammonium chloride). The flux dissolves and absorbs any remaining impurities, moisture or oxide film on the metal surface and ensures that clean steel contacts the molten zinc the moment it enters the bath.

Galvanising

Upon immersion in the bath, the surface of the steel is immediately wetted by the molten zinc and reacts to form zinc-iron alloy layers. To allow formation of the galvanised coating, the steel section must remain in the bath until the temperature of the steel reaches 450°C. The steel section is then withdrawn from the zinc bath at a controlled rate and carries with it a coating of molten zinc which solidifies to provide the relatively pure outer zinc coating. The result is a tough, zinc and zinc iron alloy coating, metallurgically bonded to and completely covering the base steel.

When higher strength steel is to be galvanised, suitable precautions should be taken to minimise the risk of critical weld cracking.

Hot dip galvanised surface

The Galvanising Process

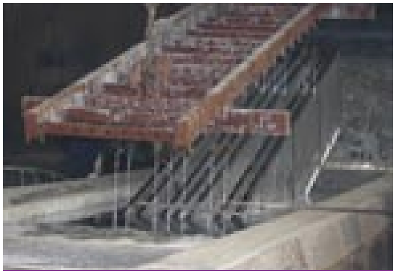

Step 1: Preparation


Step 2: Degreasing


Step 3: Pickling


Step 4: Rinsing


Step 5: Pre-Flux


Step 6: Galvanising Bath


Step 7: Quenching


Step 8: Finishing

Step 1

Preparation for galvanising: Items are tied and prepared on jig. Safety checks for drainage holes for structure items and fabricate pipes.

Step 2

Soil and grease removal: Hydronet Degreaser is used to remove oil and grease.

Step 3

Scale removal or pickling: Subsequently the steel passes through an acid bath to remove surface rust and mill scale to produce a clean metallic surface.

Step 4

Rinsing: To remove acid and iron salt.

Step 5

Prefluxing: The cleaned steel is next immersed in a hot flux solution (usually mixture of film flux and zinc ammonium chloride) to prevent oxidation and ensure that the surface is chemically clean before its immersion in molten zinc.

Step 6

Hot Dip Galvanising: The steel section is next immersed in molten zinc where it immediately reacts to form the zinc-iron alloy layers on its surface. The period of immersion depends solely on the zinc and weight of the steel product.

Step 7

Quenching: The steel section is then withdrawn at a controlled speed. In addition to the zinc/iron alloy layers, a coating of relatively pure zinc solidifies at the surface when chilled in water. This total zinc coating is metallurgical bonded to steel, completely covering the whole section.

Step 8

All materials are transferred to the de-racking section for final inspection and touch up of any bare spots and removal of sharp edges.

Galvanising Thickness

The minimum coating thickness is stipulated in ISO 1461:1999 "Hot dip galvanized coatings on fabricated iron and steel articles – Specifications and test methods".

Table 4 – Coating minimum thickness on galvanised steel (not centrifuged)

Article and Its Thickness	Local coating thickness (minimum)[a] µm	Mean coating thickness (minimum)[b] µm
Steel ≥ 6 mm	70	84
Steel ≥ 3 mm to < 6 mm	55	70
Steel ≥ 1.5 mm to < 3 mm	45	55
Steel <1.5 mm	35	45
Castings ≥ 6 mm	70	80
Castings < 6 mm	60	70

[a] *The mean value of coating thickness obtained from the specified number of measurements within a reference area for a magnetic test or the single value from a gravimetric test.*

[b] *The average value of the local thickness either on one large article or on all the articles in the control sample.*

Inspection and Testing of Galvanised Coatings

Visual inspection is the simplest and most important means of assessing the quality of hot dip galvanised coatings. This serves to pick out superficial defects and provide information about faults in the process. The coating must be smooth, reasonably bright, continuous and free from major imperfections such as flux, ash, and dross inclusions.

Although the dross trapped in the galvanised coating may give the coating a rough or gritty appearance, its presence is not detrimental to the coating's performance as the corrosion resistance of zinc dross is identical to that of the galvanised coating.

Coating thickness measurement (eddy current)

Touch-up and Repair

Applying zinc-rich paint to the steel surface gives corrosion protection to the underlying steel. This process is also used to touch-up or repair galvanised coatings. When the uncoated areas exceed 0.5% of total surface of a member or 10 cm^2, the component has to be re-galvanised, unless otherwise agreed between the purchaser and the galvaniser.

Alternatively, repair uncoated areas by using zinc thermal spraying in accordance with BS EN 22063 or zinc rich primer to BS 4652. Zinc rich paints are a form of zinc coating that are widely used for touch-up and repair of damaged galvanised coatings because of their relative ease of application. Zinc-rich paints can provide very good protection if used in accordance to the above Standards.

Fixings can also be hot dip galvanised and this provides superior protection compared to other methods of metallic coating, eg electroplating. Due to the thickness and robustness of the galvanised coatng on the fixings, check after galvanising to ensure free running on the bolt. Re-tap nuts, if necessary, to ensure satisfactory tightening. There will still be adequate protection on the inside of the nut due to its contact with the galvanised bolt thread.

Stage 1: Blow-out from over lapping area on this fabrication has caused a galvanized coating defect

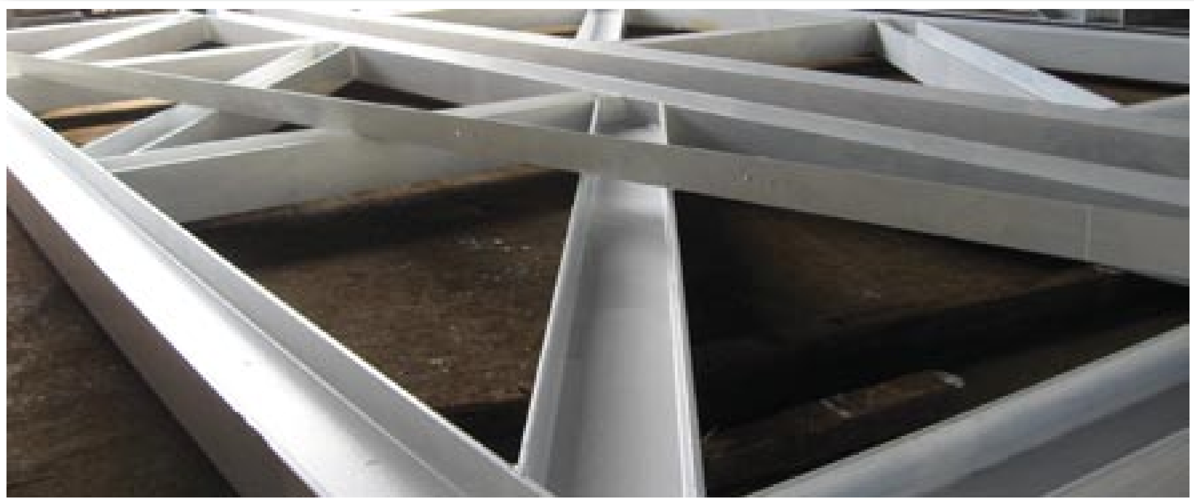
Stage 2: Surface to be repaired is cleaned by grinding

Stage 3: Repair uncoated areas using zinc thermal spray or zinc rich primer

Painting of Hot Dip Galvanised Steel

The standards referred to is ISO 12944-5 Paints and Varnishes - Corrosion protection of steel structures by protective paint systems - Part 5: Protective paint systems. Below is an example of a paint system:

Prior to painting, the surface has to be degreased by using a detergent wash or steam cleaning followed by etch priming with T-wash. For the barrier coat, Epoxy Micaceous Iron Oxide (MIO) can be applied at 100 microns minimum DFT (Dry Film Thickness). For the finishing coat, use Acrylic Polyurethane 50 microns minimum DFT.



Painted galvanised steel section

Anticorrosion Paint & Coating

Painting is basically the first line of defense or barrier against corrosion, and this is why all paint manufacturers call it protective coating. It protects the substrate from onset of corrosion.

For each type of corrosion protection requirement, an individual paint or a combination of paint systems can be used. The success of any paint application depends on several factors, namely

- Sustainability
- Surface preparation
- Film thickness applied
- Methods of application
- Conditions during application

Sustainability

Before a painting system is even applied, working with the manufacturer early in a project will ensure the painting system used is fit for purpose and its life span is maximised. For example, if the life of a painting system is lower than the design life of the structure then it is inevitable that at some point, the painting system will need to be replaced – sometimes on more than one occasion.

Choose a long lasting coating system for structures such as bridges, as maintenance may involve re-blasting and re-applications of coatings and this may not be feasible to implement

Such maintenance may constitute major refurbishment involving the re-blasting and re-application of coatings, which is not always ideal for buildings, bridges or sports stadia and means that more non-renewable materials and energy will be consumed reinstating the painting system.

Correctly and realistically specifying long lasting systems (both in terms of corrosion and colour/gloss durability) at the early design phase helps to limit the environmental impact of corrosion protection over the lifetime of an asset and reduce future maintenance.

Surface Preparation

Surface cleanliness and preparation are essential for the success of any protective paint. The performance of any paint coating is directly dependent upon the correct and thorough preparation of the surface prior to coating. The most expensive and technologically advanced coating system will fail if the surface preparation is incorrect or incomplete.

Good surface preparation requires selection of right abrasive/right equipment/skilled operator and a good Inspector. Typically a coating system can last for 20 years with proper surface preparation.

BS EN ISO 12944:1998 standard gives guidelines on surface preparation, paint system types, environmental corrosivity categories and durabilities.

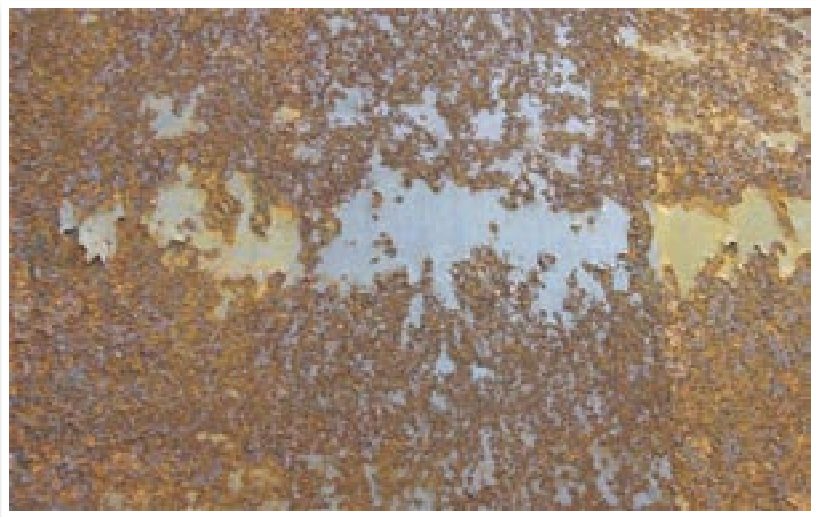
The surface cleanliness at the time of coating is to be in accordance with BS 7079 Part A1, Grade Sa 2-1/2.

After surface preparation the surface roughness is to be compatible with the coating to be applied in accordance with BS 7079 Part C2.

Measure the surface profile of the steelwork to be coated using the methods in BS 7079 Part C2. If necessary, rectify all defects during surface preparation using the methods in BS 7079 Part C2.

Sa 2-1/2 surface

Removal of Contaminants



Surface contaminants such as rust are to be thoroughly removed

The surface to be painted must be completely cleaned before painting, as the roughness of the steel surface will influence the adhesion of the paint and the corrosion protection. Surface contaminants such as salts, oils, grease, rust and millscale are to be thoroughly removed. The most common method is by solvent washing, followed by wiping dry with clean rags. Proprietary emulsions, degreasing compounds and steam cleaning are also commonly used.

Loosely adhering millscale, rust and old paint coatings may be removed from steel by hand wire brushing, sanding, scraping and chipping. However these methods may not be that effective and likely to leave a layer of tightly adhering rust on the steel surface. Power tool cleaning will be more effective and less laborious than hand tool cleaning.

For application on a new smooth surface, abrasive blasting is necessary to take away mill scale and to obtain the desired roughness (or "surface profile") to ensure coating adhesion.

For application on old, galvanised or rusty surfaces, loose particles must be removed and the surface should be degreased. In the case of a painted surface, the paint must be removed by abrasive blasting, high pressure water jetting or a chemical pickling process.

Film Thickness

An adequate film thickness is essential for the success of any coating system. Under application will generally result in premature failure. The actual dry film thickness recommended for a particular surface will depend on the type of coating system being used and the nature of the surface. Measuring instruments for film thickness should be calibrated on smooth steel in accordance with ISO 2808, Method 6.

Air spraying of protective coating

Method of Application

Protective coatings can be applied by brush, roller, conventional air spray, pressure pot spray or airless spray. The advantages and disadvantages of each method are briefly stated here:

Method	Advantage	Disadvantage
Brush Application	Good for coating small areas, where good penetration of rusty steel substrates is required.	Depending on paint type, may need twice the coats to achieve similar build to that by airless spray application. Requires considerable care when brushing, otherwise result in poor finish.
Roller Application	Faster than brush on large, even surfaces.	Control of film thickness not easily achieved.
Conventional Air Spray	Simple and inexpensive	High build coatings generally cannot be applied by this method as most paints have to be thinned to a suitable viscosity for satisfactory atomisation, and so lose their high build properties.
Pressure Pot Spray	Large quantities of paint can be applied	-
Airless Spray	High build coatings can be applied without thinning. Very rapid application is possible. Less dust and fume.	With some products, the decorative effect achieved with airless spray is not as good as conventional spray.

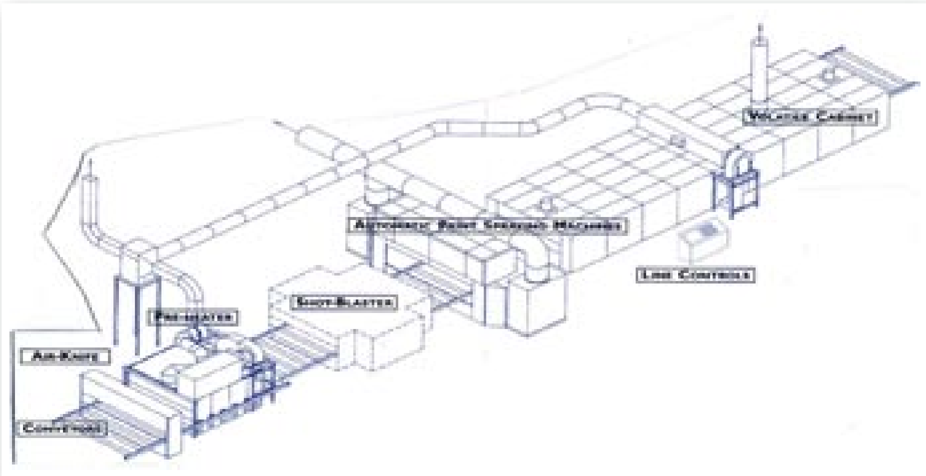
Shop Primers

Shop primer is applied immediately to the blast-cleaned steel surface for temporary protection against corrosion during fabrication, transport, installation and storage. The shop primer is then painted over with the finishing paint system, which usually includes a new primer coat. The top coat should have high resistance to abrasion and aggressive environmental conditions and should be stable.

If the components are to be welded, a weldable primer is to be applied. Weldable primers are usually applied in a factory shop by automatic spray equipment and are very thin (typically 15-25 microns) and fast drying. Guidance on shop primers is given in standards EN ISO 12944-5, appendix B and EN 10238 - Automatically blast cleaned and automatically primed structural steel products.

Completion

Upon completion, the painted product should not be exposed to rain within 4 hours. Visual inspection should be carried out to ensure proper application. The painted surface should be even, non-peeling and free of bubbles.



Shop primer line

Reliability

Protective coatings give excellent performance in many applications. However, as with most paint coatings, the quality of the application is a major factor in determining the long-term performance of the coating. The factors affecting coating quality include:

- Initial steel surface condition (new, rusty, contaminated)
- Surface preparation (blasting equipment, operator skill, access, design)
- Weather conditions (wet, dry, dew point)
- Paint application (equipment, operator skill, paint mixing, pot life)
- Paint curing (humidity, temperature, time)
- Handling (paint hardness, full curing time, handling methods)

Some Recommendations for Coating Steel Surfaces:

1) Abrasive blast new steel. Old steel should be abrasive blasted or hydroblasted (ultra high pressure water jetting) down to 'white' metal. The initial abrasive blast gives a metal a surface profile which is very important for a good coating bond. Hydroblasted surfaces will need to be checked to ensure that the revealed surface profile is suitable.

2) Treat with a soluble/insoluble salt remover. This is becoming more recognized as an important pre-coating step.

3) Use organic zinc-rich primer. However for shop applications, inorganic zinc should be used instead.

4) A solvent based (greater than 0% VOC) epoxy intermediate coat with a urethane topcoat, or a polysiloxane topcoat.

The steel sections at the Henderson Waves are coated with a polysiloxane topcoat

Cathodic Protection

The phenomena of galvanic corrosion and the galvanic series are the basis of Cathodic Protection (CP), a system in which the structure to be protected is made the cathode. For example if iron and copper are connected in sea water the iron corrodes; connect a piece of zinc into the system and a current flows from the zinc to the iron and copper and turns the iron into a cathode, i.e. the non-corroding pole in the electrochemical cell.

Cathodic protection using sacrificial anodes is established for the protection of steelwork under immersed conditions. For large installations, e.g. marine jetties, an "impressed current" system is often used. In this system the anode is inert, e.g. graphite or titanium, and a DC supply provides the voltage.

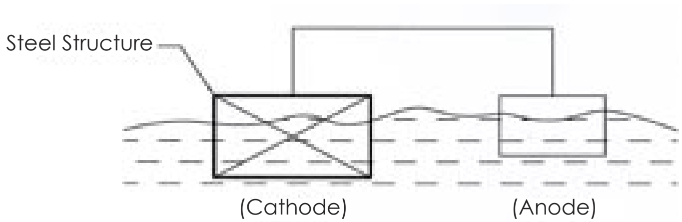
Setting up a cathodic protection system on an immersed or semi-immersed structure requires expert advice. There are however three points to remember when considering a CP system.

a. To do their job, sacrificial anodes must corrode! They require regular inspection to ensure they are replaced before they disappear completely.

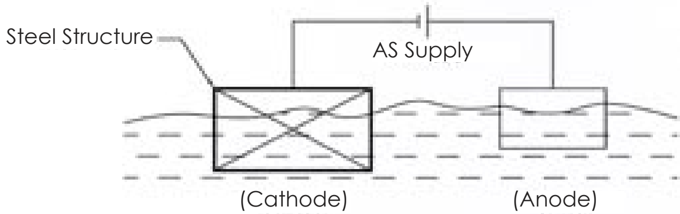
b. There must be sufficient anodes to give the correct current density over the complete surface to be protected.

c. In systems using an external DC supply the polarity of the electrical connection is vital. Reversed connections can cause extremely rapid corrosion of the item the system is supposed to protect!

Cathodic protection may be the best solution for steel structures in water, as illustrated in the following figure.



Cathodic protection using sacrifical or galvanic anode



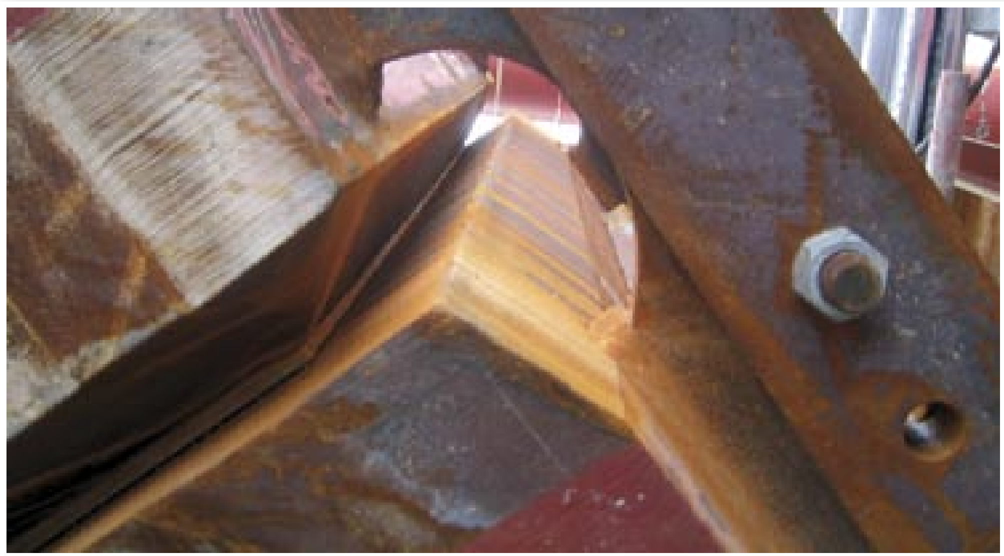
Steel sturctures in water

Selection of Corrosion Protection System

The selection of protective coatings must be considered carefully to ensure that the proper coating is chosen for the intended application and service environment. The corrosion resistance of the coating varies depending on the coating thickness.

When choosing a protective system, the maintenance cycle is an important consideration. The 'design' of the steel members and the way in which they are jointed will affect the maintenance cycle.

Poorly prepared steel surfaces prevent the protective treatment subsequently applied from achieving its design life. Corrosion prevention treatments can be either organic (paint), metallic (zinc, etc.), duplex (metallic and organic) or cathodic. Alternatively, in order to limit or prevent corrosion, the steel itself can be of a weathering or stainless grade. Regular inspection of the structure and proper routine maintenance prevents major remedial work being necessary to the corrosion prevention treatment.



The 'design' of the steel member and the way in which they are jointed will affect the maintenance cycle

Specifications

Writting the specification for corrosion protection is intended to provide clear and precise instructions to the contractor on what is to be done and how it is to be done. It should be written in a logical sequence, starting with surface preparation, going through each paint or metal coat to be applied and finally dealing with specific areas, e.g. welds. It should also be as brief as possible, consistent with providing all the necessary information. The most important items of a specification are as follows:

- The method of surface preparation and the standards required. This can often be specified by reference to an appropriate standard, e.g. BS 7079: Pt A1 Grade Sa 2-1/2
- The maximum interval between surface preparation and subsequent priming
- The types of paint or metal coatings to be used, supported by standards where these exist
- The method/s of application to be used
- The number of coats to be applied and the interval between coats
- The wet and dry film thickness for each coat
- Where each coat is to be applied (i.e. shops or site) and the application conditions that are required, in terms of temperature, humidity etc.
- Details for treatment of welds, connections, etc
- Rectification procedures for damage, etc.

Information such as type of paint, method of application and location of application (shop/site) should be written clearly in the specification

Good Practices of Corrosion Protection

Inspection

Regular inspection of steel structures, especially those exposed to coastal and marine environments, form the basis of a good maintenance programme.

The basic form of inspection is visual inspection. Dirt, loose paint or corroded surface must be removed before inspection as they will interfere with an accurate assessment of the extent of deterioration. However, protective coatings which are not defective should not be removed.

Visual inspections can be used to determine the location and relative extent of corrosion on many structures. However, the thickness of metals cannot always be determined by direct measurement such as normal caliper as access to both sides is not always possible. The effects of corrosion at the back of a metal may reduce its thickness significantly and yet may not affect the front surface. Hence, thickness measurement by ultrasonic thickness gauges etc. can in many cases give accurate and quantitative determinations of the extent of corrosion without access to both sides of the metal.

Other Non-Destructive Testing (NDT) methods such as ultrasonic flaw detection and radiography (x-ray) can be employed to determine metal thickness and to detect internal flaws. However, the operation of these instruments and interpretation of results depend on the skill and experience of the NDT operator.

Inspection and Testing Agency

To ensure that the protective treatment work have been properly carried out on the structural steelwork, it may be necessary to appoint an Independent Inspection and Testing Agency (ITA) to perform the following scope of services:

(a) Review the proposed protective treatment system

(b) Review the quality control plan

(c) Assess the condition of substrate

(d) Check dew point, relative humidity and metal temperatures

(e) Check condition of substrate for contamination and rust grade

(f) Inspect surfaces after preparation for grade and amplitude

(g) Check the wet and dry film thicknesses, if applicable

(h) Witness all preparation and coating procedures

(i) Prepare protective treatment inspection reports

Steel structures, especially those exposed to coastal and marine environments, have to be regularly inspected

Maintenance / Repair of Steel Structures

Upon completion of inspection, the structural engineer will carry out an assessment on the condition of the structure and recommend appropriate measures to ensure structural soundness.

Depending on the extent of deterioration, the structural engineer may recommend one or more of the following approaches:

(a) Re-apply the corrosion protection system to the affected members.

(b) Strengthen the affected members and re-apply the protective paint coating.

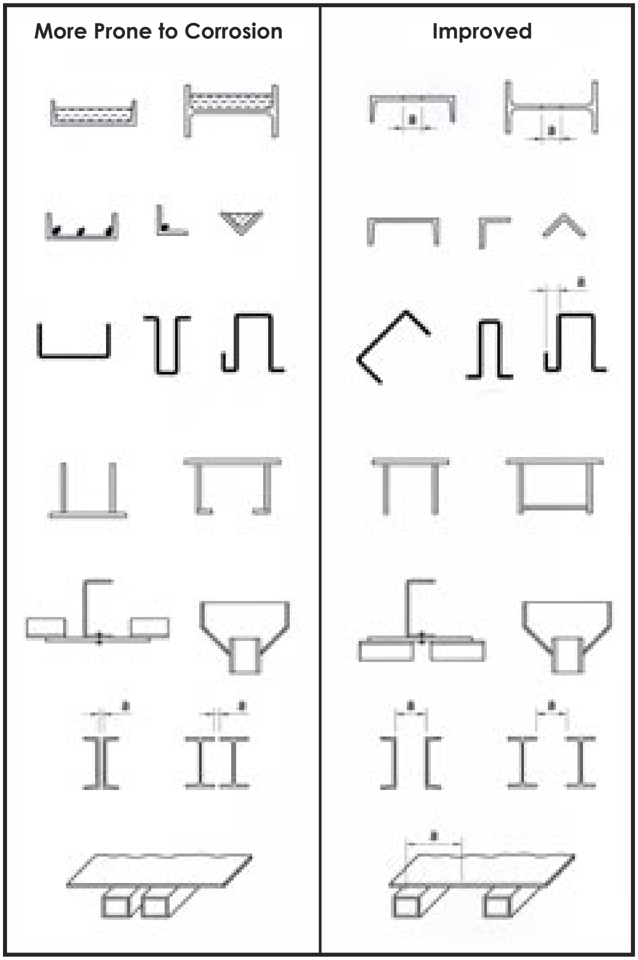
(c) Replace with another new section.

If corrosion is limited to a small area, it may be more economical or practical to strengthen than to replace existing members

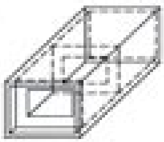
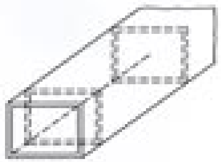
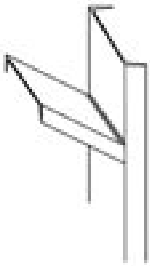
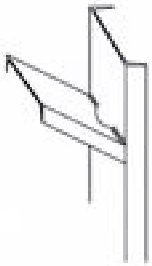
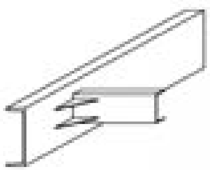
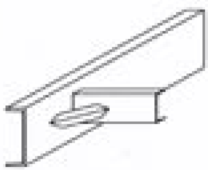
Detailing to Minimise Corrosion

Details should be designed to shed water and avoid collection of dirt whenever possible.

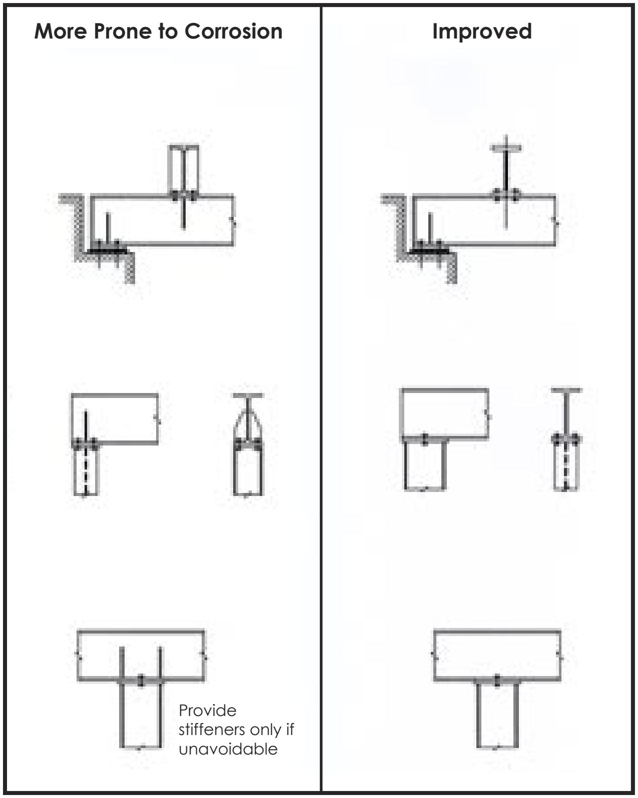
A. Design to avoid formation of humid and dusty zones. Provide drainage holes and openings with a > 30mm to drain moisture and dirt.



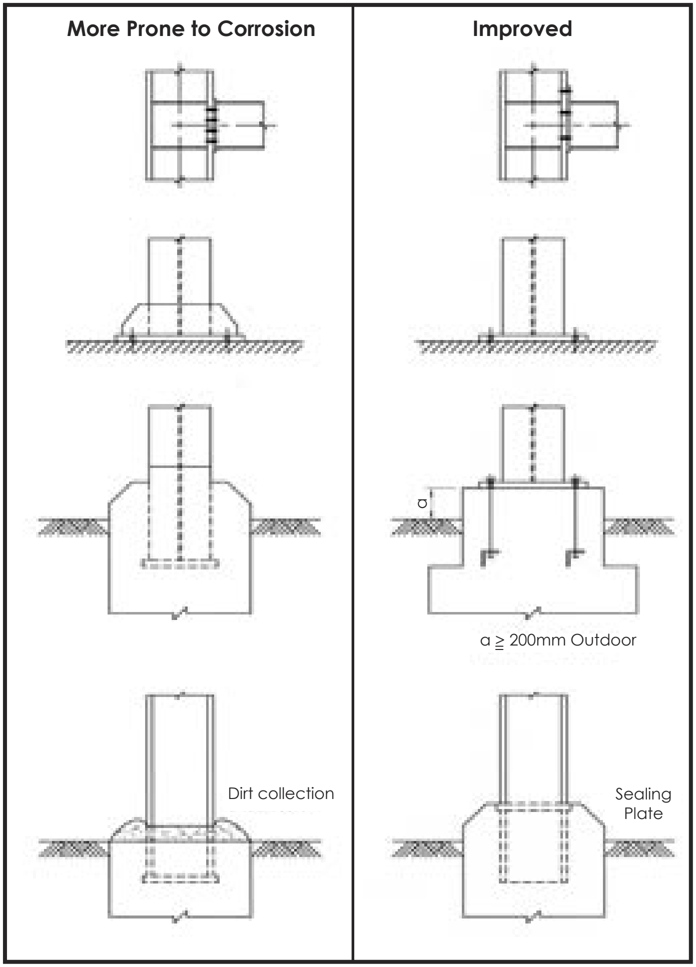
B. Design to avoid entrapment of moisture and dirt and corrosive elements on or between parts of structures. Use hermetic sealing for hollow sections, provide drainage holes between inclined members and stiffeners.

More Prone to Corrosion	Improved
 Open	 Hermetic Welded Attention for pressure fluctuations on walls due to - changes in temperature - changes in barometric pressure - consumption of oxygen through rust formation
	
	

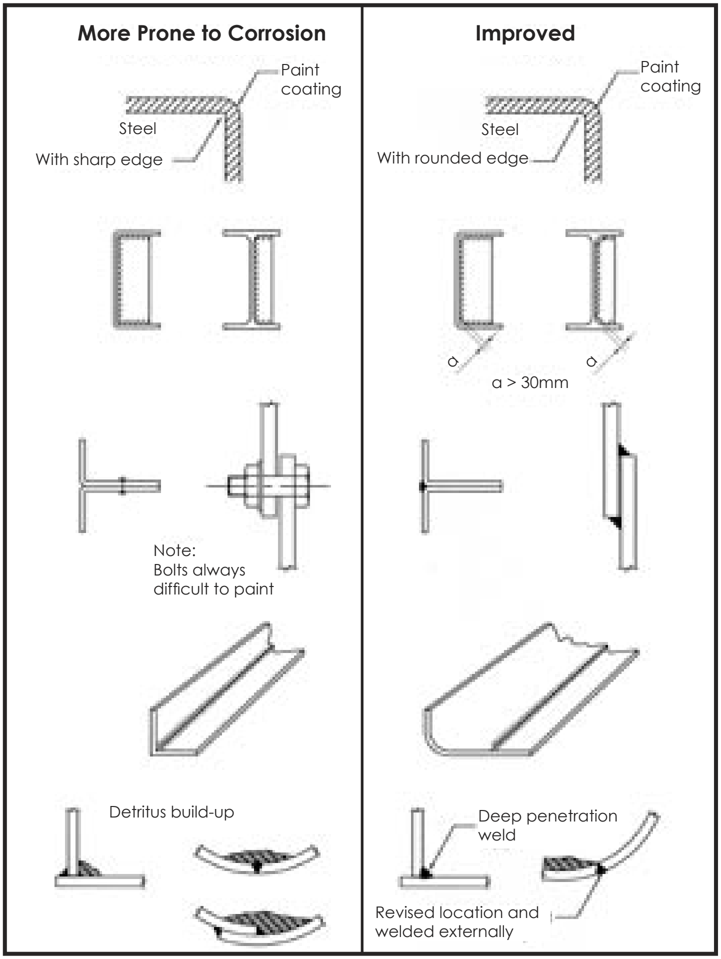
C. Design without edges and corners to avoid entrapment of moisture and dirt. If possible, avoid stiffeners.



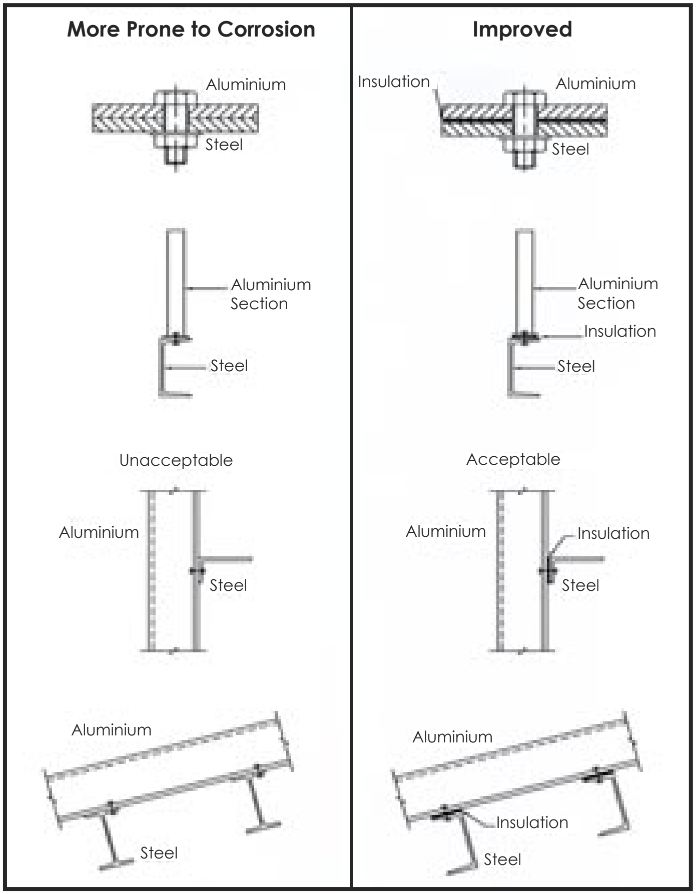
D. Provide good structural detailing to avoid corrosion.



E. Design with rounded angles to avoid corrosion. Edges and corners are corrosion sensitive points even when protected by coatings.



F. Avoid bi-metallic contact to prevent galvanic corrosion by using an insulation material.



Annexes

Annexes

National Productivity and Quality Specifications (NPQS)

Sections C5-10 and C5-20 of the NPQS provides the general requirements for protection of structural steelwork against corrosion.

The general standards referred to are:

BS EN ISO 1461	Hot dip galvanised coatings on fabricated iron and steel articles. Specifications and test methods.
BS EN 10155	Structural steels with improved atmospheric corrosion resistance. Technical delivery conditions.
BS 7079	Preparation of steel substrates before application of paints and related products. Part A1: Visual assessment of surface cleanliness.
BS EN ISO 12944	Paints and varnishes – corrosion protection of steel structures by protective paint systems.
BS EN ISO 14713	Protection against corrosion of iron and steel in structures – zinc and aluminium coatings - Guidelines.
BS EN 22063	Metallic and other inorganic coatings – thermal spraying – zinc, aluminium and their alloys.

The standards pertaining to inspection, cleaniness of steel surface, surface roughness and surface treatment are listed here for reference.

Standard Number	**Title**
BS 7079: Part A1 :Supplement 1:1989	Preparation of steel substrates before application of paints and related products. Visual assessment of surface cleanliness. Representative photographic examples of the change of appearance imparted to steel when blast-cleaned with different abrasives.
BS 7079:Part F1:1994, ISO 11126-1:1993	Preparation of steel substrates before application of paints and related products. Non-metallic blast-cleaning abrasives. General introduction and classification.
BS 7079-0:1990	Preparation of steel substrates before application of paints and related products. Introduction.
BS 7079-A3:2002, ISO 8501-3:2001	Preparation of steel substrates before application of paints and related products. Visual assessment of surface cleanliness. Preparation grades of welds, cut edges and other areas with surface imperfections. A3: Preparation grades of welds, cut edges and other areas with surface imperfections.
BS 7079-D1:1993, ISO 8504-1:1992	Preparation of steel substrates before application of paints and related products. Methods for surface preparation. General principles.
BS 7079-D2:1993, ISO 8504-2:1992	Preparation of steel substrates before application of paints and related products. Methods for surface preparation. Abrasive blast-cleaning.

Standard Number	Title
BS EN ISO 11124-2:1997, BS 7079-E2:1994	Preparation of steel substrates before application of paints and related products. Specifications for metallic blast-cleaning abrasives. Chilled-iron grit.
BS EN ISO 11124-3:1997, BS 7079-E3:1994	Preparation of steel substrates before application of paints and related products. Specifications for metallic blast-cleaning abrasives. High-carbon cast-steel shot and grit.
BS EN ISO 11124-4:1997, BS 7079-E4:1994	Preparation of steel substrates before application of paints and related products. Specifications for metallic blast-cleaning abrasives. Low-carbon cast steel shot.
BS EN ISO 11125-1:1997, BS 7079-E6:1994	Preparation of steel substrates before application of paints and related products. Test methods for metallic blast-cleaning abrasives. Sampling.
BS EN ISO 11125-2:1997, BS 7079-E7:1994	Preparation of steel substrates before application of paints and related products. Test methods for metallic blast-cleaning abrasives. Determination of particle size distribution.
BS EN ISO 11125-3:1997, BS 7079-E8:1994	Preparation of steel substrates before application of paints and related products. Test methods for metallic blast-cleaning abrasives. Determination of hardness.
BS EN ISO 11125-4:1997, BS 7079-E9:1994	Preparation of steel substrates before application of paints and related products. Test methods for metallic blast-cleaning abrasives. Determination of apparent density.
BS EN ISO 11125-5:1997, BS 7079-E10:1994	Preparation of steel substrates before application of paints and related products. Test methods for metallic blast-cleaning abrasives. Determination of percentage defective particles and of microstructure.

Standard Number	Title
BS EN ISO 11125-7:1997, BS 7079-E12:1994	Preparation of steel substrates before application of paints and related products. Test methods for metallic blast-cleaning abrasives. Determination of moisture.
BS EN ISO 11126-1:1997, BS 7079-F1:1997	Preparation of steel substrates before application of paints and related products. Specifications for non-metallic blast-cleaning abrasives. General introduction and classification.
BS EN ISO 11126-10:2004, BS 7079-F10:2004	Preparation of steel substrates before application of paints and related products. Specifications for non-metallic blast-cleaning abrasives. Almandite garnet.
BS EN ISO 11126-3:1998, BS 7079-F3:1994	Preparation of steel substrates before application of paints and related products. Specifications for non-metallic blast-cleaning abrasives. Copper refinery slag.
BS EN ISO 11126-5:1998, BS 7079-F5:1994	Preparation of steel substrates before application of paints and related products. Specifications for non-metallic blast-cleaning abrasives. Nickel refinery slag.
BS EN ISO 11126-6:1998, BS 7079-F6:1994	Preparation of steel substrates before application of paints and related products. Specifications for non-metallic blast-cleaning abrasives. Iron furnace slag.
BS EN ISO 11126-8:1998, BS 7079-F8:1994	Preparation of steel substrates before application of paints and related products. Specifications for non-metallic blast-cleaning abrasives. Olivine sand.
BS EN ISO 11126-9:2004, BS 7079-F9:2004	Preparation of steel substrates before application of paints and related products. Specifications for non-metallic blast-cleaning abrasives. Staurolite.
BS EN ISO 11127-1:1998, BS 7079-F11:1994	Preparation of steel substrates before application of paints and related products. Test methods for non-metallic blast-cleaning abrasives. Sampling.

Standard Number	Title
BS EN ISO 11127-2:1998, BS 7079-F12:1994	Preparation of steel substrates before application of paints and related products. Test methods for non-metallic blast-cleaning abrasives. Determination of particle size distribution.
BS EN ISO 11127-3:1998, BS 7079-F13:1994	Preparation of steel substrates before application of paints and related products. Test methods for non-metallic blast-cleaning abrasives. Determination of apparent density.
BS EN ISO 11127-4:1998, BS 7079-F14:1994	Preparation of steel substrates before application of paints and related products. Test methods for non-metallic blast-cleaning abrasives. Assessment of hardness by a glass slide test.
BS EN ISO 11127-5:1998, BS 7079-F15:1994	Preparation of steel substrates before application of paints and related products. Test methods for non-metallic blast-cleaning abrasives. Determination of moisture.
BS EN ISO 11127-6:1998, BS 7079-F16:1994	Preparation of steel substrates before application of paints and related products. Test methods for non-metallic blast-cleaning abrasives. Determination of water-soluble contaminants by conductivity measurement.
BS EN ISO 11127-7:1998, BS 7079-F17:1994	Preparation of steel substrates before application of paints and related products. Test methods for non-metallic blast-cleaning abrasives. Determination of water-soluble chlorides.
BS EN ISO 8501-1:Supplement:2001, BS 7079A1:Supplement 1:1996	Preparation of steel substrates before application of paints and related products. Visual assessment of surface cleanliness. Representative photographic examples of the change of appearance imparted to steel when blast-cleaned with different abrasives.

Standard Number	Title
BS EN ISO 8501-2:2001, BS 7079-A2:1996	Preparation of steel substrates before application of paints and related products. Visual assessment of surface cleanliness. Preparation grades of previously coated steel substrates after localized removal of previous coatings.
BS EN ISO 8501-3:2007, BS 7079-A3:2006	Preparation of steel substrates before application of paints and related products. Visual assessment of surface cleanliness. Preparation grades of welds, edges and other areas with surface imperfections.
BS EN ISO 8502-10:2004, BS 7079-B10:2004	Preparation of steel substrates before application of paints and related products. Tests for the assessment of surface cleanliness. Field method for the titrimetric determination of water-soluble chloride.
BS EN ISO 8502-11:2006, BS 7079-B11:2006	Preparation of steel substrates before application of paints and related products. Tests for the assessment of surface cleanliness. Field method for the turbidimetric determination of water-soluble sulfate.
BS EN ISO 8502-12:2004, BS 7079-B12:2004	Preparation of steel substrates before application of paints and related products. Tests for the assessment of surface cleanliness. Field method for the titrimetric determination of water-soluble ferrous ions.
BS EN ISO 8502-5:2004, 7079-B5:2004	Preparation of steel substrates before application of paints and related products. Tests for the assessment of surface cleanliness. Measurement of chloride on steel surfaces prepared for painting (ion detection tube method).
BS EN ISO 8502-8:2004, BS 7079-B8:2004	Preparation of steel substrates before application of paints and related products. Tests for the assessment of surface cleanliness. Field method for the refractometric determination of moisture.

Standard Number	Title
BS EN ISO 8502-9:2001, BS 7079-B9:1998	Preparation of steel substrates before application of paints and related products. Tests for the assessment of surface cleanliness. Field method for the conductometric determination of water-soluble salts.
BS EN ISO 8503-1:1995, BS 7079-C1:1989	Preparation of steel substrates before application of paints and related products. Surface roughness characteristics of blast-cleaned steel substrates. Specifications and definitions for ISO surface profile comparators for the assessment of abrasive blast-cleaned surfaces.
BS EN ISO 8503-2:1995, BS 7079-C2:1989	Preparation of steel substrates before application of paints and related products. Surface roughness characteristics of blast-cleaned steel substrates. Method for the grading of surface profile of abrasive blast-cleaned steel. Comparator procedure.
BS EN ISO 8503-3:1995, BS 7079-C3:1989	Preparation of steel substrates before application of paints and related products. Surface roughness characteristics of blast-cleaned steel substrates. Method for the calibration of ISO surface profile comparators and for the determination of surface profile. Focusing microscope procedure.
BS EN ISO 8503-4:1995, BS 7079-C4:1989	Preparation of steel substrates before application of paints and related products. Surface roughness characteristics of blast-cleaned steel substrates. Method for the calibration of ISO surface profile comparators and for the determination of surface profile. Stylus instrument procedure.
BS EN ISO 8503-5:2004, BS 7079-C5:2004	Preparation of steel substrates before application of paints and related products. Surface roughness characteristics of blast-cleaned steel substrates. Replica tape method for the determination of the surface profile.

Standard Number	Title
BS EN ISO 8504-1:2001, BS 7079-D1:2000	Preparation of steel substrates before application of paints and related products. Surface preparation methods. General principles .
BS EN ISO 8504-2:2001, BS 7079-D2:2000	Preparation of steel substrates before application of paints and related products. Surface preparation methods. Abrasive blast cleaning. Part 2: Abrasive blast cleaning.
BS EN ISO 8504-3:2001,.BS 7079-D3:1993	Preparation of steel substrates before application of paints and related products. Surface preparation methods. Hand-and power-tool cleaning.

Protective Paint Systems

The protective paint systems are addressed in the following standards:

Standard	Description
ISO 12944-1.	Paints and varnishes -- Corrosion protection of steel structures by protective paint systems -- Part 1: General introduction. • The standard classifies protective paint systems by durability. The durability class does not imply any guarantee period but the expected serviceable life before repainting for maintenance.
ISO 12944-2.	Paints and varnishes -- Corrosion protection of steel structures by protective paint systems -- Part 2: Classification of environments. • The standard specifies the corrosivity categories according to the type of atmosphere and stress caused by immersion (tables 1 and 2)
ISO 12944-3.	Paints and varnishes -- Corrosion protection of steel structures by protective paint systems -- Part 3: Design considerations.
ISO 12944-4.	Paints and varnishes -- Corrosion protection of steel structures by protective paint systems -- Part 4: Types of surface and surface preparation. • The standard makes reference to surface preparation standards

Standard	Description
ISO 12944-5.	Paints and varnishes -- Corrosion protection of steel structures by protective paint systems -- Part 5: Protective paint systems. • The standard specifies the most common types of anti-corrosive paint and gives instructions for the selection of these for different environmental classes.
ISO 12944-6. ISO 12944-7.	Paints and varnishes -- Corrosion protection of steel structures by protective paint systems -- Part 6: Laboratory performance test methods. Paints and varnishes -- Corrosion protection of steel structures by protective paint systems -- Part 7: Execution and supervision of paint work.
ISO 12944-8.	Paints and varnishes -- Corrosion protection of steel structures by protective paint systems -- Part 8: Development of specifications for new work and maintenance. • The standard gives detailed instructions for the development of specifications.

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