Corus Construction & Industrial

Corrosion protection of steel bridges

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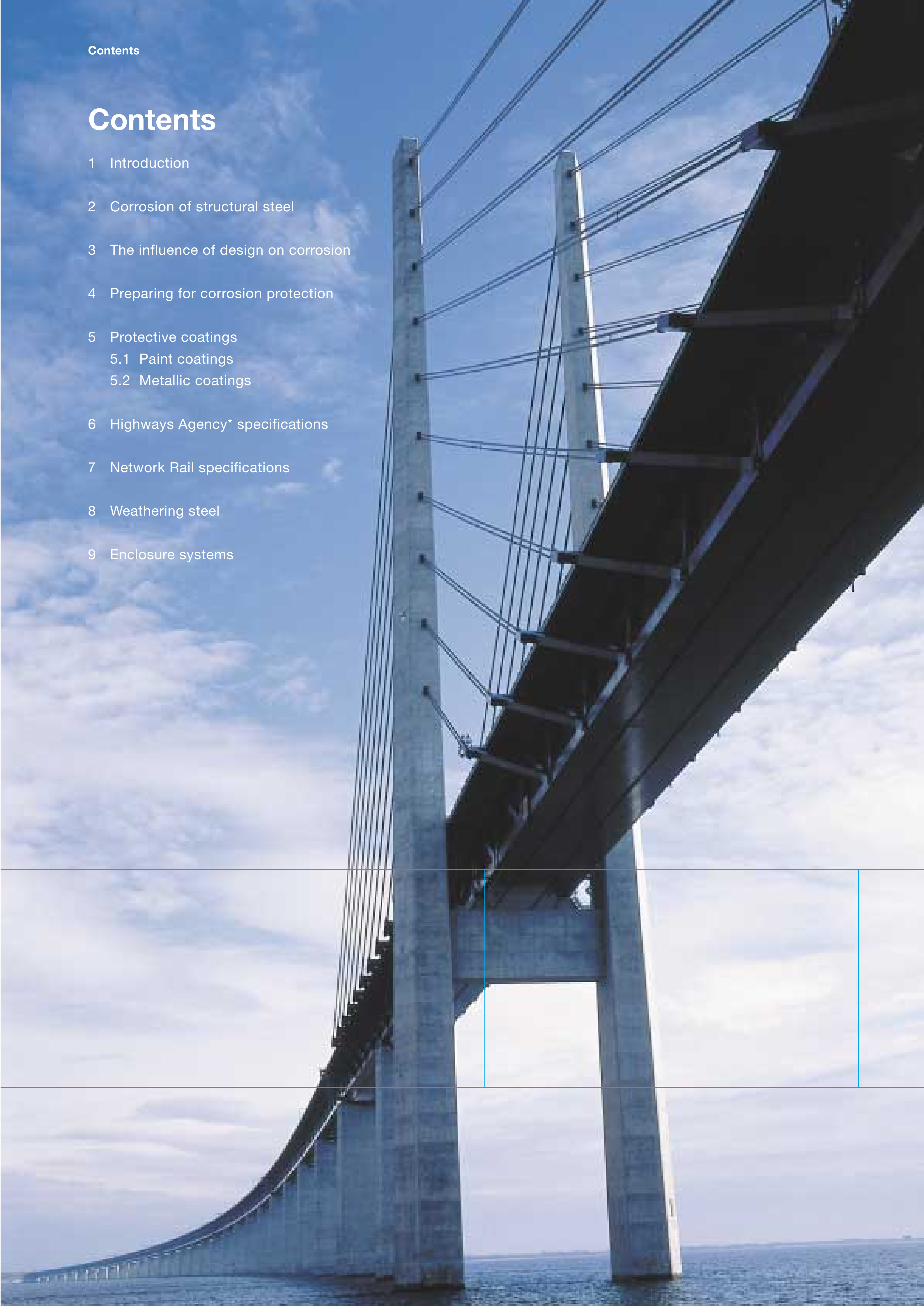


1. Introduction

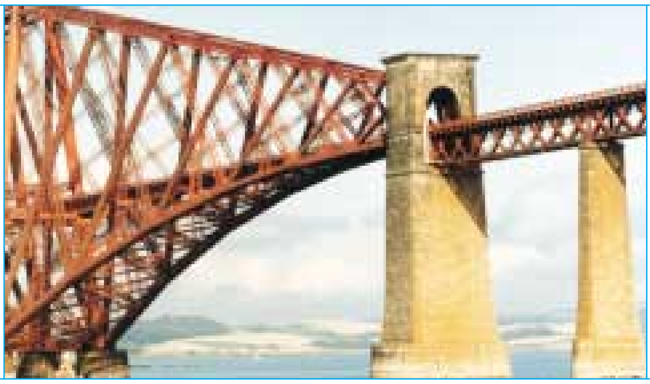
The use of steel for modern bridges has grown significantly over the last 25 years. Engineers and specifiers have recognised the benefits that steel offers as a construction material, which combined with imaginative designs has resulted in some striking bridges that have not escaped the public's attention.

The use of steel in bridges goes back over 100 years. A notable example is the imposing Forth Rail bridge in Scotland, which was completed in 1890. The scale and size of this significant landmark was a major achievement in construction engineering, and the structure has stood the test of time. The surface preparation and painting systems used on this bridge, and on similar old steel bridges, are quite primitive by modern standards and frequent maintenance is required to ensure a continued serviceable life.

Modern bridges currently have a design life requirement of 120 years, and the performance of the protective system is a critical factor. Furthermore, reductions in the number of repainting cycles have become significant in the evaluation of whole life costs.

There has been a widely held view that most steel bridges require frequent attention to maintain the original protective coating system. In reality, coating lifetimes to first major maintenance have progressively increased from 12 and 15 years to 20 and 25 years.

From the continued developments in coating technology, modern high performance coating systems may be expected to achieve lives to first major maintenance in excess of 30 years on thoughtfully designed steel bridges. In addition, the use of weathering steel, and enclosure systems, offer very low maintenance alternatives.



1. Left: Oresund Bridge (photo courtesy of Ove Arup Partnership)
   Sweden
2. Above: Forth Rail Bridge
   Scotland

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* Any reference to the Highways Agency is intended to include the other Overseeing Organisations:

- Scottish Executive
- Welsh Assembly Government
- Department for Regional Development (NI)

2. Corrosion of structural steel

The corrosion of steel can be considered as an electrochemical process that occurs in stages. Initial attack occurs at anodic areas on the surface, where ferrous ions go into solution. Electrons are released from the anode and move through the metallic structure to the adjacent cathodic sites on the surface, where they combine with oxygen and water to form hydroxyl ions. These react with the ferrous ions from the anode to produce ferrous hydroxide, which itself is further oxidised in air to produce hydrated ferric oxide (i.e. red rust.) The sum of these reactions can be represented by the following equation:

$$Fe + 30_2 + 2H_20 = 2Fe_20_3.H_20$$

(Steel) + (Oxygen) + (Water) = Hydrated ferric oxide (Rust)

The process requires the simultaneous presence of water and oxygen. In the absence of either, corrosion does not occur.

However, after a period of time, polarisation effects such as the growth of corrosion products on the surface cause the corrosion process to be stifled. New, reactive anodic sites may be formed thereby allowing further corrosion. In this case, over long periods, the loss of metal is reasonably uniform over the surface, and this is usually described as 'general corrosion'. A schematic representation of the corrosion mechanism is shown in Figure 1.

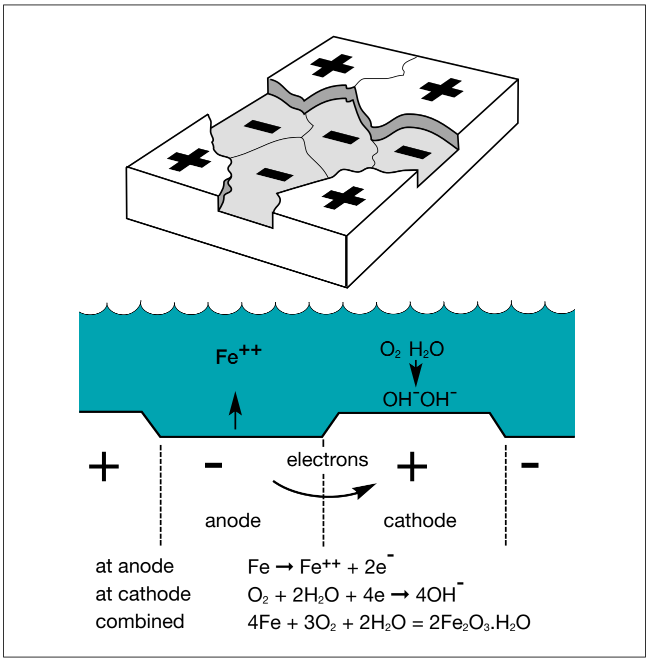


Figure 1. Schematic representation of the corrosion mechanism for steel

1. Docklands Light Rail Bridge
London, England

Corrosion rates

The principle factors that determine the rate of corrosion of steel in air are:

'Time of wetness'

This is the proportion of total time during which the surface is wet, due to rainfall, condensation etc. It follows, therefore, that for unprotected steel in dry environments (e.g. enclosures), corrosion will be minimal due to the low availability of water.

‘Atmospheric pollution’

The type and amount of atmospheric pollution and contaminants (e.g. sulphates, chlorides, dust etc.)

Sulphates

These originate from sulphur dioxide gas produced during the combustion of fossil fuels, e.g. sulphur bearing oils and coal. The sulphur dioxide gas reacts with water or moisture in the atmosphere to form sulphurous and sulphuric acids. Industrial environments are a prime source of sulphur dioxide.

Chlorides

These are mainly present in marine environments. The highest concentration of chlorides is to be found in coastal regions and there is a rapid reduction moving inland. In the U.K. there is evidence to suggest that a 2 kilometre strip around the coast can be considered as being in a marine environment.

Both sulphates and chlorides increase corrosion rates. They react with the surface of the steel to produce soluble salts of iron, which can concentrate in pits and are themselves corrosive.

Within a given local environment, corrosion rates can vary markedly, due to effects of sheltering and prevailing winds etc. It is therefore the 'micro-climate' immediately surrounding the structure which determines corrosion rates for practical purposes.

Because of variations in atmospheric environments, corrosion rate data cannot be generalised. However, environments can be broadly classified, and corresponding measured steel corrosion rates provide a useful indication of likely corrosion rates. More information can be found in BS EN ISO 12944, Part 2 and ISO 9223.

3. The influence of design on corrosion

The design of a structure can affect the durability of any protective coating applied to it. Old steel bridges designed with many small structural components and fasteners, e.g. bracings and rivets, are more difficult to protect than modern designs with large flat surfaces.

The articulation of a bridge also influences its durability as leaking deck joints have often been the source of corrosion problems. Ideally, expansion joints should be avoided by the use of continuous and integral construction. However, if expansion joints are unavoidable they should be located away from the ends of the girders, and a positive non-metallic drainage system should be provided to convey any leaks away from the steelwork.

Detailing is important to ensure that the protective treatment can be applied to all surfaces, to avoid the creation of water and dirt traps that would encourage corrosion, and to ensure that future inspections and maintenance can be carried out effectively.

Access for coating application and maintenance

Access to all surfaces to provide both the initial surface treatment and subsequent maintenance painting is essential. Narrow gaps, difficult to reach corners, and hidden surfaces should be avoided wherever possible. Similarly, clearance between connecting members at junctions, and the degree of internal angles at skewed web stiffeners should allow access for coating and inspection. Refer to Figure 2.

Copes

A typical detail that is difficult to protect is a cope hole in a web stiffener. Unless the hole is very large, it is virtually impossible to blast clean the surface properly and to apply a protective treatment to the surface. Ideally copes should be avoided by using close fitting snipes and a continuous weld around the corner. Although this may form a moisture/dirt trap, it is considered a better detail than having a drainage path through a cope where the protection system is at its most vulnerable.

If cope holes are used, they should be circular and of at least 40mm radius, preferably more. Cope holes formed by 45° snipes should not be used. The weld will not be returned through the hole, which creates the additional problem of a narrow crevice.

Avoidance of moisture and debris traps

Details that could potentially trap moisture and debris should be avoided where possible. Measures that can be taken include:

- Grind flush welds on horizontal surfaces.
- Curtail transverse web stiffeners short of the bottom flange.
- Avoid using channels with toes upward.
- Arrange angles with the vertical leg below the horizontal.
- Avoid the use of ‘T’ section bearing stiffeners.

Crevices

Crevices attract and retain water through capillary action, and should be avoided. HSFG bolted joints pose a particular problem, so welded connections are preferable in terms of corrosion protection. However, crevice effects on HSFG bolted connections can be minimised by limiting the bolt spacing and edge distance, using flexible cover plates, and sealing the edges of the joint. Crevices at the intersections of cross bracings should be avoided by using a packing plate the same thickness as the web stiffener, and a single HSFG bolt through all three pieces.

Drainage and ventilation

Provision should be made for adequate drainage and ventilation to enable the steel to dry out, e.g. minimise the ‘time of wetness’. Closely spaced girders should be avoided and deck run-off should be directed away from steel surfaces. In addition, the use of wide cantilevers with suitable drip details should be considered.

General

Guidance for the prevention of corrosion by good design detailing can be found in BS EN ISO 12944, Part 3.

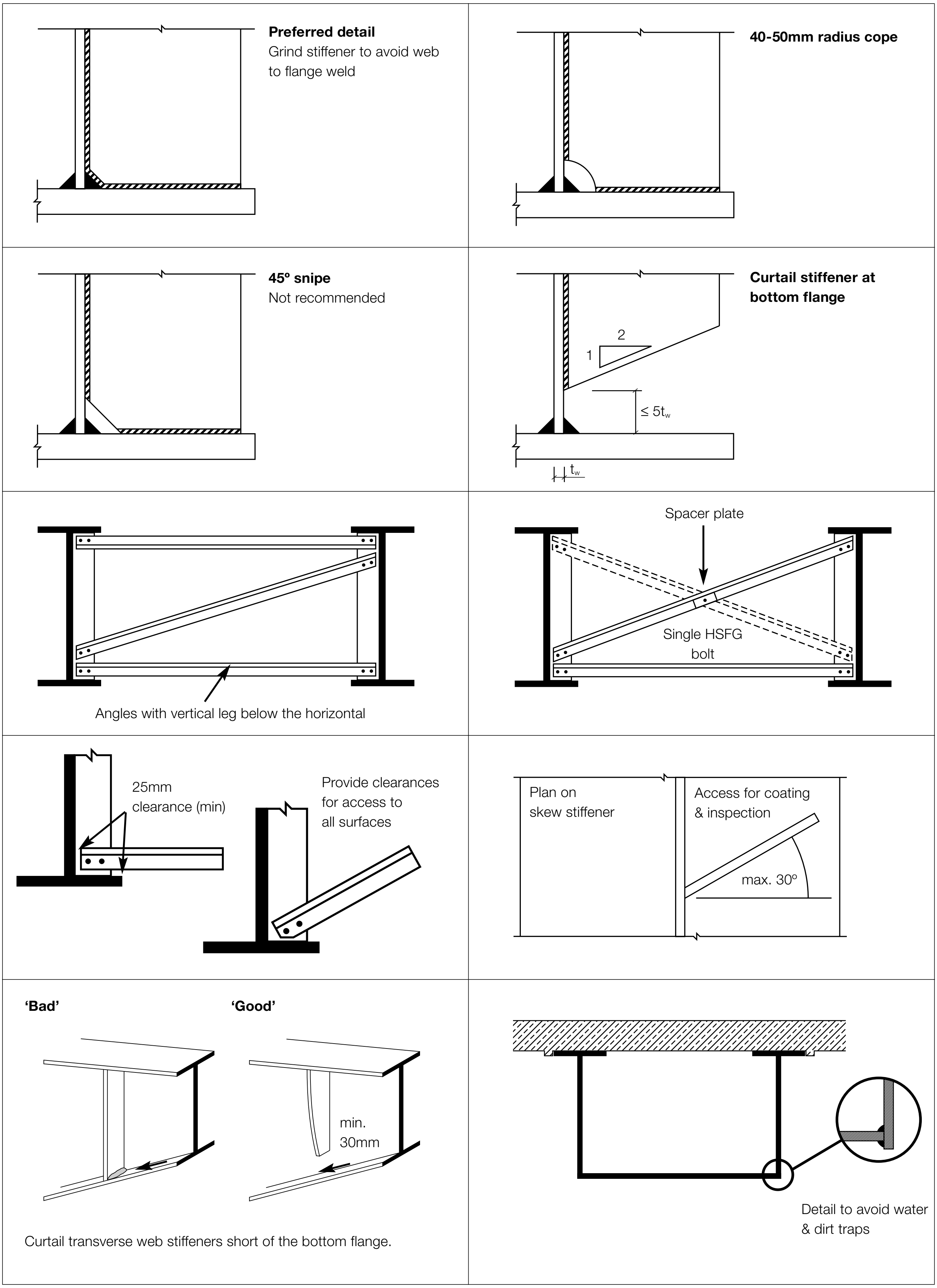


Figure 2. Detailing for durability

4. Preparing for corrosion protection

The application of a protective coating system is the most common way of preventing corrosion. The effectiveness of the system depends upon the initial surface condition, the coating materials, the application procedures, the access for application and the environment under which the work is done.

Initial surface condition

Structural steel elements in new bridges are usually either hot rolled sections or, on large bridges, fabricated plate girders. The initial steel surfaces normally comply with rust grades A or B according to ISO 8501-1: 2001, (BS 7079, Part A1 1989). Material which is pitted, i.e. rust grades C or D, should be avoided if possible, since it is difficult to clean all the corrosion products from the pits during surface preparation.

Surface preparation

Surface preparation is the essential first stage treatment of a steel substrate before the application of any coating, and is generally accepted as being the most important factor affecting the total success of a corrosion protection system.

The performance of a coating is significantly influenced by its ability to adhere properly to the substrate material. Residual millscale on steel surfaces is an unsatisfactory base to apply modern, high performance protective coatings and is therefore removed by abrasive blast cleaning. Other surface contaminants on the rolled steel surface, such as oil and grease are also undesirable and must be removed before the blast cleaning process.

The surface preparation process not only cleans the steel, but also introduces a suitable profile to receive the protective coating.

Surface cleanliness

Various methods and grades of cleanliness are presented in ISO 8501-1: 2001, (BS 7079, Part A1 1989) This standard essentially refers to the surface appearance of the steel after abrasive blast cleaning, and gives descriptions with pictorial references of the grades of cleanliness. The standard grades of cleanliness for abrasive blast cleaning are:

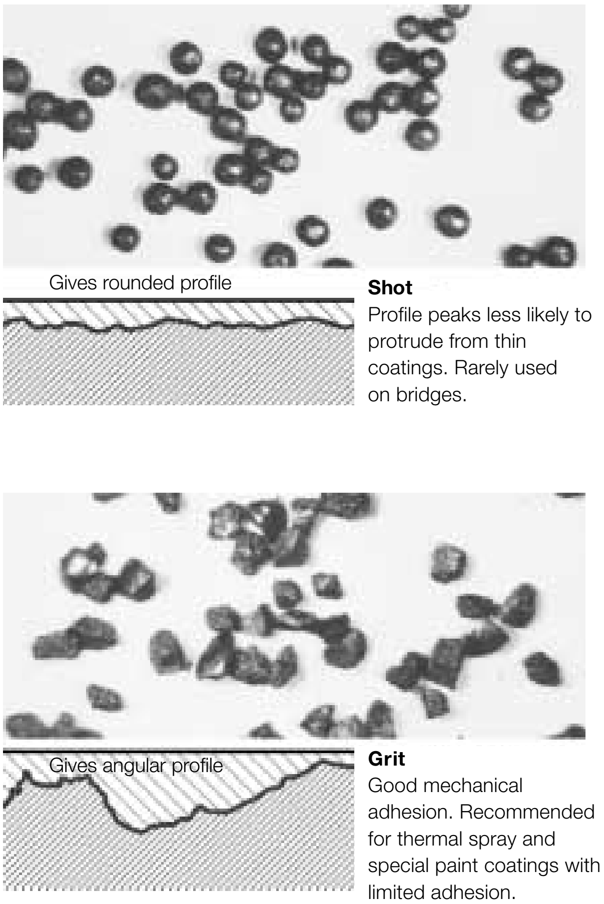
Sa 1 – Light blast cleaning
Sa 2 – Thorough blast cleaning
Sa 2½ – Very thorough blast cleaning
Sa 3 – Blast cleaning to visually clean steel

Specifications for bridge steelwork usually require either Sa 2½ or Sa 3 grades.

The cleaned surfaces should be compared with the appropriate reference photograph in the standard according to the specification.

Surface profile and amplitude

The type and size of the abrasive used in blast cleaning have a significant effect on the profile and amplitude produced. In addition to the degree of cleanliness, surface preparation should also consider 'roughness' relative to the coating to be applied. High build paint coatings and thermally sprayed metal coatings need a coarse angular surface profile to provide a mechanical key. This is achieved by using grit abrasives. Shot abrasives are used for thin film paint coatings such as pre-fabrication primers, but such coatings are rarely used on bridges. (Refer to Figure 3).



Shot
Profile peaks less likely to protrude from thin coatings. Rarely used on bridges.

Grit
Good mechanical adhesion. Recommended for thermal spray and special paint coatings with limited adhesion.

Figure 3. An illustration of the surface profile compatibility

The surface treatment specification should describe the surface roughness required, usually as an indication of the average amplitude achieved by the blast cleaning process. Several methods have been developed to measure or assess the distance between the peaks and troughs of blast cleaned surfaces. These have included comparator panels, special dial gauges, replica tapes and traversing stylus equipment.

Surface dust

The blast cleaning operation produces large quantities of dust and debris that must be removed from the abraded surface. Automatic plants are usually equipped with mechanical brushes and air blowers. Other methods can utilise sweeping and vacuum cleaning. However, the effectiveness of these cleaning operations may not be readily visible, and the presence of fine residual dust particles that could interfere with coating adhesion can be checked for using a pressure sensitive tape pressed onto the blast cleaned surface. The tape, along with any dust adhering to it, is then placed on a white background and compared to a pictorial rating. This method is described in ISO 8503 Part 5 2004, (BS 7079 Part C5, 2004).

Soluble iron corrosion products

Depending upon the condition of the steelwork prior to blast cleaning, there may be surface contaminants present other than millscale and rust. Initial steel surface conditions of Grades A to C are unlikely to be affected. Grade D condition (steelwork that is pitted) could contain contaminants within the pits that are not removed by the dry blast cleaning process, but this is rarely encountered on new works. Methods of testing for soluble surface contaminants on new blast cleaned steel are available and are currently being developed into standards.

Additional surface treatments

Sawn and flame-cut edges introduce a localised increase in hardness and roughness that requires removal to ensure that the coating adheres and is of sufficient thickness.

1. Left: All A1(M) bridges
Yorkshire, England

On outside arrises, there is a potential problem of providing adequate coating cover to the sharp corners. Consequently BS 5400: Part 6 calls for them to be smoothed by grinding or filing. It is generally considered sufficient to smooth the corner to a radius of about 2mm; chamfering to 45° is also effective but it is difficult to avoid leaving some sharp edges when attempting this with hand tools.

Stripe coating along corners and edges is often specified to provide good local coverage of the coating to achieve a thickness comparable with that achieved on a flat surface.

The corners of rolled sections generally do not require grinding, as they are usually smooth as a result of the rolling process.

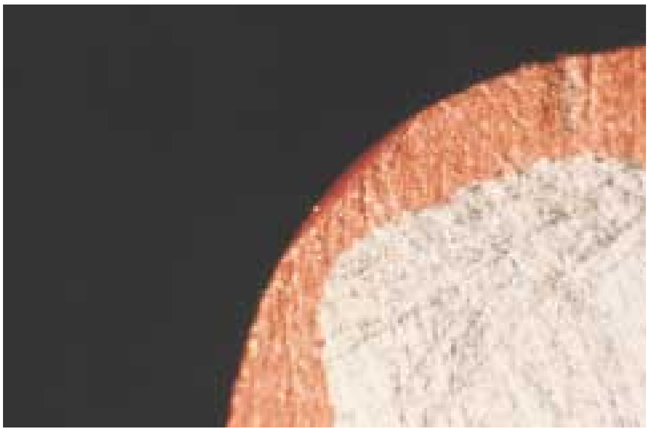


Figure 4. Cross-section showing reduction in coating thickness at a corner (image courtesy of Steel Protection Consultancy)

Site connections and splices

Girder splices and connection details are often not given full protection in the shop, leaving the connection zones to be made good on site. A frequent consequence is that these zones are the least well prepared and protected, and are the first to show signs of breakdown. Hence, it is important to pay special attention to the corrosion protection of these areas.

Welded connections

At welded connections, the key factors in ensuring the effectiveness of the coating system are the effectiveness of the protection before final coating. The areas locally to welds are usually masked, to prevent them being coated. The masking stays in place until the joint is welded; this is not an ideal form of protection if there is prolonged exposure before welding.

After welding, it is essential that the joint surfaces, including the weld itself, are prepared to the specified standard of cleanliness and profile. Because of the contamination that occurs from the welding flux, particular attention needs to be paid to cleaning off all residues.

The surfaces of welds themselves should not need any grinding if they comply with the requirements of BS EN 1011: Part 2 for smoothness and blending into the parent metal. However, rough profiles, badly formed start-stops, sharp undercut and other defects such as adherent weld spatter should be removed by careful grinding. Particular attention needs to be paid to the blast cleaned profile because weld metal is harder and site blast cleaning is more difficult than shop blasting.

Bolted connections

HSFG bolted connections merit particular consideration, both of the surfaces that will remain exposed and of those that will not (e.g. the faying surfaces). The friction surfaces are usually either unpainted or metal sprayed without sealer. Hence, they need to be protected (usually by masking tape) until the parts are finally bolted together.

Attention should be paid to the removal of any adhesive used on the protective films for the faying surfaces, and to the removal of any lubricants used on the threads of bolts. Care should also be taken to avoid contamination of surfaces during bolting up. For example, older air-power wrenches tend to produce a fine oily/misty exhaust which may settle on the surface.

Surfaces in contact with concrete are usually, with the exception of a marginal strip at the edges of the interface, blast cleaned bare steel. The marginal strip should be treated as an external surface, except that only the shop coats need be applied. The width of the marginal strip should ideally be at least equal to the required cover to the reinforcement, for the same exposure condition. A width of 50mm is common. Any aluminium metal spray on surfaces in contact with concrete needs to receive at least one coat of paint to prevent the reaction that may occur between concrete and aluminium. It is recommended that any shear connectors are positioned such that they (and their welds) do not lie within the marginal strip; they should also be protected against overspray of the coating.

5. Protective coatings

Both metal and paint coatings, sometimes in combination, are applied to protect steel bridges. Metal coatings on structural members are either thermally sprayed or hot-dip galvanized. In the case of fasteners, these may be electroplated, sherardized or hot-dip galvanized. All of these types of coatings are included in the Highways Agency* and Network Rail specifications.

5.1 Paint coatings

Paint systems for steel bridges have developed over the years in response to technological advancements that have brought improved performance, and more recently to comply with industrial environmental legislation. Previous 5 and 6 coat systems have been replaced with 3 and 4 coat alternatives, and the latest formulations have focussed on application in even fewer numbers of coats, but with increasing individual film thickness. Examples of this are epoxy and polyester glass flake coatings that are designed for high build thickness in one or two coat applications. Also single coat high build elastomeric urethane coatings (to d.f.t. of 1000µm) which have been used on several new bridges in Scotland since 1988.

Modern specifications usually comprise a sequential coating application of paints or alternatively paints applied over metal coatings to form a 'duplex' coating system.

The protective paint systems usually consist of primer, undercoat(s) and finish coats. Each coating 'layer' in any protective system has a specific function, and the different types are applied in a particular sequence of primer followed by intermediate/build coats, and finally the finish or top coat.

Primers

The primer is applied directly onto the cleaned steel surface. Its purpose is to wet the surface and to provide good adhesion for subsequently applied coats. In the case of primers for steel surfaces, these are also usually required to provide corrosion inhibition.

Intermediate (undercoats) coats

Intermediate or undercoats are applied to 'build' the total film thickness of the system. Generally, the thicker the coating the longer the life. Undercoats are specially designed to enhance the overall protection and, when highly pigmented, decrease permeability to oxygen and water. The incorporation of laminar pigments, such as micaceous iron oxide (MIO), reduces or delays moisture penetration in humid atmospheres and improves tensile strength. Modern specifications now include inert pigments such as glass flakes to act as laminar pigments. Undercoats must remain compatible with finishing coats when there are unavoidable delays in applying them.

Finishes

The finish provides the required appearance and surface resistance of the system. Depending on the conditions of exposure, it must also provide the first line of defence against weather and sunlight, open exposure, and condensation (as on the undersides of bridges).

The paint system

The various superimposed coats within a painting system have to be compatible with one another. They may be all of the same generic type or different, but all paints within a system should normally be obtained from the same manufacturer and applied in accordance with their recommendations.

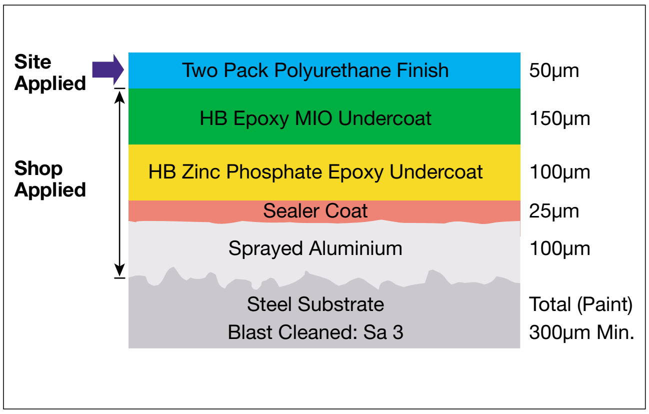


Figure 5. Schematic cross-section through a typical modern high performance coating system

5.2 Metallic coatings

The two most commonly used methods of applying metallic coatings to structural steel are thermal (metal) spraying and hot-dip galvanizing. In general, the corrosion protection afforded by metallic coatings is largely dependent upon the choice of coating metal and its thickness, and is not greatly influenced by the method of application.

Thermal spray coatings

In thermal spraying, either zinc or aluminium can be used. The metal, in powder or wire form, is fed through a special spray gun containing a heat source which can be either an oxygas flame or an electric arc. Molten globules of the metal are blown by a compressed air jet onto the steel surface.

Figure 6. Cross-section through a thermally sprayed aluminium coating

No alloying occurs and the coating that is produced consists of overlapping platelets of metal, and is porous. The adhesion of sprayed metal coatings to steel surfaces is considered to be essentially mechanical in nature. It is therefore necessary to apply the coating to a clean roughened surface and blast cleaning with a coarse grit abrasive is normally specified.

The pores are subsequently sealed by applying a thin organic coating that penetrates into the surface. Typically specified coating thicknesses vary between 100-200 μm (microns) for aluminium, and 100-150 μm for zinc.

Thermal spray coatings can be applied in the shops or at site, there is no limitation on the size of the workpiece and the steel surface remains cool so there are no distortion problems.

The protection of structural steelwork against atmospheric corrosion by thermal sprayed aluminium or zinc coatings is covered in BS EN 2063:2005, and guidance on the design of articles to be thermally sprayed can be found in BS EN ISO 14713:1999.

Hot-dip galvanizing

Hot-dip galvanizing is a process that involves immersing the steel component to be coated in a bath of molten zinc after pickling and fluxing and then withdrawing it. The immersed surfaces are uniformly coated with zinc alloy and zinc layers that form an integral bond with the substrate.

As the zinc solidifies, it usually assumes a crystalline metallic lustre, often referred to as spangling. The thickness of the galvanized coating is influenced by various factors including the size and thickness of the workpiece, the steel surface preparation, and the chemical composition of the steel. Thick steel parts and steels which have been abrasive blast cleaned tend to produce relatively thick coatings.

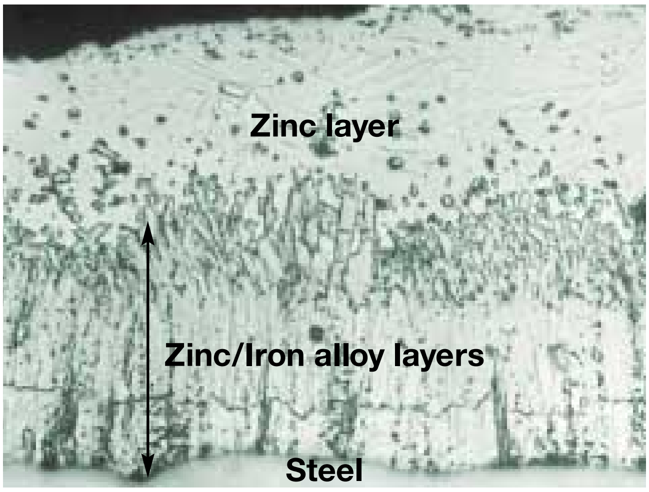


Figure 7. Cross-section through a typical hot-dip galvanized coating

Since hot-dip galvanizing is a dipping process, there is obviously some limitation on the size of components that can be galvanized. However, 'double-dipping' can often be used when the length or width of the workpiece exceeds the size of the bath.

Some aspects of the design of structural steel components need to take the galvanizing process into account, particularly with regards the ease of filling, venting and draining and the likelihood of distortion. To enable a satisfactory coating, suitable holes must be provided in hollow to allow access for the molten zinc, the venting of hot gases, and the subsequent draining of zinc. Further guidance on the design of articles to be hot-dip galvanized can be found in BS EN ISO 14713: 1999. The suitability of steels for hot-dip galvanizing should also be checked with the supplier.

For many applications, hot-dip galvanizing is used without further protection. However, to provide extra durability, or where there is a decorative requirement, paint coatings are applied. The combination of metal and paint coatings is usually referred to as a 'duplex' coating. When applying paints to galvanized coatings, special surface preparation treatments should be used to ensure good adhesion. These include light blast cleaning to roughen the surface and provide a mechanical key, the application of special etch primers or 'T' wash, which is an acidified solution designed to react with the surface and provide a visual indication of effectiveness.

Distortion of fabricated steelwork can be caused by differential thermal expansion and contraction and by the relief of unbalanced residual stresses during the galvanizing process.

The specification of hot-dip galvanized coatings for structural steelwork is currently covered by BS EN ISO 1461:1999.

Bolts, nuts and washers

The exposed surfaces of bolted fasteners need to be protected to at least the same level as the primary members of steelwork. Indeed the crevices associated with these fasteners are particularly vulnerable. Short-term protection of the fastener can be obtained by the specification of an electroplated or sherardized coating, but the full coating system should be applied after assembly. Hot-dip galvanized fasteners are commonly specified and they should be overpainted after assembly. The Highways Agency* Specification for Highway Works (SHW) requires stripe coats to be applied to all fasteners, including washers.

1. Left: Renaissance Bridge
   (Photo courtesy of Angle Ring Co. Ltd)
   Bedford, England
2. Right: Hot-dip galvanised steel bridge
   (Photo courtesy of Forestry Civil Engineering)
   Scotland

6. Highways Agency* specifications

The Highways Agency's requirements for new structures are described in the Manual of Contract Documents for Highway Works (MCDHW):

- Volume 1: Specification for Highway Works, Series 1900: Protection of Steelwork Against Corrosion.
- Volume 2: Notes for Guidance on the Specification for Highway Works, Series 1900: Protection of Steelwork Against Corrosion.

These documents consider the environment, accessibility, required durability of the systems and finish colour. The factors to be taken into account when selecting an appropriate system are described below, and a summary table of suitable protective systems for bridges (Table 19/2B) is presented in Figure 8.

Accessibility
For the purposes of maintenance painting, new structures are described as either 'Ready Access' where there are limited restrictions for working, or 'Difficult Access' where a structure crosses a busy motorway or railway.

Required durability
The minimum requirements for coating systems are currently as follows:

- No maintenance for 12 years.
- Minor maintenance from 12 years.
- Major maintenance after 20 years.

Colour
Reference is made to the BS 4800 range, description and any special finish e.g. gloss/low sheen.

Figure 8. Summary Table of the Highways Agency* Table 19/2B from 1900 Series, May 2005 Amendment

System type	Access type	Metal	1st coat	2nd coat	3rd coat	4th coat	Minimum total dry film thickness of paint system (µm)	Estimated cost £/m^2 (2001)
I	R	–	Zinc phosphate HB QD epoxy (2 pack) primer	MIO, HB QD epoxy (2 pack) undercoat	‖ Polyurethane (2 pack) finish or MC polyurethane finish		300	15
			Item 111	112	‖ 168 or 164			
II	D	Aluminium metal spray (100µm)	Aluminium epoxy sealer	Zinc phosphate HB QD epoxy (2 pack) primer	MIO HB QD epoxy (2 pack) undercoat	‖ Polyurethane (2 pack) finish or MC polyurethane finish	300	25
			Item 159	111	112	‖ 168 or 164		
II (Alternative)	D	–	Zinc Phosphate epoxy (2 pack)	HB glass flake epoxy (2 pack)	Polyurethane (2 pack) finish or MC polyurethane finish		475	19^{+}
			Item 110	123	168 or 164			
III	R or D	–	Zinc phosphate HB QD epoxy primer	‖ MIO HB QD epoxy (2 pack) finish			200	13
			Item 111	‖ 112				
IV	R or D	HDG	'T' wash	Zinc phosphate epoxy sealer or extended cure epoxy (2 pack) MIO primer	Epoxy MIO (2 pack) HB QD or extended cure	‖ Polyurethane (2 pack) finish	175	26
			Item 155	110 or 121	112 or 121	‖ 168 or 169		

Key: R = Ready D = Difficult HB = High Build MC = Moisture Cured MIO = Micaceous Iron Oxide QD = Quick Drying ‖ = To Site
Corus would like to thank Leigh's Paints, Cleveland Bridge UK Ltd. and Fairfield-Mabey Ltd. for their assistance with the estimated costs on Figures 8 & 9.

7. Network Rail specifications

Network Rail's requirements for protective treatments to be used on bridges are given in the following documents.

- RT/CE/S/039: Specification RT98-Protective treatments for Railtrack Infrastructure.

- RT/CE/C/002: Application and Reapplication of Protective Treatment to Railtrack Infrastructure.

The documents provide the performance specification and certification requirements for the protective treatments, and consider the basis for selection of systems from the specifications. A summary table of the main systems for new works is reproduced in Figure 9. Other systems are available, e.g. hot-dip galvanizing and systems suitable for the interior of box girders. Refer to RT98 for full details.

The choice of protective treatment depends upon the life requirement of the structure, and the environment and access for maintenance which is usually classed as difficult due to the need for rail possessions to carry out the work.

Environment

The environment is classified in accordance with BS EN ISO 12944: Part 2. The corrosivity categories (C grades) for exterior environments are designated as; C2- Low, C3-Medium, C4-High and C5 Very High. Generic descriptions of these exterior environments are provided in the above documents.

Required durability

A suggested service life of a coating system is defined according to the type and number of coats within a particular system, and the environment category. Service lives ranging from 5 to 25+ years are assumed in Table 3 of RT/CE/C/002.

Colour

Top coats are normally required to have a Class A Match to BS 4800 or BS 381 shades.

Figure 9. Summary Table: Railtrack RT/C/039, Protective Treatments for New Works – Issue 4 February 2002

[+] Note that rates for glass flake systems do not include spark testing.

Reference number	Title	Surface preparation and profile	Coats and thicknesses (stripe coats omitted)				Estimated cost £/m^2 (2001)
			A	B	C Intermediate Coat	D Top Coat	
N1	Thermally sprayed metal/ epoxy	Sa 3 75 to 100µm	Aluminium or zinc 100µm min.	Epoxy sealer 25µm max.	Either; HS epoxy primer, epoxy MIO epoxy intermediate 150µm min.	Either; polyurethane, acrylic urethane, epoxy acrylic, flouropolymer or polysiloxane 50µm min.	22
N2	Epoxy glass flake	Sa 2½ 75 to 100µm	Epoxy blast primer 25µm min.	–	Epoxy glass flake 400µm min.	Either; polyurethane, acrylic urethane, epoxy acrylic, flouropolymer or polysiloxane 50µm min.	19[+]
N3	Polyester glass flake	Sa 2½ 75 to 100µm	Epoxy blast primer 25µm min.	–	Polyester glass flake 400µm min.	Either; polyurethane, acrylic urethane, epoxy acrylic, flouropolymer or polysiloxane 50µm min.	21[+]
N4	Epoxy MIO	Sa 2½ 75 to 100µm	Epoxy blast primer 50µm min. or Zinc rich epoxy blast primer 50µm min.	(a) High solids epoxy primer 100µm min. or epoxy MIO intermediate coat 125µm min.	Epoxy MIO intermediate coat 125µm min. (if previous coat (a)) otherwise: epoxy intermediate coat 100µm min.	Either; polyurethane, acrylic urethane, epoxy acrylic, flouropolymer or polysiloxane 50µm min.	16
N5	Elastomeric urethane	Sa 2½ 75 to 100µm	Epoxy blast primer 25µm min.	–	Elastomeric polyurethane 1000µm min.	Either; moisture cured urethane, polyurethane, acrylic urethane, epoxy acrylic, flouropolymer, polysiloxane or elastomeric polyurethane 50µm min.	18

8. Weathering steel

Weathering steels are high strength low alloy steels, which under normal atmospheric conditions give an enhanced resistance to rusting compared with that of ordinary carbon manganese steels. These steels are generally specified to BS EN 10025-5:2004, and have similar mechanical properties to conventional grade S355 steels to BS EN 10025-2:2004. The most commonly used grade for bridges in the UK is S355J2W+N.

In the presence of moisture and air, the alloying elements in weathering steel produce a rust layer, which adheres to the base metal. This rust 'patina' develops under conditions of alternate wetting and drying to produce a protective barrier, which impedes further access of oxygen and moisture. The resulting corrosion rate is much lower than for conventional structural steels. Refer to Figure 10.

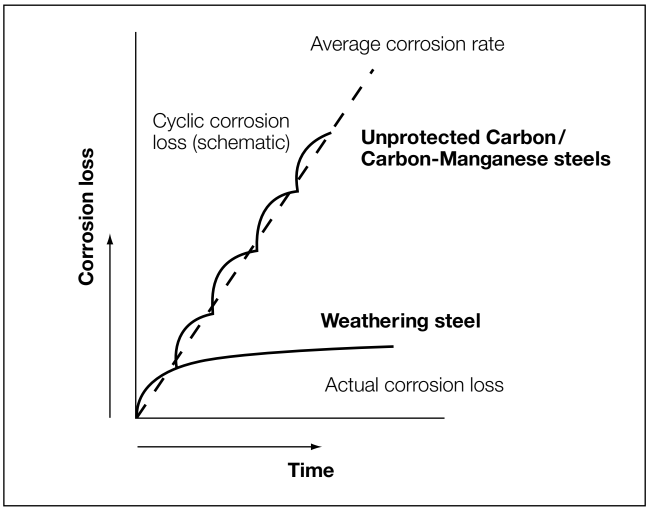


Figure 10
Schematic comparison between the corrosion loss of weathering and carbon steels

Benefits

Weathering steel bridges do not require painting. Periodic inspection and cleaning should be the only maintenance required to ensure the bridge continues to perform satisfactorily. Hence, weathering steel bridges are ideal where access is difficult or dangerous, and where future disruption needs to be minimised.

Cost savings from the elimination of the protective paint system outweigh the additional material costs. Typically, the initial costs of weathering steel bridges are approximately 5% lower than conventional painted steel alternatives. In addition, the minimal future maintenance requirements of weathering steel bridges greatly reduces both the direct costs of the maintenance operations, and the indirect costs of traffic delays or rail possessions.

Limitations on use

Weathering steel bridges are suitable for use in most locations. However, there are certain environments where the performance of weathering steel will not be satisfactory, and these should be avoided:

- Highly marine environments (coastal regions).
- Continuously wet or damp conditions.
- Certain highly industrial environments.

The use of de-icing salt on roads both over and under weathering steel bridges may lead to problems in extreme cases. Such extreme cases include leaking expansion joints where salt laden run-off can flow directly over the steel, and salt spray from roads under wide bridges with minimum headroom where 'tunnel-like' conditions are created.

1. Left: Nunholme Viaduct
   Dumfries, Scotland.
2. Right: Slochd Beag Bridge
   Inverness, Scotland

Appearance

The attractive appearance of mature weathering steel bridges blends in well with the surrounding countryside, but it is important to note that the colour and texture vary over time, and with exposure conditions. Initially, weathering steel bridges appear orange-brown, which many consider unattractive, as the 'patina' begins to form. However, the colour darkens during the construction period and within 2-5 years it usually attains its characteristic uniform dark brown, sometimes slightly purple colour. The speed with which the 'patina' forms, and the colour develops, depends mainly on the environment and exposure conditions.

Design considerations

Although the corrosion rate of weathering steel is much lower than conventional carbon steel it cannot be discounted, and allowance for some loss of section over the life of the bridge must be made. The thickness lost depends on the severity of the environment, and is defined for highway bridges in BD7/01 as follows:

Atmospheric Corrosion Classification (ISO 9223)	Weathering Steel Environmental Classification	Corrosion Allowance (mm/exposed face)
C1, C2, C3	Mild	1.0
C4, C5	Severe	1.5
(none)	Interior (Box Girders)	0.5

Detailing considerations

Formation of the protective rust 'patina' of weathering steel only occurs if the steel is subjected to alternate wetting and drying cycles. Hence, weathering steel bridges should be detailed to ensure that all parts of the steelwork can dry out, by avoiding moisture and debris retention and ensuring adequate ventilation.

Expansion joints should be avoided where practicable by the use of continuous and integral construction, or detailed to convey any leaks away from the steelwork. It may also be prudent to locally paint the ends of beams directly beneath such deck joints.

Run-off from the steelwork during the initial years, as the 'patina' develops, will contain corrosion products which can stain substructures. This potential problem can be avoided by providing drip details on the bottom flanges of girders, ensuring bearing shelves have generous falls to internal substructure drainage systems, and by wrapping substructures in protective sheeting during construction.

Remedial measures

In the unlikely event that weathering steel bridges do not perform satisfactorily, rehabilitation is feasible. This normally involves the sealing of crevices, blast cleaning to remove the rust 'patina', and repainting either in part or of the whole bridge. Alternatively, the steelwork can be enclosed in a proprietary system.

Further information

1. Bridges in Steel – The Use of Weathering Steel in Bridges, ECCS (No.81), 2001.
2. Guidance Notes on Best Practice in Steel Bridge Construction, SCI-P-185, The Steel Bridge Group, The Steel Construction Institute, May 2002 (GN1.07, Use of weather resistant steel).
3. BD 7/01 Weathering steel for highway structures, Design Manual for Roads & Bridges, Vol. 2, Section 3, Highways Agency*, London, 2001, The Stationary Office.
4. Weathering steel bridges, Corus Construction & Industrial, 2005.

9. Enclosure systems

Enclosure systems offer an alternative method of protection for the structural steelwork of composite bridges, whilst at the same time provide a permanent access platform for inspection and maintenance.

The enclosure approach was proposed in 1980 by the Transport Research Laboratory after finding that clean steel does not corrode significantly at relative humidities up to 99%, provided that environmental contaminants are absent. The concept, therefore, was to enclose steel bridge beams, already sheltered by a concrete deck, with lightweight and durable materials, thereby reducing the corrosive effects of the environment to which the bridge is exposed.

Testing

Tests have been undertaken on a variety of enclosed bridges (approximately 10) over a number of years. Measurements have been made of humidity, temperature, time of wetness, atmospheric chlorides and sulphur dioxide. Corrosion rates have been measured on bare steel test panels. The results of such tests, carried out both inside and outside the enclosures, confirm that the method produces an environment of low corrosivity for bare steel with corrosion rates only 2% to 11% of those measured outside enclosures. This suggests that painted steel within enclosures will remain maintenance free for decades. The enclosure method is also applicable to unpainted steel, and would extend the life of weathering steel bridges constructed in unfavourable environments.

Figure 11. Key benefits of enclosure systems

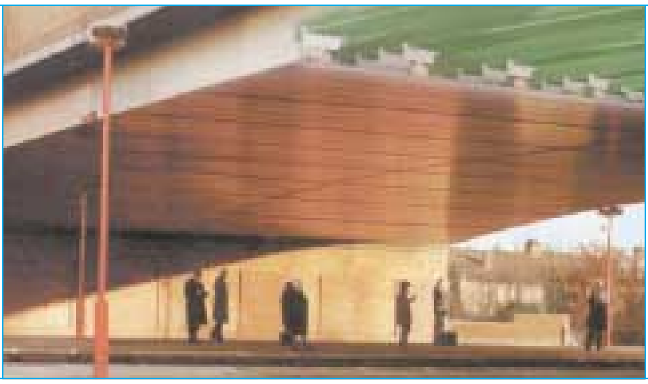
Examples of enclosure

Examples of enclosure of bridges include the following:

1. Rogiet Bridge, Monmouthshire

The enclosure system was attached to steelwork of this new motorway bridge next to the site, prior to being lifted into position over 3 night possessions, which minimised both disruption to rail services and construction costs. The enclosure envelope provided access for completion of the deck construction, avoiding further rail disruption. It also created an environment suitable for the use of a reduced paint specification (internal box girder) for the steelwork, which again minimised cost and future maintenance requirements.

1. Left: Bromley South Bridge Enclosure
   Kent, England
2. Right: Rogiet Bridge
   Monmouthshire, Wales



2. Hardy Lane, South Gloucestershire
Side road bridge over motorway. The enclosure attached to this new bridge enabled the use of a reduced paint specification with the added benefit of lower future maintenance and therefore lower costs. It also provides access at all times to the bridge without costly disruption to the motorway.

3. Tees Viaduct, Middlesbrough
The enclosure was attached as a retrofit to this viaduct over River Tees, rail lines and roads. This was the first major application (1988) of a GRP panel enclosure system in Europe to provide access for inspection, steelwork and deck refurbishment, and to reduce the cost of future maintenance.

Economics of enclosure

The economics of installing enclosure systems can be estimated from an assessment of the size, location and accessibility of the bridge, taking into account the reduction in costs associated with construction times, temporary works, road and rail traffic disruption, and paint systems. Additional benefits may also be realised on existing bridges, where an enclosure retrofit can minimise risk and enable comprehensive inspections and maintenance to be carried out.

An analysis of the total expenditure for the construction, subsequent maintenance and traffic disruption costs can demonstrate the viability of enclosures. Reference to Highways Agency* documents BD67/96 and BA67/96, ‘Enclosure of bridges’ is suggested to estimate the viability of enclosure systems for appropriate bridges.

Further information

1. BD 67/96 and BA 67/96 'Enclosures of Bridges Design Manual for Roads and Bridges' Volume 2, Section 2, Highways Agency* London, 1996, The Stationary Office.
2. Transport Research Laboratory, Research Report No 83 ‘Enclosure – An Alternative to Bridge Painting’.
3. Transport Research Laboratory, Research report No 293, ‘Corrosion Protection – The Environment Created by Bridge Enclosure’.
4. Steel Bridgework Corrosion Protection, The Tees Viaduct Enclosure System – BS Research, Technical Note SL/S/TN/31/-/C available from Corus UK, Swinden Technology Centre.

1. Left: Hardy Lane Bridge
   Gloucestershire, England
2. Right: Tees Viaduct
   Middlesbrough, England

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