Corus Construction & Industrial

Weathering steel bridges

Contents

1. Above: Slochd Beag Bridge
   Inverness, Scotland
2. Left: Lincluden Viaduct
   Dumfries, Scotland
3. Right: Obridge Viaduct
   Somerset, England

Introduction

Weathering steel is a high strength low alloy steel that in suitable environments forms an adherent protective rust 'patina' to prevent further corrosion.

The corrosion rate is so low that bridges fabricated from unpainted weathering steel can achieve a 120 year design life with only nominal maintenance. Hence, a well detailed weathering steel bridge in an appropriate environment can provide an attractive, very low maintenance, economic solution in many locations.

This publication highlights the benefits of weathering steel bridges, describes the limitations, and comments on both the material availability and the appearance of such bridges. It also provides advice on a range of issues including design and detailing, fabrication and installation, inspection and maintenance, and remedial measures should corrosion rates exceed those anticipated at the design stage.

Weathering steel

Weathering steels or weather resistant (WR) steels are colloquial terms used to describe structural steels with improved atmospheric corrosion resistance.

1. Main picture: Shanks Millennium Bridge
   Peterborough, England.
2. Below: Surtees Bridge
   Cleveland, England.

These steels are high strength low alloy steels, that under normal atmospheric conditions give an enhanced resistance to rusting compared with that of ordinary carbon manganese steels. Weathering 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 bridgeworks in the UK is S355J2W+N.

How weathering steels work

In the presence of moisture and air, all low alloy steels have a tendency to rust, the rate of which depends on the access of oxygen, moisture and atmospheric contaminants to the metal surface. As the process progresses, the rust layer forms a barrier to the ingress of oxygen, moisture and contaminants, and the rate of rusting slows down.

The rust layers formed on most conventional structural steels detach from the metal surface after a critical time, and the corrosion cycle commences again. Hence, the rusting rate progresses as a series of incremental curves approximating to a straight line, the slope of which depends on the aggressiveness of the environment.

With weathering steel, the rusting process is initiated in the same way, but the specific alloying elements in the steel produce a stable rust layer that adheres to the base metal, and is much less porous. 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 reduction in corrosion rates is clearly illustrated in figure 1.

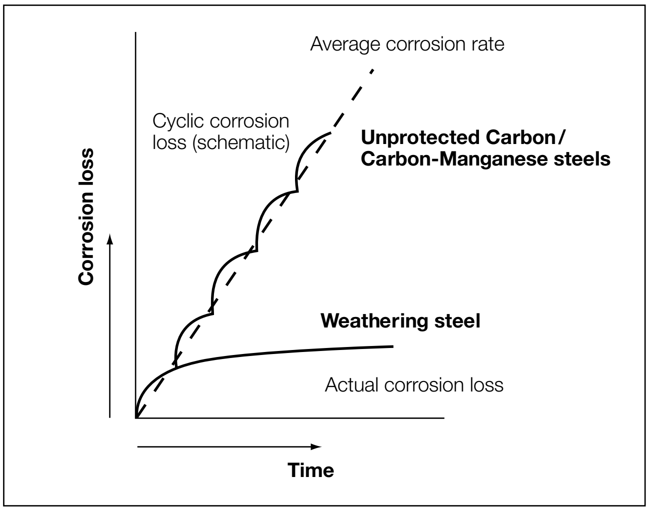


Figure 1
Schematic comparison between the corrosion loss of weathering and carbon steels

Benefits of weathering steel

Weathering steel bridges have much to offer and have a good track record.

Conventional steel bridges taking advantage of the latest advances in automated fabrication and construction techniques are able to provide economic solutions to the demands of safety, rapid construction, attractive appearance, shallow construction depth, minimal maintenance, and flexibility in future use. Weathering steel bridges have all these qualities, yet offer further benefits.

Weathering steel bridges also have a good track record. A recent study by TRL indicates that weathering steel bridges built over the last 20 years are generally performing well. Where problems have been encountered, they have been the direct result of specific faults such as leaking deck joints, rather than any general inadequacy in corrosion performance. See reference 5 (page 23) for further details.

1. Above: M18 over East Coast Mainline
   Doncaster, England
2. Left: Slochd Beag Bridge
   Inverness, Scotland
3. Right: Lincluden Viaduct
   Dumfries, Scotland

Very low maintenance	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.
Initial cost benefits	Cost savings from the elimination of the protective paint system outweigh the additional material costs. Typically, the costs of weathering steel bridges are approximately 5% lower than conventional painted steel alternatives. This was illustrated in a recent study on eight bridges in the UK. (Reference 4)
Whole life cost benefits	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, leading to major savings far in excess of the 5% on capital costs.
Speed of construction	Overall construction durations are reduced as both shop, and site painting operations are eliminated.
Attractive appearance	The attractive appearance of mature weathering steel bridges often blends pleasingly with the environment, and improve with age.
Environmental benefits	The environmental problems associated with paint VOC emissions, and the disposal of blast cleaning debris from future maintenance work are avoided.
Safety benefits	Health and safety issues relating to initial painting are avoided, and the risks associated with future maintenance are minimised.

Limitations on use

Weathering steel bridges are generally suitable for use in most locations.

However, as with other forms of construction, there are certain environments which can lead to durability problems. The performance of weathering steel in such extreme environments will not be satisfactory, and these should be avoided:

Marine environment

Exposure to high concentrations of chloride ions, originating from sea water spray, salt fogs or coastal airborne salts, is detrimental. The hygroscopic nature of salt adversely affects the 'patina' as it maintains a continuously damp environment on the metal surface. In general, weathering steel should not be used for bridges within 2km of coastal waters, unless it can be established that chloride levels do not exceed the salinity classification of S2 (cl < 300mg/m^2/day) to ISO 9223.

De-icing salt

The use of de-icing salt on roads both over and under weathering steel bridges may lead to problems in extreme cases. These include leaking expansion joints where salt laden run-off flows directly over the steel, and salt spray from roads under wide bridges where 'tunnel-like' conditions are created. However, salt spray is unlikely to be a problem for typical weathering steel composite overbridges even at standard headrooms of 5.3m, which are now permitted in BD7/01.

'Tunnel-like' conditions are produced by a combination of a narrow depressed road with minimum shoulders between vertical retaining walls, and a wide bridge with minimum headroom and full height abutments. Such situations may be encountered at urban / suburban grade separations. The extreme geometry prevents

1. Above: Obridge Viaduct
   Somerset, England
2. Left: Footbridge
   Near Bracknell, England
3. Right: Slochd Beag Bridge
   Inverness, Scotland

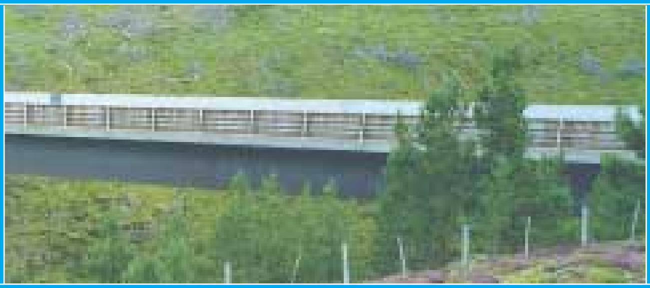
roadway spray from being dissipated by air currents, and it can lead to excessive salt deposits on the bridge girders.

Continuously wet / damp conditions

Alternate wet / dry cycles are required for the adherent 'patina' to form. Where this cannot occur, due to continuously wet or damp conditions, a corrosion rate similar to that of conventional carbon steel may be expected. Examples include weathering steel elements immersed in water, buried in soil or covered by vegetation. Design standard BD7/01 requires a minimum headroom of 2.5m for crossings over water to avoid such damp conditions.

Atmospheric pollution

Weathering steel should not be used in atmospheres where high concentrations of corrosive chemicals or industrial fumes, specifically SO_2, are present. Such environments with a pollution classification above P3 (SO_2 > 250µg/m^3) to ISO 9223 should rule out the use of weathering steels. However, this is an extreme level, which is rarely encountered.



Advice on environmental classification

The International Standards Organisation document ISO 9223 describes two methods for classifying atmospheric corrosivity, one based on environmental data and the second on corrosion rate tests.

Environmental data approach

This method combines measurements of the following three key factors to determine the overall corrosivity classification (C1-C5) of the environment.

- Time of wetness (T1-T5)
- Atmospheric sulphur dioxide pollution (P0-P3)
- Airborne salinity (S0-S3)

Corrosion rate approach

Corrosion rates are measured for standard metal specimens exposed for a year in the required location to a standard procedure given in ISO 9226.

Unfortunately, both methods require measurements to be taken over a year to obtain representative average values. In most situations this will not be possible or practical at the design stage, so in the absence of a scientific approach, a judgement needs to be made. ISO 12944: Part 2 relates the classifications C1-C5 to descriptions of typical environments, and is a good starting point. Refer to the following table based on the ISO 12944 descriptions.

Environment category	Typical environment
C1	Interior environments only.
C2	Atmospheres with low levels of pollution. Mostly rural areas.
C3	Urban and Industrial atmospheres with moderate sulphur dioxide pollution. Coastal areas with low salinity.
C4	Industrial areas and coastal areas with moderate salinity.
C5-I	Industrial areas with high humidity and aggressive atmospheres.
C5-M	Coastal and offshore areas with high salinity.

Further information to assist in making a judgement can be derived from a site visit to assess the nature of the bridge location and through contact with the local authority to determine future development plans. In addition, information on levels of sulphur dioxide pollution can be found from The UK National Air Quality Information Archive available through the National Environment Centre of AEA Technology at their web site; www.aeat.co.uk/netcen/airqual/statbase/concns/auto1.html

1. Left: Findhorn Viaduct
   Inverness, Scotland
2. Right: Obridge Viaduct
   Somerset, England

Availability

Weathering steel plates and HSFG bolts are readily available but there are limitations the designer should be aware of.

1. Left: Footbridge
   York University, England
2. Right: A6182 over East Coast Mainline
   Doncaster, England

Plates

Plates may be obtained direct from the mill, where a minimum quantity of 5T per width and thickness applies. Corus currently supplies S355J0W, S355J2W and S355K2W weathering steel plates to BS EN 10025-5: 2004 within the following parameters:

Parameter	Production process	
	Normalised	Normalised rolled
Max. Plate Width	3.75m	3.75m
Max. Plate Length	17.0m	18.3m
Max. Gauge	100mm	65mm
Max. Plate Weight	14.5T	14.5T
CEV* (Max. / Typical)	0.52/0.50	0.47/0.44**

* Carbon Equivalent Value
** Low CEV weathering steel up to 85mm thick, Normalised

If plates outside these parameters are required, please contact the Corus Technical Sales & Marketing.

Sections

Corus no longer produce rolled sections in weathering grades. This is not a problem for main girders that are generally fabricated from plate, but care is required when determining an appropriate bracing strategy.

'Ladder deck' bridges

The nature of 'ladder deck' bridges is that they only require bracing at intermediate supports. 'Knee bracing' using short lengths of rolled sections should be avoided, and the most economic solution is the use of a deep fabricated plate girder.

'Multi-girder' bridges

The bracing for this type of deck should generally take the form of fabricated plate girders as stiff transverse beams in an 'H' configuration. However, for deep main girders, angles or channels fabricated from weathering grade plate may be required to form a triangulated bracing system.

Steelwork contractors have a wealth of knowledge and experience, and would be pleased to assist in design development to achieve the most economic bracing strategy for a weathering steel bridge.

Hollow sections

The minimum quantity for hollow sections specified to BS 7668: 1994 is 150T per order, as a cast will have to be made specially. Within this quantity, a mixture of section sizes may be ordered, with the minimum quantity of each section being dependent on the section size. Contact the Corus Technical Sales & Marketing for further details.

HSFG bolts

Over recent years, weather resistant grade HSFG bolts have been imported from North America in imperial sizes. However, Cooper and Turner in the UK now stock weather resistant grade HSFG bolts, with chemical compositions complying with ASTM, A325, Type 3, Grade A and in metric sizes (M24 and M30).

Appearance

The attractive appearance of mature weathering steel bridges blends in well with the surrounding countryside.

It is important to note that the colour and texture vary over time and with exposure conditions. Examples of mature weathering steel bridges are illustrated throughout this brochure.

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.

1. Above: Findhorn Viaduct
   Inverness, Scotland.
2. Left: Nunholme Viaduct
   Dumfries, Scotland.
3. Right: Dalscone Viaduct
   Dumfries, Scotland.

The speed with which the 'patina' forms, and the characteristic colour develops, depends mainly on the environment and exposure conditions. In an industrial atmosphere the weathering process will generally be more rapid, and the final colour darker, than in a rural environment.

The texture of weathering steel is influenced by the orientation, and degree of shelter of the girders. Surfaces facing south and west, and those subjected to frequent wet / dry cycles, develop a smoother fine-grained texture. Whereas, sheltered girders and surfaces facing north and east tend to have a coarse granular texture.

Design and detailing

The satisfactory performance of weathering steel bridges can be achieved by following normal good practice in steel bridge design and detailing.

Certain aspects do require further consideration due to the nature of weathering steel and these are outlined here.

Design considerations

Although the corrosion rate of weathering steel is much lower than conventional carbon steel it cannot be totally 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 with a corresponding corrosion allowance 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

Notes

- Bridges over roads subjected to de-icing salt to be classed as ‘severe’.
- No allowance required for interior faces of sealed box girders.
- Allowances apply to all fillet and partial penetration butt welds.
- No allowance is normally made to weathering steel HSFG bolts.
- Allowances apply to all structural elements, including stiffeners and bracing etc.

These additional thickness allowances should not be included in the effective sections for stress analysis. However, they may be included in the section properties for global analysis of the structure if so desired.

Detailing considerations

Formation of the protective rust ‘patina’ of weathering steel only occurs if the steel is subjected to wet/dry cycles. Hence, it is important that the bridge be detailed to ensure such cycles can occur. Advice on good structural detailing for weathering steel bridges is available in references 4, 6, and 7, but the key issues are summarised here:

Expansion joints

Leaking expansion joints allowing salt-laden water to flow over the ends of beams has been identified as the main cause of defects in existing weathering steel bridges. Hence, the issue of joints requires careful consideration. Ideally, expansion joints should be avoided by the use of continuous and integral construction. However, if they are unavoidable they should be located away from the ends of the beams, and a positive non-metallic drainage system should be provided 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, the colour of which should be selected to match the anticipated final colour of the mature steel.

Drainage of weathering steel

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.

- Grind flush weld details which may cause water traps.
- Provide 50mm copes where stiffeners are attached to the bottom flange.
- Avoid closely spaced girders to aid ventilation.
- Avoid overlaps, pockets and crevices, which can attract moisture by capillary action.
- Hermetically seal box girders, or provide adequate access, drainage, and ventilation.
- Ensure that web plates of box girders extend 20mm below the bottom flange.

For steel composite decks, consideration should be given to providing wide deck cantilevers, with well formed drip details to shelter the girders from wind blown rain. In addition, any outlet pipes from the deck above the girders should be non-metallic and of sufficient length that the salt-laden water does not spray onto steelwork surfaces.

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 and ensuring bearing shelves have generous falls to internal substructure drainage systems.

Compatibility with other materials

Although rust staining should not occur on a well detailed weathering steel bridge, it is worth noting that concrete, stone and unglazed brick are difficult to clean. Hence, it is recommended that substructures are sealed with washable organic coatings to facilitate cleaning with commercial products, should rust staining occur. Other issues to consider include:

- Elements buried in soil should be painted.
- Interfaces between steel and concrete should be sealed with an appropriate sealant.
- Elements encased in concrete need not be painted.
- Connections to galvanically dissimilar materials such as zinc or cadmium plated bolts, should be avoided.

As with other forms of construction, the removal of graffiti from weathering steel bridges is difficult, so measures to discourage public access to the girders should be considered. However, this should be balanced with the need to provide access for inspection, monitoring and cleaning.

1. Far left: Doveridge Bypass **Derby, England.**
2. Left: Lincluden Viaduct **Dumfries, Scotland.**
3. Right: Dalscone Viaduct **Dumfries, Scotland.**

Fabrication and installation
Weathering steel bridges present no particular problems to the experienced fabricator.

1. Left: Biggleswade Bridge
   Biggleswade, England.
2. Right: Dalscone Viaduct
   Dumfries, Scotland.

Welded connections
The welding of structural weathering steels is similar to that of conventional structural steels, but such steels generally have higher CEV levels, which need to be considered when defining preheat levels. Reference should be made to EN 1011 Part 2 for determining appropriate welding parameters. Note that Corus has recently developed a lower CEV weathering steel through the normalised rolled process route, details of which are included on page 13 of this brochure.

For weathering steels, electrodes of matching chemical composition to the parent metal should be used for the capping runs of multi-run fillet and butt welds. However, conventional C-Mn electrodes may be used for the body of such welds. Conventional C-Mn electrodes may also be used for butt welds with a single run each side, and single run fillet welds of up to 8mm leg length, as there is sufficient dilution of the alloying elements from the parent metal in the weld pool to give the required corrosion resistance. For further details see references 9 and 10.

One final aspect to consider on welded connections is that all joints, including fillet welds, should be continuously welded to avoid moisture and corrosion traps such as crevices.

Bolted connections
Weathering grade HSFG bolts, nuts and washers with chemical compositions complying with ASTM A325, Type 3, Grade A, or equivalent, should be used for all bolted joints. ‘Load-indicating’ washers should not be specified, as they are not readily available in weathering grades and would create crevices with the consequent risk of corrosion. Hence, other forms of tightening such as the ‘part-turn’ method should be used. Note that for the design of such bolted connections, the slip factor may be taken as that for conventional structural steel.

Bolted connections inevitably introduce overlapping plates and the potential problem of crevices. However, careful detailing of the joint by adopting the following guidance will avoid the subsequent corrosion risks associated with crevices.

- Ensure good fit-up using flexible cover plates.
- Max. bolt spacing adjacent to an edge = 14t, but not > 180mm.
- Max. edge distance from bolt centreline = 8t, but not > 130mm.
  (Where t is the thickness of the thinner plate).

If this guidance cannot be met, the edges of the joint should be protected by a suitable sealant.

Surface preparation
Abrasive blast cleaning to a minimum standard of Sa2, should be carried out after fabrication and prior to delivery on site, to assist with the formation of a uniform rust 'patina'. The use of paint, wax, or crayon etc. for marking steelwork during fabrication and erection should be avoided, as these are difficult to remove, and will interfere with the weathering process.

Installation
Care should be taken on site with both storage and handling of the steelwork such that the developing rust ‘patina’ is not damaged. Although the ‘patina’ will re-form, it will appear non-uniform until that time. In addition, grout runs from deck concrete operations should be avoided, as they will adversely affect the steelwork, which may necessitate a final blast cleaning after site erection. During construction, piers and abutments should be protected from rust staining as the ‘patina’ forms by wrapping them in protective sheeting until the final construction inspection is made.

Inspection, monitoring and maintenance

All bridges require routine inspection, monitoring and occasional maintenance to ensure satisfactory performance. In this respect, weathering steel bridges are no different.

It is important to identify any of the specific problems to which such bridges are occasionally prone as early as possible to allow appropriate remedial measures to be taken.

Bridge inspections

Visual inspections of weathering steel bridges should be carried out by suitably experienced inspectors at least every 2 years. The surface condition of the 'patina' is a good indicator of performance. An adherent fine grained rust 'patina' indicates that corrosion is progressing at an acceptable rate, whereas coarse laminated rust layers and flaking suggests unacceptable performance. Other signs to look for, and areas to investigate during visual inspection include:

- Leaking expansion joints.
- Accumulation of dirt or debris.
- Moisture retention due to overgrown vegetation.
- Faulty drainage systems.
- Condition of sealants at concrete / steel interfaces.
- Excessive corrosion products at bolted joints (‘pack-out’).

If any serious problems are highlighted by the visual inspection, the cause should be traced and the problem rectified as soon as possible.

Monitoring of steel thickness

The corrosion rate of weathering steel bridges should be monitored every 6 years, by measuring the remaining steel thickness at clearly identified critical points on the structure. These points should be defined on the as-built drawings or in the bridge maintenance manual, along with original (reference) thickness measurements taken at the end of the construction period.

If after a period of say 18 years, the predicted loss of section over the life of the structure exceeds the original allowance, then remedial measures may need to be taken. The 18 year period is suggested as initially the corrosion rate is high while the 'patina' forms, before slowing down to a more characteristic rate. Refer to figure 1 on page 5. Thickness measurements should be taken using specialist portable ultrasonic equipment, that will not damage the protective rust 'patina'.

Routine maintenance

Surfaces contaminated with dirt or debris should, where practical, be periodically cleaned by low pressure water washing, taking care not to disrupt the protective 'patina'. Such cleaning should also be carried out annually, at the end of the de-icing period, if in practice it is found that chlorides are adversely affecting the stability of the rust 'patina', and causing corrosion of the substrate. Overhanging vegetation causing continuous dampness should be removed, and drainage systems should be regularly cleared. Any leaks should be traced to their source, and the drainage systems or joints responsible should be repaired or replaced. Finally, if there is evidence of 'pack-out' of crevices at bolted joints, then the edges of the joint should be sealed with an appropriate sealant.

1. Main picture: A50/A38 junction
   Derby, England.
2. Right: Biggleswade Bridge
   Biggleswade, England.

Remedial measures

In the unlikely event that weathering steel bridges do not perform satisfactorily, rehabilitation is feasible.

Remedial measures include 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. For further details see reference 4.

1. Above: Doveridge Bypass
   Derby, England.
2. Right: Lincluden Viaduct
   Dumfries, Scotland.

References

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Note

References 7 & 10 are jointly published by:

- The Highways Agency
- Scottish Executive
- Welsh Assembly Government
- The Department for Regional Development Northern Ireland

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