Use of weather resistant steel

No. 1.07

Scope

This Guidance Note gives brief advice on the use in bridges of weather resistant steel (often called weathering steel or, in CEN terminology, 'steels with improved atmospheric corrosion resistance').

General

Weather resistant steel is a low alloy steel that forms a protective oxide film or 'patina' that, in a suitable environment, seals the surface and reduces corrosion loss.

Reasons for use

Use of uncoated weather resistant steel may achieve the following benefits, relative to bridges with coated structural steelwork:

Reduced first costs:

- saves painting costs
- saves construction time

(The savings offset a slight increase in material cost)

Reduced maintenance:

- no need to repaint
- reduces traffic delays during maintenance
- not as dependent on weather conditions
- reduces need for access (especially beneficial where access is difficult, e.g. over a motorway, railway or river)

These savings can lead to reduced whole life costs.

Restrictions on use

Weather resistant steel is **not suitable** for the following environments:

- where there is an atmosphere of concentrated corrosive or industrial fumes. This may be defined as having a pollution classification above P3 to ISO 9223 (SO_2 > 250 µg/m^3 or 200 mg/m^2 per day). See reference 21.
- where steelwork is continuously wet or damp (the protective layer does not form, and the steel rusts in the same way as ordinary carbon steel)
- where steel is exposed to high concentrations of chloride ions or salt spray. (This may be defined as an environment having a salinity classification greater than S2 to ISO 9223 (Cl > 300 mg/m^2 per day) - see BD 7/01, Ref 17). Caution is therefore needed when considering use within 2 km of a coast.
- where the use of de-icing salt is likely to lead to substantial deposits of chloride on steel surfaces, e.g. where salt laden water would flow directly over the steel or where salt spray from roads would settle under wide bridges when 'tunnel-like' conditions are created (see further comment on Page 5).
- where steel is buried in soil.
- where the headroom to steel over water is less than 2.5 m.

Note that weather resistant steel **is suitable** for overbridges at standard minimum headroom of 5.3 m.

Steel design

Steel grade

Steel should be specified to EN 10025-5 (Ref 15). There is another standard for structural hollow sections in weather resistant steel, BS 7668 (Ref 16), but this is seldom relevant due to the lack of availability of such products - see further advice on availability at the end of this Note.

Loss of section

- Allowance should be made for the formation of rust and the resultant loss of structural section over the life of the bridge.
- The thickness lost depends on the severity of the environment, and the following allowances for this loss are recommended:

Atmospheric Corrosion Classification (ISO 9223)	Weathering Steel Environmental Classification	Thickness allowance on each exposed face
C1, C2, C3	Mild	1.0 mm
C4, C5	Severe	1.5 mm

  – Interior faces of ventilated boxes: allow 0.5 mm.
  – Interior faces of sealed boxes: no allowance needed.

- All fillet welds and partial penetration welds should adopt the same allowance as the adjoining plate.
- No further allowance is needed for full penetration butt welds (already allowed in parent plates).
- The allowance should be made on all structural elements, including stiffeners,

bracings, etc. No allowance should be made to weather resistant steel bolts.

Global analysis and stress analysis
The analysis of the structure can be carried out using gross cross section properties, but stress calculations should be based on the net section after deduction of corrosion allowances.

Fatigue design
Fatigue need not be of any more concern than with other structural steels. Although the small corrosion pits on a weather resistant steel surface would lead to a lower fatigue resistance in elements that are unwelded and free from holes and stress concentrations, the defects or imperfections inherent in welded details usually govern fatigue life. The corrosion pits on a weathered surface are smaller than weld defects and therefore do not affect the fatigue life. Although Table 8.1 of EN 1993-1-9 (Ref 22) 'downrates' the fatigue category for five unwelded details if the element is of weathering steel, the modified category is in most cases not less than the limit in Table NA.1 of the UK NA.

Additionally, the corrosion allowance provides additional reserve in the calculation of design life.

Detailing
The detailing of weather resistant steel bridgework is essentially the same as for coated steelwork, except that the consequences of poor detailing are likely to be more severe in terms of poor durability and appearance. The following advice is particularly appropriate to bridges with weather resistant steel.

- Detail girders to encourage drainage. Avoid traps for moisture and debris (e.g. grind flush the top surface of all butt welds on the bottom flanges of beams, provide 50 mm radius cope holes where web stiffeners are attached to the bottom flange), and provide good ventilation.
- Ensure good access for inspection, monitoring and cleaning of debris, etc.
- If there are local areas that would be subject to especially severe conditions, specify local painting (although it is better to adopt measures to avoid severe conditions, if that is possible).
- Minimise the number of deck joints, ideally use continuous or integral construction.
- Where joints do occur, ensure access is good and ensure that a positive drainage system is provided, preferably of a non-metallic type.
- Locate joints such that leaks would not run down the steel face or stain materials that cannot be easily cleaned. Avoid concrete, galvanised steel, unglazed brickwork, stone and wood where there may be run-off.
- A sealant should be provided at interfaces between weathering steel and concrete.
- Avoid crevices, e.g. lapping plates, otherwise capillary action will occur and rust packing will distort or burst the connection.
- Ensure water/condensation will not form localised drips; this would cause pitting in the steel section.
- For slab-on-beam highway bridges, choose wide cantilevers with well-formed drips (this avoids staining of girder face and possible differential corrosion), although cantilevers in excess of about 2 m are more difficult to construct and are therefore rarely used.
- Avoid bi-metallic joints, which may promote local corrosion. Note that small components of 'more noble' metals (such as stainless steel bolts) are unlikely to cause problems. (For further comment on bi-metallic joints at bearings, see Page 6.)
- Measures to discourage public access to the girders should be considered to reduce the incidence of graffiti, which is difficult to remove.

Reference 11 gives some typical good and bad details.

Drainage from weather resistant steel
Ensure that run-off water from the steel surface cannot run down concrete faces (e.g. avoid crossheads that project beyond the outer edges of box girders).

- Provide generous falls to bearing shelves.
- Provide drip plates to collect or deflect water.

- Non-metallic outlet pipes from the deck should be of sufficient length to ensure that the discharged water does not spray onto the adjacent steelwork.

Welding of weather resistant steel:
EN 1090-2 requires in clause 7.5.10 that "Welds on steels with improved atmospheric corrosion resistance shall be carried out using appropriate welding consumables". These may be matching consumables, containing approximately ½% Copper and other alloy elements for Submerged Arc Welding (121, 122), Manual Metal Arc (111) and Metal Active Gas (135) processes. Alternatively, they shall be either 1Cr ½ Mo, or 2 Ni for 121 and 122 processes; or 1Cr ½ Mo, or 2½ Nickel for 111 and 135 processes.

The term 'matching' in relation to electrodes is a little misleading. In reality it means electrodes which will cause the welds to weather in a similar manner to the parent material.

However, it has been shown in practice that it is best to avoid the use of matching electrodes in some situations, because the resulting weld metal becomes copper-rich, and this can lead to difficulties if the weld is also restrained. Hence, the use of C-Mn consumables is recommended only for the following situations:

- Single run fillet welds up to 8 mm leg length using the processes 121 to 125, 135 and 136. (Note that with deep penetration, 8 mm leg length fillet welds provide the equivalent strength of 'ordinary' 10 mm fillet welds).
- Butt welds formed by a single run from each side.
- Square edge butt welds using the 'punch-through' technique with the 121 to 125 processes.

(The first two situations are covered in the SHW, clause 1805.5, Ref 19.)

For the above situations there is enough dilution of the weather resistant steel alloying elements into the weld pool to give the corrosion resistance.

EN 1090-2 states that for multi-run fillet and butt welds, the main body of the weld can be made using C-Mn electrodes, capped off with matching electrodes. It is important that any exposed edges should also be capped with matching electrodes.

Multi-run butt welds using the semi automatic sub arc process and weather resistant steel electrodes give satisfactory results. Such welds are usually used for pre-assembly butts in webs and flanges, and are therefore unrestrained. Such butted plates are often subsequently cut into their final shape after welding and it is therefore useful to have the full weather-resistant properties throughout the thickness of the weld.

Bolted connections

- Use preloaded bolts, even for non-structural connections, to ensure close contact and avoid crevice corrosion.
- Specify bolts with similar weathering properties, i.e. with chemical compositions complying with ASTM A325, Type 3, Grade A, or equivalent. Never use ordinary plated bolts, as protection would be sacrificed.
- The slip factor may be taken as that for ordinary structural steel, and research (Ref 6) has shown that the effect of rusting caused by weathering of the faying surfaces between their preparation and assembly is not normally significant.
- Adjacent to an edge, use a maximum bolt spacing of 14 times the thickness of the thinner plate or 175 mm (whichever is less); use a maximum edge distance of 8 times the thickness of the thinner plate or 125 mm. (Alternatively, protect the joint.)
- Do not specify load-indicating washers, as this leaves crevices (in any case, they are not available in weather resistant steel).

Where bolt spacings are wider than recommended above, or where there are features thought to increase the risk of water intake, the joints should be protected by suitable sealants.

Surface finish

- For uniform appearance, specify the removal of mill scale and contaminants and give an all-over post fabrication blast clean with chilled iron grit or non-metallic grit to a minimum standard of Sa2

- The use of wax base markers (during fabrication) must be prohibited, because trace amounts will remain, even after blasting, and these will become very apparent after weathering
- Local painting of vulnerable areas may be acceptable: select a colour match corresponding to that which will exist after about two years of weathering (i.e. dark brown).
- Do not use enclosures for new weathering steel bridges. They are designed to inhibit corrosion and are therefore not compatible or economic for use with weather resistant steels. However, they may be appropriate as a remedial measure in the unlikely event that the weathering steel does not perform satisfactorily.

The external faces of outer girders may sometimes be painted for reasons of appearance. However, this will reduce the cost and maintenance benefits of using weather resistant steel.

The outer surfaces of box girders may also be painted for aesthetic reasons, or where the external environment is not suitable for unpainted weathering steel. The use of weathering steel in such cases yields health and safety benefits, because maintenance work inside the box girder is minimised.

Construction

Care is needed 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 and monitoring

- ‘As-built’ records should show vulnerable locations and record initial steel thicknesses at specific and re-locatable (well marked) positions.
- Visual inspection of critical areas should be carried out at intervals not exceeding two years; thickness measurements should be taken at six-yearly intervals. If, after at least 18 years, the predicted loss of section exceeds the original loss allowances over the design life (120 years according to the NA to BS EN 1993-2, Ref 22), then a protective system may have to be provided at an appropriate time.
- Inspectors assessing surface condition should be able to distinguish between a tightly adhering rust coating (which is performing satisfactorily) and one that has granular or flaky appearance (which are danger signs). The surface may be ‘dusty’ in the early stages; this is acceptable.

Routine maintenance

Surfaces contaminated with dirt or debris should be periodically cleaned by low-pressure water washing where practical, taking care not to disrupt the protective ‘patina’. 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. 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.

Remedial measures

If in practice it is found that chlorides are adversely affecting the stability of the rust ‘patina’, and causing corrosion of the substrate, then annual low-pressure water washing at the end of the de-icing period can alleviate the problem.

Other remedial measures include blast cleaning to remove the rust ‘patina’, and repainting either in part or of the whole bridge, and enclosure of the steelwork in a proprietary system.

Removal of graffiti

The removal of chalk graffiti should be achievable by using low pressure water jetting, taking care not to disrupt the protective rust 'patina'. Such an operation is unlikely to affect the durability of the structure.

The removal of spray paint will probably require higher pressures that are more likely to remove the protective rust 'patina', particularly if abrasives have to be used. Unfortunately, it is difficult to predict the degree of damage to the rust 'patina' (and hence the effect on durability) as that depends on how hard it proves to remove the paint. This in turn depends on a number of factors including the type of spray paint, the age of the graffiti, and the original condition of the rust 'patina'. However, should removal of the rust 'patina' be required to remove the graffiti, then the weathering process will have to start again. Clearly it is not advisable to do this too many times, as it will adversely affect the durability of the structure.

In terms of developing a maintenance strategy, a fall back position (if repeated graffiti removal does adversely affect the durability) would be to locally paint the affected area (i.e. outside face of the outer girder) in a colour to match that of the mature steel.

Availability

As weathering steel is not produced in the same quantities as conventional structural steels, designers should take into account the availability of weather resistant steel plates, sections and bolts at both the concept and detail design stages. The following comments relate to availability from Tata Steel.

Plates

Plates may be obtained direct from the mill, where a minimum quantity of 5 tonnes per width and thickness applies, or from ASD Glen Metals (the UK main steel stockist for weathering grades). Details of available plate lengths, widths, and thicknesses are given on SteelConstruction.info (Ref. 12)

Sections

Tata Steel no longer produce rolled sections in weather resistant steel grades. I-section girders for ladder deck cross girders and for main girders of short span multi-girder bridges can be economically fabricated from plate. Angle and channel sections for bracing members can also be fabricated from plate and since the quantity of these members is likely to be small in most cases, there is only a modest cost penalty. Nevertheless, it may be more economic to choose arrangements that use minimal amounts of bracing – avoiding the use of knee bracing in ladder deck construction, for example, or using a stiff I-section between a pair of girders, rather than a triangulated arrangement of angles. Steelwork contractors can advise on the practicability of fabricating bracing members and the alternative options.

Hollow Sections

Hollow sections to BS 7668 are no longer available from Tata Steel. If the use of such sections is desired, then an alternative supply route should be established at a very early stage in the design process.

Bolting assemblies for preloading

The majority of weathering grade preloaded bolts (HSFG bolts) used in bridge construction are currently imported. Many come from North America (in imperial sizes and to US specifications), but often they can be sourced from elsewhere in metric sizes.

Hence, the recommended approach to this issue is to standardise the connection design on the use of M24 bolts, but to choose bolt spacings to suit 1” bolts, as this will maximise the procurement options available to steelwork contractors, i.e. they can substitute 1” bolts for M24s without adversely affecting the layout or design of the connection.

Alternatively, if it is known that the steelwork contractor will be importing weathering grade bolting assemblies from North America, it is clearly more economic to use the additional resistance due to the slightly larger 1” bolts in the connection design.

It is advisable to talk to fabricators about the use of such bolts at an early stage in the design process, and be flexible to accommodate alternative proposals.

Additional comment

‘Tunnel-like’ conditions

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

Risk of bimetallic corrosion at bearings

For bi-metallic corrosion to occur two dissimilar metals need to be in direct electrical contact with each other and an electrolyte. Aspects that influence bimetallic corrosion are the nature and conductivity of the electrolyte, the relative surface areas of the anodic and cathodic metals, and the respective positions in the galvanic series.

For the majority of weathering steel bridges, the only area to consider in terms of this effect is the connection between the steel girders and the structural bearings.

For the case of weathering steel girders on ordinary structural steel bearings, there is no significant difference between the reactivity of the two metals and as the ordinary structural steel is painted, there is no contact with an electrolyte. Hence bimetallic corrosion is unlikely to occur.

For the case of weathering steel girders on stainless steel bearings, there is a significant difference between the reactivity of the two metals and as both metals are uncoated, there is potential for contact with an electrolyte. However, the surface area of the weathering steel (that would corrode preferentially to the stainless steel) is vast in comparison to the small stainless steel bearing. In addition, the bearings are generally sheltered, so electrolyte is rarely present. Hence, the level of bimetallic corrosion is unlikely to be significant.

However, It is advisable to seal the interface between the stainless steel bearing and weathering steel tapered bearing plate, as this will reduce the level of localised bimetallic corrosion. The sealant removes the risk of accelerated corrosion associated with crevices, and effectively introduces a break in the electrical circuit that reduces the level of bimetallic corrosion. For the circuit to be complete, a film of water would have to extend from the bearing over the surface of the sealant and on to the tapered plate

Further reading and references

Research papers:

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21. ISO 9223: 2012, Corrosion of metals and alloys – Corrosivity of atmospheres – Classification, International Standards Organisation.
22. EN 1993, Eurocode 3, Design of steel structures:

    EN 1993-1-8:2005, Design of joints

    EN 1993-1-9:2005, Fatigue

    EN 1993-2:2006, Steel bridges

    Plus the UK National Annexes:

    NA to BS EN 1993-1-8:2005, BSI, 2008

    NA to BS EN 1993-1-9:2005, BSI, 2008

    NA+A1:2012 to BS EN 1993-2: 2006, BSI, 2008