The maintenance of historic iron and steel structures: coping with corrosion

G. G. Nieuwmeijer
History of Structural Design Group, Department of Architecture, Delft University of Technology, The Netherlands

Abstract

Corrosion is the most dangerous enemy of historic iron and steel structures. After a general introduction to the structural engineering aspects of corrosion, this paper will focus on the relation between corrosion and structural detailing.

To provide insight into the most sensitive aspects in and around renovation and restoration and to be able to take adequate measures it is necessary to have some knowledge of the various types of corrosion. Cast iron, wrought iron and various types of steel behave differently from each other.

Close attention should be paid to corrosion, especially in the places where different types of metal are in contact with each other. External factors such as relative humidity and air pollution also play a role. Usually corrosion is promoted by inadequate structural detailing because in earlier times little was known about this process. A summary of a number of important errors is presented. It may be necessary to carry out modifications during restoration or renovation.

As many structures are important for historical and cultural reasons, adaptations should always be made in an honest and sympathetic way.

1 Introduction

In nature metals occur in the form of ores that consist primarily of metal oxides. The addition of adding energy reduces the ores to metals, which have a tendency to return to a condition in which there is minimal energy and thus, when nothing is done to this, to corrode.

Corrosion is damage to metal caused by complex electrochemical reactions. For iron and steel this is termed rusting. Rust is a mixture of iron oxides and iron

WIT Transactions on The Built Environment, Vol 83, © 2005 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)

hydroxides. The electrochemical process requires the presence of an oxidator (oxygen) and a reducing element (metal) in an ion conducting liquid such as rainwater. Oxygen and moisture are prerequisites for the corrosion process.

For a very long time a protective layer has been used to seal off the metal. Such layers must be closely bonded with surface of the metal. Comprehensive literature on the pre-treatment of iron and steel and the application of the layers is available and the same is true for cathodic protection, which is only briefly considered here.

In the 19^{th} century and at the beginning of the 20th century the need for good detailing often went unrecognised. Many joint and connections were simply asking for corrosion because dirt and moisture could accumulate in them. These are the places where corrosion begins and after some time is the most severe. Examples include profiles where dirt and moisture accumulate, cracks where structural elements are joined and the sometime excessive distance between rivets.

2 Types of corrosion

In the electrochemical reactions electrons are transferred and thus there are electric currents. The electrons move from a negative pole, the anode, to a positive pole, the cathode. To explain which places are most sensitive to corrosion and to provide some basis for the assessment of the structural detailing, first the most important types of corrosion are described. These are uniform corrosion, pitting corrosion, crevice corrosion and galvanic corrosion.

2.1 Uniform corrosion

Uniform corrosion occurs when oxidation and reduction reactions are equally distributed in time and space over a metal surface. Continually changing cathodic and anodic areas are formed on micro scale. Metallurgical factors such as small local differences in composition and inclusions can lead to local corrosion.

2.2 Pitting corrosion

Pitting corrosion is a form of local damage in which the depth of the damage is greater than its diameter. The corrosion under the surface is usually greater than the surface suggests. Pitting corrosion often occurs under layers of dirt or where the metal is tarnished. Small openings in the protective layer caused by damage or inclusions in the metal are important causes of pitting corrosion.

2.3 Crevice corrosion

Serious local damage can occur in crevices. These may be crevices between similar or different metals or between a metal and a non-metal surface. A necessary condition for this type of corrosion is the presence of a small amount of water in the crevice. Crevice corrosion can also occur under a layer of dirt, sand or rust. The presence of aggressive anions, such as OH^- and CL^- accelerates the damage.

Crevice corrosion may occur when metal parts are locally joined. Dirt and moisture collects, so that corrosion quickly occurs. This often happens when brackets and windows are fitted against struts, gutters are being supported by a longitudinal beam or brackets and frameworks are installed on facades that are infilled with masonry. With riveted elements too, crevice corrosion may occur when the distance between the rivets is too big and a split occurs between the two parts.

Figure 1: Platform roof HS Station Den Haag. Crevice corrosion between the cast iron bracket and the wrought iron strut. The pressure of the rust has demolished the bracket.

Figure 2: Engine House, Zeche Zoller II, Dortmund-Bövinghausen. Severe corrosion has occurred on the facade between the masonry and the framework.

2.4 Galvanic corrosion

This occurs when two different electrically conductive metals are bonded to each other in a corrosive environment. Metals are ordered in the electrochemical series of metals and the degree of corrosion depends on their relative positions in this series. The metals are ranked in relation to each other according to the their equilibrium potential in relation to hydrogen gas. The electric current, and thus the corrosion, is dependent on the position of the metals in the electrochemical series and on the magnitude of the contact surface. In principle the metal with the lowest electrochemical potential is corroded, while the metal with a higher electrochemical potential remains undamaged.

However, if the area of the metal with a higher electrochemical potential is larger than the area of the metal with a lower electrochemical potential the latter will be more severely corroded than in the case where when area of the metal with the higher electrochemical potential is smaller.

An example is provided by a scratch in the protective layer of tin or zinc that covers steel. Tin has a higher electrochemical potential than steel and the area of tin in the corrosion area is relatively big. The steel will be severely corroded. Zinc has a lower electrochemical potential than steel and the area of steel is relatively small. The zinc will be only slowly corroded and the zinc compounds will fill the scratch and protect the steel. Zinc plating is thus a good means of protection. When zinc anodes are applied to steel in a moist atmosphere this is termed cathodic protection. The zinc is slowly corroded and the steel is protected. This protection is used for ships, pipelines and lock doors.

Kalium	- 2.92 V	Nikkel	- 0.23 V
Natrium	- 2.72 V	Tin	- 0.14 V
Magnesium	- 2.30 V	Lood	- 0.12 V
Aluminium	- 1.30 V	Koper	+ 0.34 V
Zink	- 0.76 V	Zilver	+ 0.38V
Chroom	- 0.56 V	Kwik	+ 0.80 V
Ijzer	- 0.44 V	Goud	+ 1.38 V
Cadmium	- 0.40 V		

Figure 3: Electrochemical series of metals arranged according to their electrical equilibrium potential in relation to hydrogen gas.

Figure 4: Comparison between the corrosion of tin-plated and galvanised steel. Tin has a higher electrochemical potential than steel and the surface of the corrosion area is relatively large. The steel is severely corroded. Zinc is has a lower electrochemical potential than steel. The steel area is relatively small. The zinc is corroded and the steel remains undamaged. Zinc compounds will fill up the scratches. Galvanisation thus provides protection.

3 Influences and materials

3.1 Influence on corrosion

The composition and homogeneity of the material and the environment are all important. Small differences in composition and inclusions can be a source of corrosion. The addition a few parts of copper or chromium per mille considerably increases resistance to corrosion. This is also the case to a lesser degree when iron contains carbon and silica as cast iron does. The degree of contamination, the relative humidity and the temperature of the air all exert a major influence. In industrial areas the corrosion rate is considerably higher than in a rural area. This is primarily attributable to the sulphur and chloride that is present in industrial areas.

During the steam age the iron platform roofs of railway stations were in an aggressive environment. The smoke, containing sulphur from the coal was ejected with the exhausted steam. At present the situation of the roofs is not much better. The copper dust deriving from the overhead wire adheres to the structure and causes galvanic corrosion.

In air	**In water**
Industrial area 100 um/jaar	Seawater 100 um/jaar
Town area 50 um/jaar	River-wate 50 um/jaar
Rural area 10 um/jaar	Drinking-water 10 um/jaar

Figure 5: Corrosion rates of unprotected steel in air and water.

Because so much coal was burnt during the 19th and early 20th centuries the air contained relatively high amounts of sulphur, which at that time made a major contribution to corrosion. Where there is contact with piped water or seawater big variations in the rate of corrosion can be observed. Rainwater also contains varying amounts of dissolved gasses from which acids or salts can be formed.

Iron begins to rust at relative humidity of around 60%. As the relative humidity increases the rate of corrosion accelerates. When the air contains hygroscopic chlorides, as it does close to the sea, the corrosion starts at a relative humidity of around 40%

The rate of corrosion also increases as the temperature increases. At 40C the corrosion rate is circa twice that at 22 C. Figure 7 also shows the relation with acidity. In an aggressive environment stress concentrations caused by loading or deformation during manufacture can also accelerate corrosion.

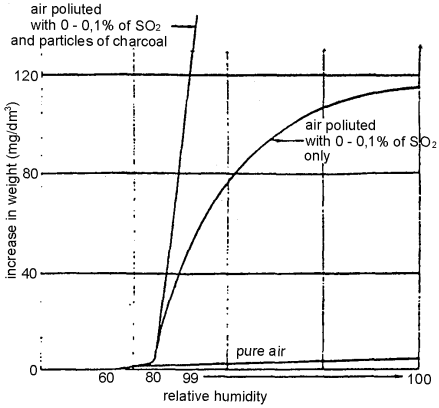


Figure 6: The influences of relative humidity and air pollution on the corrosion of iron.

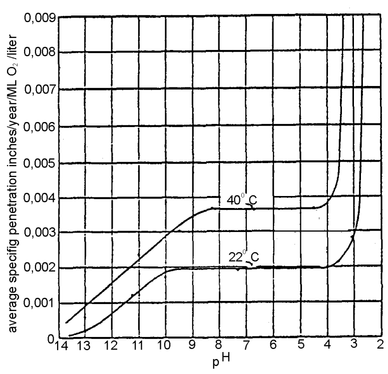


Figure 7: The influence of temperature and acidity on the rate of corrosion.

3.2 Corrosion depending on the material

Cast iron elements are always relatively thick, so a small loss of material will not have a big influence. The relatively high carbon and silica content contributes to resistance to corrosion. Because the outer surface has been in contact with the moulding sand it may have a higher silica content. Owing to the good outer layer it may occur that old cast iron elements may retain their original shape and yet still be damaged internally. Wrought iron has a layered structure. The slag in the layers consists largely of iron silicates that are relatively corrosion resistant. As a result the rate of corrosion perpendicular to the layers is many times lower than that parallel to the layers. In the 19^{th} century during the manufacturing process attention was focussed on the improvement of the mechanical properties of iron and there was less interest in its sensitivity to corrosion of iron. At that time little was known about the influence of certain elements in the iron. Even today the effect of certain elements is still unclear. Corrosion is a complex process that depends on many factors that are not mentioned here. However it can be stated that usually the corrosion resistance of cast iron is better than that of wrought iron and that steel is the most corrosion sensitive of these three metals.

4 Structural detailing

Corrosion and the damage arising from this depends very closely on the bearing elements, structural detailing and finishing processes. Water deriving from precipitation or condensation must be drained off and moving air must dry out the structure, including the finishing details. With an open roof the lower temperature can give rise to condensation on the underside. In conservatories and glass houses the glazing bars may also give rise to condensation on the inside.

If gaps between structural elements cannot be avoided they must be wide enough for air currents to pass though and dry the elements and also for the maintenance of the protective layer. The wrong type of weld can also give rise to condensation. In order to fulfil their function, dewatering holes must have a minimum diameter of 30 mm. To ensure that the protective layer is thick enough sharp bends must be avoided and in view of the danger of galvanic corrosion direct contacts between two different metals must be avoided. Bird droppings that have a high degree of acidity can damage the structure but birds can be kept away by using netting or ultra sonic noise sources.

In the past less attention was paid to finishing than at present. In old structures details that seem to be inviting corrosion are sometimes found. During restoration these details must be altered so that the building will again last for a considerable time, but alterations should be kept to the absolute minimum. Some examples of corrosion sensitive details and the changes made during restoration follow and a number of general points of interest for the structural detailing are also given.

4.1 Platform roof, H.S. Station Den Haag

At some points the cast iron window frames were attached to the wrought iron struts by clamps and rusting of the wrought iron occurred. The volume of rust is seven times greater than that of the original iron and the resulting pressure caused some of the windows to break. Mounting the window frames by using strips on the struts made it possible to ensure that the structure dries out after rain and that good maintenance is possible. The cast iron brackets that support the gutters were attached to the struts by hooks and bolts. The holes for the hooks allowed dirt and moisture to accumulate behind the brackets, leading to corrosion, during restoration the hooks were removed and the joint were closed with foam strips and mastic.

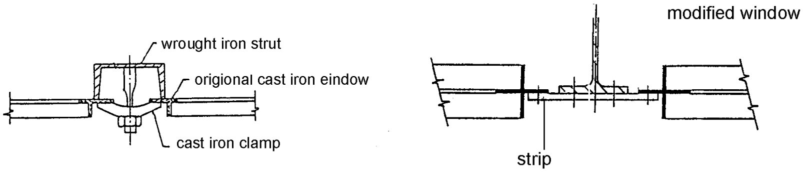
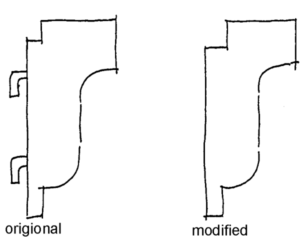


Figure 8: The platform roof at HS Station, Den Haag. Original and modified window mountings.

The trusses were bolted to the cast iron columns that stand on the platforms. The bolts passed through the columns from truss to truss and the columns also provided drainage for the rainwater. A number of these bolts were almost completely rusted through. During the restoration process separate rainwater drainage pipes were installed in the columns and the bolts no longer ran through the columns from truss to truss.



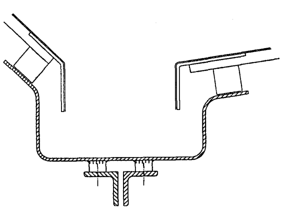


Figure 9: Platform roof HS Station Den Haag. Original attachment of the brackets by hooks and modified attachment with bolts.

Figure 10: Platform roof Den Bosch Station. Modified support for the gutters on distance blocks.

4.2 Platform roof at Den Bosch Station

The original gutters were supported by girders. Both the gutters and the upper sides of the girders were severely corroded. During the restoration the gutters were replaced by galvanised steel gutters with welded support blocks on the undersides. This created spaces of 20 mm between the gutters and the girders. The blocks have tapped holes so that the gutters can be bolted onto the underside.

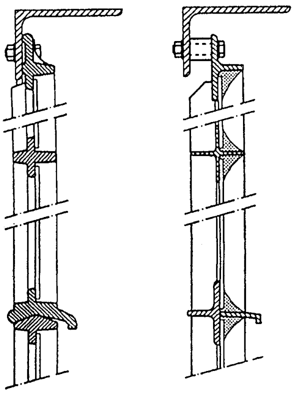


Figure 11: Platform roof Den Bosch Station. Original and modified window supports.

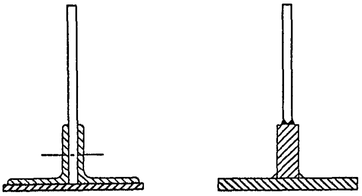


Figure 12: Platform roof Den Bosch Station. Original and modified lower edges of the truss.

The cast iron window frames were replaced by frames of nodular cast iron and the mounting was changed by the fitting of distance pieces so that the structure can dry out well and it is easy to maintain.

In the lower edges of the trusses water and dirt that cannot escape accumulates. Big parts of these trusses were seriously corroded so the lower edges were replaced by an edging of welded strips with the same outer measurements as the original profile.

4.3 The Palm House, Kew Gardens

The wrought iron glazing bars were seriously corroded. The upper sides are in outside air while on the inside condensation occurs. These glazing bars were replaced by stainless steel glazing bars of the original size. Because of the phased production process the bars were extruded rather than being rolled.

4.4 Points of attention for structural details

Figure 13 gives an overview of these. With composite profiles the pre-treatment and the protection require that there is a minimum distance between the profiles. The relation between this distance and the size of the profiles is given in Figure 14.

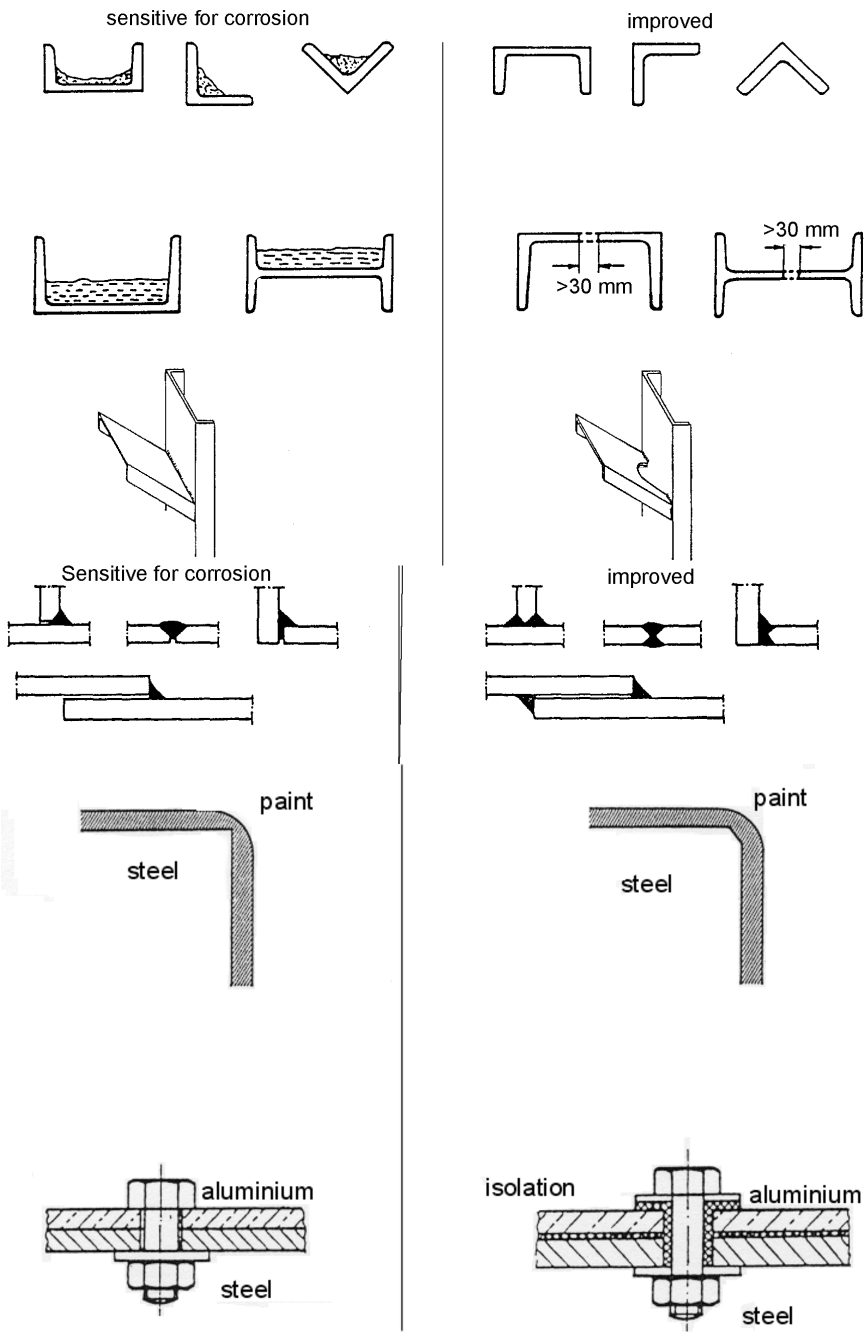


Figure 13: Points of interest in the detail of structures.

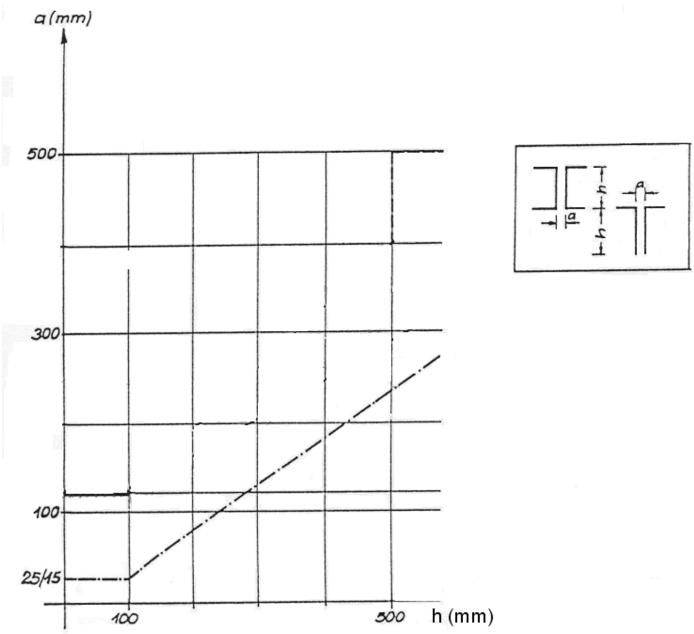


Figure 14: The relation between distance and height for composite profiles with regard to pre-treatment and protection.

5 Conclusion

In the past little attention was paid to corrosion when iron and steel structures were being designed. When these structures are being restored close attention should be paid to the use of the structural elements and their connections. Places where water and dirt can accumulate and where iron and steel are in contact with other metals must be modified. The distance between rivets must be smaller than the maximum distance to prevent crevice corrosion.

Steel is more sensitive to corrosion than wrought iron, which in turn is more prone to corrosion than cast iron. Because many structures are important for historic and cultural reasons, modifications should be made in an honest way. The appearance must be changed as little as possible but an experienced eye should be able to detect changes, so there is no falsification of history.

References

[1] Material from the archives of the History of Structural Design Group, Faculty of Architecture, Delft University of Technology.