

CORROSION PROTECTION FOR BRIDGE DECK STRUCTURES

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1.0 INTRODUCTION

Corrosion, fire protection and fatigue failure of steel structures are some of the main concerns of an engineer involved in the design and construction of structural steel work and these aspects do warrant extra attention. A review of international literature and the state of the art in constructional steelwork would reassure the designer that many aspects of corrosion, fire and fatigue behaviour of structural steel work, are no longer the major issues. For example, the steel construction industry has developed excellent protective coatings that would retain service life even after 20 years without any serious attention! Similarly the emergence of 'fire engineering of steel structures' as a specialised discipline has addressed many of the concerns regarding the structural steel work under fire. In India 'Fire Resistant Steels (FRS)' are available which are quite effective in steelwork subjected to elevated temperatures. They are also cost effective compared to mild steel! Similarly, fatigue behaviour of steel structural systems has been researched extensively in the past few decades and has been covered excellently in the published literature[1-7]. Many countries have a separate code of practice, which deals exclusively with the fatigue resistance design of steel structural systems. Today, substantial information and guidelines are available

to the designers so that these three aspects

could be handled in a routine manner. In this chapter we will review aspects of corrosion, fire protection and fatigue behaviour of structural steelwork briefly and outline suitable prevention methods.

2.0 CORROSION OF STEEL

There is a mindset among many Indian designers, that steel corrodes the most in India compared to other countries. This conception is very much untrue! No doubt, steel corrodes all over the world but the difference is, the problem is better tackled in the advanced countries. With the advent of new technologies of corrosion protection and better understanding of the material behaviour of steel, corrosion of steel no longer causes any undue worry for structural designers involved in structural steelwork. Nevertheless, a designer involved in structural steel work must be aware of the phenomena of corrosion and its prevention methods, both simple and detailed[8-13].

2.1 Corrosion mechanism as a miniature battery

Every metal found in nature has a characteristic electric potential, based on its atomic structure and also the ease with which the metal can produce or absorb electrons. Those metals, which provide electrons more readily, are

called anodes and those that absorb electrons are called cathodes[14-21]. Anodes and cathodes are called electrodes and if they get connected in the presence of an electrolyte (a conducting medium), they form a battery as shown in Fig.1.

No material individually can be called as cathode or anode, as they can serve both the functions depending on the relative potential of the material to which they are connected. For example, steel is anodic in the presence of stainless steel or brass and cathodic in the presence of zinc or aluminium. From the mechanism shown in Fig. 1, we see that two bodies of different electric potential electrically connected together in the presence of an electrolyte, the anodic body provide electrons to the cathode (To remember easily: Anodes-Away; Cathodes-Collect). In this process the anode is gradually destroyed, in other words it corrodes. On the other hand, a body will not corrode until it is immersed in or wetted by an electrolytic solution and gets electrically connected to another body having a more positive electric potential. This is the main principle called “**eliminate the electrolyte**”, using which we devise many of the corrosion prevention methods, in structural steel work[22-26].

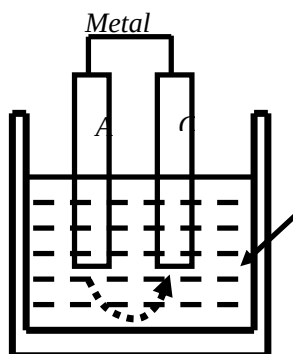


Fig.1 Mechanism of

2.2 Corrosion of steel

In the case of steel, when favourable condition for corrosion occurs, the ferrous ions go into solution from anodic areas. Electrons are then released from the anode and move through the cathode where they combine with water and oxygen to form hydroxyl ions. These react with the ferrous ions from anode to produce hydrated ferrous oxide, which further gets oxidised into ferric oxide, which is known as the ‘red rust’. Let us consider a portion of steel member, which is slightly rusted as shown in Fig. 2.

The portion of the surface protected by the oxide film (rust) would be cathodic with respect to a portion, which is not so protected. Therefore, there will be a difference in electrical potential and hence the anode will corrode, forming rust on its surface. As rust builds up on one portion of the body, it becomes less anodic with respect to a previously rusted area. In this way they form and reform batteries and corrode the entire surface.

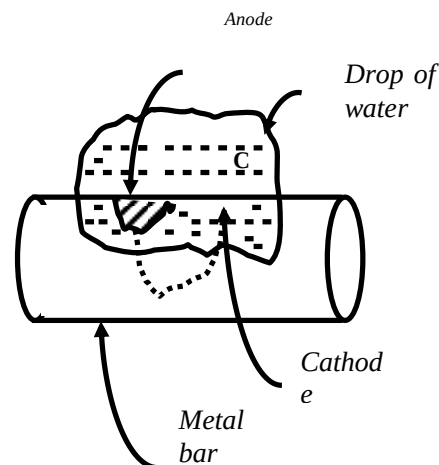


Fig. 2 Mechanism of Corrosion in steel

From the above discussion, it is clear, that the main interest of the structural designers is to prevent the formation of these “corrosion batteries”. For example, if we can wipe out the ‘drop of water’ shown in Fig. 2, the corrosion will not take place! Hence using the “*eliminate the electrolyte*” principle, wherever possible we need to device detailing and protection to surfaces of structural steel work to ensure that the combination of oxygen and water are avoided and hence the corrosion batteries are avoided[27-32].

2.3 Types of corrosion encountered in practice

Let us briefly review the types of corrosion encountered in structural steel elements:

Pitting corrosion: As shown in Fig. 2, The anodic areas form a corrosion pit. This can occur with mild steel immersed in water or soil. This common type of corrosion is essentially due to the presence of moisture aided by improper detailing or constant exposure to alternate wetting and drying. This form of corrosion could easily be tackled by encouraging rapid drainage by proper detailing and allowing free flow of air, which would dry out the surface.

Crevice corrosion: This again is due to improper detailing where the tops of the crevices become localised anodes and corrosion occurs at this point. The principle of crevice corrosion is exemplified in Fig. 3. The oxygen content of water trapped in a crevice is less than that of water, which is exposed to air. Because of this the crevice

becomes anodic with respect to surrounding metal and hence the corrosion starts inside the crevice.

Bimetallic corrosion: When two dissimilar metals (for e.g. Iron and Aluminium) are joined together in an electrolyte, an electrical current passes between them and the corrosion occurs. This is because, metals in general could be arranged, depending on their electric potential, into a table called the ‘galvanic series’. The farther the metals in the galvanic series, the greater the potential differences between them causing the anodic metal to corrode. A common example is the use of steel screws in stainless steel members and also using steel bolts in aluminium members. This type of bi-metallic corrosion is easy to spot and understand. Obviously such a contact between dissimilar metals should be avoided in detailing[33-37].

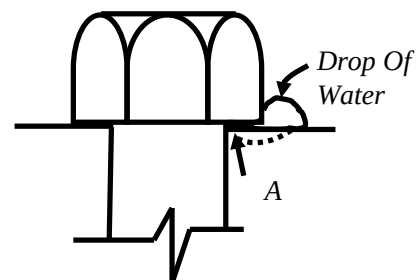


Fig.3 Mechanism of crevice

Stress corrosion: This occurs under the simultaneous influence of a static tensile stress and a specific corrosive environment. Stress makes some spots in a body more anodic (especially the stress concentrated zones) compared with the rest as shown in Fig. 4. The crack tip in Fig. 4 is the anodic part and

it corrodes to make the crack wider. This corrosion is not common with ferrous metals though some stainless steels are susceptible to this.

Fretting corrosion: If two oxide coated films or rusted surfaces are rubbed together, the oxide film can be mechanically removed from high spots between the contacting surfaces as shown in Fig. 5.

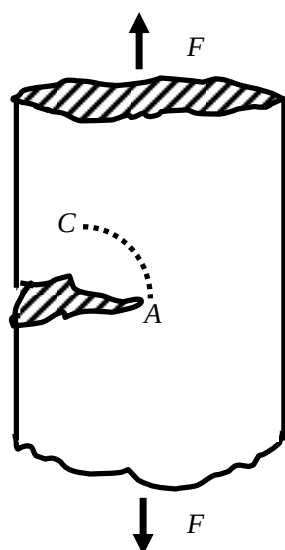


Fig. 4 Mechanism of stress corrosion

These exposed points become active anodes compared with the rest of the surfaces and initiate corrosion. This type corrosion is common in mechanical components[42-45].

Bacterial corrosion: This can occur in soils and water as a result of microbiological activity. Bacterial corrosion is most common in pipelines, buried structures and offshore structures.

Hydrogen embrittlement: This occurs mostly in fasteners and bolts. The atomic hydrogen may get absorbed into

the surface of the fasteners. When tension is applied to these fasteners, hydrogen will tend to migrate to points of stress concentration. The pressure created by the hydrogen creates and/or extends a crack. The crack grows in subsequent stress cycles. Although hydrogen embrittlement is usually included in the discussion about corrosion, actually it is not really a corrosion phenomenon[38-41].

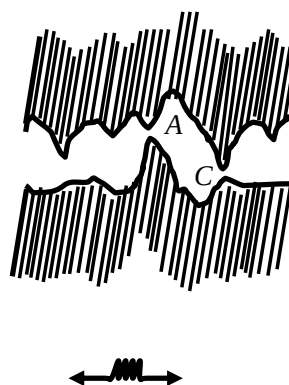


Fig. 5 The mechanism of fretting corrosion

3.0 CORROSION PROTECTION TO STRUCTURAL STEEL ELEMENTS

Taking care of the following points can provide satisfactory corrosion protection to most structural steel elements:

- Avoiding of entrapment and accumulation of moisture and dirt in components and connections by suitable detailing as shown in Fig. 6
- Avoiding contact with other materials such as bimetallic connections, as explained in the earlier section.

- Detailing the structural steel work to enhance air movement and thereby keeping the surfaces dry as shown in Fig.7
- Providing suitable drain holes wherever possible to initiate easy draining of the entrapped water as shown in Fig. 8

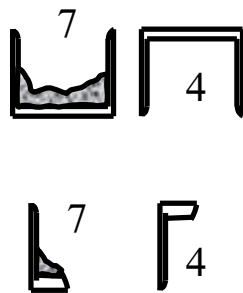


Fig.6 Simple orientation of members to avoid dirt and water entrapment

- Providing suitable access to all the components of steel structures for periodic maintenance, cleaning and carrying out inspection and maintenance at regular intervals.
- Providing coating applications to structural steel elements. Metallic coatings such as hot-dip galvanising, metal spray coatings, etc. are very effective forms of corrosion protection. Cleaning of the surfaces and applying suitable paints is the most commonly used and reliable method of corrosion protection. This is discussed in detail in the next section.

3.1 Surface preparation

Before applying any protective coating to structural steel work, it is very essential that the surface must be free of dirt and other materials that would affect its adhesion. In this section we review the surface preparation methods which are commonly employed in structural steel work[46-50].

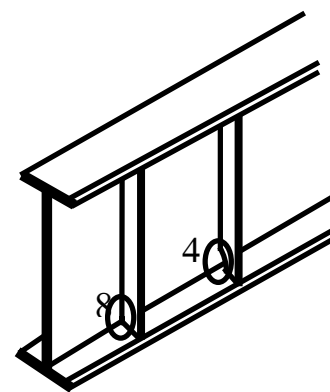


Fig.7 Detailing to enhance air movement between joints

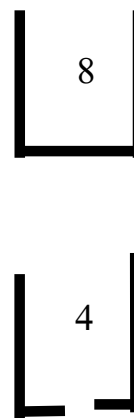


Fig.8 Provision of drain holes wherever possible.

Structural steel comes out of the mill with a mill scale on its surface. On weathering, water penetrates into the fissures of the mill scale and rusting of the steel surface occurs. The mill scale loses its adhesion and begins to shed. Mill scale therefore needs to be removed before any protection coatings are applied. The surface of steel may also contain dirt or other impurities during storage, transportation and handling. The various surface preparation methods are briefly explained below[7-16].

Manual preparation: This is a very economical surface cleaning method but only 30% of the rust and scale may be removed. This is usually carried out with a wire brush.

Mechanical preparation: This is carried out with power driven tools and up to 35% cleaning can be achieved. This method is quite fast and effective.

Flame cleaning: In this process an Oxy-gas flame causes differential thermal expansion and removes mill scale more effectively.

Acid pickling: This involves the immersion of steel in a bath of suitable acids to remove rust. Usually this is done before hot dip galvanising (explained in the next section).

Blast cleaning: In this process, abrasive particles are projected at high speed on to the steel surface and cleaning is effected by abrasive action. The common blast cleaning method is the 'sand blasting'. However in some states of India, sand blasting is not allowed due to some environmental reasons.

3.2 Preventive coatings

The principal protective coatings applied to structural steel work are paints, metal coatings or combination of these two. Paints basically consist of a pigment, a binder and solvent. After the paint has been applied as a wet film, the solvent evaporates leaving the binder and the pigment on the surface. In codes of practices relating to corrosion protection, the thickness of the primer, the type of paints and the thickness of the paint in term of microns are specified depending upon the corrosive environment. The codes of practice also specify the frequency with which the change of paint is required. Metal coatings on structural steel work are almost either zinc or aluminium. Hot dip Zinc coatings known as "galvanising", involves dipping of the steelwork into a bath of molten Zinc at a temperature of about 450°C. The work piece is first degreased and cleaned by pickling to enhance the wetting properties. Sometimes hot dip aluminising is also done. Alternatively, metal coating could also be applied using metal spraying.

3.3 Weathering steels

To protect steel from corrosion, some countries produce steels which by themselves can resist corrosion. These steels are called as "*weathering steels or Corten steels*". Weathering steels are high strength alloy weldable structural steels[44-49], which possess excellent weathering resistance in many non-polluted atmospheric conditions. They contain up to 3% of alloying elements such as chromium, copper, nickel, phosphorous, etc. On exposure to air, under suitable conditions, they form adherent protective oxide coatings. This acts as a protective film, which with time

and appropriate conditions causes the corrosion rate to reduce until it is a low terminal level. Conventional coatings are, therefore, not usually necessary since the steel provides its own protection. Weathering steels are 25% costlier than the mild steel, but in many cases the total cost of the structure can be reduced if advantage is taken of the 30% higher yield strength compared to mild steel.

3.4 Where does corrosion matter in structural steel work?

The corrosion of steel in a dry interior environment is virtually insignificant. For example, structural steel work in the interiors of offices, shops, schools, hostels, residences, airport terminals, hospitals etc. will not corrode noticeably during the expected 50-year life of the structure. Hence *in these situations no protective coating is required and the structural steel work may be left exposed*. Only when the structural steel work is exposed to moisture in an interior environment such as kitchens, sports halls etc. a little attention is needed in the detailing of the steel work and also thin protective coatings. Structural steel work will need protective coatings in slightly intensive corrosive environment such as some industrial buildings, dairies, laundries, breweries etc. The above mentioned situations can be termed as 'low to medium' risk categories. Structural steel work exposed to high humidity and atmosphere, chemical plants, foundries, steel bridges, offshore structures would fall into the "high risk" category. Structural steel work that is categorised into high-risk group requires better surface preparation and sufficient thickness of the anti-corrosive paints. As

we review the protective coatings such as the paints available in the market today many of the paints can perform very satisfactorily for 5-7 years. Specially prepared epoxy paints when applied in sufficient thickness after a good surface preparation, can last as high as 20 years!! Corrosion of steel is no longer the major problem that it once was and the protective methods no longer pose any major disincentive for using steel in the building industry. For the purpose of selecting a suitable paint system, if appropriate, the risk groups of structural steel work [15-19] are classified according to their location and their intended service; however the same classification can also be done depending on the exterior environment of the structural steel work as in Table.1

Table 1 Exterior environment and corrosion risk (Source: British Steel)

	Exterior Environment	Areas appropriate	Corrosion risk
1.	Normal Inland	Most rural and urban areas	Low
2.	Polluted Inland	High airborne sulphur dioxide	Significant
3.	Normal Coastal	As normal inland plus high airborne salt levels	High
4	Polluted Coastal	As polluted inland plus high airborne salt levels	Very high

In the aggressive environment such as the cases 2,3 and 4 in Table 1, appropriate technologies are available to

counter corrosion. There is a range of corrosion protection methods, depending upon the environment and desired life of the protection method, the details of which are presented briefly in Table 2. Expert help should be obtained when the corrosion risk is “high” or “very high”.

4.0 CONCLUSION:

The mechanism of corrosion and the possible ways of its prevention has been discussed in the foregoing sections. The following are the three broad categories of corrosion prevention methods.

- I. As mentioned earlier, corrosion does not occur in the absence of water. Corrosion protection can be achieved by a number of methods (e.g.)
 - (a) Application of coatings to separate the metal from its environment.
 - (b) Avoiding exposure to moisture and air.
 - (c) Attention to detailing of the structures to encourage rapid drainage of water.
- II Corrosion does not occur in the absence of Oxygen and water. This can be achieved by
 - (a) Deaeration of water
 - (b) De-humidification of the atmosphere
 - (c) Application of certain surface coatings
- III Corrosion does not occur if the basic electro-chemical reaction is suppressed
 - (a) The use of corrosion inhibitors would suppress either anodic or cathodic

reactions and hence the corrosion is prevented.

- (b) The other method is the application of cathodic protection, which floods the surface with free electrons and prevents formation of anodes.

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