CORROSION OF STRUCTURAL STEELS & ITS PREVENTION – A PRACTICAL APPROACH

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Executive Summary

The cost of Corrosion in India is currently estimated at about Rs. 24,000 Cr/ year. Although corrosion could be said to be natures method of recycling, or of returning of a metal to its lowest energy form, it is an insidious enemy that destroys our cars / plumbing systems / buildings / bridges / engines / factories etc. Avoiding detrimental corrosion requires interdisciplinary approach by the designer. The approach paper is written from various resources keeping the same in mind. This paper explains the process of environmental attack on steel and shows that there is as such no problem in ensuring durability of steel structures, if proper protection measures are employed. The paper is organized into six major sections. The first section deals with the introduction where typical ratio of steel vs. cement is stated. Section two discusses the topic like Corrosion definition, measurement of corrosion, simple way to explain Corrosion mechanism and Corrosion rates as a function of various factors. Section three deals with Corrosion from the design standpoint, selection of materials and design details to minimize Corrosion? Finally how do we place an economic value on our selection of alternate material or use of coatings. The Section four describes the Corrosion prevention and its Control. Design considerations are discussed to minimize Corrosion and various methods available to control corrosion including paint systems. Special emphasis has been given to Corrosion on Steel Structures. Section five gives an insight into the perception and reality on the corrosion problem. Section six covers some examples of longevity of steel structures. Finally Section seven touches upon specific cases for Corrosion Protection with special reference to Cable Stay Bridges, Coating of Rebars and relevant IS standards.

We are sure that this approach paper will help to understand corrosion in a simple way and references to key literature will be a valuable guide. This is not cookbook for Corrosion avoidance. A road map of references provided here should be useful. This approach paper could not have been possible without the generous guidance from Dr. R. Narayanan, Dr. S R Mediratta, Director General and Mr.A C Sarkhel.

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1.0 INTRODUCTION

Civil structures are designed for different life spans varying from 25-35 years in case of offshore platforms to as long as 100-200 years in case of dams as given in **Table 1**. The construction of structures involves use of structural steel, reinforced cement concrete (RCC) and prestressed concrete (PSC). In view of the numerous advantages steel intensive construction offers, the current trend in most of the advanced countries is primarily based on steel or steel-concrete composite construction, whereas in India RCC and PSC design options are predominantly employed. This has resulted in very low (about 0.31) steel to cement consumption ratio as compared to more than 1.5 in the UK and more than 1 in other advanced countries such as USA, Japan and Germany.

Table 1: Lifetime of Structure(1)

Civil Work	Expected Lifetime (years)
Housing	60-100
Dams	100-200
Industrial buildings	30-60
Bridges	100-120
Offshore Platforms	25-35
Nuclear containments	30-50

One of the main reasons advanced by construction industry in India for preferring RCC and PSC over steel or steel-concrete composite option is unfounded fear of deterioration of structural steel due to environmental corrosion thereby affecting durability. It has been a misconception with many that RCC and PSC do not have the risk of degradation or corrosion of reinforcements and/or cables in cable stay or cable suspension structures.

There is also a perception among many Indian designers that the domestic steel produced currently corrodes at higher rate than that produced and used in India 4-5 decades back. This perception is based on general observation and not on actual facts. Further, designers have a feeling that steel corrodes faster in India than in other countries. This perception is also not supported by any scientific and technical reasoning or data.

This paper explains the process of environmental attack on steel and shows that there is no problem of durability of steel structures in India or abroad, if proper protective measures are employed. High performance paints/coatings are now available to be applied after proper surface preparation for providing durable life.

There are number of examples of structures built in steel more than 100 years ago being in use even today. This clearly indicates that durability can be ensured if properly designed, constructed and maintained. The properly protected steel buildings are very durable, without facing any corrosion(2). Even exposed steel structures such as bridges have served more than a century, still going strong in service. Concern about durability of steel structures is unwarranted as long as attention is paid to detailing and providing suitable corrosion protection measures at the design stage itself.

2.0 THE CORROSION PROCESS

The nature of corrosion of structural steel, its prevention and control have been discussed in considerable detail by Kalyanaraman(2) and others(1,3-12). Some of the important points brought out by these authors are briefly discussed in the following sections.

2.1 What is Corrosion?

Corrosion is defined as the destruction or deterioration of a material because of its reaction with environment. When metals revert to their combined state, they corrode. Corrosion may affect one or more properties of the metal, which need to be preserved,

In case of corrosion of iron and steel, iron oxidizes into iron oxides. These oxides are usually weaker than steel. They are loosely attached and spall off from the surface. This leads to reduction in strength and reliability of structures.

2.2 Measurement of Corrosion

During the process of corrosion, weight of material decreases and depth of corrosion layer/pits increases. Further, flow of current is observed in case of bimetallic corrosion and mechanical properties such as yield (YS) and tensile strength (UTS) are decreased. These effects are measured in units(10) as given below and give the progress of corrosion process.

Corrosion effect	Unit
Weight change	g /m^2 /year
Increase in corrosion depth	μm /year; mpy (mil per year)
Corrosion current	mA /cm^2
Decrease in Y.S, UTS	% / year

2.3 Reactions during Corrosion

The corrosion of steel is a chemical process wherein steel oxidizes into more stable iron oxide. For the process to take place, both moisture and air (oxygen) are required. The corrosion of steel can be understood as an electrochemical reaction between steel or its alloy and the surrounding environment. The process can be considered as a simple electrolytic cell.

The mechanism of corrosion can be understood in terms of a battery, which contains electrodes i.e. anode and cathode, which are connected in presence of an electrolyte (a conducting medium) as shown in **Fig. 1.**

Fig. 1: Mechanism of Corrosion in Terms of Miniature Battery$^{(10)}$

Depending upon the relative potential with respect to another material to which it is connected, it can serve as an anode or cathode. Plain carbon or structural steel is anodic in presence of stainless steel or brass and cathodic in the presence of zinc or aluminum as can be seen in **Fig. 2**. The anodic material provides electrons to the cathode and in the process the former is gradually destroyed i.e. it corrodes. It can be inferred that structural steel will not corrode until it is immersed in or wetted by an electrolytic solution and gets electrically connected to another metal or alloy having a more positive electric potential. Thus elimination of electrolyte itself can be effective for corrosion prevention.

Steel is a multi-crystalline material. The grains exhibit potential difference under this condition **(Fig. 3)$^{(2)}$.** The moisture and oxygen in the environment provide the necessary electrolyte to set up the current flow from one grain (+ve potential, cathode) to another grain (-ve potential, anode). This leads to corrosion of the grains at anode of the electro-chemical cell.

$$\begin{aligned} Fe + O_2 + H_2O &\rightarrow 2OH^{--} + Fe^{2+} \\ &\rightarrow Fe\,(OH)_2 \end{aligned}$$

$$\begin{aligned} 2Fe(OH)_2 + O_2 &\rightarrow Fe_2O_3.H_2O = 2(F_eOOH) \\ &\rightarrow Fe_3O_4 + H \text{ (under acidic conditions)} \end{aligned}$$

Anodic End
(More prone to corrosion)

Magnesium its alloy Zn and its alloy Al and its alloy Cadmium	↑	Tendency to inhibit corrosion of Structural steel

STRUCTURAL STEEL

Cast Iron Steel Lead Brass Copper	↓	Tendency to accelerate corrosion of structural Steels .

Cathodic End
(Less prone to corrosion)

Fig. 2: General Galvanic Series(3)

Fig. 3: Electrochemical Mechanism of Corrosion in Steel(8)

The process 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 cathode sites on the surface, where they combine with oxygen and water to form hydroxyl ions. The hydroxyl ions react with ferrous ions from the anode to produce ferrous hydroxide, which itself is further oxidized in air to produce hydrated iron oxide i.e. red rust.

After a period of time, polarization 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 on the surface and this type of corrosion is described as “general corrosion”.
Two important points emerge:

- For iron and steel to corrode, it is necessary to have the simultaneous presence of water and oxygen.
- All corrosion occurs at anode; no corrosion occurs at cathode.

2.4 Corrosion Rates

The rate of corrosion depends upon a number of factors, the important among them being time of wetness, level of pollutants in and pH of the surrounding environment..

2.4.1 Time of Wetness(3)

Time of wetness due to rainfall, condensation etc, when plenty of atmospheric oxygen is available, affects the rate of corrosion; higher rates being at longer duration of wetness. In dry environments e.g. inside buildings, corrosion is negligible due to the low availability of moisture. The requirement for application of paints or coatings in-doors becomes unnecessary other than for aesthetic considerations or fire protection purpose.

2.4.2 *Atmospheric Pollution*(3)

The type and amount of atmospheric pollution and contaminants e.g. sulphates, chlorides and dust affect the corrosion rate. Both sulphates and chlorides increase corrosion rates by reacting 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 winds.

Sulphates

Level of sulphur dioxide in the atmosphere is increasing as a result of increased combustion of fossil fuels e.g. sulphur bearing oils and coal as a result of industrialization. The sulphur dioxide gas reacts with water or moisture in the atmosphere to form sulphurous and sulphuric acids, which accelerate corrosion. Industrial environments are prime sources of sulphur dioxide.

Chlorides

These are mainly present in marine environments. The highest concentration of chlorides is found in coastal regions and there is a rapid reduction while moving inland from the coast. Two-kilometer strip along the coast is generally considered as the marine environment.

2.4.3 Cementitious Materials

Portland cement is an alkaline material due to the presence of $Ca(OH)_2$ and other soluble alkali salts. The pH of a saturated $Ca(OH)_2$ solution is approximately 12.5. At such a value, steel is passivated even in presence of moisture and oxygen because of formation of a thin film of oxide, generally considered to be γFeOH. Corrosion rate increases as the pH value decreases upto 10, it remains almost constant between pH value of 4 and 10 and increases sharply when pH value falls below 4 as shown in **Fig. 4**