Cost Effective Ways to Protection Steel Structures from Environments

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Steel corrodes when exposed to myriad conditions including outdoor atmosphere. It is noteworthy that all types of steel including the low alloy type are prone to rust in moist atmosphere. Rusting is an electrochemical process characterized by exchange of electrons. In some cases, the additions of 0.3% copper to carbon steel can reduce the rate of rusting to a greater extent. The elements Cu, P, Cr and Ni have all been shown to improve resistance to atmospheric corrosion. Formation of a dense, tightly adhering rust scale is responsible in lowering the corrosion rate leading to use without protection and can also extend paint life by decreasing the amount of corrosion underneath the paint. The rate of rusting is usually higher in the first year of exposure to atmosphere than in subsequent years, and increase significantly with the degree of pollution and moisture in the air. Alloying elements contribute to a more compact and less porous corrosion product as surface film. Adherent, protective films on these steels seal the surface against further penetration of water, which does not easily wet the oxide surface. Compact surface oxide films develop more rapidly in industrial atmospheres containing SO_2, which is probably involved in film formation in presence of moisture by forming sulphurous and sulphuric acids which are very corrosive. This theory was based largely on the observation that the corrosion products formed on steel when exposed to industrial atmosphere were usually rich in sulphates. However, the corrosion rates of weathering steels are not reduced in industrial atmospheres to levels lower than those in non corrosive rural or semi rural atmosphere. Periodic drying is required for the surface film to develop its protective properties.Further the development of improved weather resistant steel & high performance paints/coatings system can protect the steel even in most aggressive environments. Normally the lifetime of the protection system is not the same as the lifetime of the steel structure it protects. The protective system usually required has various lifespan. All Civil structures are designed for specific life spans based on durability as given in Table 1

Table 1: Lifetime of Structure & Durability

Civil Work	Life Span (years)		Durability	Years
Housing	60-100		Low	2-5

Dams	100-200			
Indl buildings	30-60		Medium	5-10
Bridges	100-120			
O/shore Platforms	25-35		High	>10

There are many options available to the architect or engineer for selecting aesthetically pleasing coating system for steel, which will provide many years of maintenance free operation. Hence the purpose of this paper is to provide an insight to professional engaged in design of building & bridges using structural steel on corrosion protection system.

DETERIORATIONS & SOLUTIONS

Structural steel will not corrode until it is immersed / 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. The durability of steel-concrete slab is adversely affected by corrosion of the reinforcements. The reinforcement bars, in contact with oxygen, changes to Fe_2O_3 and Fe_3O_4, which fill much larger volume than steel; this volume increase generates tensile stresses in the concrete, which fails along the bars. In a sound concrete the pH value of the cement paste is about 12-13, offering a protection to steel by the formation of a thin layer of bonded and insoluble oxide, which stops the reaction of oxidation. The corrosion is possible with a lower pH of cement paste, in the range of 8 to 9. The pH lowering is often created by the carbonation, the ingression carbon dioxide from the atmosphere into the concrete. Also the ingression of chlorides and Nacl existing in a marine environment greatly accelerates the corrosion rate.

TMT bars as well as CRS grades containing small percentage of Cu and Cr and these bars have 1.5 – 1.9 times better corrosion resistance than that of CTD bars. Similarly Stainless steel bars/galvanized bars have also been developed for use in hostile environments. It can be used in combination with carbon steel, for example, in the repair / renovation of structures, where it will provide enhanced durability over repair using carbon steel. The use of all these grades will enhance the durability of reinforced concrete structures.

CORROSION BASICS

Corrosion is defined as the destruction or deterioration of a material because of its reaction with environment. Iron oxidizes into iron oxides which are weaker than steel. Both moisture and air (oxygen) are required for the corrosion of steel to take place. The corrosion of steel is an electrochemical reaction between steel and the surrounding medium. Over time, anodes are destroyed as shown in Fig. 1. Thus elimination of electrolyte itself can be effective for corrosion prevention. The important parameters for corrosion are:

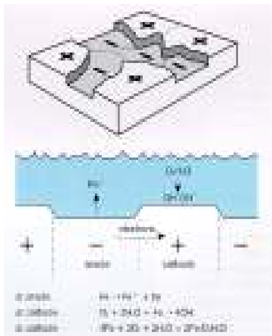

Fig 1: Mechanism of Corrosion

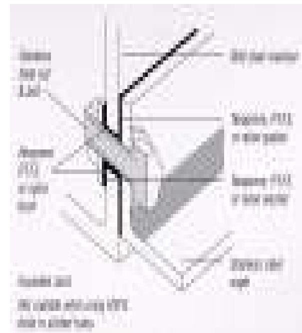

Fig 2: Prevention of Bi metallic Corrosion

Rate-Corrosion rate depends upon factors, such as period of wetness, level of pollutants in and pH of the surrounding environment.

Wetness- 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.

Pollution - Both sulphates and chlorides increase corrosion rates by reacting with the surface of the steel. Structural Engineers needs to be concerned about two types of corrosion in steel structures.

General Corrosion- It is characterized by chemical or electro-chemical reaction that proceeds uniformly over the entire or large area of the exposed surface. The metal becomes thinner and eventually it fails. This form of corrosion can be prevented or reduced by proper selection of materials or the protective method or considering a sacrificial thickness in the design calculations and thus is not of great concern. Further life of the structure can be accurately estimated.

Galvanic/Two-metal Corrosion-A potential difference usually exists between two dissimilar metals when they are immersed in a corrosive or conductive solution. Metals are placed in contact (or otherwise electrically connected), a corrosion cell is formed and potential difference produces electron flow between them. Some metals (e.g. CI, SS, Cu) cause structural steel to corrode preferentially whereas other metals (e.g. Zn, Al, Mg) corrode preferentially themselves, thereby protecting the steel. Figure 2 shows preventions of corrosion from two different metals.

CORROSION PREVENTION & CONTROL

Ideally, the metal selected or protective system applied to the metal should be such that no corrosion occurs at all, but this is seldom technologically or economically feasible. It is necessary, therefore, to tolerate a rate and a form of corrosion that will not be significantly detrimental to the properties of the metal during the anticipated life of the structure. Generally corrosion rate up to 225 μm/year in case of bare plain carbon structural steel and up to 100 μm/year in case of stainless steel are tolerated. However, suitable protection must be employed, if corrosion penetration in bare condition exceeds 1,500 μm/year for mild steel and 500 μm/year in case of stainless steel as indicated in Table 2.

Table 2: Average Corrosion Penetration (μm/year)

Usability	Expensive Material (Ag, Ti, Zr)	Moderately Expensive Material (Al., Cu., SS)	Cheap Material (MS,CI)
Satisfactory	<75	<100	<225
Acceptable	75 - 250	100 - 500	225 - 1500
Not acceptable	> 250	> 500	> 1500

STEEL STRUCTURES

Corrosion in structural elements is important depending upon environment. The rate of corrosion of depends upon how long the steel remains wet. The protection problem arises from rain rapidly saturating the outer skin, particularly through mortar joints, and wetting the exposed steelwork. The design should ensure adequate drainage the steelwork. Various parts of connections need to be protected by a coating system including high performance paint systems. Based on need stainless steel, weathering steel or hot dip galvanized connections/fasteners are to be considered. Nowadays hollow sections are used very efficiently for steel structures and Inner surface of these sections need protection if the section is sealed. Completely open sections, e.g. box girders, may require internal protection. Galvanizing, fusion bonded epoxy coatings or chemical resistant paints are all possible solutions. Sheet profiles used, as cladding is available with hot dip zinc or zinc/aluminium coated for protection

PROTECTION OPTIONS

Design Stage: Designs can never be absolute and often there is a tendency for compromise based on cost and availability of materials and resources. The prevention of corrosion should be taken into account during the design and detailing stage of a project itself. The following points are to be taken into consideration. Figure 3 provides typical design tips.

- Entrapment of Moisture and Dirt/ Radius edges and corners
- Provide vent-holes and drain-holes for items to be hot-dip galvanized
- Provide adequate access for metal spraying, paint spraying, etc.
- Flat surface, Ease of maintenance
- Contact with other Materials &Coating Application

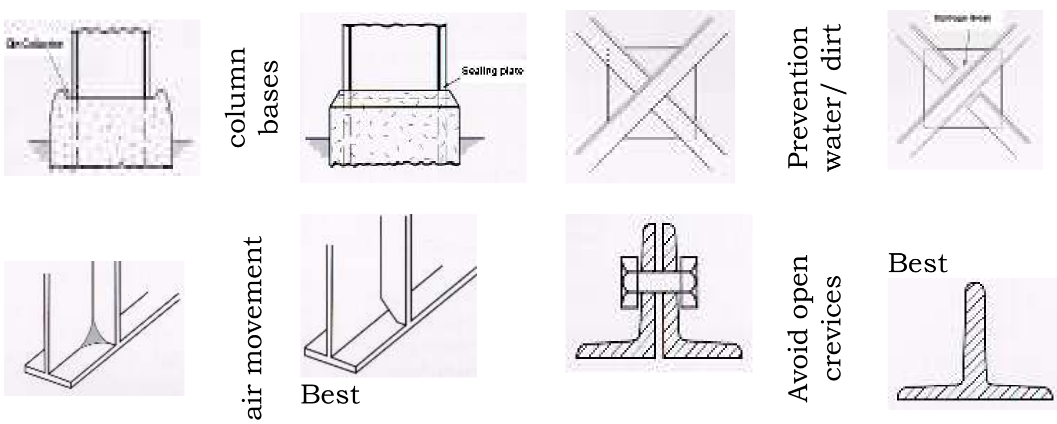

Fig 3: Typical Design Tips.

Material selection - At ordinary atmospheric temperatures oxidation of steel takes place in the presence of moisture. Therefore the only way to prevent the atmospheric oxidation is to create a barrier between the steel surface and the atmosphere. Weather resistant steel rusts at a much lower rate than plain carbon steels and under a favourable climatic condition develops an impervious adherent rust layer of hydrated iron oxide over the surface of steel. This acts as a protective film, which with time causes the corrosion rate to reduce reaching a terminal level usually between 2-3 years. Paint systems suitable for conventional structural steel are equally applicable for weather resistant steel, whenever painting is required to further enhance corrosion resistance.

MAJOR PROTECTION METHODS

Quite apart from the simple fact that the methods of protection are by no means universally applicable, choice is partly governed by the actual environmental conditions and partly by economic considerations. The latter include not only the initial cost of application and replacement of corroded parts or structure itself, but in some cases renewal of the protecting medium. The protection methods can be divided into the following categories.

- Controlling electrode potential by applying cathodic/anodic protection.
- Addition of corrosion inhibitors to the environment
- Applying organic or inorganic protection coatings.
- Inorganic/Metal Coatings or Organic/Paint Systems

Sacrificial metal coating/cathodic protection is used extensively and coating material is zinc, Al, Mg and their alloys whose electrode potentials are more negative than Fe or steel. Al/Zn/Mg provides cathodic protection to iron and steel. For many applications metal-spray coatings are further protected by the subsequent application of paint coatings. A sealer is first applied which fills the pores in the metal spray coatings and provides a smooth surface for application of the paint coating.

SURFACE PREPARATION

Metal surface is covered with a paint system, which is able to prevent or delay the corrosion of the metal surface. Durability of each paint system is a function of surface preparation and this may be done by various methods depending upon the situation/locations. There are several standards like SSPC, Sa, NACE etc corresponding to Hand and power tools, Blast cleaning, Flame cleaning, Wet (Abrasive) blast cleaning, Commercial metal cleaners and Acid Pickling

STEELWORK FLOW AND COSTING

Structural steel received from plants used for any construction activities contains mill scales and these are basically rust. Hence proper sequence of work is to be followed in order to achieve the right performance of desired coating system.Various grades of paints are available in the market and these are selected based on performance, cost, end application etc. Table 3 shows generic types of paints with their relative properties and table 4 shows cost comparison of various paints.

Table 3: Generic Paints and Properties

Paint Type	Cost	Surface Tol	Remarks
Alkyds	Low Medium	Moderate	Good decorative properties
Acrylated Rubber	Medium	Poor	High build films remain soft and are susceptible to 'sticking'
Epoxy	Medium-High	Very Poor	Very susceptible to chalking in UV
Urethane	High	Very Poor	Better decorative properties than epoxies
Organic /Inorganic Silicate	High	Very Poor	May require special surface preparation

Table 4: Cost Comparison

Substrate	System	Coats	Price /Lt	Rs/Sq mt	Term
Carbon steel	Epoxy	3	200	56	Short
Carbon steel	Epoxy + PU	3	200	72	Long
Carbon steel	Zn-silicate+ Epoxy PU	4	300	115	Long
Galvanized steel	PU finish	3	80	55	Long
Pipe line (int)	Glass Epoxy	2	1000	680	Long

PROTECTION GUIDE FOR STEELWORK

The table 5 provides guidelines to practsing Engineers for designing the paint systems for durability of steel structures like bridges, flyovers and buildings. The paint system suggested are tried and tested in the actual field-testing stations. After two years of exposure of all the selected paint system found to be free from deterioration and also cost effective.

In the absence of relevant IS code of practices, ISO 12944 and associated ASTM G 50 standards were used for conducting systematic study using high performance coatings. The generic paint formulations (Alkyd, Epoxy, Zinc Silicate, Chlorinated Rubber, PU etc) for different environmental conditions with respect to durability were chosen. Both generic and trade name of the applied paints are given in the specification table. The designed paint systems as indicated are found to be intact and no damage occurred during the period mentioned. The paint systems suggested above have been tested in our country at Dehradun (Normal Inland), Delhi (Polluted Inland), Jamshedpur (Polluted Inland), Kolkata (Polluted Coastal), Digha (Normal costal) and Chennai (Polluted coastal). Hence the recommended paint system may be considered as guidance to draw specification for any new steel structures considering the identical environments of the places. Recommended Specification for New Steelwork exposed to Environments is given in the tables where both trade name and generic system names are indicated along with dry film thickness (dft) for different durability.

Table 5: Recommended Paint System

Normal Inland

	Primer (µm)	Intermediate (µm)	Top Coat (µm)	Dft(µm)
Low Durability (2 -5 years)	Interprime 198	-	Interlac 665	100
	Alkyd(60)		Alkyd(40)	
	Neropoxy Zn Phosphate	-	Nerochlor Finishing Enamel	100
	Epoxy Zinc Phosphate(50)		Chlorinated Rubber(2X25)	
Medium Durability (5- 10years)	Intergard 251	-	Interthane 990	125
	Epoxy Zinc Phosphate (75)		Acrylic Aliphatic PU (50)	
	Neropoxy Zn Phosphate	-	Nerothane Enamel	160
	Epoxy Zn Phosphate(2X50)		Acrylic Aliphatic PU(2X30)	
High Durability (10 – 15 years)	Intergard 251	Intergard 475HS	Interthane 990	250
	Epoxy Zinc Phosphate (75)	Epoxy MIO (125)	Acrylic Aliphatic PU(50)	
	Neropoxy Zn Phosphate	Neropoxy MIO	Nerothane Enamel	210
	Epoxy Zinc Phosphate(50)	Epoxy MIO(100)	Acrylic Aliphatic PU(2X30)	

Polluted Inland

	Primer (µm)	Intermediate (µm)	Top Coat (µm)	Dft(µm)
Low Durability (2 -5 years)	Intergard 251	-	Interthane 990	125
	Epoxy Zinc Phosphate (75)		Acrylic Aliphatic PU(50)	
	Neropoxy Zn Phosphate	-	Nerothane Enamel	160
	Epoxy Zinc Phosphate(2X50)		Acrylic Aliphatic PU(2X30)	
Mediu	Intergard 251	Intergard 475HS	Interthane 990	200

	Epoxy Zinc Phosphate (50)	Epoxy MIO (100)	Acrylic Aliphatic PU (50)	
	Neromastic 400	-	Nerothane Enamel (2X30)	260
	Surface Tolerant Epoxy(2X100)		Acrylic Aliphatic PU	
High Durability (10 – 15 Years) years)	Interzinc 52	Intergard 475 HS	Interthane 990	225
	Epoxy Zinc Rich (50)	Epoxy MIO (125)	Acrylic Aliphatic PU (50)	
	Neropoxy Zinc Rich	Neropoxy MIO	Nerothane Enamel	225
	Epoxy Zinc Rich(50)	Epoxy MIO(125)	Acrylic Aliphatic PU(50)	

Normal Coastal

	Primer (µm)	Intermediate (µm)	Top Coat (µm)	Dft µm
Low Durability (2 -5 years)	Intergard 251	Intergard 475 HS	Interthane 990	225
	Epoxy Zinc Phosphate (75)	Epoxy MIO (100)	Acrylic Aliphatic PU(50)	
	Amerlock 400	-	Nerothane Enamel	220
	Surface Tolerant Epoxy(2X80)		Acrylic Aliphatic PU(2X30)	
Medium Durability (5- 10years)	Interzinc 52	Intergard 475 HS	Interthane 990	250
	Epoxy Zinc Rich (50)	Epoxy MIO (150)	Acrylic Aliphatic PU (50)	
	Neropoxy Zinc Rich	Neropoxy MIO	Nerothane Enamel	235
	Epoxy Zinc Rich (50)	Epoxy MIO(125)	Acrylic Aliphatic PU(2X30)	
High Durability (10 – 15 years)	Interzinc 52	Intergard 475 HS	Interthane 990	275
	Epoxy Zinc Rich (75)	Epoxy MIO (150)	Acrylic Aliphatic PU (50)	
	Amercoat 4120(I)	Amercoat 385MIO	Amercoat 450GL	250
	Epoxy Zinc Rich(70)	Epoxy MIO(100)	Acrylic Aliphatic PU (2X40)	

Polluted Coastal

	Primer (µm)	Intermediate (µm)	Top Coat (µm)	Dft, µm
Low Durability (2 -5 years)	Intergard 251	Intergard 475 HS	Interthane 990	250
	Epoxy Zinc Phosphate (75)	Epoxy MIO (125)	Acrylic Aliphatic PU (50)	
	Amerlock 400	-	Nerothane Enamel	260
	Surface Tolerant Epoxy(2X100)		Acrylic Aliphatic PU(2X30)	
Medium	Interzinc 52	Intergard 475 HS	Interthane 990	275

	Epoxy Zinc Rich (75)	Epoxy MIO (150)	Acrylic Aliphatic PU (50)	
	Amercoat 4120	Amercoat 385MIO	Amercoat 450GL	250
	Epoxy Zinc Rich(70)	Epoxy MIO(100)	Acrylic Aliphatic PU(2X40)	
High Durability (10 – 15 Years) +	Interzinc 52	Intergard 475 HS	Interthane 990	325
	Epoxy Zinc Rich (75)	Epoxy MIO (200)	Acrylic Aliphatic PU (50)	
	Dimetcote 9FT	Amercoat 385MIO	Amercoat 450GL	275
	Inorganic Zn Silicate(65)	Epoxy MIO(130)	Acrylic Aliphatic PU(2X40)	

Blue: - Akzo Nobel Coatings India Pvt. Ltd

CONCLUSIONS

Cost effective corrosion protection of structural steelwork should present little difficulty for common applications and environments. There are many steel structures that have continued in use satisfactorily for many years even in adverse conditions. Today, modern durable protective coatings are available which, when used appropriately, allow extended maintenance intervals and improved performance. The key to success lies in recognizing the corrosion rate of the environment to which the structure will be exposed and in defining clear and appropriate coating specifications. A steel structure exposed to an aggressive environment needs to be protected with a sophisticated treatment and may need to be designed with maintenance in mind if extended life is required. The optimum protection treatment, which combines appropriate surface preparation, suitable coating materials, required durability and minimum cost, is available with modern surface treatment technology.