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Sub : Literature on Corrosion Protection in Concrete Structures.

- Ref** :
1. A&C Slip No. 7 to IRS: CBC vide RDSO letter No: CBS/Codes/A&C, Dated 26.06.2018.
 2. RDSO "Technical literature on corrosion/carbonisation protection in concrete structures" issued vide BS-88R of April 2018.
 3. Railway Board letter No: 2018/05/CE-III/BR/Concrete Code, Dated 08.02.2018.

Measures and stipulations to prevent corrosion in concrete structures are contained in Indian Railways Standard Code of Practice for Plain, Reinforced & Prestressed Concrete for General Bridge Construction (Concrete Bridge Code). RDSO has also issued guidelines from time to time to assist field Engineers in the matter. In order to compile the relevant provisions at one place as per the directives of Board vide ref 3 above, RDSO Guideline No BS-88R on subject matter was issued on 06.04.2018.

However, in terms of A&C Slip No. 7 to IRS: CBC dated 26.06.2018 the necessary changes in Para 3.8 of RDSO Guideline No BS-88R (April 2018) have been made. Accordingly updated RDSO Guideline No BS-88R (August 2018) has been uploaded on website www.rdsr.railnet.gov.in (10.100.2.19) which replaces previous guideline no BS-88R (April 2018).

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सत्यमेव जयते

GOVERNMENT OF INDIA
MINISTRY OF RAILWAYS
(Railway Board)

**LITERATURE ON CORROSION
PROTECTION IN CONCRETE
STRUCTURES**

AUGUST - 2018

BS-88R

ISSUED BY

RESEARCH DESIGNS AND STANDARDS ORGANISATION

LUCKNOW - 226011

Preface

The deterioration of concrete structures is a major challenge that Civil Engineers face. Corrosion of embedded reinforcement in concrete is one of the major factors causing premature failure of concrete structures. Carbonation of concrete and chloride attack are major causes leading to corrosion of steel in concrete. Research has led to development of various preventive and protective measures to arrest corrosion of reinforcement steel.

In addition to aspects included in IRS Concrete Bridge Code, this technical literature provides useful information on aspects like mechanism of corrosion of steel embedded in concrete, causes of corrosion, effect of corrosion and protective measures, etc.

The contents of this compilation by RDSO are based on available technical knowledge and literature.

The contribution made by Sri M. P. Singh, Director/B&S/CB-I& Sri A. K. Pandey, ADE/B&S/CB-I in preparation of this technical compilation is appreciated.

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Annexures

Annexure-I	RDSO Specification No: M&C/PCN/126-2008*
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Note: For * Marked specifications upto date versions are to be referred

CHAPTER – 1

Introduction

- 1.1 Reinforced concrete is one of the most versatile and widely used construction material. There is a common belief that RCC/PSC is durable and requires minimal maintenance and if properly done, it has adequate durability under normal conditions of exposure. This has been demonstrated by a large number of concrete structures built over the past 100 years or so in different parts of the world.
- 1.2 The initial RCC structures in India were built in early 20th century. An outstanding example of durable RCC is famous “The Gate Way of India” in Mumbai. The structure has 13 m long RCC piles and domes of reinforced concrete. The structure is now >75 years old and stands as a monument of durable reinforced concrete exposed to severe environment as the structure is hugging the Arabian Sea. This was followed by many RCC buildings, tanks, towers and bridges.
- 1.3 Most of the structures built during the first half of the century have performed well. However, quite a number of structures built during the last 40 years have suffered durability issues. The deterioration has been particularly noticed in the structures in the region of severe exposure conditions such as coastal areas. The major concern of the construction industry all over the world nowadays is the structural damage due to reinforcement corrosion, which adversely affects in a significant manner, the strength, durability and stability of the structure.
- 1.4 Adoption of good design and construction practices such as ensuring adequate concrete cover, use of low permeability concrete, appropriate quality control, use of corrosion inhibitors and concrete coating, etc. has led to reduced occurrence of corrosion in reinforcement steel. Also, to avoid catastrophic failures, it is necessary to conduct periodic condition surveys of all structures whether bridges, buildings or industrial structures. The state of corrosion of rebar can be identified by potential mapping, resistance survey, impedance analysis or ultrasonic and acoustic scanning. This data can be continuously monitored and decision for preventive and protective measures is to be taken.
- 1.5 This report compiles literature regarding Corrosion/Durability. Detailed study and practical training of each aspect covered in brief that is necessary for construction of durable structures.

However this report cannot be construed as an all comprehensive reference on concrete. For areas not covered in this report, users are requested to refer to relevant standard codes inclusive of Indian Railway Standards.

CHAPTER- 2

Basics of Corrosion& Durability

2.1 Steel is used in concrete principally as reinforcement. Concrete ordinarily provide an almost ideal environment for protecting steel from corrosion. Its high alkalinity causes the formation of a thin invisible protective passive film of Ferric Oxide (Fe_2O_3) on the steel (thickness approx. $10000 \text{ \AA}$). It is expected that when the embedded steel is protected from air by an adequate thick cover of low permeability concrete, the corrosion of steel would not arise. However, this expectation is not fully met in practice, as is evident from the unusually high frequency with which the RCC & PSC Structures suffer damage due to steel corrosion. The magnitude of damage is especially large in structures exposed to marine environments. The damage to concrete resulting from corrosion of embedded steel manifests in the form of expansion, cracking and eventually spalling of the cover concrete.

2.2 Mechanisms of Concrete Deterioration by Corrosion of Embedded Steel.

2.2.1 Corrosion of steel in concrete is an electrochemical process. The electrochemical potentials, to form the corrosion cells, may be generated in two ways:

- (i) Concentration cells may be formed due to differences in concentration of dissolved ions in the vicinity of steel, such as, chlorides and oxygen.
- (ii) Composition cells may be formed when two dissimilar metals are embedded in concrete, such as steel rebar's and aluminium conduit pipes, or when significant variations exist in surface characteristics of the steel.

2.2.2 As a result, one of the two metals (or some part of the metal when only one metal is present) becomes anodic and the other cathodic. The fundamental chemical changes occurring at the anodic and cathodic areas are as follows:

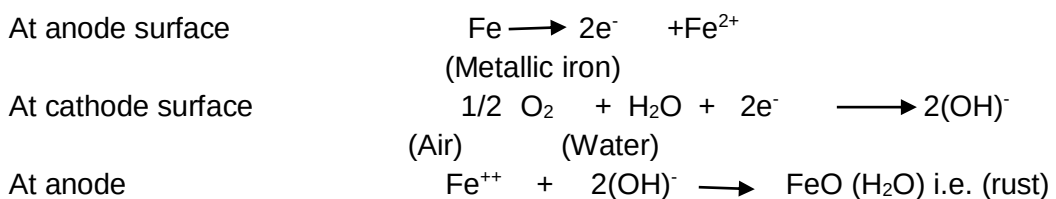


Fig. below illustrates the electrochemical process of steel corrosion in moist and permeable concrete. The galvanic cell constitutes an anode process and a cathode process.

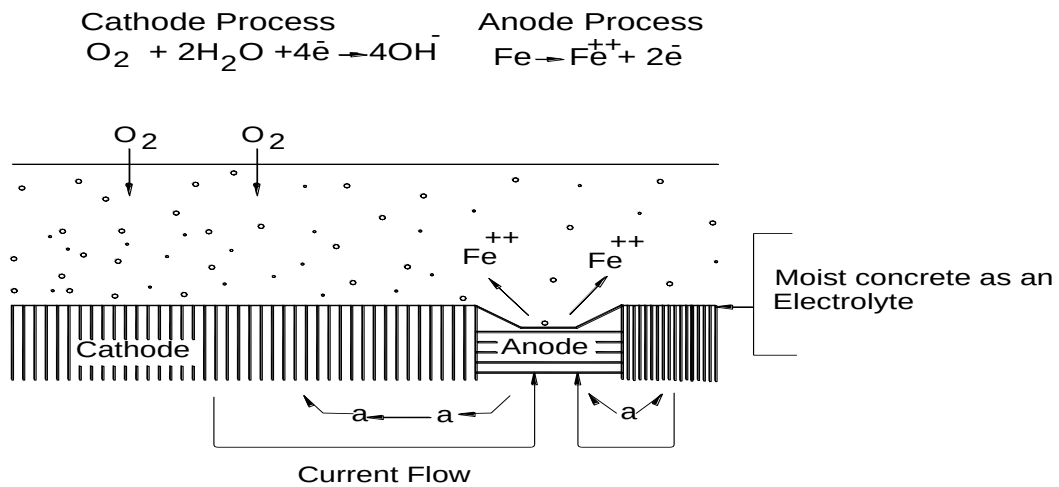


Fig: Electrochemical Process of Steel Corrosion

2.2.3 The transformation of metallic iron to rust is accompanied by an increase in volume which, depending on the state of oxidation, may be as large as 600 % of the original metal as shown in figure below. This volume increase is believed to be the principal cause of concrete expansion and cracking. It should be noted that the anodic reaction involving ionization of metallic iron will not progress far unless the electron flow to the cathode is maintained by consumption of the electrons at the cathode; for this the presence of both air and water at the surface of the cathode is absolutely necessary. Also, ordinary iron and steel products are covered by a thin iron-oxide film which becomes impermeable and strongly adherent to the steel surface in alkaline environments, thus making the steel passive to corrosion; that is, metallic iron will not be available for the anodic reaction until the passivity of steel is destroyed.

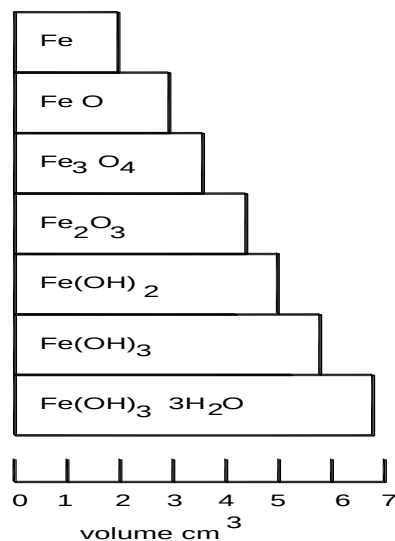


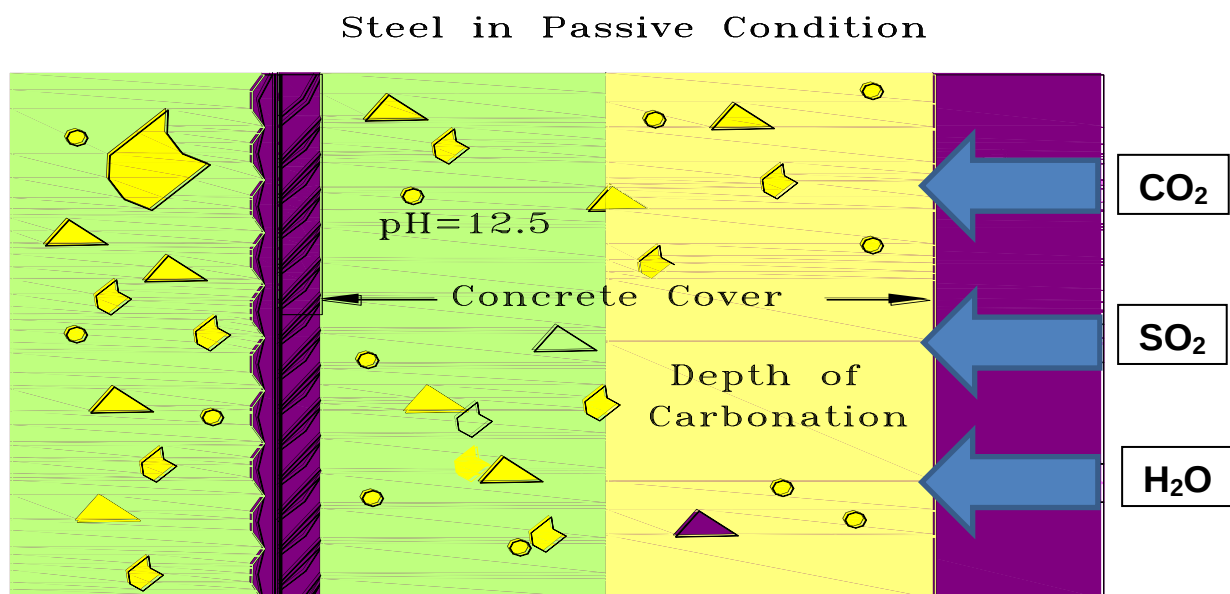
Fig: Increase in Volume of Embedded Steel due to Oxidation

2.2.4 The anode process cannot occur until the protective or the passive iron oxide film is either removed in an acidic environment (e.g., carbonation of concrete) or made permeable by the action of Cl^- ions. The cathode process cannot occur until a sufficient supply of oxygen and water is available at the steel surface. The electrical resistivity of concrete is also reduced in the presence of moisture and salts.

2.2.5 Carbonation

The Carbon-dioxide gas present in the atmosphere combines with hydrated concrete (alkaline hydroxides) and partly neutralizes the alkaline nature of concrete. This process is known as carbonation. Carbonation brings down the pH value of concrete from above 12-13 to less than 9. When depth of carbonation increases and becomes equal or more than the depth of cover of reinforcement, it breaks down passive film surrounding steel and makes embedded steel active.

Concrete is under continuous attack of aggressive environmental agencies. Good concrete and sufficient cover is the answer for durability



2.2.5.1 Rate of Carbonation:

The rate of carbonation depends on the following factors.

1. The amount of pore water i.e. Relative Humidity.
2. Grade of Concrete
3. Permeability of Concrete
4. Whether Concrete is protected or not
5. Thickness of Cover
6. Time

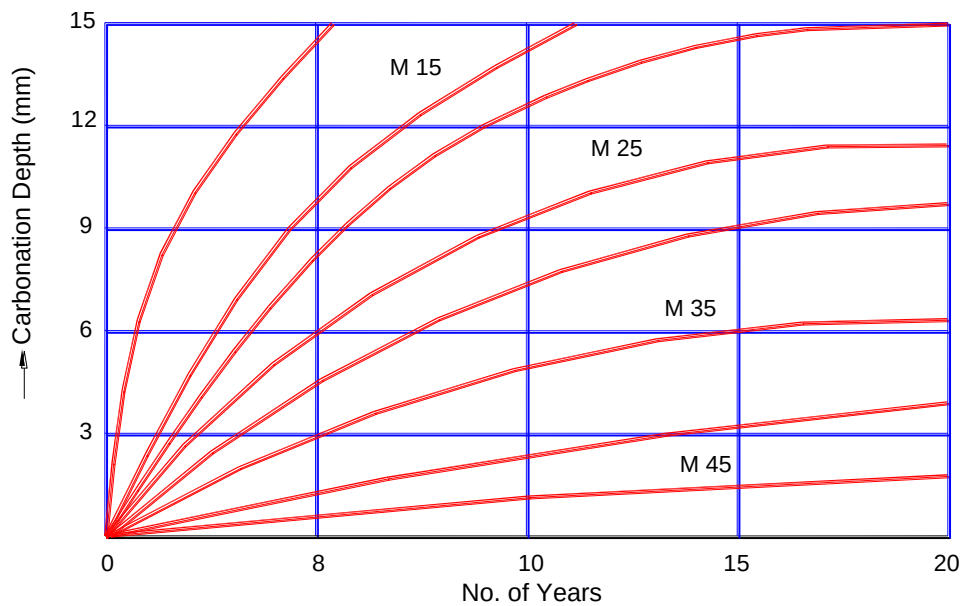


Fig: Depth of Carbonation with respect to Strength (Grade) of Concrete

The rate of carbonation is slower in stronger concrete being denser. It again indicates that the permeability of the concrete, particularly that of skin concrete is much less at lower W/C and as such the diffusion of CO_2 is slower in comparison to permeable concrete with higher W/C ratio.

It is interesting to know that if pore is filled with water the diffusion of CO_2 is very slow. But whatever CO_2 is diffused into the concrete, is readily becomes dilute carbonic acid reducing the alkalinity of concrete.

On the other hand if the pores are rather dry, that is at low relative humidity the CO_2 remains in gaseous form and does not react with hydrated cement. The moisture penetration from external sources is necessary to carbonate the concrete.

The highest rate of carbonation occurs at a relative humidity of between 50 and 70 per cent.

It is now well recognized that concrete needs protection for longer durability. Protective coating is required to be given for long span bridge girders, flyovers, industrial structures and chimneys. The fig. below shows carbonation depth of protected and unprotected concrete.

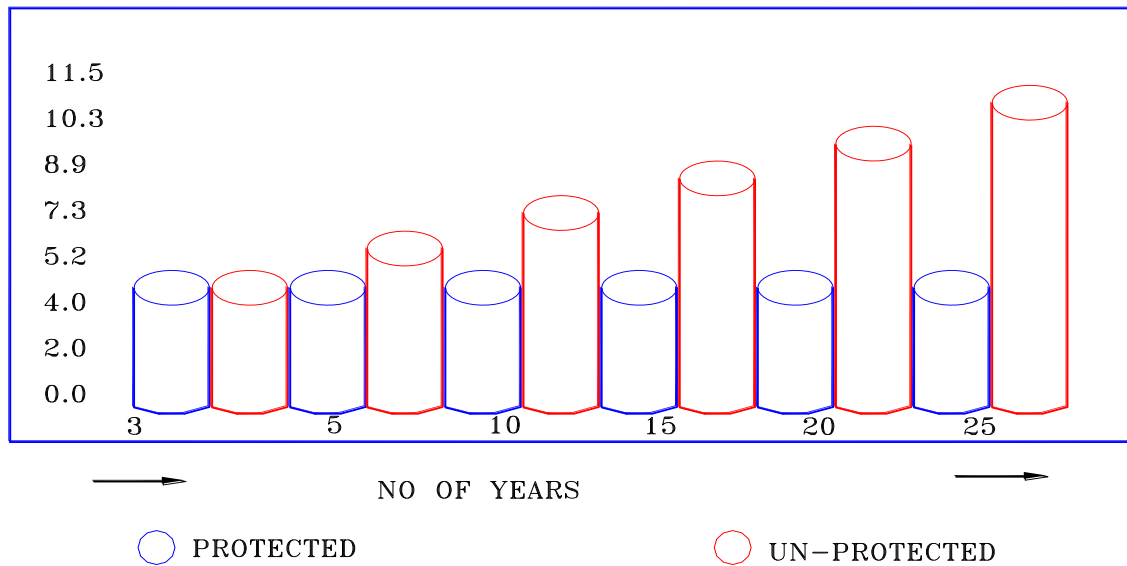


Fig: Depth of Carbonation for protected and un-protected concrete with age.

Table 1 below shows the depth of carbonation in various grades of concrete with age.

Table 1

Age-years	Depth of Carbonation (mm)	
	M20	M40
2	5.0	0.5
5	8.0	1.0
10	12	2.0
50	25	4.0

Depth of cover plays an important role in protecting the steel from carbonation. The Table 2 below shows relationships between W/C, depth of cover and time in years for carbonation depth to reach the reinforcement.

Table 2
Approximate Relation among W/C Ratio, Cover & Life

WC Ratio	Depth of cover (mm)			
	15	20	25	30
0.45	100+	100+	100+	100+
0.50	56	99	100+	100+
0.55	27	49	76	100
0.60	16	29	45	65
0.65	13	23	36	52
0.70	11	19	30	43
Time in years for carbonation				

Measurement of depth of carbonation:

A common and simple method for establishing the extent of carbonation is to treat the freshly broken surface of concrete with a solution of phenolphthalein in diluted alcohol. If the Ca(OH)_2 is unaffected to CO_2 the colour turns out to be pink. If the concrete is carbonated it will remain uncoloured. It should be noted that the pink colour indicates that enough Ca(OH)_2 is present but it may have been carbonated to a lesser extent. The pink colour will show even up to a pH value of about 9.5.

Measurment of Depth of Carbonation



Fig: Pink Colour indicates that Ca (OH)_2 is unaffected by carbonization. The uncoloured portion indicates that concrete is carbonated.

2.2.6 Chloride attack

Free chloride ions present in concrete surrounding reinforcement; react with alkaline solution at anode to form hydrochloric acid which destroys the passive protective layer on the reinforcement steel. The surface of steel then becomes activated to form the anode, with the passive surface forming the cathode, setting the electrolytic process. Presence of free chloride ions in concrete depends upon total chloride contents of concrete. Chlorides are present in concrete due to ingredients, mixing water and calcium chloride used as accelerating admixtures etc. Chlorides enter concrete due to salt water spray in sea shore or through atmosphere.

In the absence of chloride ions in the solution, the protective film on steel is reported to be stable as long as the pH of the solution stays above 11.5, since normally hydrated Portland cements contain alkalis of about 20 percent by weight

in the pore fluid. In exceptional conditions (e g., when concrete has high permeability and most of the hydroxide are either carbonated or neutralized by an acidic solution), the pH of concrete in the vicinity of steel may be reduced to less than 11.5 thus, destroying the passivity of steel and setting the stage for the corrosion process.

In the presence of chloride ions, depending on the $\text{Cl}^- / \text{OH}^-$ ratio, it is reported that the protective film may be destroyed even at pH values considerably above 11.5. When $\text{Cl}^- / \text{OH}^-$ molar ratios are higher than 0.6, steel seems to be no longer protected against corrosion, probably because the iron oxide film becomes either permeable or unstable under these conditions. Furthermore, when large amounts of chloride are present, concrete tends to hold more moisture, which also increases the risk of steel corrosion by lowering the electrical resistivity of concrete.

Once the passivity of the embedded steel is destroyed, it is the electrical resistivity and the availability of oxygen that control the rate of corrosion. In fact, significant corrosion is not observed as long as the electrical resistivity of concrete is above 50 to 70 $\times 10^3 \Omega \text{ cm}$. It may be noted that the common sources of chloride in concrete are ingredients, admixtures, penetration of sea water and atmospheric gases.

Due to similar mechanism, bimetallic contact increases the risk of corrosion of steel. Thus, bimetallic contact needs to be avoided as far as possible. If it is unavoidable like in case of buildings, approval of competent authority shall be taken prior to execution of work.

The Bureau of Indian Standard earlier specified the maximum chloride content in cement as 0.05 percent. But it is now increased; the allowable chloride content in cement is 0.1 per cent. **IS 456 of 2000** limits the chloride content as (Cl) in the concrete at the time of placing as shown in *Table 3* below.

Table 3 Limits of Chloride Content of Concrete (IS 456 of 2000)

Sl. No.	Type of Use of Concrete	Maximum Total acid soluble chloride content. In kg/m^3 of concrete
1.	Concrete containing metal and steam cured at elevated temperature and prestressed concrete	0.4
2.	Reinforced concrete or plain concrete containing embedded metal	0.6
3.	Concrete not containing embedded metal or any material requiring protection from chloride	3.0

The amount of chloride required for initiating corrosion is partly dependent on the pH value of the pore water in concrete. At pH value of less than 11.5, corrosion

may occur without the presence of chloride. At pH value greater than 11.5 a good amount of chloride is required.

Limiting values of chloride contents, above which corrosion may be imminent, for various values of pH are indicated in Table 4. The total chloride in concrete is present partly as insoluble chloro-aluminates and partly in soluble form. It is the soluble chloride, which is responsible for corrosion of reinforcement.

Table 4
Limiting Chloride content corresponding to pH of concrete

PH	Chloride content g/litre	ppm
13.5	6.7400	6740
13.0	2.1300	2130
12.5	0.6720	672
12.0	0.2130	213
11.5	0.0670	67
11.0	0.0213	21
10.0	0.0021	2
9.02	0.0002	0.2

Chloride Permeability Based on Charge Passed
(As per ASTM C 1202)

Chloride Permeability	Charges passed (Coulombs)	Type of Concrete
High	≤ 4000	High water-cement ratio ≤ 0.6
Moderate	2000 to 4000	Moderate W/C ratio (0.4 to 0.5)
Low	1000 to 2000	Water-cement ratio ≤ 0.4
Very Low	100 to 1000	Latex modified concrete
Negligible	≤ 100	Polymer Impregnated concrete

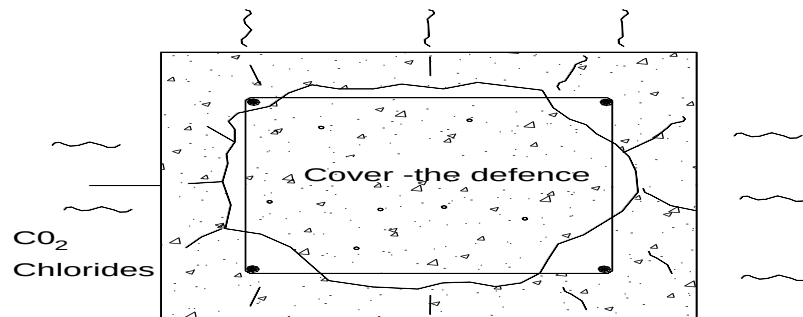
2.3 Durability:

2.3.1 It is essential that every concrete structure should continue to perform its intended functions in terms of strength and serviceability, during the specified/traditionally expected service life. It follows that concrete must be able to withstand the processes of deterioration to which it is subjected.

2.3.2 Durability does not mean an indefinite life. Moreover, routine maintenance of concrete is essential. Until recently, developments in cement and concrete technology have been concentrated on achieving higher strengths under the presumption that, strong concrete is durable too. For many conditions of exposure, both strength and durability have to be considered at the design stage itself.

(a) THE ENEMY: Carbon dioxide, Chlorides, Oxygen, Moisture & Temperature

(b) ATTACK VS DEFENCE



(c) DURATION OF BATTLE-10, 20, 50 Years?

(d) DEFEAT = Corrosive Expansion of 2 to 4 x Vol of replaced steel
= Spalling, Delamination, Cracking

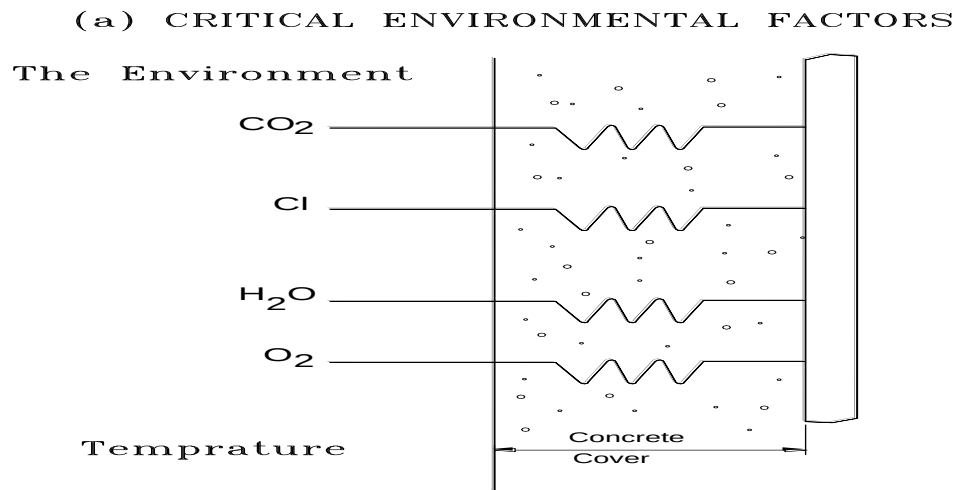
Fig: Enemies of Durability and the Battle for Survival

The figure above explains the enemies of durability and the battle for survival.

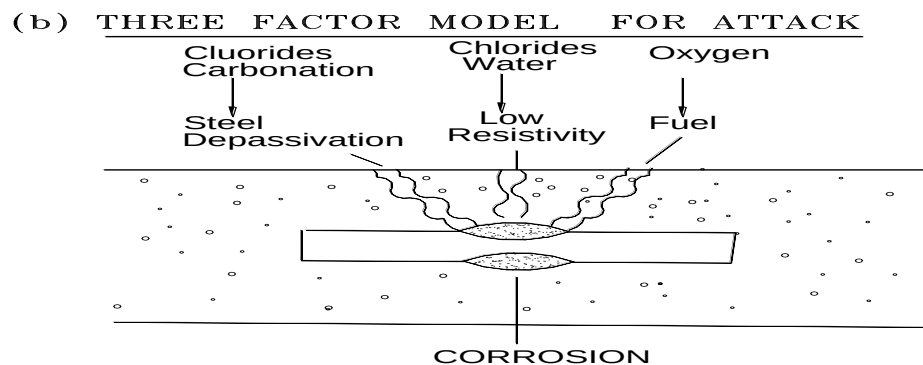
2.4 Causes of deterioration:

2.4.1 Most of the problems arise due to environment penetrating into the concrete. It may not be practical to keep it away totally, as the consequences of penetration of a few millimetres may not be significant. Durability and damage in many cases depends solely on the performance of the outer layers of concrete and not the full body of the concrete.

2.4.2 Fig. below shows the environmental loads/factors responsible for the steel to corrode. These are salt deposited on the surface, or carbon dioxide from the air, together with moisture and oxygen.



2.4.3 On the basis of laboratory tests and surveys of old structures, a useful and simple, 3-component model as shown in Fig. below was developed for defining whether corrosion damage would occur:-



- i) Chlorides or carbonation have to be present to destroy the alkali protection to the reinforcement provided by the cement at casting.
- ii) A low concrete electrical resistivity is required to permit electrochemical corrosion. Value less than 5,000 to 10,000 ohm cm is critical.
- iii) Oxygen from the atmosphere has to get through the concrete Cover.

All three conditions have to exist before corrosion and damage can occur.

2.4.4 Following Fig. shows there are two stages in any attack process

- i) t_0 , the time for the environment to penetrate into the concrete to a level where attack starts i.e. when the chloride or carbonation has reached the reinforcement.

- ii) t_1 , the time taken for deterioration of a sufficient level to occur to be of concern i.e. when corrosion due to oxidation of the steel has developed sufficiently to cause spalling and cracking of the cover. Whether moisture getting into concrete is vulnerable to alkali / aggregate reactivity, or CO_2 getting in the concrete cover region and causing corrosion to reinforcement both are part of this second stage process.

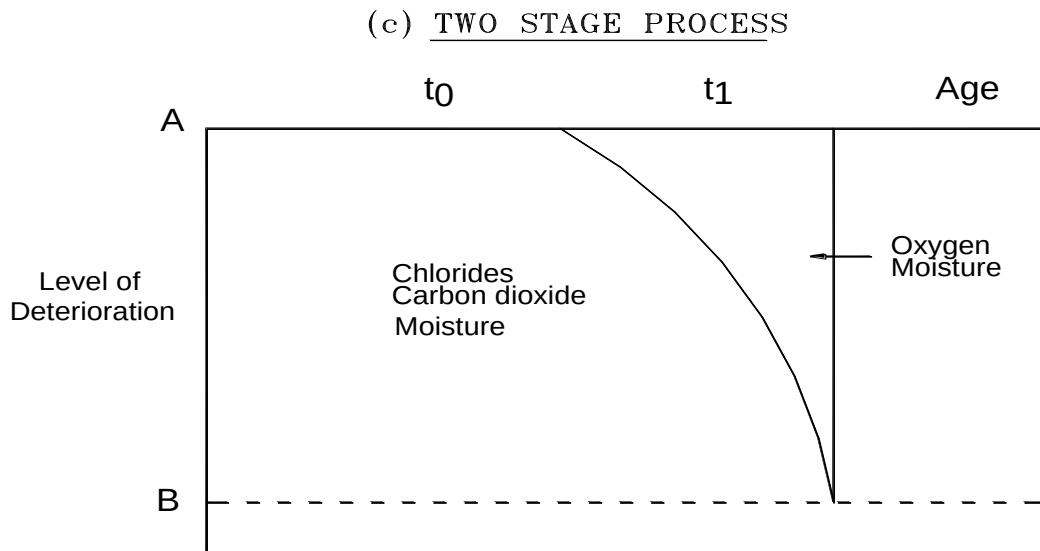


Fig: Corrosion Damage Model

2.4.5 Chloride Attack: The penetration of chlorides is faster than the carbonation although both react with the cement to varying degrees, slowing their ingress. For damage prediction purposes, the level of chloride critical to corrosion initiation is still debated, from 0.2 to 0.4% total chloride by weight of cement, or to a specific ratio of free chloride in the pore water to its OH^- content. In order to safeguard concrete against Chloride attack, total Chloride content by weight of cement needs to be controlled. It may be determined as per BS: 1881 Pt.124 and restricted as given below:

- | | |
|--|-------|
| a) For prestressed concrete works | |
| i) Under extreme and very severe environment | 0.06% |
| ii) Under severe , moderate and mild environment | 0.10% |
| b) For RCC works | 0.15% |

2.4.6 Carbonation: Limited data so far indicates that CO_2 gas present in air varies from 0.04% in rural environments to 0.4% in urban environments. The carbon-dioxide penetrates into the concrete and carbonates the hydrated cement. The rate of carbonation is greatest at around 50 -70% relative humidity. Random wetting will lead to an overall reduction in carbonation.

2.4.7 Resistivity: The electrical resistivity of the concrete is of importance to certain corrosion processes, and is very much dependent on moisture content of the concrete.

Following Fig. shows how, with moisture contents over 4%, the resistivity is below the critical value of about 10,000 ohm cm.

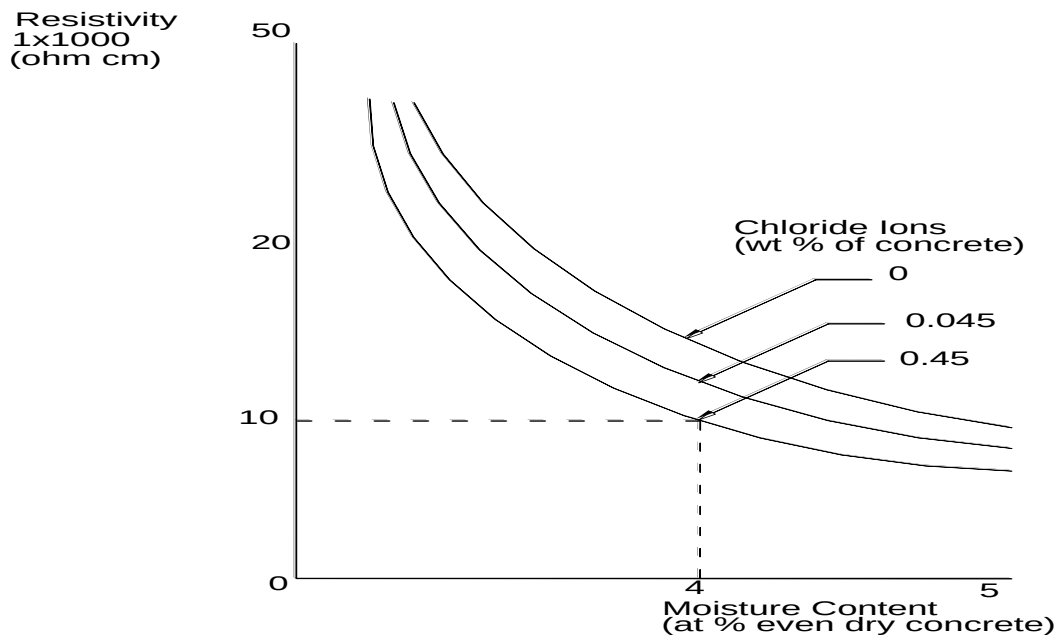


Fig: Effect of Moisture Content on Electrical Resistivity

Fig. below shows that wetting can reduce the resistivity due to absorption of the water into dry concrete.

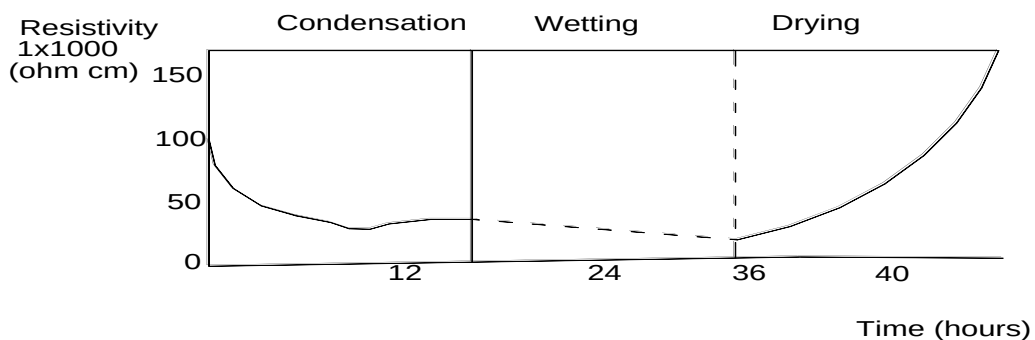


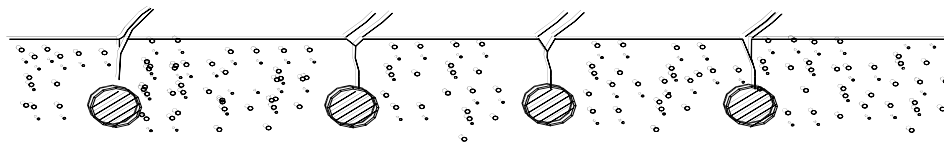
Fig: Effect of Wetting and Drying on Electrical Resistivity

2.4.8 Corrosion Damage

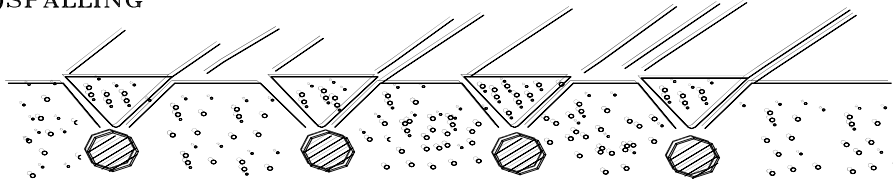
The volume of the iron oxides formed is 2 to 6 times greater than the steel corroded, thus inducing bursting stresses in the concrete around the bar. This causes cracking of the concrete with time (t_i).

The different forms of damage can vary, as shown in Fig. below, according to the spacing and size of the rebar and its cover and its thickness; from thin longitudinal cracks (Fig. a), to pop outs (Fig. b), to de-lamination (Fig. c) with little visible external signs of distress but hollowness on tapping, to chunks dropping off or hanging on at corners (Fig.d).

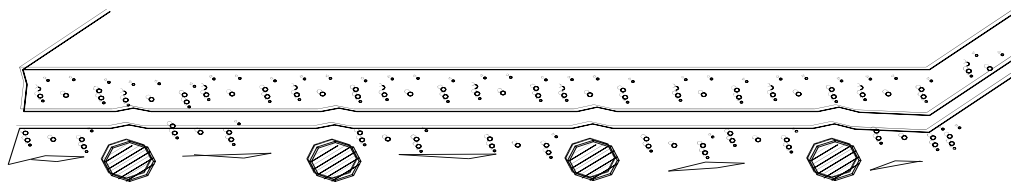
(a) CRACKING



(b) SPALLING



(c) LAMINATION



(d) CORNER EFFECTS



Fig: Different Forms of Corrosion Damage

In many cases it is observed that only the outer surface of the rebar need to corrode to induce damage, and it is identified that only about 0.01mm of corrosion product is sufficient to cause damage. Stirrups may be the first to crack or spall concrete due to their lower cover.

The damages, if local, may have only a limited effect on the structure's performance, but for other reasons may be unacceptable and require repair. De-laminations over large areas may well reduce the flexural capacity of a slab, particularly as corrosion of the exposed steel may then accelerate.

2.5 Typical concrete durability problems:

Problems	Causes	Solutions
1. Corrosion of pre-stressing steel (in Bridges)	<ul style="list-style-type: none"> • Use of improper Materials. • Use of improper grout openings or vents. • Use of improper grout equipment's. • Improper mixing of grouts. • Improper grouting operations. • Non follow up of proper precautions during grouting. • Use of corroded, poorly jointed cable sheaths- Leakage of grout. • HTS procured in: advance and lack of protection -use of corroded strand. 	<ul style="list-style-type: none"> • Proper Materials as per Appendix D of IRS: CBC shall be used. • Proper grout openings or vents as per Appendix D of IRS: CBC shall be used. • Proper grout equipment's as per Appendix D of IRS: CBC shall be used • Proper mixing of grouts as per Appendix D of IRS: CBC shall be ensured. • Proper grouting operations as per Appendix D of IRS: CBC shall be used. • Proper precautions during grouting as per Appendix D of IRS: CBC shall be followed. • Use fresh tested sheathing as per specification as laid down in Para 7.2.6.4.2 of IRS Concrete Bridge Code. • HTS wire shall be stacked for minimum duration duly property packed and stored. It should be quenched with water soluble corrosion resistive oil.

	<ul style="list-style-type: none"> • Voids in grouted ducts. • Corrosion of strands due to insufficient cover. 	<ul style="list-style-type: none"> • Requisite grouting techniques and equipment's are to be used. • HTS wire shall not have lesser cover than that stipulated in IRS: CBC.
2. Corrosion of Reinforcement (Spalling, Cracking & De-lamination of concrete cover e.g. - bridges, buildings and marine structures in Marine Environment.	<ul style="list-style-type: none"> • Use of high W/C ratio • Too low cement Content • Use of rusted bars • Poor mix, Poor Site Control, Poor Concrete, Honey Combing & Cracks • Porous cover blocks. 	<ul style="list-style-type: none"> • Use low W/C ratio as per IRS: CBC is to be used. • High Cementitious Material Content as per IRS: CBC is to be used. • Use clean bars coated with cement based coating system. • Follow good, construction practices. • Use quality cover blocks of same grade of concrete as that of surrounding concrete
3. Freeze / Thaw damage to exterior in hilly regions.	<ul style="list-style-type: none"> • Too wet mix 	<ul style="list-style-type: none"> • Use low W/C ratio as per IRS: CBC • Use quick setting cement of high grade. • Follow suitable method of concreting in cold weather.
4. Corrosion of anchorages	<ul style="list-style-type: none"> • Long exposure of tendon before/after stressing • Inordinate delay in grouting. • Improper grouting of ducts • In appropriate protection of cable ends. 	<ul style="list-style-type: none"> • Protection of cable ends before stressing. Stressing should be done as early as possible. • Grouting should be done immediately after stressing. • Proper grouting of ducts. Proper choice of grout materials. • Proper Anticorrosive protection to be provided immediately after grouting.

CHAPTER 3

Codal Provisions for Corrosion Protective Measures

3.0 Based on recommendations of Extra Ordinary BSC held in June 1999 at Pune duly approved by Railway Board vide letter no. 99/CE-I/BR-II/10 dated 24.3.2000, durability aspects like permeability test, minimum clear cover to steel, protective coating over steel and concrete, minimum grade of concrete, minimum cementitious material content, maximum water cement ratio, maximum limit of chloride content for RCC/PSC works etc. have been included in IRS Concrete Bridge Code. These aspects, hold good for structures other than bridges also.

3.1 Provisions of IRS: CBC regarding durability are reproduced as under:-

5.4 Durability

5.4.1 *The durability of concrete depends on its resistance to deterioration and the environment in which it is placed. The resistance of concrete to weathering, chemical attack, abrasion, frost and fire depends largely upon its quality and constituents materials. Susceptibility to corrosion of the steel is governed by the cover provided and the permeability of concrete. The cube crushing strength alone is not a reliable guide to the quality and durability of concrete; it must also have adequate cement content and a low water-cement ratio. The general environment to which the concrete will be exposed during its working life is classified in three levels of severity that is, moderate, severe and extreme, as described below:*

ENVIRON MENT	EXPOSURE CONDITION
Moderate	Concrete surface protected against weather or aggressive conditions. Concrete surface sheltered from severe rain or freezing whilst wet concrete exposed to condensation, concrete structure continuously under water, concrete in contact with non-aggressive soil/ground water.
Severe	Concrete surface exposed to severe rain, alternate wetting and drying or occasional freezing or severe condensation. Concrete exposed to aggressive sub-soil/ ground water or coastal environment.
Extreme	Concrete surface exposed to sea water spray, corrosive fumes or severe freezing conditions whilst wet. Concrete structure surfaces exposed to abrasive action, surfaces of members in tidal zone. All other exposure conditions which are adverse to exposure conditions covered above.

5.4.2 Permeability:

5.4.2.1 One of the main characteristics influencing the durability of any concrete is its permeability. Therefore, tests for permeability shall be carried out for concrete bridges as recommended in clause 5.4.2.2. With Strong, dense aggregates, a suitably low permeability is achieved by having a sufficiently low water-cement ratio, by ensuring as thorough compaction of the concrete as possible and by ensuring sufficient hydration of cement through proper curing methods. Therefore, for given aggregates, the cement content should be sufficient to provide adequate workability with a low water-cement ratio so that concrete can be completely compacted by vibration. Test procedure for penetration measuring permeability has been given in Appendix-G of IRS: CBC. The depth of penetration of moisture shall not exceed 25mm.

5.4.2.2: Permeability test:

- (i) Permeability test shall be mandatory for all RCC/PSC bridges under severe and extreme environment.
- (ii) Under moderate environment, permeability test shall be mandatory for all major bridges and for other bridges permeability test is desirable to the extent possible.
- (iii) Permeability test is required for RCC/PSC structural element only.

5.4.3 Maximum Water Cement Ratio – The limits for maximum water cement ratio for design mix shall be based on environmental conditions as defined in Clause 5.4.1. The limits for maximum water-cement ratio for different environmental conditions shall be as given in **Table4(a)**.

**TABLE 4 (a): MAXIMUM WATER/CEMENT RATIO
(Clause 5.4.3)**

Environment	Maximum Water-Cement Ratio		
	Plain concrete (PCC)	Reinforced concrete (RCC)	Prestressed concrete (PSC)
Moderate	0.50	0.45	0.40
Severe	0.45	0.40	0.40
Extreme	0.40	0.35	0.35

5.4.4 Minimum Grade of Concrete – From durability consideration, depending upon the environment to which the structure is likely to be exposed during its service life, minimum grade of concrete shall be as given in **Table 4(b)**.

**TABLE 4(b): MINIMUM GRADE OF CONCRETE
(Clause 5.4.4)**

A) For Bridges in Pre-stressed Concrete and Important Bridges:

Structural Member	Moderate exposure	Severe exposure	Extreme Exposure
PCC Member	M-25	M-30	M-35
RCC Member	M-30	M-35	M-40
PSC Member	M-35	M-40	M-45

B) For Bridges other than mentioned above and sub-structure:

Structural Member	Moderate exposure	Severe exposure	Extreme Exposure
PCC Member	M-15	M-20	M-25
RCC Member	M-20	M-25	M-30

5.4.5 Cementitious Material Content:

Depending upon the environment to which the structure is likely to be exposed during its service life, minimum cementitious material content in concrete shall be as given in **Table 4(c)**. Maximum cementitious material content shall be limited to 500kg/m³.

**TABLE 4(c): MIN. CEMENTITIOUS MATERIAL CONTENT
(Clause 5.4.5)**

Exposure conditions	Minimum Cementitious Material Content in Kg/m³		
	PCC	RCC	PSC
Moderate	240	300	400
Severe	250	350	430
Extreme	300	400	440

5.4.6 Total Chloride contents: -

The total chloride content by weight of cement shall not exceed the following values: -

- a) For prestressed concrete works –
 - (i) Under extreme environment 0.06%
 - (ii) Under severe and moderate environment 0.10%
- b) For RCC works 0.15%

3.2 Provisions of IRS: CBC regarding cracking are reproduced as under:-

10.2.1 Cracking- Cracking of concrete shall not adversely affect the appearance or durability of the structure. The engineer should satisfy himself that any cracking will not be excessive, having regard to the requirements of the particular structure and the conditions of exposure. In the absence of special investigations, the following limit shall be adopted.

(a) **Reinforced concrete** – Design crack widths, as calculated in accordance with 15.9.8.2, shall not exceed the values given in Table 10 under the loading given in 11.3.2:

TABLE 10: DESIGN CRACK WIDTHS
[Cl. 10.2.1 (a)]

Exposure Conditions	Design crack width in mm
Moderate	0.25
Severe	0.20
Extreme	0.10

Note – Exposure conditions are as defined in 5.4.1.

(b) **Prestressed Concrete Structures and Elements** –

No tensile stresses are permitted and therefore, no cracks shall occur under the loading given in 11.3.2.

3.3 Provisions of IRS: CBC regarding Cover to Reinforcement are reproduced as under:-

15.9.2 Clear Cover to Reinforcement

15.9.2.1 “Clear cover” is the least distance from outer most surface of steel or binding wire or its end to the face of the concrete.

15.9.2.2 Clear cover is the dimension used in design and indicated on the drawings. The clear cover shall not be less than the size of the bar or maximum aggregate size plus 5mm ; in the case of a bundle of bars (see.15.9.8.1), it shall be equal to or greater than the size of a single bar of equivalent area plus 5 mm.

From durability consideration, minimum clear cover shall be as under:

Type of structure	Extreme Environment	Severe environment	Moderate Environment
Slab	50	35	25
Beam /Girder	60	50	35
Column	75	75	50
Well, pile & footing	75	75	50

15.9.2.4 The clear cover shall not exceed 75 mm in any type of structure.

3.4 Provisions of IRS: CBC regarding Admixtures are reproduced as under:-

4.4 Admixtures – *The Chief Engineer may permit the use of admixtures for imparting special characteristics to the concrete or mortar on satisfactory evidence that the use of such admixtures does not adversely affect the properties of concrete or mortar particularly with respect to strength, volume change, durability and has no deleterious effect on reinforcement.*

4.4.1 *The admixtures, when permitted, shall conform to IS:9103.*

4.4.2 *Calcium chloride or admixtures containing calcium chloride shall not be used in structural concrete containing reinforcement, pre-stressing tendons or other embedded metal.*

4.4.3 *The admixture containing Cl & SO₃ ions shall not be used. Admixtures containing nitrates shall also not be used. Admixtures based on thiocyanate may promote corrosion and therefore shall be prohibited.*

3.5 Corrosion Inhibiting Admixtures:

Corrosion inhibitors, which come in powder, gel and liquid form, retard the rate of the corrosion reaction. These are widely used in many industries to effectively reduce the corrosion rate of steel and other metals. Commercial products for the control of corrosion of steel reinforcement in atmospherically exposed concrete were first produced in the 1970's. These delay the onset of corrosion and reduce the rate of further corrosion. These can be introduced into the concrete mix at the time of construction/ repair or (in a suitable formulation) applied to the surface of an existing concrete structure. There are three main types of inhibitors:

3.5.1 Anodic Inhibitors

Corrosion can be prevented or delayed by using certain corrosion inhibiting chemicals which retard the corrosion reaction at the anode such as nitrites, phosphates, benzoates etc. There is concern that at low dosage they will suppress generalized corrosion but may fail to eliminate all anodic sites. Of the available materials, the most widely used anodic inhibitor is based on calcium nitrite but has proved to be deleterious at high chloride concentrations. It is added to the concrete during mixing of concrete. The typical dosage is of the order of 10 - 30 litres per m³ of concrete depending on chloride levels in concrete.

3.5.2 Cathodic Inhibitors

These inhibitors retard the reaction at the cathode and prevent oxygen from reaching the reinforcing steel. At low dosages, they are effective at reducing corrosion rates but are generally less efficient than the anodic type.

3.5.3 Bipolar Inhibitors

These retard the corrosion process both at the anode and at the cathode. These combine the benefits of both anodic and cathodic inhibitors at relatively low dosages. In this category Organic Migratory Bipolar Corrosion Inhibitors are most widely used.

The Bipolar corrosion inhibitor chemistry involves migration of its molecules by electron density distribution to both the anodic and cathodic sites of the steel. By virtue of its high vapour pressure, very high affinity and virtue of diffusion, these inhibitors migrate towards the steel in concrete and get deposited as a monomolecular layer. This is true even in dense concrete. This barrier coating then raises the chloride threshold concentration for corrosion. Furthermore, the inhibitor within the concrete matrix reduces the rate of chloride ion migration towards steel. It also dislodges previously absorbed chloride ions and water molecules on the steel surface.

The basic advantage of the product lies in the ease of use. Studies have proved that addition of these types of corrosion inhibitors has no deleterious effect on the properties of concrete. Concrete penetrating corrosion Inhibitors play a major role in inhibiting the corrosion process (upon addition into the concrete matrix). The European Committee for standardization (CEN) pr. ENV 1504-9 recommends application of Concrete penetrating corrosion inhibitors as a proven corrosion control strategy. SHRP-S-666 (Strategic Highway Research Programme) has recommended these types of corrosion inhibitors for concrete structures subjected to chloride-induced corrosion. General Building Corporation of Japan has evaluated this product in concrete extensively and has reported rebar life extension by six times. Two codes available internationally for testing these types of inhibitors are ASTM G 109 & JIS A 6205.

These are available both as surface applied as well as admixed inhibitors. Surface applied inhibitors are used by spraying on the surface of the structure so that protection to the unexposed reinforcement is taken care of. Admixed inhibitors are used in the fresh mortar/concrete being placed for strengthening the structure.

3.5.3.1 Specification for Bipolar Admixed Corrosion Inhibitors

As per RDSO Specification No: M&C/PCN/126-2008. **(Annexure-I)**

3.5.3.2 Acceptance Criteria:

Bipolar Admixed Corrosion Inhibitors shall be tested as per RDSO Specification No: M&C/PCN/126-2008 from reputed laboratories of CSIR /RDSO.

3.6 Coating of Concrete Surface

3.6.1 Provisions of IRS: CBC regarding Coating of Concrete Surface are reproduced as under:-

Vide C.S. No.2 dated: 14.01.2015, Clause 5.4.7 has been introduced in IRS: CBC which is reproduced as under:-

5.4.7 Coatings for Concrete

5.4.7.1 *In order to provide adequate resistance against corrosion of embedded material in RCC Structures, concrete shall be provided with suitable coating depending upon the environmental conditions.*

The recommended coating is as under:

<i>Aggressive Environment (Severe & Extreme)</i>		<i>Non aggressive environment (Moderate)</i>
<i>Super Structure of Bridges</i>	<i>Substructure of Bridges (in affected part only)</i>	<i>All structures</i>
<i>Epoxy-Phenolic IPN (Inter Penetrating Network) Coating or CECRI Integrated four coat system</i>	<i>Coal tar Epoxy Coating</i>	<i>No coating is necessary</i>

5.4.7.2 *The frequency of coating shall depend upon the condition of the existing coatings.*

3.6.2 Epoxy Phenolic IP Net (Inter-Penetrating Polymer Network) Protective Coating system (CBRI Roorkee):

3.6.2.1 Materials

1. The coating materials shall meet the standards specified by various codes and formulation set forth by the CBRI-Roorkee.
2. A written certification shall be furnished to Railways which properly identifies the number of each batch of coating material used in the work, date of manufacture, name and address of manufacturer, material quantity and a statement that the coating material used meets the requirements specified by CBRI-Roorkee.
3. The coating material shall be stored in the manner as per recommendations of the manufacturer until ready for use. The coating material shall be used within the manufacturer's written recommended shelf life.
4. When a representative sample of the material is to be sent to outside laboratory, then the sample shall be packaged in an airtight container and identified by batch number. The sample will be got tested at Tenderer/ Contractor's cost from reputed laboratories of CSIR /RDSO.

3.6.2.2 Specifications of Coating Material

S. No.	Description	Primer coat	Middle coat	Top coat
1.	Base	Interpenetrating Polymer (Epoxy phenolic)	Interpenetrating Polymer (Epoxy phenolic)	Interpenetrating Polymer (Polyurethane)
2.	Colour	Clear	Pigmented	Pigmented
3.	Shelf Life	One year in tightly sealed container	One year in tightly sealed container	One year in tightly sealed container
4.	Dry film thickness (Microns)	55-65 per coat	90-100 per coat	40-50 per coat
5.	Coverage	6-8 sq.mt/lt.	5-7 sq.mt/litre	5.5-6.5 sq.mt/litre
6.	Mix proportion	Base:1 PBV*/ Curing Agent: 1 PBV* *PBV-parts by volume	Base:1 PBV*/ Curing Agent: 1PBV* *PBV-parts by volume	Base:1 PBV*/ Curing Agent: 1PBV* *PBV-parts by volume
7.	Application	By Brush or airless spray	By Brush or airless spray	By Brush or airless spray

Material should conform to following properties:

- a) Tensile strength: Minimum tensile strength of the coating must be minimum 12 N/mm² and it should be determined as per ASTM D-2370-73
- b) Elongation: Minimum elongation of the coating must be 10% and it should be determined as per ASTM D-2370-73
- c) Specific permeability: The maximum value must be 0.15 mg/cm²/mm/24hr and it should be determined as per ASTM D-1653-74
- d) Adhesion with concrete: The minimum adhesion with concrete by pullout method must be 2.5N/mm² and it should be determined as per BS-3900-E-10-79
- e) Minimum Initial Impedance of $1 \times 10^7 \Omega$ and 30 days minimum Impedance of $1 \times 10^6 \Omega$

3.6.2.3 Surface Preparations

In order to have better bonding, the concrete surface should be clean, dry and mechanically sound. The surface of the concrete structure to be coated shall be cleaned of all traces of mould oil, laitance, salt deposits by mechanized means. The surface should be thoroughly scrubbed using power tools/sweep blasting. Finally, the surface should be washed with clean water jet to remove any salt deposits. The surface should be dried. All the protrusions should be removed and cracks, joints should be sealed with polymer modified mortar/putty. It is not necessary to fill in blow holes or pug holes prior to application of coating.

3.6.2.4 Application of Coating

- 1. Mix the base and curing agent in prescribed proportion by volume thoroughly and allow it to remain in a container for ten minutes.
- 2. A primer coating shall be applied to the cleaned surface after surface preparation within the pot life.
- 3. After air curing, successive coats should be applied with time lag as per manufacturer's specification.
- 4. The coating shall be applied by airless spray or other approved means.

3.6.2.5 Coating Thickness

During the application of IPN system clean, abraded steel plates of approximately 10cm x 8cm shall be adhered to the concrete surface by means of putty/ adhesive in such a way that these can be detached. IPN system can be applied over the plates in the course of application over the concrete surface. Dry film thickness (DFT) can be measured using magnetic electrometer. DFT measurement should be done at every 500 to 600 sq. m area or as per the direction of Engineer-in-charge.

For acceptance purpose, at least 60% of all recorded total thickness measurement of the coating shall meet specification criteria.

3.6.2.6 Coating Continuity

The coating shall be visually inspected after curing for continuity of the coating and shall be free from holes, voids, contamination, cracks and damaged areas discernible to the unaided eye.

3.6.2.7 Permissible Coating Damage and Repair of Damaged Coating

1. All coating damage shall be repaired with patching material by the contractor at his own cost.
2. Repaired areas shall have a minimum coating thickness as per specification.
3. Repair of damaged coating shall be done in accordance with the patching material manufacturer's written recommendations within the accepted rates.

3.6.2.8 Inspections

The official representing the concerned department shall have free entry at all times to the parts of the contractor's works. The contractor shall provide the Department's representative all reasonable facilities to satisfy that the material is being used in accordance with this specification. Authorised Licensee has to approve workmanship/ quality of coating before submission of Bill.

3.6.2.9 Material Acceptance Criteria:

Manufactures/ suppliers of the IPN system shall have a proven case history of successful application of minimum 10 years to bridge structures in Indian tropical condition. Also Licensee has to give 5 years Performance Guarantee.

3.6.2.10 Detailed Specifications of materials and quality control measures may be obtained from CBRI, Roorkee.

3.6.3 CECRI Integrated Four Coat System:

Central Electro-Chemical Research Institute at Karaikudi has developed a coating system for controlling corrosion. This system is applied on the concrete surface and helps in controlling carbonation and weathering effects. The system comprises of 4 coats such as primer coat, middle coat and top coat all these are epoxy based. The fourth coat is finish coat of polyurethane and is recommended wherever the surface or part of the structure is exposed to ultra violet radiation.

Before application, the substrata is thoroughly cleaned to remove the dust, hardened cement slurry, oily residues etc., by scrubbing with coarse wire brushes, grinding or sweep blasting methods depending on site requirements. Residual amounts of de-moulding agents, curing agents should be completely removed. Any cracks, crevices or surface blemishes should be treated with sealant prior to primer application. The subsequent coats shall be applied by brush or spray with an interval of 24 hours between the two coats.

3.6.3.1 Details of anti-corrosive coating to concrete surface:

It's a four coat system consisting of three coats of epoxy-polyamide system followed by one coat of polyurethane sealant coating. The epoxy-polyamide system consisting of two parts, one of which contain epoxy resin medium with pigments and the other part the polyamide curing agent. The resin and hardener paints are to be mixed thoroughly well before the application either by brush or spray technique.

The polyurethane sealant coat also consists of two parts. The pigments are dispersed in polyol medium and the other part is the poly-isocyanate curing agent. These two are mixed thoroughly well before the application either by brush or spray technique.

A. Four coat system

1. Epoxy Iron Oxide Primer
2. Epoxy MIO Under Coat
3. Epoxy TiO_2 Finish Coat
4. Aliphatic Polyurethane Sealer Coat

Laboratory investigation	a. Total thickness of the system= 260-280 μ b. Salt spray test, ASTM B117 = 2500 hrs c. QUV Weather meter test, ISO 12944 = 2500 Hrs
Major Raw Materials to be utilized	All raw materials are available indigenously. Epoxy Resin, Polyurethane Resin, MIO, TiO_2 and Iron Oxide with solvents.
Major Plant Equipment and Machinery Required	Attritor, Weighing Machines, Packing Containers

3.6.3.2 Application:

Concrete surface to be painted shall be allowed maturation time of minimum 28 days before applying primer coating. Primer coating shall be applied to the cleaned surface after surface preparation within the pot life. After air-curing, intermediate and top coatings should be applied with time lag as per manufacturer's specifications. The coating shall be applied by brush or air-less spray gun.

The paint application should aim to achieve minimum dry film thickness as specified by CECRI. Some typical thicknesses used are as under:

1. Primer 100 microns
2. Undercoat 100 microns
3. Top coat 120 microns
4. Sealing coat 40 microns

The DFT (Dry film thickness) shall be measured on 100 mm x 100 mm steel plate attached with epoxy on the concrete surface at the rate one per 10m².

3.6.3.3 Acceptance Criteria:

CECRI Integrated four Coat System/Materials should be tested as per CECRI Specifications from reputed laboratories of CSIR /RDSO.

3.6.3.4 The detailed Specifications of materials and quality control measures may be obtained from CECRI, Karaikudi.

3.7 Coal tar Epoxy: These have both properties of coal tar and epoxy. These have good adhesion to concrete and chemical resistance. These are applied by roller, conventional means or by airless spray. These are applied in two coats having total thickness of 15 to 20 microns. These have been used in 1987 to 1991 in Thane Creek Railway Bridge on the piers in the tidal & splash zones. The coatings are intact as seen in 1998. This is the cheapest and best coating for substructure and coating over liner plates provided in the tidal & splash zones.

3.7.1 These coatings are to be done as per IS 14948.
Mandatory tests are to be done from reputed laboratories of CSIR /RDSO.

3.8 Provisions of IRS: CBC regarding Corrosion resistant measures to reinforcement are:-

Vide A & C Slip No. 7 Dated: 26.06.2018, Clause 7.1.5 has been modified and is reproduced as under:-

7.1.5 Corrosion resistance measures– In order to ensure adequate resistance against corrosion for reinforcement bars, following measures may be taken depending upon the environmental conditions:

- a) Removal of loose mill scales, loose rust and dust from the surface of the reinforcement bar shall generally be sufficient.
- b) In Extreme Cases, say up to 30 Km from Coastal Areas and in unavoidable circumstances, Stainless Steel Reinforcement Bars may be used. Properties of stainless steel reinforcement shall not be inferior to the carbon steel reinforcement of corresponding strength class.

Regarding Stainless Steel Reinforcement, Indian Standard Code “IS 16651: 2017 - High Strength Deformed Stainless Steel Bars and Wires for Concrete Reinforcement – Specification” to be referred.

REFERENCES

- Specifications for Road & Bridge Works issued by MORT & H and published by Indian Road Congress.
- IRC – Highway Research Board – Special Report on “State of Art: Corrosion & Corrosion Protection of Pre-stressed Concrete Bridges in Marine Environment.”
- Steel Corrosion in Concrete by Aron Bentur, Sidney Diamond & Neal S. Berke published by E&FN Spon – London.
- Corrosion of Reinforcement in Concrete Construction by C.L. Pagci P.B. Bamforth, J.W. Figg (U.K.).
- Corrosion Reinforced Steel in Concrete by Tonini-Gaides - ASTM Special Publication 713.
- Concrete bridge Practice (Construction, Maintenance & Rehabilitation by Dr. V.K. Raina.
- FIP Recommendations – Corrosion Protection of Unbonded Tendons.
- FIP Guide to Good Practice – Maintenance of Pre-stressed Concrete Structures.
- IS 12594: 1988 HOT – DIP Zinc Coating on Structural Steel Bars for Concrete Reinforcement.
- CRRRI Paper on “Critical Evaluation of Fusion Bonded Epoxy Coated Reinforcements and other Protective Coating on Reinforcement” by M.V. Bhaskar Rao.
- FIP Guide to Good Practice – Practical Construction.
- Technical Report by Mr. P. Xercavins. PX consultants, France (Formerly Technical Director of STUP, France).
- Corrosion Handbook, a Joint Publication of the Electrochemical Society of India and Associate (Data) Publishers Pvt. Ltd.
- Report on Investigation of Sharavathi Bridge, by STUP Consultants Limited/Hyder Consulting Limited, U.K. and STATS, U.K.
- Specifications received from CBRI/Roorkee.
- RDSO's guidelines vide BS:88 of 2008
- IS: 9103*
- IS 14948*
- IS 16651*: 2017 - High Strength Deformed Stainless Steel Bars and Wires for Concrete Reinforcement – Specification
- IS: 9077*

Note: For * Marked specifications upto date versions are to be referred

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**RDSO SPECIFICATION
No. M&C/PCN/126-2008**

**SPECIFICATION FOR BIPOLAR
CONCRETE PENETRATING
CORROSION INHIBITING ADMIXTURE
TO
PROTECT EMBEDDED STEEL
REINFORCEMENT IN CONCRETE
FROM CORROSION**

RESEARCH DESIGNS & STANDARDS ORGANISATION

Manak Nagar , LUCKNOW – 226 011

Price:

Ref.-MCM-1706	Page 2 of 13	Effective from June 2008	M &C/PCN/126/2008
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RDSO SPECIFICATION NO. M&C/PCN/126/2008

SPECIFICATION FOR BIPOLAR CONCRETE PENETRATING CORROSION INHIBITING ADMIXTURE TO PROTECT EMBEDDED STEEL REINFORCEMENT IN CONCRETE FROM CORROSION

0.0 FOREWORD

- 0.1 This specification prescribes the requirements and test methods of physico – chemical characteristics including performance test for evaluating the efficiency of the product in the laboratory for protecting steel reinforcement embedded in concrete from corrosion.

1.0 SCOPE

- 1.1 This standard prescribes the requirements and methods of test for the material known as Bipolar Concrete Penetrating Corrosion Inhibiting Admixture (CPCIA). The CPCIA shall be Bipolar in nature and concrete penetrating type which upon addition into the concrete matrix inhibits the corrosion process. It need not be in direct contact with the steel. Its vapors penetrate through fissures, honeycomb structure of concrete, pure water solution added in concrete and seals steel reinforcement at both anodic & cathodic sites, for inhibition. This is due to the bipolar mechanism property of the system. Non-concrete penetrating, nitrite & nitrate corrosion inhibitors are excluded from this scope.

The product shall be suitable to protect embedded steel reinforcement bars used in concrete structures from corrosion.

2.0 TERMINOLOGY

- 2.1 For the purpose of this standard the definitions as given in latest versions of ASTM-G1, ASTM-G3, ASTM-G109, ASTM-C 1202, JIS-Z-1535, AASHTO T259, IS:101(Part1/sec.5)-89, IS:456-2000, IS:1202-97, IS:1448-67, IS:1786-85, IS:9103-99 etc. shall apply.
- 2.2 Rounding off, of observed values on different tests shall be in accordance with IS: 2-1960.

3.0 SAMPLING

3.1 The representative samples of the material shall be drawn by the purchaser or the Inspecting authority as per the table given below:

Scale of Sampling for CPCIA

No. of containers in (N)	No. of containers to be selected for sampling (N)
Up to 50	1
51-100	2
101-200	3
201-300	3
301-500	4
501-800	5
801-above	6

3.2 For tender evaluation, the cost of 225 kg. of CPCIA in ready to use condition shall be taken into consideration for cost comparison.

4.0 PROPERTIES

4.1 General : The material shall comply with the requirements specified in Clause 5.0 , Table-I and Table-II of this specification.

4.2 Unless otherwise specified, the following testing conditions shall apply.

4.2.1 All the tests shall be conducted at room temperature $27 \pm 2^{\circ}\text{C}$ and relative humidity at $65 \pm 5\%$ in a well ventilated chamber free from draught and dust.

5.0 REQUIREMENTS

5.1 The admixture shall be supplied in one pack.

5.2 There are two types of requirements that the material should meet in order to be considered for usage in the railways.

5.2.1 Properties which can be evaluated in short duration (can be performed at a lab or at sites with proper testing facilities) as laid down in Table –I.

5.2.2 Properties which can be evaluated by performing long duration tests as laid down in Table–II.

5.2.3 All the tests performed under Indian tropical conditions, mentioned in Table-I and Table-II are mandatory requirements for the approval of product/manufacturer.

5.2.4 Approving authorities certificate for long term tests and Suppliers test certificate meeting the short term requirements may be accepted by the purchaser. However, Short term tests may be cross checked with NABL accredited laboratory if desired.

5.3 The recommended dosage of CPCIA in concrete shall be preferably 1% (w/w of Cement) or as recommended by the manufacturer.

5.4 Tests specified in Table II shall be performed in triplicate.

TABLE –I

REQUIREMENT OF BIPOLAR CONCRETE PENETRATING CORROSION INHIBITING
ADMIXTURE (Short Term Tests)

Sr. No.	Characteristics	Requirements	Methods of Tests
1.	Appearance	Brownish Liquid free from any visible residual deposits	Visually
2.	Odour	Mild Ammonical Odour	By smell
3.	Skin irritation	No irritation	By applying on reverse of the palm for 05 minutes.
4.	Ph i) As in supplied condition ii) 1% dilution ,w/w	i) 9.0-11.0 ii) 9.0-11.0	pH meter / Standard pH paper
5.	Specific Gravity at 27 ± 2°C	1.04-1.06	IS 1448-1967
6.	Viscosity of the material as in supplied condition, by Ford cup No 4, at 27 ± 2°C	10 -20 sec.	IS: 101(Pt.1/Sec.5)- 1989
7.	Accelerated Corrosion Test, for 21 hrs. i) Raw water without CPCIA* ii) Raw water with CPCIA*	i) Excessive corrosion spots. ii) There shall not be more than 1-2 corrosion spots.	Appendix-I

TABLE -II

REQUIREMENT OF BIPOLAR CONCRETE PENETRATING CORROSION INHIBITING ADMIXTURE (Long Term Tests)

Sr. No.	Characteristics	Requirements	Methods of Tests
1.	Immersion test for 720 hrs. (Rebar weight loss method) i) Without CPCIA* ii) With 1% CPCIA*	i) 40.00 mpy, max. ii) 2.00 mpy, max.	Appendix-II and ASTM G 1
2.	Effect of Concrete admixture on compressive strength i) Wth out CPCIA* ii) With 1% CPCIA*	Concrete strength in sample with CPCIA* should be ≥ concrete strength in sample without CPCIA*	Appendix-III & IS 9103-1999
3.	Polarization test by Tafel polarization with 3.5% Sodium Chloride, for 20 days i) Without CPCIA* ii) With 1% CPCIA*	Rate of corrosion shall be i) 45 mpy, max. ii) 9 mpy, max.	Appendix-IV and ASTM-G 3 and IS 9103-1999
4.	Effect of CPCIA* on corrosion of embedded steel rebars exposed to chloride environments after 09 cycles (14 days wetting and 14 days drying) as per ASTM G-109. i) Without CPCIA* ii) With 1% CPCIA*	Rate of corrosion shall be i) 25.00 Coulombs, max. ii) 0.50 Coulombs, max.	Appendix-V and ASTM G-109
5.	Chloride Migration profile properties of concrete with and without CPCIA i) Chloride % in concrete at 30 mm depth after 90 days. (For all types of cements e.g. OPC,PPC,PSC,SRC) ii) Ability to resist chloride ion penetration (RCPT) (For all types of cements e.g. OPC, PPC,PSC,SRC) a) Concrete grade M-30, Water cement ratio: 0.45 b) Concrete gradeM-40, Water cement ratio: 0.40	With out CPCIA* With 1% CPCIA* Chloride % shall be 0.025%, max. Nil Resistance to chloride ion penetration shall be 1650 1000 Coulombs, max. Coulombs, max. 1550 1000 Coulombs, max. Coulombs, max.	Appendix-VI and AASHTO T-259 i) IS:456-2000 ii) ASTM C-1202-1997

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Note

1. CPCIA*: Concrete Penetrating Corrosion Inhibiting Admixture. The CPCIA shall be used as 1% w/w of cement or as recommended by the manufacturer for conducting the tests mentioned in Table-II except Immersion test for 720 hrs mentioned at S. No. 1 where it shall be used as 1% w/w of water or as recommended by the manufacturer.
2. Wherever required, rebar's conforming to IS: 1786-1985 shall be used for testing purposes.

6.0 SAFETY TO CONSTRUCTION MATERIAL

CPCIA should not degrade, or damage the construction materials.

- i) Concrete
- ii) Aggregates
- iii) Steel reinforcement
- iv) Formwork/Shuttering

7.0 SAFETY FOR APPLICATION

The CPCIA should not cause harm to personnel by mean of inhalation or skin contact. All precautionary measures shall be intimated by the manufacturers clearly in writing along with instructions of usages. However final decision about adoption of such measurers shall lie with the Railways and shall depend upon the conditions prevailing on the Railways at the time.

8.0 WASTE WATER DISCHARGE

The waste discharge shall be in accordance with the laws of pollution control in force from time to time.

9.0 PACKING

The material shall be packed in suitable air tight polyethylene containers preferably of capacity 20 kg / 200kg or as agreed by purchaser and supplier

10.0 MARKING

- 10.1 Each container shall be legibly and indelibly marked with the following:
 - a) Name of the material
 - b) Name of the manufacturer
 - c) Volume / weight of material
 - d) Specification number
 - e) Batch No. or Lot No. in code or otherwise
 - f) Month and year of manufacture

11.0 INSPECTION

- 11.1 At the time of initial approval of the product or firm, full testing as mentioned in Clause 5.2.3 shall be carried out.
- 11.2 In case of acceptance testing, Inspecting Authority shall draw the sample as per Clause 3.1, from the batch under consideration and the material shall be tested for the tests stipulated in Table-I.

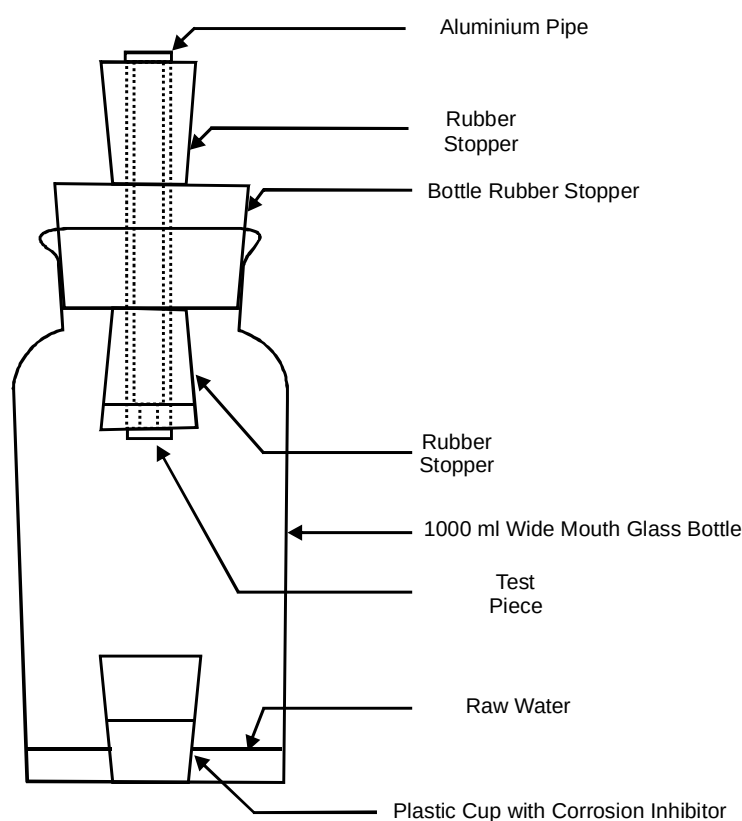
11.2.1 Long duration tests need substantial amount of time. The testing facilities for these tests may not be available in each and every lab therefore, Approving authority's certificate for long term tests as stipulated in Table-II & Supplier's test certificate/NABL accredited laboratory test certificate meeting the short term tests as stipulated in Table-I may be accepted by the purchaser for acceptance of the material. However if desired by the purchaser, long term tests may also be organized to be carried out at any IITs / NABL accredited laboratory.

APPENDIX-I

MODIFIED ACCELERATED CORROSION TEST (BASED ON JAPANESE STANDARD JIS Z 1535)

TEST PROCEDURE

Attach steel test pieces conforming to IS: 1786-1985 (of size approx. 15mm dia and 12mm thickness drilled from one side c/c to a dia of 10mm and a depth of 10 mm to hold the aluminium pipe) after thorough cleaning to white metal by using 1000 grade grit paper and subsequently polishing with 3/0 grade and finally with 4/0 grade grit paper to the Aluminium pipe with the help of cello tape so that it is firmly attached. The aluminium pipe is then slid upwards till the test piece rests in the slot provided in the rubber cork, as shown in the figure.



Assembly with Corrosion Inhibitor

Pour 100 ml of tap water in both the bottles. Fill the plastic cup with 25 ml CPCIA solution as in supplied condition. In one of the bottles place the plastic cup with the CPCIA solution so that the cup is placed in the tap water. Allow to remain for 18 hours at ambient temperature. After 18 hrs. add chilled water having temperature below 1.0 °C into the aluminium pipes and allow to remain for 3 hrs. The temperature of the chilled water in the aluminium pipes shall be maintained at 2.0 ± 0.5 °C by frequently changing the chilled water with the help of the pipette. Observe the steel test pieces after the experiments i.e. 18+3=21 hrs., for any corrosion spots.

APPENDIX-II

IMMERSION TEST (REBAR WEIGHT LOSS TEST) (AS PER ASTM G 1)

TEST PROCEDURE

Take six pieces of Tor steel rebar conforming to IS: 1786-1985 of size approx. 40 mm length and 10 mm dia. Clean the rebar of any rust, mill scale etc., with the help of steel wire brush, till it has overall a shining surface. Now clean all the six pieces with solvent such as benzene/acetone to remove any loose rust /dust from the surface. Dry at $100 \pm 2^\circ\text{C}$ for 15 minutes in an oven. Cool and take the weights of all the six pieces and record it.

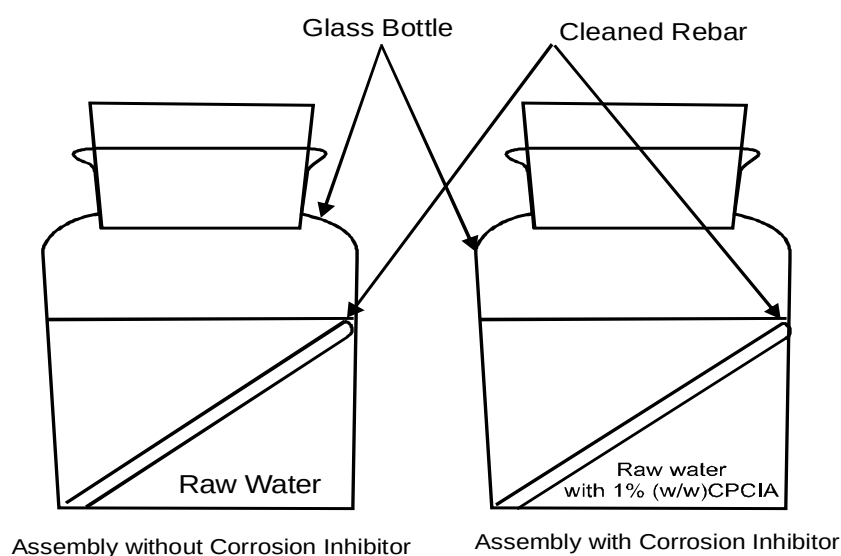
Take six transparent glass/plastic bottles of approx. 150 ± 10 ml with air tight caps. Clean all the bottles with tap water and then fill them with 100 ml of tap water so that the bottles are approx. three fourth filled. In three of the six bottles, add CPCIA 1%, w/w or as recommended by the manufacturer of the water in the bottle. Now put one cleaned and weighed rebar test piece completely immersed in water/water + CPCIA, in all the six bottles and close the cap.

After 30 days (720 hrs.), take out all the six test pieces and put them in Clark solution (prepared by dissolving 20 gms. of Antimony trioxide and 50 gms of Stannous chloride in 1000 ml of Con. Hydrochloric acid, S.G. 1.18) so that corrosion products are dissolved. After complete removal of corrosion products (in 5 minutes approximate), take out the test pieces and wash in running water and finally with distilled water. Then wash the test pieces, with solvent such as benzene/acetone. Dry at $100 \pm 2^\circ\text{C}$ for 30 minutes in an oven. Cool and take the weights of all the six pieces and record it.

Calculate the corrosion rate in mpy, by using the formula

$$\text{Corrosion rate (mpy)} = 534 (W1-W2) / DAT$$

Where W1-W2 is the weight loss in mg., D is the density of steel , A is the area in sq. inch and T is the time of exposure in hrs



APPENDIX-III

TEST FOR EFFECT ON COMPRESSIVE STRENGTH BY ADDITION OF CPCIA

TEST PROCEDURE

Cast three concrete blocks of size 100mm x 100mm x 100mm each with out and with CPCIA 1% (w/w) of cement or as recommended by the manufacturer, by casting the concrete of M 20 grade as per Clause 6.2.3 of IS 9103-1999.

The above casted blocks shall be demoulded after 24 hrs. . These blocks shall be moist cured for 28 days. After completion of the curing period, the blocks of each type shall be tested for compressive strength in compression testing machine (Universal Tensile Machine) and data recorded.

APPENDIX-IV

BRIEF OUTLINES OF ELECTROCHEMICAL POLARIZATION TEST CONDUCTED ON STEEL REBARS EMBEDDED IN CONCRETE (AS PER ASTM G 3)

Cast three concrete cylinders, of size 75mm dia and 150mm length each without and with CPCIA 1% (w/w) of cement or as recommended by the manufacturer, by casting the concrete of M 20 grade as per Clause 6.2.3 of IS 9103-1999, and placement of one cleaned rebar conforming to IS:1786-1985 of size 375 mm length and 12 mm dia (preferably cleaned by pickling in Hydrochloric acid 20% (v/v) approximately, till surface shines and washed in running water) in each block .

The above casted blocks shall be de molded after 24 hrs. These blocks shall be moist cured for 28 days.

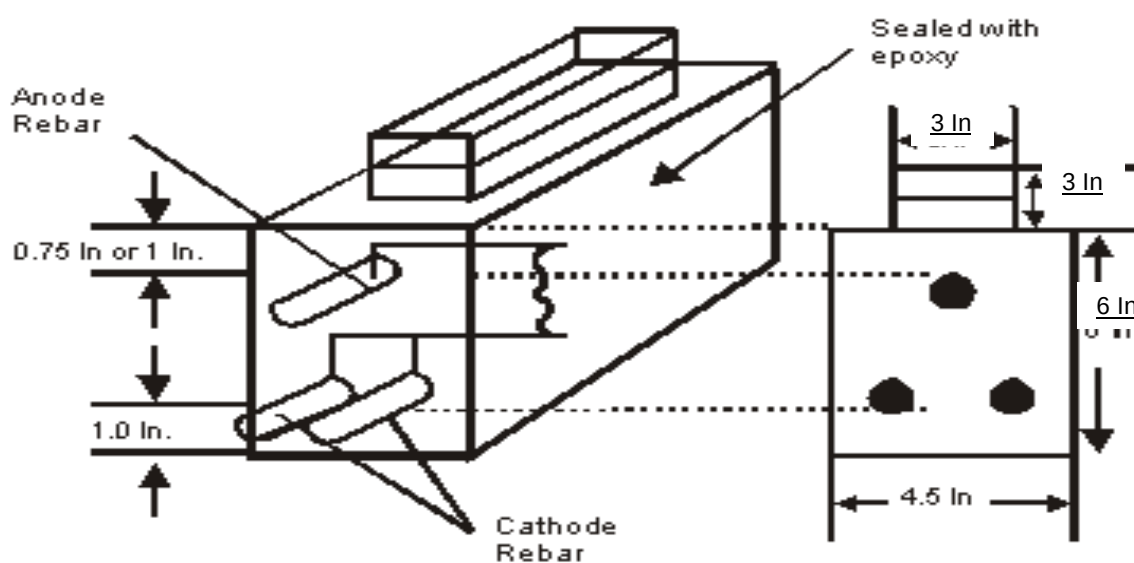
After completion of the curing period, the blocks shall be subjected for Polarization test for 20 days as per ASTM G-3 and observations recorded.

APPENDIX-V

BRIEF OUTLINES OF LONG TERM CORROSION TEST (AS PER ASTM G 109 – 2005)

Three specimens each of control concrete and that of CPCIA admixed concrete (1% w/w of cement or as recommended by the manufacturer) should be cast as per the size 280mmx150mmx115mm and with placement of three cleaned reinforcement bars conforming to IS:1786-1985 (preferably cleaned by picking in Hydrochloric acid 20% (v/v) approx, till surface shines and washed in running water) of size 12mm and length 375 mm as per the details shown in the drawing. Admixture shall be added as per manufacturers recommended dosage. All the casted concrete samples shall be moist cured for 28 days.

Ponding of samples with 3% NaCl solution as shown in the drawing to be continued and measuring of voltage across 100 ohm resistor to be continued beginning of the second week of ponding. Calculate the current I_c from the measured voltage and record. Also measure the corrosion potential of the bars against reference electrode. The experiment should be continued till the macrocell current reaches a value of 10 μ A. After the experiment break the specimens and examine the rebars for extent of corrosion, measure the corroded area and record.



Note - All Measurements in In. (25.4 mm = 1 In.)

FIG. 3 Concrete Beam

APPENDIX-VI

BRIEF OUTLINES OF RESISTANCE OF CONCRETE TO MIGRATION OF CHLORIDE ION TEST (As per AASHTO T259)

A. Chloride Ion Penetration (Salt Ponding Test) (As per IS:456-2000)

Cast three concrete blocks of size 300mmx300mmx75mm each without and with CPCIA 1% (w/w) or as recommended by the manufacturer, by using the concrete mix as under:

	M 30	M 40	
i) Cement, grade 53 -----	50	50	Kg.
ii) Sand coarse	: 104	87	Kg.
iii) Aggregate, M1, passes through 20 mm and retained on 10 mesh	: 160	134	Kg.
iv) Water (Subject to 55±5 slump)	: 24	20	Kg.
v) CPCIA	: 0.5	0.5	Kg.
or as recommended by the manufacturer			
with each type of cement given below			

- i) Ordinary Portland Cement
- ii) Portland Pozzolana Cement
- iii) Portland Slag cement
- iv) Sulphate resisting Cement

AASHTO T259 test (commonly referred to as the salt ponding test) is a long-term test for measuring the penetration of chloride ions into concrete. Three slabs of 75 mm thick and having a surface area of 300 mm square shall be casted. These slabs are moist cured for 14 days and then stored in drying room at 50 percent relative humidity for 28 days. The sides of the slabs are sealed but the bottom and top face are not. After the conditioning period, a 3 percent NaCl solution is ponded on the top surface for 90 days, while the bottom face is left exposed to the drying environment (see figure1).

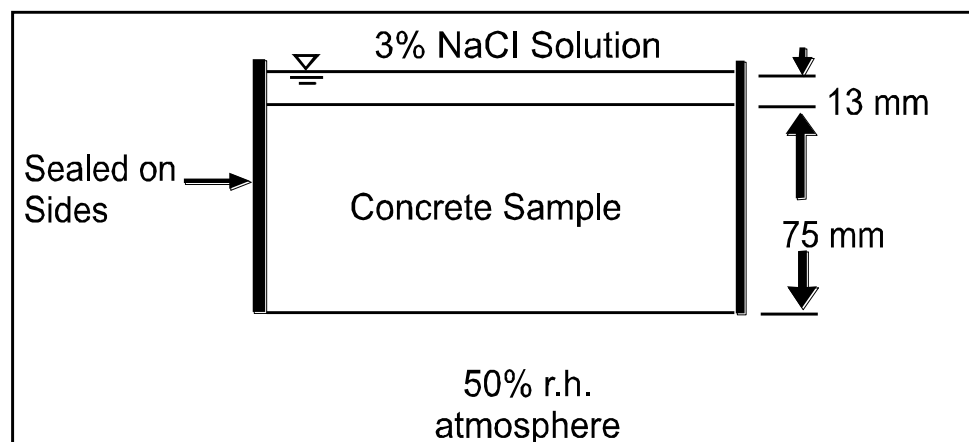


Figure 1. AASHTO T259 (Salt ponding) test setup

At the end of this time (90 days) the slabs are removed from the drying environment and the chloride concentration of 10 mm thick slices is then determined (AASHTO T259). Two or three slices are taken at progressive depth. The salt ponding test does provide a crude one-dimensional chloride ion ingress profile. Test results should meet the requirements as stipulated in IS: 456-2000

B. Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration (Rapid Chloride Permeability test) (As per ASTM C-1202-1997)

Cast three concrete cylinders of size 50 mm thick, 100 mm diameter without and with CPCIA 1% (w/w) or as recommended by the manufacturer, by using the concrete mix as under.

	M 30	M 40	
i) Cement, grade 53	: 50	50	Kg.
ii) Sand coarse	: 104	87	Kg.
iii) Aggregate, M1, passes through 20 mm and retained on 10 mesh	: 160	134	Kg.
iv) Water (Subject to 55±5 slump)	: 24	20	Kg.
v) CPCIA	: 0.5	0.5	Kg.

or as recommended by the manufacturer with each type of cement given below

- Ordinary Portland Cement
- Portland Pozzolana Cement
- Portland Slag cement
- Sulphate resisting Cement

As per ASTM C 1202-1997 a test, a water-saturated, concrete specimen is subjected to a 60 V applied DC voltage for 6 hrs. using the apparatus shown in Figure 2. In one reservoir is a 3.0% NaCl solution and in the other reservoir is a 0.3 M NaOH solution. The total charge passed is determined and this is used to rate the concrete's resistance to chloride ion penetration.

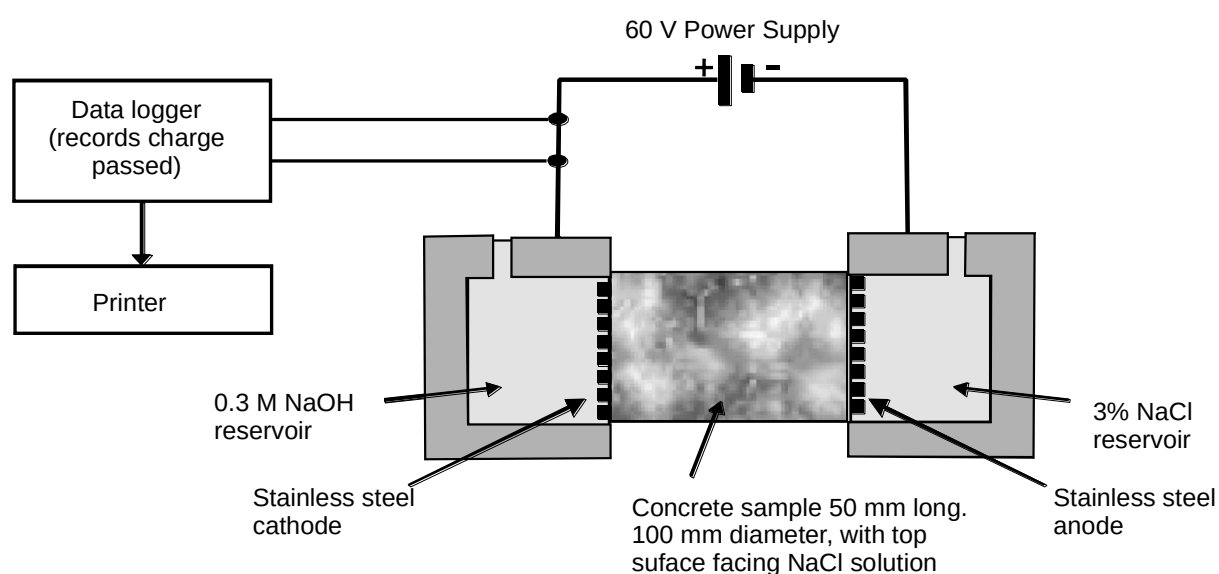


Figure : AASHTO T277 (ASTM C1202) test setup.