



**Ambuja
Cement**

DURABILITY OF CONCRETE

AMBUJA TECHNICAL LITERATURE SERIES

24

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(HINDI, MALAYALAM, KANNDA & SINHALA)

DURABILITY OF CONCRETE

1.0 INTRODUCTION

It is estimated that worldwide consumption of concrete today is around 8.8 billion tons per year. Due to massive developments taking place in a Country like ours, it is expected to grow steadily during the next century.

Concrete is a very durable material but at the same time concrete structures have shown poor durability and loss of strength within a few years of their service life. A collapsed RCC structure in Figure 1, barely two decades old is one such example. This is true the world over. Gigantic amount of money is being spent on maintenance, repairs run annually into billions of dollars even in developed countries.

In a concrete structure premature deterioration, excessive wear and unsatisfactory service life can occur either due to the concrete chemically reacting with environmental pollutants or rusting of steel in concrete subsequently causing spalling or disintegration.



Figure 1 : The light which was to have brightened the sky was extinguished — "Akash Deep" collapsed at Opera House, Mumbai.

“Prevention is better than Cure”. It is therefore essential to design, plan and construct reinforced concrete structures with proper control at every stage first by preventing porosity of any nature and secondly by ensuring that properties of concrete materials and their proportions are suitable enough to face the environmental pollutants

2.0 CONTROLS

To achieve good durability of concrete the following factors should be properly controlled:

- (a) Structural design.
- (b) Study of environment in which the structure is being constructed. Temperature, humidity and chemical conditions to be examined.
- (c) Concrete Specifications such as maximum water to cement ratio, maximum cement content, type of cement and grade of concrete.
- (d) Quality of concrete cover around the steel reinforcement and embedments. This includes the quality of concrete cover blocks as well. Figure 2 shows deterioration of concrete due to poor quality of concrete around the steel reinforcement.
- (e) Selection of all materials of concrete and good concrete mix design.
- (f) Workability and cohesiveness of concrete mix.



Figure 2 : Column showing porous concrete due to improper mix and incorrect construction practices.

- (g) Batching, mixing, transporting, placing, compacting and most important curing. Concrete in plastic form should be uniform and care should be taken to prevent segregation. Figure 3 shows large voids due to segregation of concrete at the column bottom.
- (h) Maintenance and usage in service life. Concrete structures are often tampered with or modified. Structures are often overloaded without any consideration about its loads carrying capacity. Figure 4 shows a structural collapse probably attributable to poor maintenance and negligence.



Figure 3 : RCC column displaying porosity due to segregation of concrete whilst placing.

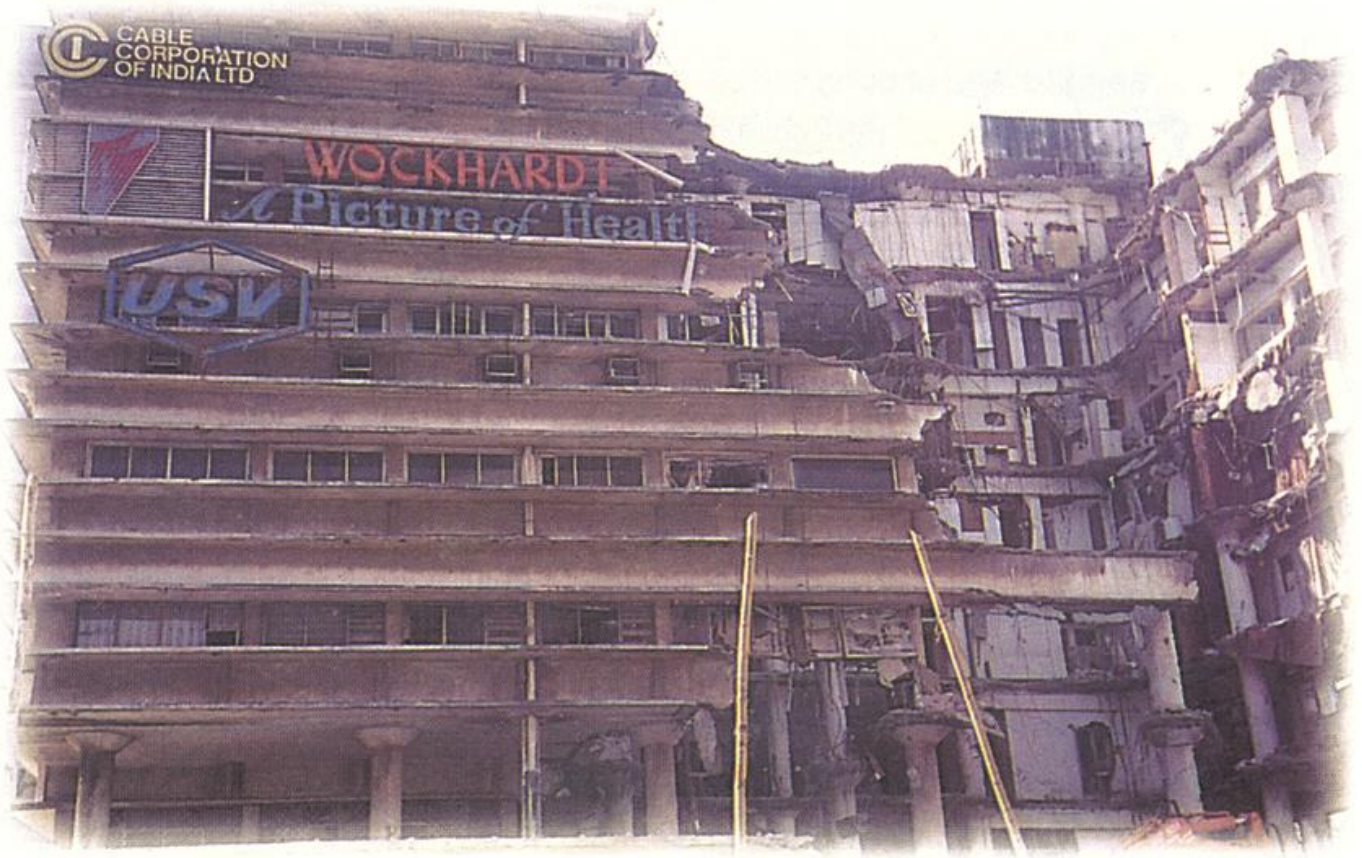


Figure 4 : Unhealthy RCC structure which housed a company which was a Picture of Health — Poonam Chambers, Worli, Mumbai collapsed on 16th September, 1997.

3.0 CAUSES & PREVENTIVE MEASURES

Deterioration of concrete can take place basically due to porosity.

Concrete has porosity of several types:

- ☐ Capillary pores
- ☐ Entrapped air
- ☐ Honey combs
- ☐ Cracks

3.1 Porosity in Concrete

There can be micro or macro pores present in concrete. Micro pores are in form of capillary pores in the cement gel. Macro pores can be due to entrapped air as a result of stiff workability or poor compaction. Honey-combing as a result of segregation or use of non cohesive mix causes large voids. Leaching of excess lime also causes porosity.

3.1.1 Capillary Pores

Capillary pores in concrete can be as large as 5 μm in diameter. Number and size of pores depend on water to cement ratio (W/C) used and the extent of chemical hydration that has taken place. The relation between the age of concrete at which capillary pores get blocked (concrete becomes almost impermeable) and W/C is given in Table No.1.

Table No. 1

W/C	Age at which capillary pores become blocked
0.40	3 days
0.45	7 days
0.50	14 days
0.55	3 months
0.60	6 months
0.70	over 1 year
over 0.70	infinity

Table No.1 clearly shows that as W/C increases the concrete remains permeable for a longer period thereby permitting ingress of moisture and chemicals to penetrate it, leading to corrosion of reinforcement and creating other durability problems. Concrete with W/C=0.7 remains vulnerable to chemical and moisture ingress for over one year while concrete with W/C=0.4 almost becomes impermeable within 3 days of casting.

3.1.2 Permeability of Concrete

Concrete produced with low water to cement ratio displays low coefficient of permeability of concrete as compared to concrete produced with high water cement ratio.

Table No.2 below gives the coefficient of permeability of concrete made using same materials but with different W/C ratios.

Table No. 2

Coefficient of Permeability for different W/C		
Sr. No.	W/C	Coefficient of Permeability (Valenta)
1.	0.35	1.05×10^{-3}
2.	0.50	10.30×10^{-3}
3.	0.65	1000×10^{-3}

The above table clearly indicates that lower the W/C, lower is the permeability. The coefficient of permeability increases about 1000 times with the increase in W/C from 0.35 to 0.65.

Table 3 below also shows the permeability and porosity in air of cement pastes hardened upto 90 days using Ordinary Portland Cement with three different W/C.

Table No. 3

Permeability ($\text{m}^2 \times 10^{-17}$)						Porosity (%)				
Curing (days) W/C	1	3	7	28	90	1	3	7	28	90
0.32	5.60	0.30	0.12	0.00	0.00	20.80	19.7	14.4	9.80	5.90
0.40	18.70	0.59	0.07	0.07	0.00	33.30	28.6	20.9	16.80	11.10
0.50	214.00	14.70	2.35	0.19	0.00	43.50	37.8	32.2	20.80	14.50

From the above table, it is very clear that W/C remaining constant permeability and porosity rapidly reduces with increase in curing period. At the same time, with increase of W/C the permeability and porosity also increase at the same curing period.

3.1.3 Permeability & Porosity of concrete made from Pozzolanic Cements

Permeability of pozzolanic cement pastes which is initially higher as compared to OPC tends to become lower as the curing period proceeds. Even though pozzolanic pastes are always more porous than those made up of OPC, the permeability of pozzolanic cement pastes is identical to that of OPC after a lapse of time. For the first 7 to 15 days cement hydration only involves the clinker and gypsum fractions. Pozzolanic material or flyash will hydrate later on at a slower rate and within an already rigid structure. Some lime reaction products are formed mostly through complex process of dissolution, transportation and precipitation. Mass precipitation into the pores previously formed by hydration of the clinker fraction is not able to fill the larger pores completely but blocks smaller capillaries connecting larger pores or, at least reduce their openings considerably. As a consequence, porosity of pozzolanic cement pastes remains higher than or at the most becomes the same as OPC, but the permeability becomes lower.

Concrete made up with 35% flyash containing cements has turned out to be 2 to 5 times less permeable than concrete manufactured with OPC or blast furnace slag cements. Concretes made using pozzolanic cement have a better flexural / compressive strength ratio and reduced tendency towards cracking than concrete made using OPC.

3.1.4 Leaching

Water can decompose any of the hydrated compounds present in concrete. If concrete comes in continuous contact with water or moisture, the free lime occurring in hardened concrete being easily soluble is the first compound to be attacked and will leach out. This lime extraction to the concrete surface increases both porosity and permeability. The soluble calcium hydroxide leaches through the capillary pores of concrete and leaves a passage for other pollutants such as water, chlorides and sulphates to enter. This also causes alkalinity of concrete to drop initiating corrosion of steel within the concrete.

3.2 Cracks in Concrete

In modern concrete structures not enough attention is being paid to the fundamental principles of concrete technology governing cracking. In general cracks in concrete range in widths from 0.1 mm to 1.0 mm and are primarily caused due to the following :

- ☐ Temperature gradient including frost action.
- ☐ Humidity gradient (Drying Shrinkage)
- ☐ Rapid drying conditions (Plastic Shrinkage)
- ☐ Structural overloading, cyclic or impact loading.
- ☐ Inadequate structural design and detailing.
- ☐ Chemical causes including corrosion of reinforcement.

Concrete starts cracking at an early age when it is still in plastic stage (for details refer our booklet on “Plastic Cracking of Concrete”). When freshly hardened concrete is exposed to temperature and humidity gradient it experiences thermal and drying shrinkage strains. One of these two gradient will have more dominating effect on concrete depending on the following.

- ☐ Temperature and humidity of the environment.
- ☐ Size of the structural element.
- ☐ Temperature of concrete.
- ☐ Physical and Chemical properties of concrete materials.
- ☐ Mix proportion of concrete materials.

Under the restraining conditions in hardened concrete, shrinkage strain causes a tensile stress. The concrete material will develop cracks when this induced tensile stress exceeds the tensile strength of concrete. However, due to viscoelastic behaviour (creep) of concrete material some of the stress is relieved and it is the residual stress, after the relaxation due to creep, that will be responsible for cracking.

Cracks on concrete surfaces may or may not influence the strength. However, cracks on concrete surfaces will seriously effect the durability of concrete specially when it is exposed to aggressive environment and number of cyclic loading conditions. Under such conditions cracks wider than 0.3 mm seldom heal. Many standards recommend 0.15 mm as the maximum crack width at the tensile face of a reinforced concrete structure subjected to alternate drying and wetting conditions or is located in the tidal zone and subjected to sea water sprays.

In concrete design and construction practice, crack widths are generally controlled by proper deployment of the primary reinforcement and by use of secondary reinforcement. However, it is well established that reinforcement steel does not prevent cracking or reduce cracking. It simply transforms a few wide cracks into many fine cracks and micro cracks.

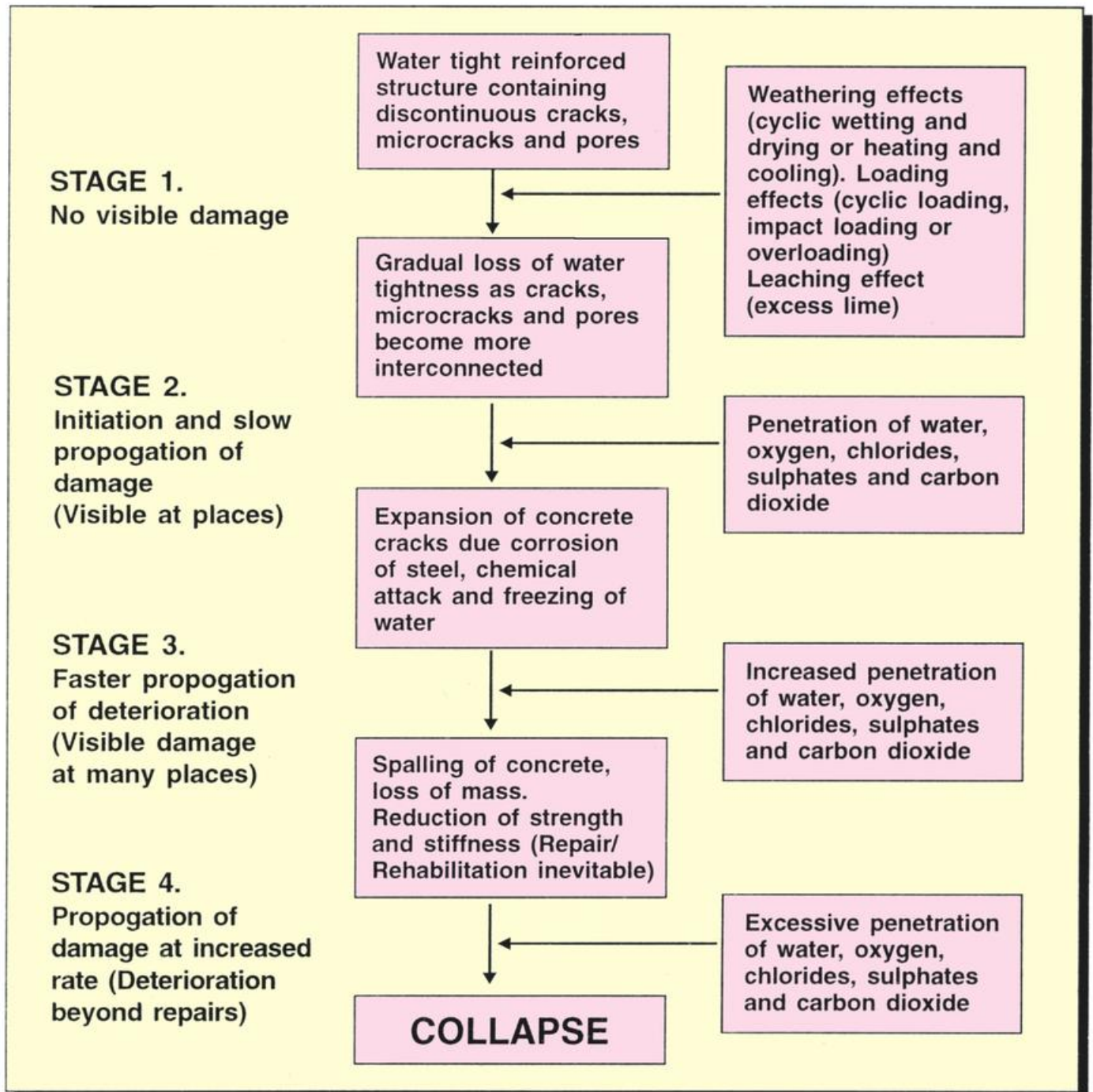
Deterioration of concrete takes place in stages. The speed of deterioration and damage to concrete will greatly depend on the following factors :

- ☐ Continuous or discontinuous cracks, microcracks and pores.
- ☐ Weathering effects such as cyclic heating and cooling or wetting and drying.
- ☐ Cyclic loading or impact loading.
- ☐ Environmental action of aggressive chemical ions and their penetration.

If cracks and pores are continuous deterioration due to penetration of aggressive chemical ions will be faster. When the cyclic weathering and loading conditions are very repeatative the discontinuous pores and cracks will become continuous and aggressive chemical ions will cause deterioration at first, gradually and later at an increasing rate. The stagewise model of concrete deterioration is given in Figure No. 5.

The model given in Figure No. 5 shows stagewise concrete deterioration due to environmental and other effects.

Figure No. 5



3.3 Entry of Chemicals

Chlorides, water, carbon dioxide and sulphates are most harmful to concrete and the steel within it. While chlorides and water enter through the pores and cracks in concrete and cause corrosion of steel the carbon dioxide and sulphates chemically react with concrete and cause deterioration and reduction of durability. Chlorides to a certain extent also cause swelling of concrete.

The environment in which the concrete structure is to be constructed influences the various parameters of concrete mix design and selection of materials rather than just the characteristic strength.

The chemical substances which need to be considered for their aggressive effect on concrete are water, chloride ions, carbon dioxide and sulphate ions.

Each chemical substance is briefly discussed alongwith the necessary preventive measures in this write-up.

4.0 WATER

While water is required for cement hydration and later for curing of concrete, it is harmful to reinforcement steel after concrete has been taken in service.

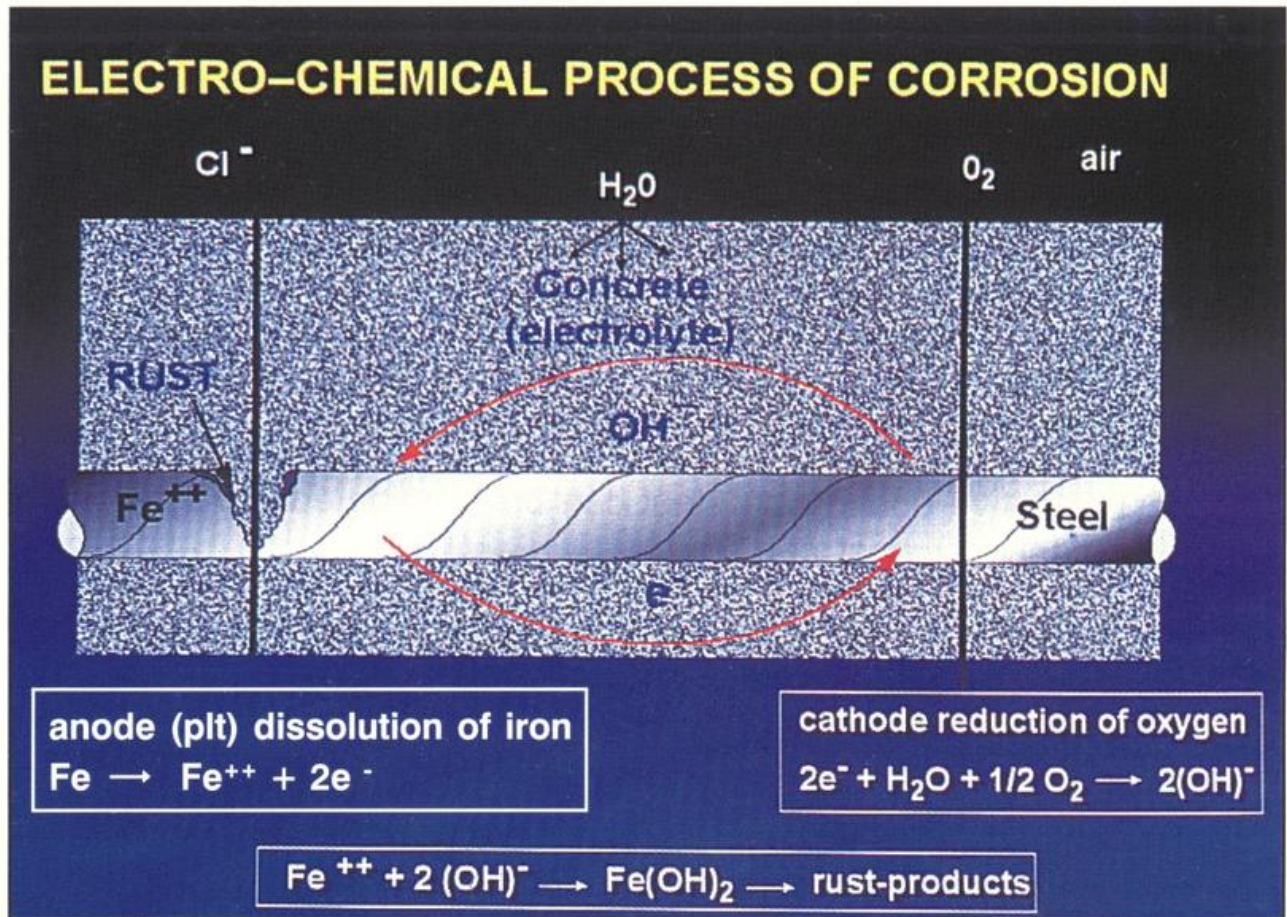
Ingress of water can take place through capillary pores, cracks or voids in concrete surface. When the water penetration is beyond the concrete cover, and it reaches the reinforcement steel inside, it is dangerous. Water can cause corrosion of steel and subsequent disintegration. Water is the primary vehicle for the diffusion of other aggressive ions, such as chlorides and sulphates, into the concrete mass.

4.1 Corrosion

Before we discuss the problems of ingress of water and chlorides in concrete, it is important to understand the mechanism of corrosion of steel in concrete and the damage it causes to concrete structure.

Mechanism of corrosion of steel is an electro-chemical process. The electro-chemical process starts when there is a potential difference caused due to difference in concentration of dissolved ions such as alkalies, chlorides and oxygen, in the vicinity of steel. Due to the potential difference some parts of the metal become anodic and the other parts become cathodic. Dissolution or pitting of iron takes place on the anodic parts and reduction of oxygen takes place on the cathodic parts. Rust appears on the anodic part as iron (ferrous) gets converted to ferrous oxide or ferrous hydroxide. For this chemical process presence of moisture and oxygen is necessary. The concrete acts as an electrolyte and the electro-chemical process takes place as shown in Figure No.6.

Figure No. 6 : ELECTRO-CHEMICAL PROCESS OF CORROSION



Depending on the state of oxidation, metal get converted to rust (corrosion product) which may occupy 6 to 8 times the original size of steel. This growth creates tensile stresses within the concrete mass surrounding the reinforcement steel. As concrete is weak in taking tensile or expansive forces it cracks and spalling of concrete takes place. Figure 7 shows spalling of concrete of a building column.

4.2 Preventive Measures:

To avoid corrosion of steel, following preventive measures are to be taken.

- ❑ Concrete mix should be designed with as low a water cement ratio as possible depending on environmental conditions in which the



Figure 7 : Spalling of concrete of a building column due to rusting of steel reinforcement.

structure is proposed. Some guidelines as per Bureau of Indian Standards are given in subsequent paras and they must be followed.

- ❑ Concrete should be made in such a manner that voids due to entrapped air or segregation do not occur.
- ❑ Plastic and drying shrinkage cracking of concrete should be avoided by taking adequate care in designing concrete mixes and by proper construction practices, specially curing.
- ❑ Concrete mix should have good workability and cohesiveness and must be placed and compacted properly.
- ❑ Protective coating on steel can be considered as a second line of defence against corrosion.

5.0 CHLORIDE

5.1 Harmful Effects of Chloride

The chloride ions in concrete can have harmful effect on concrete as well as on reinforcement. In the first case chloride penetration brings about concrete swelling of 2 to 2.5 times larger than that observed with water penetration. This causes slight reduction of concrete strengths as well as causes leaching of concrete making it more porous and vulnerable. In the second case presence of chloride near the reinforcement steel is extremely dangerous. If the chloride to hydroxide ratio near the reinforcement steel drops below 0.3 passivation is destroyed and corrosion is inevitable. Chlorides have therefore to be prevented from entering into concrete.

Chlorides can be present in concrete materials and are termed as “domestic” chlorides or chlorides can be present in the environment around the concrete structure and are termed as “foreign” chlorides.

5.2 Limitation of chlorides in materials

The amount of chlorides permitted in concrete so far as corrosion of reinforcements is concerned is limited to acid-soluble chloride content of 0.15% by weight of cement, at the time of placing concrete. This is recommended in IS:456 Code of Practice for Plain and Reinforced Concrete.

5.3 Tricalcium Aluminate (C_3A)

There has been a lot of discussion about the limits of chloride in concrete about “domestic” chloride versus “foreign” chloride. If there is uniform distribution of chlorides, corrosion may be minimal. Further, even if the chloride is initially uniformly distributed, a non-uniform distribution eventually may result, due to movement of water containing chloride in solution. Some of the “domestic” chloride can become chemically fixed by reactions with C_3A components of the Portland cement forming calcium chloroaluminate hydrates. This not only explains the good performance of portland cement containing high amounts of calcium aluminate, but also advocates such cements as a solution to the problem.

It is not advisable to use Sulphate Resistant Cements in environment where excessive chlorides are present as Sulphate Resistant Cements have low C_3A content and therefore less ability to form calcium chloroaluminate hydrates.

5.4 Chloride Diffusion

To protect reinforcement from chlorides penetration, it is essential to produce impermeable concrete (concrete having a low water to cement ratio) and give thicker cover to reinforcement steel. Figure 8 shows precast concrete piles of N 32.5 concrete grade made using pozzolana Portland cement and concrete cover to reinforcement was 75 mm. Piles were driven in soils containing very high concentration of chlorides in ground water and sub soil.

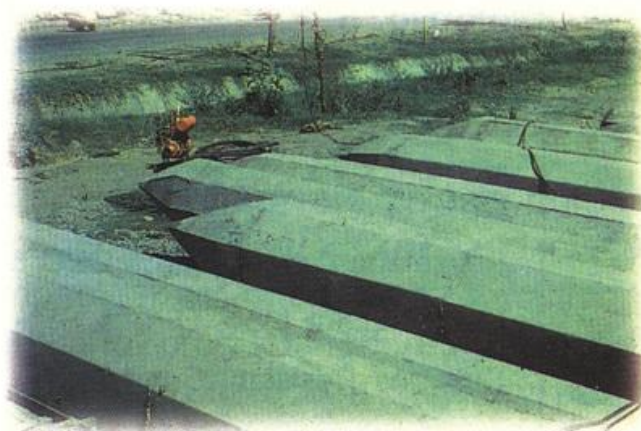


Figure 8 : Precast concrete piles of N 32.5 grade - Trombay, Mumbai.

Studies have been undertaken and it is observed that with all mix parameters remaining the same, reduction of W/C reduces chloride ion penetration into the concrete to a considerable extent. Table No.4 below shows that chloride diffusion in concrete mixes reduces considerably as the W/C reduces.

Table No. 4

Chloride diffusion in concrete mixes for different W/Cs		
Sr. No.	W/C	Chloride Diffusion $\times 10^{-8}$ Sq.cm / S
1.	0.40	1.05×10^{-3}
2.	0.50	10.30×10^{-3}
3.	0.61	1000×10^{-3}

5.5 Blended Cements in Chloride Environment

It is also recommended to use blended cements containing Pozzolanic materials or slag as the chloride diffusion through cement pastes of these cements is at a very slow rate than compared to OPC and sulphate resistant cements.

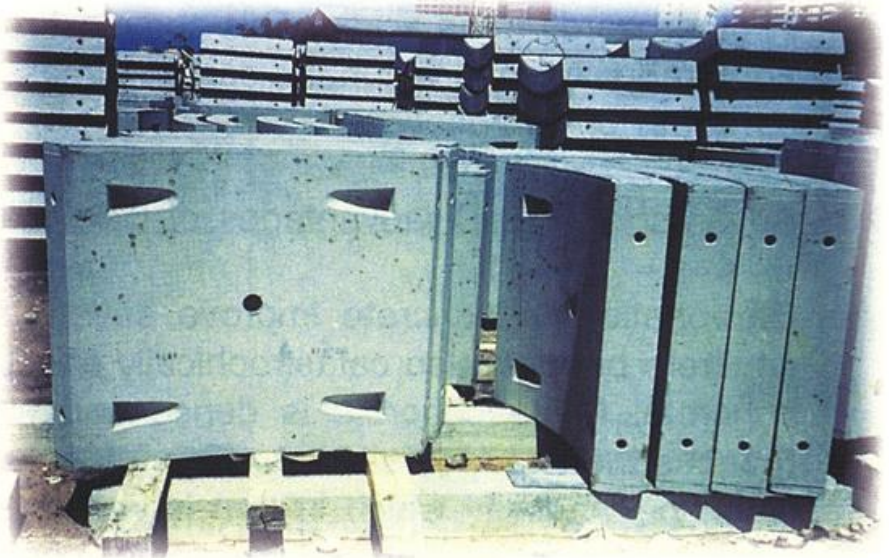
Table No.5 given below shows chloride diffusion in various types of cement pastes having constant W/C=0.5 at 25°C.

Table No. 5

Type of Cement	Chloride Diffusion Sq.cm / S $\times 10^8$
OPC	4.47
Pozzolana Cement (70% OPC & 30% flyash)	1.47
Slag Cement (35% OPC & 65% slag)	0.41
Sulphate Resistant Cement	10.00

The above table clearly shows that cement with 65% slag is most suitable while sulphate resistant cement is least suitable in chloride environment. Pozzolanic material if present around 33% is considered to be very effective in reduction of chloride diffusion into concrete. However, percentage of pozzolana being restricted to 25% in IS 1489 and slag being restricted to 65% in IS 455 concrete can be manufactured using pozzolana or slag as mineral additives. Therefore it is possible to use higher percentage of such materials in very aggressive environment wherein high proportions of chloride are present.

Figure 9 shows precast concrete liners for sewerage outfall tunnel cast using 30% cement and 70% ground granulated slag to produce concrete of N 45 grade.



6.0 CARBONATION

6.1 Alkalinity of Concrete *Figure 9 : Precast concrete liners for sewerage outfall tunnel at Bandra, Mumbai*

Concrete is an alkaline substance and provides excellent protection to reinforcement embedded inside. The alkaline environment forms a protective oxide film which passivates the steel and protects it from corrosion. Concrete initially has a pH value of above 13.

Due to leaching, carbonation and defective construction practice the pH value drops rapidly. Once pH value of concrete in the cover area drops below 10, corrosion of steel reinforcement is inevitable and therefore concrete durability is at stake.

This is however dependent on the quality of concrete and its porosity mainly in the cover area. Dense concrete well produced and placed without segregation and proper compaction will offer good protection to steel embedded in it. It is also essential to produce concrete using low water cement ratio so that it has minimum unblocked capillary pores. Concrete of higher strength have lower water to cement ratio and hence they are preferred.

6.2 Process of Carbonation

Concrete carbonation has been on the increase these days on account of increase in levels of environmental pollutants specially in urban areas and industrial townships. As hydrated calcium silicates and aluminates are less stable than calcium carbonate, concrete carbonation cannot be avoided. The carbon dioxide in the atmosphere in presence of water reacts with the concrete surface and concrete gets carbonated or

in other words turns acidic. This chemical reaction starts at the surface and gradually goes within the concrete mass and is generally measured as depth of carbonation.

6.3 Advantages and Disadvantages of Carbonation

Carbonation of concrete improve several characteristics of ordinary concrete but can also catastrophically affect the durability of reinforced concrete. If the concrete is dense and well compacted carbonation reduces the total porosity, specific surface of cement pastes as well as water permeability which in turn increases resistance to sulphate and aggressive ion penetration. In reinforced concrete these beneficial effects are associated with large decrease in alkalinity or drop in pH value.

The alkalinity of concrete on carbonation, loses the pH value from around 13.5 to 8.3. Therefore steel is no longer passivated by the alkaline concrete around it. Oxidation of reinforcement steel therefore takes places in presence of moisture and oxygen and rusting occurs. The rust increases the volume of steel and ultimately results in cracking and spalling of concrete.

6.4 Rate of Carbonation

The rate of carbonation depends on various factors which can be sub divided into three groups.

- ☐ Concrete Quality.
- ☐ Environmental Conditions.
- ☐ Type of cement used.

The influence of first two groups is very clearly understood. The concrete at the surface should be very dense, well compacted and well cured.

Studies have indicated that carbonation depths are much less in high strength concrete than in low strength concrete, all other parameters remaining the same. Table No. 6 below gives the carbonation depths for various concrete grades based on some accelerated studies.

Table No. 6

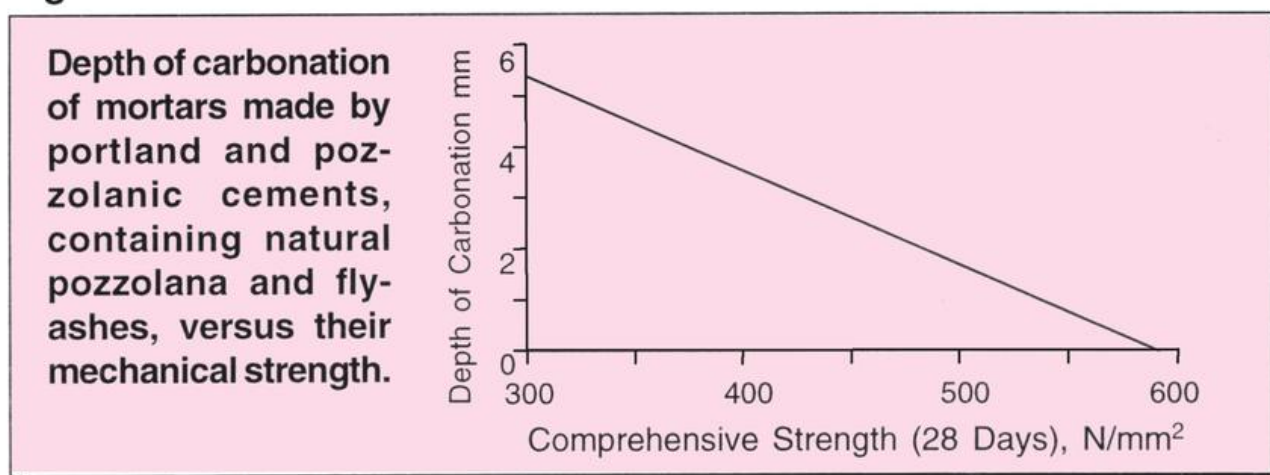
Estimated 20 years Carbonation depths for different grades of concrete		
Sr. No.	Estimated 20 yrs. depth (mm)	28 days compressive strength (N/m ²)
1.	6 mm	58.00
2.	14 mm	41.50
3.	22 mm	31.50
4.	33 mm	21.00

The above studies clearly indicate that if low strength reinforced concretes such N 15 and N 20 are used then the carbonation depths will be very high resulting in carbonation of concrete and loss of passivation offered by concrete to steel embedded in it.

It is also established that where there is excessive pollution and presence of carbon dioxide, the concrete carbonates very fast and to a greater depth.

The influence of cement type is still not unanimously acknowledged. Works carried out some years ago have shown OPC pastes to be more suitable than blended cements pastes to oppose carbonation on account of their higher calcium hydroxide content.

However, on plotting 365 days carbonation depth values versus 28 days compressive strength as shown in Figure 10 below it is clearly seen that carbonation decreases as strength of concrete increases. This is quite logical as strength and resistance to fluid penetration both are dependent on concrete porosity. It can therefore be said that concrete strengths being equal, carbonation depth remains the same, either with OPC or blended cement.

Figure No. 10

7.0 SULPHATES

Sulphates are generally found in ground water and subsoil. Sea water also contains large quantity of sulphates. Sulphates can be naturally occurring or could be as a consequence of industrial waste.

7.1 Factors Causing Deterioration

Calcium, sodium, magnesium and ammonium sulphates (in increasing order of hazard) are harmful to concrete as they can lead to concrete swelling and consequent cracking. The degree of deterioration will depend upon the following:

- ☐ Concentration and type of sulphates present in the environment
- ☐ Characteristics of concrete.
- ☐ Type of cement used.

Calcium sulphate reacts with calcium aluminate in cement hydrates forming an expansive ettringite. Sodium sulphate reacts with calcium hydroxide and forms expansive gypsum in presence of aluminates and may in turn lead to the formation of ettringite. Magnesium sulphates react with cement compounds thus decomposing cement itself and subsequently producing gypsum and ettringite.

7.2 Selection of Cement

For minimising the danger of sulphate attack low C_3A content cements are recommended. Sulphate resistant cement with very low C_3A content is most suitable. However if chlorides are also present in the ground water and sub-soil in addition to sulphates then it is not recommended for use in view of the vulnerability of low C_3A cement pastes to chloride ion diffusion. Blended cements are most preferred when both sulphates and chlorides are together present in the environment.

Blended cements have low C_3A content and also enable production of pastes containing small amount of calcium hydroxide. The pozzolana cements have also shown great sulphate resistance which is probably due to the composition and the structure of the pores in hydrated pastes.

7.3 Recommendations

Classification and composition of various types of cement in different environmental conditions is given in Table No. 7a below.

Table No. 7a : Sulphate resistant cements - Classification and composition

TYPE OF CEMENT	CHEMICAL RESISTANCE TO SULPHATES		
	Moderate	High	Very High
Ordinary Portland	$C_3A < 8\%$	$C_3A < 5\%$ $2C_3A + C_4AF < 25\%$ or $C_4AF + C_2F < 25\%$	$C_3A = 0\%$ $C_4AF < 20\%$ or $C_4AF + C_2F < 20\%$
Pozzolana	No special prescription	$C_3A < 6\%$	$C_3A < 3.5\%$
Slag	Slag $> 36\%$	Slag $> 70\%$	Slag $> 70\%$ and $C_3A < 2\%$

Requirements of concrete exposed to Sulphate attack are given in Table 7b below.

Table 7b : Concrete exposed to Sulphate Attack

Class	Concentration of Sulphates Expressed as SO_3			Type of Cement	Dense, fully compacted concrete made with 20mm nominal maximum size aggregate complying with IS : 383-1970	
	In Soil Total SO_3 %	SO_3 in 2:1 water : soil extract g/L	In ground water g/L		Cement content not less than kg/m ³	Free water cement ratio
1.	Less than 0.2	Less than 1.0	Less than 0.3	Ordinary Portland cement or Portland slag cement or Portland Pozzolana cement	280	0.55
2.	0.2 to 0.5	1.0 to 1.9	0.3 to 1.2	Ordinary Portland cement or Portland slag cement or Portland Pozzolana cement	330	0.50

Table 7b : Contd.

Table 7b : Concrete exposed to Sulphate Attack (Contd.)

Class	Concentration of Sulphates Expressed as SO ₃			Type of Cement	Dense, fully compacted concrete made with 20mm nominal maximum size aggregate complying with IS : 383-1970	
	In Soil Total SO ₃ %	SO ₃ in 2:1 water : soil extract g/L	In ground water g/L		Cement content not less than kg/m ³	Free water cement ratio
2. (contd.)	0.2 to 0.5	1.0 to 1.9	0.3 to 1.2	Supersulphated cement or sulphate resisting Portland cement	310	0.50
3.	0.5 to 1.0	1.9 to 3.1	1.2 to 2.5	Supersulphated cement or sulphate resisting Portland cement	330	0.50
				Portland Pozzolana cement or Portland slag cement	350	0.45
4.	1.0 to 2.0	3.1 to 5.6	2.5 to 5.0	Supersulphated sulphate resisting Portland cement	370	0.45
5.	Over 2.0	Over 5.6	Over 5.0	Supersulphated cement or sulphate resisting Portland cement	400	0.40

NOTES :

- (i) Cement contents given in above table for Ordinary Portland Cement is irrespective of grades of cement.
- (ii) Use of supersulphated cement is generally restricted where the prevailing temperature is below 40°C.
- (iii) Supersulphated cement gives an acceptable life provided that the concrete is dense and prepared with a water/cement ratio of 0.4 or less, in mineral acids, down to pH 3.5
- (iv) The cement contents given in Class 2 are the minimum recommended. For SO₃ contents near the upper limit of Class 2, cement contents above these minimum are advised.
- (v) For severe conditions such as thin sections under hydro-static pressure on one side only and sections partly immersed, considerations should be given to a further reduction of water/cement ratio.
- (vi) Portland slag cement conforming to IS:455-1989 with slag content more than 50 percent exhibits better sulphate resisting properties.
- (vii) Where chloride is also encountered alongwith sulphate in soil or ground water, ordinary portland cement with C₃A content from 5 to 8 percent shall be desirable to be used in concrete, instead of sulphate resisting cement.

8.0 CONCRETE IN MARINE ENVIRONMENT

8.1 Aggressive Attacks on Concrete:

Concrete in marine environment faces a simultaneous physical, chemical and mechanical deterioration process.

The concrete structure is generally divided in three zones when it is placed or constructed in marine environment. Each zone is subjected to different types of attack as shown below in Table No.8.

Table No. 8

Sr. No.	Zone	Type of Attack
1.	Atmosphere - The part of structure above the highest high tide level or splash zone	Chemical & Physical
2.	Tidal - The zone between the highest high tide and lowest low tide	Chemical & Physical & Mechanical
3.	Submerged - The zone always submerged in sea water	Chemical & Physical

From Table No.8, it is evident that Tidal Zone faces the most aggressive conditions (*See Figure 11*). Besides physical and chemical reactions, it also faces mechanical forces and therefore deterioration on any marine or off shore structure is generally observed to be more severe, on the



Figure 11 : Trombay jetty showing concrete deterioration in the atmosphere and tidal zone

portion which is in the tidal zone. Besides, the tidal zone faces alternate wetting and drying cycles which accelerates chemical action of salts and water on reinforcement steel and concrete around it.

8.2 Chemical Attack

Sea water has a very high salt content (around 3.5%). Amongst these salts, chloride and sulphates are most predominant and cause aggressive reactions greatly affecting durability and strength of the structure.

Sodium and Potassium chlorides are generally present in sea water in high proportions. However, they are not that dangerous so as to cause serious durability problems as compared to Magnesium chlorides and sulphates present in sea water in smaller proportions. Magnesium salts present in sea water causes most of the chemical attacks thus sea water is classified as highly aggressive. Magnesium Hydroxide is formed as a result of chemical reaction. This compound being insoluble precipitates. In dense concrete the magnesium hydroxide (brucite) tends to seal the pores and thereby reduces and prevents penetration of chlorides and sulphates into the concrete mass. It also reduces leaching.

The other aggressive action on concrete comes from carbon dioxide which is dissolved in sea water. The dissolved carbon dioxide or carbonic acid leach away the calcium from hydrated cement paste resulting in destroying the passivation action of concrete on reinforcement steel. The leaching action also causes reduction of concrete mass. The reaction between carbon dioxide (CO_2) and calcium ions occurs in the surface layer of permanently submerged areas of concrete. Calcium carbonate is formed and precipitation of this compound in the cement paste pores act as a seal thereby protecting the concrete from ingress of other harmful chemicals.

While CO_2 and Mg ions are stopped by the first layers of concrete due to precipitation, chlorides and sulphates penetrate slowly into the concrete where their concentration decreases from the surface inwards. The chemical attack will therefore greatly depend on concrete porosity and permeability to sea water and the aggressive chemicals within it.

As blended cement pastes have clearly shown their ability to block chloride ion penetration better than other types of cements they are generally preferred for improving the durability of concrete.

The reaction of CO_2 and Mg ions on concrete surface and the precipitation of Magnesium hydroxide and calcium carbonate within the pores of hydrated pastes helps in waterproofing the concrete surface and therefore the ingress of chloride and sulphate ions into the concrete mass further inside is greatly reduced. Even though appreciable amounts of aggressive chemicals are present in sea water the damage is relatively less as

compared to the damage that can be caused to the structure exposed to surface water having same concentration of sulphates and chlorides.

As Pozzolanic or slag cements have more compact pastes they hinder the sulphate penetration besides their low C_3A content and low calcium hydroxide content help in further reduction of aggressive action of sulphates on concrete.

8.3 Vulnerable Concrete in Tidal Zone

The zones in Tidal and Atmospheric locations are more vulnerable to aggressive action of sea than the zone fully submerged in water. This is on account of four main reasons given below.

- 8.3.1 The rate of corrosion of embedded steel is dependent on the availability of oxygen. Dissolved oxygen in sea water is very less and hence corrosion of the reinforcement steel seldom takes place in the totally submerged areas. In the tidal and atmospheric zones where oxygen is present in adequate quantity corrosion of steel is much faster.
- 8.3.2 In the portion of concrete structure above sea level, the sea water rises upwards by capillary action. The water evaporates leaving behind crystals of dissolved salts. With the progressive wetting and drying cycles this crystalline growth gradually increases causing tensile stresses. When these tensile stresses exceed that of concrete, disintegration of concrete surface takes place.
- 8.3.3 Due to fluctuation of sea water level, the leached salts and corroded concrete fragments gets washed away and erosion of concrete takes places resulting in loss of mass.
- 8.3.4 The mechanical impact of sea waves is active in tidal zone only. This therefore continuously increases the wear and tear of concrete in this zone.

8.4 Preventive Measures:

The following preventive measures are recommended:

- 8.4.1 Selection of cement will play a very important role in sea water environment. Slag and Pozzolonic cements must be preferred. Alternatively, mineral additives like ground granulated blast furnace slag or flyash or micro silica can be successfully used with Ordinary Portland Cement.

8.4.2 The FIP recommendations for concrete exposed to sea water are given in Table No.9.

Table No. 9

Specification	Exposure Zones		
	Submerged	Splash	Atmospheric
Max. water cement ratio	< 0.45	< 0.45	< 0.45
Min. cement content (kg / m ³)	360	400	360
Min. cover (mm).			
- reinforcing steel	50	65	65
- prestressing steel	50	90	90

8.4.3 Codal Requirements:

The following codal requirements are proposed in the IS 456 under revision.

Table No. 10(a) : Exposure classifications are defined as follows

Environmental Exposure	Exposure Classifications
* Coastal (excluding tidal and splash zone)	Severe
Permanently submerged	Severe
Exposed to sea water spray	Very Severe
Tidal zone	Extreme
* Coastal zone upto 1 km from the coastal line.	

Table No. 10(b) : Requirement for Reinforcement Concrete Exposed to Sea Water

Exposure Classification	f* N/mm ²	Cover (mm)	Cement content (mm)	W/C ratio max.
Severe	25	45	350	0.45
Very Severe	35	50	400	0.45
Extreme	40	75	400	0.40
* 28 days compressive strength measured on 150 mm cube specimens.				

9.0 ALKALI AGGREGATE REACTION

9.1 Causes

Several harmful chemical reactions between aggregates and Ordinary Portland Cements have been reported. The most common reaction is the one between certain types of silica occurring in aggregates and alkalies present in cement. The types of silica which are alkali reactive are opal, chalcedony and tridymite.

Due to this reaction a gel made up of alkaline and alkaline - earth silicate is formed. This gel has a tendency to absorb water and swell. The swelling causes internal stress and when this stress exceeds the tensile strength of the pastes cracking of concrete can occur.

This problem cannot be always solved by changing the aggregates. Therefore cement of appropriate chemical composition has to be used. It is believed that expansive reaction does not occur with Portland Cements containing Na_2O equivalent ($\text{Na}_2\text{O} + 0.658 \text{K}_2\text{O}$) not exceeding 0.6%. However, tolerable limits of alkalies per cubic meter of cement are also suggested by some specifications. Alkali content less than 1.8 kg per CuM of concrete is considered as safe limit. While concrete containing 3.8 to 4 kg per CuM of alkalies is potentially dangerous.

Using blastfurnace slag cements and Pozzolanic cements is yet another solution. However, some pozzolanas contain excessive alkalies and hence quantity and quality of blended material will also influence the alkali silica reaction.

9.2 Preventive Measures

The following measures will have to be followed for preventing the alkali silica reaction:

- ☐ Use non reactive aggregates from alternate source.
- ☐ Use low alkali cement as suggested above.
- ☐ Control total alkali content in concrete.
- ☐ Reduce cement content in concrete by using proper chemical admixtures.
- ☐ Use blended cements or use mineral additives as part replacement of cement.
- ☐ Use alkali silica reaction inhibiting salts.
- ☐ Control dampness around the structure.

10.0 CONCLUSIONS

If durable concrete structures are to be produced all controls listed in Point No.2 must be properly exercised. Certain common parameters emerge and must be noted.

- 10.1 It is very important to control the water to cement ratio while designing and producing concrete mixes. Low water to cement ratio gives low permeability of water and other aggressive chemicals. It also means high strength. This is probably the only reason why concretes in many developed countries are not considered to be of structural grade if their strengths are below N40.
- 10.2 Concrete must have good workability and cohesiveness. This reduces the chances of porosity due to entrapped air and honeycombing.
- 10.3 All steps of concrete making must be properly supervised and controlled. Each step has a significant role to play in durability and therefore cannot be ignored.
- 10.4 There are several reasons due to which concrete cracks. It is not possible to completely avoid cracking. It is difficult to cover all such reasons in this writeup. However proper design, selection of materials including the chemical admixtures, curing and protection against wind, low humidity and high ambient temperatures, is necessary to reduce cracking.
- 10.5 Services, like electrical conduits, water and drainage lines embedded within the concrete structure or tampering and modifying a concrete structure can pose a serious threat to durability and hence before taking any action durability aspects must be considered.
- 10.6 Blended cements, mineral additives and chemical additives have a significant role to play in durability and advantages in their use should be fully exploited.
- 10.7 Minimum cement content and maximum water to cement ratio will depend on the environmental conditions prevailing around the proposed structure. For details see Table Nos. 1a, 1b and 1c (As per IS:456 under revision) given in our publication on "Concrete Mix Design".

Lastly it is essential to remember that failures occur on account of just four reasons or a combination of them.

❑ Ignorance.

❑ Carelessness.

❑ Greed.

❑ Negligence

These are simple words but can have very significant meaning specially when one reads about loss of life and property due to collapses and failures of RCC structures just few years old (*See Figures 1, 4 and 12*).



Figure 12 : Those whom God love die young. "Shiv Chandan" building barely a teenager collapsed at Amboli Naka, Andheri, Mumbai on 1st September 1994.

11.0 REFERENCES

- (1) The role of the additions to cement in the Concrete Durability
- F Massazza, Reprint from Il Cemento, Volume 84, Oct-Dec 1987.
- (2) Pozzolanic Cements: An answer to Durability Problems
- Franco Massazza, Italcementi SpA, Bergamo Italy
Third NCB International Seminar on Cement and Building Materials,
New Delhi, Jan 21-25, 1991.
- (3) Developments & Applications in Concrete Construction
- C M Dordi, Gujarat Ambuja Cements Ltd., Proceeding of
XVI All India Builders' Convention at Bombay 19th to 21st January'96.
- (4) Economy & Durability with Admixtures
- Peter J Egan, International Manager - Concrete Industry, Fosroc
International Ltd.
- (5) Durable Concrete Structures
- Dr C Rajkumar, National Council for Cement & Building Materials-
Seminar on Concrete for the 21st Century Meeting the Challenges, The
Indian Scenario organised by Maharashtra India Chapter of American
Concrete Institute on 3rd May 1996.
- (6) Draft IS 456 under revision, Bureau of Indian Standards.
- (7) Durability - Critical Issues for the Future
- P. Kumar Mehta, Concrete International - July 1997.
- (8) Durability of Concrete
- C. M. Dordi, S. S. Kulkarni and M. T. Tendulkar. Proceedings of one
day seminar on Cement / Concrete and Admixtures for Sub-Structures
organised by Indian Geotechnical Society, Mumbai. Chapter on 29th
Nov. 1997.



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