UNIT 8 DURABILITY OF CONCRETE

Structure

8.1 INTRODUCTION

You have already studied about the properties of Hardened concrete, i.e. strength of concrete in previous unit. Now you will study about the durability of hardened concrete in this unit.

It is important for a construction material, specially for a versatile construction material like concrete to be durable and withstand the conditions for which it has been designed without deterioration. The durability aspect of concrete is also vital as it has indirect effect on economy, serviceability and maintenance.

The question then arises, as to what are the factors which affect durability of concrete. The main factors which stand out are the external factors or the environment and secondly internal factors or causes within the concrete. Normally, concrete fails due to a combination of these factors. The environmental factors could be quantified as physical, chemical and mechanical which could be collectively summarised as :

i) Weathering,

ii) Occurrence of extreme temperatures; fire and frost effect,

iii) Attack by natural or industrial liquids like sulphate, sea water, acids, oils and sewage,

iv) Exposure conditions,and

v) Abrasion and cavitation.

The internal factors are the,

i) Alkali- aggregate reaction (discussed under unit 2 – Aggregates),

ii) Difference in thermal properties of aggregate and cement paste, and

iii) Permeability of concrete.

The major mechanisum through which all these factors affect durability of concrete is the volume change caused in concrete. Therefore, we will also study about the **Cracks in Concrete** which are due to volume change.

We will start with **Permeability of Concrete** because it mainly determines the vulnerability of concrete to external agencies.

Objectives

At the end of this unit, you should be able to :

* describe the factors which affect durability of concrete,
* distinguish between effects of different factors,
* describe the sulphate attack and methods to control it,
* describe frost effect on fresh and hardened concrete,
* describe how durability of concrete is affected by different factors through volume change in concrete, and
* distinguish between different types of cracks and their repair.

8.2 PERMEABILITY OF CONCRETE

Permeability of concrete determines the penetration of aggressive environmental agencies and hence its vulnerability. For example, the relative ease with which concrete can become saturated with water, depending upon its permeability, decides the extent to which it will be affected by frost. Also this ingress of moisture in reinforced concrete, in presence of air results in corrosion of steel and hence cracking and spalling of concrete. It also decides the extent to which the aggressive chemicals will be able to attack it. The permeability of concrete is also of great interest and importance in relation to water tightness of liquid retaining structures, and roofs and toilets which also are in touch with moisture.

A study of permeability of concrete, necessitates our recalling the structure of hydrated cement paste which you studied in unit 1 : Cements.

You would recall that the hydrated cement paste consists of gel pores and capillary cavities. The gel has porosity of 28 %, but its pores are so small that appreciable amount of water cannot pass through them. In fact the permeability is only 1\100th of that of the paste. Therefore, you could say that gel pores do not contribute to the permeability of the concrete.

Let us now see what causes permeability in concrete. It is seen that extent of capillary cavities depends on water-cement ratio. At lower water cement ratio, the capillary cavities are less in diameter as well in extent. They get filled up within a few days by the hydration products of cement. On the other hand due to higher water-cement ratio (>0.7) unduly large cavities are formed, which gel is unable to fill and they remain empty and are responsible for the permeability of concrete. In order to understand the reduction in permeability with progress of hydration, see the Table 8.1.

Table 8.1 : Reduction in Coefficient of Permeability of Cement Paste (Water / Cement=0.7)with Progress of Hydration.

Sl. No	Age (Days)	Coefficient of Permeability (m / sec)
1)	Fresh	2×10^{-6}
2)	5	4×10^{-10}
3)	6	1×10^{-10}
4)	8	4×10^{-11}
5)	13	5×10^{-12}
6)	24	1×10^{-12}
7)	Ultimate	6×10^{-13} (Calculated)

The value of coefficient of permeability even at 8 days is 4×10^{-11}. metre/second is so small and comparable to a rock like granite that physically no water will permeate through it in a perceptible manner. But then this is contrary to what is observed in actual practice, wherein concrete exhibits much more permeability than stated above. Is it due to the aggregates ? Well in general, it is seen that the aggregates obtained from rocks like quartz, granite, sand stone etc. are as impermeable as the paste. Therefore, it is clear that the fault lies elsewhere i.e. there are other causes, which have been listed below :

a) Formation of micro-cracks due to long-term drying shrinkage.

b) Rupture of bond between interface of paste and aggregate due to differential thermal stresses.

c) Cracks developed on account of structural stresses.

d) Entrapped air due to insufficient compaction.

e) Volume change in concrete on account of various reasons.

There are several ways by which impermeability of concrete can be improved :

i) By use of pozzollonic materials, the leaking of calcium hydroxide is prevented and hence porosity is controlled.

ii) By air-entrainment upto 6%.

iii) High pressure steam cured concrete exhibits better impermeability due to coarser gel and hence lower drying shrinkage.

8.3 CHEMICAL ATTACK OF CONCRETE

In normal building construction, concrete is not exposed to any serious chemical attack. However in certain specialist situations like structures in sea, sulphate infested soils, tanneries and industries producing, handling and storing chemicals, the concrete is exposed to the chemical attack to different degrees. In order to ensure that proper concrete is prepared for such structures, it is necessary to understand the mechanism of these attacks, which we will do now.

8.3.1 Sulphate Attack

Sulphate attack on concrete takes place when the structure is in contact with soils containing alkali, magnesium and calcium sulphates which are in solution form due to ground water.

i) Mechanism

The sulphates of various bases react with cement in different ways.

a) Sodium, potassium and ammonium sulphates first react with $Ca(OH)_2$ to form gypsum which in turn reacts with hydrated calcium aluminates to form calcium - sulpho - aluminate.

This chemical reaction is as below :

$$Ca(OH)_2 + Na_2SO_4\,10\,H_2O \longrightarrow CaSO_4 . 2\,H_2O + 2\,NaOH + 8\,H_2O$$

$$3\,CaO\,Al_2O_3 . 19H_2O + 3\,(CaSO_4 . 2H_2O) + 16\,H_2O \longrightarrow 3\,CaO . 2Al_2O_3 . 3CaSO_4 . 31H_2O$$

The extent to which the first stage reaction proceeds depends on the ambient condition and concentration of sulphates. Gypsum ($CaSO_4$) also forms Calcium Sulpho aluminate directly as per the second stage of reaction.

b) Magnesium sulphate has much more active action as it reacts not only with calcium hydroxide and hydrated calcium aluminates as shown above, but also decomposes the hydrated calcium silicates completely. In reaction form this can be written as :

$$3\,CaO.2SiO_2.aq + 3\,MgSO_4.\,7\,H_2O \rightarrow CaSO_4.2H_2O + 3\,Mg(OH)_2 + 2\,SiO_2.aq$$

ii) Adverse Effects

The products of reactions, i.e. gypsum and calcium sulpho aluminates have considerably greater volume than the compounds they replace and hence the sulphate attack leads to expansion and consequent disruption of concrete. In case of Magnesium sulphate, because of very low solubility of magnesium hydroxide, the reaction proceeds to completion and hence is very severe compared to other sulphate attacks. Also the rate of sulphate attack increases with the increase in the strength of the solution. A saturated solution of magnesium sulphate can cause serious damage to concrete with higher water cement ratio, in a relatively short time; while low water cement ratio concrete can withstand this attack for 2 to 3 years. Further, the rate of attack also depends upon the rate at which the sulphate consumed in the reaction is replenished. This situation could be visualized by you, when you could imagine a structure retaining sulphate bearing water on one side. In a sea structure this could happen due to alternate wetting and drying as a result of tidal variation or spraying.

Let us now examine various methods and techniques which could help you in controlling the sulphate attack on structures, you may be planning to build in future.

iii) Methods of Controlling Sulphate Attack

a) Use of Sulphate Resisting Cement

We have discussed this in detail in Unit 1, Cements. Here the cement used possesses low C3A content, which provides the most efficient method of resisting sulphate attack. High resistance to sulphate attack has been found for portland cements containing not more than 5.5 per cent C3A.

b) Quality Concrete

It is a well known fact that a well designed, mixed, placed and compacted concrete would be dense and impermeable and would exhibit higher resistance to sulphate attack. To be dense, the concrete must have a low water/cement ratio.

c) Addition of Pozzolona

Improved resistance to sulphate attack is obtained by addition of pozzolonas to cement. This helps in removing $Ca(OH)_2$ and thus increasing imperviousness of concrete.

d) Use of Air-entrainment

Air entrainment to the extent of six per cent has beneficial effects towards sulphate resistance. This is perhaps due to resulting reduction in segregation, bleeding, improved workability and general improved impermeability of concrete.

e) High Pressure Steam Curing

This curing method improves sulphate resistance by changing C3A H6 into a less reactive phase and also by removal of calcium hydroxide through use of silica. Silica is always mixed/used when high pressure steam curing method is adopted.

Minimum cement content and maximum water cement ratio recommended are available in Table 8.2 given below for concrete exposed to sulphate attack.

Table 8.2 : Requirements for Concrete Exposed to Sulphate Attack

Class	Type of Cement	Concentration of Sulphates Expressed as SO_3			Requirements for Dense, fully Compacted Concrete made with Aggregates Complying with IS : 383 – 1970	
		In Soil	SO_3 in 2 : 1 Water Extract (g/lt)	In Ground Water	Minimum Cement Content (kg/m^3)	Max. Free Water/ Cement Ratio
1)	Ordinary Portland cement or Portland slag cement or Portland pozzolana cement.	< 0.2	—	< 30	280	0.55
2)	Ordinary Portland cement or Portland slag cement or Portland pozzolana cement.	0.2 to 0.5	—	30 to 120	330	0.50
	Supersulphate Cement.				310	
3)	Supersulphate Cement.	0.5 to 1.0	1.9 to 3.1	120 to 250	330	0.50

Note : This table applies only to concrete made with 20 mm aggregates complying with the requirements of IS : 383 – 1970. For 40 mm aggregate value may be reduced by about 15 per cent and for 12.5 mm aggregate value may be increased by about 15 per cent.

8.3.2 Sea Water Attack

Concrete is extensively used in the construction of marine structures like harbours, docks, break waters and jetties. The concrete in sea water environment may suffer :

a) Due to attack of dissolved chemicals on the product of hydration.

b) Crystallisation of salts within the concrete under conditions of alternate wetting and drying.

c) Mechanical attrition and impact by waves.

d) Corrosion of reinforcement.

These attacks render the concrete more vulnerable to other agencies of destruction.

a) You have already studied in 8.3.1 (b) the adverse effects of magnesium sulphate on concrete. This has also been assumed to be one of the primary factors responsible for chemical attack of concrete by sea water by expansion.

   However in case of sea water the deterioration has been found to be predominantly due to erosion or loss of constituents due to bleeding. Therefore summing up, one can say that sea water attack consists both of expansion due to sulphates and leaking due to chlorides.

b) You may also note that

   i) most severe attack in sea water occurs just above the level of high water,

   ii) the portion between low and high water marks is less affected, and

   iii) the area below the low water level which are continuously immersed in sea water are least affected. The most severe attack mentioned above at (i) is due to crystallisation of salts.

c) Frost action affects durability in cold climatic regions where the pore water at the spray level of concrete freezes thus causing disrupting. This freezing of water may also take place between the low and high tidal levels.

d) In shallow zones of the sea, the sea water holds certain quantity of silt and sand. These materials together with impact and mechanical force of wave action cause abrasion of concrete thus affecting durability.

e) As far as corrosion is concerned, it is predominant in concrete reinforced with reinforcement. This occurs due to percolation and attack of sea water on steel reinforcement which results in higher volume thus exerting pressure on surrounding concrete causing lack of durability.

The above mechanisms also act as pointers in formulating steps to improve durability of concrete to be used in sea water. These pointers are :

i) Use cement with low C3A content and concrete should have low water/cement ratio and richer mix.

ii) Provide adequate cover to reinforcement.

iii) Use of pozzolonic materials improves durability.

iv) Where possible, use high pressure steam cured prefabricated concrete panels.

As a guidance, the Table 8.3 which follows give the minimum cement content of concrete to ensure durability under specified conditions of exposure.

Further Table 8.4 which follows gives the lowest compressive strength recommended for various exposure conditions.

8.3.3 Oils and Acids Attack

We will study this aspect of durability for mineral organic oils, acids, vegetable and animal oils and fats, action of molasses and action of sewage on concrete.

a) Action of Mineral Oils

It is observed that mineral oils like petrol and petroleum distillates in general seriously affect the hardening process of fresh concrete but do not attack. Also lubricating oils which are entirely of mineral origin do not attack concrete. However, cresotes which contain phenols may have some adverse effects on concrete. You might have observed that at places concrete tanks have been used for storage of mineral oils. In such situation, durability is improved through improvement of imperviousness of concrete by using rich concrete and through surface treatments like application of four coats of sodiumsilicate.

Table 8.3: Minimum Cement Content Required in Cement Concrete to Ensure Durability under Specified Conditions of Exposure.

Sl. No	Exposure	Plain concrete		Reinforced concrete	
		Min. Cement Content (Kg/m^3)	Max. W/C Ratio	Min. Cement Content (Kg/m^3)	Max. W/C Ratio
1)	**Mild** - for example, completely protected against weather, or aggressive conditions, except for a brief period of exposure to normal weather conditions during construction.	220	0.7	250	0.65
2)	**Moderate** - for example, sheltered from heavy and wind driven rain and against frezzing, whilst saturated with water ; buried concrete and concrete in soil and concrete continuously under water.	250	0.6	290	0.55
3)	**Severe** - for example, exposed to sea water, alternate wetting and drying and to freezing whilst wet, subject to heavy condensation or corrosive fumes.	310	0.5	360	0.45

Table8.4 : Lowest Characteristic Compressive Strength Recommended for Particular Conditions of Exposure and Nominal Cover to Reinforcement.

Sl. No.	Exposure	Lowest Characterstic Compressive Strength (kg/cm^2)						
		Nominal Cover ** (mm)						
		15	20	25	30	40	50	60
1)	**Mild** - for example, completely protected against weather, or aggressive conditions, except for a brief period of exposure to normal weather conditions during construction.	300	250	200	200	200	200	200
2)	**Moderate** - for example, sheltered from severe rain and against frezzing while saturated with water. Buried concrete continuously under water.	NA	500	400	30	250	250	250
3)	**Severe** - for example, exposed to driving rain, alternate wetting and drying to freezing while wet. Subject to heavy condensation or corrosive fumes.	NA	NA	500	40	300	250	250
4)	**Very severe** - exposed to sea water or moorland water and with abrasion. Subject to salt used for de-icing.	NA NA	NA NA	NA 500	NA 500	NA 400*	500 300*	400 300*

NA indicates that the combination of strength and cover is not advised.

* only applicable if the concrete has entrained air.

** These values should be increased by 10 mm whenever the table is applied to light weight concrete, except for internal noncorrosive conditions.

b) Action of Organic Acids

The action of organic acids on concrete is corrosive. While Formic Acid is more corrosive, the tannic acid and phenols are only mildly corrosive. Further Oleic and Stearic acids, though insoluble in water, have some corrosive action on concrete. In case of acetic acid, lacticacid and butyric acid, the severity of attach depends upon their concentration and temperature.

c) **Action of Vegetable and Animal Oils and Fats**

Most of the vegetable oils cause slow deterioration of concrete due to presence of small amounts of fatty essence. Rancid animal oils containing considerable acid content, produce corrosive action which is also true in case of some fish oils. Also, laboratory observations indicate that cotton-seed oils rapidly attack portland cement concrete.

d) **Action of Molasses**

Concrete tanks have been used satisfactorily for storage of molasses, thus indicating that action of their sugar content is not of much consequence, though it causes gradual corrosion. All that you have to ensure is that the concrete is well cured at least for 28days and that additional imperviousness is imparted to the inner surface of concrete tank by treating it with tar or asphalt or sodium silicate.

e) **Action of Sewage**

It has been seen that if the sewage contains more than 150 ppm of soluble sulphate salts, sulphate attack may occur. But, domestic sewage rarely contains this amount of sulphate salts and hence is not detrimental. However, hydrogen sulphide gas emanating from sludge digestion tank can promote the formation of sulphuric acid which can attack the concrete surface above the liquid level. Concrete sewers running full are not attacked. Certain industrial wastes containing higher concentration of sulphates are injurious to durability of concrete.

You may ensure that concrete pipes used for sewage are made from well compacted rich concrete of, low water cement ratio. The formation of sulphuric acid can be avoided by ensuring sufficient quantity of flow, proper ventilation of sewers and by avoiding stagnation of sewage.

SAQ 1

a) What is the effect of permeability on durability of concrete ?

b) How can you improve durability of concrete in sea water ?

c) How does sewage affect concrete durability ?

d) What is the minimum cement content specified for Reinforced Concrete in mild exposure conditions ?

e) How does addition of pozzollona help in improving resistance of sulphate attack ?

8.4 THERMAL PROPERTIES OF CONCRETE

Concrete is used extensively in situations where temperatures are either very high or low. Some of these are firepit, chimney, chemical factory, nuclear reactor, constructions in hot regions and cold storages. The study of thermal behaviour of concrete in these situations gives us a good understanding of durability of concrete. This is now discussed.

8.4.1 Thermal Conductivity of Concrete

You must be aware that the ability of the concrete to conduct heat is indicated by its thermal conductivity and is measured in joules per second per square metre of area of concrete when the temperature difference is 1°C per metre thickness of concrete. The thermal conductivity depends upon the composition of concrete with respect to

i) Type of aggregate,

ii) Amount of aggregate, and

iii) Moisture content.

The effect of type of aggregate on thermal conductivity can be best judged from the Table 8.5.

Table 8.5 : Values of Conductivity Recommended by London And Stacey

Sl. No.	Unit Weight kg/m³	Conductivity, Jm/m² s° C							
		For Concrete Protected from Weather				For Concrete Exposed To Weather			
		Aerated concrete	Light Weight concrete with Foamed Slag	Light Weight Concrete With Expanded Clay Or Slintered Fly Ash	Normal Weight Aggregate Concrete	Aerated Con-crete	Light Weight Concrete With Foamed Slag	Light Weight Concrete With Expanded Clay Or Slintered Fly Ash	Normal Weight Aggre-gate Concrete
1)	320	0.109	0.087	0.130		0.123	0.100	0.145	
2)	480	0.145	0.116	0.173		0.166	0.130	0.187	
3)	640	0.203	0.159	0.230		0.223	0.173	0.260	
4)	800	0.260	0.203	0.303		0.273	0.230	0.332	
5)	960	0.315	0.260	0.376		0.360	0.289	0.433	
6)	1120	0.389	0.315	0.462		0.433	0.360	0.519	
7)	1280	0.476	0.389	0.562		0.533	0.433	0.635	
8)	1440		0.462	0.678					
9)	1600		0.549	0.794	0.706				0.808
10)	1760		0.649	0.952	0.838				0.952
11)	1920				1.056				1.194
12)	2080				1.315				1.488
13)	2240				1.696				1.904
14)	2400				2.267				2.561

You must have observed from this table that the thermal conductivity variation with density in case of normal weight concrete is not appreciable, while it varies considerably in case of light weight concretes because of appreciable quantity of air contained in them.

Generally, we can note that basalts have low conductivity, dolomite and lime stone have average conductivity and quartzs possess high conductivity.

However, moisture content of concrete is an important factor and conductivity increases with increase in moisture content.

We now discuss coefficient of thermal expansion which affects the stability and durability with variation in temperature.

8.4.2 Coefficient of Thermal Expansion

You are already aware from the Unit on Aggregate that too much of thermal incompatibility between the aggregate and paste (the two important phases of concrete) causes differential expansion and contraction resulting in disruption of interface bond in these two phases. Hence, it affects the durability of concrete. The Table 8.6 gives the coefficient of thermal expansion of concrete at high tempearatures.

Table 8.6 : Coefficient of Thermal Expansion of Concrete at High Temperatures.

Sl. No.	Curing	Water/ Cement Ratio	Cement Content (kg/m^3)	Aggregate	Linear Coefficient of Thermal Expansion at the Age of			
					28 days		90 days	
					Below 260° C 10-6/ °C	Above 430° C 10-6/ °C	Below 260° C 10-6/ °C	Above 430° C 10-6/° C
		0.4	435		7.6	20.3	6.5	11.2
1)	Moist	0.6	310	Calcareous	12.8	20.5	8.4	22.5
		0.8	245	gravel	11.0	21.1	16.7	32.8
2)	Air	0.4	435		7.7	18.9	12.2	20.7
3)	50 per cent	0.6	310	Calcareous	7.7	21.1	8.8	20.2
4)	relative humidity	0.8	245	Gravel	9.6	20.7	11.7	21.6
5)	Moist air	0.68	355	Expanded	6.1	7.5	–	–
		0.68	355	Shale	4.7	9.7	5.0	8.8

It can be observed that the coefficient increases with increase in water/cement ratio and varies with type of aggregate used.

8.4.3 Fire Resistance of Concretes

Fire resistance of concrete structures is primarily dependent on three factors :

i) Capacity of concrete to withstand heat,

ii) Conductvity of concrete, and

iii) Coefficient of thermal expansion of concrete.

In the case of reinforced concrete, the type of concrete and cover to reinforcement play a major role. The high temperarature gradient causes differential expansion and separation between surface and interior. Heating of reinforcement and consequent expansion causes loss of bond and loss of strength of reinforcement.

The best fire resistant aggregates are basalts, dolerites, dense limestone, blast furnace slag aggregate and even broken brick aggregate.

Concrete does not show appreciable loss of strength upto a temperature of 300° C, but the loss of strength may be 50 per cent or more at about 500°C .

While we have studied the effects of high temperatures, let us now examine the behaviour and effect on durability of concrete due to Freezing and Thawing.

8.5 RESISTANCE OF CONCRETE TO FREEZING AND THAWING

In India, certain regions experience sub zero temperatures in winter. Concrete structures in such regions undergo cycles of freezing and thawing and their durability is affected due to frost action. Let us first examine the effect on fresh concrete.

8.5.1 Frost Effect on Fresh Concrete

Fresh concrete contains considerable quantity of fresh water which gets converted into ice lenses at freezing temperatures. The ice lense formation in fresh concrete results in about 9% increase in volume and causes permanent damage to concrete and the structural integrity cannot be recovered even if the concrete is made to harden later at higher temperatures. Even during hardening, the concrete should be protected from extremely low temperatures. Therefore, you may make a note that while concreting in cold weather, ensure that the temperature of fresh concrete is maintained above 0°C.

8.5.2 Frost Effect on Fully Hardened Concrete

The concrete is vulnerable to frost damage even when it is fully hardened. It has been estimated that freezing of water in hardened concrete could exert pressures of about 140 Kg per sq cm and if strength of concrete is less than this it could get damaged severely. The damage increases due to alternate cycles of freezing and thawing. Further, the damage multiplies when more than one face of the concrete structure is exposed to frost and it remains wet for a long time. Some examples could be, roof parapets, road kerbs, isolated columns, and concrete members in hydraulic structures just above water level.

8.5.3 Explanation for Frost Damage

There are several theories to explain frost damage.

a) One theory attributes the damage to non-accommodation/insufficient accommodation of increase in volume caused due to freezing of free water held in concrete, because of less empty space available.

b) Another theory links the failure to the production of pressure due to the growth of ice lenses parallel to the surface of the concrete owing to the migration of water from capillaries where the freezing point is depressed.

c) The next theory explains the failure to generation of water pressure within the capillary cavities with the growth of ice crystals. This hydraulic pressure can only be relieved by flow of water in other spaces as the ice formed on the surface seals the exterior. This local pressure causes damage to concrete when it exceeds the tensile strength of concrete. In general, we can state that the resistance of concrete to frost action depends upon :

   i) Strength of the paste,
   ii) Water/cement ratio (see Figure 8.1),
   iii) Type of aggregate used,
   iv) Age of concrete,
   v) Duration and extent to which the concrete is subjected to freezing action, and
   vi) Degree of saturation of concrete.

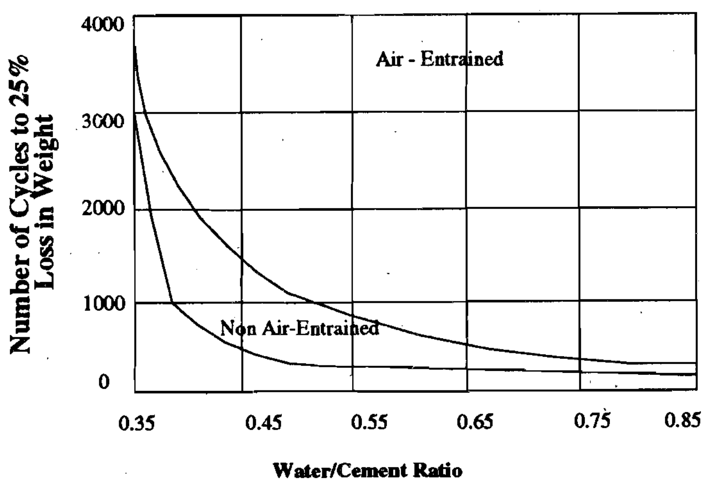


Fig. 8.1 : Influence of Water/cement Ratio on The Frost Resistance of Concrete Moist-cured For 28 Days.

8.5.4 Air Entrained Concrete

In ordinary concrete, there may exist big voids interconnected by capillaries which may be formed by bleeding. However, in air entrained concrete, though the total air voids are more, the voids are in the form of minute, discrete bubbles of comparatively uniform size and regular spherical shape. This air void system reduces the tendency of formation of large crystals of ice in the concrete. Also the interconnected air void system acts as buffer space to relieve the internal pressure.

8.5.5 Assessment of Frost Damage

There are several methods to assess frost damage. One method assesses it through loss of weight of a concrete sample subjected to a certain number of cycles of freezing and thawing. Another method assesses it through change in the dynamic modulus of elasticity. Blanks uses durability factor for this purpose and defines it as **Number of cycles** of freezing and thawing to produce failure divided by one hundred. However, A.S.T.M. calculates durability factor by continuing freezing and thawing for 300 cycles or until the dynamic modulus of elasticity is reduced to 60% of its original value, whichever occurs first.

$$\text{Durability factor} = \frac{\text{Number of cycles at end of the test} \times \text{\% of original modulus of elastisity}}{300}$$

SAQ 2

a) What is the mechanism of sulphate attack ?

b) What steps would you take as site engineer to combat sulphate attack ?

c) How does the frost effect on fresh concrete differ from that on hardened concrete ?

d) Describe any one theory to illustrate the mechanism of frost damage to concrete ?

8.6 RESISTANCE TO EROSION, ABRASION AND CAVITATION

We now move on to examine another aspect of durability. Let us first recapitulate the various terms. Erosion refers to the wearing action by fluids while abrasion occurs through friction. Cavitation refers to damage which occurs due to non-linear flow of water at velocities greater than 12 metres per second. You will find such action prominently in roads, pavements, industrial flow and in hydraulic structures.

The resistance to these damaging actions could be quantified as below :

a) The resistance is related to compressive strength of concrete and hence use concrete with higher compressive strength.

b) Rough and angular aggregate which possess better bond and inter locking effect resist the abrasion very well. Also these aggregates should be well embedded in the cement paste matrix.

c) To avoid cavitation, provide smooth surface free from irregularities. Use well cured, smooth finished high strength concrete. Epoxy screeding and polymer application to the surface improves resistance against cavitation.

8.7 CRACKS IN CONCRETE

Concrete is subjected to tensile stresses in structures. However the concrete cracks when these tensile stresses exceed its tensile strength. This happens often and cracks tend to become one of the inherent defects. The reasons for cracking in concrete are many and have been listed for pre-hardening and hardened stage separately in the Tables 8.7 and 8.8 respectively.

Table 8.7 : Types and Causes of Concrete Cracks in Prehardening.

Primary Classification	Secondary Classification	Cause	Example or Contributing Conditions	Remedy
Constructional Movements	Subgrade	Settlement of subgrade	Moisture changes in Subgrade or lack of compaction of subgrade	Control of subgrading
	Formwork	Movement of formwork	Swelling of wood or pressure of wet concrete	Construction of adequate forms
Settlement Shrinkage	Reinforcement or formwork obstructions	Settlement of concrete during setting	Settlement around obstructions, mix too fluid	Dense mixes with low water content and adequate compaction of low lifts
Setting Shrinkage	Plastic shrinkage	Chemical reactions	Cracks occur soon after placing and under moist conditions	Remedy not clear but refloating eliminates cracks
	Drying shrinkage	Rapid drying while setting occurs	Cracking of exposed surfaces due to high wind low humidity or temperature differential	Proper protection

Table 8.8 : Types and Causes of Concrete Cracks after Hardening.

Primary Classification	Secondary Classification	Cause	Example or Contributing Conditions	Remedy
Drying shrinkage		Loss of water	Cracking of building slabs and walls	Dense mixes with low cement and water
Chemical action	Concrete	Expansion of internal mass resulting in cracking of external skin	Relative aggregates	Low alkali cement and nonreactive aggregates
	Steel		Corrosion of reinforcement	Thick and dense layer of protective concrete
Temperature	Internal	Differential expansions and contractions	Heat of hydration of cement : aggregates of normal thermal expansion	Low heat cement and control of temperature rise : aggregates of normal thermal expansion
	External	Climatic changes	Large slabs or walls without adequate joints	Adequate expansion contraction joints
		Frost and ice action	Spalling of surface	Air entrain- ment and sound effects
Structural failure		Excessive Tensile stresses due to loads	Building settlement, excessive loads, vibration, earthquakes, and insufficient reinforcement	Correct design or structure

However, these defects could be overcome by following certain good rules listed below for your ready reference :

a) Strength

Use high strength concrete with low water/cement ratio, using good clean fine and coarse aggregates with correct proportioning. Ensure that fresh concrete is not subjected to drying by hot sun or dry wind which can cause plastic shrinkage cracks. Ensure that the formwork is sound and rigid and there is no sagging or bulging. Take care against sulphate attack, alkali-aggregate reaction and action of frost as discussed earlier.

b) Joints

The location of construction, expansion and construction joints should be well thought out to reduce cracks. Minimise construction joints, while expansion and contraction joints should be provided at suitable intervals considering factors like thickness, temperature variation, coefficient of thermal expansion etc.

c) Mass Concrete

Heat of hydration in mass concrete causes expansion and shrinkage resulting in development of tensile stresses in the interior of mass concrete. So proper care like use of low heat cement should be resorted to. In an extreme case you have to resort to precooling, post cooling, insulating the exposed surfaces during cold weather and designing to minimise strains around galleries and other openings.

d) Drying Shrinkage

Concrete undergoes drying shrinkage whenever its surfaces are exposed to low humidity air. The most effective way to reduce cracking in this regard is to reduce water content, use adequate and properly positioned reinforcement and by use of control joints.

While lower water content is possible with efficient vibration, the properly positioned reinforcement through bond stresses distributes the cracks tnus reducing their size.

e) Control Joints

The use of control joints or dummy joints is one of the effective methods to prevent formation of unsightly cracking. Large areas of walls, slabs and pavements, if not provided with dummy joints, would do so by developing cracks at random in order to accommodate the shrinkage. However by providing dummy joints at locations of your choice, you are able to guide the crack development at predetermined locations.

f) Permissible Cracks Widths, Reinforced Concrete

The Table 8.9 is based on recommendations of American Concrete Institute Committee 224 and gives a general guidance for tolerable crack widths at the tensile face of reinforced concrete structures.

Table 8.9 : Permissible Crack Widths, Reinforced Concrete

Sl.No	Exposure Conditions	Maximum Allowable Crack Width (mm)
1)	Dry or protective membrane	0.03
2)	Humidity, Moist air, Soil	0.30
3)	De-icing chemicals	0.18
4)	Seawater and Seawater spary; wetting and drying	0.15
5)	Water retaining structures	0.09

8.8 HOW TO REPAIR CRACKS IN CONCRETE

At the outset, let us bear in mind that all possible precautions should be taken during concreting itself to achieve quality concrete. The **repair** situation should arise only as a special case and should not become a routine matter.

Some details about crack repairs are described below :

i) To begin with, the crack is cut into V shaped groove and all loose material is removed. The groove is then watered and kept wet for sometime. When this water has dried and the concrete is still in moist condition, a thin cement slurry is poured or brushed into the groove followed by mortar of 1:3 or 1:4 composition. After proper mortar filling, the location is covered with wet hessian cloth for about 24 hours. After this water curing is done. To obtain better results shrinkage grout or expensive cement may be used. Several chemical bonding agents are also available which provide strong bond between old and new concrete. These have been described in Unit 02 in **Engineering Materials**.

ii) In case cracks are too fine, then you may fill them up with pure epoxy compound. Also epoxy mixed with clean sand has been found to be very successful in sealing both major and minor cracks. But if the cracks are deep, then you may have to do grouting with cement slurry, cement mortar or epoxy under pressure so as to reach all the nooks and corners of the crevices.

The durability of the concrete can also be increased particularly on the surface by applications of different materials which make it water-proof hardened and resistant to chemical attack. We will persue these now.

8.9 SURFACE TREATMENT TO CONCRETE

Some of the commonly used surface treatments are :

i) Sodium silicate, magnesium or zinc flouride

ii) Drying oils like Tung or Linseed oil

iii) Chlorinated rubber paints and neoprene paints

iv) Epoxy paints

v) Silican Fluoride treatment

vi) Polymer impregnation

The surface of the hardened and dry concrete can be made abrasion resistant and less dust generating by application of solutions of sodium silicate, magnesium or zinc sulphates or silico fluorides. Drying oil like tung oil or linseed oil can be used. Alternatively, carborundum or fused alumina or finely divided iron aluminium chloride preparations may be added in the surface layer while placing the fresh concrete.

Floor paints also provide reasonable durability if the traffic on floor is not heavy. Paints containing synthetic resins particularly polyurethanes or epoxies or chlorinated rubber provide greater resistance to wear. They also protect against solutions of salts and dilute acids.

Sodium silicate and silico fluoride applications provide protection against mild conditions of attack by aqueous solutions or organic liquids. Bitumen and coal tar gives protection against insects and borers. Some plastic materials, rubber latex glass fibre coatings and PVC linings have also been successfully employed to improve durability of concrete.

Ocrate Process is another important surface treatment in which the concrete member is impregnated with **silico fluoride** under pressure. This process is very useful in improving durability of precast concrete pipes for sewage disposal and piles for foundation.

Another modern method of improving durability is the polymer impregnation of concrete. Here precast conventional concrete is used and dried in oven or by dielectric heating. The air in open cells is removed by vacuum. Then a low viscosity monomer is diffused into the open cells and polymerised by using radiation, application of heat or by chemical initiation. It has been observed that this process results in highly improved freeze-thaw resistance, resistance to sulphate attack, acids, abrasion and wear and skid.

8.10 CARBONATION

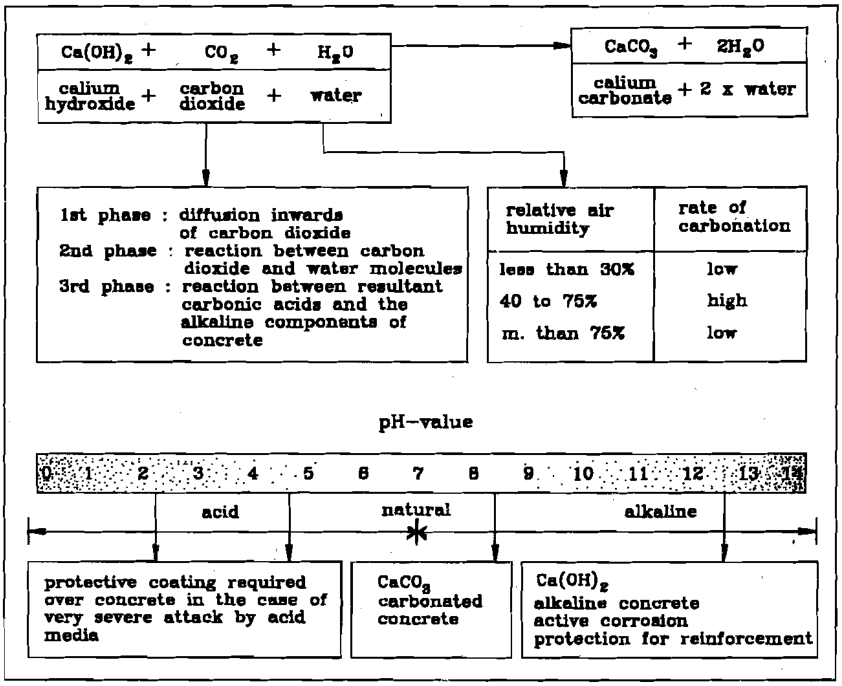
It has been established that the increasing environmental stress is one of the essential factor which cause concrete damage. The cause of this kind of damage is explained in more detail below.

It is recognised that steel embedded in a heavily alkaline medium with pH-values from 9 upwards will not rust. During the setting of concrete, cement begins to hydrate, this chemical reaction between cement and water in the concrete causes calcium-hydroxide to be formed from the cement clinker. This ensures the concrete's alkalinity, producing a pH-value of more than 12.6 which renders the steel surface passive.

Protection of the reinforcement from corrosion is thus provided by the alkalinity of the concrete, which leads to a passivation of the steel. The reserve of calcium-hydroxide is very high, so there is no need to expect steel corrosion even when water penetrates to the reinforcement of the concrete. Because of this, even the occurrence of small cracks (up to 0.1mm in width) or blemishes in the concrete need not necessarily lead to damage.

Environmental influences and carbon dioxide in particular, will reduce the concrete's pH-value (carbonation) and thus remove the passivating effect, in conjunction with existing humidity, the result is corrosion of the reinforcement.

The carbonation of concrete :



SAQ 3

a) What steps would you take to minimise cracks in concrete ?

b) What are the permissible crack widths for reinforced concrete ?

c) What procedure would you follow to repair cracks in concrete ?

d) How can you improve resistance of concrete against cavitation ?

(Note : Check your answers with the information given in the preceding text.)

8.11 SUMMARY

The durability of concrete refers to its ability to withstand both external factors like weathering, extreme temperatures, attack by natural or industrial liquids, abrasion and cavitation and internal factors like alkali-aggregate reaction, thermal properties of constituents of concrete and permeability of concrete.

We have learnt that the permeability of concrete plays an important role in determining the durability as it determines the degree of penetration of aggressive environmental agencies and hence the vulnerability of concrete . This is particularly true in regard to attack of chemicals like sulphates, oils and acids, sewage and molasses and seawater. The abrasion, erosion and cavitation mainly affect the surface layers of concrete and it is seen that high compressive strength, well cured smooth finished concrete coupled with selective surface treatments impart sufficient durability to combat these agencies.

You have also studied that temperatures whether extremely high or low, both are detrimental to concrete durability. It is seen that concrete does not show appreciable loss of strength upto temperatures of 300 degree C, but the loss may be 50 per cent or more at about 500 degree C. The effect of frost damage is related to cycles of freeze and thaw and the damage depends upon whether it is fresh or hardened concrete. Air entrained concrete is a very practical solution in these situations.

Cracks are inherent in concrete and the reason for cracking are different for prehardening and hardened stages of concrete. But then you have seen that the solution to avoid then lies very much with the site engineer in the form of production of quality concrete with due regard to its placement, joints, drying, shrinkage etc. Repair of these cracks when required, as you must have appreciated, can be done by filling or grouting with cement based or chemical based bonding agents. And lastly, we examined as to how surface treatments can improve durability of concrete.

8.12 KEY WORDS

Abrasion : Wearing action by friction.

Erosion : Wearing action by fluids.

Durability : Ability to resist certain external and internal agents.

8.14 ANSWERS TO SAQs

Check your Answers of all SAQs with preceeding text.