Unit 3

Module 2

Elasticity of concrete:

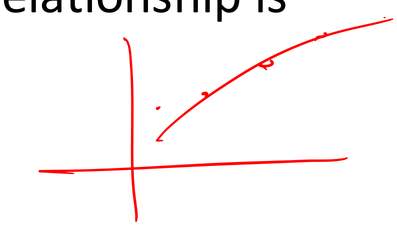
Grade ⇒ mix

1 : 1½ : 3

1 : 2 : 3

- Deformation of concrete depends upon the magnitude of the load, the rate at which the load is applied and the elapsed time after which the observation is made.
- In other words, the rheological behavior of concrete i.e., the response of concrete to applied load is quite complex
- The knowledge of rheological properties of concrete is necessary to calculate deflection of structures, and design of concrete members with respect to their section, quantity of steel and stress analysis.
- The modulus of elasticity is determined by subjecting a cube or cylinder specimen to uniaxial compression and measuring the deformations by means of dial gauges fixed between certain gauge length.
- Dial gauge reading divided by gauge length will give the strain and load applied divided by area of cross-section will give the stress.
- A series of readings are taken and the stress strain relationship is established.

(modulus of elasticity = unit stress / unit strain)

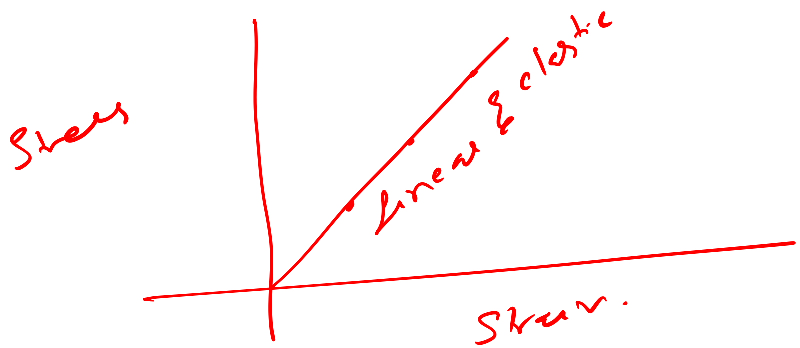


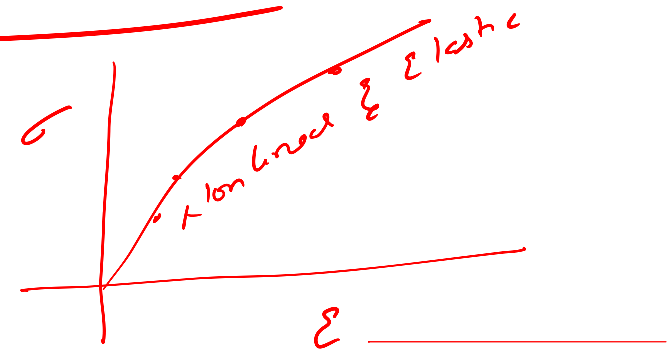
Modulus of Elasticity :- ~~of~~ of Concrete.

It is the measurement of the Stiffness of the Concrete which is a good indicator of Strength.

At a higher value of modulus of Elasticity, the Concrete can withstand higher stress ~~and become brittle~~.

In general Concrete has an Elastic modulus in a range of 30 to 50 GPa.





- The knowledge of rheological properties of concrete is necessary to calculate deflection of structures, and design of concrete members withrespect to their section, quantity of steel and stressanalysis. When reinforced concrete is designed byelastic theory it is assumed that a perfect bond existsbetween concrete and steel. The stress in steel is “m”times the stress in concrete where “m” is the ratiobetween modulus of elasticity of steeland concrete, known as modularratio.
- The accuracy of design will naturally be dependent upon the value of the modulus of elasticity of concrete, because the modulus of elasticity of steel is more or less a definite quantity.

$$\frac{E_s}{E_c}$$

- The modulus of elasticity is determined by subjecting a cube or cylinder specimen to uniaxialcompression and measuring thedeformations by means of dial gauges fixed between certain gauge length.
- Dial gauge reading divided by gauge length will give the strain and load applied divided by area of cross section will give the stress. A series of readings are taken and the stress-strain relationship is established.

- The modulus of elasticity can also be determined by subjecting concrete beam to bending and then using the formulae for deflection and substituting other parameters. The modulus of elasticity so found out from actual loading is called static modulus of elasticity. It is seen that even undershorts term loading concrete does not behave as an elastic material.
- However, up to about 10-15% of the ultimate strength of concrete, the stress-strain graph is not very much curved and hence can give more accurate value. of modulus of Elasticity
- For higher stresses the stress-strain relationship will be greatly curved and as such it will be inaccurate. Figure 8.1 shows stress strain relationship for various concrete mixes.

strain

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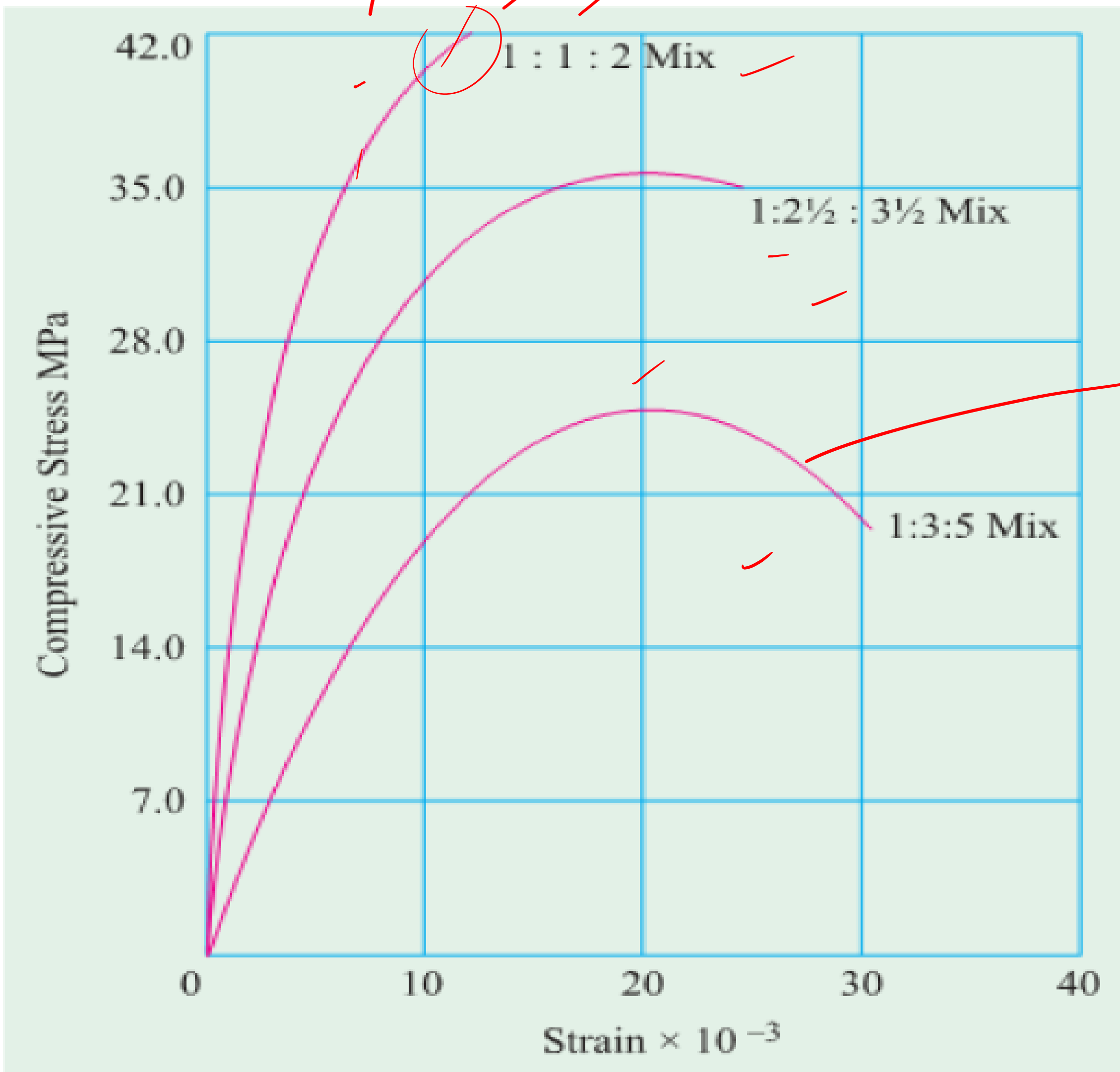


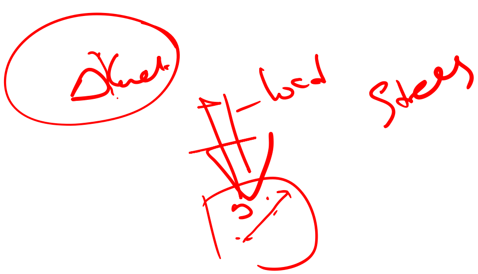
42.0
35.0
28.0
21.0
14.0
7.0
Compressive Stress MPa
0
10
20
30
40
Strain × 10 −3
1 : 1 : 2 Mix
1:2½ : 3½ Mix
1:3:5 Mix

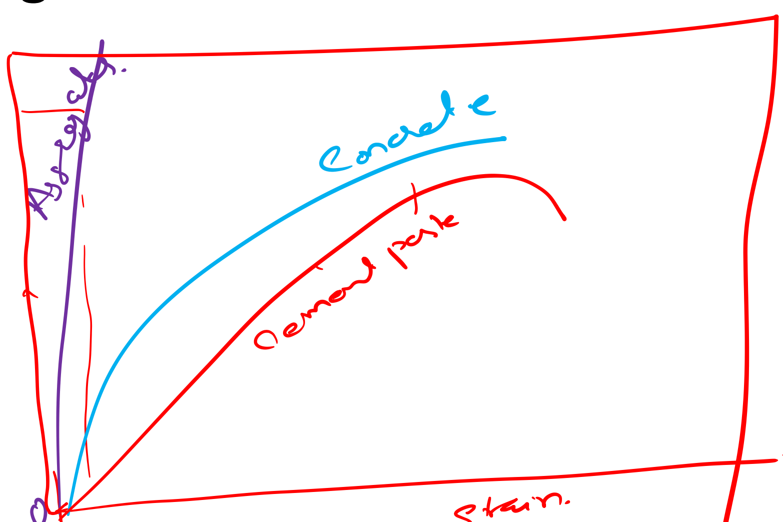
Reason's: The failure of bond @ the interface increases at a faster rate than ~~the~~ applied stress.

Relation between modulus of elasticity and strength:

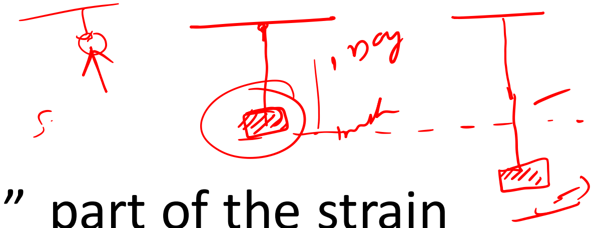
- Modulus of elasticity of concrete increases approximately with the square root of the strength. IS 456 of 2000 gives the Modulus of elasticity as $\boxed{E_C = 5000 \sqrt{f_{ck}}}$ → Compressive strength.
- where EC is the short term static modulus of elasticity in N/mm2.
- The modulus of elasticity determined by subjecting a concrete beam to bending is called static modulus of elasticity.

Concrete = Cement paste + Aggregates + water + F.A

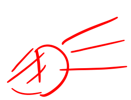




Creep:



- Creep can be defined as "the time-dependent" part of the strain resulting from stress.
- The relation between stress and strain for concrete is a function of time. The gradual increase in strain,
- without increase in stress, with the time is due to creep.
- From this explanation creep can also be defined as the increase in strain under sustained stress.
- All materials undergo creep under some conditions of loading to a greater or smaller extent.
- But concrete creeps significantly at all stresses and for a long time.
- Under sustained stress, with time, the gel formed, the adsorbed water layer, the water held in the gel pores and capillary pores yields, flows and readjust themselves, which is termed as creep in
- concrete.

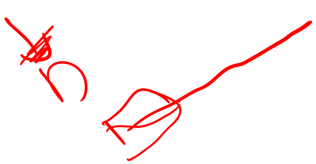


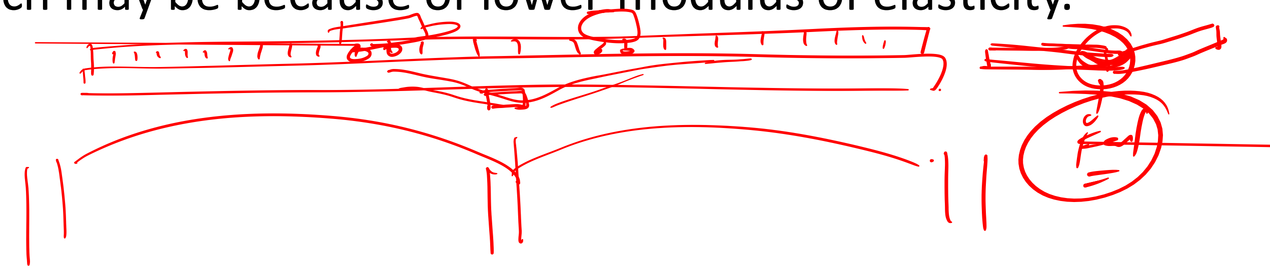

What Is Creep In Concrete ?
By : Anamika Gupta

Factors affecting creep:

(cement paste.

- **i) Influence of aggregates:**
- Aggregate undergoes very little creep. It is really the paste which is responsible for the creep.
- However, the aggregate influences the creep of concrete through a restraining effect on the magnitude of creep. The paste which is creeping under load is restrained by aggregate which do not creep.
- The stronger the aggregate the more is the restraining effect and hence the less is the magnitude of creep.
- The modulus of elasticity of aggregate is one of the important factors influencing creep. It can be easily imagined that the higher the modulus of elasticity the less is the creep.
- Light weight aggregate shows substantially higher creep than normal weight aggregate which may be because of lower modulus of elasticity.





microscopic structure of

new gel creep ↑ creep ↓

w/c ↑ stgh ↓ creep ↑

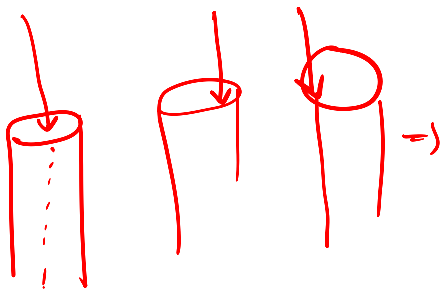
- **ii) Influence of mix proportions:-**
- The amount of paste content and its quality is one of the most important factors influencing creep.
- A poorer paste structure undergoes higher creep. Therefore, it can be said that creep increases with increase in water/cement ratio.
- In other words, it can also be said that creep is inversely proportional to the strength of concrete.

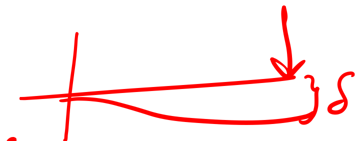
  creep $\propto \frac{1}{\text{strength}}$

- Broadly speaking, all other factors which are affecting the water/cement ratio is also affecting the creep.
- **iii) Influence of Age:-**
- *Age at which a concrete member is loaded will have a predominant effect on the magnitude of creep. This can be easily understood from the fact that the quality of gel improves with time.Such gel creeps less, whereas a young gel under load being not so stronger creeps more*

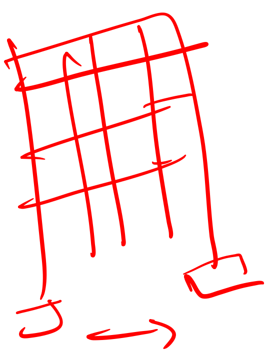
Effects of creep on Concrete and R.C.C.

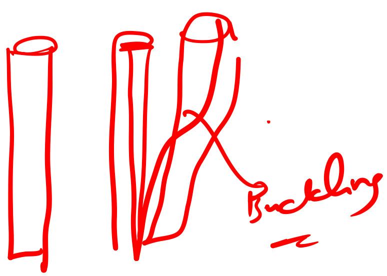
In R.C.C beams creep increases the deflection with time and may be a critical consideration in design.

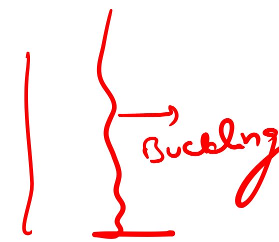




Eccentrically loaded columns creep increases the deflection

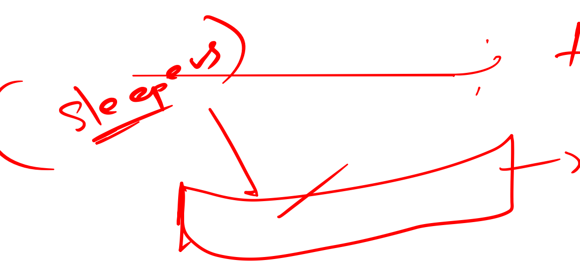






Mass Concrete Structure. → Dams

temp → Interior of Dam and Surface of Dam



→ stress induced is called prestressed

P.S.C

Shrinkage:

- Volume change is one of the most detrimental properties of concrete, which affects the long-term strength and durability.
- One of the important factors that contribute to the cracks in floors and pavements is due to
- shrinkage.
- The term shrinkage is used to describe various aspects of volume changes in concrete due to loss of moisture at different stages due to different reasons.

Types of shrinkage:

- Shrinkage is classified into the following ways:
- a) Plastic shrinkage
- b) Drying shrinkage
- c) Autogeneous shrinkage
- d) Carbonation shrinkage

a) Plastic Shrinkage:

- Shrinkage of this type occurs soon after the concrete is placed while the concrete is still in the plastic state. Loss of water by evaporation from the surface of concrete or by the absorption by aggregate or subgrade, is believed to be the reasons of plastic shrinkage.

- The loss of water results in the reduction of volume. The aggregate particles or the reinforcement comes in the way of subsidence due to which cracks may appear at the surface or internally around the aggregate or reinforcement.

- In case of floors and pavements where the surface area exposed to drying is large as compared to depth, when this large surface is exposed to hot sun and drying wind, the surface of concrete dries very fast which results in plastic shrinkage.

- Sometimes even if the concrete is not subjected to severe drying, but poorly made with a high water/cement ratio, large quantity of water bleeds and accumulates at the surface. When this water at the surface dries out, the surface concrete collapses and causing cracks

- From the above it can be inferred that high water/cement ratio, badly proportioned concrete, rapid drying, greater bleeding, unintended vibration etc., are some of the reasons for plastic shrinkage.

- Plastic shrinkage can be reduced mainly by preventing the rapid loss of water from surface.

- This can be done by covering the surface with polyethylene sheeting immediately on finishing operation; by monomolecular coatings by fog spray that keeps the surface moist; or by working at night.
- *An effective method of removing plastic shrinkage cracks is to re-vibrate the concrete in a controlled manner*.

b) Drying shrinkage:

- Just like hydration of cement, the drying shrinkage is also an everlasting process when concrete is subjected to drying conditions. Loss of water held in gel pores causes drying shrinkage.
- Under drying conditions, the gel water is lost progressively over a long time, as long as the concrete is kept in drying conditions.
- The magnitude of drying shrinkage is also a function of the fineness of gel. The finer the gel the more is the shrinkage.
- **c) <u>Autogeneous Shrinkage:</u>**
- In a conservative system i.e. where no moisture movement to or from the paste is permitted, when temperature is constant some shrinkage may occur. The shrinkage of such a conservative system is known as autogeneous shrinkage.
- Autogeneous shrinkage is of minor importance and is not applicable in practice to many situations except that of mass of concrete in the interior of a concrete dam.
- The magnitude of autogeneous shrinkage is in the order of about 100×10^{-6}.

d) Carbonation Shrinkage:

- Carbonation shrinkage is a phenomenon very recently recognized. Carbon dioxide present in the atmosphere reacts in the presence of water with hydrated cement.
- Calcium hydroxide [Ca(OH)2] gets converted to calcium carbonate and also some other cement compounds are decomposed.
- Such a complete decomposition of calcium compound in hydrated cement is chemically possible even at the low pressure of carbon dioxide in normal atmosphere.
- Carbonation penetrates beyond the exposed surface of concrete very slowly.
- *Magnitude of carbonation shrinkage is very small when compared to long term drying shrinkage and hence this aspect is not of much significance.*

Factors affecting shrinkage:

- One of the most important factors that affect shrinkage is the drying condition or in other words, the relative humidity of the atmosphere at which the concrete specimen is kept.
- If the concrete is placed in 100 per cent relative humidity for any length of time, there will not be any shrinkage, instead there will be a slight swelling
- Magnitude of shrinkage increases with time and also with the reduction of relative humidity. The rate of shrinkage decreases rapidly with time. It is observed that 14 to 34 per cent of the shrinkage occurs in 2 weeks, 40 to 80 per cent of the shrinkage occurs in 3 months and 66 to 85 per cent of the shrinkage occurs in one year

- Another important factor which influences the magnitude of shrinkage is water/cement ratio of the concrete. With increase in w/c ratio, shrinkage increases.
- Aggregate plays an important role in the shrinkage properties of concrete. The grading of aggregate by itself may not directly make any significant influence.
- But since it affects the quantum of paste and water/cement ratio, it definitely influences the drying shrinkage indirectly.
- The aggregate particles restrain the shrinkage of the paste.
- Harder aggregate with higher modulus of elasticity, like quartz, shrinks much less than softer aggregates such as sandstone.
- *By taking proper precautions the magnitude of shrinkage can only be reduced, but cannot be eliminated*

Durability:

- Concrete structures built in highly polluted urban and industrial areas, aggressive marine environment, harmful sub-soil water in coastal area and many other hostile conditions are not durable because materials used for construction are found to be non-durable in those conditions.
- Advancement in concrete technology is mostly concentrated on the strength of concrete.
- But now, it is recognized that strength of concrete alone is not sufficient, the degree of harshness of the environmental condition to which concrete is exposed over its entire life is equally important.
- *Therefore, both strength and durability are to be considered at the design stage*.
- **Durability definition:-**
- The durability of cement concrete is defined as its ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration.
- Durable concrete will retain its original form, quality, and serviceability when exposed to its environment.

Definition of Durability:

- **Significance of Durability:**
- When designing a concrete mix or designing a concrete structure, the exposure condition at which the concrete is supposed to withstand is to be assessed in the beginning with good judgment.
- In case of foundations, the soil characteristics are also required to be investigated. The environmental pollution is increasing day by day particularly in urban areas and industrial atmospheres.
- It is reported that in industrially developed countries over 40 per cent of total resources of the building industries are spent on repairs and maintenance.

Chemical Action:

- When dealing with the durability of concrete, chemical attack which results in volume change, cracking of concrete and the consequent deterioration of concrete becomes an important part of
- discussion.
- Under chemical attack, sulphate attack, alkali-aggregate reaction, acid attack and effect of sea water will be discussed.
- **Sulphate attack:**
- Most soils contain some sulphate in the form of calcium, sodium, potassium and magnesium. They occur in soil or ground water. Of all the sulphates, magnesium sulphate causes maximum damage to concrete. A characteristic whitish appearance is the indication of sulphate attack.

- The term sulphate attack denote an increase in the volume of cement paste in concrete or mortar due to the chemical action between the products of hydration of cement and solution containing sulphates.
- In the hardened concrete, calcium aluminate hydrate (C-A-H) can react with sulphate salt from outside. The product of reaction is calcium sulpho aluminate, forming within the framework of hydrated cement paste.
- Because of the increase in volume of the solid phase which can go up to 227 per cent, a gradual disintegration of concrete takes place.

- The rate of sulphate attack increases with the increase in the strength of solution.
- A saturated solution of magnesium sulphate can cause serious damage to concrete with higher water cement ratio in a short time.
- However, if the concrete is made with low water cement ratio, the concrete,can withstand the action of magnesium sulphate for 2 or 3 years.
- Concentration of sulphates is expressed as the number of parts by weight of SO_3 per million parts.
- 1000 PPM is considered moderately severe and 2000 PPM is considered very severe, especially if $MgSO_4$ is the predominant constituent

Methods of Controlling Sulphate Attack:

- (a) Use of Sulphate Resisting Cement
- (b) Use of air-entrainment
- (c) Quality Concrete
- (d) Use of pozzolana
- (e) High Pressure Steam Curing

- (a) Use of Sulphate Resisting Cement
- The most efficient method of resisting the sulphate attack is to use cement with the low C3A content. In general, it has been found that a C3A content of 7% gives a rough division between cements of good and poor performance in sulphate waters
- (b) Quality Concrete:
- A well designed, placed and compacted concrete which is dense and impermeable exhibits a higher resistance to sulphate attack.
- Similarly, a concrete with low water/cement ratio also demonstrates a higher resistance to sulphate attack

- (c) Use of air-entrainment:
- Use of air-entrainment to the extent of about 6% (six per cent) has beneficial effect on the sulphate resisting qualities of concrete. The beneficial effect is possibly due to reduction of segregation, improvement in workability, reduction in bleeding and in general better impermeability of concrete.
- (d) Use of pozzolana:
- Incorporation of or replacing a part of cement by a pozzolanic material reduces the sulphate attack. Admixing of pozzolana converts the leachable calcium hydroxide into insoluble nonleachable cementitious product.
- This pozzolanic action is responsible for impermeability of concrete. Secondly, the removal of calcium hydroxide reduces the susceptibility of concrete to attack by magnesium sulphate.

- (e) High Pressure Steam Curing:
- High pressure steam curing improves the resistance of concrete to sulphate attack. This improvement is due to the change of $C3AH6$ into a less reactive phase and also to the removal or reduction of calcium hydroxide by the reaction of silica which is invariably mixed when high pressure steam curing method is adopted.
- <u>Alkali-Aggregate Reaction:</u>
- Alkali-aggregate reaction (AAR) is basically a chemical reaction between the hydroxyl ions in the pore water within concrete and certain types of rock minerals which sometimes occur as part of aggregates.
- Since reactive silica in the aggregate is involved in this chemical reaction it is often called alkali-silica reaction (ASR).

- The reaction produces alkali-silica gel of unlimited swelling type under favorable conditions of moisture and temperature in voids and cracks and further it causes disruption and pattern cracking. The crack width can range from 0.1 mm to as much as 10 mm.
- Alkali content (Na_2O + 0.658 times K_2O content of clinker) in cement should be less than 0.6 per cent by mass of cement. Alkali content of 0.6 could be considered as a threshold point of high alkali cement.
- Alkali-silica reaction takes place only at high pH values. The pH of the pore water depends on the alkali content of cement. Heigh alkali cement may lead to a pH of about 13.5 to 13.9 and low alkali cement results in a pH of about 12.7 to 13.1. Therefore, low alkali cement which produces low pH value in the pore water is safe against potentially reactive aggregate.

Acid Attack:

- Concrete is not fully resistant to acids. Most acid solutions will slowly or rapidly disintegrate portland cement concrete depending upon the type and concentration of acid. Certain acids, such as oxalic acid and phosphoric acids are harmless.
- The most vulnerable part of the cement hydrate is Ca(OH)2, but C-S-H gel can also be attacked. Siliceous aggregates are more resistant than calcareous aggregates.
- Concrete can be attacked by liquids with pH value less than 6.5. But the attack is severe only at a pH value below 5.5. At a pH value below 4.5, the attack is very severe.
- If the attack proceeds, all the cement compounds are eventually broken down and leached away, together with any carbonate aggregate material. With the sulphuric acid attack, calcium sulphate formed can proceed to react with calcium aluminate phase in cement to form calcium sulphoaluminate, which on crystallization can cause expansion and disruption of concrete

Concrete in Sea Water:

- Large numbers of concrete structures are exposed to sea water either directly or indirectly. For several reasons, effect of sea water on concrete deserves special attention.
- The coastal and offshore structures are exposed to simultaneous action of a number of physical and chemical deterioration process.
- The concrete in sea water is subjected to chloride induced corrosion of steel, freezing and thawing, salt weathering, abrasion by sand held in water and other floating bodies.
- Sea water generally contains 3.5 per cent of salt by weight. The ionic concentration of $Na+$ and $Cl–$ are the highest, typically 11,000 and 20,000 mg/litre respectively. It also contains $Mg2+$ and $SO42–$, typically 1400 and 2700 mg/litre respectively.
- The PH of sea water varies between 7.5 and 8.4. The average value is 8.2. Sea water also contains some amount of $CO2$.

- Magnesium sulphate reacts with free calcium hydroxide in set Portland cement to form calciumsulphate, at the same time precipitating magnesium hydroxide.
- $MgSO_4$ also reacts with the hydrated calcium aluminate to form calcium sulpho aluminate. These have often been assumed to be the actions primarily responsible for the chemical attack of concrete by sea water.
- Concrete will have lost some part of lime content due to leaching. Both calcium hydroxide and calcium sulphate are considerably more soluble in sea water and this, will result in increased leaching action. Concrete undergoes several reactions concurrently when subjected to sea water.
- As concrete is not 100% impervious, water that permeates into the concrete cause corrosion of steel. The product of corrosion being of higher volume than the material they replace, exert pressure which results in lack of durability to reinforced concrete.

- It is also seen that the lack of durability is more in case of reinforced concrete than the identical plain concrete.
- Using rich concrete with low water/cement ratio mainly makes the concrete impervious to the attack of sea water, and also having very little capillary pores does not hold water, to cause expansion either by freezing or by crystallisation of salt.
- Provision of adequate cover is another desirable step for increasing durability of reinforced concrete. Use of pozzolanic material is yet another desirable step that could be taken to improve durability against sea water.

Corrosion of Steel

- It can be noted that no corrosion takes place if the concrete is dry or probably below relativemhumidity of 60 percent because enough water is not there to promote corrosion.
- It can also be noted that corrosion does not take place if concrete is fully immersed in water because diffusion of oxygen does not take place into the concrete. Probably the optimum relative humidity forcorrosion is 70 to 80 per cent.
- The products of corrosion occupy a volume as many as six times the original volume of steel depending upon the oxidation state.
- The increased volume of rust exerts thrust on cover concrete resulting in cracks, spalling or delamination of concrete. With this kind of situations concrete loses its integrity. The cross section of reinforcement progressively reduces and the structure is sure to collapse

Corrosion control:

- It has been reported that 40% of failure of structures is on account of corrosion of embeddedsteel reinforcement in concrete. Therefore corrosion control of steel reinforcement is a subject of paramount importance.
- Proper mix design, use of right quality and quantity of cement for different exposure conditions is to be adopted.
- Use of supplementary cementitious materials such as fly ash, ground granulated blast furnace slag (ggbs), silica fume etc. are required to be used as admixtures or in the form of blended cement in addition to lowest possible W/C ratio to make concrete dense.

- These materials improve more than one properties of concrete which will eventually reduce corrosion of reinforcement.
- Tests on mortar containing ggbs have shown that water permeability is reduced by a factor up to 100.
- In short it can be said that if we make good concrete with low permeability and improved
- microstructure, it will be durable by itself and also it can take care of the reinforcement contained in it to a great extent.

Table 9.16. Nominal cover to meet the Durability Requirements as per IS 456 of 2000.

Exposure	*Nominal Concrete cover in mm not less than*
Mild	20
Moderate	30
Severe	45
Very Severe	50
Extreme	75

Permeability:

- Permeability of concrete is also an important point for durability of concrete in addition to w/c ratio.
- **Permeability of cement paste:**
- The cement paste consists of C-S-H gel, Ca(OH)2 and water filled or empty capillary cavities.
- Although gel is porous to the extent of 28 per cent, the gel pores are so small that hardly any water can pass through under normal conditions.
- The permeability of gel pores is estimated to be about 7 x 10–16 m/s. That is approximately about 1/100 of that of paste.
- Therefore, the gel pores do not contribute to the permeability of cement paste.
- The extent and size of capillary cavities depend on the W/C ratio. It is one of the main factors contributing to the permeability of paste.
- At lower W/C ratio, not only the extent of capillary
- cavities is less but the diameter is also small. The capillary cavities resulting at low W/C ratio, will get filled up within a few days by the hydration products of cement.

- Only large cavities resulting from higher W/C ratio (say more than 0.7) will not get filled up by the products of hydration, and will remain as un segmented cavities, which is responsible for the permeability of paste.
- Cement paste even with high W/C ratio of 0.70 is quite impervious as that of granite with coefficient of permeability of 5.35 x 10–11 m/s.
- However in actual practice, it is noticed that mortar and concrete exhibit much high permeability.
- *Higher permeability of mortar or concrete in actual structures is due to the following reasons.*
- *(a) Formation of micro-cracks developed due to long term drying shrinkage and thermal stresses.*
- *(b) The large micro-cracks generated with time in the transition zones.*
- *(c) Cracks generated through higher structural stresses.*
- *(d) Due to volume change and cracks produced on account of various minor reasons.*
- *(e) Existence of entrapped air due to insufficient compaction*
- *Coefficient of permeability increases more than 100 times when W/C ratio increased from 0.4 to 0.7*

Permeability of Concrete:

- Theoretically, the introduction of aggregate of low permeability into cement paste, it is expected to reduce the permeability of the system because the aggregate particles intercept the channels of flows and make it take a circuitous route.
- Compared to neat cement paste, concrete with the same W/C ratio and degree of maturity, should give a lower coefficient of permeability.
- But in practice, it is seen from test data it is not the case. The introduction of aggregate, particularly larger size of aggregates increases the permeability considerably. This may be because of formation of micro cracks.
- Drying shrinkage, thermal shrinkage and externally applied load may cause cracks in weak transition zone (cavities formed around aggregates) at the young age.
- It is reported that the size of the cracks in transition zone is much bigger than most of the capillary cavities present in cement paste.
- The use of pozzolanic materials in optimum proportion reduces the permeability of concrete.