ACT Unit 4

Durability of Concrete.

Introduction, Permeability of Concrete, Chemical attack, acid attack, efflorescence, Corrosion in concrete. Thermal conductivity, Thermal diffusivity, Specific heat, Alkali Aggregate Reaction IS 456 - 2000 requirement for durability.

Introduction

It is essential that every concrete structure should continue to perform its <u>Intended function</u>

- Maintain Required Strength
- Serviceability conditions satisfied

during the specified or traditionally expected service life. Concrete must be able to withstand the process of deterioration to which it can be expected to be exposed. Such a concrete is <u>said to be</u> durable.

<u>durable</u>.

" Durability may be defined as the property required for fulfilling all the service requirements of a structure during its intended life with the expected maintenance"

<u>Maintence</u> is an integral part of serviceability & concrete structure. Even though structures are designed with over specification, it requires maintenance, as it cann't remain "New" throughout its intended life span.

Concrete if fact has the inherent ability to sustain without damage all designed loads and environmental effects provided for, but it is important to protect it against chemical or physical attack.

" 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 orginal form, quality & serviceability when exposed to its environment

" A durable concrete is one that performs satisfactorily in the working environment during its anticipated exposure conditions during service - IS 456 - 2000

" Durability of concrete is its ability to resist weathering action, chemical attack, abrasion or any other process of deterioration. (ACI)

" When exposed to environment durable concrete is likely to retain its original form, quality and serviceability during its life time."

" Durable concrete envisage limits for maximum water cement ratio, minimum cement content, cover thickness, type of cement used and presence of amount of chloride and sulphate in concrete. IS - SP - 28

" As low permeability as possible under situation : IS - SP - 23.

"Durability of concrete can be defined to mean " its resistance to deteriorating influences, which may reside inside the concrete itself, or which are present in the environment to which the concrete is exposed"

Features of Durable Concrete

1. A durable concrete is one that performs satisfactorily in the working environment during its anticipated exposure conditions during service.

- ~~It wi~~ Durable concrete will retain its original form, quality and serviceability when exposed to its environment

- It should not disintegrate or show sign of wearing under adverse conditions.

Consequence of Improper Quality and Inadequate durability

1. Loss of Strength of Concrete.
2. Concrete liable to be easily affected by ~~deterrents~~ deterrents
3. Corrosion of rebar
4. Loss of serviceability
   Unpleasant appearance.
5. Danger to persons & properties.
6. Expensive repair cost
7. Poor perception of concrete as a material
8. Poor perception of agencies involved.
9. Reduction of service life.
10. External agencies like weathering, attack by natural or industrial liquids, gases, Bacterial growth etc..
11. Alkali- Aggregate reaction.
12. Ingression of moisture / air facilitating
13. Corrosion of steel and cracking concrete cover.

Factor's Influencing Durability of Concrete
IS 456-2000.

(*) Environment, Freezing & Thawing, Exposure to aggressive Chemicals
(*) Type & Quality of Constituent materials
(*) Cement content & w/c ratio of concrete.
(*) Workmanship - especially in compaction curing
(*) Cover to Embedded Steel
(*) Shape & Size of the Member.
(*) Workmanship to obtain full compaction & efficient curing

Factor's Affecting durability

Durability depends on Two main factor's
(a) Concrete Systems
(b) The service Environment

(a) Quality & Quantity of materials used. processes involved in manufacture of concrete.

(b) Physical action & Chemical action on concrete

IS 456-2000

Exposure Conditions & Nominal Cover to meet the durability requirement

Type of Exp	Environment descrip	Nominal Cover in mm
Mild		20

Durability

- **Concrete System**
  - **Materials**
    - Binder type
    - Binder Content
    - Aggregates
    - Admixtures
    - Mix design.
  - **Process**
    - * Mixing
    - * Transportation
    - * Compaction
    - * Curing
    - * Temperature.
    - * Workmanship
    - *
- **Aggressiveness of the Environment**
  - **Physical**
    - Abrasion
    - Erosion
    - Cavitation
    - Freeze & Thaw.
    - Impact
  - **Chemical**
    - Dissolution
    - Leaching
    - Expansion
    - Alteration
    - Sulphates, Chlorides, CO_2, Natural water

Selection of Good Quality materials.

(free from unsound materials like free lime excess gypsum.)

* Cement - Reputed manufacturer.
* Sand (River/crushed, Silt < 5%)
* Aggregates (Cubical in shape, Innocuous)
* Water (Tested) - PH - 6 to 8
* Admixture (Reputed manufacturer)
* Compatibility of Cement & plasticizer (PC based or ~~Naphtha~~ Naphtha based) & 3rd Generation Super plasticizer of Poly-Carboxylates base, Polyacrylates based or Mono vinyl alcohols based.

Unsound Materials

* Cement or aggregates is considered unsound when they cause unacceptable volume change, hardened concrete or mortar which causes cracks & affects durability
* Aggregate containing certain materials such as shale, clay lumps, coal, Iron-pyrites etc show unsoundness later when concrete undergoes freezing or wetting & drying or & Thawing
* More moisture absorption in aggregate is often used as a rough Index for unsoundness.

Impact of W/c ratio on durability

* Permeability is the contributory factor for volume change & higher W/c ratio is the fundamental cause of higher permeability. Use of higher W/c ratio → Higher Permeability → more volume change – cracks – disintegration – failure of concrete. — cyclic process in concrete.

* For Durable concrete, use of Lowest possible W/c ratio (Gel/space ratio) is the fundamental requirement to produce dense and impermeable concrete.

* Modern super plasticizers of polymer base are so efficient that it is now possible to make flowing concrete with W/c as low as 0.31 or even low as 0.29 with increased slump more than 250mm.

Process

Workmanship for durable concrete.

- Batching
- mixing
- Transportation
- placing
- Compaction — Ensuring suitable workability Employing appropriate placing & compaction equip
  - 1% voids reduces strength by 5%.
  - ~~Adequacy~~ compaction Adequate without segregation
- Finishing
- protection
- Curing.

Environment

Physical

Temperature, moisture,
alternate wetting + drying
Freezing + Thawing

Temperature.

- significantly affects rate of hydration of cement
- Leads to plastic shrinkage cracks in fresh concrete.
- Volume changes & cracks especially in mass concrete.
- Spalling & disintegration of concrete @ higher temper. > 250°C.
- Variation in ambient temp causes secondary stresses in structures.

Moisture.

- Shrinkage on drying, consequent volume change and cracking
- Induce corrosion of steel
- acts as carrier of chemicals inside the body of concrete.
- Causes efflorescence & deposition of CaOH on surface.
- Seepage/Leakage cause inconvenience to occupants and deteriorates structures due to permeable concrete.

Alternative wetting & Drying

- Secondary stresses in Str.
- accelerates steel corrosion.

Chemical

Acidic
gaseous
alkaline
corrosive.

Chemical Environment attack affecting durability

when dealing with durability. Chemical attack which results in volume change, cracking & consequent deterioration of concrete becomes major concern.

Types of Chemical attack.

- Sulphate attack
- Alkali aggregate reaction.
- Chloride ion attack - corrosion
- Carbonation
- Acid attack.
- effect of concrete in sea water.

- Chemical attack on concrete

Freezing & Thawing

- Leads to expansion of concrete & cracking
- Ice melting salts cause erosion of concrete.

Chemical attack.

The durability of concrete gets affected by Chemical attack, which happens as a results of the reaction between aggressive substances (ions or molecules) and ingredients of concrete.

However, whether aggressive substance enter Concrete from the atmosphere or are already present in it, They have to be transported to meet reactive part of concrete for starting the reaction. If no transportation takes place, There will be no reaction.

Therefore pre conditions for a Chemical reaction to take place is the presence of water in some form (moisture or gas)

The reaction that leads to deterioration are.

a) The reactions of acids, ammonium Salts, magnesium salts, and soft water with the hardened cement

b) The reaction of sulphates with the aluminates in concrete.

(c) reaction of ~~alkaline~~ Alkali with the reactive aggregates.

Acid attack.

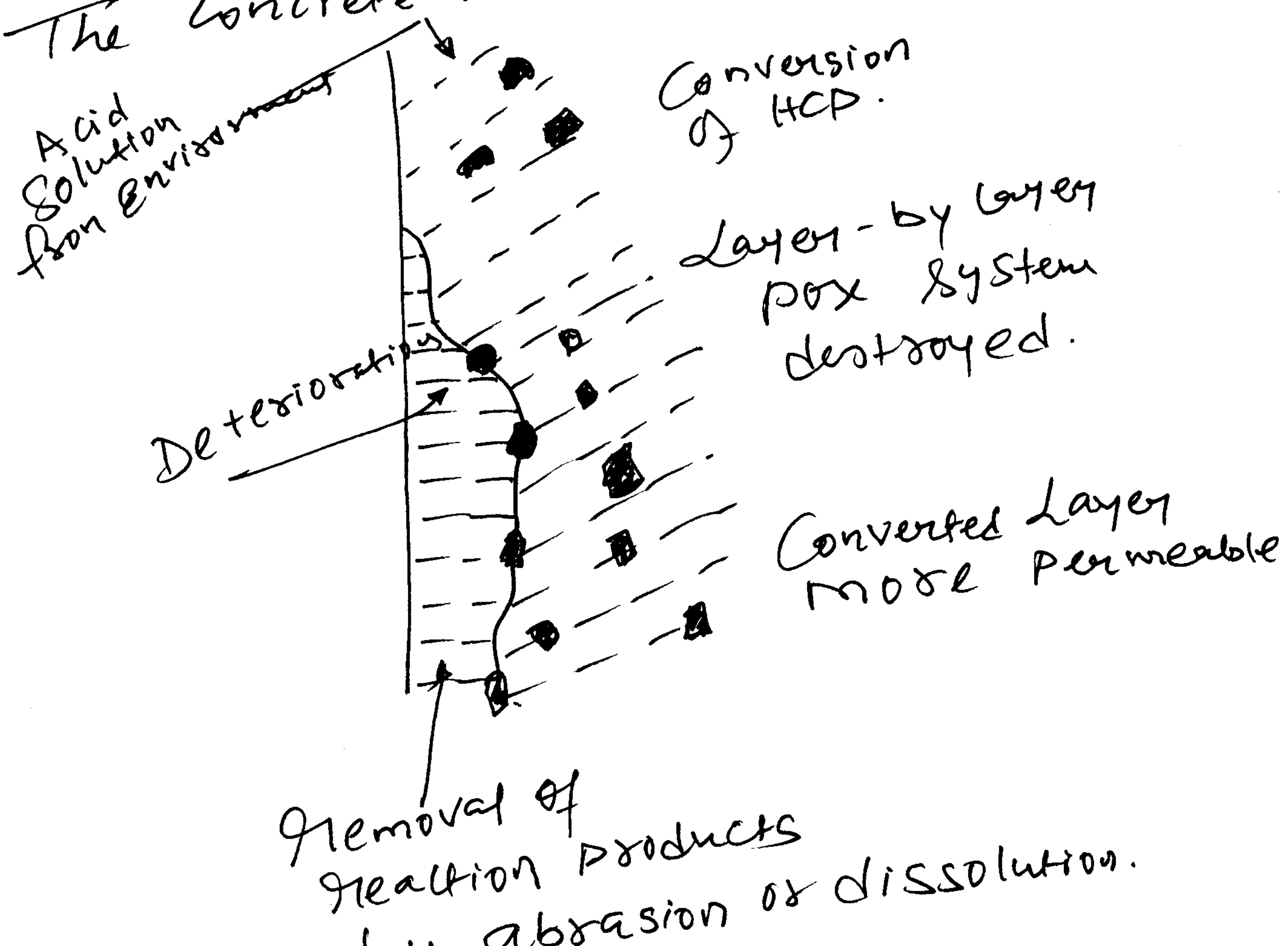
The action of acids on hardened concrete is the conversion of calcium compounds into the calcium salts of ~~act~~ attaking acids ~~products~~

Hydrochloric acid with concrete produces Calcium chloride.

Sulphuric acid ⟶ Calcium Sulphates which precipitate as gypsum.

Nitric acid ⟶ Calcium Nitrate, which is very soluble.

As a result of these reactions, the concrete structure gets destroyed.



Effect of ~~a~~ acid attack.

The rate of the reaction depends on the solubility of the calcium salts that gets formed. The less soluble the salts, the more passive the reaction. If the salt is soluble, the rate of reaction depends on the rate of dissolution of the salts.

Acid attacks completely convert the HCP, destroying the pore system. Therefore, in the case of acid attack, the permeability of sound concrete is less important compared to the reactions that take place. However, in the case of the attack by sulphate and alkalies, permeability is of great important.

1. Explain the Influence of w/c ratio ~~and~~ and age on permeability of concrete - 07 - (2 times)
2. Discuss permeability of concrete - 06.
3. Mention three parameters included in the concrete work specification to Ensure for permeability of concrete.
4.

~~The coefficient K is expressed in m/s.~~

Permeability of Concrete

Concrete Tech. AM Neville & JJ Brooks

Durability ⇒ Permeability

Lack of durability ~~is~~ can be caused by
a) External agents arising from the environment.
b) Internal agents within the concrete.

Cause can be physical, mechanical and chemical

→ Physical causes arise from the action of frost and from differences between thermal properties of aggregate and of the cement paste.

→ Mechanical ~~properties~~ causes are mainly by abrasion

→ Chemical causes

① Attack by sulphates, acids, sea water, chlorides

② Chloride attack induce electro chemical corrosion of steel reinforcement.

As all these attacks, takes place within concrete mass, the attacking agents must be able to penetrate throughout the concrete, which therefore has to be permeable.

Permeability is therefore of critical interest. The attack is aided by the internal transport agents by diffusion due to internal gradients of moisture and temperature and by **Osmosis**.

"Permeability" →

Permeability

it is the ease with which liquids or gases can travel through the concrete.

This property is of interest in relation to the liquid retaining structure & water-tightness & to chemical attack.

Permeability of concrete is measured by means of simple laboratory tests & results are mostly comparative.

"The side of concrete specimen are sealed and water under pressure is applied to the top surface only. When steady state conditions have been reached (about 10 days) the quantity of water flowing through a given thk of concrete in a given time is measured"

$$K = \frac{1}{A} \times \frac{dq}{dt} \times \frac{L}{\Delta h} = \text{Coefficient of Permeability}$$

Darcy's Equation

$\frac{dq}{dt}$ = Rate of flow of water.

A = c/s area of the sample.

Δh = drop in hydraulic head through the sample

L = Thickness of the sample.

Further test is prescriby by BS 1881 : part-5 : 1970.

~~gives info about very thin skin of concrete only~~

For initial surface absorption which is defined as the rate of flow of water into concrete per unit area, after a given time under constant applied load & @ given temp.

The coefficient K is expressed in m/s.

Permeability of concrete to air or other gases is of interest in structures such as sewage tanks and gas purifiers, pressure vessels of Nuclear reactor's.

However There is no unique relation between air & water permeabilities for any concrete, although they are both mainly dependant on the water/cement ratio and the age of concrete.

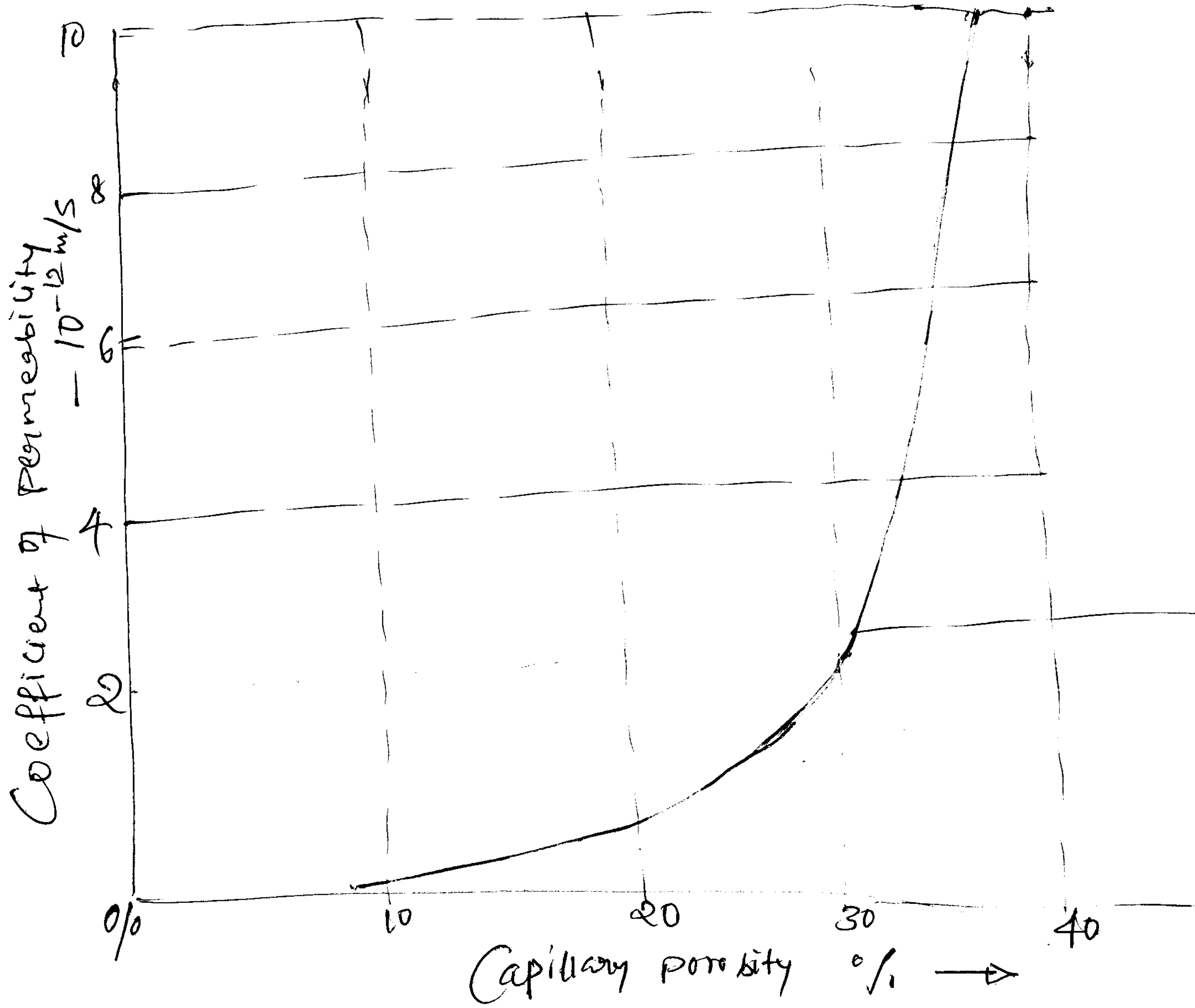
For concrete made with the usual normal weight aggregate, permeability is governed by the porosity of the cement paste.

However the relationship is not simple as the pore size distribution is a governing factor.

Example.

porosity of the cement gel is 28%, but its permeability is very low ie around 7×10^{-16} m/s because of the extremely fine texture of the gel and very small size of the gel pores.

The permeability of the hydrated cement paste as a whole is greater because of the presence of Larger capillary pores & its permeability is Generally a function of capillary porosity.



Relation between Permeability and Capillary porosity of Cement paste. (from T.C. POWERS)

Since Capillary porosity is Governed by the
a) water/cement ratio
b) Degree of hydration.

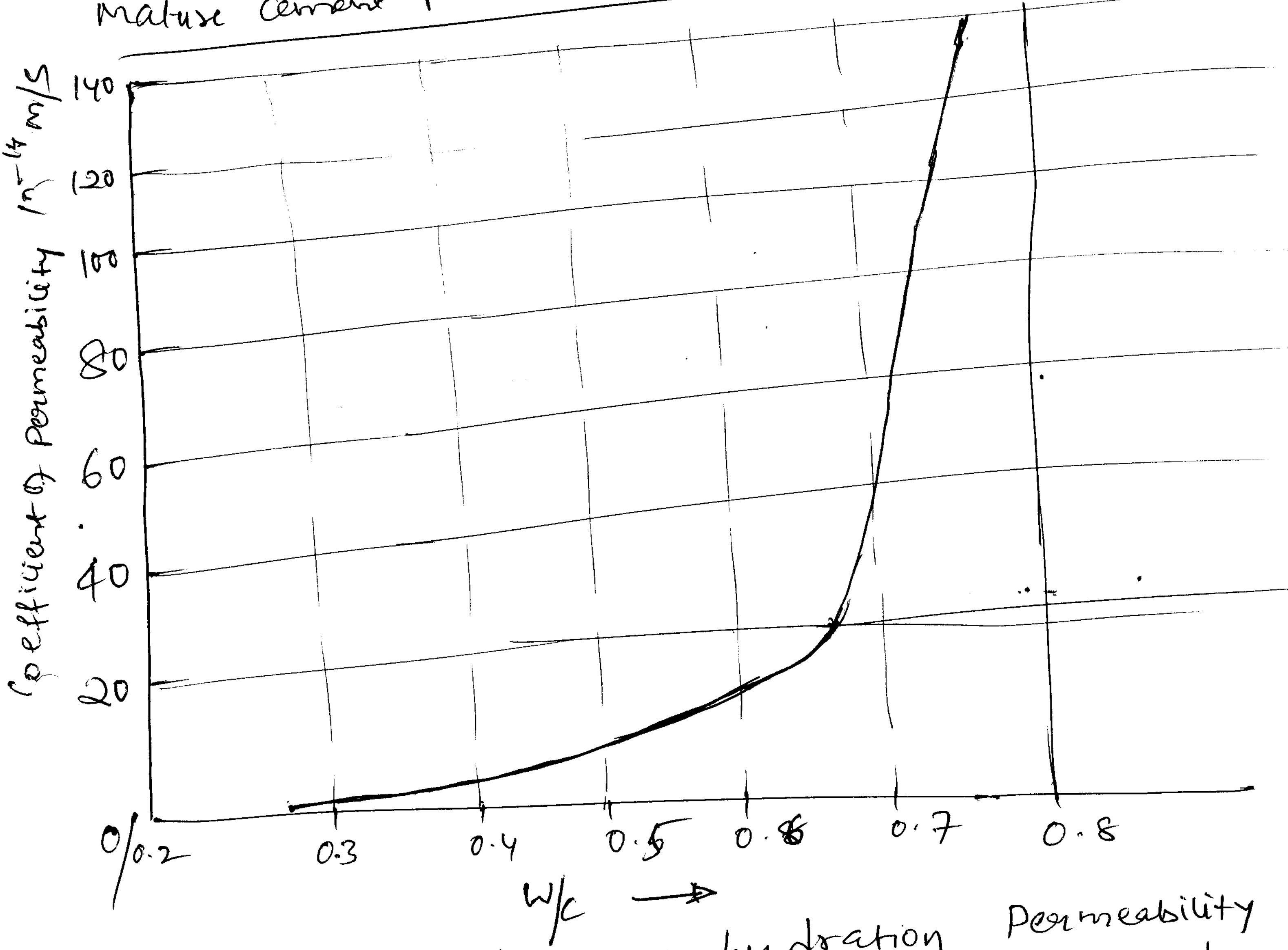
$$P_c = \frac{\left\{\frac{w}{c} - 0.36h + a/c\right\}}{0.317 + w/c + a/c}$$

$$x = \frac{0.678\,h}{0.318h + \frac{w}{c} + \frac{a}{c}}$$

$$P_t = \frac{(w/c + a/c - 0.17h)}{(0.317 + w/c + a/c)}$$

The Permeability of Cement paste is also mainly dependant on a) w/c ratio, and (b) degree of hydration.

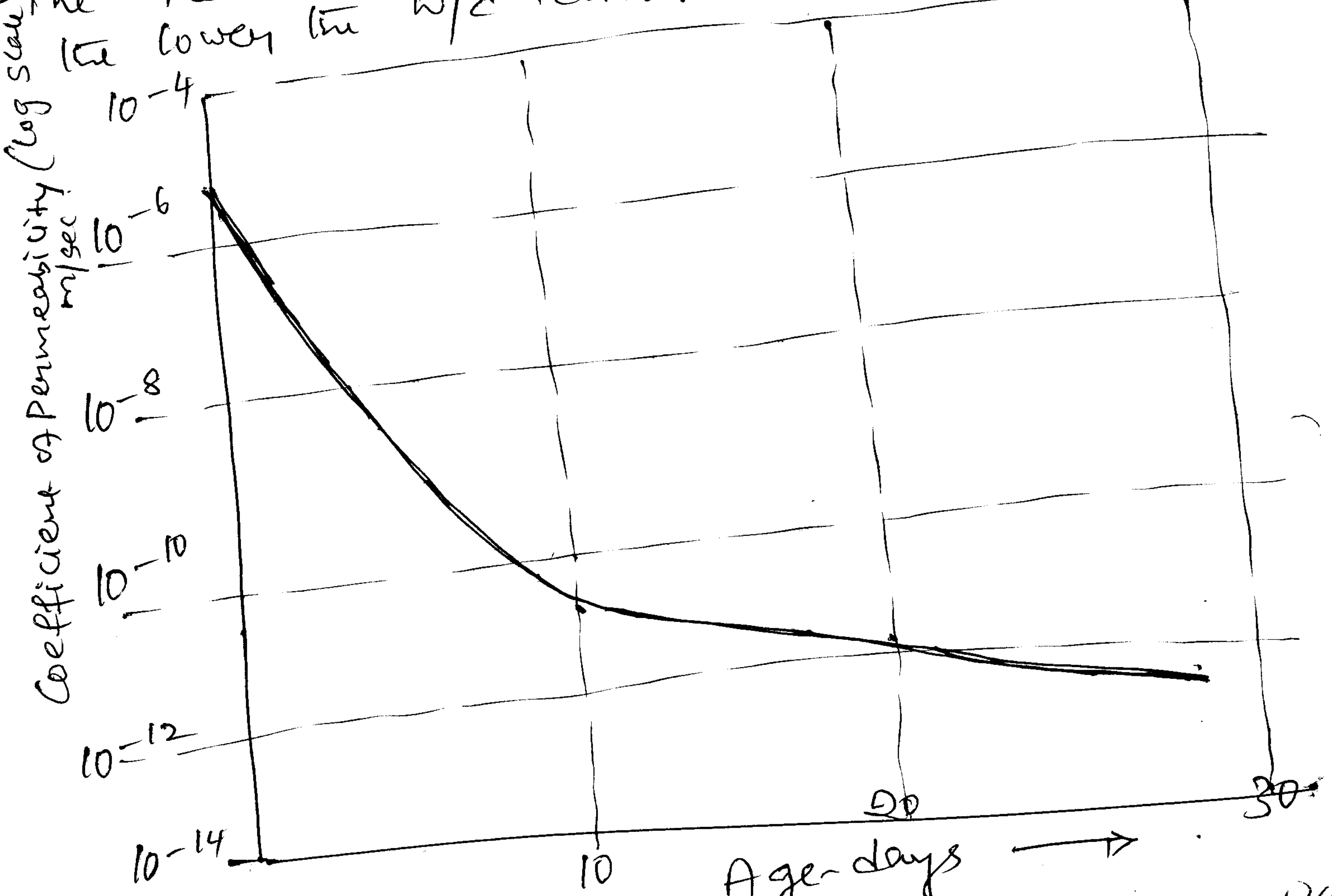
Relationship between permeability & w/c for a mature cement paste (93 % of hydration)



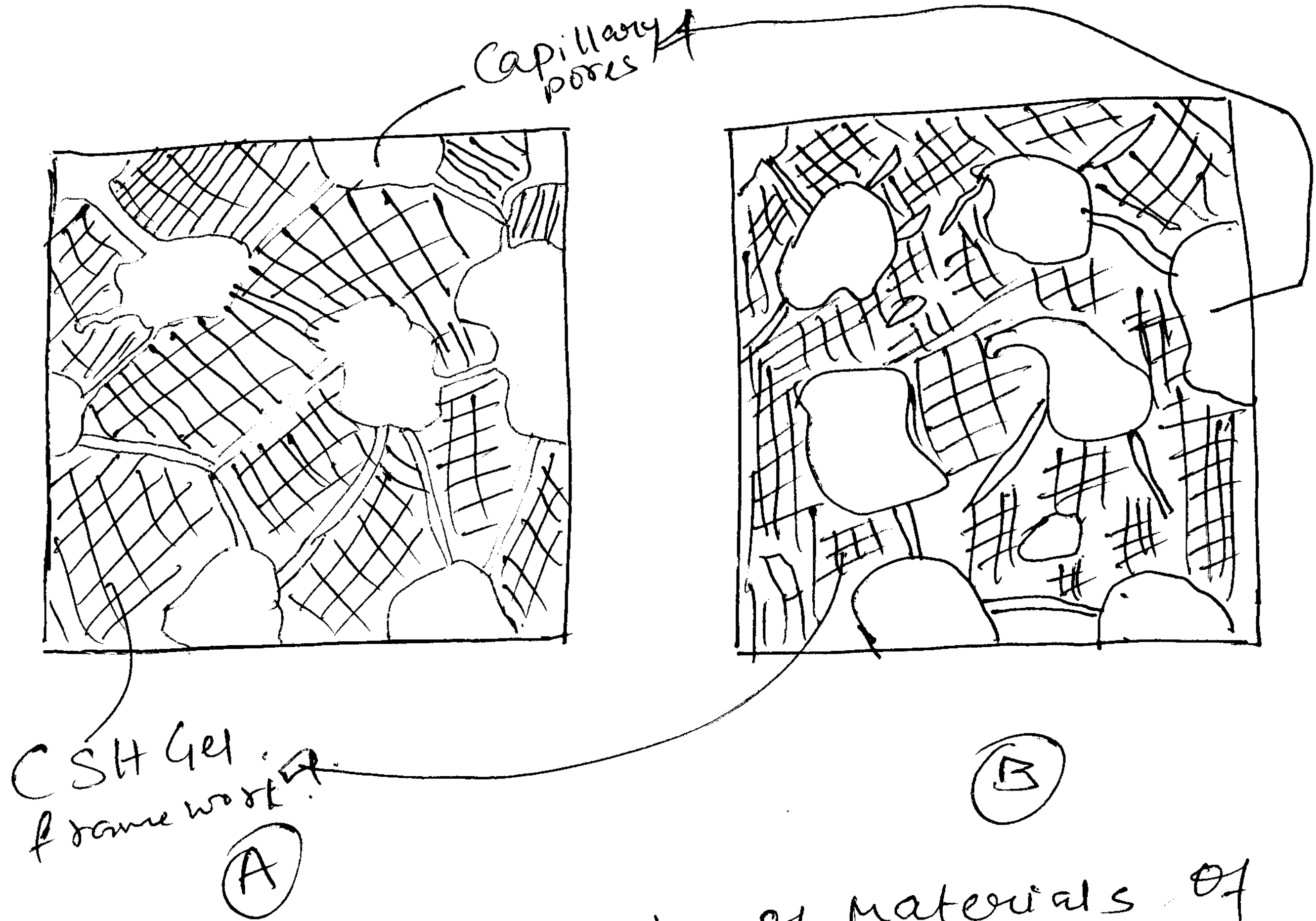
(*) For a given degree of hydration, permeability is lower for pastes with lower w/c ratio's, especially below a water/cement ratio of about 0.6, @ which the capillaries become segmented or discontinuous.

(*) For a given w/c, the permeability decreases as the cement continues to hydrate &

fills some of the original water space, The reduction in permeability being faster the lower the w/c ratio.



Reduction in Permeability of Cement Paste with the progress of hydration
w/c = 0.7



Schematic representation of materials of similar porosity but

a) High Permeability — Capillary pores are interconnected by large passages and

b) Low permeability — Capillary pores segmented and only partly connected.

→ The large influence of segmenting of ~~Capillary~~ capillaries on permeability illustrates that fact that permeability is not a simple function of porosity.

It is possible for two porous bodies to have similar porosities but different permeabilities. (Refer fig A & B above)

In fact only one large passage connecting capillary pores will result in a large permeability, while the porosity will remain virtually unchanged.

From the durability point of View, it is required to achieve low permeability as quickly as possible. Hence a mix with a low w/c ratio is advantageous because the stage @ which the capillaries becomes segmented is achieved after a shorter period of moist curing.

ACI standard 301-89

- To be water tight, structural concrete should have a w/c ratio of not more than 0.48 for exposure to fresh water and not more than 0.44 for exposure to sea water
- A maximum permeability of 1.5×10^{-11} m/s is often recommended.

The permeability of concrete is Generally of the same order ~~as that of cement paste (moist cured)~~ when it is made with normal weight aggregate. which have a permeability similar to that of the cement paste, but the use of a more porous aggregate will increase the permeability of concrete.

Interruption of moist curing by a period of drying will also cause an increase in permeability because of the creation of water passages by minute shrinkage cracks around the aggregate particles (especially the large one)

→ Permeability of steam cured concrete is generally higher than that of moist-cured concrete and, except for concrete subjected to long curing temperature cycle, supplemental fog curing may be realised to achieve an acceptably low permeability.

→ While a low w/c ratio is essential for the concrete to have a low permeability, it is not by itself sufficient. The concrete must be dense and therefore a well graded aggregate has to be used.

———x———x———

Other References.

M. S. Shetty — Concrete Technology

Chapter no 9.7

Pg 373 to 376.

———x———x———x

Durability

Chemical attack.

Durability of concrete is influenced by chemical attack, which results in volume changes, cracking of concrete and the consequent deterioration of concrete. ~~is very important~~

~~we will on~~

(A) ~~Sulphate attack~~.

(7 marks)

* What is Sulphate attack? Explain briefly the methods of controlling Sulphate attack

(B)

Sulphate Attack.

Most soils contain some sulphates in the form of calcium, sodium, potassium and magnesium. They occur in soil or ground water. Because of solubility of calcium sulphate is low ground waters contains more of other sulphates + less of calcium sulphates. Ammonium sulphate is frequently present in agricultural soil and water from the use of fertilizers or from sewage ~~of~~ of industrial effluents. Decay of organic matter in marshy land, shallow lakes often leads to the formation of H_2S, which can be transformed into sulphuric acid by bacterial action. Water used in concrete cooling towers can also be a potential source of sulphate attack on concrete. Therefore sulphate attack is a common occurrence in natural or industrial situations.

→ Concrete attacked by sulphates has a characteristic whitish appearance & ~~fotted~~ Followed by cracking & spalling of the concrete.

→ The reason for this appearance is that the essence of sulphate attack is the formation of calcium sulphate (Gypsum) and calcium sulpho aluminate ~~(Etter~~ (Ettringite)
Both products occupying a greater volume than the compounds which they replace so that expansion & disruption of hardened concrete take place.

→ Gypsum is added to the cement clinker in order to prevent flash set by the hydration of Tri calcium aluminate (C_3A) Gypsum reacts quickly with C_3A to produce Ettringite which is harmless because, at this stage, the concrete is still in a semi-plastic state so that expansion can be accommodated.

→ A similar reaction takes place when hardened concrete is exposed to sulphates from external sources.

→ A typical sulphate solution is the ground water of some clays which contains sodium, calcium or magnesium sulphates.

→ ~~The sulphat~~ Solid sulphates do not attack the concrete severely but when the chemicals are in solution, they

find entry into porous concrete and react with hydrated cement products.
The sulphates react with both $Ca(OH)_2$ and the hydrated C_3A to form Gypsum and Ettringite respectively.

→ Of all the sulphates, Magnesium sulphates causes maximum damage to concrete, because it leads to the decomposition of the hydrated calcium silicates as well as of $Ca(OH)_2$ & of hydrated C_3A; A characteristic whitish appearance is formed; which is hydrated Magnesium silicate: This has no binding properties.

⇒ The extent of sulphate attack depends on its concentration and on the permeability of concrete, i.e. on the ease with which sulphate can travel through the pore system. If the concrete is very permeable, so that water can percolate right through its thickness, $Ca(OH)_2$ will be leached out. Evaporation @ the far surface of the concrete leaves behind deposits of calcium carbonate, formed by the reaction of $Ca(OH)_2$ with CO_2; This deposit, of whitish appearance is known as "EFFLORESCENCE".

⇒ Efflorescence is generally not harmful, However extensive leaching of $Ca(OH)_2$ will increase porosity so that concrete becomes progressively weaker and more prone to chemical attack.

⇒ Crystallization of other salts also causes efflorescence.

⇒ Salts attack Concrete only when present in Solution's, and not in Solid form.
The Strength of the Solution is Expressed as Concentration, for Example: as the number of parts by mass of Sulphur trioxide (SO_3) per million parts of water (PPM).

**xx ⇒ A Concentration of 1000 PPM is Considered to be moderately Severe, and 2000 PPM is Very Severe, especially if Magnesium Sulphate is the predominant Contituent.

⇒ Since it is C_3A that is attacked by Sulphates, The vulnerability of Concrete to Sulphate attack can be reduced by the use of Cement Low in C_3A ie Sulphate resisting Cement (Type V)

⇒ Improved resistance is obtained also by the use of Portland blast furnace Cement and of Portland - pozzolan Cement.

⇒ However it must be emphasized that the type of Cement is of secondary importance, or even of none unless the Concrete is dense and has Low permeability. ie Low w/c ratio

⇒ w/c ratio is the vital factor but a high Cement content facilitates full compaction at Low water/Cement ratio's.

*xxx → "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 Hardned concrete, Calcium aluminate Hydrate 'C-A-H' can react with sulphate salt 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 upto 227%, a gradual disintegration of concrete takes place.

Sodium sulphate attacking $Ca(OH)_2$

$$Ca(OH)_2 + Na_2SO_4 \cdot 10H_2O \rightarrow CaSO_4 \cdot 2H_2O + 2NaOH + 8H_2O$$

Sodium sulphate with calcium aluminate hydrate.

$$2[3CaO \cdot Al_2O_3 \cdot 12H_2O] + 3[Na_2SO_4 \cdot 10H_2O] \rightarrow 3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 31H_2O + 2Al(OH)_3 + 6NaOH + 17H_2O$$

Method's of controlling sulphate attack

a) use of sulphate resisting cement

b) Quality control

a well designed, place 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 ; upto 6% entrainment have beneficial effect on the sulphate resisting qualities of concrete.

d) use of pozzolana. Admixing of pozzolana converts the leachable calcium hydroxide into insoluble non-leachable cementitous products.

e

(e) High pressure Steam Curing

High pressure Steam curing improve the resistance of concrete to sulphate attack. This improvement is due to the change of C_3AH_6 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 steam curing method is used.

(f) Use of High Alumina Cement.

additional Study

MS Shetty

Page no 420 – 422 – 423 – 24 & 25

Durability

"Alkali - Aggregate reaction".

Discuss briefly alkali - aggregate reaction? What precautions are necessary to minimize?
Explain the Mechanism, symptom & prevention of Alkali - Silica reaction in concrete.
Mention Alkali - Silika reaction? What circumstances are required for the alkali - Silica reaction (ASR) to take place.

———— x ———— x ————

The reaction between the alkalies in cement (mainly Sodium and potassium hydroxides) and the reactive silica (SiO_2) found in aggregates in the presence of water (hydroxl ions) can cause expansion and serious cracking in hardened concrete.

$$\underset{\text{Silica}}{SiO_2} + \underset{\text{Alkali}}{2\,NaOH} + \underset{\text{Water}}{H} \rightarrow \underset{\text{Alkali silica Gel}}{Na_2SiO_2\,2H}$$

The alkali - silica Gel is expansive in nature, due to this considerable internal busting force gets generated, which can results in serious cracking.

The circumstances required for the alkali - silica reaction (ASR) to take place are.

a) The presence of reactive aggregate.
b) High alkali content in cement used for making the concrete and
c) Concrete in a wet conditions.

All these conditions are required for the damage to occurs. These conditions exists in humid (dams, bridge pier, sea walls) and exposed environments (roads and building exterior's)

ASR leads to expansion and cracking of concrete, loss of strength, and pop outs and exudation of alkali-silica gel.

When it is necessary to use aggregates from a previously unknown source, it is important to investigate it for reactive silica.

The following methods may be used to prevent ASR damage.

a) Limiting alkali content

- Use of low alkali cement
- Limiting other sources of salt such as contaminated aggregates, penetration of sea water, & use of defying solution.
- Limiting the max cement content in concrete to a low value.

(b) Limiting reactive aggregate

Size, Qty, Reactivity

(c) Limiting the presence of moisture.

- Relative humidity < 75%
- Repairing cracks, leaking joints etc.

(D) ← Using pozzolanic mineral admixture
  - use of blast-furnace slag
  - Using silica fume, volcanic ash, metakaolin

(e) using air entrainment to allow
expansion
(f) Structural design - Limiting access to
water
- Avoiding de-icing salt
- Ensuring adequate compaction.
- obtaining good finished surfaces
- with proper curing.

IS: 2386 (Part VII) - 1963

Mortar bar method of testing for the
determination of the potential alkali reactivity
of the cement - aggregate combination.
The expansions developed by the combinations in
mortar bars are measured during storage @
under prescribed conditions for testing
different intervals of time.
A mortar using 1 part of cement & 2.25
parts of graded aggregate by weight is
prepared. The amount of mixing water is
so chosen as to produce a flow of 105-120
in a standard flow test.
The water is placed in a dry bowl. Cement is
added to it & mixed for 30 sec.
Half of the aggregate is added & mixed for 30 sec.
The remaining aggregates are added &
mixed. The mould is filled in 2 layers
and compacted with tamper.
The specimen is left in the mould for 24 hrs.
After which it is removed & its
length is measured.

It is Then protected aganist Loss of Moisture and placed in container, but not in contact with water.

The Specimen is measured periodically @ Intervals of 1, 2, 3, 6, 9 + 12 months.

The difference in length of Specimen is Calculated

The Expansion of prisms observed in the Sample aggregate is finally compared with companion prism made with Known aggregates having no alkali reaction.

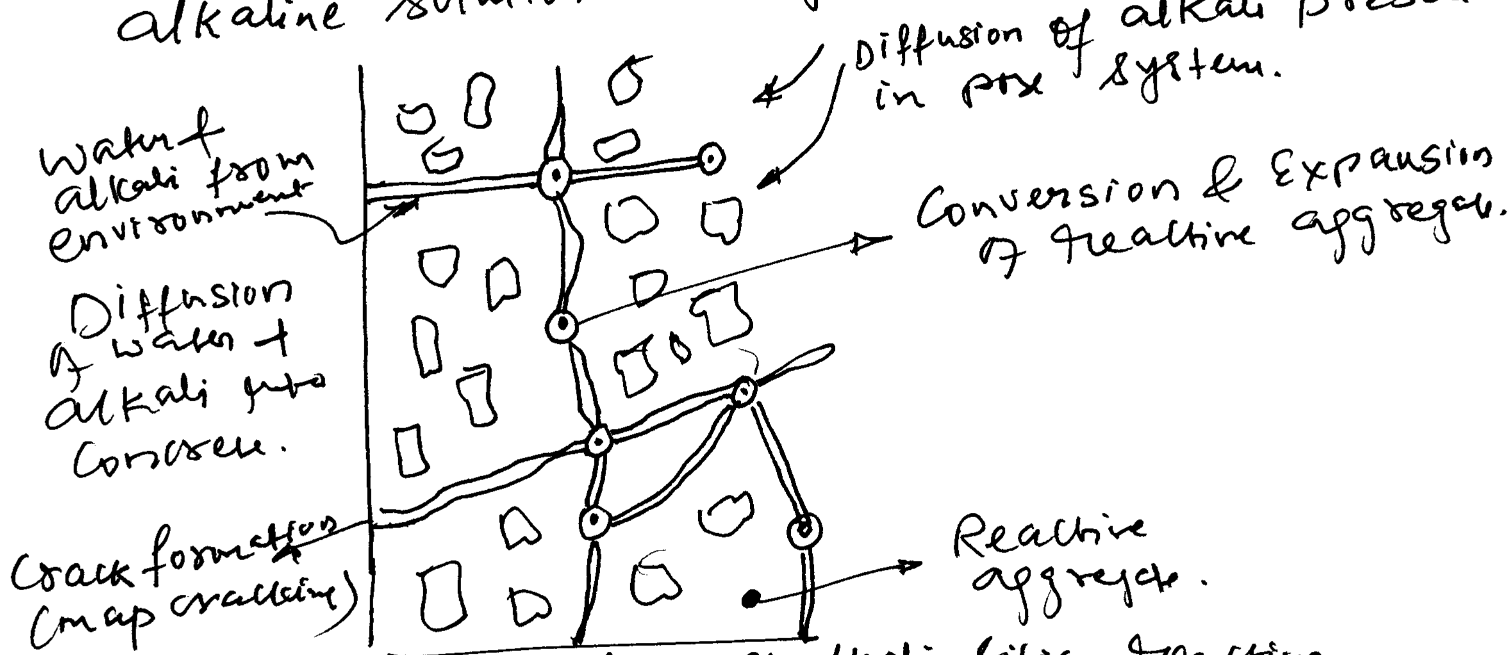
———— x ————

Alkalies only attack the reactive aggregates in concrete.

The reactive Substance is not the Cement, but it is aggregates, which contains Silica.

The alkaline Solution in the pores is Lime saturated and contains potassium and Sodium ions.

Silica Containing aggregates react with this alkaline Solution leading to disruptive Expansion



Effect of alkali-Silica reaction.

Visible Map cracking, POP-outs and weeping of glassy pearls are the various manifestations of this problem.

The reaction depends upon:

a) The reactivity of aggregates based on the pressure of reactive amorphous silica.

(b) The grain size of aggregates.

(c) The alkali calcium concentration in the pore water.

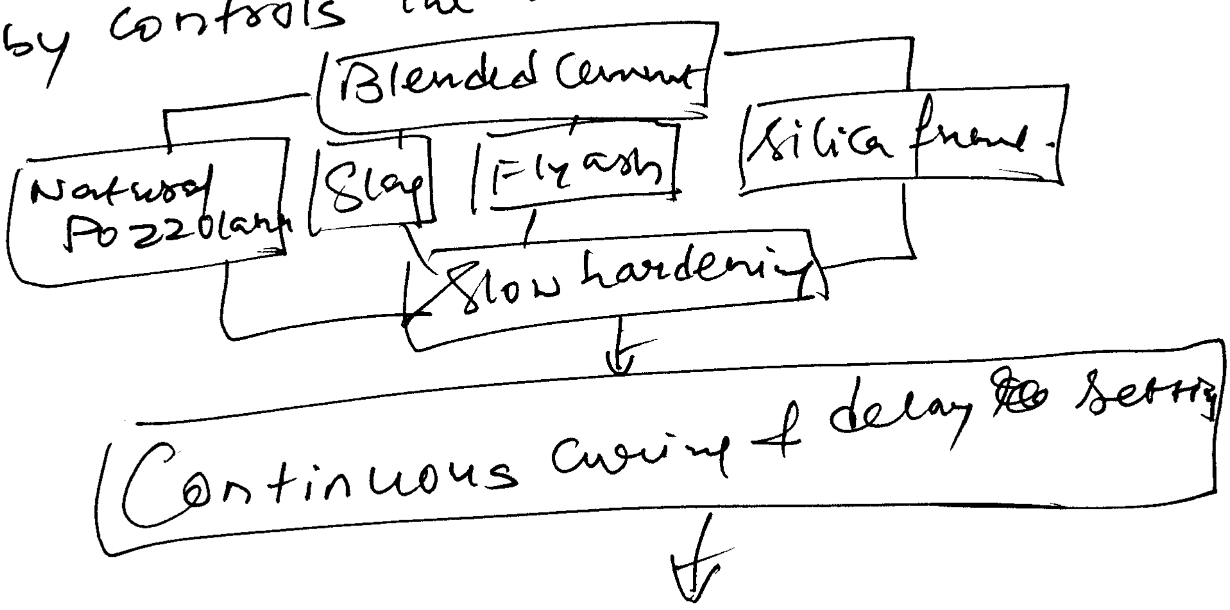
(d) The type of cement

(e) The Exposure conditions.

(f) The amount of water available.

(g) The rate of transport. (Internal)

The use of blended or slag cement limits the reaction by limiting the presence of alkaline solution in the pore water. Good curing helps in reducing the permeability & thereby controls the alkali - silica reactions.



Unit 4

Durability

Corrosion in Concrete.

Q. What is carbonation of concrete? How does it influence the corrosion of steel? — 10 —

Q. Describe corrosion of steel in concrete containing calcium chloride? — 07 —

Q. Explain corrosion in reinforced concrete. — 08 —

Carbonation

Concrete made with portland cement is highly alkaline due to the presence of calcium hydroxide. This alkalinity present in the pore water of concrete can be reduced by the acidic compounds in the atmosphere, especially CO_2 & SO_2.

The effect of reduction of the pH value of concrete by these chemicals is know as "Carbonation"

→ Concrete gets carbonated on the surface, including on the sides of cracks and whenever it is in contact with the atmosphere.

→ This carbonated concrete does not provide the necessary protection to steel reinforcement.

The rate of carbonation is determined by the chemical reaction between CO_2 & $Ca(OH)_2$ in pore water, resulting in the formation of $CaCO_3$

$$CO_2 + Ca(OH)_2 \longrightarrow CaCO_3 + H_2O$$

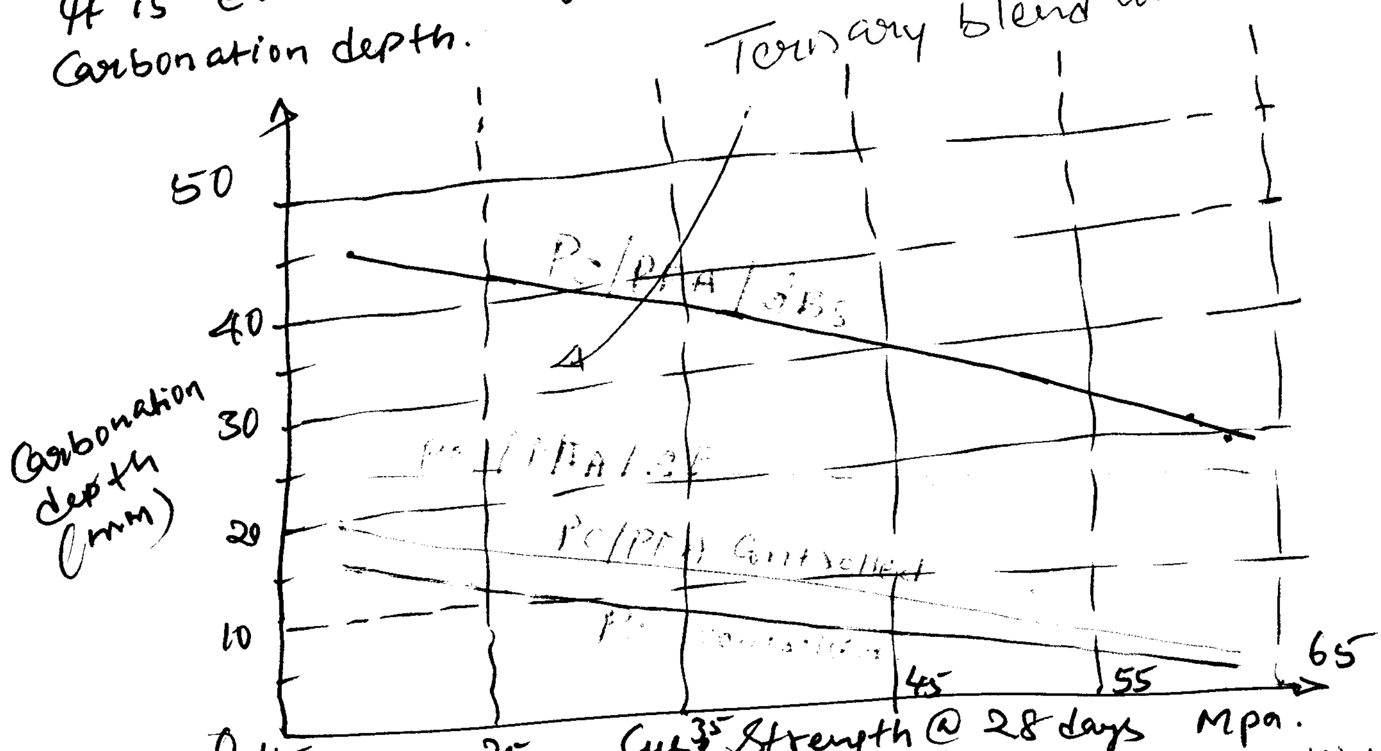
Thus the rate of diffusion of CO_2 inwards through concrete is an important parameter. This diffusion takes place through pore structure of concrete.

The chemical reaction takes place fast and the period of diffusion is the ~~de~~ real defence against carbonation.

The more water there in the concrete (with larger W/c ratio), the more rapidly carbonation takes place. Hence, the use of a low W/c ratio for making concrete ensures a definite defence against carbonation.

→ xxxx ←

Mineral admixture cannot control carbonation. A recent study by Jones et al (1997) suggests concrete made with portland cement has lowest carbonation depth. It is evident that higher strength can control carbonation depth.



Importance of concrete strength in controlling carbonation depth.

ABCD (?)

Carbonation test

Carbonation by atmospheric carbon dioxide reduces the alkalinity (PH) of concrete and increases the risk of reinforcement corrosion.

The Extent of carbonation can be assessed by treating a freshly exposed concrete surface with a "phenolphthalein" Indicator.

The color change of phenolphtalein corresponds to a pH of about 9.

A purple color indicates highly alkaline good concrete; while no change in color indicates an acidic concrete pH < 5.

(* * *) " Carbonation of concrete is a process by which CO_2 from the air penetrates into concrete and react's with $Ca(OH)_2$ to form Calcium carbonate"

CO_2 by itself is not reactive. In the presence of moisture, CO_2 changes into dilute carbonic acid which 'attacks the reinforcement and also reduces alkalinity of concrete"

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xxxxx

Age-years	Depth of Carbonation (mm) M20	M40
2	5.0	0.5
5	8.0	1.0
10	12.0	2.0.
50	25	4.0

xxxxx

Atmospheric air contain's CO_2 and its concentration will be around 0.03% by volume near rural / Forest / un Inhabitation area. But It has higher concentration in big cities and town (Around 0.3 to 0.5% by volume)

The PH value of pore water in the hardned concrete is generally between 12.5 to 13.5 depending upon alkali content of cement. The high alkalinity form's a thin passivating layer around steel reinforcement and potect it from action of oxygen & water. As long as steel is placed in a alkaline condition's, It is not going to corrode. Such condition is known as "passivation"

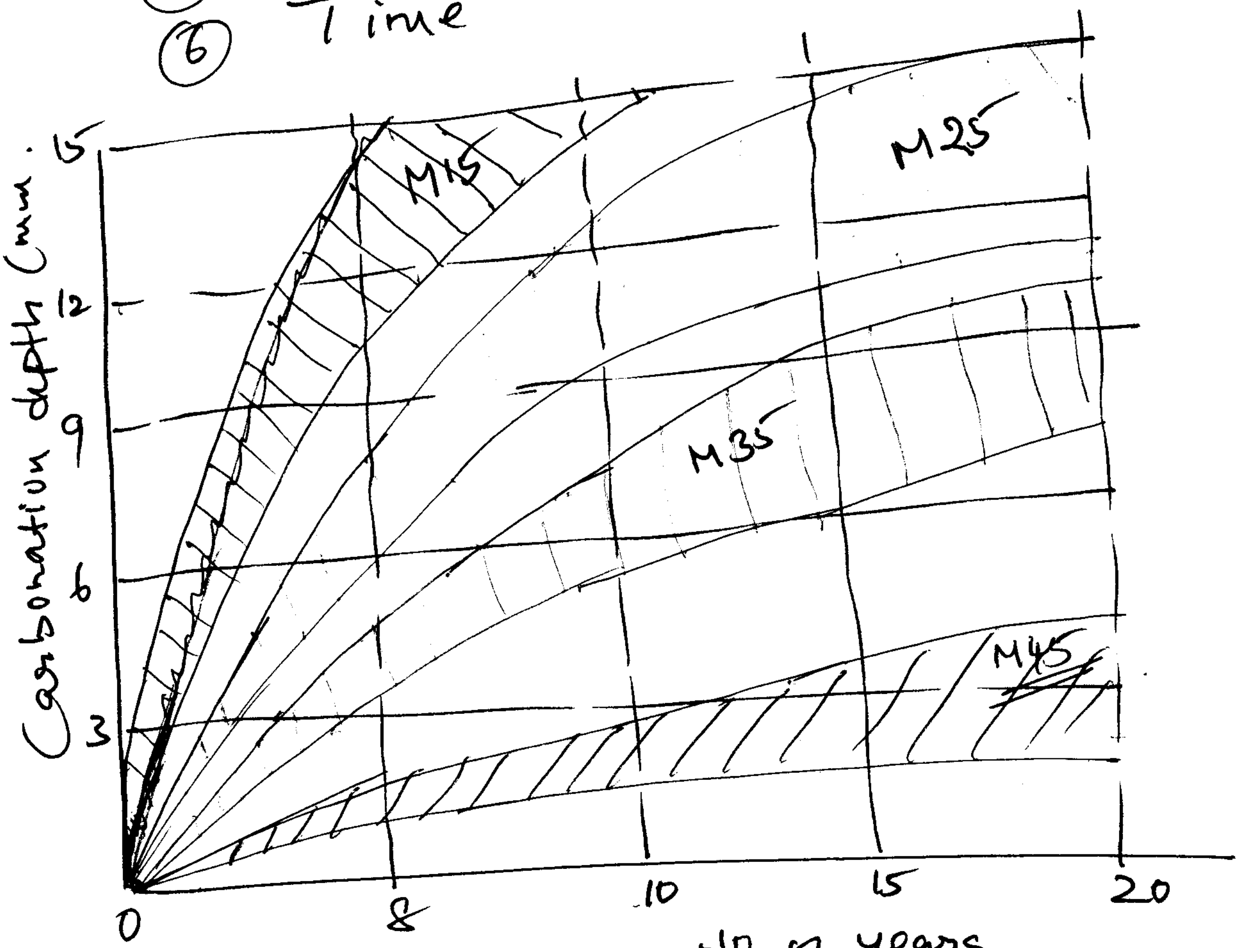
In practice CO_2 permeates into concrete through capillary pores and reduces the alkalinity of concrete pore water from 13.5 to in and around 9 to 8.3, during the process of carbonation. When all $Ca(OH)_2$ is carbonated, PH value will be ≤ 8.3 & protective layer gets destroyed and steel is exposed to "corrosion".

Hence carbonation process along with action of oxygen & moisture are main factor's which induces corrosion of reinforcement (Embedded Steel)

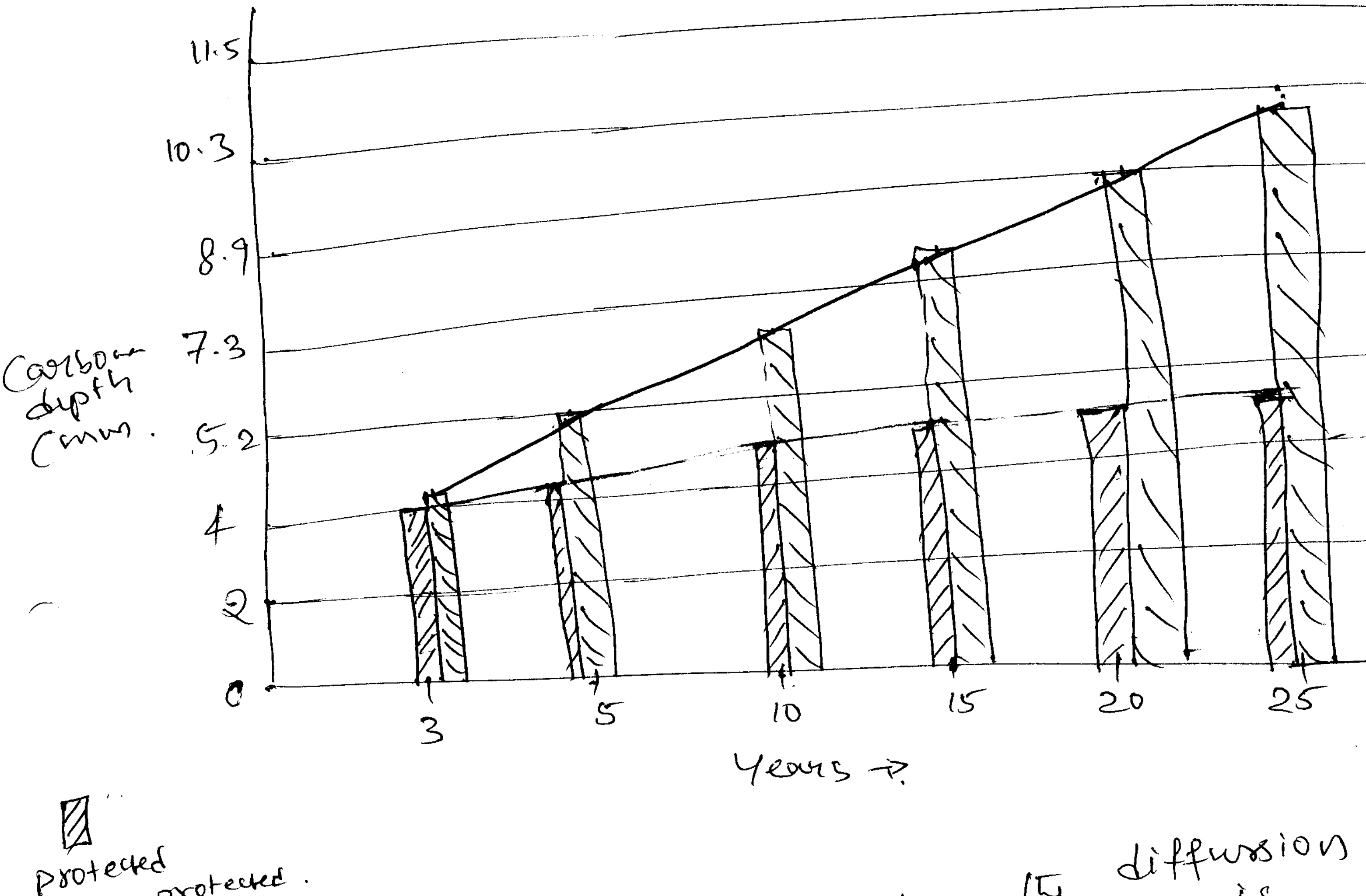
Rate of Carbonation.

The rate of carbonation depends on:

1. Level of pore water ie relative humidity
2. Grade of concrete.
3. Permeability of concrete.
4. whether concrete is protected or not
5. depth of cover
6. Time



Depth of Carbonation with respect to Strength (Grade) of concrete.



→ If pore is filled with water the diffussion of CO_2 is very slow, But whatever CO_2 is diffussed into the concrete, is readily formed into dilute carbonic acid, which reduces alkalinity.

On the other hand if the pores are rather dry, That is Low relative humidity the CO_2 remains in gaseous form and doesn't react with hydrated cement.

"The Moisture Penentration from External source is necessary to carbonate the concrete"

The highest rate of carbonation occurs @ a relative humidity of between 50% to 70%.

The rate of carbonation depth will be slower in case of Stronger Concrete for the obvious reason that Stronger concrete is much denser with Low w/c ratio. Also Permeability of the Concrete, particularly that of Skin concrete is much less @ lower w/c. & as such the diffussion of CO_2 doe'snt take place faster, as in the case of more permeable concrete with higher w/c.

Concrete requires protection for longer durability. Hence protective coatings are applied over concrete surfaces of Long Span Bridges, flyovers, industrial Structures, Chimneys. The depth of carbonation for both protected & unprotected concrete Structures are given.

Depth of Cover plays an important role in ~~protection for longer durability~~. protecting Steel from Carbonation. The table below gives relationship between w/c, depth of cover, time in years for carbonation depth to reach the reinforcement

Approximate relation's between w/c depth of cover & time in years for carbonation depth to reach the reinforcement

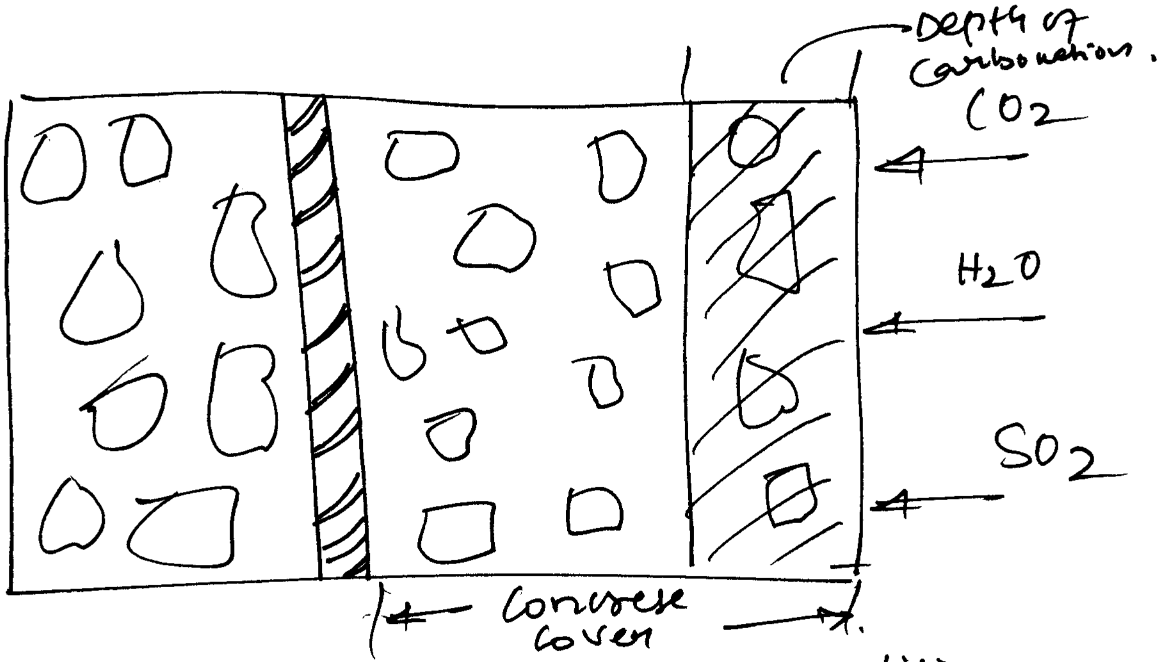
w/c ratio	Depth of cover (mm)			
	15	20	25	30
0.45	100+	100+	100+	100+
0.50	56	99	100+	100+
0.55	27	49	76	100
0.60	16	29	45	65
0.65	13	23	36	52
0.70	11	19	30	43.

Time in yrs for carbonation.

Measurement of Depth of carbonation.

ABCD

x



Steel in passivative condition.

Concrete is under continuous attack by aggressive Environmental agencies Good concrete & sufficient cover is the answer for durability

Corrosion of Steel

(Chloride Induced)

"Corrosion is defined as the destruction or ~~detero~~ detereoration of materials in Environments to which they are exposed".

Concrete durability is directly influenced by Corrosion of Embedded Steel reinforcement.

- "Corrosion is defined as the destruction or deterioration of materials due to chemical or electro chemical reaction with the Environment"

Corrosion of Steel is Loss of Steel properties due to Rusting.

The Corrosion of Steel reinforcement is the depassivation of Steel with reduction in concrete alkalinity through Carbonation.

- Corrosion deteriorates Concrete because the products of corrosion - Ferric oxide, brown in colour - occupies a greater volume (more than 2 to 10 times) than Steel and Exerts Substantial busting stresses on the surrounding concrete. The outward Manifestations of rusting include staining, cracking and spalling of concrete.

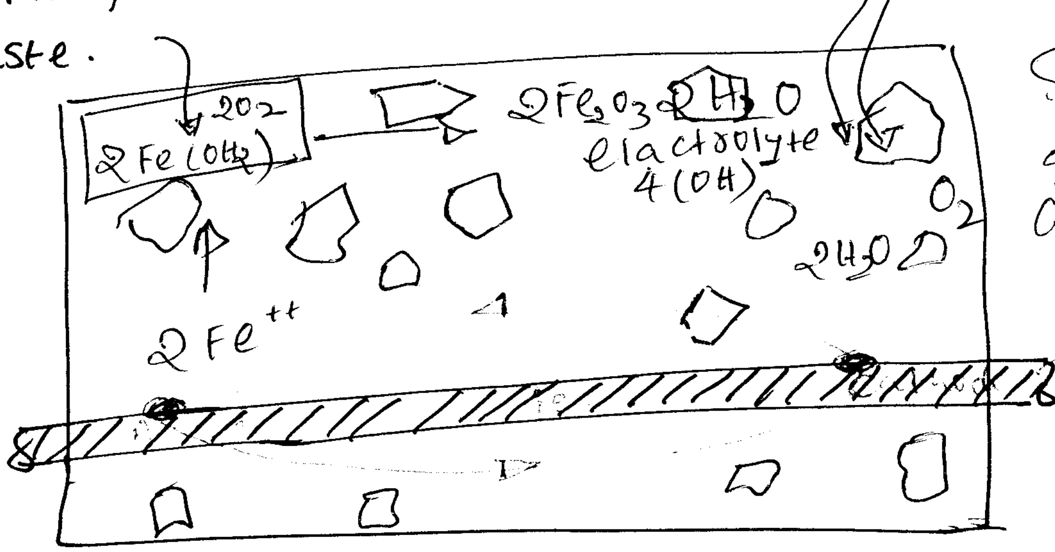
The progress of the process of Corrosion is Generally in Geometric progression wrt time. Consequently C/s of Steel is reduced.

With progress of time Structural distress may occur either due to the Loss of the bond between Steel & concrete, due to the Cracking & Spalling of Concrete, or as a result of the reduced Steel C/s area.

This ~~later~~ latter effect can be of special concern in Structures containing high strength prestressing Steel in which a small amount of metal loss could induce a tendon failure.

———— x ————

Corrosion of Steel in Concrete is an electrochemical process. When there is a difference in electrical potential along the Steel reinforcement in Concrete, an electrochemical cell is set up. In the Steel, one part becomes anode and another part becomes cathode connected by electrolyte in the form of pore water in the hardened cement paste.



Simplified model representing Corrosion mechanism.

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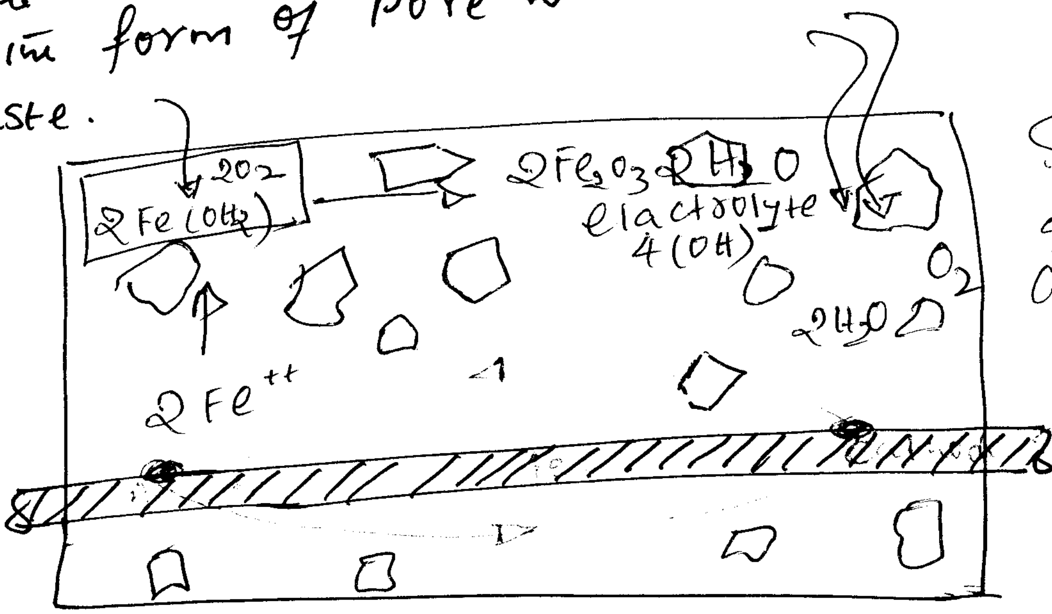
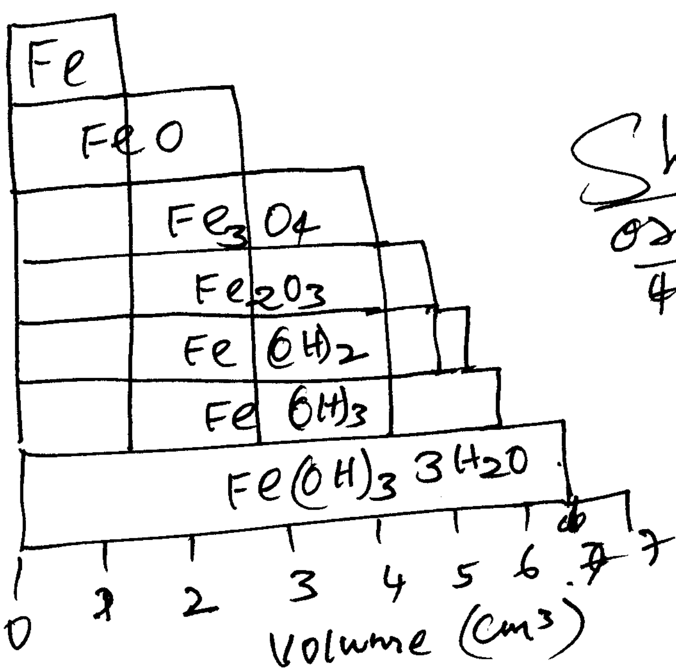


Simplified model representing Corrosion mechanism.

The positively charged ferrous ions Fe^{++} at the anode pass into solution while the negatively charged free electrons e^- pass through the steel into cathode where they are absorbed by the constituents of the electrolyte & combine with water and oxygen to form hydroxyl ions $(OH)^-$

These travel through the electrolyte and combine with the ferrous ions to form ferric hydroxide which is converted by further oxidation to "Rust"



Shows that, depending on the oxidation state, mettallic ~~iron~~ Iron can increase more than 6 times in volume.

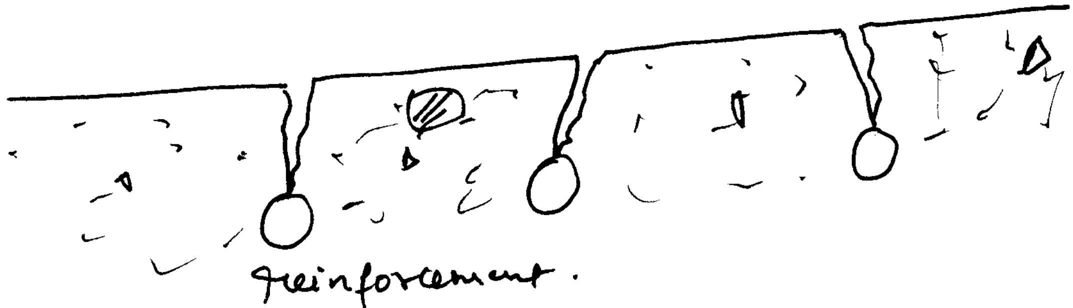
Anodic reactions

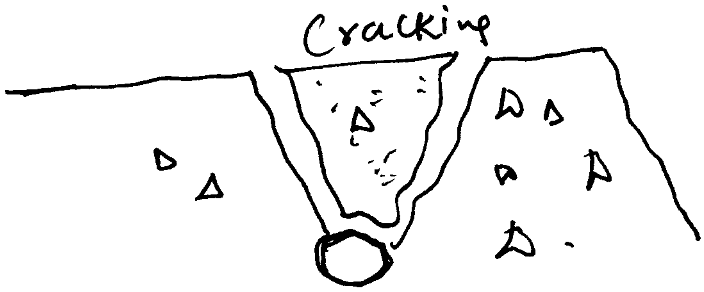
$$Fe \rightarrow Fe^{++} + 2e^-$$

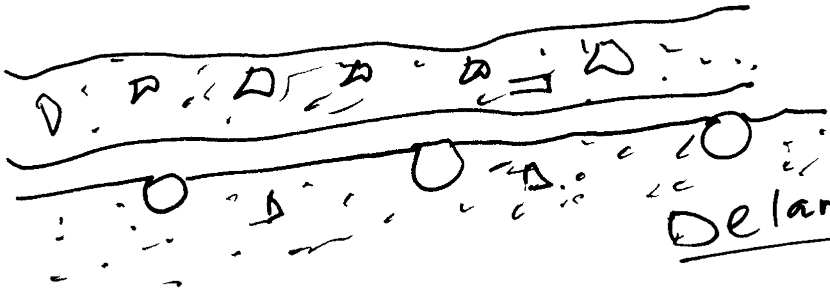
$$Fe^{++} + 2(OH)^- \rightarrow Fe(OH)_2 \quad \text{Ferrous hydroxide.}$$

$$4Fe(OH)_2 + 2H_2O + O_2 \rightarrow 4Fe(OH)_3$$

Ferric oxide.







Diagrammatic representation of damage induced by Corrosion cracking, Spalling and delamination.

Cathodic reaction.

$$4e^- + O_2 + H_2O \rightarrow 4(OH)^-$$

No Corrosion will take place, If the Concrete is dry or probably below relative humidity of 60% because enough water is not there to promote corrosion.

Corrosion will not take place, If concrete is fully Immersed in water because diffussion of oxygen does not take place into the concrete.

Optimum humidity required for Corrosion to happen is 70 to 80%.

"The products of corrosion occupy a volume as many as 6 times the original volume of steel depending upon the oxidation state"

The increased volume of rusts exerts thrust on cover concrete resulting in cracks, spalling or delamination of concrete. With this kind of situations concrete loses its integrity. The c/s of reinforcement progressively reduces and the structure is sure to fail or collapse.

———x———

Corrosion Control

→ Good quality of concrete through good construction practices.
- Selection of materials
- Storage Transp, Placement, Compaction,
- Mixing, curing
- mix design.
- Durability, Strength etc.
-
-

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M.S Shetty page 439 to 446.

Corrosion Control

- It had been established, that 40% of Structural Failure of RCC/PSC members are due to corrosion of Steel
- Good Quality of concrete is basic requirement for corrosion control. Good Quality Concrete covers all aspects starting from material selection, storage, handling, transporation, placement, Concrete mixing, handling, curing. It also covers handling of w/c → workability → Super plasticizers.
- proper mix design, use of right quality and Quantity of Cement for different exposure Conditions is to be adopted.
- Objective is to produce Concrete which has very Low permeability and High durability
- ~~Test's have Shown that~~
- Use of Supplementary cementitious materials such as fly ash, ground granulated blast furnace slag (GGBS), Silica fume ect are recognised to be used as admixture or in addition in the form of blended cement to make 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.
- Improvement in the micro structure of hydrated Cement paste is ultimately responsible for protecting the Steel reinforcement from corrosion.

In Short, If we make good concrete with Low permeability and improved micro structure, It will be durable by itself and It can take care of the reinforcement contained in it to a great extent.

Steel

a) Metallurgical Method.

b) Corrosion inhibitors. — Cement Coating.

(c) Coatings to reinforcement —