RETROFITTING AND REHABILITATION OF STRUCTURES

Course: PE 821 CE (PROFESSIONAL ELECTIVE – III)

Bachelor of Engineering (B.E.), Year IV, Semester II

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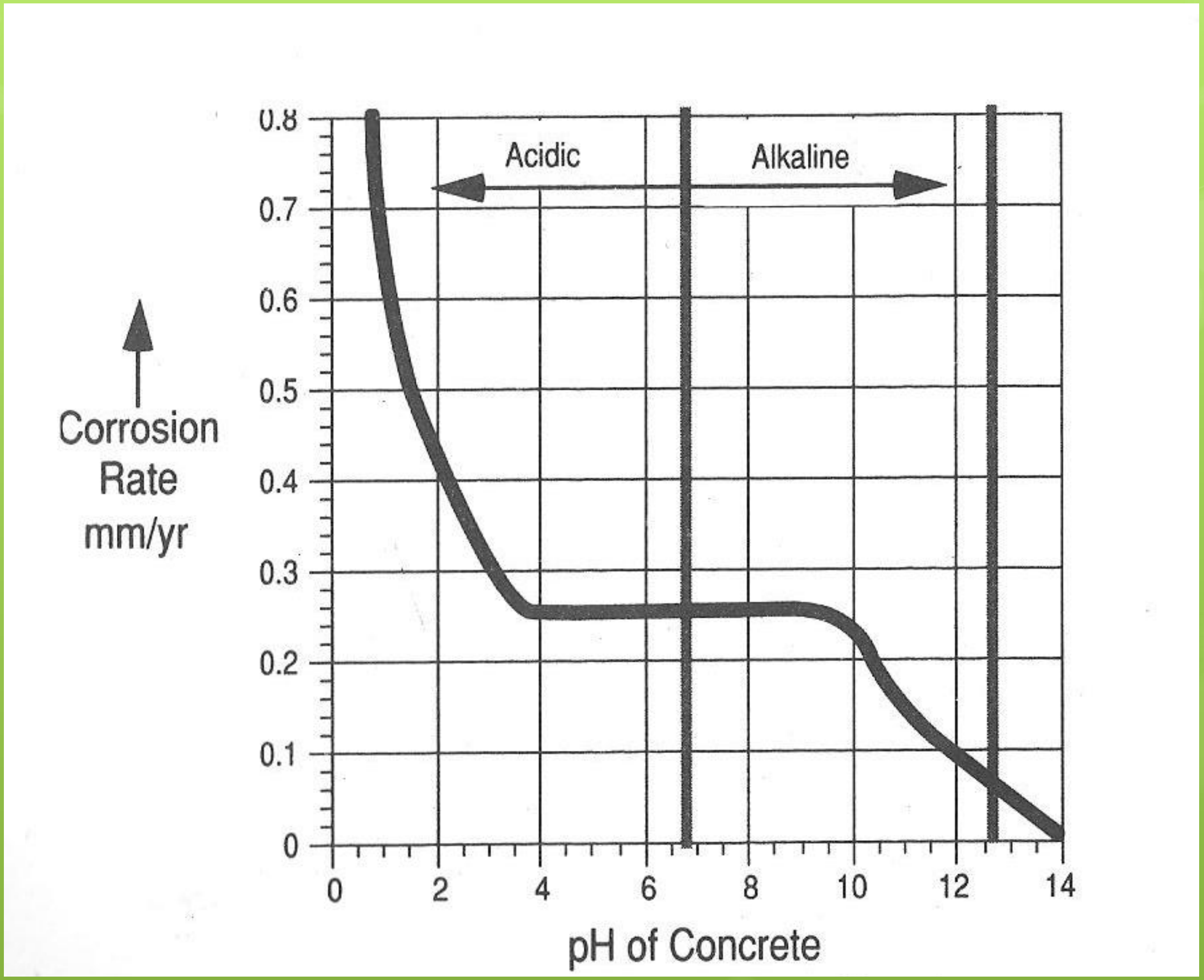
Unit II (b) : Corrosion of Steel Reinforcement

- Causes
- Mechanisms
- Prevention

Corrosion of Steel Reinforcement

Embedded Metal Corrosion Process

Embedded Metal Corrosion Process



Metal Corrosion is highly dependent on the pH of concrete

Embedded Metal Corrosion Process

Concrete is a high alkaline - pH of fresh concrete is between 12 and 13.

In this range of alkalinity, embedded steel is protected from corrosion by a passivating film bonded to the reinforcing bar surface.

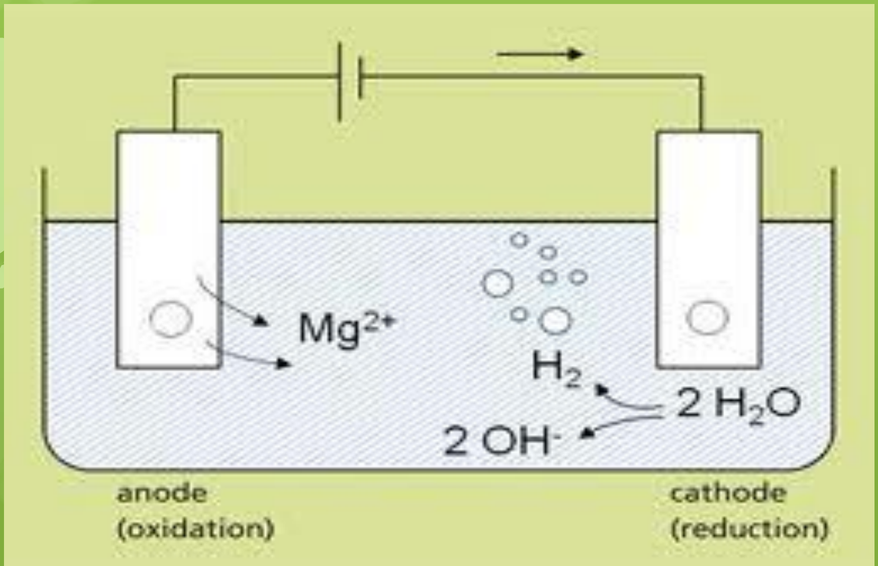
However, when the passivating film is disrupted, corrosion may take place.

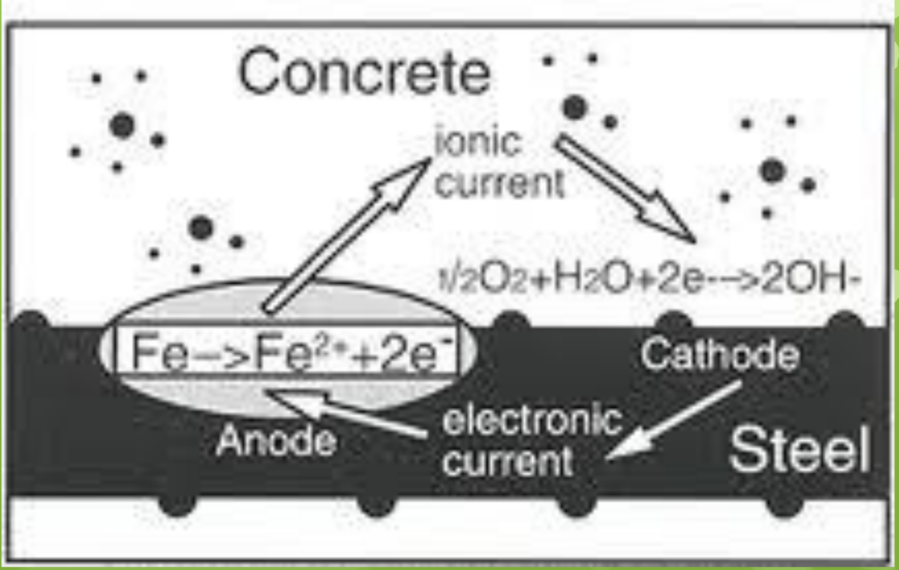
Embedded Metal Corrosion Process

- An Electrochemical Process

An electrochemical process requires an anode, cathode and an electrolyte.

Moist Concrete forms an Electrolyte.
Steel reinforcement provides anode and cathode.

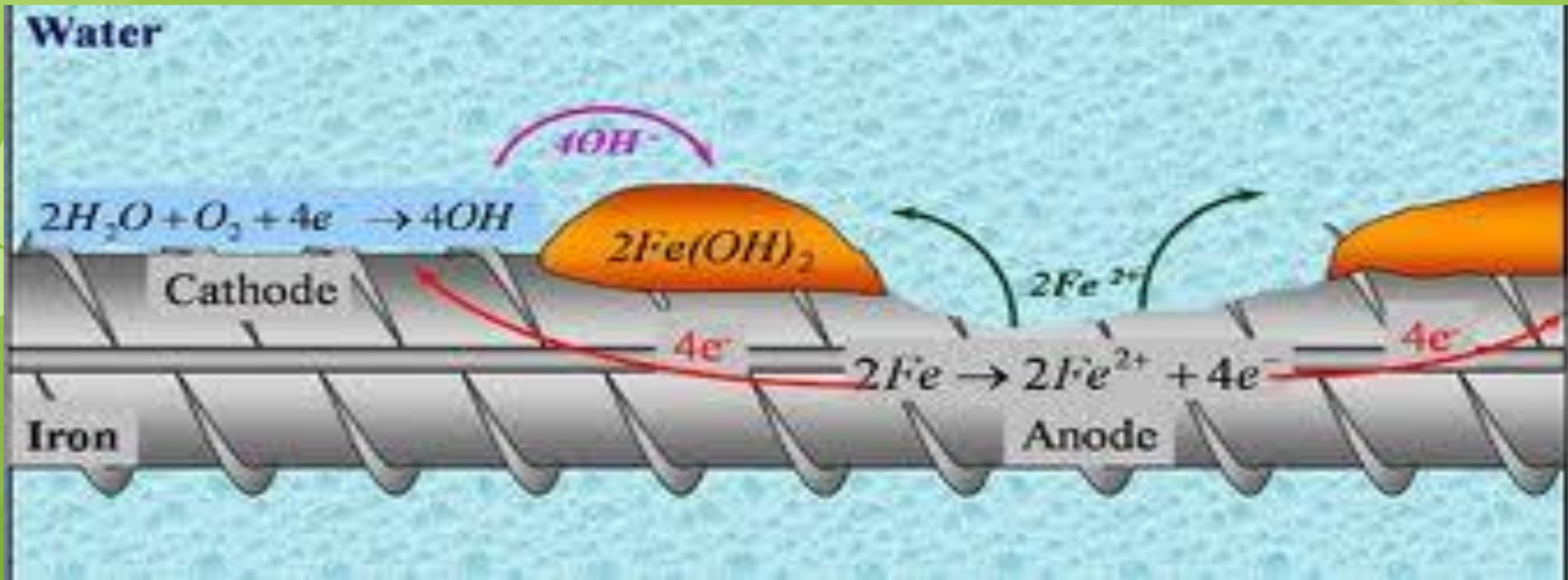




Embedded Metal Corrosion Process

- An Electrochemical Process

Electrical current flows between the cathode and anode, and the reaction results in an increase in metal volume as the Fe (Iron) is oxidized into $Fe(OH)_2$ and $Fe(OH)_3$ and precipitates as FeO OH (rust color). Water and oxygen must be present for the reaction to take place.



Embedded Metal Corrosion Process

- Contributing Factors

In good quality concrete the corrosion rate will be slow.

Accelerated corrosion will take place if

- the pH (alkalinity) is lowered (carbonation)
- if aggressive chemicals or dissimilar metals are introduced into the concrete
- presence of stray electrical currents and concentration cells caused by an uneven chemical environment.

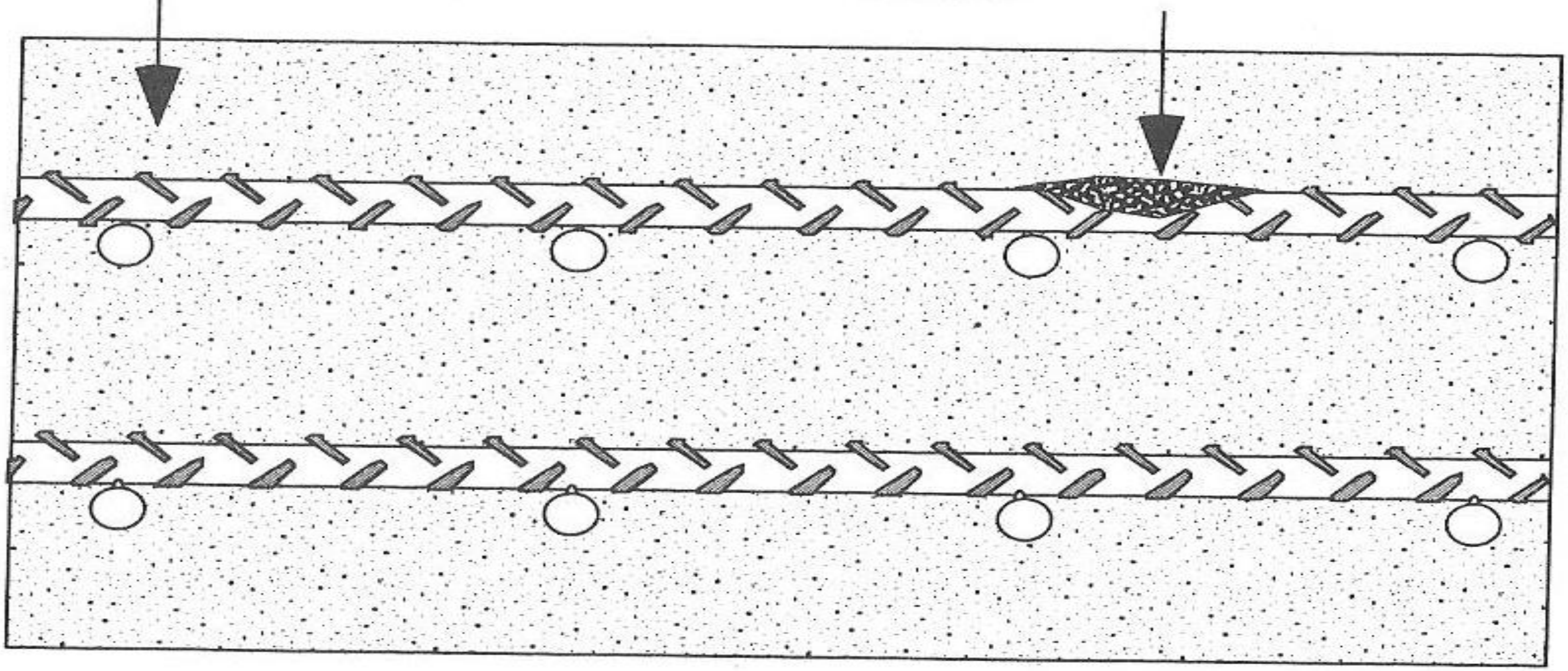
Corrosion Inhibitors

High quality concrete

High pH (Alkalinity) ccncrete protects steel surface from corrrosion.

Corrosion Promoters:

- -Oxygen
- -Water
- -Stray electrical currents
- -Uneven chemical environment around reinforcement
- -Environments that lower the pH (alkalinity)
- -Chlorides



Corrosion of Steel Reinforcement

Effects on Reinforcement Corrosion

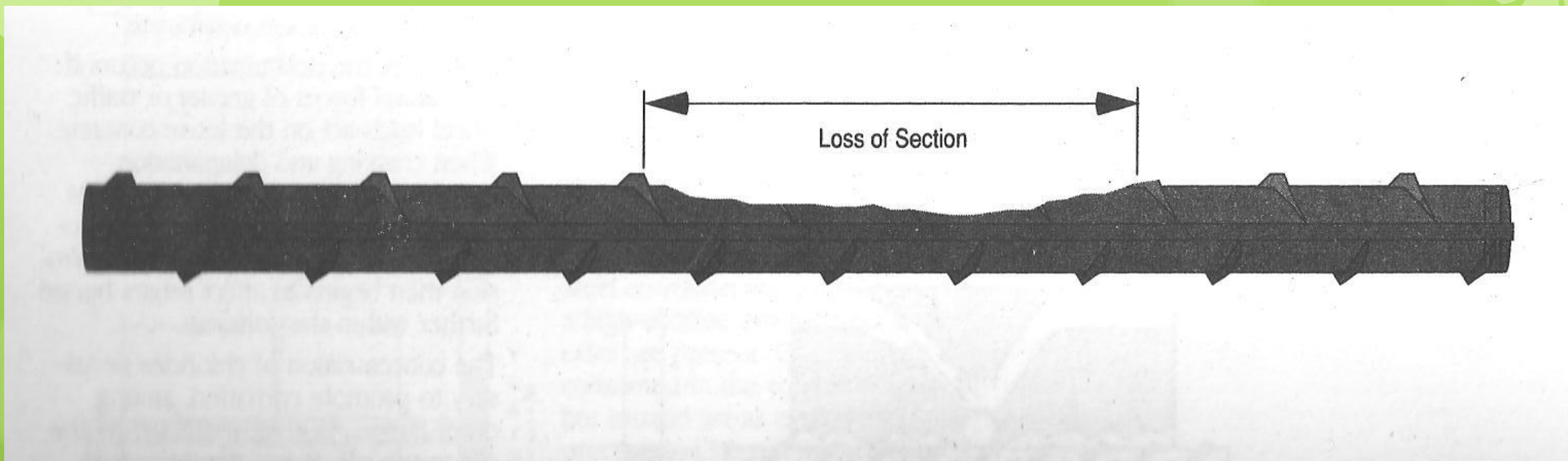
Effects of Rebar Corrosion

1- Cracking and Spalling

In compressive members, cracking and spalling of concrete reduces the effective cross section of the concrete, thereby reducing the ultimate compressive load capacity.

Effects of Rebar Corrosion

2- Reduction of Structural Capacity



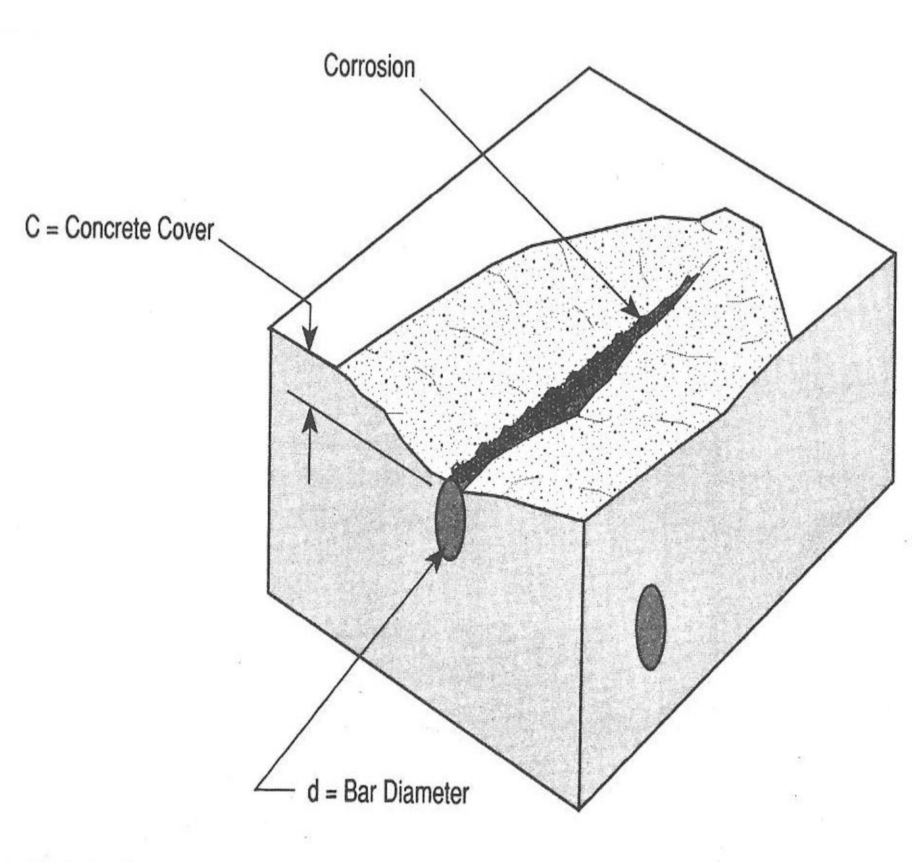
The research conducted on flexural beams found that in steel with more than 1.5 percent corrosion, the ultimate load capacity began to fall, and at 4.5 percent corrosion, the ultimate load was reduced by 12 percent probably as a result of reduced bar diameter.

ACI Structural journal, March-April 1990, p.220

Embedded Metal Corrosion

- Factors Influencing Cracking and Spalling

1. Concrete tensile strength
2. Quality of concrete over the reinforcing bar
3. Bond or condition of the interface between the rebar and surrounding concrete.
4. Diameter of the reinforcing bar
5. Percentage of corrosion by weight of the reinforcing bar.



Embedded Metal Corrosion

- Factors Influencing Cracking and Spalling

With the cover-to-bar diameter ratio (C/D) of 7, concrete cracking starts when corrosion reaches 4 percent, whereas, with a (C/D) ratio of 3, only 1 percent corrosion is enough to crack the concrete

C/D Ratio	Cover in./mm	Bar Size	Corrosion % to Cause Cracking
7	3.5/89	#4	4%
3	1.5/38	#4	1%

Effects of Rebar Corrosion

- Cracking and Spalling

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Corrosion of Steel Reinforcement

Chloride Induced Corrosion

Embedded Metal Corrosion

- Induced by Chloride Penetration

Source of Chlorides:

Environments containing chlorides, such as sea water or de-icing salts.

Penetration rate of chlorides into concrete depends on:

- The amount of chlorides coming into contact with concrete.
- The permeability of the concrete.
- The amount of moisture present.

Embedded Metal Corrosion

- Chloride Penetration Mechanism

The concentration of chlorides in contact with the reinforcing steel will cause corrosion when moisture and oxygen are present. As the rust layer builds, tensile forces generated by the expansion of the oxide cause the concrete to crack and delaminate.

Spalling of the delamination occurs if the natural forces of gravity or traffic wheel loads act on the loose concrete. When cracking and delamintaion progress, accelerated corrosion takes place because of easy access of corrosive salts, oxygen and moisture.

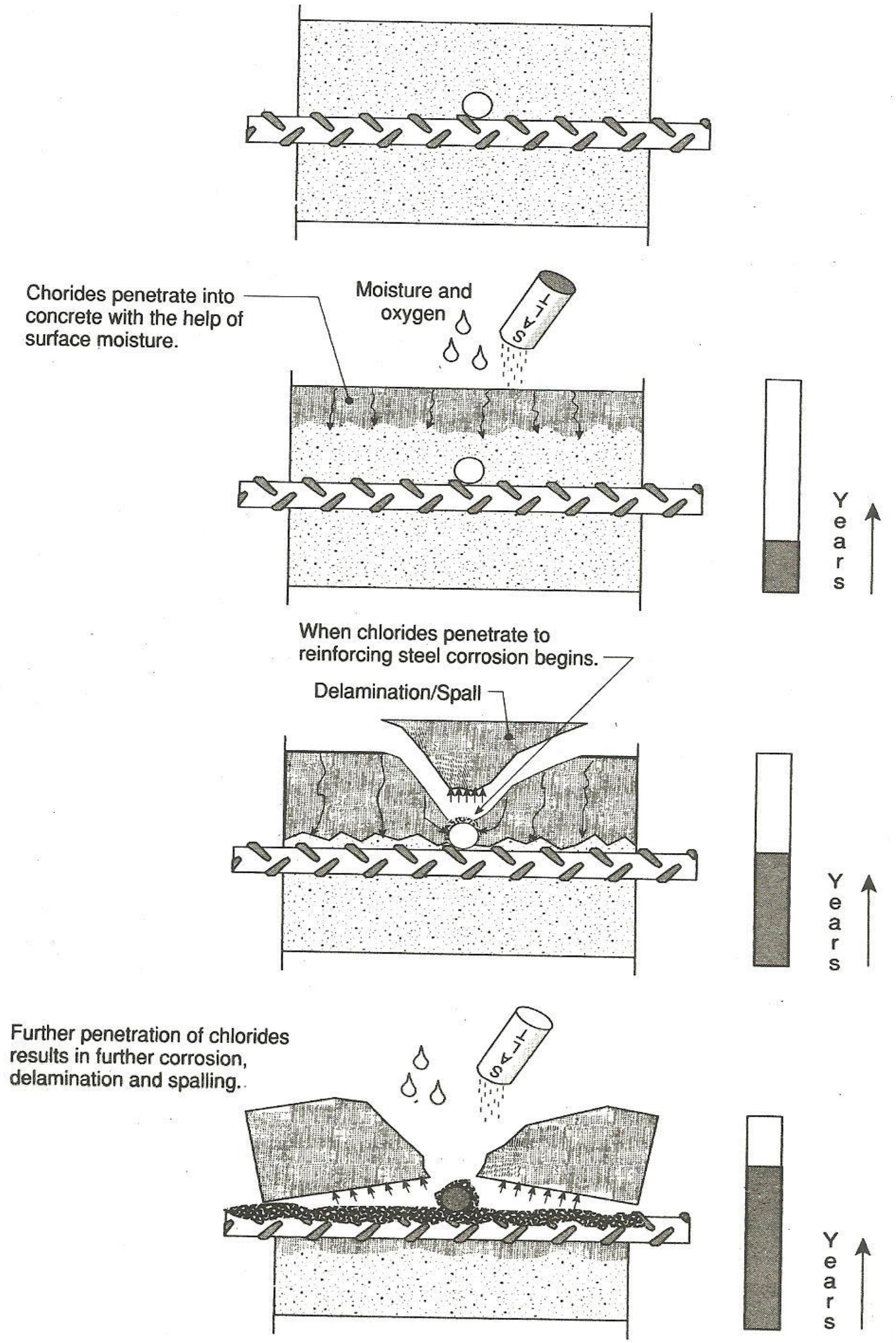
Corrosion then begins to affect rebars buried further within the concrete.

Embedded Metal Corrosion

- Chloride Penetration Mechanism

Influence of pH:

The concentration of chlorides necessary to promote corrosion is greatly affected by the concrete's pH. It was demonstrated that a threshold level of 8000 ppm of chloride ions was required to initiate corrosion when pH was 13.2. As the pH was lowered to 11.6 corrosion was initiated with only 71 ppm of chloride ions.



Embedded Metal Corrosion

- Chlorides through de-icing salts

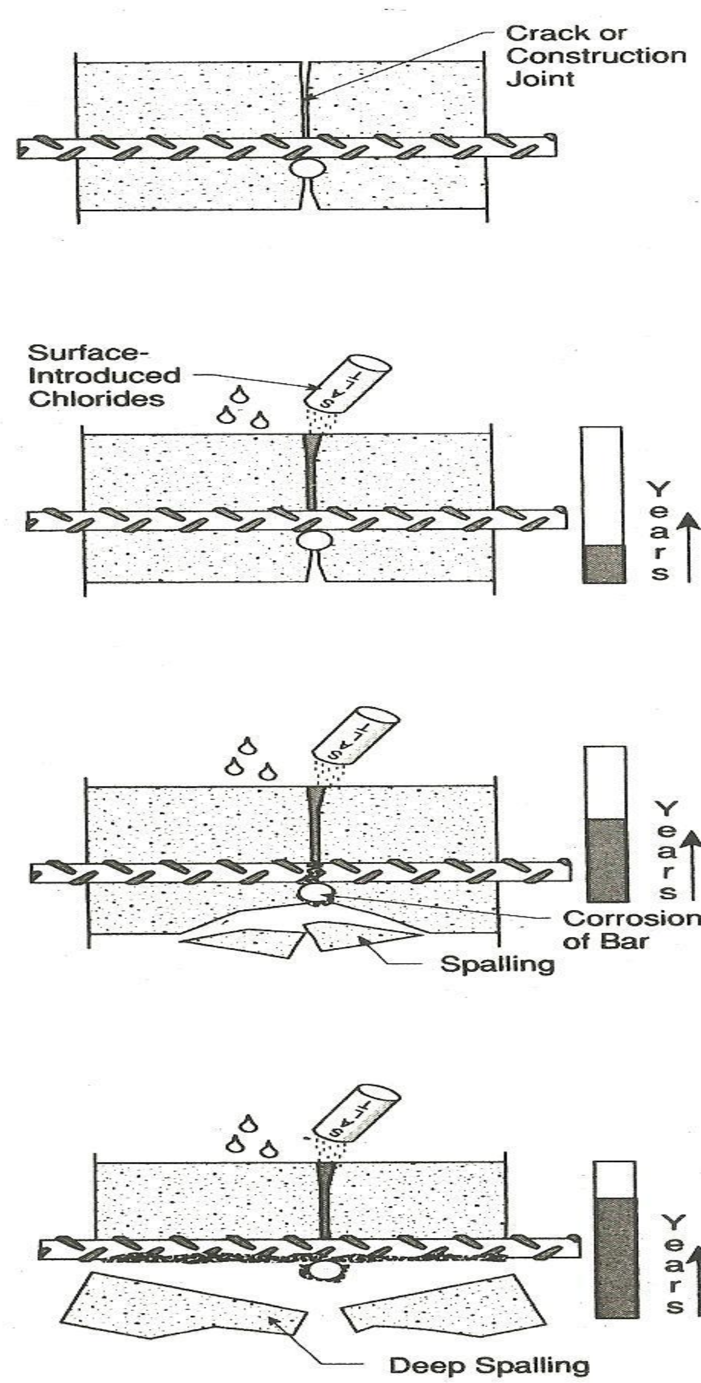
Cracks and construction joints in concrete permit corrosive chemicals such as de-icing salts to enter the concrete and access embedded reinforcing steel.

Embedded Metal Corrosion

- Chloride Penetration aided by cracks and construction joints

Tolerable crack widths to avoid rebar corrosion

Exposure Condition	Tolerable Crack Width (In.)	(mm)
Dry air, protective membrane	0.016	0.41
Humidity, moist air, soil	0.012	0.30
De-icing chemicals	0.007	0.18
Seawater and seawater spray; wetting and drying	0.006	0.15
Water-retaining structures*	0.004	0.10



Embedded Metal Corrosion

Cast - in Chlorides

Chlorides cast into the concrete.

Chlorides may be introduced deliberately as a accelerator, or in the form of natural ingredients found in some aggregates.

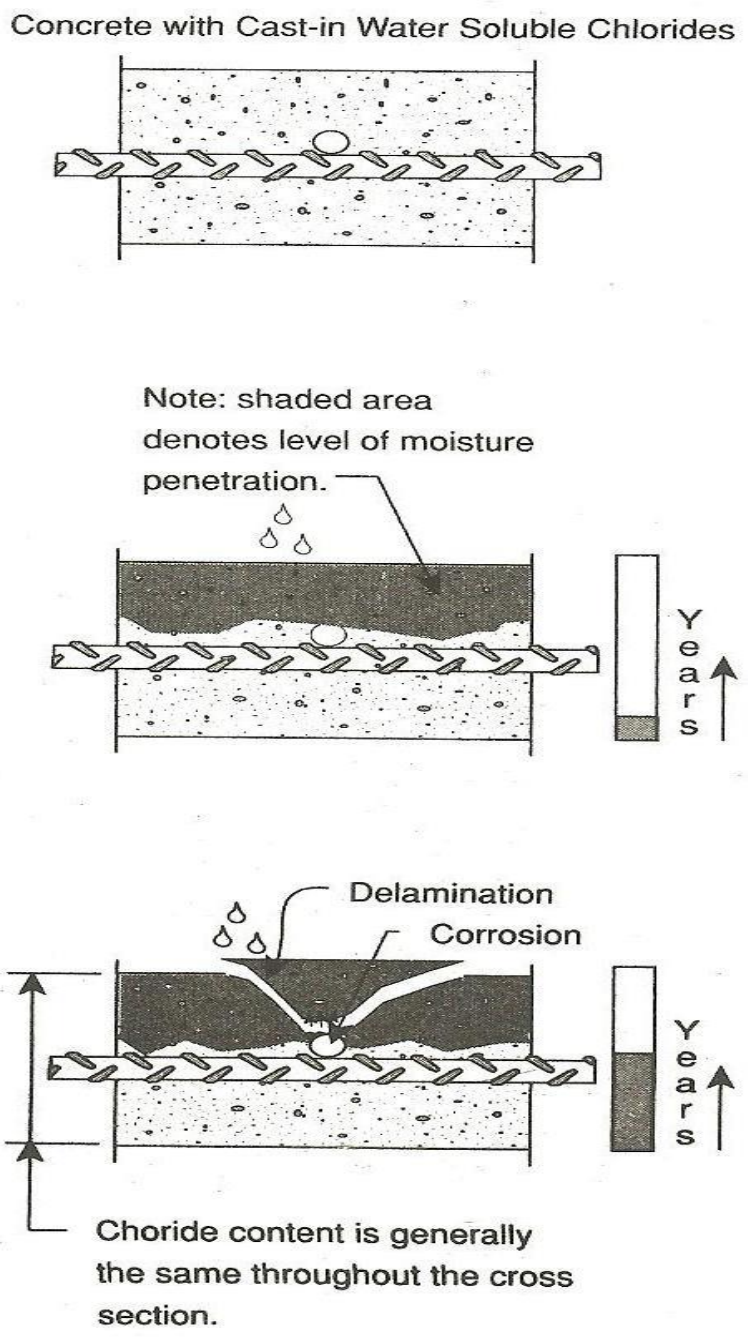
Concrete made of beach sand or having seawater for mixing water will result in cast-in chlorides.

Chlorides occur in either water soluble or acid soluble form. Chlorides used as admixtures are water soluble, while those found in aggregate sources may be only acid soluble. Water soluble chlorides are the most damaging, since they readily become free to attack surrounding reinforcing steel.

Embedded Metal Corrosion

Cast - in Chlorides limits suggested by ACI

Service condition	% of CI to weight of cement
Prestressed concrete	0.06
Conventionally reinforced concrete in a moist environment and exposed to chloride	0.10
Conventionally reinforced concrete in a moist environment not exposed to chloride	0.15
Above-ground building construction where concrete will stay dry	No limit



Corrosion of Steel Reinforcement

Carbonation aids Corrosion

Embedded Metal Corrosion

Carbonation aids Corrosion

What is carbonation?

Carbonation is the formation of calcium carbonate (CaCO3) by a chemical reaction in the concrete.

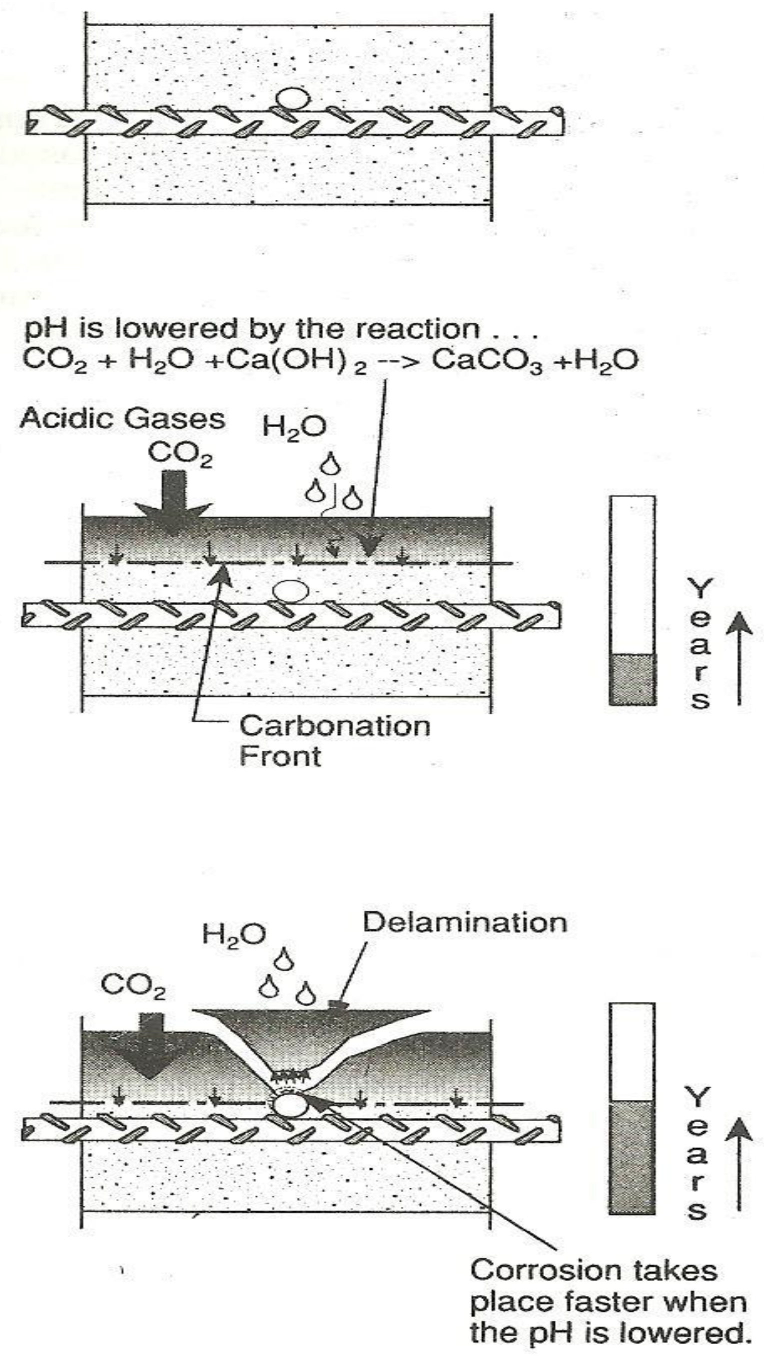
The creation of calcium carbonate requires three equally important substances: carbon dioxide (CO_2), calcium phases (Ca), and water (H_2O). Carbon dioxide (CO_2) is present in the surrounding air, calcium phases (mainly $Ca(OH)_2$ and CSH) are present in the concrete, and water (H_2O) is present in the pores of the concrete.

Cement Carbonation -reduces pH of concrete

When these reactions take place the pH value will start falling. The normal pH-value of concrete is above 13 and the pH-value of fully carbonated concrete is below 9.

Once the carbonation process reaches the reinforcement, and the pH-value drops beneath 13 the passive "film" on the re-bars will deteriorate and corrosion will initiate on the reinforcement.

In good quality concrete, the carbonation process is very slow. It has been estimated that the process will proceed at a rate up to 0.04in. (1mm) per year. The process requires constant change in moisture levels from dry to damp to dry.



Corrosion of Steel Reinforcement

Dissimilar Metal Corrosion

Embedded Metal Corrosion

Dissimilar Metal Corrosion

Also called as **galvanic corrosion**

Corrosion can take place in concrete when two different metals are cast into a concrete structure, along with an adequate electrolyte. A moist concrete matrix provides for a good electrolyte.

Different metals have different rates of electrochemical activity.

Below is a list of metals in increasing order of activity:

1. Zinc
2. Aluminum
3. Steel
4. Iron nickel
5. Tin
6. Lead
7. Brass
8. Copper
9. Bronze
10. Stainless steel
11. Gold

Embedded Metal Corrosion

Dissimilar Metal Corrosion

Also called as **galvanic corrosion**

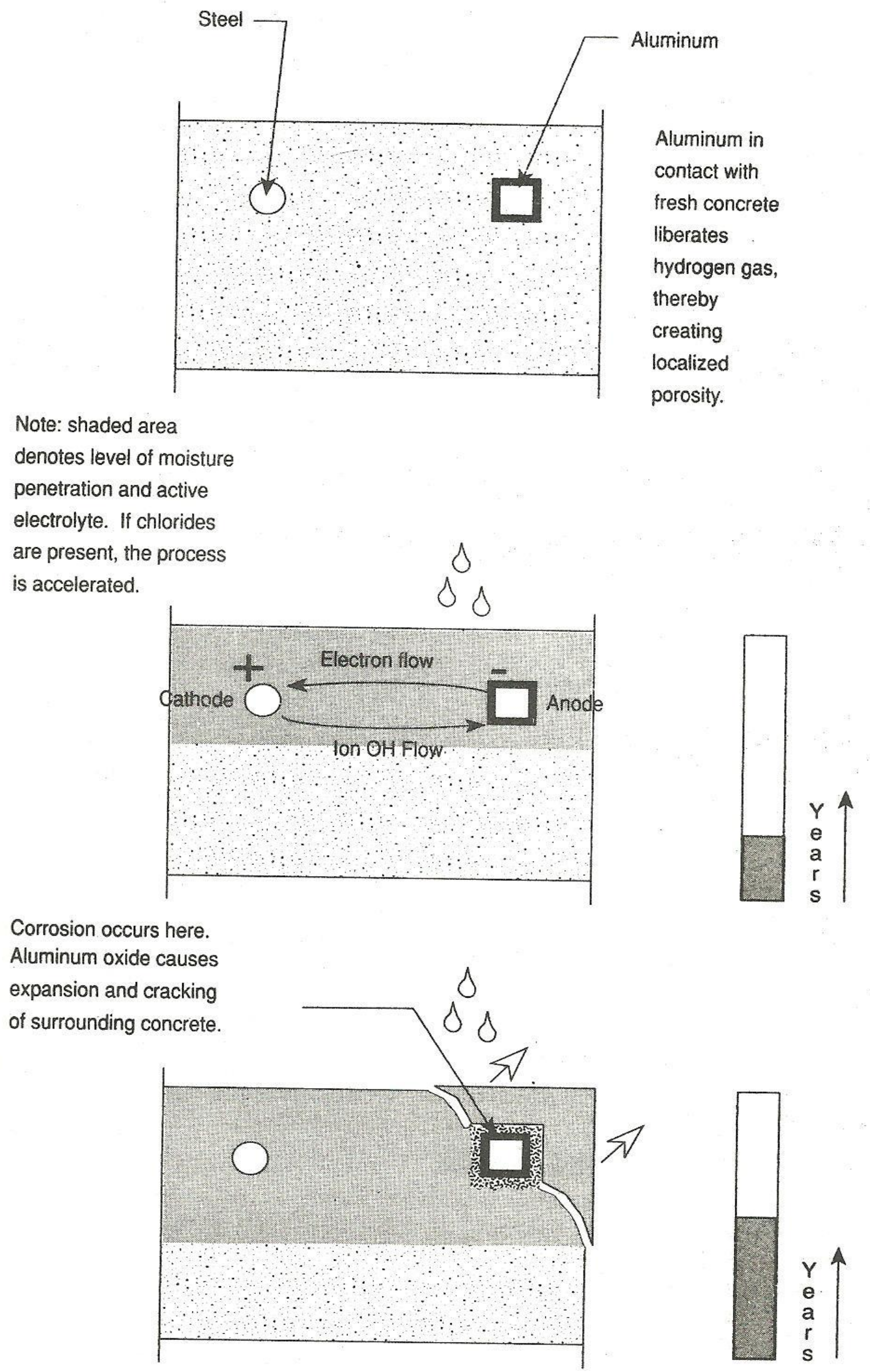
When two metals are in contact via an active electrolyte, the less active metal (lower number) in the series is corroded.

One of the most common situations found in concrete is the use of aluminum cast into reinforced concrete.

Aluminum has less activity than steel; therefore, the aluminum Is the metal that corrodes. The steel will actually become cleaned, and the aluminum surfaces will grow a white oxide, which will cause tensile forces to crack the surrounding concrete.

Embedded Metal Corrosion

Dissimilar Metal Corrosion Mechanism



Corrosion of Steel Reinforcement

Prevention

PREVENTION METHODS

1) Keep concrete always dry, so that there is no H_2O to form rust. Also aggressive agents cannot easily diffuse into dry concrete. If concrete is always wet, then there is no oxygen to form rust.

2) A polymeric coating is applied to the concrete member to keep out aggressive agents. A polymeric coating is applied to the reinforcing bars to protect them from moisture and aggressive agents. The **embedded epoxy-coating on steel bars provide a certain degree of protection to the steel bars and,** thereby, delay the initiation of corrosion. These coatings permit movement of moisture to the steel surface but restrict oxygen penetration such that a necessary reactant at cathodic sites is excluded.

3) Stainless steel or cladded stainless steel is used in lieu of conventional black bars.

PREVENTION METHODS (contd…)

4) **FLY ASH : Using a Fly Ash concrete with very low permeability,** which will delay the arrival of carbonation and chlorides at the level of the steel reinforcement. Fly Ash is a finely divided silica rich powder that, in itself, gives no benefit when added to a concrete mixture, unless it can react with the calcium hydroxide formed in the first few days of hydration. Together they form a calcium silica hydrate (CSH) compound that over time effectively reduces concrete diffusivity to oxygen, carbon dioxide, water and chloride ions.

5) A portion of the chloride ions diffusing through the concrete can be sequestered in the concrete by combining them with the tricalcium aluminate to form a calcium chloro-aluminate (Friedel's salt). It can have a significant effect in reducing the amount of available chlorides thereby reducing corrosion.

6) **Electrochemical injection of the organic base corrosion inhibitors, ethanolamine and guanidine,** into carbonated concrete.

PREVENTION METHODS (contd…)

7) The rougher the steel surface, the better it adheres to concrete. oxidation treatment (by water immersion and ozone exposure) of rebar increases the bond strength between steel and cement paste to a value higher than that attained by clean rebars. In addition, surface deformations on the rebar (such as ribs) enhance the bond due to mechanical interlocking between rebar and concrete.

8) As the cement content of the concrete increases (for a fixed amount of chloride in the concrete), more chloride reacts to form solid phases, so reducing the amount in solution (and the risk of corrosion), and as the physical properties improve, the extent of carbonation declines, so preventing further liberation of chloride from the solid phase.

9) **Electrochemical Chloride Extraction (ECE) is a relatively new technology for which long-term** service data are limited. This method employs a temporary anode that is operated at current density

THANK YOU