LECTURE NOTES

ON

REHABILITATION & RETROFITTING OF STRUCTURES

B. Tech VII Sem (IARE-R16)

PREPARED BY

Mr. A.JAGADISH BABU

ASSISTANT PROFESSOR

Department of Civil Engineering

INSTITUTE OF AERONAUTICAL ENGINEERING

(Autonomous)

Dundigal – 500 043, Hyderabad

UNIT - I

INTRODUCTION

Defects: These are the flaws that are introduced through poor design, poor workmanship before a structure begins its design life or through inadequate operation and maintenance during its service life.

Repair: Process of reconstruction and renewal of the existing buildings, either in whole or in part.

Renovation: Process of substantial repair or alteration that extends a building's useful life.

Remodeling: Essentially same as renovation – applied to residential structures.

Rehabilitation: An upgrade required to meet the present needs – being sensitive to building features and a sympathetic matching of the original construction or the process of repairing or modifying a structure to a desired useful condition.

Restoration: The process of re-establishing the materials, form and appearance of a structure.

Renovation: Process of substantial repair or alteration that extends a building's useful life.

Remodeling: Essentially same as renovation – applied to residential structures.

Rehabilitation: An upgrade required to meet the present needs – being sensitive to building features and a sympathetic matching of the original construction.

Strengthening: The process of increasing the load-resistance capacity of a structure or portion.

Retrofitting: The process of strengthening of structure along with the structural system, if required so as to comply all relevant codal provisions in force during that period.

Demolition: The process of pulling down of the structure not deemed to be fit for service.

Need for Repair and Rehabilitation of Structures:

The extent of deterioration to concrete structures globally is occurring at an alarming rate. It is now been confirmed that even if the structural design abides by all the specific building code requirements like the concrete quality, cover etc., there is still an acceptable high risk of deterioration of concrete and corrosion of reinforcement. Steel corrosion is found to be most severe cause of deterioration of reinforced concrete that can create cracks, spalls the concrete cover, reduce the effective c/s area of the reinforcement and lead to collapse.

The following facts clearly reveal the current status of the existing infrastructure degradation

- In USA about 40% of the highway bridges, about 3,00,000 have been rated as structurally deficient or functionally obsolete or both need about US $100 billion as estimated expenditure to improve the service life and performance level.

- The situation in India is not better. The reliable figures for estimated expenditure are not available, but it is substantially very high.

The list of possible causes of distress and deterioration in concrete is a long one. The success of any repair program depends upon the correct detection of this distress and deterioration, and cause that lead to deterioration. A rationale approach to any repair and rehabilitation work is to consider the source of the problem and the symptoms together.

The repaired and cured structure has to extend its life for a desirable period. The repair of the repaired structure must be avoided.

Difference between defects, distress and deterioration

Defects: The defects are the flaws those creeps into structure because of design mistakes or poor workmanship during manufacturing, fabrication and construction, before it begins its service life, or by inappropriate operation and maintenance during its service life. **The flaw that has a potential to lead to a failure, becomes a defect.**

Distress: It is a collective term for the physical manifestation of problems such as cracks, spalls, pop-outs, staining, decay or corrosion. **Distress can be thought of as the symptoms indicating that the defects are present.**

Deterioration: It is the gradual loss of the desired material properties due to different degradation factors. Deterioration unlike defects, may not surface at the beginning of the service life of a structure, but is rather time-dependent. However, some forms of deterioration may develop early in the service life of structure and others manifest later.

Fig. 1 Deterioration of concrete cover

Fig. 2 Load induced deterioration

Road Map to Repair of Structures

The objective of any repair/rehabilitation or strengthening works is to enhance the performance of the structure, extend the service life or increase the load carrying capacity. A rational approach to any repair and rehabilitation work is to consider the source of the cause of the deterioration and symptoms together because treating only the symptoms without adequate understanding of the cause of the problems leads to defects camouflaged beneath the finishes. In any circumstances, the repair of repairs has to be clearly avoided. This can be achieved only if the repair work is carried as per the following steps:

- Condition Evaluation
- Determination of the cause of the deterioration
- Selection of repair methods and materials
- Preparation of drawings and specifications
- Bid and negotiation process
- Execution Process
- Appropriate quality control measures
- Maintenance after completion of the repair works

Problems to be Addressed

- Aging of structures-Expected life and performance
- Deterioration of concrete-causes and effects
- Durability considerations
- Distress diagnostics and performance monitoring-Non-Destructive test methods.
- Damage assessment and evaluation models
- Structural condition assessment
- Analysis and Design of repairs-suitable repair techniques
- Materials for protection, repair and rehabilitation
- Repair Techniques-Shotcreting, guniting etc
- Refurbishment and Strengthening techniques

- Seismic retrofitting
- Bridge rehabilitation

Durability and Permeability Aspects of Concrete

The survey shows that an increase in the strength of cement or concrete has most of the time being accompanied by the corresponding increase in pre-mature deterioration problems. The pre-mature deterioration has been observed even when the concrete construction has been carried out following the best of the practice in terms of its constitution, placement, curing. The other factors that contribute to pre-mature deterioration is the use of cements with higher amount of C3S, increasing the fineness of cement and high w/c ratio, all with common end purpose to gain very high and early strength of concrete.

A durable concrete as per IS 456:2000 is one that performs satisfactorily in the working environment during its anticipated exposure condition during its service life.

Mechanism of Deterioration

Most of the degradation processes encountered by concrete structures such as corrosion, alkali aggregate reaction, sulfate attack and many other types of physical and chemical deterioration, require water, dissolved chemicals and presence of oxygen.

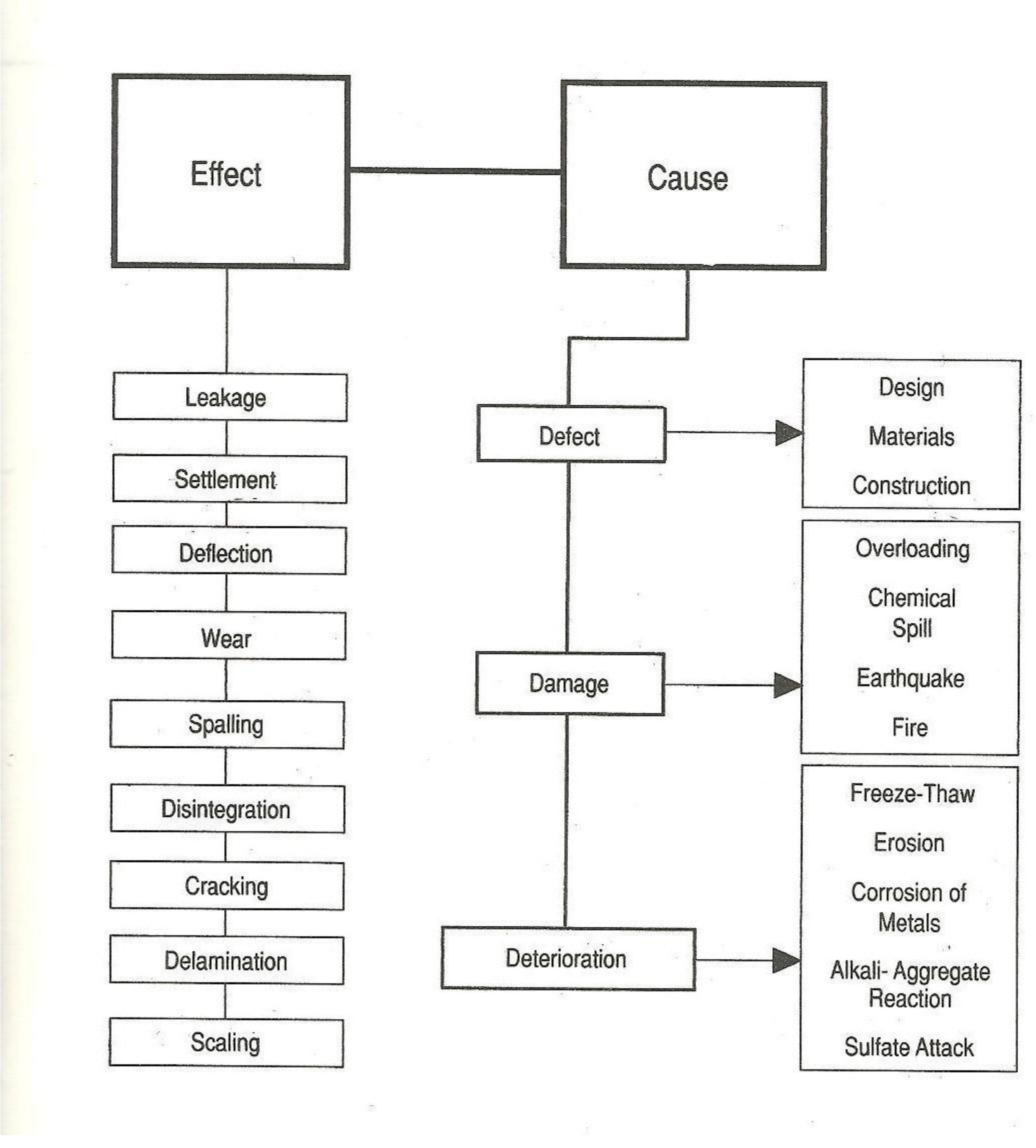
The two main factors, water tightness and durability of concrete have a major bearing in the resistance of the RCC structures to physical and chemical deterioration. The concrete used in RCC is considered to be substantially water tight and gives enduring performance till the time the capillary pores and micro-cracks ingrained inside the concrete joins with cracks developed due to environmental attack.

The interfacial transition zone which is the region between the coarse aggregate particles and the bulk hydrated cement paste plays a major role in degradation.

When the concrete mixture is consolidated after placement, along with the entrapped air, a part of the mixing water is also released. The released water travels to the surface of concrete owing to its low density. However, all the bleeding water is not able to find its way to the surface. Due to wall effect of coarse aggregate particles, water films get formed around the particles. This accounts for higher w/c ratio in the vicinity of the aggregate surfaces causing a heterogeneous distribution of water in the system. The dissolution of calcium sulphate and calcium aluminate compounds during hydration process produces calcium sulphate, hydroxyl, and aluminate ions that combine to form ettringite and calcium hydroxides (Ca(OH)2) in the adjacent region of aggregate as in the bulk paste.

Owing to higher w/c ratio these crystalline products continue to grow to relatively large crystals in the vicinity of the aggregate. The process of the formation of more porous framework also continues in tandem owing to the evaporation of more water. The interfacial transition zone being porous and weak is susceptible to cracking when subjected to tensile stresses induced by differential movements arising due to the structural loading as well as due to weathering effects, such as exposure to cycles of heating and cooling, wetting and drying leads to the formation of the micro-cracks. Thus concrete has micro-cracks in the interfacial transition zone, even before the structure is loaded.

Micro-cracking in the interfacial transition zone not only influence the mechanical properties, but also the permeability and durability of the concrete structures subjected to severe environmental exposure. The process of chemical and physical deterioration of concrete with time or reduction in durability is generally dependent on the presence and transport of the deleterious substances through concrete. Thus permeability of concrete has greater effect on durability of concrete. The rate of fluid transport in concrete is much larger by percolation through an interconnected network of micro-cracks, macro cracks, voids and inherent capillary porosity.



Distress: Distress can be thought of as the symptoms indicating that the defects are present.

Types of Distress

Blow holes- sometimes also bug-holes, are individual rounded or irregular cavities that are formed against the formwork and become visible on stripping of the formwork.

Cold joints- These are created when new concrete is poured against the concrete that has just hardened.

Honey Combing- It refers to voids caused by the mortar not filling the spaces between the coarse aggregate particles.

Crazing- It is the network of fine random cracks that are formed due to the shrinkage of the layer relative to the base concrete. It does not pose any structural or Serviceability problem.

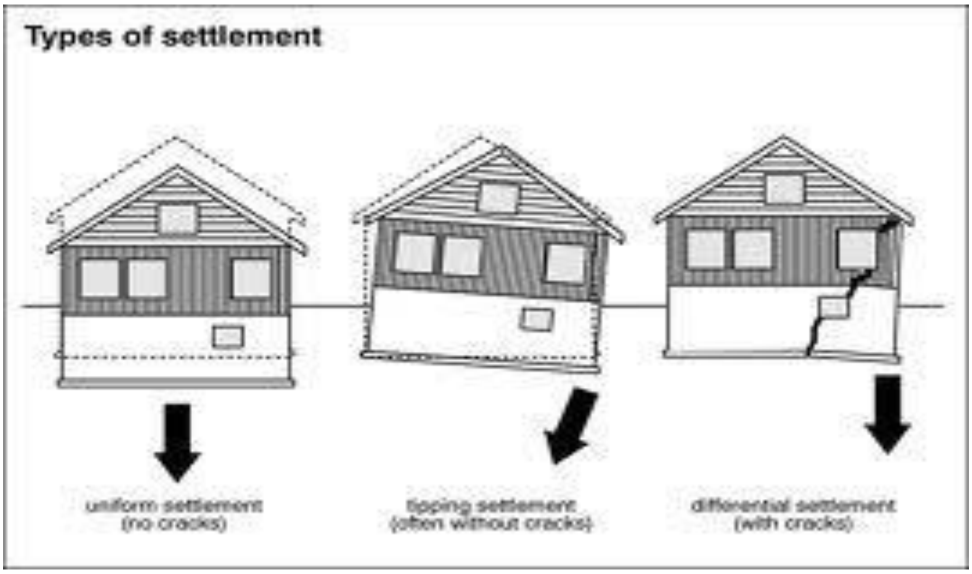
Pop-outs- Rough conical depressions in the concrete surface caused by the expansion of the deleterious aggregate particles near the surface or expansion due to freezing are called pop-outs.

Disintegration two terms generally used to mark this they are Scaling- Localized flaking or peeling away of the near surface portion of the hardened concrete due to freeze thaw, Dusting- White powdery formation on the surface of hardened concrete that receives excessive traffic.

Cracking- Cracking in concrete is inherent. Type of structure and nature of cracking is the major concern. Cracks in the concrete does not always mean that the structure is unusable.

- **Structural Cracks-** Structural cracks are those that may occur due to deficient designs, overloading, abnormal vibrations, use of inferior quality materials, foundation placed on uncompacted/loose soils, adoption of improper construction practices, poor workmanship, etc.

- **Non-Structural Cracks-** These cracks occur due to the internally induced stresses in building material or due to the temperature induced movement of the materials. These cracks mar the appearance of the structure and at time may give a feeling of instability.



Spalling- It is development of the fragments usually in the shape of the flakes, due to corrosion of steel or freeze thaw effects.

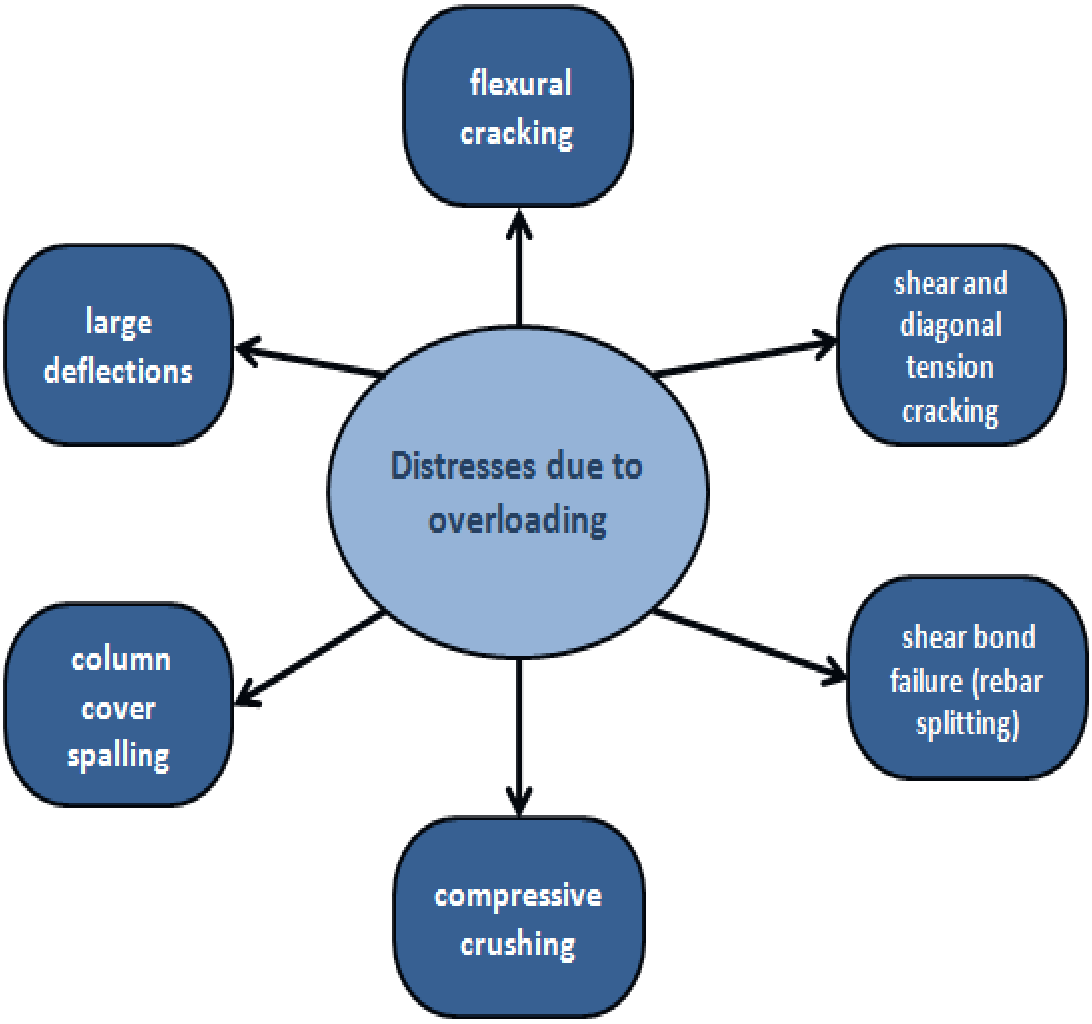
Stain- It is white powdery surface which may be caused by alkali-aggregate reactions. The stain may sometimes be colored due to corrosion of reinforcement.

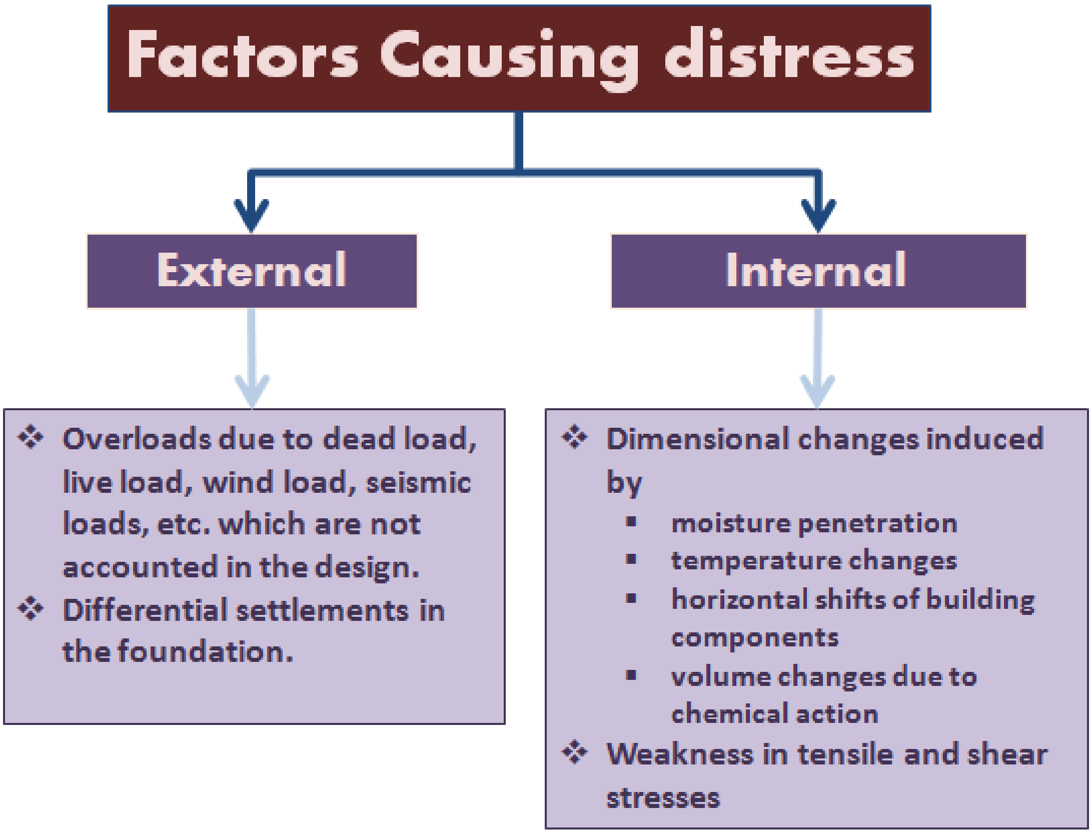
Erosion- It could be due to abrasion, erosion which is marked by smooth, well-worn abraded surface of concrete, while in cavitation- erosion concrete appears to be very rough and pitted.

Corrosion- Rusting of steel in concrete, this results in cracking or spalling.

Deflection-It is the bending or sagging of the reinforced concrete structural elements like beams, slabs, columns, etc., which can be due to overloading, corrosion, or by creep in concrete.

Scaling of Concrete





Possible Causes of Damage

Pre-Construction stage:

- Poor Design
- Poor Design Detailing
- Poor Deflection Estimations
- Faulty Design of Rigid Joints in Precast Elements
- Faulty Design Estimations at changes in section

Preventive Measures: Through careful design by experienced design engineers

- Construction stage
- Local settlement of Subgrade

Mechanism: Pouring fresh concrete some-times may cause subgrade below it to compress or settle. Uneven stresses thus created cause cracks in the concrete.

Preventive Measures

Pour concrete on compacted subgrade to prevent cracking. If the subgrade is not compacted, the soil, and concrete above it, will settle and cause the slab to crack. Most rental companies have equipment available to properly compact the subgrade, and it is well worth the investment.

- **Swelling of formwork**

  Mechanism: Formwork absorbs moisture from concrete or the atmosphere, which results in swelling of form. Crushing of wale in the formwork also causes movements of forms. These result in cracks in the concrete while setting.

  Preventive Measures
  - Coating of the formwork with moisture resistant material.
  - Using unyielding lateral ties with good end anchorage.

- **Internal settlement of cracks**

Mechanism: Differential settlement between the surface and the interior volume of the concrete suspension causes surface cracks. Concrete on the surface sets faster than the interior suspension.

Preventive Measures

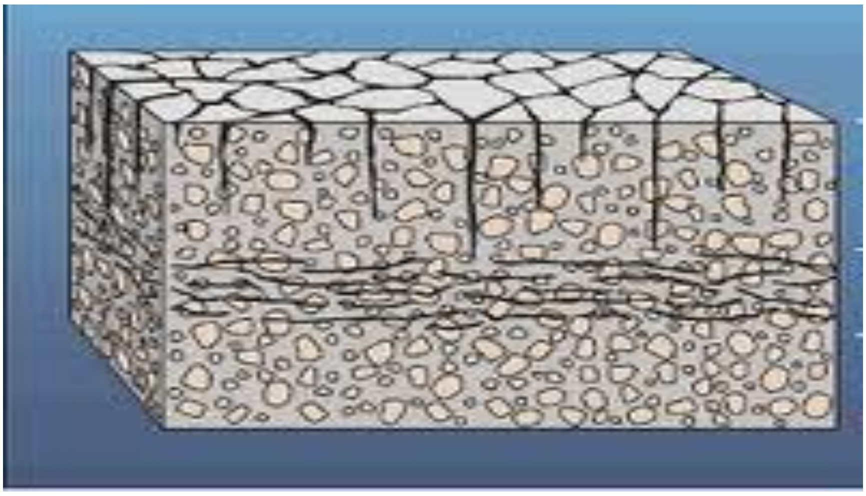
- Surface cracks can be cured and closed by delayed finishing.
- Curing of concrete must start immediately after casting to delay setting of the surface concrete.
- Good compaction will also help prevent this defect.

- **Setting shrinkage**

Mechanism: While setting the concrete shrinks giving rise to surface cracks resembling the scales of the alligator.

Preventive Measures

- ➢ Good and timely curing will help avoid this type of damage.

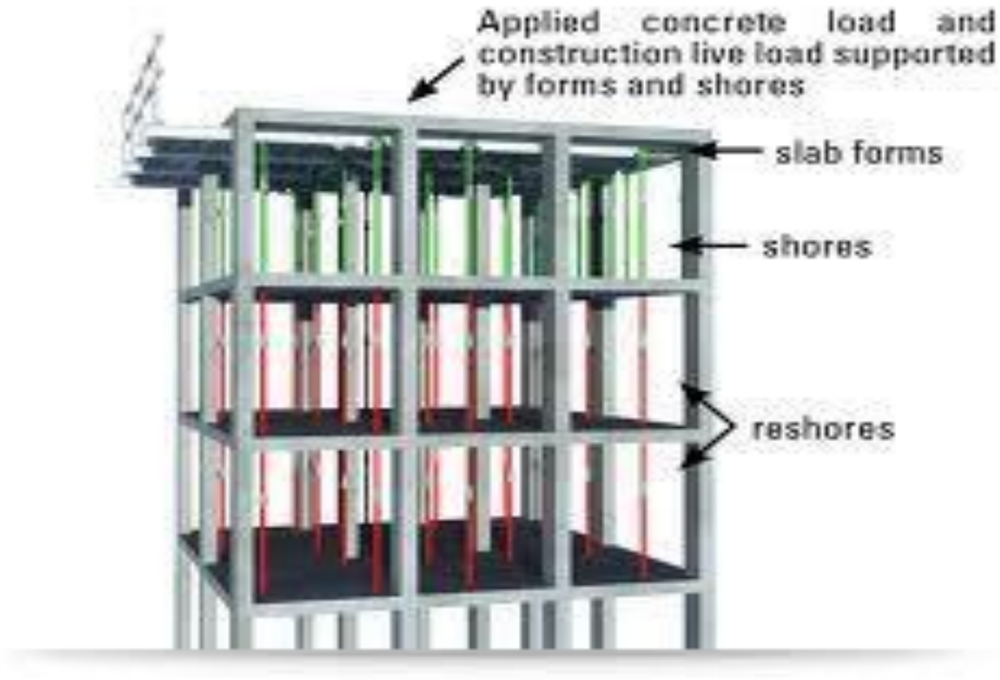


- ➢ **Premature removal of shores**

Mechanism: Premature removal of shores from freshly poured concrete causes re-distribution of stresses on formwork, causing movements and cracking of concrete.

Preventive Measures

- ➢ Shores must be removed only after the concrete has gained sufficient strength.



- **Vibrations**

Mechanism: Vibrations due to indiscreet walking over concrete and dumping construction materials, etc., can also lead to cracking.

Preventive Measures

- Workers have to be trained in avoiding such carelessness
- **Adding Excess water to Concrete mix:** Water that is added to increase slump decreases durability. Excess water added during finishing causes scaling, crazing and dusting of concrete.
- **Improper curing:** Curing is the most abused aspect of concrete construction. Improper curing causes cracking and surface disintegration. It may also lead to structural cracking. Curing of concrete, if not started soon after its placement, results into setting of the surface concrete that leads to differential settlement.
- **Improper timing of finishing of concrete:** Finishing the surface too soon, i.e., toweling when the bleed water is still there leads to formation of cold joints.
- **Inadequate number of joints:** Inadequate number of contraction joints or fails to make expansion joints wide enough to accommodate the temperature expansion results in severe damage.
- **Improper grading of slab surfaces:** Drains in the slabs requiring draining for runoff must be provided at low and not at high points. Improper location of drains or slope-pitch may result into standing water that causes leakages through cracks and joints.

- **Post-Construction stage**
  - Temperature Stresses
  - Corrosion of steel
  - Aggressive action of chemicals
  - Weathering action
  - Overloading
  - Moisture effects
  - Natural disasters
  - Fire

- **Temperature Stresses**

Causes: Cracks in concrete can be produced due to temperature stresses due to:

i. Difference in temperature inside and outside the building.

ii. Variation in the internal temperature due to heat of hydration.

Mechanism: The temperature difference within concrete structure results in differential volume change. When the tensile strain due to differential volume change exceeds the tensile strain capacity of concrete, it cracks. The heat of hydration of cement raises the temperature of concrete, so that the concrete is usually slightly warmer than its surroundings when it hardens resulting into tensile stress and eventually it cracks in different layers.

Preventive measures:

- The finishing of the surface should be such that it reflects solar radiation and not absorbs it.
- Good concrete mix with low heat of hydration
- Allowing for movements by using properly designed contraction joints
- Correct detailing

Corrosion of Reinforcement

Causes: Corrosion of reinforcement bars can be due to: Entry of moisture through cracks, availability of oxygen and moisture at rebar level, carbonation and entry of acidic gaseous pollutants that reduce the pH of concrete, ingress of chloride ions, relative humidity & electrochemical action.

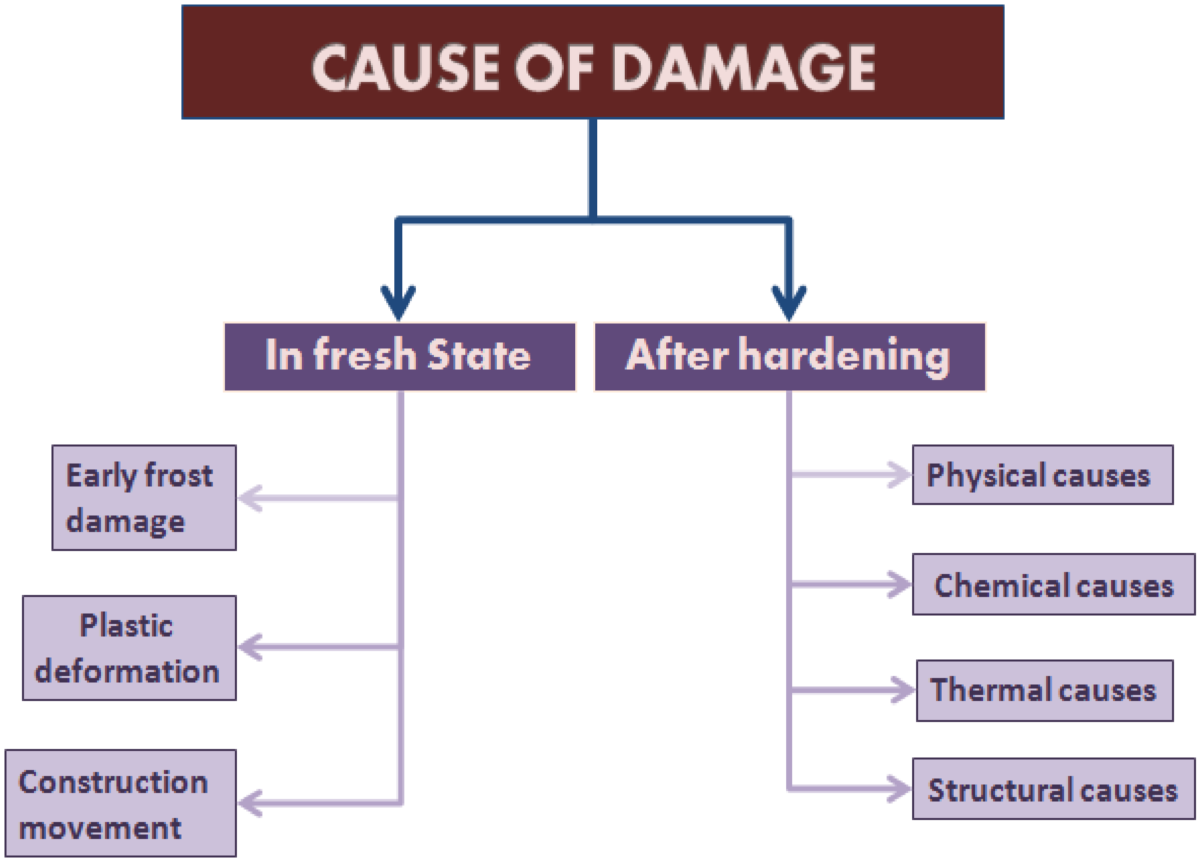
Mechanism of Corrosion: The corrosion process that takes place in concrete is electrochemical in nature very similar to a battery. The mechanism of corrosion involves four basic elements
Anode: Site where metal atoms lose electrons i.e., where corrosion is initiated.
Cathode: Site where electrons flow to and combine with other metallic and non-metallic ion.
Electrolyte: A medium capable of conducting electric current by ionic current flow.

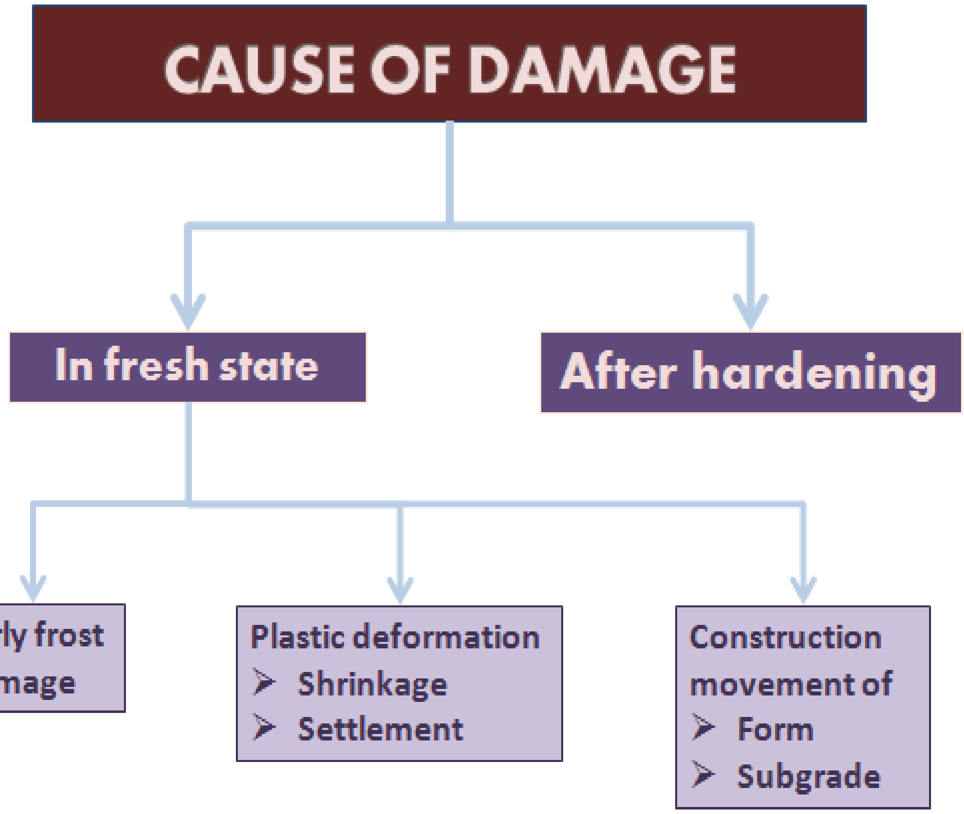
Metallic path: Connection between the anode and cathode that completes the circuit.
At, anode the oxidation process releases Fe^{++} ions to concrete pore solution which flows to cathode to combine with hydroxyl ions to form Ferrous hydroxide, $Fe(OH)_2$. In highly alkaline solution and in absence of chloride ions, the anodic dissolution reaction of iron is balanced by the cathodic reaction. Fe^{2+} ions combine with OH^- ions to produce the stable passive film.

Preventive measures:

- Seal the crack before it reaches the reinforcement bar
- Protect against corrosive chemical action by
  - i. Keeping structures clean
  - ii. Painting
  - iii. Prevent from absorbing moisture
  - iv. Provide bituminous or zinc coatings.
  - v. Encase using fibre wrapping systems .

- Proper finishing


CAUSE OF DAMAGE
In fresh State
After hardening
Early frost damage
Plastic deformation
Construction movement
Physical causes
Chemical causes
Thermal causes
Structural causes


CAUSE OF DAMAGE
In fresh state
After hardening
Early frost damage
Plastic deformation
Shrinkage
Settlement
Construction movement of
Form
Subgrade

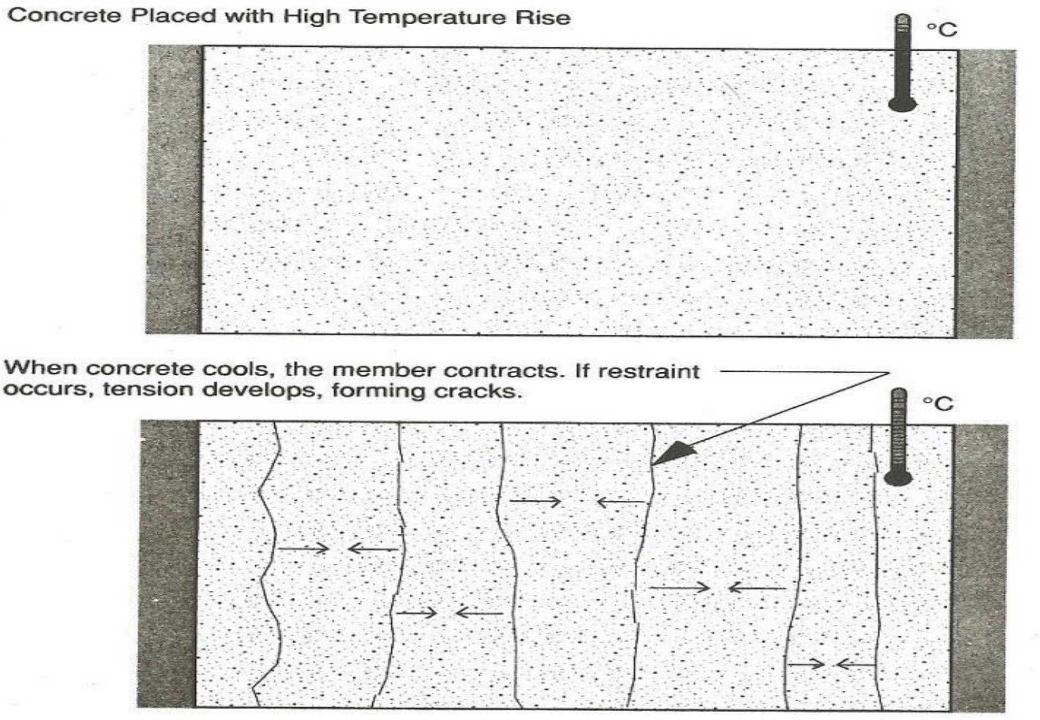
Mechanism of Damage:

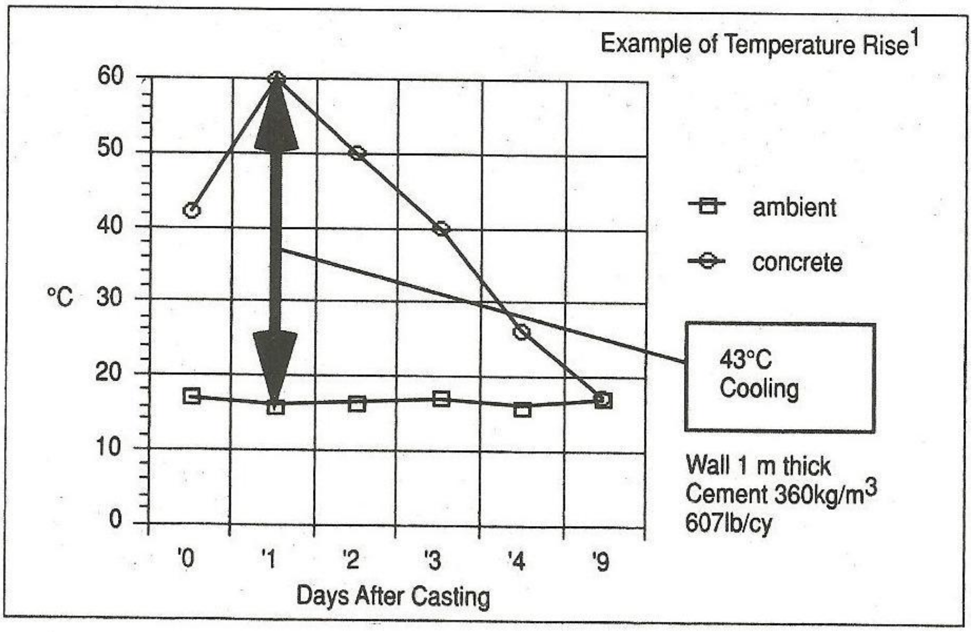
Early Frost Damage: When fresh concrete is exposed to extremely low temperatures, the free water in the concrete is cooled below its freezing point and transforms into ice, leading to a decrease in the compressive strength of concrete. When freezing takes place after an adequate curing time, the decrease in compressive strength does not occur.

Fig.1 Cracks due to Early Frost Damage

Early thermal contraction: Fresh concrete undergoes temperature rise due to cement hydration. When concrete is cooling to the surrounding ambient temperature in a few days, the concrete has very little tensile strength.

Weak tensile strength + thermally contracting concrete = tension cracks



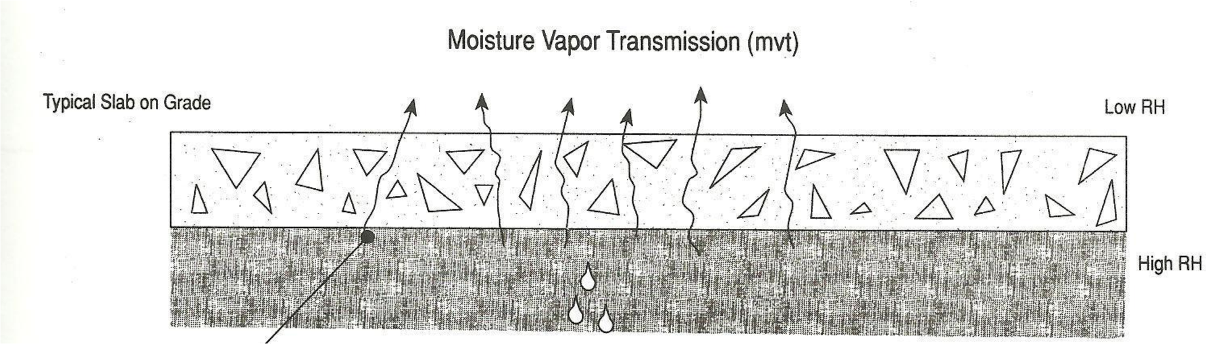


Factors effecting early temperature rise in fresh Concrete:
Initial temperature of materials: Warm materials lead to warm concrete. Aggregate temperature is most critical.
Ambient temperature: Higher ambient temperature leads to higher peaks
Dimensions: Large sections generate more heat.
Curing: Water curing dissipates the build-up of heat. Avoid thermal shock.
Formwork removal: Early removal of formwork reduces peak temperature.
Type of formwork: Wood form produces higher temperatures than steel forms.
Cement Content: More cement in the mix means more heat.
Cement Type: Type III cement produces more heat than most other cements
Admixtures: Fly ash reduces the amount of heat build-up

Plastic Deformation
Shrinkage Cracks:
Plastic shrinkage cracks appear in the surface of fresh concrete soon after it is placed. These cracks appear mostly on horizontal surfaces, and are usually parallel to each other 1-3 feet apart, shallow and not reaching the perimeter of the slab.

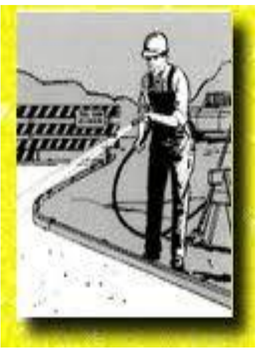
Mechanism of shrinkage Cracks:

- Rapid loss of water from the surface of concrete before it has set causes these cracks.
- It is critical when rate of evaporation of surface moisture exceeds the rate at which rising bleed water can replace it.
- Water receding below the concrete surface forms menisci between fine particles of cement and aggregate causing a tensile force to develop in the surface layer.
- If the concrete surface has started to set and has developed sufficient tensile strength to resist these tensile forces, cracks do not form.
- If the surface dries very rapidly before concrete starts to set then cracks develop as the plastic concrete begins to stiffen.



Remedial Measures:

- Dampen the sub-grade and forms when conditions for high evaporation state exist.
- Prevent excessive surface moisture evaporation by providing fog sprays and erecting wind breaks.
- Cover concrete with wet burlap or poly-ethylene sheets between finishing operations.
- Use cooler concrete in hot weather and avoid excessively high concrete temperatures in cold weather.
- Cure properly as soon as finishing has been completed.

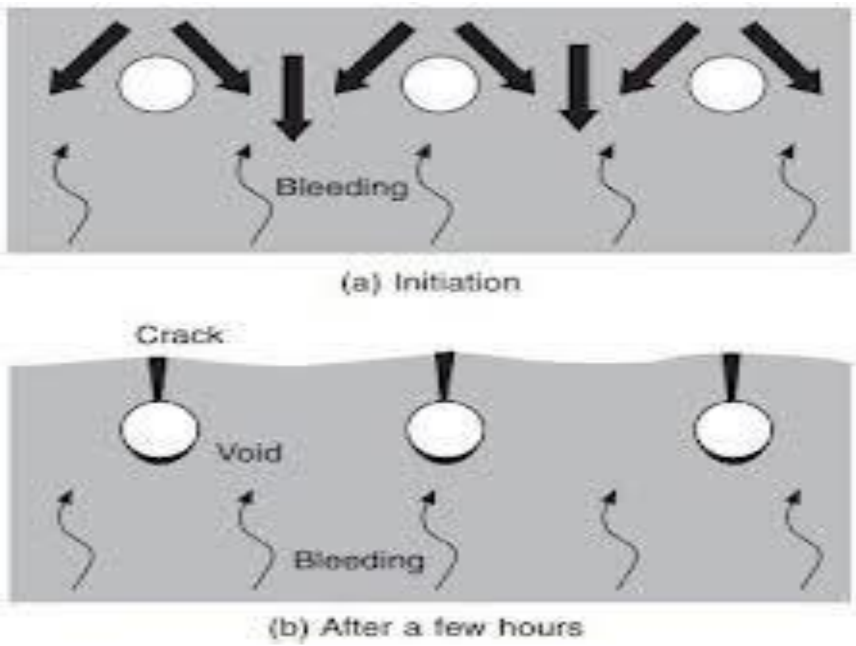


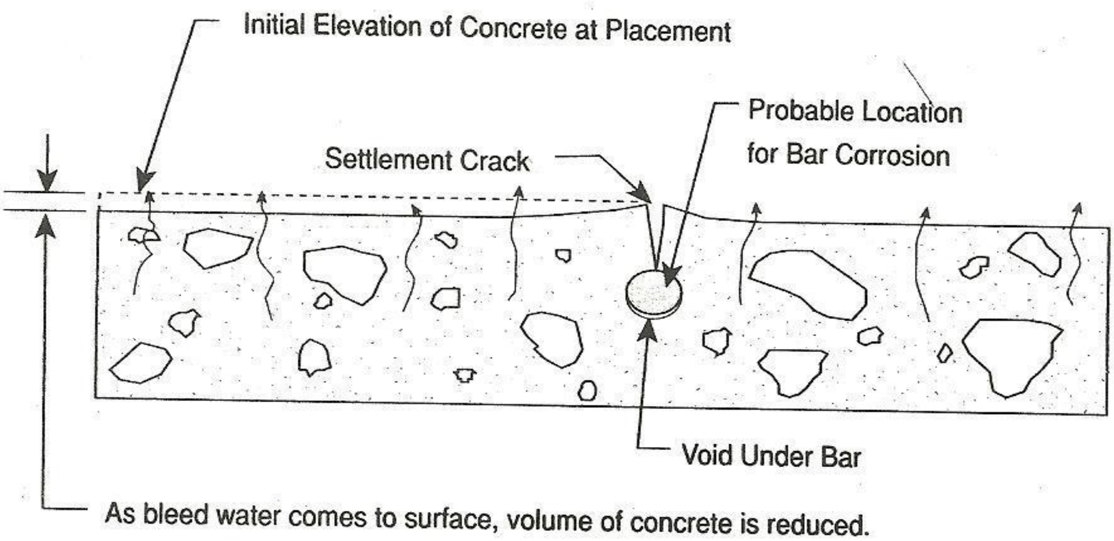
Settlement (subsidence)

Mechanism:

- Plastic settlement is caused due to bleeding, which refers to the migration of water to the top of concrete and the movement of solid particles to the bottom of fresh concrete.

- The expulsion of water during bleeding results in the reduction of the volume of fresh concrete. This induces a downward movement of wet concrete.
- If such movement is hindered by the presence of obstacles like steel reinforcement, cracks will be formed.
- Plastic-settlement cracks appear in fresh concrete directly over embedded objects such as reinforcing bars or post-tensioning tendons. They occur because the concrete settles and the embedded objects do not.
- In some cases the whole reinforcing grid appears as cracks on the floor surface.
- Plastic-settlement cracks are most likely where reinforcing bars or post-tensioning tendons are large in diameter and close to the surface.





Causes of Plastic Deformation:

Poor construction practices

- Low sand content and high water content
- Large reinforcement bars
- Poor thermal insulation
- Restraining settlement due to irregular shape
- Excessive, uneven absorbency
- Low humidity
- Insufficient time between top-out of columns and placement of slab and beam
- Insufficient vibration
- Movement of formwork

Probability of cracking – A function of
(1) Cover
(2) Slump
(3) Bar size

Probability of Subsidence Cracking (%)

	2" Slump			3" Slump			4" slump		
Cover	# 4	# 5	# 6	# 4	# 5	# 6	# 4	# 5	# 6
3/4 "	80.4	87.8	92.5	91.9	98.7	100	100	100	100
1"	60	71	78.1	73	83.4	89.9	85.2	94.7	100
1.5 "	18.6	34.5	45.6	31.1	47.7	58.9	44.2	61.1	72
2"	0	1.8	14.1	4.9	12.7	26.3	5.1	24.7	39

4 bar = 12.7 mm dia; # 5 bar = 15.875 mm dia; # 6 bar = 19.05 mm dia (Imperial sizes)

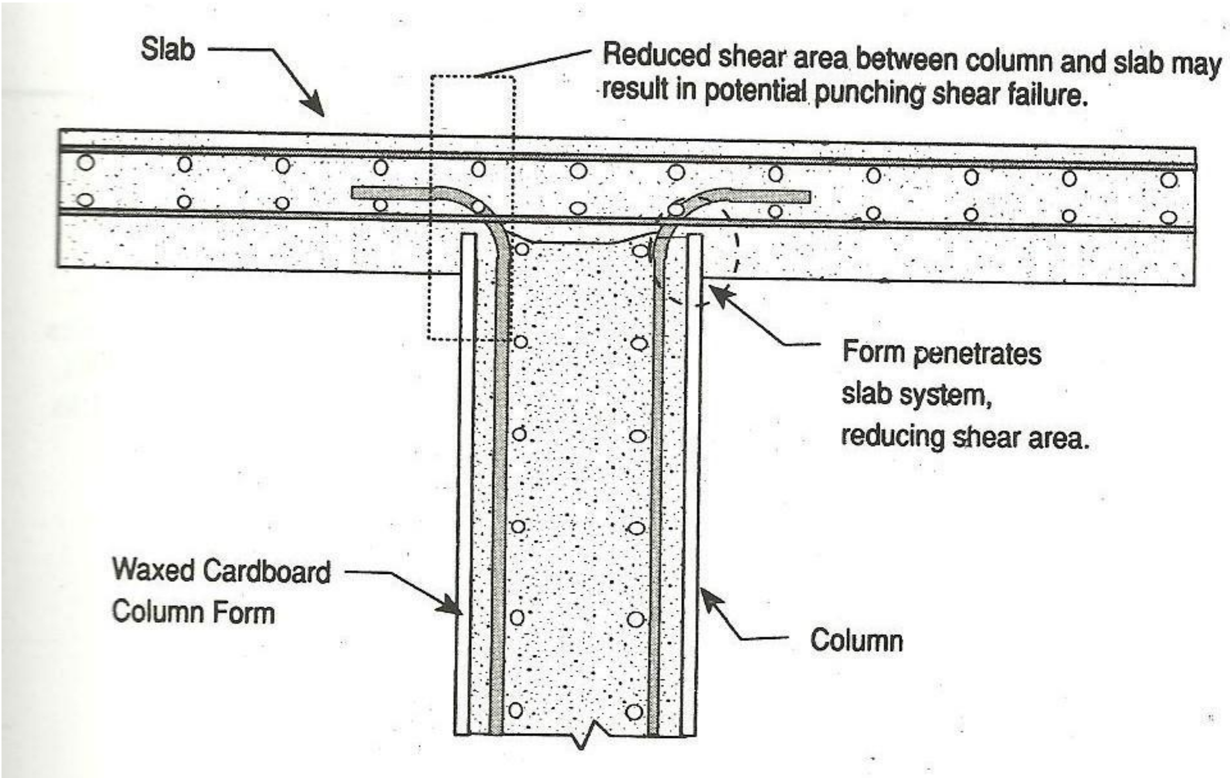
NCHRP 297, Table 4, p.11 (Taken from: P.H. Emmons - p68)

Remedial Measures

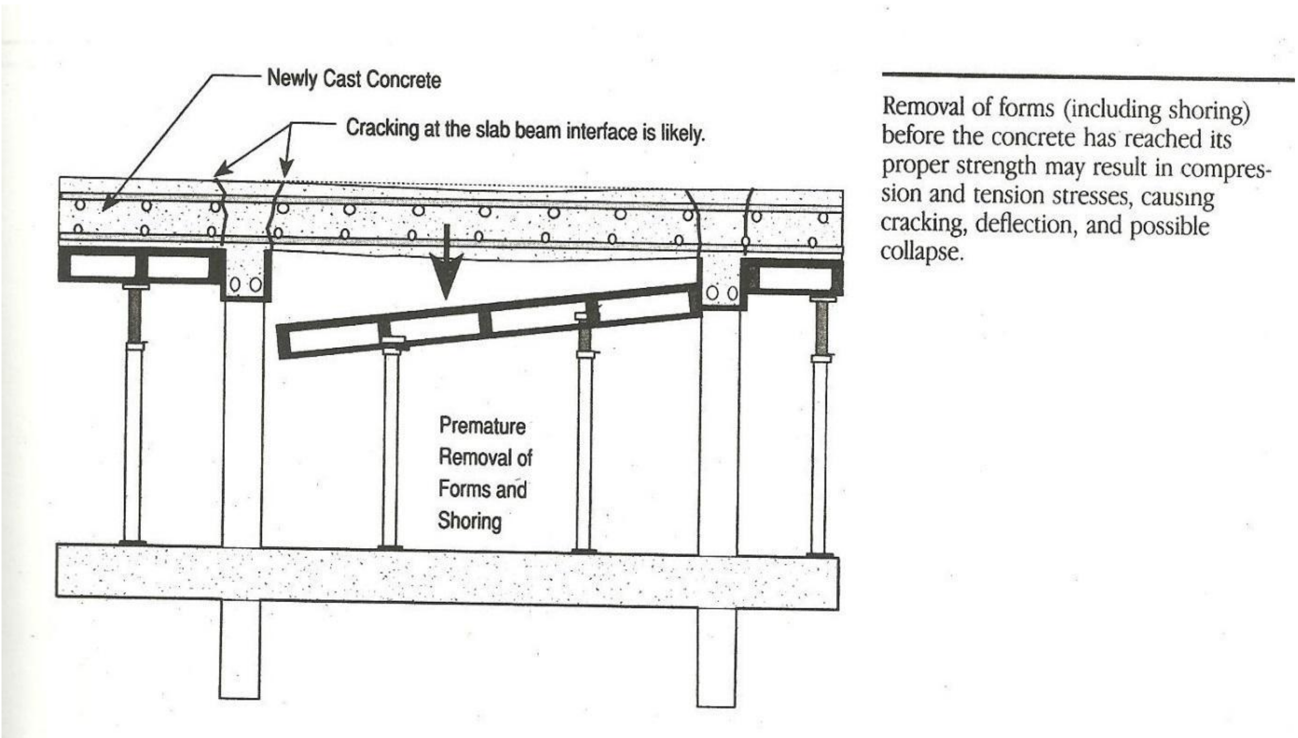
- Use the largest possible coarse aggregate.
- Ensure the coarse aggregate is evenly graded.
- Use less water in the concrete mix (but beware the effect on workability and finishbility).
- Leave a generous surcharge when striking off.

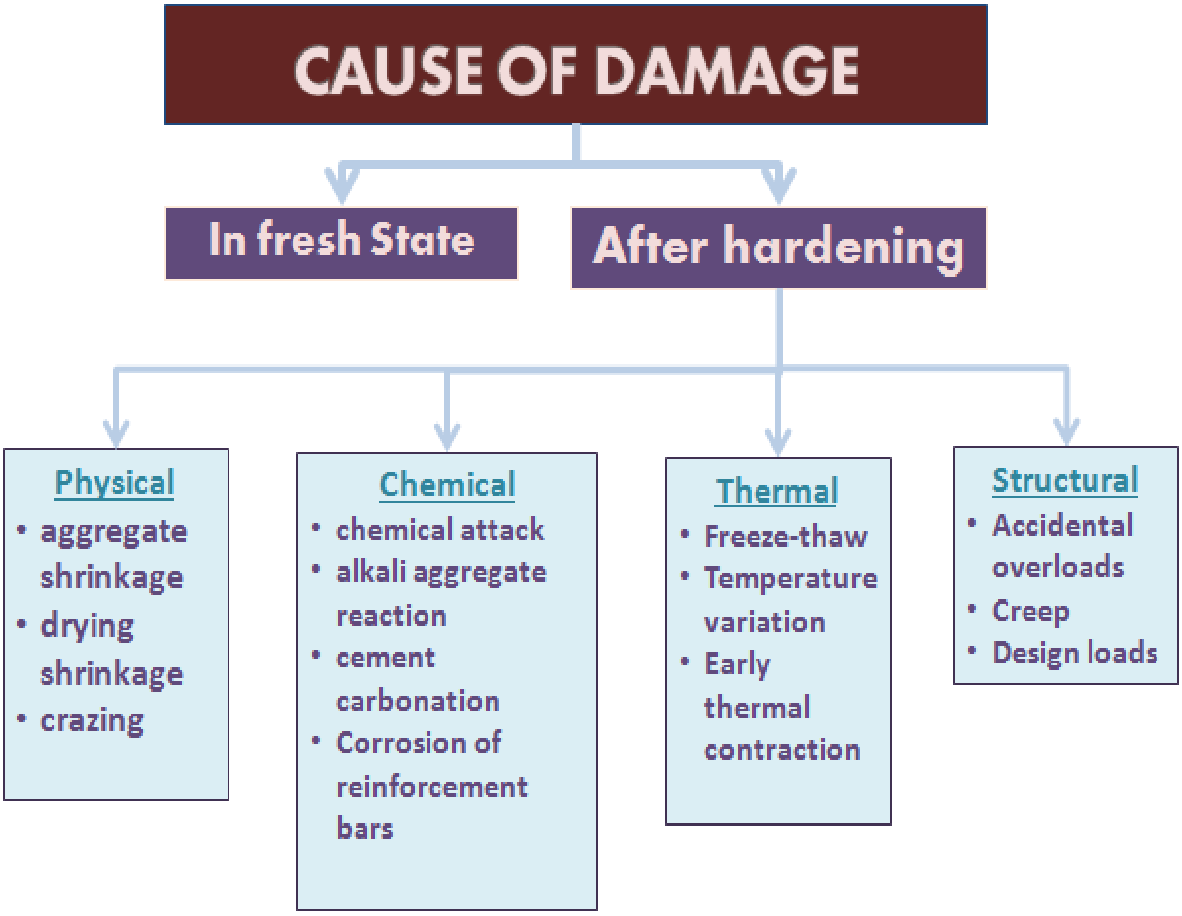
- Place deep sections in two or more lifts. This is worth considering when a slab is being cast monolithically with thick joists or beams.

Construction Movement: Form movement



Reduced Shear between column and slab





Physical Cause
Aggregate Shrinkage
Mechanism

- Some rocks exhibit the property of absorbing water with attendant change in dimension.
- The shrinkage that occurs as the aggregate dries up is called aggregate drying shrinkage.
- Change in volume of aggregate induces cavities and leads to shrinkage, weakening of compressive strength.

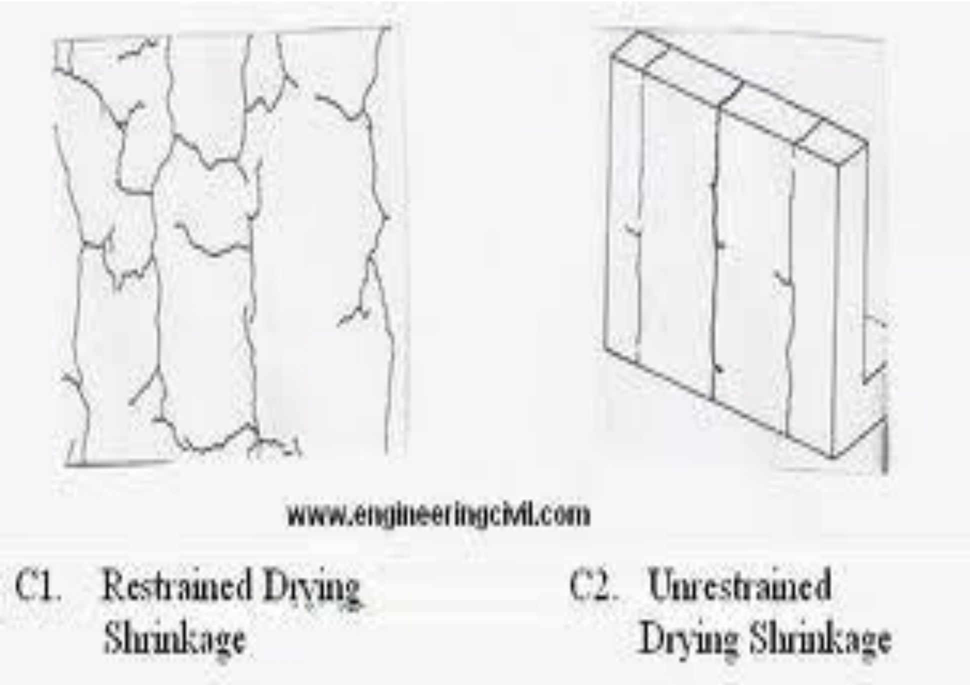
Remedial Measure

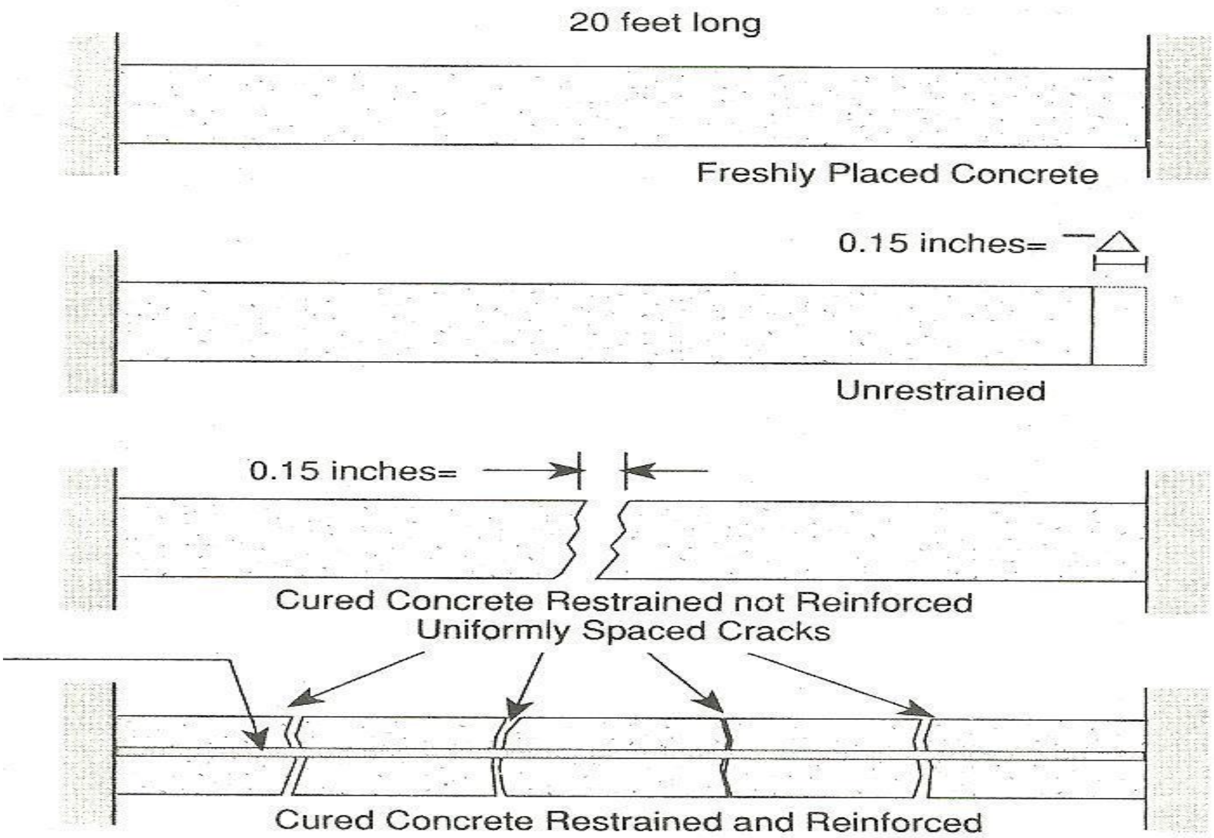
- Choose aggregate which do not have these problems

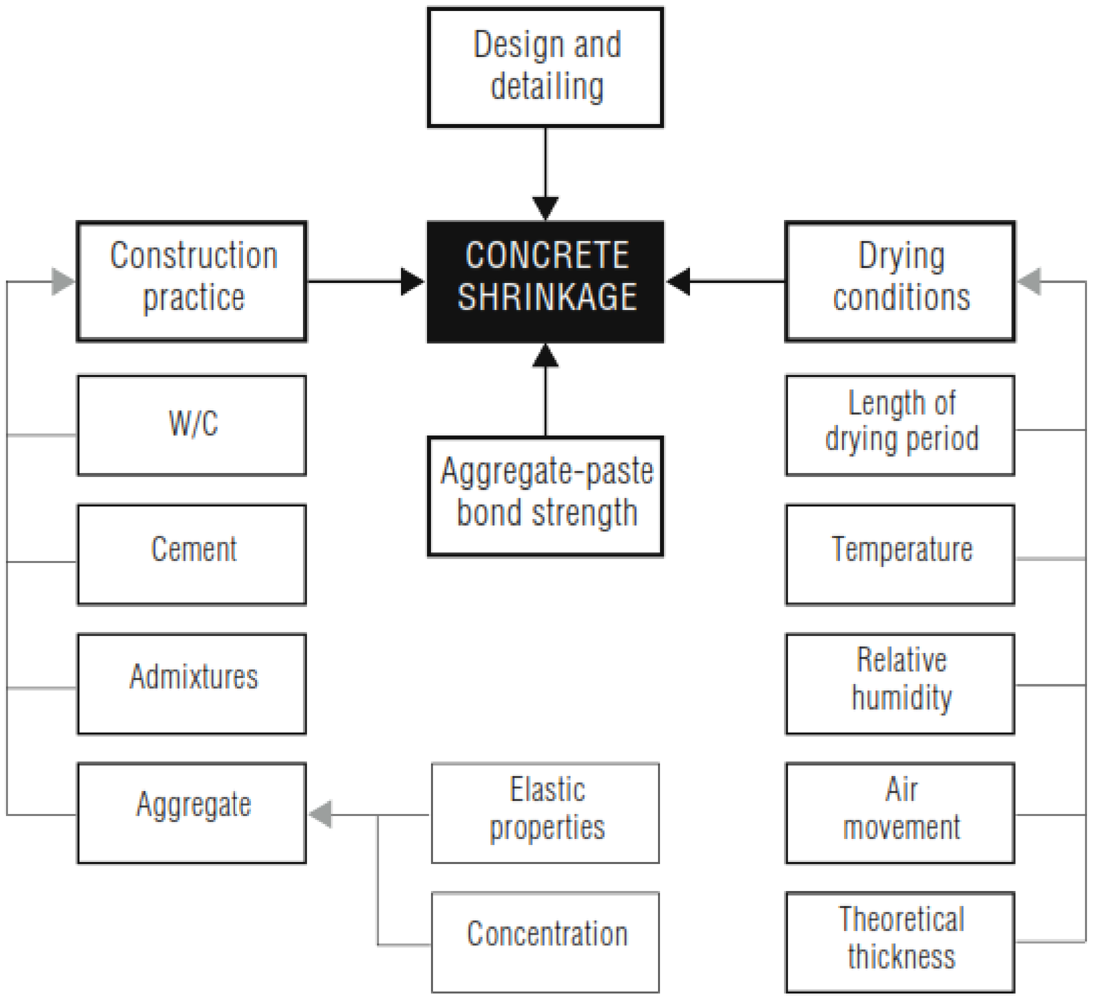
Drying Shrinkage

Mechanism: On exposure to the atmosphere, concrete loses some of its original water through evaporation and shrinks. Normal weight concrete shrinks from 400 to 800 microstrain. One micro strain is equal to 1 X 10-6 in./in.

If unrestrained, results in shortening of the member without a build-up of shrinkage stress. If the member is restrained from moving, stress build-up may exceed the tensile strength of the concrete. this over stressing results in dry shrinkage cracking.





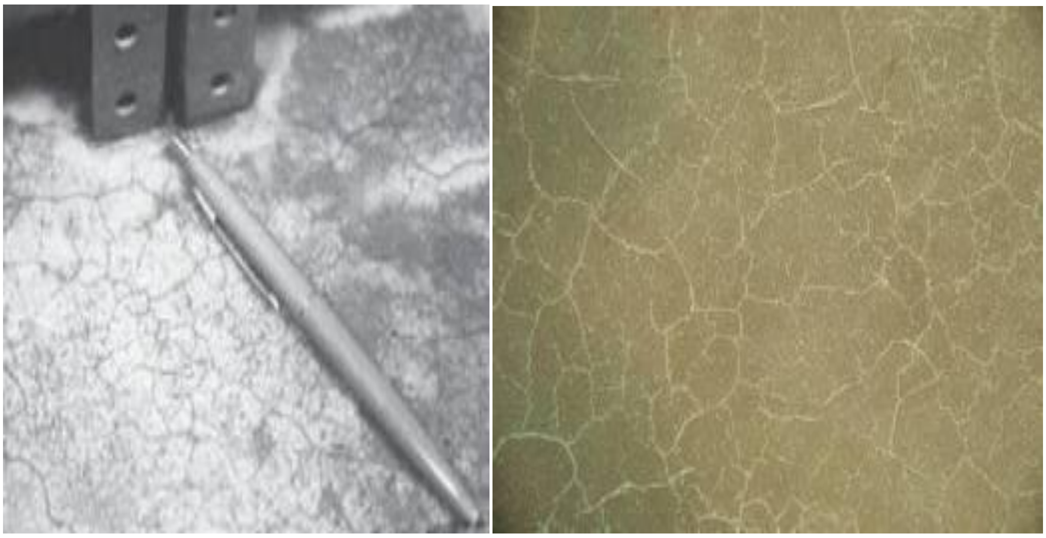


Remedial Measures

Some of the measures that can be taken to reduce the drying shrinkage of concrete include:

- Use the minimum water content (consistent with placing and finishing requirements).
- Use highest possible volume fraction of good quality aggregate and maximum possible aggregate size.
- Use Shrinkage limited Cement (Type SL) where available.
- Do not use admixtures known to increase drying shrinkage, eg those containing calcium chloride.
- Ensure concrete is properly placed, compacted and cured.
- Ensure proper placement of reinforcing steel to distribute shrinkage stresses and control crack widths.

Crazing: Crazing is the development of a network of fine random cracks or fissures on the surface of concrete or mortar caused by shrinkage of the surface layer. These cracks are rarely more than 1/8 inch deep and are more noticeable on steel-troweled surfaces.



Mechanism:
The irregular hexagonal areas enclosed by the cracks are typically no more than 1 ½ inches across and may be as small as ½ or 3/9 inch in unusual instances. Generally, craze cracks develop at an early age and are apparent the day after placement or at least by the end of the first week. Often they are not readily visible until the surface has been wetted and it is beginning to dry out.

Crazing cracks are sometimes referred to as shallow map or pattern cracking. They do not affect the structural integrity of concrete and rarely do they affect durability or wear resistance. However, crazed surfaces can be unsightly.

Why do Concrete Surfaces Craze?

- Poor or inadequate curing. Intermittent wet curing and drying or even the delayed application of curing will permit rapid drying of the surface and provoke crazing.
- Too wet a mix, excessive floating, the use of any procedures which will depress the coarse aggregate and produce an excessive concentration of cement past and fines at the surface.
- Finishing while there is bleed water on the surface or the use of a steel trowel at a time when the smooth surface of the trowel brings up too much water and cement fines.

Preventive measures

- To prevent crazing start curing the concrete as soon as possible. The surface should be kept wet by either flooding the surface with water or, covering the surface with damp burlap and keeping it continuously moist for a minimum of 3 days or, spraying the surface with a liquid membrane curing compound.
- Use moderate slump (3 to 5 inches), air entrained concrete. Higher slump (up to 6 or 7 inches) can be used providing the mixture is designed to produce the required strength without excessive bleeding and/or segregation. Air entrainment helps to reduce the rate of bleeding of fresh concrete and thereby reduces the chance of crazing.
- NEVER sprinkle or trowel dry cement or a mixture of cement and fine sand into the surface of the plastic concrete to absorb bleed water. Remove bleed water by dragging a garden hose across the surface. DO NOT perform any finishing operation while bleed water is present on the surface.

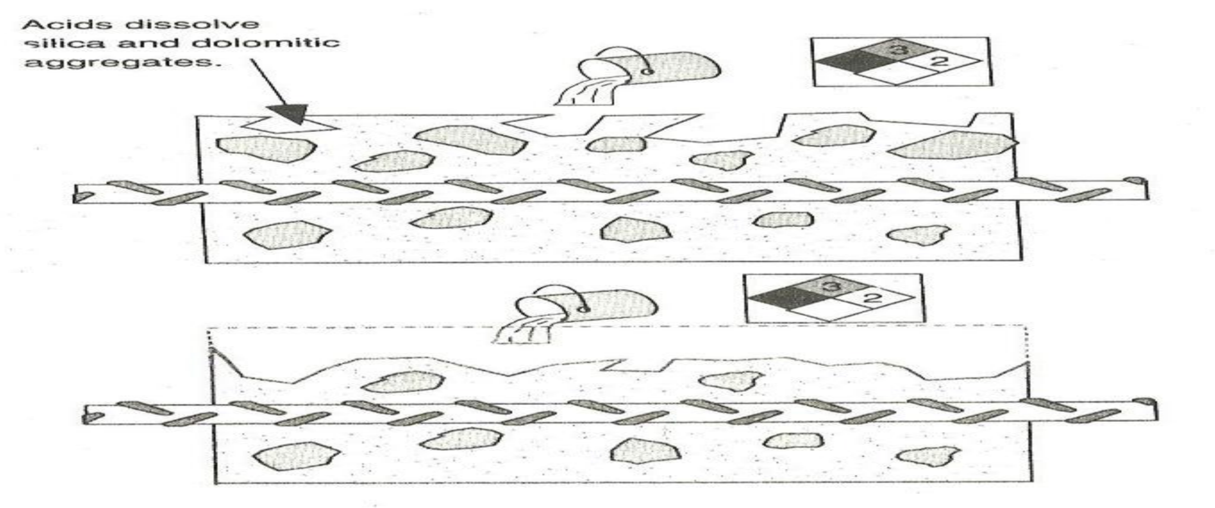
- Dampen the subgrade prior to concrete placement to prevent it absorbing too much water from the concrete. If an impervious membrane, such as polyethylene, is required on the subgrade cover it with 1 to 2 inches of damp sand to reduce bleeding.

Chemical Attack

Exposure to Aggressive Chemicals, such as:

- Inorganic Acids
- Organic Acids
- Alkaline solutions
- Salt Solutions

Acid attack on concrete: Reaction between the acid and the calcium hydroxide of the hydrated Portland cement results in water soluble calcium compounds, which are leached away.



- When limestone or dolomitic aggregates are used then the acid dissolves them.
- **Dolomite** is a carbonate mineral composed of calcium magnesium carbonate - $CaMg(CO3)^2$

Mechanism of Acid Attack

Concrete is susceptible to acid attack because of its alkaline nature. The components of the cement paste break down during contact with acids. Most pronounced is the dissolution of calcium hydroxide which occurs according to the following reaction:

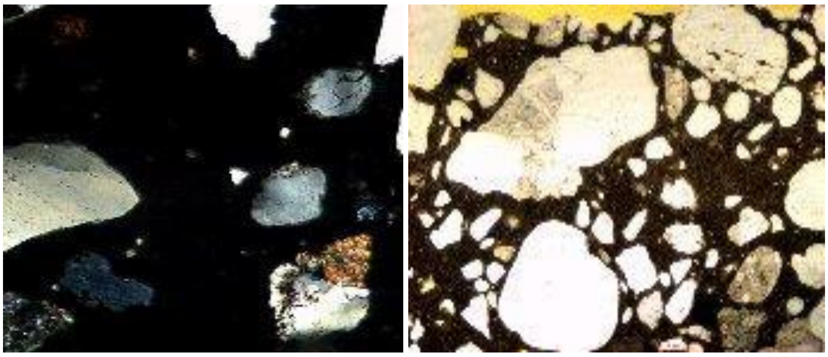
2 HX + Ca(OH)2 -> CaX2 + 2 H2O (X is the negative ion of the acid)

The decomposition of the concrete depends on the porosity of the cement paste, on the concentration of the acid, the solubility of the acid calcium salts (CaX2) and on the fluid transport through the concrete. Insoluble calcium salts may precipitate in the voids and can slow down the attack.

Acids such as nitric acid, hydrochloric acid and acetic acid are very aggressive as their calcium salts are readily soluble and removed from the attack front.

Other acids such as phosphoric acid and humic acid are less harmful as their calcium salt, due to their low solubility, inhibits the attack by blocking the pathways within the concrete such as interconnected cracks, voids and porosity.
Sulphuric acid is very damaging to concrete as it combines an acid attack and a sulfate attack.

Visual effects of Acid Attack
An acid attack is diagnosed primarily by two main features (microscopic appearance):
(1) Absence of calcium hydroxide in the cement paste
(2) Surface dissolution of cement paste exposing aggregates



Preventive Measures

- Low water-cement ratio
- Low cement content to reduce the C-S-H
- Use of pozzolanic materials like micro silica, slag to reduce the calcium hydroxide content.
- Using epoxy-bonded replacement concrete or polymer concrete which does not contain Portland cement.

Alkali–aggregate reaction (AAR)
Aggregates in most of the Concrete are chemically inert. However, certain types of sand and aggregate such as opal, chert or volcanic with high silica content are reactive with the alkalies like calcium, sodium and potassium hydroxide present in Portland cement concrete. This phenomenon of chemical reaction is referred as alkali-aggregate reaction. This reaction can cause expansion of the altered aggregate, leading to spalling and loss of strength of the concrete.

The **alkali–aggregate reaction** is a general, but relatively vague expression. More precise definition are:

- Alkali–silica reaction(ASR)
- Alkali–silicate reaction and
- Alkali–carbonate reaction

Alkali Silica Reaction (ASR)
It is the reaction between the alkalies in cement and silica-containing aggregates. The ASR reaction is the same as the pozzolanic reaction, which is a simple acid-base reaction between calcium hydroxide,

(Ca(OH)2), and silicic acid (H4SiO4, or Si(OH)4). This reaction can be schematically represented as following:

$Ca(OH)^2 + H^4SiO^4 \rightarrow Ca^2+ + H^2SiO_4^{2}- + 2\ H^2O \rightarrow CaH^2SiO^4 \cdot 2\ H^2O$

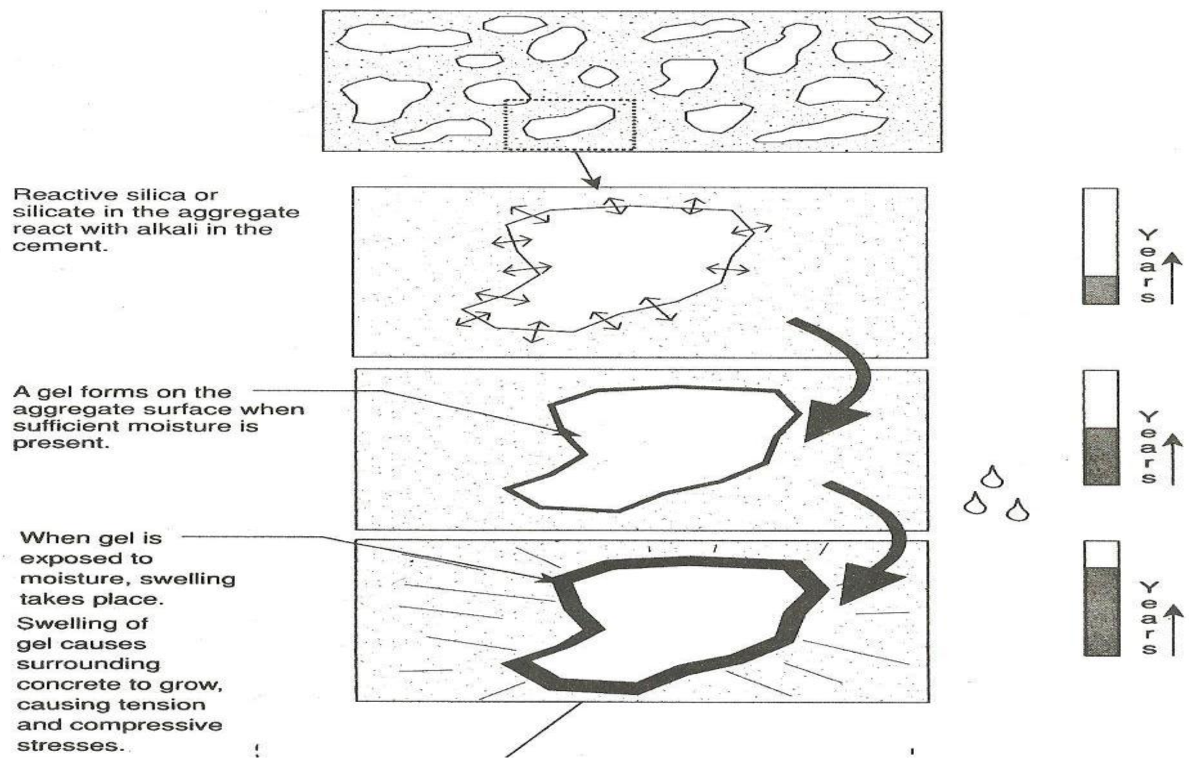
This reaction causes the expansion of the altered aggregate by the formation of a swelling gel of calcium silicate hydrate (C-S-H). This gel increases in volume with water and exerts an expansive pressure inside the material, causing spalling and loss of strength of the concrete, finally leading to its failure.

Mechanism

The mechanism of ASR causing the deterioration of concrete can be described in four steps as follows:

- The alkaline solution attacks the siliceous aggregate, converting it to viscous alkali silicate gel.
- Consumption of alkali by the reaction induces the dissolution of Ca2+ ions into the cement pore water. Calcium ions then react with the gel to convert it to hard C-S-H.
- The penetrated alkaline solution converts the remaining siliceous minerals into bulky alkali silicate gel. The resultant expansive pressure is stored in the aggregate.
- The accumulated pressure cracks the aggregate and the surrounding cement paste when the pressure exceeds the tolerance of the aggregate.

The alkali-aggregate reaction may go unrecognized for some period of time, possibly years, before associate severe distress develops.



The effect of ASR can be traced by physical appearance like expansion and cracking in concrete impacting its structural strength, elasticity and durability, visible map cracking, pop-outs, spalling of concrete and expulsion of alkali-silica gel.

Typical effect of Alkali-Aggregate Reaction

Preventive measures

- Avoiding the use of reactive aggregates.
- Use of low alkali Portland cement, slag cement or pozzolanic admixtures.
- The rate of expansion can be reduced by taking steps to maintain concrete in as dry state as possible by the use of surface coatings or impregnation material.

The repair of the concrete undergoing AAR should be carried out only after the expansion ceases because the continuing expansion will disrupt and destroy the repair material.

Alkali Silicate Reaction

In the alkali–silicate reaction, the layer of silicate minerals (clay minerals), sometimes present as impurities, are attacked,

Preventive measures

ASR can be controlled using certain supplementary cementitious materials. In proper proportions, silica fume, fly ash, and ground granulated blast-furnace slag have significantly reduced expansion due to alkali-silica reactivity. In addition, lithium compounds have been used to reduce ASR. It is also important to note that not all ASR gel reactions produce destructive swelling.

Alkali Carbonate Reaction

The **alkali–carbonate reaction** is a process suspected for the degradation of concrete containing dolomite aggregate.

Alkali from the cement might react with the dolomite crystals present in the aggregate inducing the production of brucite, (MgOH)2, and calcite (CaCO3). This mechanism was tentatively proposed by Swenson and Gillott (1950) and may be written as follows:

$CaMg(CO_3)^2 + 2\ NaOH \longrightarrow CaCO^3 + Na^2CO^3 + Mg(OH)^2$

Brucite ($Mg(OH)^2$), could be responsible for the volumetric expansion after de-dolomotisation of the aggregate, due to absorption of water.

ACR is relatively rare because aggregates susceptible to this phenomenon are less common and are usually unsuitable for use in concrete for other reasons. Aggregates susceptible to ACR tend to have a characteristic texture that can be identified by petrographers.

Sulphate Attack

Sulfate attack is a chemical breakdown mechanism where sulfate ions attack components of the cement paste. The compounds responsible for sulfate attack are water-soluble sulfate-containing salts, such as alkali-earth (calcium, magnesium) and alkali (sodium, potassium) sulfates that are capable of chemically reacting with components of concrete.

Sulfate sources:

Internal Sources:

This is more rare but, originates from such concrete-making materials as hydraulic cements, fly ash, aggregate, and admixtures.

- portland cement might be over-sulfated.
- presence of natural gypsum in the aggregate.
- Admixtures also can contain small amounts of sulfates.

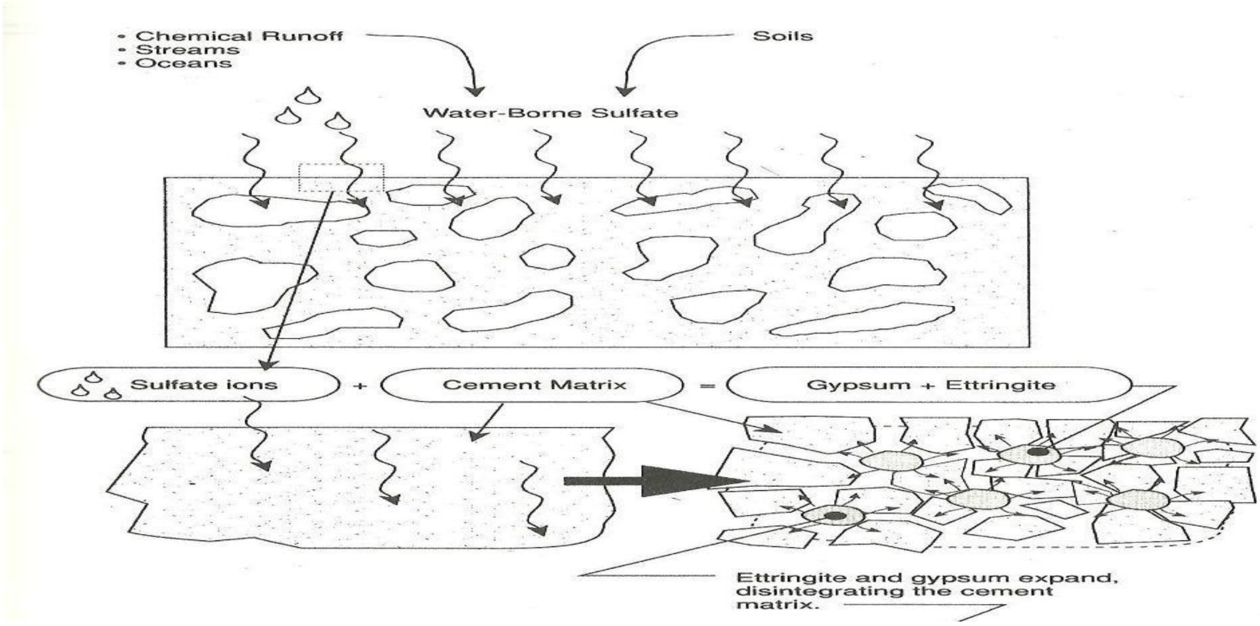
External Sources:

External sources of sulfate are more common and usually are a result of high-sulfate soils and ground waters, or can be the result of atmospheric or industrial water pollution.

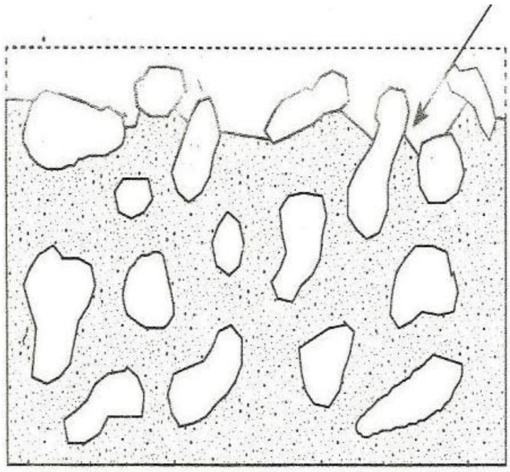
- Soil may contain excessive amounts of gypsum or other sulfate.
- Ground water be transported to the concrete foundations, retaining walls, and other underground structures.
- Industrial waste waters.
- Atmosphere near the oceans may carry sulphate contents.

Mechanism

Sulphates react chemically with cement paste's hydrated lime and hydrated calcium aluminate to form calcium sulphate and calcium sulfoaluminate. They inevitably cause expansive distrution of concrete as the volume of by-products of reactions is greater than original volume of cement paste form which they are formed. The tensile stresses developed as a result of expansion lead to development of cracks in concrete. As a result, surface scaling and disintegration set in, followed by mass deterioration. The severity of the sulphate attack depends on the types of sulphates. Severity of the attack increases from calcium sulphate to sodium sulphate to magnesium sulphate. Sodium sulphate (Na_2SO_4) also reacts with calcium hydroxide to form gypsum, which reduces paste strength and stiffness. Magnesium Sulphate ($MgSO_4$) reacts to form gypsum and destabilizes the calcium silicate hydrate (C-S-H), the strength governing phase in cement paste.



Mechanism of Sulphate Attack



Factors affecting sulfate attack:

- The exposure conditions i.e., the amount of aggressive substance
- Permeability of concrete
- Amount of water available
- Type of cement in concrete
- Alternate wetting and drying cycles

The physical manifestation of sulphate attack includes a whitish appearance followed by surface scaling and disintegration.

Preventive measures

The quality of concrete, specifically a low permeability, is the best protection against sulfate attack. The concrete must have the following other characteristics:

(a) Adequate concrete thickness

(b) High cement content – with low tricalcium aluminate

(c) Low w/c ratio

(d) Proper compaction and curing

(e) Proper proportions of admixtures such as silica fume, fly ash and ground slag improve resistance against sulfate attack.

(f) reducing the amount of reactive elements such as calcium that is needed for expansive sulphate reactions.

Cement Carbonation

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 (CO2), calcium phases (Ca), and water (H2O). Carbon dioxide (CO2) is present in the surrounding air, calcium phases (mainly Ca(OH)2 and CSH) are present in the concrete, and water (H2O) is present in the pores of the concrete.

The first reaction is in the pores where carbon dioxide (CO2) and water (H2O) react to form carbonic acid (H2CO3):

$CO^2 + H^2O \longrightarrow H^2CO^3$

The carbonic acid then reacts with the calcium phases:

$H^2CO^3 + Ca(OH)^2 \longrightarrow CaCO^3 + 2 \cdot H^2O$

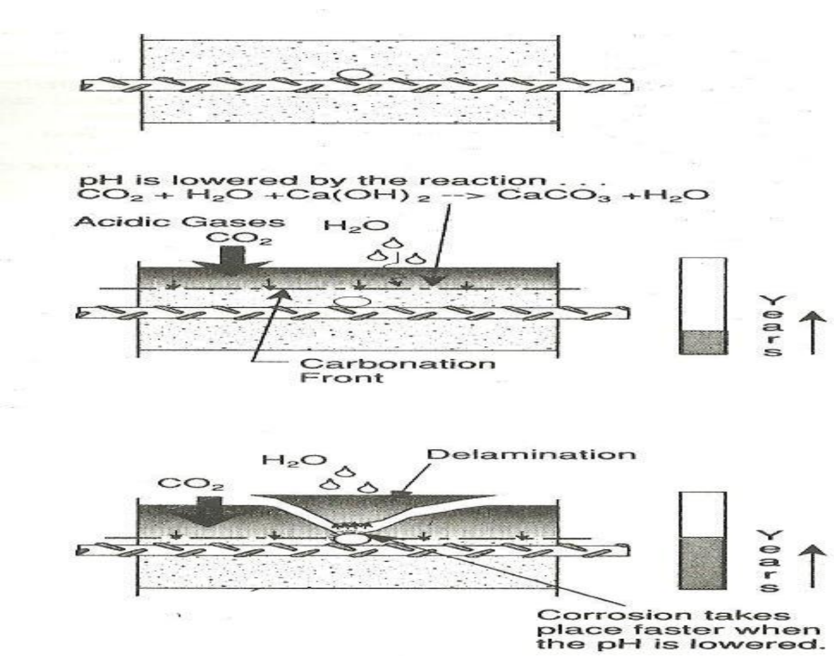
Once the Ca(OH)2 has converted and is missing from the cement paste, hydrated CSH (Calcium Silicate Hydrate - CaO•SiO2•H2O) will liberate CaO which will then also carbonate:

$H^2CO^3 + CaO \longrightarrow CaCO^3 + H^2O$

Mechanism

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.



The speed of the carbonation process through the concrete mainly depends on two parameters:

- The porosity of the concrete
- The moisture content of the concrete

In good quality concrete, the carbonation process is slow. Lesser the porosity lesser the penetration of CO_2. The carbonation process requires constant change in the moisture levels (dry to damp to dry). The process does not occur when concrete pores are filled with water – or when concrete is constantly underwater.

Corrosion:


Thermal Cause

Freeze Thaw Disintegration

Concrete is porous, so if water gets in and freezes it breaks off small flakes from the surface. Deicing salts make it worse. This is typically called scaling and it can occur during the first winter and get worse over time. When severe, it can lead to complete destruction of the concrete.

Freeze-Thaw disintegration takes place due to:

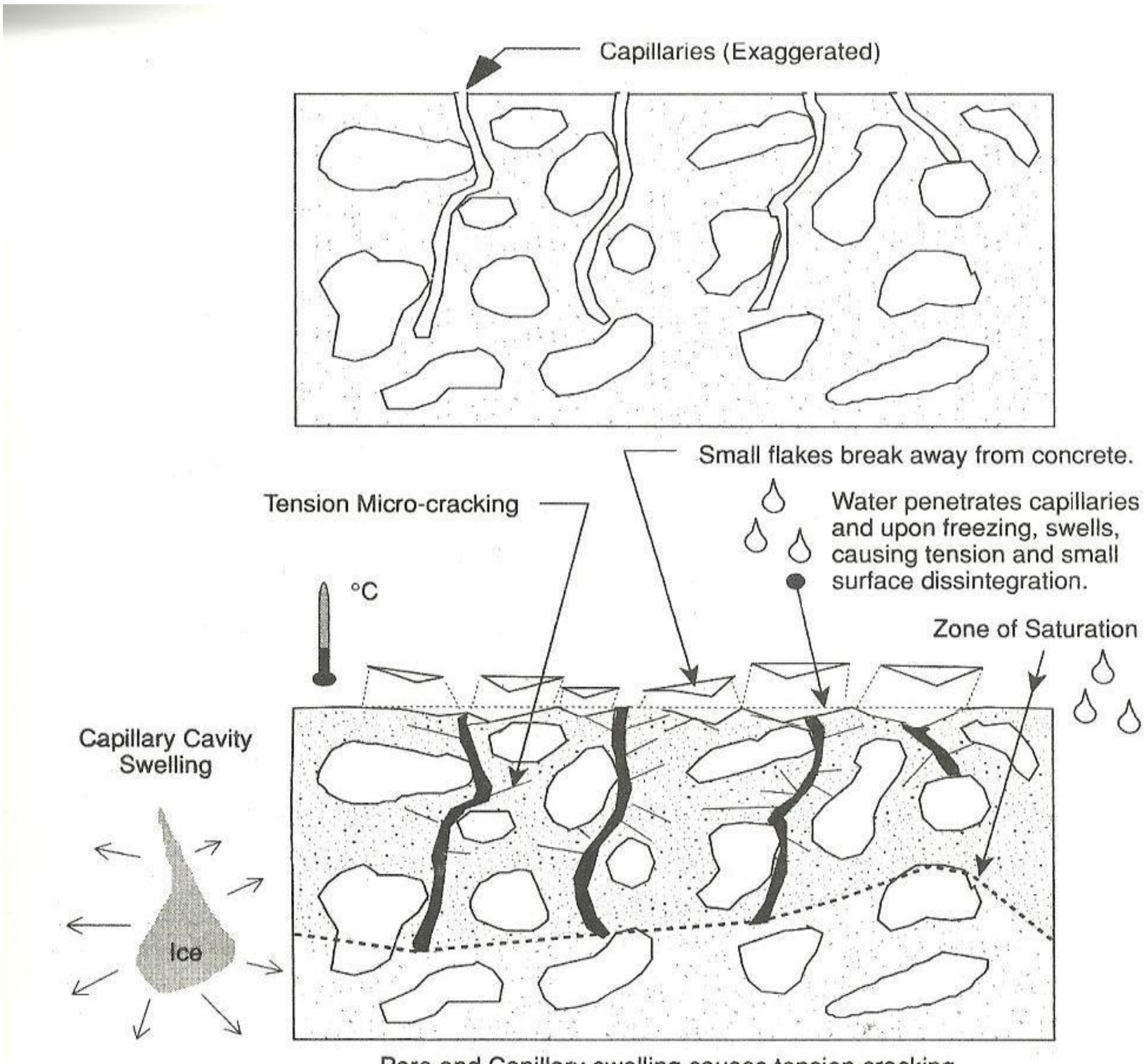
(a) Freezing and thawing temperature cycles within the concrete

(b) Porous concrete that absorbs water.

Generally occurs on horizontal surfaces that are exposed to water or on the vertical surfaces on the water line in submerged structures.

Mechanism

The freezing water contained in the pore structure expands as it converts to ice. The expansion causes local tension forces that fracture the surrounding concrete matrix. The fracturing occurs in small pieces, working from outer surfaces inward.



Pore and Capillary swelling causes tension cracking.

Macro & Microscopic Appearance

Deterioration of concrete by freeze thaw actions may be difficult to diagnose as other types of deterioration mechanisms such as ASR often go hand in hand with Freeze&Thaw (F/T). The typical signs of F/T are:

- Spalling and scaling of the surface
- Large chunks (cm size) are coming off
- Exposing of aggregate
- Usually exposed aggregate are un-cracked
- Surface parallel cracking
- Gaps around aggregate - in the ideal case

The rate of freeze-thaw deterioration is the function of:

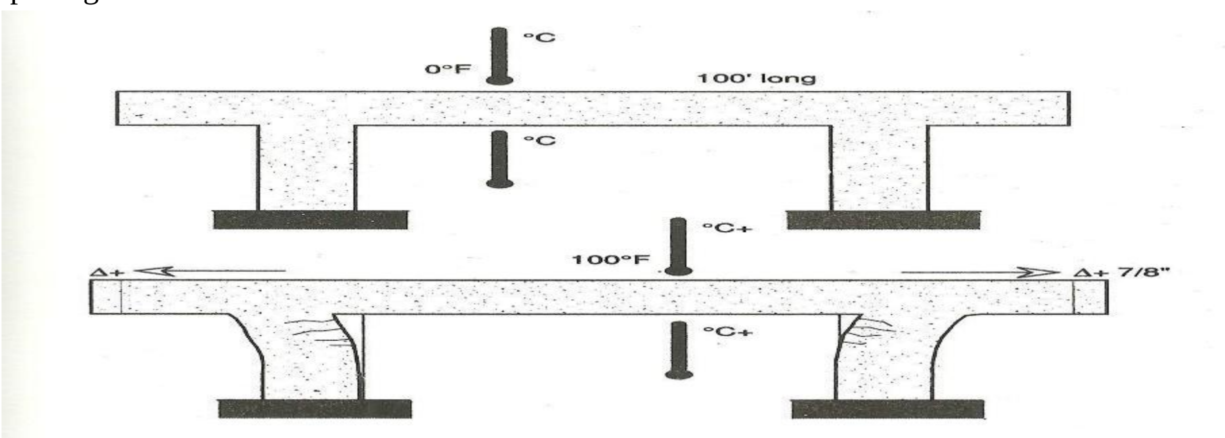
- Porosity (increases rate)
- Moisture saturation (increases rate)
- Number of freeze-thaw cycles (increases rate)
- Air entrainment (reduces rate)
- Horizontal surfaces that trap standing water (increases rate)
- Aggregate with small capillary structure and high absorption (increases rate)

Preventive Measures

To protect concrete from freeze/thaw damage, it should be air-entrained by adding a surface active agent to the concrete mixture. This creates a large number of closely spaced, small air bubbles in the hardened concrete. The air bubbles relieve the pressure build-up caused by ice formation by acting as expansion chambers. About 4% air by volume is needed and the air-bubbles should be well distributed and have a distance between each other of less than 0.25 mm in the cement paste.

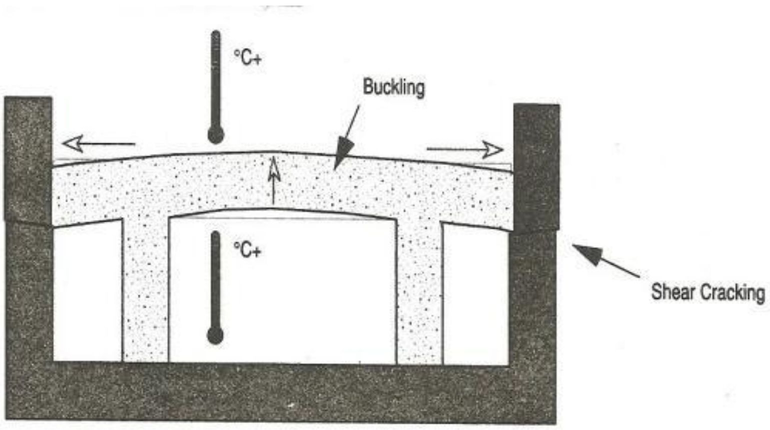
Temperature Variation:

Temperature Variation leads to Volume Changes in concrete. Resulting stresses lead to cracking, spalling and excessive deflections. Thermal Coefficient of concrete = 9 x 10-6 mm/mm/oC



Thermal Volume change leading to Shear Cracks

Solar Heating effects the structure based on its configuration. In simple span structures only up and down deflections take place and the joints are free to rotate. In continuous span structures, hinges may form due to joint rotation being restrained. These hinges open and close with daily temperature. Stress build-up in restrained structures may result in tension cracks, shear cracks or even buckling at the weakest location.



Deterioration due to abrasion, erosion, cavitations and crystallization of salt in pores: Progressive loss of mass from a concrete surface can occur due to abrasion, erosion and cavitation.

Abrasion: It is wearing away of the surface by dry attrition, repeated rubbing, rolling, sliding or frictional process. Surface abrasion is mainly caused by dry attrition as in pavements and industrial floors due to heavy trucking and vehicles. In hydraulic structures, the abrasion occurs due to the cutting action of water borne debris, the suspended solids in water i.e., rolling, sliding and grinding of debris suspended in water against the concrete structures. The factors that effect the abrasion resistance of concrete include compressive strength, aggregate properties, finishing methods, use of toppings and curing.

Erosion: It refers to manifestation of wear on the concrete surface by the abrasive actions of the suspended solid particles in fluids. The impinging, sliding, rolling action of suspended solid particles in water that come in contact with the concrete causes the surface wear. The rate of erosion depends on porosity and strength of concrete, duration of exposure, flow velocity of the water and its direction, and the amount, size, shape, density, hardness and velocity of the water borne debris.

Cavitation: It is the damage that is caused to concrete by action of high velocity water. Concrete generally shows excellent resistance to the latter, however, cavitation damage occurs when high velocity water-flows encounters discontinuities on the surface. Discontinuities, in the form of surface misalignment or abrupt change in slope, in the flow path cause the water to lift off the flow surface, creating negative pressure zones and resulting in the formation of bubbles of water vapour. These bubbles flow downstream with the water. On entering the region of high pressure, they collapse with great impact. Such high impacts can remove the particles of concrete, forming another discontinuity that creates more extensive damage. Cavitation damage results in erosion of the cement matrix, leaving harder aggregate in place.

Crystallization of salt in pores: Concrete structures when exposed to alternate wetting and drying cycles, as in case of marine structures, can result into a crystallization of salts in the pores causing stress that can damage the concrete structures. During drying, the pure water from the surface gets evaporated. Salts that are present in the sea water are left behind in the form of crystals. During the cycle of wetting, these crystals go on growing on subsequent re-wetting and as a result they keep exerting force on hardened cement paste surrounding it. Similarly, salts in ground water or damp soil get transported vertically to a concrete member through the capillary action. Above ground level, the moisture is drawn to the surface and evaporates, leaving crystals of salt growing in the surface pores, which on re-wetting grow and expand.

Structural Cause

Accidental overload

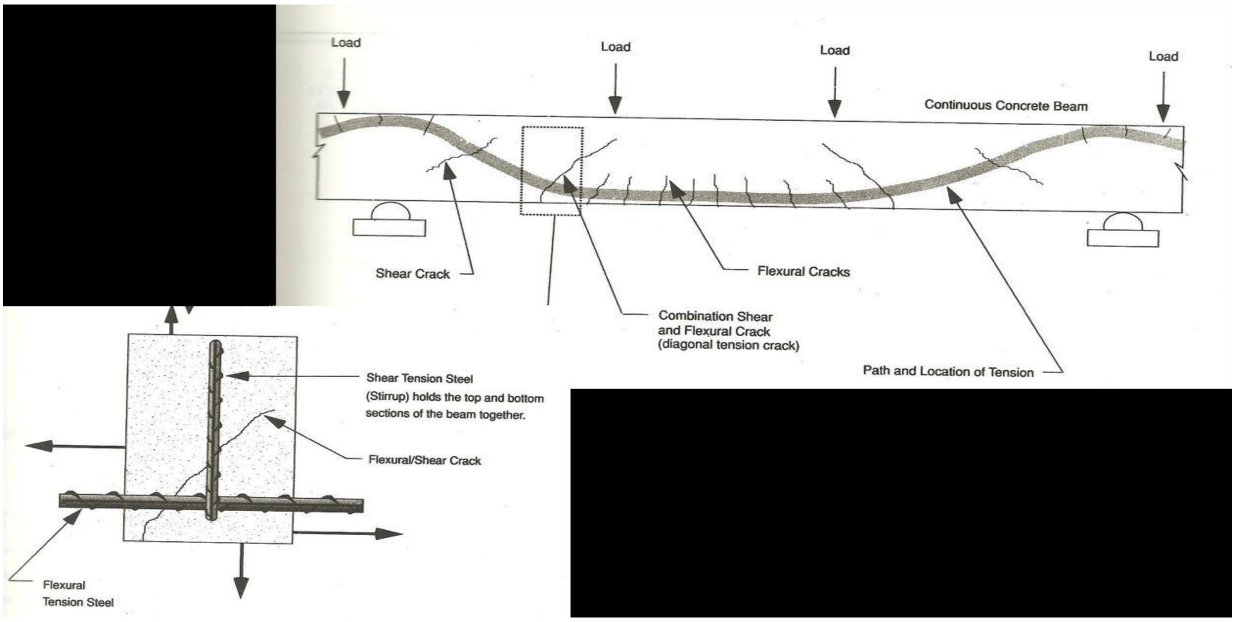
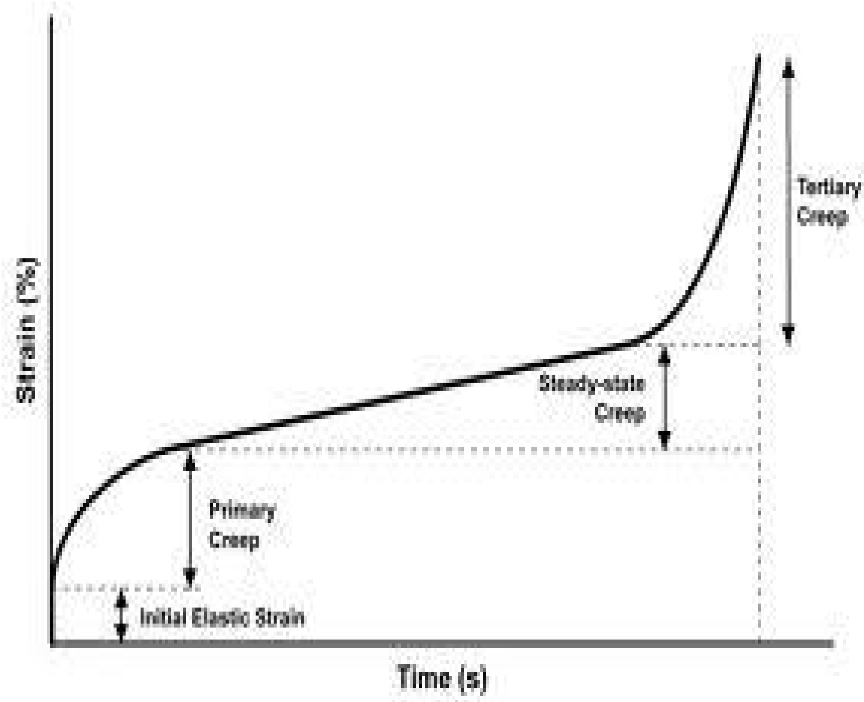
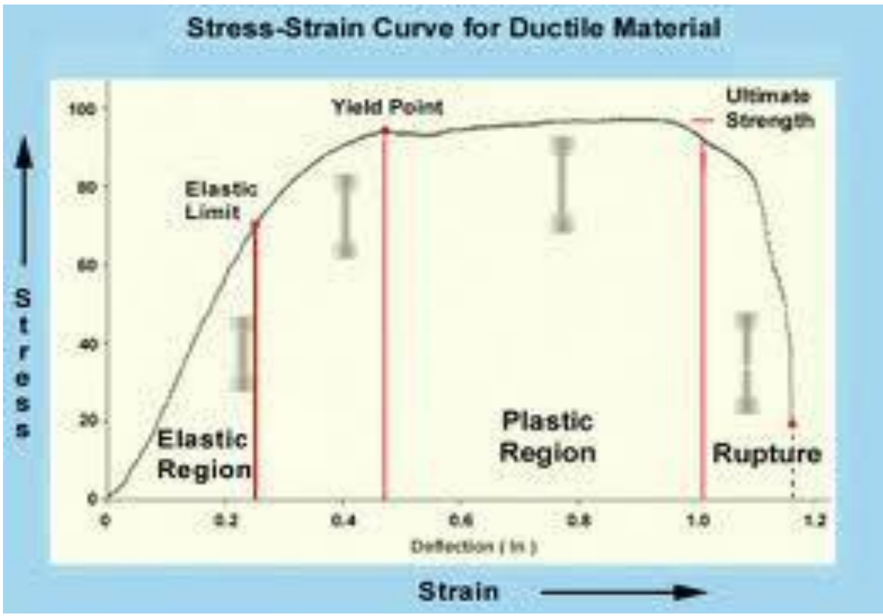


Fig. Cracking Modes in Continuous Span

Creep

Creep is the 'time-dependent' part of the strain resulting from stress. In other words, creep is the increase in strain under sustained stress.





Mechanism

Under sustained stress and with time, the hydrated cement gel, the adsorbed water layer, the water held in the gel pores and the capillary pores yields, flows and readjust themselves, resulting in shrinkage of concrete.

Causes of creep

Influence of aggregate: Stronger aggregate of high modulus of elasticity and a larger aggregate content in concrete mix reduces the magnitude of creep. Creep is the 'time-dependent' part of the strain resulting from stress.

Mix Proportions: Creep increases with increase in w/c ratio. Creep is inversely proportional to the strength of the concrete.

Influence of age: In a broad sense, the age at which the concrete is loaded has predominant effect on creep. Cement gel quality improves with time. Stresses induced on young concrete will result in large creep.

Time and the magnitude of stress are main factors affecting creep.

Effects of Creep

- Unwanted deflections in reinforced concrete beams
- In columns, creep in concrete will transfer greater load on to the reinforcing steel bars.
- In eccentrically loaded columns, creep increases the deflection and can lead to buckling.
- In mass concrete structures, creep accompanied by differential interior temperature conditions can cause cracking of the concrete.
- In pre-stressed concrete, creep reduces the pre-stressing magnitude.

UNIT - II

MAINTENANCE AND DIAGNOSIS OF FAILURE

Maintenance

Maintenance Engineering is defined as the work done to keep the Civil Engineering structures and work in conditions so as to enable them to carry out the functions for which they are constructed. It is preventive in nature. Activities include inspection and works, necessary to fulfill the intended function, or to sustain original standard of service.

Scope of maintenance

- Petty repairs, replacements and structural repairs of buildings, white and color washing, distempering and painting at prescribed intervals.
- Repair and renewal of furniture.
- Operation, periodical maintenance, repairs renewals of machinery and equipment for electric etc
- Repair of roads, culvets and resurfacing the roads.

Facts of Maintenance

Aims of Maintenance work classified as

- The avoidance of accidents, which may harm people or plant.
- The continued operation of a facility.
- The protection of the capital investment in the asset.

Maintenance work is classified as

- Preventive maintenance
- Remedial maintenance
- Routine maintenance
- Special maintenance

Maintenance work is classified as

The maintenance work done before the defects occurred in the structure is called **preventive structure.**

Remedial maintenance

It is the maintenance done after the defects in the structure. It involves the following basic steps.

- Finding the deterioration
- Determining the clause
- Evaluating the strength of the existing structures
- Evaluating the need of the structures
- Selecting and implanting the repair procedure

Routine maintenance

It is the service maintenance attended to the structure periodically. It is depends upon specifications and materials of structure, purpose, intensity and condition of use.

Special maintenance

It is the work done under special condition and requires sanction and performed to rectify heavy damage.

Importance of Maintenance various aspects of Inspection

- Improves the life of structure
- Improved life period gives better return on investment
- Better appearance and aesthetically appealing
- Leads to quicker detection of defects and hence remedial measures
- Prevents major deterioration that leads to collapse
- Ensures safely to occupants
- Ensures feeling of confidence by the user

Daily Routine Maintenance

- Basically an inspection oriented and may not contain action to be taken
- Help in identifying major changes, development of cracks, identifying new cracks etc
- Inspection of all essential items by visual observation
- Check on proper function of sewer, water lines, wash basins, sinks etc
- Check on drain pipes from roof, during rainy season

Weekly Routine Maintenance

- Electrical Accessories
- Flushing sewer line
- Leakage of water line

Monthly Routine Maintenance

- Cleaning Doors, windows, etc
- Checking Septic Tank/Sewer
- Observation for cracks in the elements
- Cleaning of overhead tanks

Yearly Routine Maintenance

- Attending to small repairs and white washing
- Painting of steel components exposed to weather
- Check of displacements and remedial measures

Stages of inspection

A. Inspection

Collect data at specified intervals in specified form

B. Analysis
i. Add latest information to database
ii. Examine progression of defects
iii. Relate defects to action criteria

C. Action possibilities
i. Note and wait for the next inspection
ii. Alter inspection frequency
iii. Institute repairs
iv. Further detailed investigation
v. Put safety procedures in place

Necessitation of the maintenance
The causes which necessitate the maintenance effects the service and durability of the structure as follows:

- Atmospheric Agencis
- Normal wear and tear
- Failure of structure

Atmospheric Agencis

Rain: It is the important source of water which affects the structure in the following ways:

Expansion And contraction

- The material is subjected to repetitive expansion and contraction while they become wet and dry and develops the stresses.
- Dissolving and carrying away minerals as it is universal solvent.

Chemical: The water available in nature contains acids and alkali and other compound in dissolved form acts over the material to give rise, which is known as chemical weathering.

i. **Wind**:It is the agent, which transports the abrasive material and assists the physical weathering.

ii. **Temperature**: The diurnal, seasonal and annual variation of the temperature, difference in temperature it causes expansion and contraction.

Normal wear and tear
During the use of structure it is subjected to abrasion and thereby it looses appearance and Serviceability.

Failure of structure

- **Improper design**- Due to incorrect, insufficient data regarding use, loading and environmental conditions, selection of material and poor detailing.
- **Defective construction**-poor materials, poor workmanship, lack of quality control and supervision.
- **Improper use of structure**- overloading, selecting the structure for the use they not designed impurities from industrial fuel burning, sea water minerals etc.

Inspection periods

- Pre-monsoon period
- Monsoon period
- Post-monsoon period

Pre-monsoon period

To decide the maintenance programmer to be done before monsoon such as cleaning of drains, checking of roof leakage, collection material etc

Monsoon period

It is needless to mention that the emergency work carried out in monsoon period.e.g: railway

- tracks, collapse of roof etc.

Post-monsoon inspection

It is made to repair the damage caused by water and draw up the programme of repair according to the priorities.

Maintenance processes

- Design for maintainability
- Preventive maintenance
- Predictive maintenance
- Reliability centered maintenance
- Reactive maintenance
- Spares management
- Maintenance logistics support
- Total productive maintenance
- Organizing for maintenance
- Computerized maintenance management program
- Statutory requirements

Inspection of building

- Condition of wall paint
- Condition of paint on woodwork and grill
- Condition of flooring

- Roof leakage, leakage etc
- Condition of service fittings
- Drainage from terrace
- Growth of vegetation
- Structural defects like Crack, Settlement, and Deflection

Repair and rehabilitation

Repair is the technical aspect of rehabilitation. It refers to the modification of a structure, partly or wholly which is damaged in appearance or serviceability.

The following factors to be considered repair of concrete structures:

- The cause of damage
- Type, shape and function of the structure
- The capabilities and facilities available with builders
- The availability of repair materials

Stages of concrete repair

Repair of concrete structures is carried out in the following stages:

- Removal of damaged concrete
- Pre treatment of surfaces and reinforcement
- Application of repair material
- Restoring the integrity of individual sections and strengthening of structure as a whole

Repair procedure

A repair procedure may be selected to accomplish on or more of the following objectives:

- To increase strength or restore load carrying capacity
- To restore or increase stiffens
- To improve functional performance
- To provide water tightness
- To improve durability
- To prevent access of corrosive material to reinforcement

Types and classification of repair

Types of repair:

- Cosmetic treatments on surfaces
- Partial replacement of surface and subsurface material
- Additional of reinforcements and bonding materials to strengthen the element
- Total replacement of the structural element

Classification of repair:

Class of damage Classification of repair Repair requirements

1. Superficial Cement mortar bonding by trowelling
2. General Non structural or minor structural ;restoring cover to rebars
3. Principal Significant loss of concrete strength; shotcreting for slabs and beams, jacketing for columns etc
4. Major Demolition and recasting required.

Methods of Repairs

The following considerations are to be taken care of and observed:

- Determination of extent, location and width of cracks
- Classification of cracks as structural and non-structural

Dormant cracks:

Dormant cracks are caused by some event in the part, which is not expected to recur. They remain constant in width, and may be repaired by filling then with a rigid material.

Active cracks:

Do not remain constant in width, but open and close as the structure in loaded, or due to thermal and hydras changes in the concrete.

Growth cracks:

Increase in width becomes the original reason for their occurrence persists.

Applications:

The repair of cracks can be achieved with the following techniques:

- Resin injection
- Routing and Sealing
- Stitching
- External stressing
- Bonding
- Blanketing
- Overlays
- Dry pack
- Vacuum impregnation
- Polymer impregnation

Rehabilitation:

The success of repair activity depends on the identification of the root cause of the deterioration of the concrete structures. The repairs can be done for the improvement of strength and durability, thus extending the life of the structure, is not difficult to achieve. It is the processes of restoring the structure to service level, once it had and now lost, strengthening consists in endowing the structure with a service level, higher than that initially planned by modifying the structure not necessarily damaged area.

The following steps are generally used in the rehabilitation of distressed concrete structure:

- Support the structural members properly as required.
- Remove all cracked, spalled and loose concrete.
- Clean the exposed concrete surfaces and steel reinforcement
- Provide additional reinforcing bars, if the loss in reinforcement is more than 10%
- Apply protective coatings over the exposed/repaired surface.

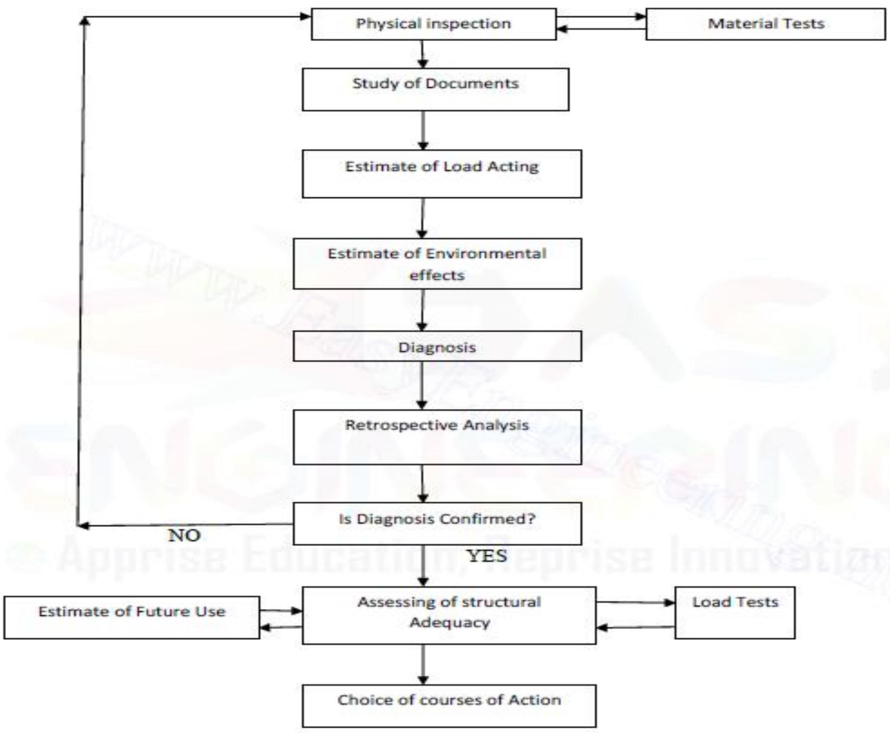
Applications:

- Shotcrete/Gunite
- Resin injection
- Dry pack and Epoxy-bonded dry pack
- Slab jacking Technique
- Sprayed concrete

Assessment procedure for evaluating a damaged structure
The following steps may necessary:

- Physical Inspection of damaged structure
- Preparation and documenting the damages
- Collection of samples and carrying out tests both in-situ and in lab
- Studying the documents including structural aspects
- Estimation of loads acting on the structure
- Estimate of environmental effects including soil structure interaction
- Diagnosis
- Taking preventive steps not to cause further damage
- Retrospective analysis to get the diagnosis confirmed
- Assessment of structural adequacy
- Estimation on future use
- Remedial measures necessary to strengthen and repairing the structure
- Post repair evaluation through tests
- Load test to study the behaviour
- Choice of course of action for the restoration of structure.

Flowchart for Assessment procedure for damaged structure



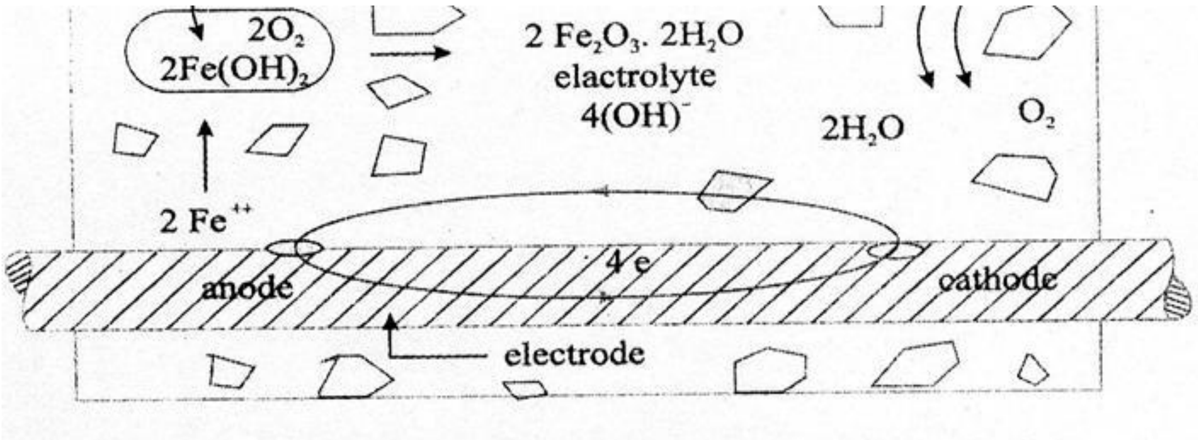
UNIT - III

DAMAGES AND THEIR REMEDIES

Corrosion is defined as the process of deterioration (or destruction) and consequent loss of a solid metallic material, through an unwanted (or unintentional) chemical or electro-chemical attack by its environment, starting at its surface, is called Corrosion. Thus corrosion is a process of 'reverse of extraction of metals".

Corrosion Mechanism – Wet or Electro-Chemical Corrosion

Corrosion of steel concrete is an electro-chemical process. When there is a difference in electrical potential, along the reinforcement in concrete, an electro-chemical cell is set up. In the steel, one part becomes anode (an electrode with a +ve charge) and other part becomes cathode, (an electrode with a –ve charge) connected by electrolyte in the form of pore water, in the hardened cement paste. The +vely charged ferrous ions Fe+ at the anode pass into solution, while the –vely charged free electrons –pass through the steel into cathode, where they are absorbed by the constitutents of the electrolyte, and 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.



Simplified model representing corrosion mechanism

The reactions are described below:

Anodic Reactions:

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

Fe+++ 2(OH)2 ⟶ Fe(OH)2

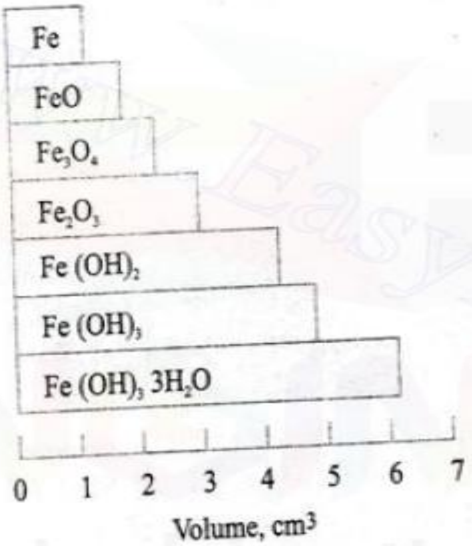
Fe(OH)2.2H2O +O2 ⟶ 4Fe(OH)3

Cathodic Reaction

4e- +O2+H2O ⟶ 4(OH)

It can be noted that no corrosion takes place if the concrete is dry probably below relative humidity of 60%, because enough water is not there to promote corrosion. it can also be noted that corrosion does not take place, id concrete is fully immersed in water, because diffusion of oxygen does not take place into the concrete. probably the optimum relative humidity for corrosion is 70-80%

The products of corrosion occupy a volume as much as 6 times the original volume of steel, depending upon the oxidation state. Figure below shows the increase in volume of steel, depending upon the oxidation state.



Shows that, depending on the oxidation state, metallic iron can increase more than six times in volume

It may be pointed out that though the 2 reactions Fe2 and OH originate iron the anode and cathode respectively, their combination occurs more commonly at the cathode, because the Sn. aller Fe2+ ions diffuse more rapidly than the larger OH ions. So, corrosion occurs at the anode, but rust is deposited at or near the cathode.

Increase the oxygen content has 2 effects :
(i) it forces the cathodic reaction to the right, producing more OH- ions and
(ii) it removes more electrons and therefore, accelerates the corrosion at the anode.

Each of these effects, in turn, supply more reactants for the forming reaction. Obviously, presence of oxygen greatly accelerates both corrosion and rust formation, with the corrosion occurring the entire anode, but the rust forming at the cathode.

Corrosion Inhibitors

A corrosion inhibitor is an admixture that is used in concrete to prevent the metal, embedded in concrete form cording. There exists various types of inhibitors like Cathode, Anode, mixed and Dangerous, Safe.

Of the available corrosion inhibiting materials, the most wide used admixture is based on calcium nitric. It is added to the concrete during mixing of concrete. The typical dosage id of the order of 10-30 litres per m3 of concrete, depending on the chloride levels in concrete.

In the high pH of concrete the steel is protected by a passivating layer of ferric oxide, on the surface of steel. (passivation may be defined as ‘phenon enon in which a metal or an alloy exhibits a much higher corrosion resistance, than expected from its position in the electrochemical series.

Passivity is the result of the formation of a highly protective, but very thin, (about 0.0004mm thick) and quite invisible film on the surface of metal or an alloy, which makes it more fine). However, the passivating layer also contains some ferrous oxide, which can initiate corrosion, when the chloride ions reach the steel. The nitrite ions present in the corrosion inhibiting admixture will oxidize the ferrous oxide.

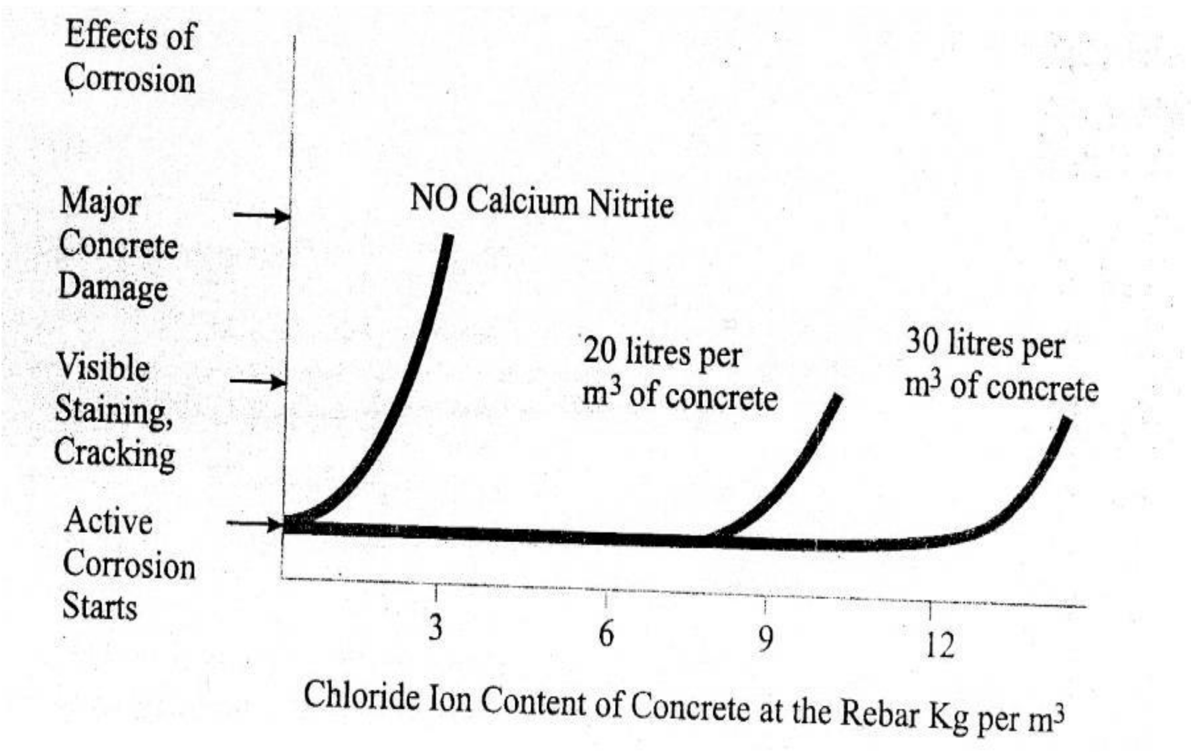
Passivating layer even in the presence of chlorides. The concentration of nitrite must be sufficient, to cope up with the continuing ingress (entrance) of chloride ion.

Calcium nitrite corrosion inhibitor comes in a liquid form, containing about 30% calcium nitrite solids by weight. The more corrosion inhibitor is added, the longer the onset of corrosion will be delayed.

Since most structures in a chloride environment reach a leyel of about 7 Kg of chloride iron per m^3 during their service life, use of less than 18 litres/m3 of calcium nitrite solution is not recommended.

Figure shows that without an inhibitor, the reinforcing steel starts to corrode, when the chloride content at the rebar reaches a threshold level of 0.7Kg/m3. Although the corrosion process starts when the thereshold level is reacted, it may take several years for staining, cracking & spalling to become apparent, (clear) and several more years before deterioration occurs.

Adding calcium nitrite increases this corrosion thereshold. When you ass 20 litres/m^3, corrosion will not begin until over 7.7 Kg/m3 of chloride is present in the concrete at the rebar.



Cathode Protection

Cathode protection is one of the effective, well known, and extensively used methods for prevention of corrosion in concrete structures in more advanced countries. Due to high cost and long term monitoring required for this method, it is not very much used in India.

The cathode protection comprises of application of impressed current, to an electrode laid on the concrete, above steel reinforcement. This electrode serves as anode and the steel reinforcement, which is connected to the negative terminal of a DC source acts as a cathode.In this process, the external anode is subjected to corrode and the cathode reinforcement is protected against corrosion and hence the name ‘Cathode Protection”.
In this process, the –ve chloride ions, which are responsible for the damage of the passivating film, are drawn away from the vicinity of steel towards the anode, where they are oxidized to form chlorine gas.

The other recent development in corrosion control methods are Re-alkalization and Desalnation. The re-alkalisation process allows to make the concrete alskline again and passivate the reinforcement steel, by electro-chemical method. This brings back the lost alkalinity of concrete of sufficiently high level to reform and maintain the passive layer on the steel.

In the desalination process, the chloride ions are removed form the concrete, particularly from the vicinity of the steel reinforcement by certain electrical method to re-establish the passive layer of the steel.

It appears that the application of cathodic systems for protection of concrete structures, offers some real hope to the concrete technologist, but the field remains open for the introduction of innovative methods to overcome problems of both technique and cost.

Corrosion Resistant Steel

It is found that susceptibility of mild steel to corrosion is not significantly affected by composition, grade or level of stress. Hence substitute steel for corrosion resistance must have a significantly different composition. Based on some success in atmospheric corrosion, weathering steels of the corten type were tested in concrete.

They did not perform will in moist concrete, containing chlorides. It is observed that weathering corrode in similar concrete environments, to those causing corrosion of high-yield steel. They noted that although the total amount of corrosion was less, than would occur on high-yield steel under similar conditions, deep localized pitting developed, which could be more structurally weakening.

Stainless steel reinforcement has been used in special applications, especially as fitments in precast members, but is generally too expensive to use as a substitute for mild steel. Very high corrosion resistance was shown by austenitic stainless steel in all the environments, in which they were tested, but the observations of some very minor printing in the presence of chlorides lead to the warning that crevice corrosion susceptibility was not evaluated in the test program.

High titanium alloy bar is being used in some countries. This bar is grouted into holes, drilled into the marble stabs, and the grouts are based either on Portland cement or Epoxy.

Coatings for Steel

The object of coating to steel bar is to provide a durable barrier to aggressive materials, such as chlorides. The coatings should be robust to withstand fabrication of ribcage, and pouring of concrete and compaction by vibrating needle.

Simple cement slurry coating is a cheap method for temporary protection, against rusting of reinforcement in storage.

Central electro chemical Research institute (CECRI), Karaikudi, have suggested a method for prevention of corrosion in steel reinforcement in concrete. The steps involved in this process are :

- **Derusting**

The reinforcement are cleaned with a derusting solution. This is followed without delay by leaning the rods, with wet waste cloth and cleaning powder. The rods are then rinsed in running water and air dried.

- **Phosphating**

- Phosphate jelly is applied to the bars, with fine brush.
- The jelly is left for 45-60 minutes, and then removed by wet cloth an inhibitor solution is then brushed over the phosphated surface.

- **Cement Coating**

Slurry is made by mixing the inhibitor solution, with Portland cement and applied on the bar. A sealing solution is brushed after the rods are air cured. The sealing solution has an in site curing effect. The second coat of slurry is then applied and the bars are air dried.

- **Sealing**

Two coats of sealing solution are applied to the bars, in order to seal the micro-pores of the cement coated an to make it impermeable to corrosive sails.

The is patent method evolved by CECRI, and license is given to certain agencies. Somehow or other, this method has not become very popular. Some experienced consultants and engineers doubt the effectiveness of this method.

It is one of the effective methods of coating rebar’s. The fusion bonded epoxy coating is a specialized job, carried out in a factory, and not at site of work. Plants are designed to coat the straight bars in a continuous process. Initially, the bar is shot blasted to remove all mill scale and to give the kind of surface finish required.

This ensures an adequate bond between epoxy and steel. The bar is then heated to a carefully controlled temperature, before passing through a spray booth. Electro-statically charged epoxy powder particulars are deposited evenly on the surface of the bar. It looks greenish in color, the coating thickness vary from 130 to 00 microns.

Although epoxy coated bars have an excellent protection to corrosion in aggressive environment, there are a few limitations.

After the treatment, cutting and bending may injure the steel, which needs certain site treatment. The site treatment is likely to be inefficient. The presence of any defect in the treated body can induce severe localized corrosion, which defeated very purpose. The bars cannot be welded. The epoxy is not resistant to rays of sun.

The bars should not be exposed to sun for long duration before use. The coating may get damage during vibration of concrete. The treatment is very costly, as that of steel. This method of protection to the steel is being given to all the flyovers, and other structures at Mumbai.

Galvanized Reinforcement

Galvanizing of reinforcement consists of dipping the steel bars in molten zinc. This result in a coating of zinc, bonded to the surface of steel. The zinc surface with calcium hydroxide in the concrete, to form a passive layer and prevents corrosion.

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UNIT - IV

MATERIALS AND TECHNIQUES OF REPAIR

Special concrete and mortar

- High Aluminates Cement Concrete
- Shrinkage Compensated Concrete
- Polymer Cement concrete
- Polymer Impregnsed Concrete
- Epoxy Concrete
- Latex modified concrete

Necessity of adding concrete chemicals

- To improve the performance of concrete
- To have the early strength gain as early as possible
- To accelerated the setting time of concrete
- To make the structure waterproof

Special elements for accelerated strength

In repairs of certain structures, particularly roadways and bridges, it may be desired that early strength gain should be rapid as possible. The engineer may, as a first approach, consider using admixtures, so that ordinary types of Portland cement can be used. The chief chemical admixture.

Now used for this purpose is Super plasticizer of one type or another. Formerly, high doses of calcium chloride were advocated, but this producer has been rejected on the basis of corrosion, problems associated with calcium chloride were advocated, but this procedure has been rejected on the basis of corrosion, problems associated with calcium chloride use. The time of setting of Portland cement concrete and its strength gain may be shortened by the use of calcium aluminates cement, because of problems associated with the conversion under hot humid conditions, of the calcium aluminates hydrates from one from to another, and the resultant strength losses, other types of cements have been preferred.

Regulated set cement is a modified Portland cement, which contains a substantial amount of calcium fluro-aluminate. This cement contains a substantial amount of fluorite as a substitute for limestone. The burning process is not without problems, due to the release of small amount of fluoro compounds.

When prepared and ground, the initial and final set of this type of cement occurs almost simultaneously, and therefore the time between mixing and set is often referred to as the handling time.

As a rule, this varies between 2 and 45minutes. The strength level is adjusted by controlling the amount of calcium fluoro-alminate in the cement.

The time of set is reduced, and compressive strength gain increased in regulated cement mortars and concrete by an increase in the cement content of mix, reduction of the w/c ratio, increased temperature of the mix and increase in curing temperature. The chemical reactions of this type of cement are much more energetic, than those of Portland cements. For that reason, retardation is necessary.

Conventional retarders for Portland cement are not effective in controlling the set of regulated set cement. However, citric acid is used in the mix as a retarder. Where practical, the setting action can be effectively controlled by reducing the mix temperature. Such reductions in the temperature of the mix are also advantageous, as the heat of hydration is considerably higher than that of Portland cement concrete. For this reasons, all exposed surfaces of newly placed regulated set Portland cement concrete must be protected from moisture loss. Chlorinated rubber, butadiene styrene sealing as well as polyethylene sheets or wet burlap are recommended for this purpose.

Special cements based on chemical reactions, which are completely different from those of normal Portland or similar cements, are now part of the technology. These include fast-setting magnesium phosphate and aluminum-phosphate cements, which used for concrete patching of pavements, allow traffic flow after only 45 minutes.

Expansive cement

Expansive cement, when mixed with water, forms a paste that, after setting, tends to increase in volume to a significantly greater degree than Portland cement paste. This expansion may be used to compensate for the volume decrease due to shrinkage, or to induce tensile stress in reinforcement.

Types of Expansive cements:

Type K:
An expansive cement containing anhydrous tetra calcium alumino-sulphate, which is burnt simultaneously with a Portland cement composition, or burnt separately, when it is to be interground with Portland cement clinker or blended with Portland cement, calcium sulphate and free lime.

Type M:
It is a mixture of Portland cement, calcium-aluminate cement and calcium sulphate.

Type S:
It is a Portland cement, containing a large compound of tricalcium-aluminate content and modified by an excess of calcium sulphate, above the usual optimum content.

In all cases, the specific surfaces or fineness of expansive cement has a major influence on its expansion characteristics.

The increase in specific surface accelerates very early formation of ettingite in the plastic mix, and as a result, with the increase in the specific surface for a given sulphate content, the amount of expansion decreases with increasing surface area.

Polymer concrete

Polymers are used in the production of 3 types of polymer concrete composites: polymer impregnated concrete (PIC), polymer concrete (PC, polymer Portland cement concrete (PPCC).

Polymer concrete is formed by polymerizing a monomer, mixed with aggregate at ambient temperature, using curing agents or a chemical catalyst. Just as cement is used as a binder in cement concrete.

Monomer or resin is added to bind preheated aggregates consisting of course fine ultrafine and other aggregates. The commonly used binders are styrene, methyl-methacrylate, polyesters and epoxies.

In the prepack method, graded dry aggregates are packed in the moulds, and polymer is poured into the voids, if necessary by vacuum process.

In the premix method, polymer and aggregates are mixed in conventional mixers and mix transferred to moulds. The mix is vibrated for compaction.

Properties

They are highly resistant to chemical attack, freeze and thaw. Permeability and absorption is almost zero.

Application

Even though the initial cost is high, the material cost efficiency is estimated to be 400% compared to ordinary cement concrete. Hence they are used to manufacture polybeton pipes for carrying chemicals in industries.

Polymer concrete has been used for surface patching and full depth patches of bridge decks, as for example, the work on the Major Degan Expressway in New York City. Manufacture of wall panels and pipes are other uses, to which this material has been put. It has been used as a corrosion resistant pipe liner, and could be used as such in repair procedures.

Sulphur – Inflitrated Concrete

New types of composites have been produced by the recently developed techniques of impregnating porous materials like concrete with sulphur. Sulphur impregnation has shown great improvement in strength. Physical properties have been found to improve by several hundred percent and large improvements in water impermeability and resistance to corrosion gave also been achieved.

In the past, some attempts have been made to use sulphur as a binding material instead of cement. Sulphur is heated to bring it not molten condition to which condition to which coarse and fine aggregates are poured and mixed together. On cooling, this mixture gave fairly good strength, exhibited acid resistance and also other chemical resistance, but it proved to be costlier than ordinary cement concrete.

Recently, use of sulphur was made to impregnate lean porous concrete to improve its strength and other useful properties considerably. In this method, the quantity of sulphur used is also comparatively less and thereby the processes is made economical. It is reported that compressive strength of about 100 MPa could be achieved in about 2 days time. The following procedures have been reported in making sulphur-infiltrated concrete.

A coarse aggregate of size 10 mm and below, natural, well graded, fine aggregate and commercial sulphur of purity 99.9 per cent are used. A large number of trail mixes are made to determine the best mix proportions. A water/cement ratio of 0.7 or over has been adopted in all the trials. A number of 5 cm cubes, 7.5 cm x 15 cm cylinders and also 10 mm x 20 cylinders are cast from each batch of concrete. These samples are stored under wet cover for 24 hours, after which they are removed from moulds and the densities determined. Control specimens are moist cured at 240C for 26 hours.

Two procedures are adopted. In procedure "A" after 24 hours of moist curing, the specimen is dried in heating cabinet for 24 hours at 1210C. Then the specimen are placed in a contained of molten sulphur at 1210C for 3 hours. Specimens are removed from the container, wiped clean of sulphur and cooled to room temperature for one hour and weighed to determine the weight of sulphur infiltrated concrete.

In procedure "B" the dried concrete specimen is placed in an airtight container and subjected to vacuum pressure of 2mm mercury for two hours. After removing the vacuum, the specimens are soaked in the molten sulphur at atmospheric pressure for another half an hour. The specimen is taken out, wiped clean and cooled to room temperature in about one hour. The specimen is wighed and the weight of sulphur-impregnated concrete is determined.

The specimens made adopting procedure A and B tested by compression and splitting tension tests. It is seen that the compression strength of sulphur-infiltrated cubes and cylinders are enormously greater than the strength of plain moist cured specimen. It is found that when water/cement ratio of 0.7 is adopted an achievement of about 7 fold increase in the strength of the test cube when procedure B is adopted and five-fold increase in strength when procedure A is adopted was obtained. When water/cement ratio 0.8 is adopted, procedure B gave about a tenfold increase in strength.

Similarly, the sulphur-infiltrated concrete showed more than four times increase in splitting tensile strength when procedure B was adopted.

It was also found that the elastic properties of sulphur-infiltrated concrete have been generally improved 100 per cent and also sulphur-infiltrated specimen showed a very high resistance to freezing and thawing. When the moist cured concrete was disintegrated after about 40 cycles, the sulphur impregnated concrete was found to be in fairly good condition, even after 1230 cycles, when procedure b was adopted and the sample deteriorated after 480 cycles when the sample was made by procedure A. table 12.8 and table 12.9 show the typical values of strength test conducted.

The improvement in strength test attributed to the fact that porous bodies having randomly distributed pores have regions of stress concentration when loaded externally. The impregnation of a porous body by some material would modify these stress concentrations. The extent of modification will depend on how well the impregnant has penetrated the smaller pores.

Application of Sulphur – Infiltrated concrete

The sulphur-infiltration can be employed in the precast industry. This method of achieving high strength can be used in the manufacture of pre-cast roofing elements, fencing posts. Sewer pipes, and railway sleepers, sulphur-infiltrated concrete should find considerable use in industrial situations. Where high corrosion resistant concrete is required. This method cannot be conveniently applied to cats-in place concrete.

Preliminary studies have indicated that sulphur-infiltrated precast concrete units are cheaper than commercial concrete. The added cost of sulphur and process should be offset by considerable savings in concrete.

The techniques are simple, effective and inexpensive. The tremendous strength gained in pressure application, where in immersion accompanied by evacuation may also offset the extra cost. The attainment of strength in about two days time makes this process all the more attractive.

Ferro cement

Ferro cement technique, though of recent origin, have been extensively used in many countries, notably in U.K. There is a growing awareness about the advantages of this technique, all over the world. It is well known that conventional reinforced concrete members are too heavy, brittle, cannot be satisfactorily repaired if damaged, develop cracks and reinforcements are liable to be corroded. The above disadvantages of normal concrete make it efficient for certain types of work.

Ferro cement is a relatively new material, consisting of wire meshes and cement mortar. This material was developed by P.L.Nervi, an Italian architect and engineer, in 1940. It consists of closely spaced wire meshes, which are impregnated with rich cement mortar mix. The wire mesh is usually of 0.5 to 1.0mm dia wire at 5mm to 10mm spacing, and cement mortar is of cement sand ratio of 1:2 with water/cement ratio of 0.4 to 0.45. The ferrocement elements are usually of the order of 2 to 3cm in thickness with 2 to 3mm external cover, to the reinforcement.

The steel content varies between 300Kg to 500kg per cubic meter of mortar. The basic idea behind this material is that, concrete can undergo large strains in the neighbourhood of the reinforcement and the magnitude of strains depends on the distribution and subdivision of reinforcement, throughout of the mass of concrete.

Ferro cement is widely accepted in UK as about building material. It has also found various other interesting civil engineering applications. The main advantages are simplicity of its construction, lesser weight of the elements due to their small thickness, its high tensile strength, less crack widths compared to conventional concrete, easy repairability, non-corrosive nature and easier mould ability to any required shape.

There is also saving in basic materials namely, cement and steel. This material is more suitable to special structures like shells, which have strength through forms and structures like roofs, silos, water tank and pipe lines.

The material is under active research in various countries, and attempts are being made to give a sound theoretical backing to establish the material behaviour. This is a highly suitable material for precast products, because of its easy adaptability to prefabrication and lesser dad weight of the units cast. The development of ferro-cement depends on suitable casting techniques for the required shape. Development of proper prefabrication techniques for ferro-cement is still not a widely explored area, and gap needs to be filled.

Fiber Reinforced Concrete

Plain concrete possess a very low tensile strength, limited ductility and little resistance to cracking, Internal micro – cracks are inherently present in the concrete and its poor tensile strength is due to the propagation of such micro –cracks eventually leading to brittle fracture of the concrete.

In the past, attempts have been made to impart improvement in tensile properties to concrete in embers, by way if using conventional reinforced steel bars and also applying restraining techniques, although both these methods provide tensile strength to the concrete members, they however, do increase the inherent Leslie strength concrete itself.

In plain concrete and similar brittle materials, structural cracks develop even before loading, particularly due to drying shrinkage or other causes of volume changes. The width of these initial cracks seldom exceeds a few microns, but their other two dimensions may be higher magnitude.

When loaded, the micro cracks propagate open up, and owing to the effect of stress concentration additional cracks form in places of motion defects. The structural cracks proceed slowly or by tiny jumps, because they are retarded by various obstacles, changes of direction in bypassing the more resistant grains in matrix. The development of such micro –cracks is the main cause of inelastic deformation in concrete.

It has been recognized that the addition of small, closely spaced and uniformly dispersed fibres to concert would act as crack arrester, and would subliminally improve its statie and dynamic properties. This type of concrete is known as Fibre Reinforced concrete. \ FRC can be defined as a composite material, consisting of mixtures of cement, mortar or concrete and discontinuous, discrete, uniformly dispersed suitable fibres. Continuous meshes woven fabrics and long wires or rods are not considered to be discrete fibres.

Fibre is a small piece of reinforcing material, possessing certain characteristic properties, they can be circular or flat. The fibre is often described by a convenient parameter called ‘aspect ratio’. The aspect ratio of the fibre is the true ratio of its diameter. Typical aspect ratio ranges from 30 to 150.

Steel fibre is one of the most commonly used generally, round fibres are used. The diameter may very from 0.25 to 0.75mm.

The steel fibre is likely to get rusted and lost some of its strengths. But investigations have shown that the rusting of fibres tacks place only at the surface. Use of steel fibres makes significant improvements in flexural, impact and fatigue strength of concrete. It has been extensively used in various types of structures, particularly for overlays of roads, airfield pavements and bridge decks. Thin shells and plates have also been contracted using steel fibres.

Polypropylene and Nylon fibres are found to be suitable to increase the impact strength. They possess very high tensile strength, but their low modules of electricity and higher elongation do not contribute to the flexural strength.

Glass fibre is a recent introduction in making fibre concrete. It has very tensile strength 1020t 4080 N/mm. Glass fibre, which is originally used in conjunction with cement was found to be affected by alkaline condition of cement. Therefore, alkali-resistant glass by trade name ‘CEMFIL’ has been developed and used. The alkali resistant fibre reinforced concrete shows considerable improvement in durability when compared to the conventional E –Glass fibre.

Carbon fibres, perhaps possess very high tensile strength -2110 to 2815 N/mm and Young’s Modulus. It has been reported that cement composite made with carbon fibre, as reinforcement, will have very high modulus of Elaticity and flexural strength. The limited studies have shown good durability. The use of carbon fibres for structure like cladding, panels and shells will have promising future.

Gunite or Shotcrete

Gunite can be defined as mortar conveyed through a hose and pneumatically projected at a high velocity on to a surface. Recently the method has been further developed by the introduction of small sized coarse aggregate into the mix deposited to obtain considerably greater thickness in one operation and also to make the process economical by reducing the cement content.

Normally fresh material with zero slump can support itself without sagging or peeling off. The force of the jet impacting on the surface compact the material. Sometimes use of set accelerators to assist overhead placing is practiced. The newly developed 'Redi-set cement" can also be used for shotcreting process.

There is not much difference guniting and shotcreting. Gunite was first used in the early 1900 and this process is mostly used of pneumatically application of mortar of less thickness, whereas shotcrete is a recent development on the similar principal of guniting for achieving greater thickness with small coarse aggregates.

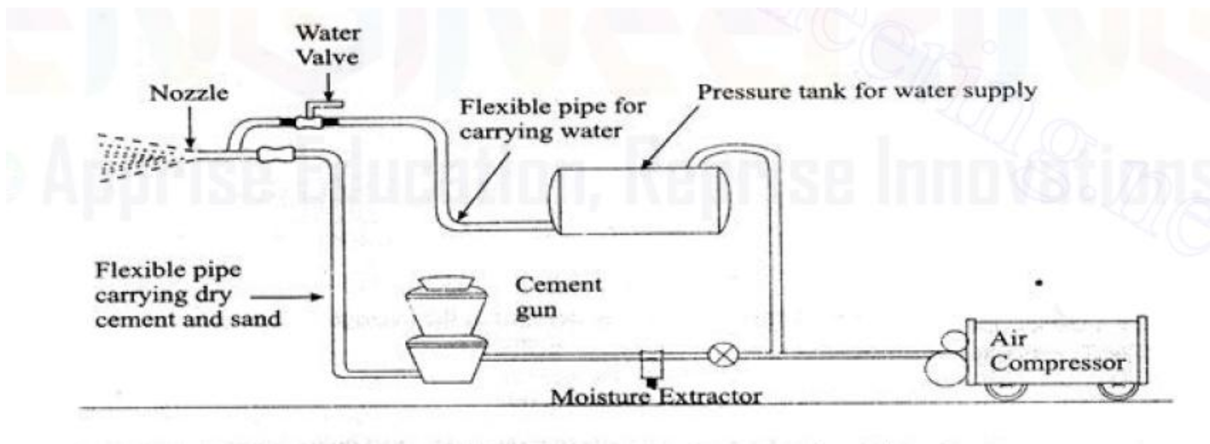
There are two different processes in use, namely the 'Wet-mix" process and the 'dry-mix" process. They dry mix process is more successful and generally used.

Dry-mix process

The dry mix process consists of a number of stages and calls for some specialized plant. A typical plant set-up is shown in Fig

The stages involved in the dry mix process is given below :

(a) Cement and sand are thoroughly mixed.



General arrangement of apparatus in gunite system.

(b) The cement/sand mixture is fed into a special air-pressurized mechanical feeder termed as "gun".

(c) The mixture is metered into the delivery hose by a feed wheel or distributor within the gun.

(d) This material is carried by compressed air through the delivery hose to a special nozzle. The nozzle is fitted inside with a perforated manifold through which water is sprayed under pressure and intimately mixed with the sand/cement jet.

(e) The wet mortar is jetted from the nozzle at high velocity onto the surface to be gunited.

The Wet-mix Process

In the Wet-mix process the concrete is mixed with water as for ordinary concrete before conveying through the delivery pipe line to the nozzle, at which point it is jetted by compressed air, onto the work in the same way, as that of dry mix process.

The wet-mix process has been generally discarded in favors of the dry-mix-process, owing to the greater success of the latter.

The dry-mix methods make use of high velocity or low velocity system. The high velocity gunite is produced by using a small nozzle and a high air pressure to produce a high nozzle velocity of about 90 to 120 metres per second.

This results in exceptional good compaction. The lower velocity gunite is produced using large diameter hose for large for large output. The compunction will not be very high.

Advantages of Wet and Dry process

Some of the advantages and disadvantages of the wet and dry processes is discussed below. Although it is possible to obtain more accurate control of the water/cement ratio with the wet process the fact that this ratio can be kept very low with the dry process largely overcomes the objection of the lack of accurate control.

The difficulty of pumping light-weight aggregate concrete makes dry process more suitable when this type of aggregate is used. The dry process on the other hand, is very sensitive to the water content of the sand, too wet a sand causes difficulties through blockade of the delivery pipeline, a difficulty which does not arise with the wet process.

The lower water/cement ratio obtained with the dry process probably accounts for the lesser creep and greater durability of concrete produced in this way compared with concrete deposited by the wet process, but air-entraining agents can be use to improve the durability of concrete deposited by the latter means. Admixtures generally can be used more easily with the wet process except for accelerators.

Pockets of lean mix and of rebound can occur with the dry process. It is necessary for the nozzle to have an area where he can dump unsatisfactory shotcrete obtained when he is adjusting the water supply or when he is having trouble with the equipment.

These troubles and the dust hazard are less with the wet process, but wet process does not normally give such a dense concrete as the dry process. Work can be continued in more windly weather with the wet process than with the dry process. Owing to the high capacities obtainable with concrete pumps, a higher rate of laying of concrete can probably be achieved in the wet process than with the dry process.

Epoxy injection

Resin injection is based to repair concrete that is cracked or delaminated and to seal cracks in concrete to water leakage. Two basic types of resin and injection techniques are used to repair concrete; epoxy resins and polyurethane resins. Epoxy resins cure to form solids with high strength and relatively high module of elasticity.

These materials bond readily to concrete and are capable, when properly applied, of resorting the original structural strength to cracked concrete. The high modules of elasticity causes epoxy resin systems to be unsuitable for rebonding cracked concrete that will undergo subsequent movement.

The epoxies, however, do not cure very quickly, particularly at low temperatures, and using them to stop large flows of water may not be practical. Cracks to be injected with epoxy resins should be between 0.005 inch and 0.25 inch in width.

It is difficult or impossible to inject resin into cracks less than 0.005 inch in width, while it is very difficult to retain injected epoxy resin in cracks greater than 0.25 inch in width, although high viscosity epoxies have been used with some success Epoxy resins cure to form relatively brittle materials with bond strengths exceeding the shear or tensile strength of the concrete.

If these materials are used to rebound cracked concrete that is subsequently exposed to loads exceeding the tensile or shear strength of the concrete, if should be excepted that the cracks will recur adjacent to the epoxy bond line. In other words, epoxy resin should not be used to rebond “working” cracks.

Epoxy resins will bond with varying degrees of success to wet concrete, and there are a number of special techniques that have been developed and used to rebound and seal water leaking cracks with epoxy resins. These special techniques and procedures are highly technical and, in most cases, are proprietary in nature.

Polyurethane resins are used to seal and eliminate or reduce water leakage from concrete cracks and joints. They can also be injected into cracks that experience some small degree of movement. Such systems, with the exception of the two-part solid polyurethanes, have relatively low strengths and should not be used to structurally rebond cracked concrete.

Cracks to be injected with polyurethane resin should not be less than 0.005 inch in width. No upper limit on crack width has been established for the polyurethane resins at the time this is being written.

Polyurethane resins are available with substantial variation in their physical properties. Some of the polyurethanes cure into flexible foams.

Other polyurethane systems cure to semi-flexible, high-density solids that can be used to rebound concrete cracks subject to movement.

Most of the foaming polyurethane resins require some form of water to initiate the curing reaction and are, thus, a natural selection for use in repairing concrete exposed to water or in wet environments.

At the time this is written, there are no standard specifications for polyurethane resins equivalent to the standard specification for Epoxy-Resin-Base Bonding Systems for Concrete. ASTM Designation C-881.

UNIT - V

STRENGTHENING AND DEMOLITION ASPECT

Repairs to overcome low member strength

Need for Strengthening:

- Load increases due to higher live loads, increased wheel loads, installations of heavy machinery or vibrations
- Damage to structural parts due to aging of construction materials or fire damage, corrosion of the steel reinforcement, and impact of vehicles
- Improvements insatiably for use due to limitation of deflections, reduction of stress in steel reinforcement and reduction of crack widths
- Special Modification of structural system due to the elimination of walls/columns and openings cut through slabs.
- Errors in planning or construction due to insufficient design dimensions and insufficient reinforcing steel.

Deflection due to strengthened in Flexural members

Many situations in which flexural members, and especially bridge girders, have been found to have less than their special attention was paid to the paid to the bond between the old concrete and the new anchor blocks. The existing concrete was cut back to the depth of the cover and roughened.

After the new block had been cast in-situ the contact surface was injected with low viscosity epoxy resin under pressure, the injection being monitored ultrasonically. Some of the new tendons were deflected at existing diaphragms, reinforced required.

In view of the importance of the new anchor blocks to the success of the repair, we might have expected that dowel bars would be provided to connect the block to the existing concrete but no mention is made of this possibility and apparently what was done has been found to be successful.

The basis of this success is the roughness imparted to the old concrete. Epoxy jointing between smooth concrete surfaces would be expected to deform over a period over a period of time and relax the stressed tendons.

Strengthening of Beams

The strengthening of a beam, the load acting on it should be reduced by removing the tiles, bed mortar etc. From the slab. In addition props may be erected at mid span of each slab and tightened in such a manner that slabs are not damaged. After chipping off of the existing plaster on the beam, additional reinforcement at the bottom of beam together with new stirrups are provided.

The bars are passed through or inserted in the supporting columns through holes of appropriate diameter drilled in the columns. The spaces between bars and surrounding holes are filled with epoxy grout to ensure a good bond.

Expanded wire mesh is fixed and anchored on three sides of the beam as shown in fig. To ensure a good bond between old concrete and polymer modified mortar, an epoxy bond coat is applied to the concrete surface.

While the bond coat is still fresh, a layer of polymer modified mortar is applied. The required thickness on all the three sides is achieved by application of 2 to 3 layers of mortar. While applying mortar at the bottom of beam, the thickness of mortar layers should be so adjusted that sagging is completely covered and beam looks deflected.

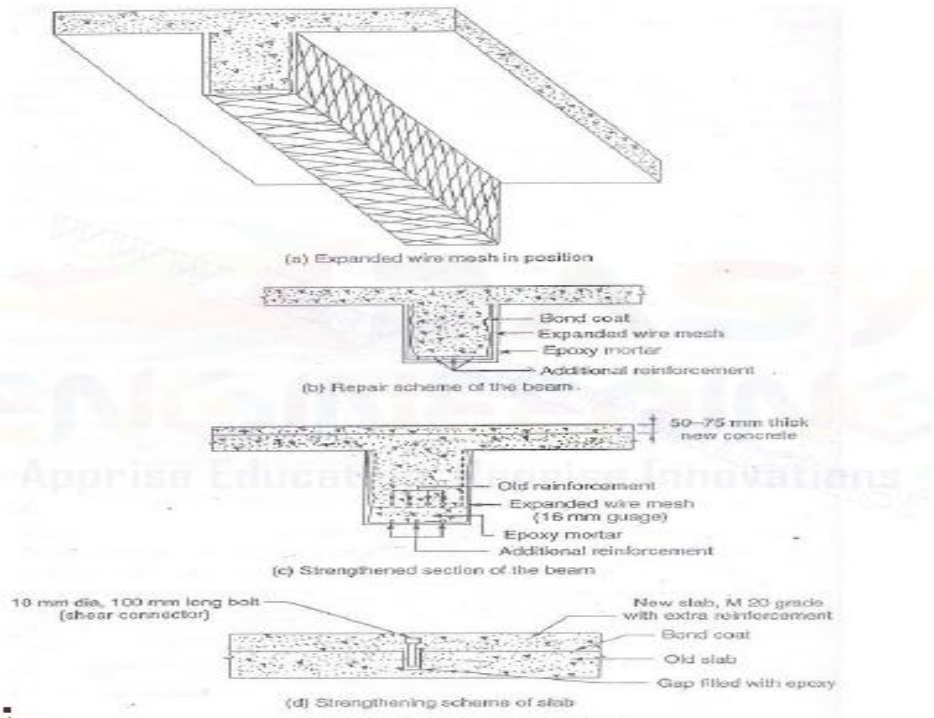
The mortar is cured for appropriate period in water and thereafter it is allowed to cure in air. Epoxy resin should also be injected in the cracks along top of beams. If new stirrups are required for shear strength enhancements should be followed.

Deflection due to Strengthening of slabs

The strengthening of slab is taken up only after the strengthening of beams is completed. A reinforced structural concrete topping over the existing slab can be used which provides a composite construction of old and new slabs, with additional depths to slab and beam.

To ensure a good bond between new and old concretes, mechanical anchorage consisting of steel bolts inserted in holes drilled into the slab at suitable intervals may be provided. The spaces surrounding the holes are filled with epoxy grout.

A shear connector is embedded for half of its length in old concrete and the remaining half which is projected will subsequently b embedded in new concrete.



Strengtheing of a slab–beam system

Before applying topping the surface of old floor slab should be thoroughly scrabbled and cleaned. Additional reinforcement may be required over the supports, because the old reinforcement at supports acquires a position which is near to the neutral axis of compositors section.

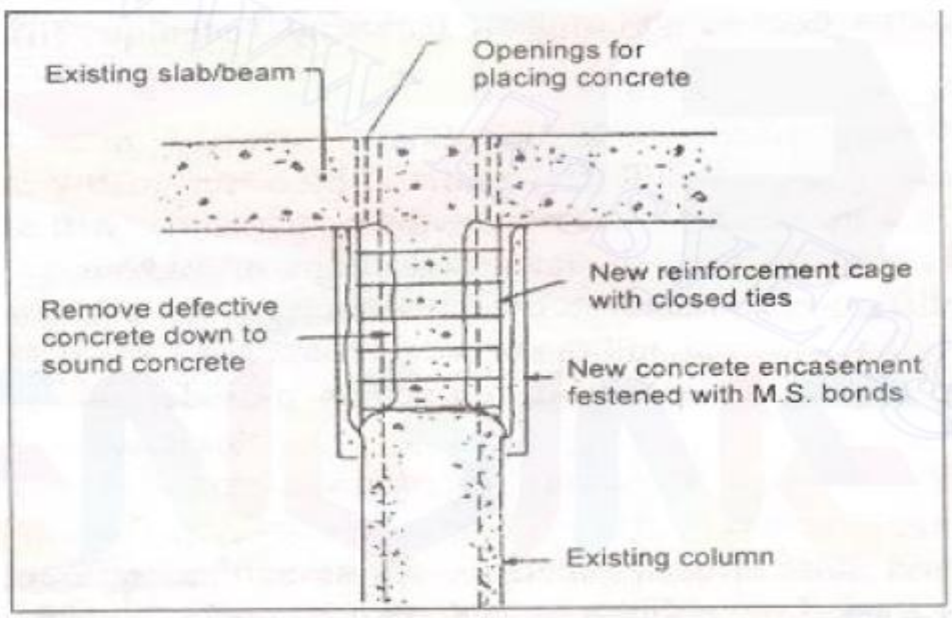
After the preparation of old concrete surface, epoxy bond coat is applied on it and while this coat is still touch-dry 25 to 50mm thick M20 grade concrete topping is laid. The thickness of topping is governed by the strength and thickness of old floor slab.

However application of topping increases the dead weight on the slab. With suitable treatment the top layer of topping maybe utilized as floor finish etc, After curing the beam and slab for 14 to 21 days props can be removed.

Deflection due to Strengthening of columns

Jacketing is the process of fastening a durable material over concrete and filling the gap with a grout that provides needed performance characteristics.

The column jacket can also be used for increasing the punching shear strength of column slab connections by using it as a column capital. When the jacket is provided around the periphery of the column, it is termed a collar. In most of the applications, the main function of the collar is to transfer vertical load to the column. Circular reinforcement can be used for load transfer. The practice of transferring load through dowel bars embedded into columns or shear keys has a disadvantage in that they require drilling of holes for dowels or cutting shear keys which are costly and time consuming, and can damage the existing column. Reinforcement encircling the column can be used to transfer the load through shear friction. The expansion of collar as it slides along the roughened surface causes the tensioning of circular reinforcement resulting in radial compression, which provide normal force needed for load transfer. The shear transfer strength is provided by both frictional resistance to sliding and dowel action of reinforcement crossing the crack.



. Process of jacketing technique

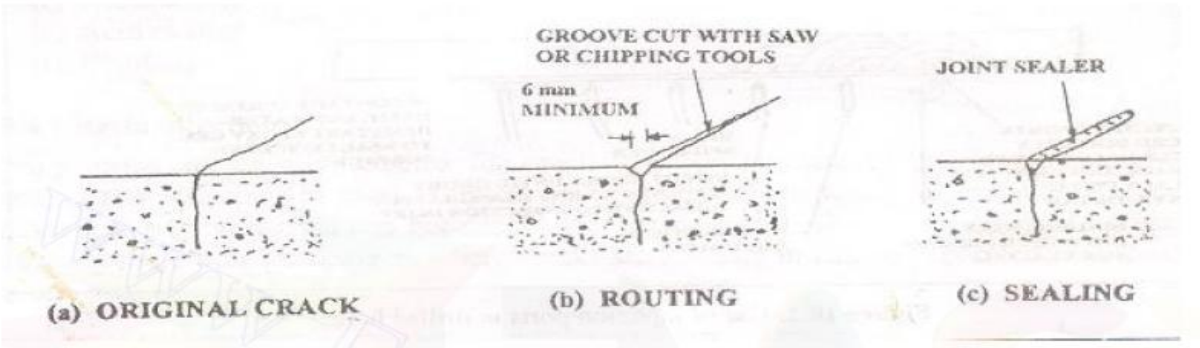
The collar is subjected to shear and bending along the collar circumference as well as direct bearing stress under concentrated load. In addition shear transfer reinforcement, the collar should be provided with reinforcement for shear and moment within collar. Column collars can be provided below the slab to act as column capital to improve punching shear strength of the slab column connection.

Cracking

Routing and sealing

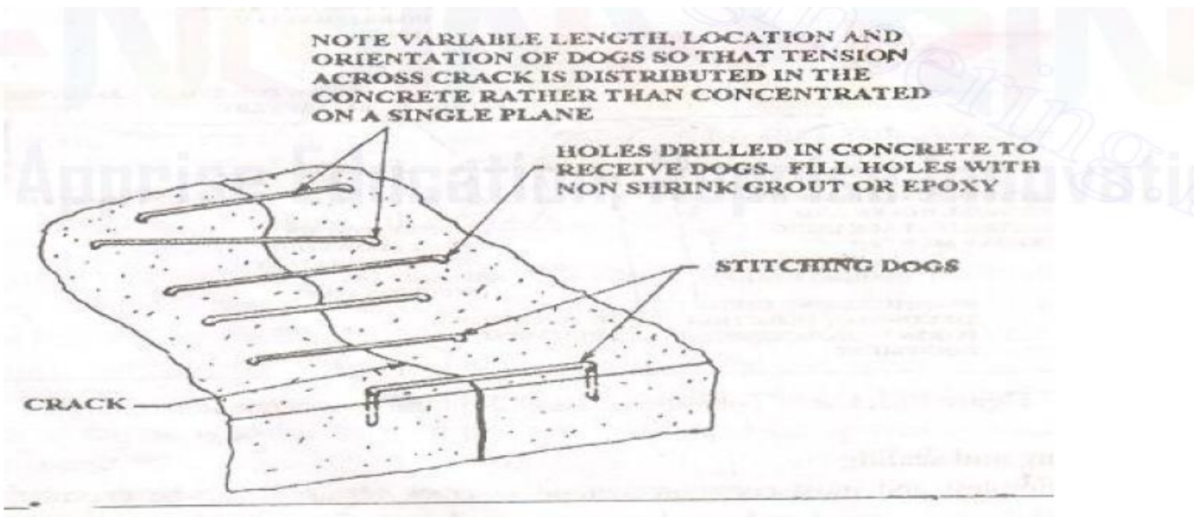
This is the simplest and most common method of crack repair. It can be executed with relatively unskilled personnel and can be used to seal both fine pattern cracks and larger isolated cracks.

The system can be used to repair dormant cracks that are of no structural significance, and is used to seal the cracks against the ingress of moisture, chemicals and carbon dioxide. This involves enlarging the crack along its exposed face and sealing it with crack fillers as shown fig. Care should be taken to ensure that the entire crack is routed and sealed.



Stitching

In this technique, the crack is bridged with U-shaped metal units stitching dogs before being repaired with a rigid resin material. This can establish restoration of the strength and integrity of cracked section; due care is to be given to make analysis check to ensure that this will perform well under applied loads shown fig.



Repair of crack by stitching

Stitching is suitable when tensile strength must be re established across major cracks, although stitching will not close the crack, and it is way of stopping the movement of active crack and thereby preventing it from spreading. Stitching dogs should be of variable length and orientation and so located that the tension transmitted across the crack is not applied to a single plane within the section but us spread over an area.

Bonding

Cracks in concrete may be bonded by the injection of epoxy bonding compounds under pressure. A usual practice is to drill into cracks from face of the concrete at several locations. Water or a solvent is injected to flush out the defect. The surface is than allowed to dry. The epoxy is injected into the drilled holes until it flows out through the other holes.

The epoxy is injected into the drilled holes until it flows out through the other holes. Bonding with epoxies-cracks as narrow as 0.0.75mm can be sealed with epoxy compounds, usually pressure injection is restored to in sealing the cracks.

Bandaging

A flexible strip is fixed over the crack with only the edged of the strip bonded. Where movement is not all in one plane, where is excessive movement beyond that which can be accommodated by a recess of convenient size, or if there are factors which prohibit the cutting of a recess, a surface bandage can be used. In areas which are subject to traffic, the flexible bondage will be coated over with a wearing course.

Chemical disruption

Resistance of concrete to chemical attack:

- The cement composition used in the concrete.
- Conditions under which the cement paste hardened
- All determine properties of concrete

Sulphate Attack

Mechanism-sulphates are found in most of the soils as calcium, potassium, sodium and magnesium sulphates. Sulphate attack occurs when pore system in concrete is penetrated by solution of sulphates.

Chemical mechanism

The effect of sulphate on concrete can be mainly, chemical and physical and they are closely related. The sulphate attack or reaction is indicated by the characteristic whitish appearance on the surface. As a result of the chemical reactions between sulphate and hydration products, changed in the microstructure and pore size distribution of the cement paste takes place. Sulphate converts calcium hydroxide into large of calcium sulphate.

$$Na^2So^4.10H^2O + Ca(OH)^2 \longrightarrow CaSO^4.2H^2O + 2NaOH + 8H^2O$$

The second hydration product, tricalcium aluminates hydrate reacts with sulphate solution to form sulpho aluminates hydrate, which has a greater volume than that of the original compound.

$$2(3CaO.Al_2O_3.12H_2O) + 3(Na_2SO_4.10H_2O) \longrightarrow 3CaO.Al_2O_3.3CaSO_4.31H_2O + 2Al(OH)_3 + 6NaOH + 17H_2O$$

When concrete cracks, its permeability increases and the aggressive water penetrates more easily in to the interior, thus accelerating the process of deterioration.

Alkali reaction

The reaction of some forms of silica and carbonates inaggregates with the alkalis in cement produces a gel, which causes expansion and cracks.

Mechanism of Alkali-aggregate reaction

This is called alkali carbonate reaction. Certain carbonate rock aggregates have been reactive in concrete. The results of these reactions have been characterized as ranging from beneficial to destructive.

The destructive category is apparently limited to reactions with impure dolomitic aggregates and are silt of either dedolomitization reactions. Visual examination of those reactions that are serious enough to disrupt the concrete in a structure will generally show map or pattern cracking and a general appearance, which indicates that the concrete swelling. A distinguishing feature which differentiates alkali-carbonate rock reaction from alkali-silica reaction is the lack of silica gel exudations at cracks. Typical alkali aggregate reaction damage is as shown fig

Factors:

- Size of the aggregate particles
- Alkali content in cement
- Fineness of cement particles
- Porosity of the aggregate particles

Weathering corrosion

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Salt attack/Weathering

Solid salts do not attack concrete, but when present in solution they can react with hardened concrete. It is a more general problem in masonary structures. Efflorescense is awhitish crystalline deposit on the surface. Efflorscence is the formation of calcilum carbonate precipitate on the concrete surface owing to carbonation.

Prevention measures

- Using sound materials free from salts
- Proper concrete proportioning
- Consolidation and Curing
- Preventing the access of moisture to the structure

Wear

The concrete has been damaged by erosion it is almost certain that any repaired section will again be damaged unless the cause of the erosion is removed. The best concrete made will not withstand the forces of cavitation or severe abrasion for a prolonged period. It may be more economical to replace the concrete periodically rather than to reshape the structure to produce streamlined flow or to eliminate the solids which are causing abrasion.

Mechanism

Abrasion-erosion damage is caused by the action of debris rolling and grinding against a concrete surface. In hydraulic structures, the areas most likely to be damaged are spillway aprons, stilling basin slabs, and lock culverts and laterals.

The sources of the debris include construction trash left in a structure, riprap brought back into a basin by eddy currents because of poor hydraulic design and riprap or debris thrown into a basin by the public. Also barges and towboats impacting on lock wells and gide wells can cause abrasions erosion damage.

Symptoms

- Concrete surfaces abraded by waterborne debris are generally smooth and may contain localized depressions.

- Mechanical abrasion is usually characterized by long shallow grooves in the concrete surface and spelling along monolith joints.
- Armor plates is often torn away or bent.

Common materials

Metallic types

- Pearlitic iron turnings
- Crushed cast iron chilled grit

Non-metallic types:

- Silicon carbide grains
- Fused alumina grains
- Natural emery grains

Fire

A fire in a concrete structure causes damage. The extent of which depends upon the intensity and duration of the fire.

The principle types of damages are

- Reduction in strength of concrete
- Cracking and spalling of concrete
- Deflection and deformation of members
- Discolouration

Concrete structures are determined by three main factors:

- The capacity of concrete itself to withstand heat
- The conductivity of the concrete to heat
- The coefficient of thermal expansion of concrete

A large number of reinforced concrete structures salvaged from destruction in fires by timely fire fighting operations can be put to further service after strengthening and providing some cosmetic repairs since the cost of restoration of such structures less than that for dismantling and construction of new ones. The fire may cause different degrees of damage to the structure: the structure may be completely burnt or destroyed; its surface may be slightly damaged or slight deformation may occur. In the first case, the whole of damaged portion has to be replaced during restoration of structure while in the latter, only repair and finishing may be required. The extent of damage caused th the structure during a fire depends on the duration of fire, and the temperature to which the structure was subjected during the fire.

High temperature during a fire reduces the strength of reinforced concrete structures due to change in the strength and deformability of materials, reduction in cross sectional dimensions, weakening of bond between the reinforcement and concrete which determines structural action under the load. When assessing the effects of a fire on a building structure, it is important to recognize that the huge expansion that occurs in the members subjected to the fire temperature may cause damage in other members remote from the fire.

Shear cracking can occur in columns and cracking resulting from inversion of moment may occur if detailing is not adequate

Restoration of fire Damaged Elements

The eccentrically loaded columns fail when reinforcement bars in tension heat up. The fire resistance of such elements can be increased by increasing the thickness of protective layer. Heat transmission and temperature of bottom reinforcement are keys to the behaviour of reinforced concrete slab exposed to fire. The reinforcing bars are assumed to retain one half of their original strength. Carrying capacity of slabs can be enhanced by increasing their thickness. For beams, depth and width can be increased. It should be kept in mind that in beams, weakening of bond between transverse reinforcement and concrete on account of heating reduces the residual shear load carrying capacity considerably.

The carrying capacity of axially loaded depends upon the cross section of the column coefficient of change in strength of concrete under high temperature and corresponding critical temperature. The carrying capacity can be restored by increasing the cross section with suitable increase in the longitudinal steel.

Leakages

Leakage in the concrete structures causes inevitable damage to the reinforcement. Construction joints, shrinkage and restraint cracks may form leak paths. The amounts of water involved vary from damp-patches which tend to evaporate as they are formed, to running –leaks which may eventually form undrained surfaces. Damp patches may also be formed when water passes through the voids along reinforcing bars formed due to **plastic settlement.**

The other common routes for larger volume leaks are **honeycombed concrete, movement joints** like expansion and contraction joints. In case of water-retaining structures, the extent of leakage may be measured by monitoring loss of liquid from the structure.

Techniques

- **Conventional leak-sealing methods**
- **Leak-sealing by injection techniques**

Conventional methods

Some sources of minor leakage may dry up by autogenously healing which is an accumulation of calcium salts along the leak path. This will obstruct the passage of water over period of time and reduce the leakage to negligible proportions.

Once leak spots have been identified, the remedial action may involve the application of local or complete surface seal in the form of a coating system.

- Surface preparations
- Filling of surface imperfections with resin-based grouts
- Application of primer
- Application of two coats of high-build paint

The procedure may require quite extensive preparatory work including the injection of suspect joints and random shrinkage cracks with allow viscosity resin.

Honey combed concrete if not particularly extensive may be filled out using a resin based mortar. Laitance and surface contaminants may be removed by sand blasting and power wire brush

Injection Sealing

From liquid flow and pressure considerations the simplest and most cost effective way is to seal the leakage from the water-retaining side of the structure. When the wet side is inaccessible, the leakage must be tackled from the dry side which is considerably more difficult. Successfull leak sealing requires injection of sealant to fill water passages completely, and it is necessary to attain a relatively high flow velocity to achieve this, because of short pot-life or working time of the typical repair material.

The first basic step is to restrict or confine the water flow to tubee through which the sealant any be introduced.

Due to possibility of concrete being stressed during injection, it is preferable to maintain lower pressures. The direct methods are very slow due to sealant being pumped slowly through very narrow passages against pressure, and the pressure cannot be maintained for long enough to achieve complete penetration. In many cases water may find another finer pathway leading from the same source. In contrast the indirect methods enable the work to be completed quickly because surface seals are not required and mechanical anchorages can be used.

Marine exposure

Durability of concrete exposed to sea-water again stresses that of all chemical and physical properties, permeability of concrete is the most important factor influencing performance. Concrete are achieved by using mixes having high cement contents and low water: cement ratios, through consolidation and control of thermal and shrinkage cracking, and limiting cracks due to mechanical loading.

Physic-chemical effects of sea water on hydrated cement as follows:

- Chemical attack by sea water on cement only occurs in the case of permeable concrete
- C4AF, in contrast to C3A has no deleterious effects
- Portland cements with C3A contents lower than 10% resist chemical attack in sea-water
- Cements containing more than 65% slag are most resistant to sea-water attack
- The effects of pozzolan depend on their mineralogical composition and reactivity
- Compressive or flexural strengths are not a good basis for assessing durability once reactions commence; a much b etter basis is the measurement of expansions as they continue

Application of materials

- Mortar placement
- Injection into cracks
- Large-scale Repair

Non-destructive Testing System:

Non-destructive evaluation is widely employed for inspecting the condition of structures. Non destructive techniques, which are less time consuming and relatively inexpensive, can be used for the following purposes:

- Test on actual structures.
- Test at several locations.
- Test at various stages.
- Assess the quality control of actual structures.
- Assess the uniformity of the concrete.
- Assess the materials used and workmanship with specification.
- Assess the poor construction practices.
- Assessment of the extent of cracks, voids, honeycombs.
- Confirmation of suspected distress due to poor design
- Assessment of partial durability
- Integrity testing of piles
- Monitoring of progressive changes in structure

The results of non-destructive tests are most useful when supplemented by a limited number of destructive test procedures. There are more testing techniques with different principles and applications are available to evaluate the properties of concrete. The concrete material is complicated that the efficiency and quality cannot be established just by one single test. Most of the tests, which are used, for estimating the parameters of concrete provide an excellent means of establishing and evaluating the uniformity of concrete.

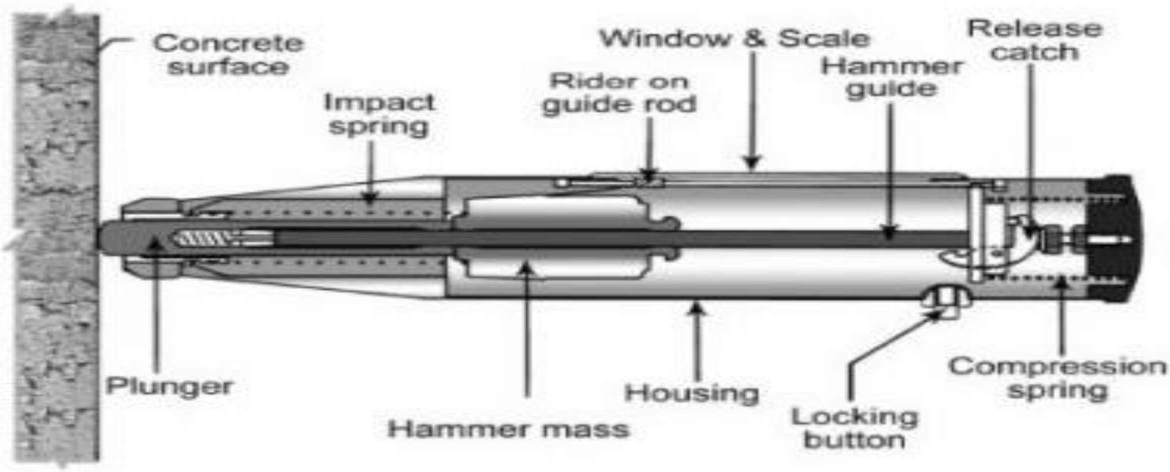
Non-Destructive Testing Methods

Potential and limitations of various non-destructive techniques cited below and are briefly discussed in the following paragraphs to apprise users of their relevance in field application:

- Surface Hardness Method
- Ultrasonic Pulse Velocity Method
- Resonant Frequency Method
- Dynamic or vibration method
- Pulse Attenuation Method
- Pulse Echo Method
- Radioactive Method
- Nuclear Methods
- Magnetic Methods
- Electro magnetic methods
- Electrical Methods
- Acoustic Emission Technique
- Radar technique
- Radiography Methods

Surface hardness test (or) Rebound Hammer Test:

The surface hardness method consists of impacting the concrete surface in a standard manner. Activating a mass by a given energy and measuring the indentation or rebound achieve this. The most commonly and widely used instrument is a "**Rebound Hammer**”. There are several types of hammers having varying impact energy from 0.07 kg m to 3 kg m the high impact energy is used for mass concrete, road pavements and airport runways. The low impact energy hammers (0.07 to 0.09 kg m) are used for small and low strength materials. A typical rebound hammer is shown in figure.



Typical Rebound Hammer

Test procedure:

The test procedure consists of applying the hammer on the concrete surface and observing the rebound reading indicated by a rider over a scale. Before applying the hammer, the surface of the concrete is cleaned and smoothened. A minimum of 10 readings is compared and each reading should not differ by more than 7 units. The average of remaining readings is determined for evaluating the strength. If more than two reading differ from the average units, than the entire set of readings are taken afresh.

The procedure for determining the rebound values has been specified in ASTM C 805-85 BIS-1331l Part 2 and also in the latest ASTM specification. Estimation of concrete compressive strength from rebound number is determined from standard calibration curve based on the laboratory results. The calibration curve should be established for each type of concrete.

The following table shows the quality of concrete cover from rebound number.

Average rebound number	**Quality of Concrete**
Greater than 40	Very good hard layer
30 to 40	Good layer
20 to 30	Fair
Less than 20	Poor concrete
0	delaminated

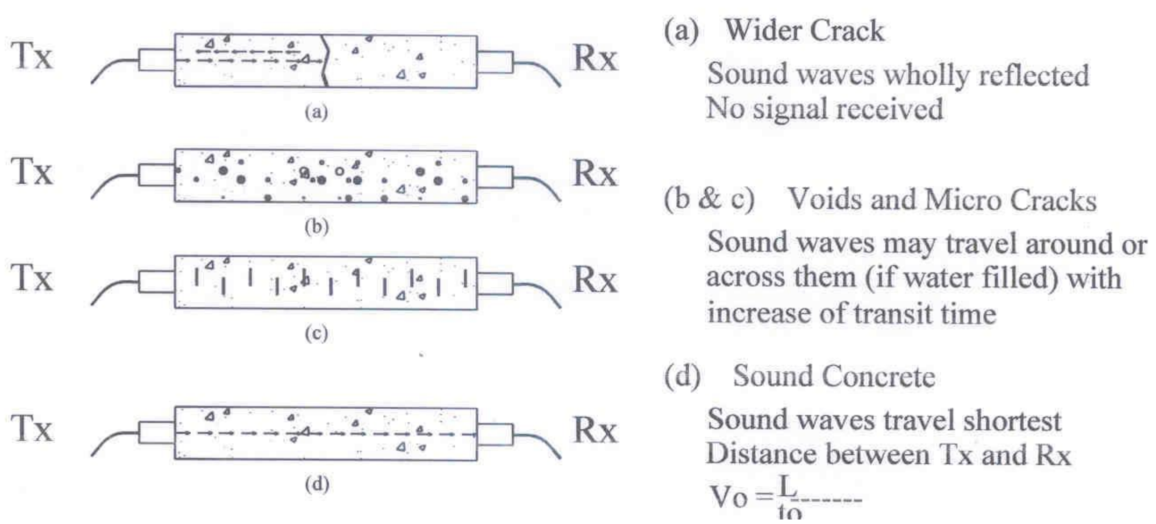
Ultrasonic pulse Velocity (USPV) test

It is most widely used test in evaluation of in-situ concrete. The method is based on the principle that the velocity of an ultrasonic pulse through any material depends upon the density, modulus of elasticity, the presence of the reinforcing steel & poision's ratio of the material.

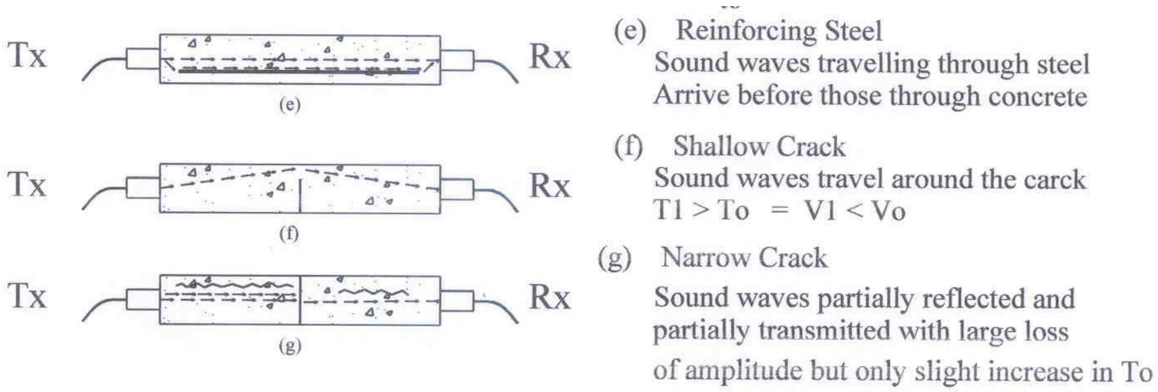
Procedure For Upv Test

- Divide the members into well defined grid points - spacing of 200 - 300 mm preferred identical to rebound hammer survey
- Each grid point is prepared to obtain smooth surface - a thorough cleaning
- Application of acoustical coupling - grease, thick oil, petroleum jelly
- Transmitting the pulses by placing the transmitter and receiving at other end (50-54 kHz)
- Recording the transit time displayed by the instrument - a reliable steady reading to be recorded
- Measurement of length between transmitter and receiver
- Calculation of velocity, V = L / T (L – Path length, T-time)

Behaviour of ultrasonic pulses in a concrete medium under different conditions



The principle of assessing the quality of concrete is that values of ultrasonic pulse velocities are found to be higher when it encounters a dense, homogeneous and uniform concrete along its path. Lower velocities are obtained in case of poorer quality.



UPV value km/sec. (V)	Concrete quality
Greater than 4.00	Very good
Between 3.50 and 4.00	Good, but porous
Between 3.00 and 3.50	Poor
Between 2.50 and 3.00	Very poor
Between 2.00 and 2.50	Very poor and low integrity
Less than 2.00	No integrity, large voids suspected

Applications: The tests help to determine the homogeneity of concrete, changes in structure of concrete with time, to assess the extent and severity of cracks in concrete. Precisely describes the areas of deteriorated and poor quality concrete.

Advantage: The test equipment is portable, can be performed quickly and has sufficient power to penetrate about 11m in good continuous concrete.

Limitations: The test does not give the precise strength of concrete. A large number of factors affect the values of pulse velocity that include surface condition and moisture content, temperature of concrete, micro-cracks in concrete, age of concrete, presence of steel rfm, aggregate type, content & size. When the concrete is subjected to abnormally high stress, pulse velocity value is reduced due to development of micro-cracks.

Identification Of Corrosion Prone-Locations Based On Upv And Rebound Hammer Readings

S. No	Test Results	Interpretation
1	High UPV Values, High Impact Hammer No.s	Not Corrosion Prone
2	Medium range UPV values, low impact hammer numbers	Surface delamination, low quality of surface concrete, corrosion prone
3	Low UPV, High impact hammer numbers	Not corrosion prone,however to be confirmed by chemical tests, carbonation, pH
4	Low UPV values, low impact hammer numbers	Corrosion prone-Requires chemical and electrochemical tests

Windsor Probe test

It is one of the most well-known penetration resistance methods. It is based on the determination of the depth of the penetration of probes (steel rods or pins) into the concrete. The apparatus used in this method is Windsor probe which is a special gun that uses a 0.32 Caliber blank with a precise quantity of powder to fire a high strength steel probe into concrete. The principle underlying the technique is that penetration depth is inversely proportional to the compressive strength of concrete, but the relation depends on hardness of aggregate. The minimum distance between the edge of concrete member should be of the order of 150 mm and that between the test positions be 200 mm.

The penetration will be effected by the presence of reinforcing bars within the zone of influence of the penetrating probe. Thus the location of the reinforcing steel should be determined prior to selecting test locations.

Manufacturers provide calibration charts of strength versus penetration for the normal probe for aggregates with hardness between 3 and 7 on Mohrs scale. However, the penetration resistance should be correlated with the compressive strength of a standard test specimen or core of the actual concrete used.

Application: This test is used for estimating the uniformity & quality of concrete. An area of poor concrete can be easily described by making a series of penetration tests at regular spaced locations. This method provides excellent means for determination of relative concrete strength in the same structure or in different structures without extensive calibration.

Advantage: The test equipment is simple, durable and requires less maintenance and can be easily used with least training given to inspectors. Can also be used in places where access is limited.

Limitation: It does not give reliable results on strength values. Type of aggregates affects the penetration depth; hence a separate calibration chart needs to be prepared for each type. This test damage the concrete leaving a hole of about 8 mm in diameter for the depth of the probe, hence minor cracks of exposed surface becomes necessary. Damage in the form of cracking may be caused in case of slender members.

Semi-destructive tests for strength estimation of concrete

Pull-off test: The pull-off test is used to determine the tensile strength of concrete by application of the in-situ concrete by application of direct tensile force. The test is also used for measuring the bond of surface repairs. A circular steel probe is glued to the concrete with an epoxy resin. Before applying the adhesive, the concrete surface is roughened with sandpaper and then degreased with the help of suitable solvent. After the epoxy resin has cured sufficiently, the metal disk is pulled off from the concrete surface manually or mechanically. The tensile strength of the bond being greater, the concrete fails in tension. The tensile force required to cause failure is recorded from which the tensile strength is calculated on the basis of the disk diameter i.e., 50 mm, and this may be converted to the compressive strength using a calibration chart appropriate to the concrete.

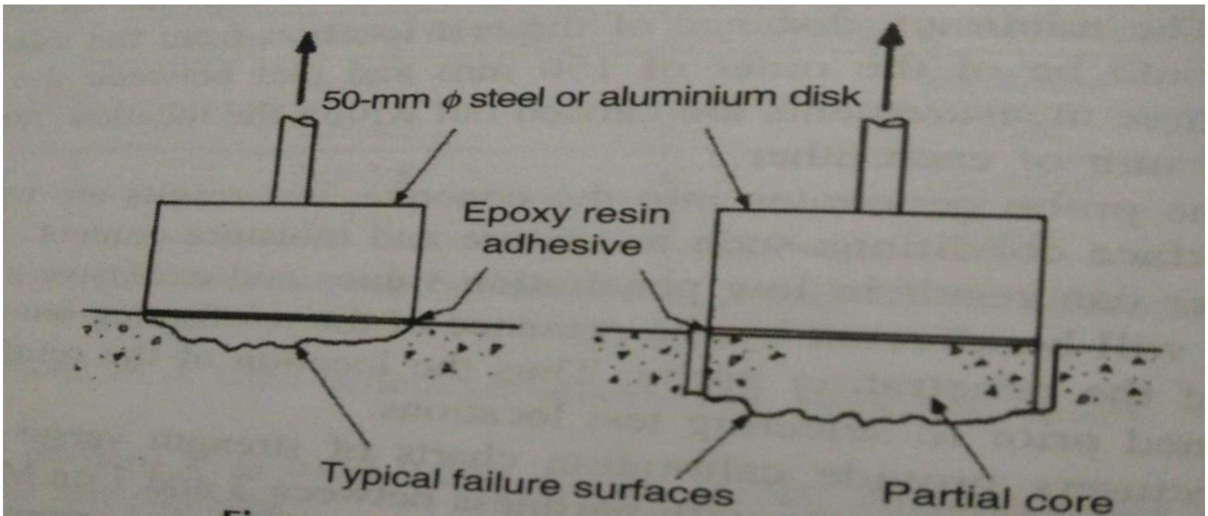


Figure 3.8 Pull-off test assembly.

Application: Assessment of the bonding strength of all kinds of applied coatings & repairs.

Advantage: The test is simple & quick to perform. Damage caused to concrete is minor and can be repaired easily.

Limitation: The main limitation is the curing time of the adhesive which is 24 hours. During testing is adhesive fails because of its inferior quality, then the entire test result becomes meaningless. Hence, six discs are to be used to determine the strength.

Core Test: The testing of the cores cut from hardened concrete is quite a well established method used for visual and petrographic analysis of concrete. Cores are sometimes sectioned or drilled to provide samples for chemical analysis. Cores are usually extracted by drilling using a diamond tipped core cutter cooled with water.

The selection of location of the cores is made after conducting NDT which can give guidance on the most suitable area of extraction.

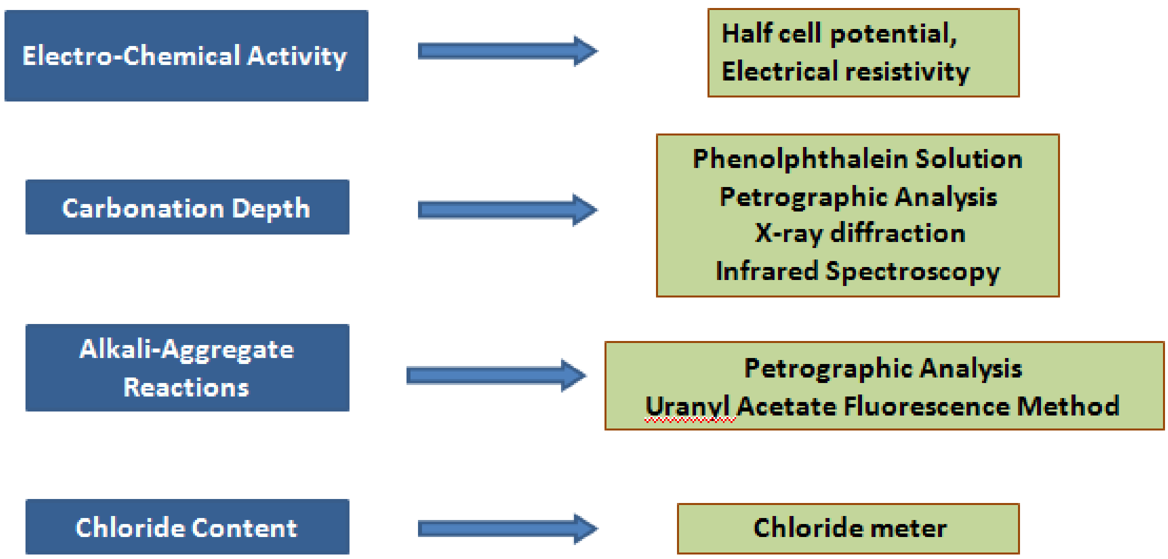
Cutting of cores require special equipment. Most of the cores are either 100 mm or 150 mm in diameter. If the core size is small in relation to the maximum aggregate size, then care must be taken during analysis. The choice of the core diameter will be influenced by length of the specimen. It is generally accepted that cores for compression testing should have a length/diameter ratio between 1 and 2. The measured compressive strength represents the equivalent strength of the cylinder having a slenderness ratio of w. Equivalent cube strength is determined by multiplying the corrected cylinder strength by 5/4.

Application: The cores confirm the findings of non-destructive tests, and helps in identifying the presence of deleterious matter in concrete, ascertaining the strength of concrete for design purpose. Cores can also be used for measurement of density. This provides a useful indication of compaction and void age.

Advantage: Cores provide the simplest method of obtaining samples of in-situ concrete. Chemical analysis can be performed on the remains of crushed core. Visual inspection of the interior of concrete can prove to be very valuable where no records of concrete are available.

Limitations: The main limitation is the cost and inconvenience, damage and localized nature of the results. The test is possible only if the quality of concrete is reasonably good in the structure that is tested. If the quality is poor, then core samples will be vulnerable to damage during coring or testing operation.

Testing For Chemical Properties



Engineered demolition techniques for dilapidated structures

Modern Demolition Techniques

- Hydralic Rock Breakers
- Diamond sawing and Drilling
- Diamond wire sawing system
- Silent expansive chemicals
- Controlled Demolition
- Hydralic Brusting / Spliting
- Thermal lancing
- Hydro demolition
- Robolic demolition
- Core Drilling – uses diamond tipped bits with hydraulic/electric/pneumatic geode drill motors – maximum dia – 2000mm.

Wire Sawing : Ultimate Demolition Tool

In wire sawing a diamond beaded wire is reared around the RCC members, to be cut. The wire is rotated at a high speed (100Km/hr) by a special machine while constantly applying a pulling force. The diamond wire penetrates and cuts through the steel and concrete. Water is used as a lubricating coolant. Wire sawing has limitations on the size of RCC member, to be cut. This technique is ideal for fast primary demolition.

Hand Sawing

Han sawing uses a light weight hand held machine, with diamond blade to cut RCC in any direction. By this technique, even over hand cutting is possible. Max. Depth of cut is 150mm.

Diamond Advantage

Time : Diamond tools cut concrete fast, reducing down time which Leeds to early project completion.

Limensional Tolerance: Diamond cutting is precise and controlled, little or no patching s required.

Structural Integrity : Diamond cutting allows removal of large amounts of concrete without damaging, remaining or surrounding structures.

Noise , Dust and Debris: Diamond cutting is relatively quiet and virtually dust free concrete pieces can be cut to specified size for easy removal.

Limited Access: Diamond cutting techniques can e used in confined areas and arrows existing equipment.

Hydraulic Splitters/Busters:

Creates enormous sresses within concrete, producing tensile cracking of concrete.

- Dismantling Tools
- Hand Operated Machines

Crane Mounted machines

- Special Machine
- Robotic machine

Tools to be used for job on Haul

The following factors should determine the technique

- Volume of concrete to be dismantled
- Space available for walling
- Risks involved
- Acceptable noise and Vibration levels

Hand Held Machines

- Electrically Operated
- Battery operated
- Pneumatic
- Hydraulic
- Engine

Key Factors

General

- Weight
- Multifunction – Drill, Chip, Hammer Drill
- Ergonomics

Technical

- Energy Per Stroke
- Material Removal Per minute
- Tool Mount Type
- Tool Life
- Maintenance Cost
- Safety Features
- Durability

Advantages & Disadvantages of Hand Held Machines

Advantages	**Disadvantages**
Easy to Handle	Requires great inuscular power
Unskilled labour can be used	Limited removal due to low hammer weight
Ideal for dismantling small volumes	Little impact from small diameter chisel

Case studies

Demolition Practice in USA

From as early as 1940, demolition works in USA were taken up with extensive applications of mechanical contrivances (something artificial) and convenient improvisations. (Provide or construct from materials etc, which is not intended for the purpose). The impact of blows from a large-sized iron ball swung from mobile crane boom brought drawn multi-storeyed apartment buildings and old structures. With the area well cordoned, off, the rubble and debris together with the rising dust were tackled in such a way, that at no stage was there any depature form the main aim of containing the effects of the demolition within the boundary. In course of time, more improvements came by, and a significant alternative developed around 1950 was the use of dynamite in a sophisticated arrangement, whereby the operation could be carried out instantaneously and with no risk to the adjacent buildings or disturbance to the neighbourhood. The term implosion referred to this new process, was synonymous with the phenomenon of an explosion that caused no scattening of material knocked off, but observed them well within the extremists of the compound.

Implosion Contract

A world wide leader in the implosion business, Controlled Demolition Inc., USA is a pioneer in this technique applied to demolition. In the works of its president Loizure, ‘it is delineate art of denoting explosives, in just the right places to make a building collapse about neatly into its footprint.” The company takes justifiable pride that it has levelled about 7000 structures till date.

It is therefore, not a wonder that its services have been hired recently in Scuttle. The project here attracted the attention, of not only professional, but every citizen around, including the die-hard, who could not tolerate the removal of any historic landmark.

Following the changing needs of the metropolis, and the American predilection for newness, Something befitting the city’s huge arena, called “Kingdome”, looked incongruous.

This large indoor stadium was a multipurpose facility built in 1936 and served as the venue for all kinds of sports events, athletic meets, public functions and even music concerts. But the authorities decided on its demolition, to pave way for a modern open air starlium.

The Implosion Technique

The unique ‘Kingdome” structure was a circular building with a strong, light roof only 5’ thick and spanning 670.

It was so strong that it could endure a earthquake, and take on two feet of snow on its top, it can be seen that breaking such a dome needed all the ingenuity and the expensive of the contracting company, which had to wind. 1 miles of detonation cord through the structure, that was expected to light up like a lightening, flash followed by the sound of explosions.

The day chosen for the demolition was a Sunday and nearly a week earlier. It is needless to add how much pre-panning and preparation had gone into this colossal scheme before actually putting into action the actual detonation. The entire series of operations formed five distinct stages from the preliminary phase, until the final explosion.

- **Stripping the Dome :** Removing of roof surfacing pieces and insulation and exposing only the concrete. Stripping of AC systems fully. Other ramp demotion and removing lower level seating outfit, leaving concrete supports like beams and columns.
- **Protecting Neighbourhood :** Wrapping nearby buildings with cushioning material, creating protective walls and berms around the site, and finally cottoning off (circle of police) the demolition area
- **Arranging Detonation Points:** Drilling about 6000 holes of 1.5 feet diameter and 5 to 6 feet deep in the ribs of the roof and supporting columns. Packing the holes with a pre calculated

measure of explosives and fixing a time delay circuit. Wrapping 10000 ft of detonation cord to connect all the explosive points.

- **Topping Up:** As a last phase, providing a thin top layer of the explosive material, and a hand denotation cord together with a fuse. This completed the arrangements.

- **Explosion:** As the cord was ignited, the fuse got set off, starting explosions in a controlled, progressive way at different intervals. The rubble from the lowest section got spread out in beams across the floor. This helped to absorb to some extent the impact from falling debris of the upper levels.

- **A great Feat:** The destruction of “Kingdome”, an architectural beauty was a great engineering love loads, increased wheel loads, installations of heavy machined in demolition technology.