||Jai Sri Gurudev||

Sri Adichunchanagiri Shikshana Trust ®

ADHICHUNCHANAGIRI UNIVERSITY

BGS INSTITUTE OF TECHNOLOGY,

B.G. Nagara-571448.

DEPARTMENT OF CIVIL ENGINEERING

SEVENTH SEMESTER CIVIL ENGINEERING
Rehabilitation and Retrofitting of Structures
SUBJECT CODE –17CV753

Prepared by,

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BGS INSTITUTE OF TECHNOLOGY

Vision

BGSIT is committed to the cause of creating tomorrow's engineers by providing quality education and inculcating ethical values.

Mission

- Imparting quality technical education by nurturing a conducive learning environment.
- Offering professional training to meet industry requirements.
- Providing education with a moral – cultural base and spiritual touch.

DEPARTMENT OF CIVIL ENGINEERING

Vision, Mission, PEOs and PSOs of the Department

Vision

Producing technically competent and Environmental friendly Civil Engineering Professionals to cope with the societal challenges.

Mission

- Imparting quality education and professional ethics by proficient faculty.
- Providing infrastructure to meet the requirements of curriculum, research and consultancy.
- Motivating towards higher education and entrepreneurship.
- Promoting interaction with design and construction industries.

Program Education Objectives

PEO 1: Graduates will be pursuing successful career & higher education.

PEO 2: Graduates will be able to design safe, economical & sustainable Civil Engineering structures conforming to standards.

PEO 3: Graduates will display professional ethics to work in a team & lead the team by effectively communicating the ideas.

PEO 4: Graduates will practice lifelong learning.

Programme Specific Outcomes

PSO 1: Graduates will be able to analyse, design and execute the Civil Engineering structures effectively for the sustainable development

PSO 2: Graduates will acquire critical thinking abilities and technical skills for the usage of modern tools in development of Civil Engineering structures.

PSO 3: Graduates will be able to get opportunities for their professional growth, demonstrate communication and aptitude skills to face the challenges and needs of our society.

PROGRAM OUTCOME

The program leading to Degree in Civil Engineering aims to provide students with a strong theoretical and practical background in relevant engineering streams. A graduate in Civil Engineering is expected to attain the capability to analyze, design, execute and acquire skills necessary to function in Government Departments, Academic institutions, Construction industries, Research and Development organizations.

Program Outcomes are

1. **Engineering knowledge**: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.
2. **Problem analysis:** Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.
3. **Design/development of solutions:** Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriateconsideration for the public health and safety, and the cultural, societal, and environmental considerations.
4. **Conduct investigations of complex problems:** Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis ofthe information to provide valid conclusions.
5. **Modern tool usage:** Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activitieswith an understanding of the limitations.
6. **The engineer and society:** Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.
7. **Environment and sustainability:** Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.
8. **Ethics:** Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
9. **Individual and team work:** Function effectively as an individual, and as a member or leaderin diverse teams, and in multidisciplinary settings.
10. **Communication:** Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.
11. **Project management and finance:** Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member andleader in a team, to manage projects and in multidisciplinary environments.

Life-long learning: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change

Course Objectives

The objective of this course is to make students to learn.

1. Investigate the cause of deterioration of concrete structures.
2. Strategise different repair and rehabilitation of structures.
3. Evaluate the performance of the materials for repair.

Course Outcomes

CO's	Description
15CV753.1	**Apply** the knowledge of science to study the various types of causes for deterioration of concrete structures.
15CV753.2	**Illustrate** the concept of repair, rehabilitation and retrofitting techniques in concrete structures
15CV753.3	**Analyze** the causes of deterioration of concrete structures by various assessment techniques.
15CV753.4	**Evaluate** the ideal material of repair and retrofitting technique for concrete structures to enhance its life-span.

Course Title: Rehabilitation and Retrofitting of Structures
As per Choice Based Credit System (CBCS) scheme]
SEMESTER:VII

Subject Code	15CV753	IA Marks	20
Number of Lecture Hours/Week	03	Exam Marks	80
Total Number of Lecture Hours	40	Exam Hours	03
CREDITS –03		Total Marks- 100	

Course Objectives: This course will enable students to;

1. Investigate the cause of deterioration of concrete structures.
2. Strategise different repair and rehabilitation of structures.
3. Evaluate the performance of the materials for repair

Modules	Teaching Hours	Revised Bloom's Taxonomy (RBT) Level
Module -1		
General: Introduction and Definition for Repair, Retrofitting, Strengthening and rehabilitation. Physical and Chemical Causes of deterioration of concrete structures, Evaluation of structural damages to the concrete structural elements due to earthquake.	08 hours	L1,L2
Module -2		
Damage Assessment: Purpose of assessment, Rapid assessment, Investigation of damage, Evaluation of surface and structural cracks, Damage assessment procedure, destructive, non-destructive and semi destructive testing systems	08 Hours	L1,L2
Module -3		
Influence on Serviceability and Durability: Effects due to climate, temperature, chemicals, wear and erosion, Design and construction errors, corrosion mechanism, Effects of cover thickness and cracking, methods of corrosion protection, corrosion inhibitors, corrosion resistant steels, coatings, and cathodic protection.	08 Hours	L1,L2,L3
Module -4		
Maintenance and Retrofitting Techniques: Definitions: Maintenance, Facts of Maintenance and importance of Maintenance Need for retrofitting, retrofitting of structural members i.e., column and beams by Jacketing technique, Externally bonding(ERB) technique, near surface mounted (NSM) technique, External post-tensioning, Section enlargement and guidelines for seismic rehabilitation of existing building	08 Hours	L1,L2,L3
Module -5		
Materials for Repair and Retrofitting: Artificial fibre reinforced polymer like CFRP, GFRP, AFRP and natural fiber like Sisal and Jute. Adhesive like, Epoxy Resin, Special concretes and mortars, concrete chemicals, special elements for accelerated strength gain, Techniques for Repair: Rust eliminators and polymers coating for rebar during repair foamed concrete, mortar and dry pack, vacuum concrete, Gunite and Shot Crete Epoxy injection, Mortar repair for cracks, shoring and underpinning	08 Hours	L1,L2,L3

Course outcomes: After studying this course, students will be able to:

1. Understand the cause of deterioration of concrete structures.
2. Able to assess the damage for different type of structures
3. Summarize the principles of repair and rehabilitation of structures
4. Recognize ideal material for different repair and retrofitting technique

Program Objectives:

- Engineering knowledge
- Problem analysis
- Interpretation of data

Question paper pattern:

- The question paper will have 5 modules comprising of ten questions. Each full question carrying 16 marks
- There will be two full questions (with a maximum of three subdivisions, if necessary) from each module.
- Each full question shall cover the topics as a module
- The students shall answer five full questions, selecting one full question from each module. If more than one question is answered in modules, best answer will be considered for the award of marks limiting one full question answer in each module.

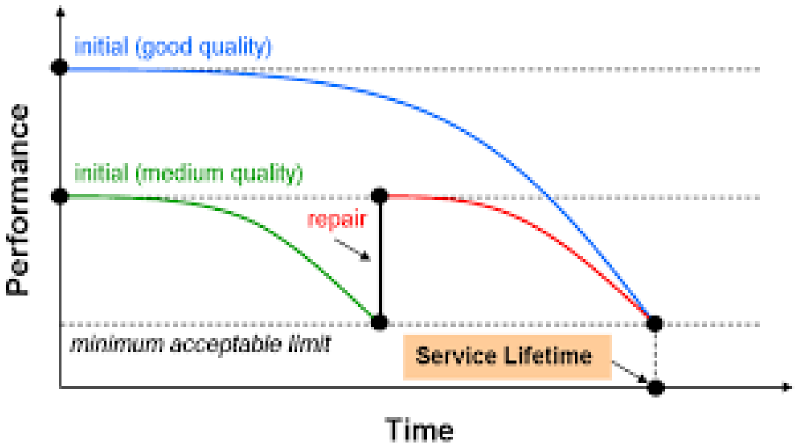
MODULE-1

Introduction

1.1 General

Concrete is the most extensively used construction material in the construction of various structures such as bridges, buildings and precast products pipes, poles, sleepers etc.From the past and even at the present times, too much emphasis is on concrete compressive strength rather than environmental factors, which is known as durability. This is one of the main reasons for serious deterioration of concrete structures that is prevalent today. Maintenance, repair and strengthening of constructed facilities/infrastructures is presently the most significant challenge facing the concrete industry

Fig 1.1: Deterioration of Concrete Structures



1.2 Durability of concrete

A concrete is said to be durable if it withstands the conditions for which it has been designed, without deterioration, over a period of years. Durability of concrete is used to characterize in broad terms the resistance of concrete to physical or chemical attacks due to the external causes or by the internal causes.

External causes – weathering, temperature, abrasion, electrolytic action and attack by natural or industrial liquids and gases.

Internal causes – Alkali aggregate reaction, volume change due to thermal properties of aggregate, cement paste and permeability of concrete

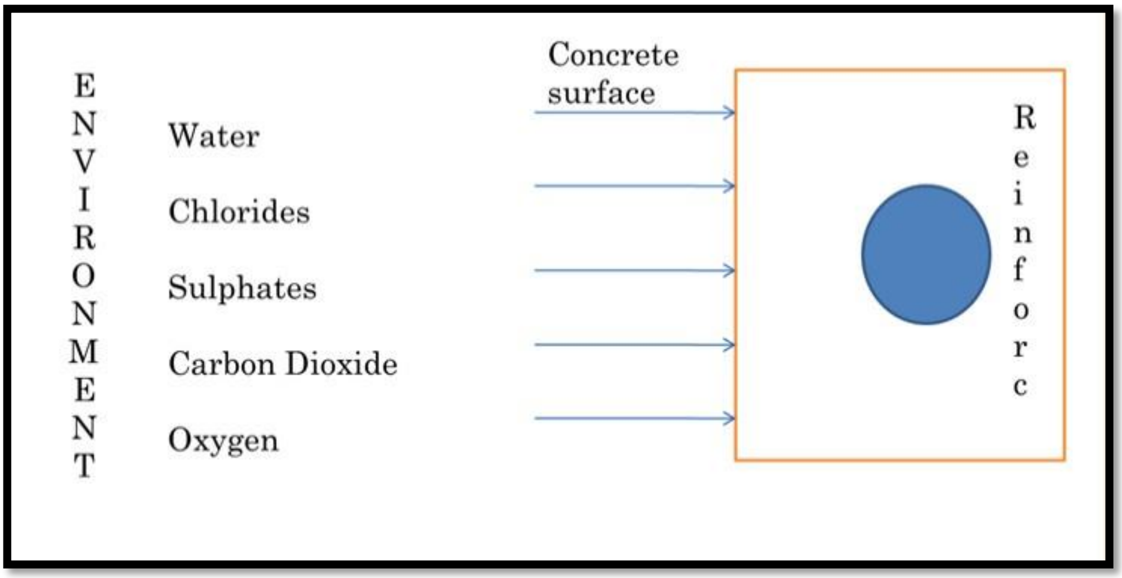


Fig 1.2: Durability of concrete

The following factors influence the durability of the concrete

1. W/C ratio
2. Curing period
3. Cement content and its properties.
4. Aggregates
5. Mix design
6. Workability
7. Admixtures
8. Thermal incompatibility of concrete constituents.
9. Transition zone
10. Environmental Interaction

1.3 Definitions

1 **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

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

OR

To bring back the position of the structure to its previous condition so it gives performance same as previously. It doesn't cover the strength aspect of the structures.

Some examples of repair…….

- ✓ Decoration of structure, Painting, White Washing.
- ✓ Checking the wiring of building.
- ✓ Replastering of any wall if required
- ✓ Repairing of damaged flooring
- ✓ Repair of door and window
- ✓ Checking or repairing of pipe line connections, gas line connections and plumbing serveries.
- ✓ Relaying disturbed roof tiles.

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

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

5 **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.

OR

Rehabilitation of a building means returning a building or a structure to a useful state by means of repair, modification, or alteration. It is related to the strength aspect of structures. To Bring back the position and condition of the structure by considering the strength aspect.

Some of the examples of Rehabilitation…..

- ✓ To fill the wide cracks using some suitable material
- ✓ Injecting epoxy like material in to cracks in walls,columns,beams, etc.
- ✓ Removal of damaged portion of masonry and reconstructing it using rich mortar mix.
- ✓ Addition of reinforcing mesh on both sides of the wall.

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

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

8 **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.

9 **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 being 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.

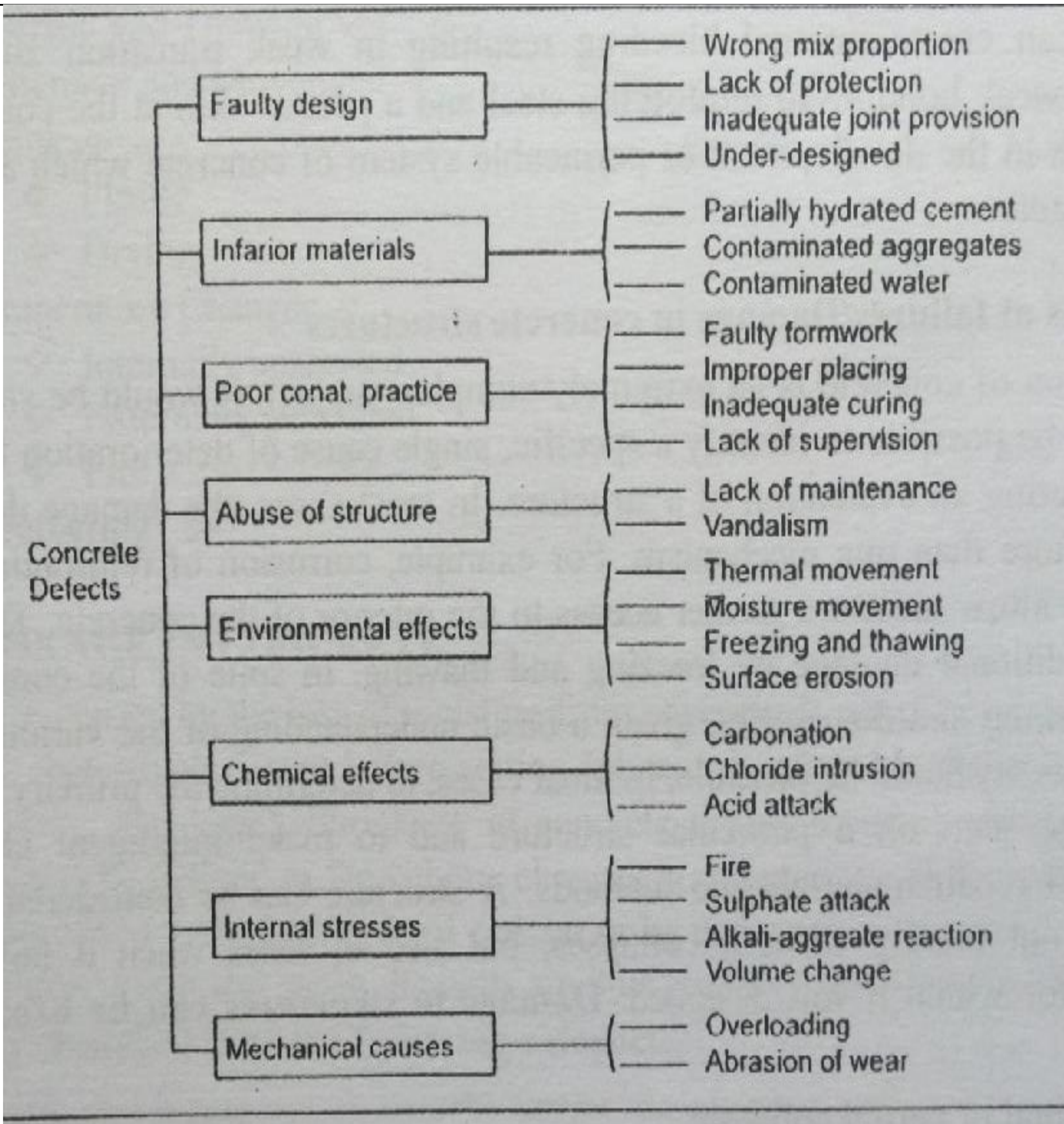
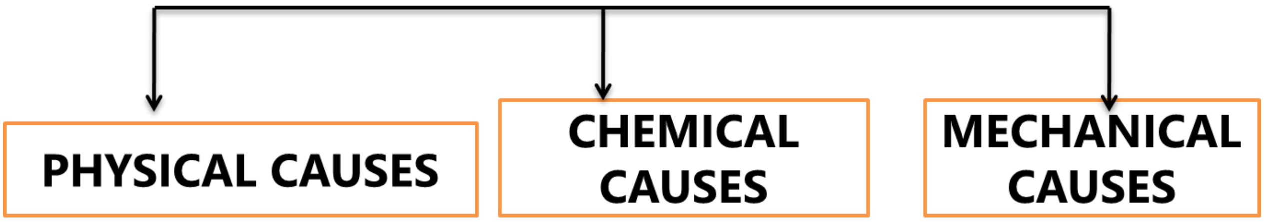


Figure 1.2. Factors causing distress in concrete structures

Causes for deterioration of concrete structures



PHYSICAL CAUSES

1. SHRINKAGE

2. FREEZING AND THAWING

3. WEATHERING

4. ABRASION, EROSION AND CAVITATION

5. TEMPERATURE

6. FIRE

7. THERMAL MOVEMENT

8. CONSTRUCTION ERRORS

9. DESIGN ERRORS

CHEMICAL CAUSES

1. Acid Attack
2. Aggressive water Attack
   Alkali carbonate rock reaction
3. Alkali silica reaction
4. Alkali Aggregate reaction
5. Sulphate Attack

MECHANICAL CAUSES

1. SETTLEMENT AND MOVEMENT

2. ACCIDENTAL LOADINGS

PHYSICAL CAUSES

1. SHRINKAGE

Shrinkage is defined as the volume changes in concrete due to loss of moisture from concrete due to evaporation or by hydration of cement.

In practice, the shrinkage is measured as linear strain in terms of mm/mm, expressed in 10-6.

Shrinkage can be classified in to following categories

1. Plastic shrinkage
2. Drying shrinkage
3. Autogenous shrinkage
4. Carbonation shrinkage

1. Plastic shrinkage

The concrete will exhibit bleeding to some degree between placing and setting time is called plastic shrinkage. Bleeding is the appearance of moisture on the surface of concrete; caused by the settling of the heavier components of the mixture. Usually, the bleed water evaporates from the concrete surface.

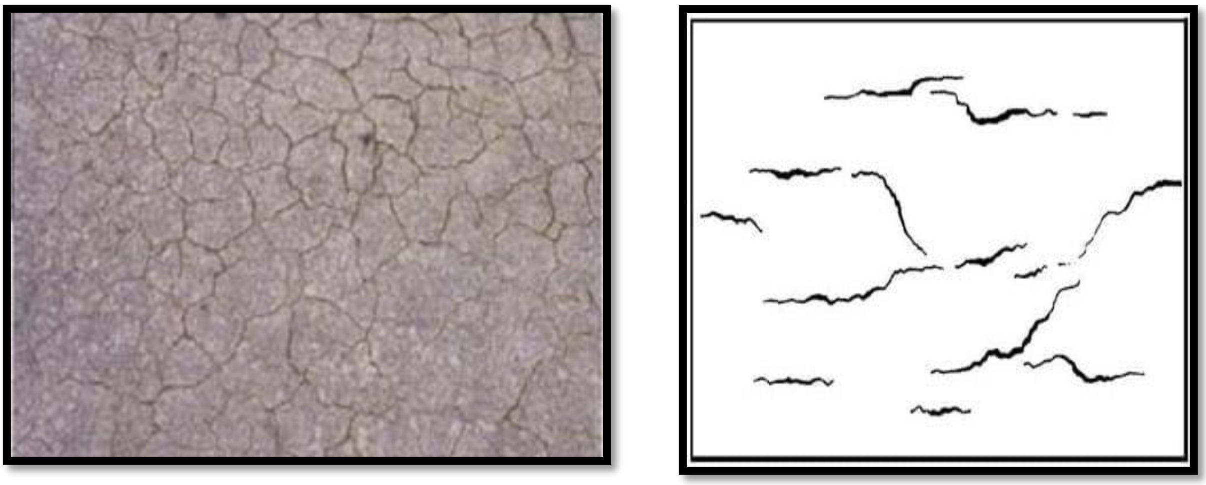


Fig 1.3: Plastic Shrinkage cracks

A typical plastic shrinkage cracks occurred due to

- ✓ *Rapid evaporation of water from the surface of concrete.*
- ✓ *Occurs within few hours after placing concrete while still it is in plastic and before it has attained sufficient strength.*
- ✓ *These cracks occur almost entirely on horizontal surfaces exposed to atmosphere. These cracks are parallel to one another are spaced 0.3m to 0.1m apart and width varying from 0.1mm to 3mm.*
- ✓ *The magnitude depends upon ambient temperature, relative humidity and wind velocity.*
- ✓ *It also depends up on the rate of evaporation of water from the surface of concrete (1kg/m2/hr)*

Elimination of plastic shrinkage cracks

Plastic shrinkage cracks can be eliminated by following measures

- ✓ *Reduce the time between placing and finishing. If there is delay cover the concrete with polythene sheets.*
- ✓ *Minimize evaporation by covering concrete with fog spray and curing compounds.*
- ✓ *Erect temporary roof to protect concrete from hot sun.*

Plastic settlement shrinkage crack

These cracks can occur concrete starts setting. This happens when

1. The concrete cover over the reinforcement is too small.
2. The mix contains too many fines.
3. The mix is too slow in releasing its bleed water.
4. This form of cracking is the easiest to identify as it reflects the location of reinforcement

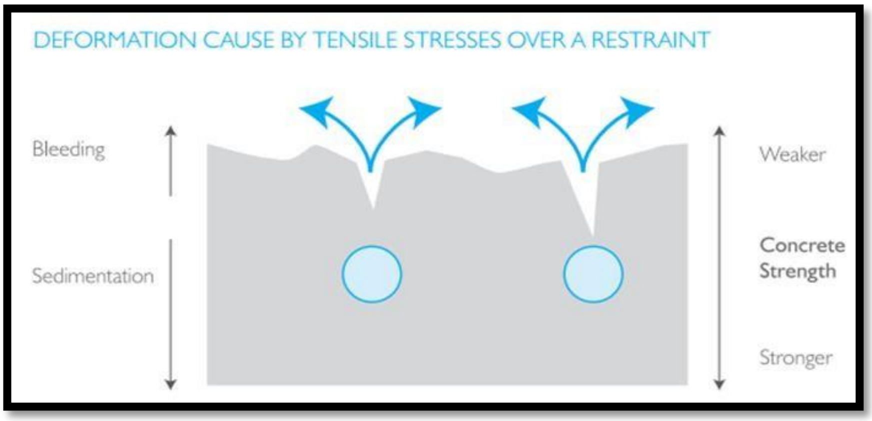


Fig 1.4: Plastic settlement cracks

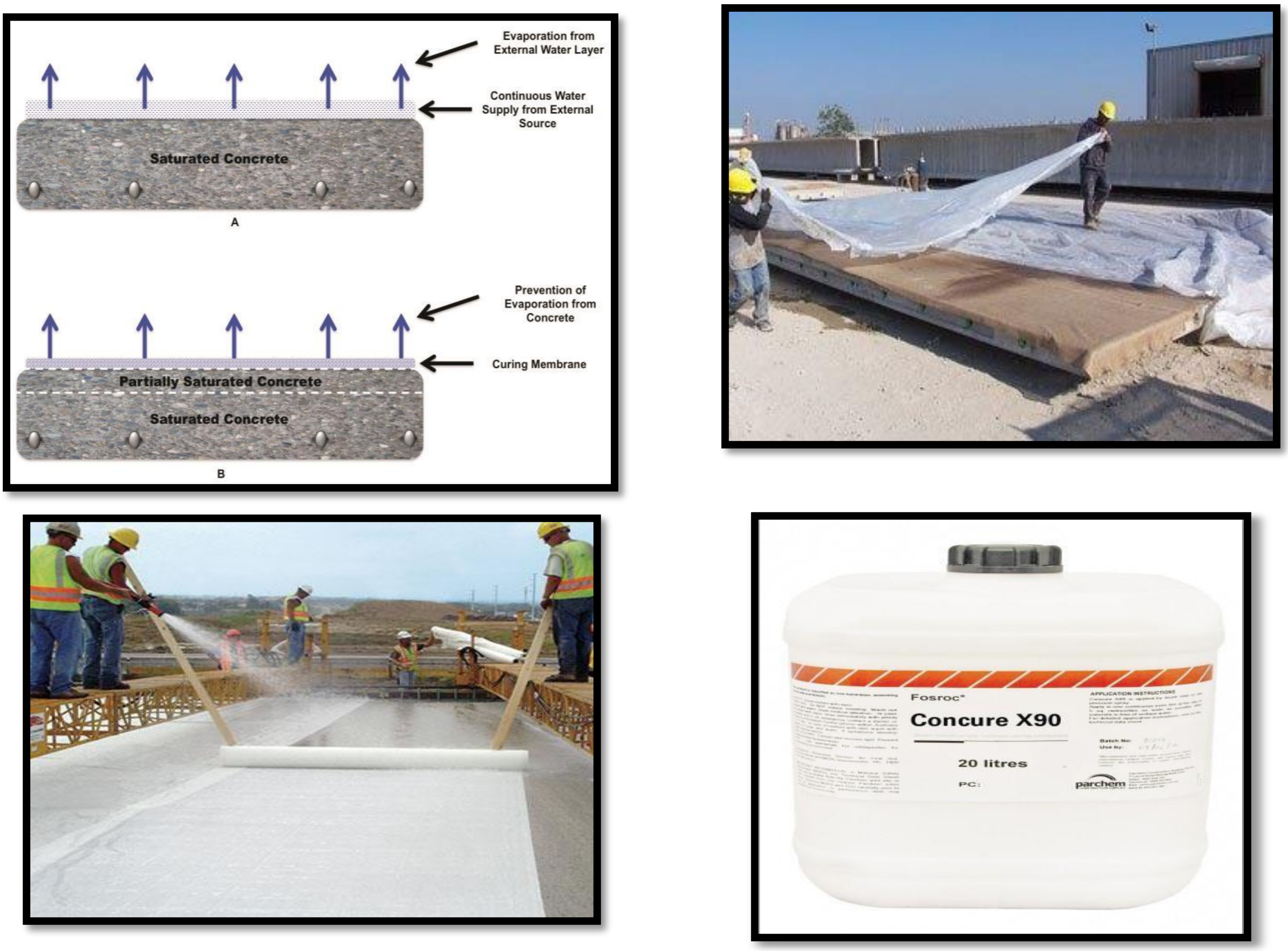


Fig 1.5: Method of prevention of plastic shrinkage cracks

2. Drying shrinkage

The loss of moisture after setting is called drying shrinkage. It is the long term change in volume of concrete.

If this shrinkage could take place without any restraint, there would be no damage to the concrete. The combination of shrinkage and restraints causes tensile stresses that can ultimately lead to cracking.

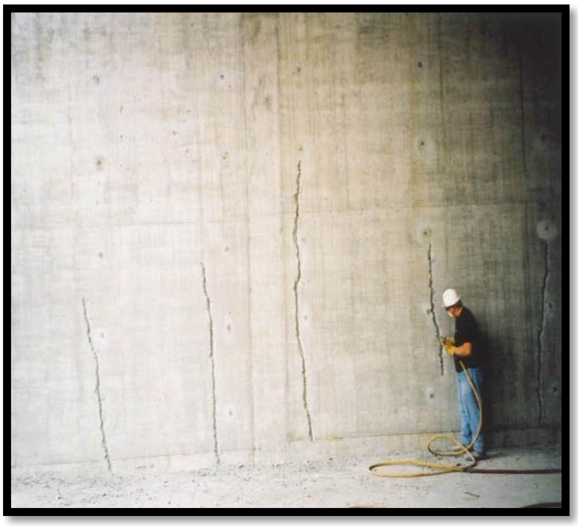
A drying shrinkage cracks occurred due to

- ✓ *These cracks is caused by physical loss (evaporation) and chemical loss(hydration) of water during the hardening process and exposure to unsaturated air.*
- ✓ *Reduction in volume of concrete can cause cracks if it is restrained and its tensile strength exceeded.*
- ✓ *These cracks appears at about 7-10 days after concreting and about 80% of drying shrinkage take place in about a year.*
- ✓ *It is influenced by cement content, water content, aggregates, curing, humidity and temperature*

- ✓ *It is confined to non-structural members, floor toppings and parapet walls*

Controlling drying shrinkage cracks

- ✓ *Use of minimum water content.*
- ✓ *Use of highest possible aggregate content.*
- ✓ *Providing adequate and early curing.*
- ✓ *Providing sufficient close spaced reinforcement.*
- ✓ *It is confined to non-structural members, floor toppings and parapet walls*



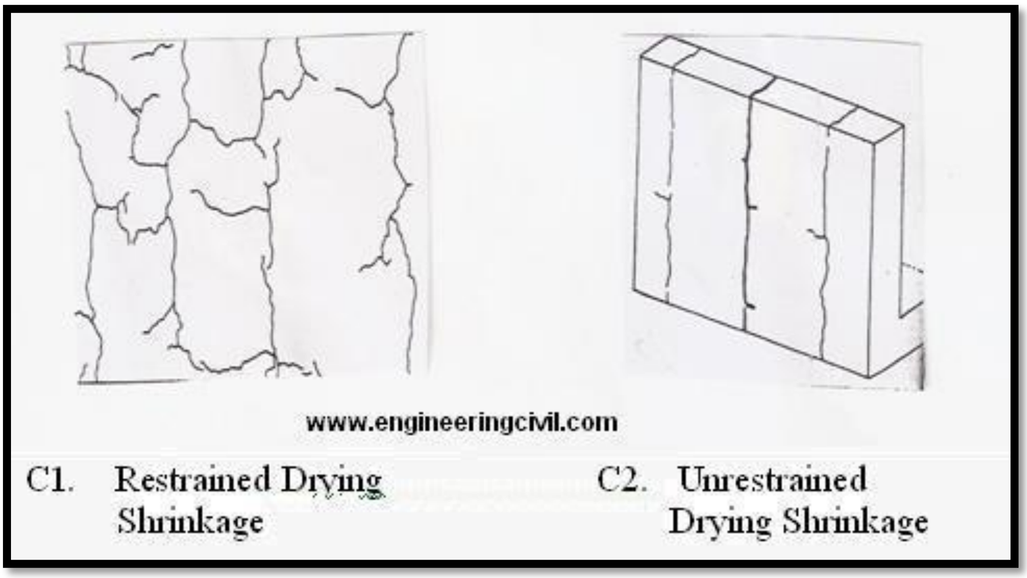


Fig 1.6: Drying shrinkage cracks

3. Autogenous shrinkage

Autogeneous shrinkage cracks occurred due to

- ✓ If no movement of water to or from set paste of concrete is allowed, then the shrinkage developed is known as autogeneous shrinkage.
- ✓ This shrinkage is caused by the loss of water consumed or used in the hydration of cement.

- ✓ The magnitude of this shrinkage is very small and is not much of significance.

Controlling Autogenous shrinkage cracks

- ➢ Consider a higher content of supplementary cementitious material like Fly ash and Ground granulated blast furnace Slag (GGBS) in the concrete mix.
- ➢ Keep the surface of the concrete continuously wet; conventional curing by sealing the surface to prevent evaporation is not enough and water curing is essential.
- ➢ Consider addition of shrinkage-reducing admixtures more commonly used to control drying shrinkage,
- ➢ Consider addition of saturated lightweight fine aggregates

4. Carbonation shrinkage

Carbonation is the reaction of CO2, which is present in the atmosphere with hydrated cement. The CO2 in presence of moisture forms carbonic acid that reacts with calcium hydroxide - Ca(OH)2, a product of hydration to form Calcium Carbonate (CaCO3).

- ✓ Carbonation shrinkage is probably caused by the dissolution of crystals of calcium hydroxide and deposition of calcium carbonate in its place.
- ✓ The carbonation proceeds from the surface of concrete inwards, but does so extremely slowly.
- ✓ The actual rate of carbonation depends on the permeability of the concrete, its moisture content and on the CO2 content and relative humidity of the ambient medium.
- ✓ Concrete made with high water-cement ratio and inadequately cured will be more prone to carbonation i.e. there will be a greater depth of carbonation.

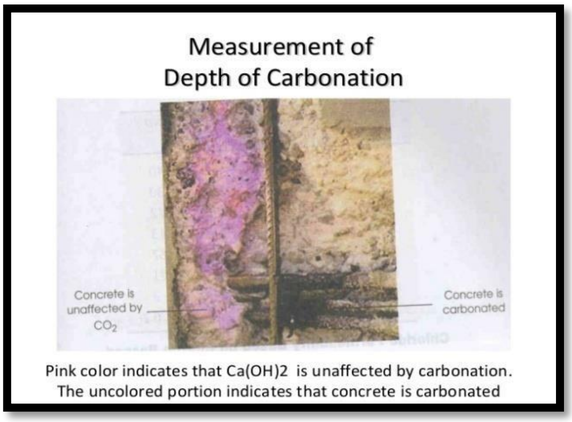


Fig 1.7: Carbonation shrinkage

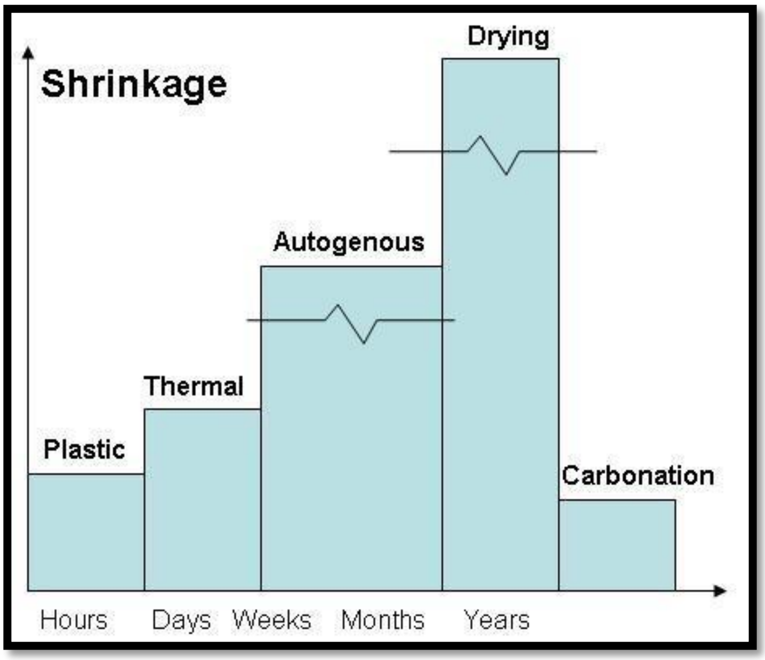


Fig 1.8 : Graphical representation of formation of various shrinkage

2. FREEZING AND THAWING

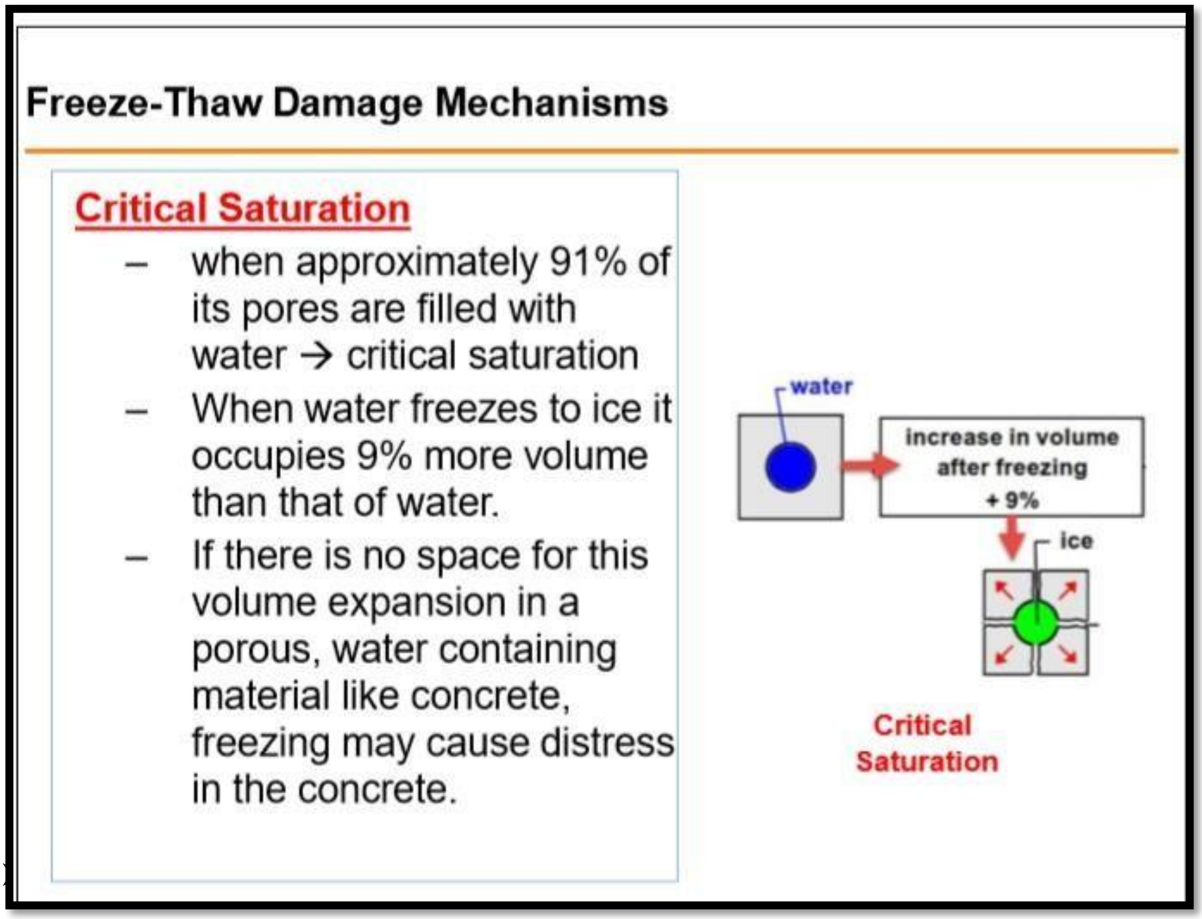
Freeze-thaw disintegration or deterioration takes place when the following conditions are present.

(a) Freezing and thawing temperature cycles within the concrete.

(b) Porous concrete that absorbs water (water-filled pores and capillaries)

Mechanism

- As the temp. of a critically saturated concrete is lowered during cold weather, the freezable water held in the capillary pores of the cement paste and aggregates expands upon freezing. If subsequent thawing is followed by refreezing the concrete is further expanded, so that repeated cycles of freezing and thawing have a cumulative effect.
- Concrete hydraulic structures are vulnerable to freezing and thawing. Exposure in such areas as the top walls, piers, parapets and slabs enhances the vulnerability of concrete to the harmful effects of repeated cycles of freezing and thawing.
- The use of de-icing chemicals on concrete surfaces may also accelerate damage caused by freezing and thawing and may lead to pitting and scaling.
- It involves the development of osmotic and hydraulic pressure during freezing, principally in the paste, similar to ordinary frost action.



water, or on vertical surfaces that are at the water line in submerged structures.

- Freezing water contained in the pore structure expands as it is converted into ice.

Preventive Measures

1. *Use of lowest practical water-cement ratio and water content.*
2. *Use of air entrainment.*
3. *Use of durable aggregate.*
4. *Adequate curing of concrete prior to exposure to freezing conditions.*
5. *Designing the structure to minimize the exposure to moisture.*

3. WEATHERING

- *It is defined as change in colour, texture, strength, chemical composition, or other properties of a natural or artificial material due to the action of weather.*

1. The damage from freezing and thawing is the most common weather related physical deterioration.
2. Alternate wetting and drying, and heating and cooling may cause cracking in concrete due to weathering.

3. If the volume changes due to these processes are excessive, cracks may develop.
4. The damage due to these factors may appear in the form of general flaking and spalling of concrete from the surface of concrete.
5. Concrete generally loses strength with increase in temperature about 300 C, damage being greater with aggregate having higher coefficient of thermal expansions.

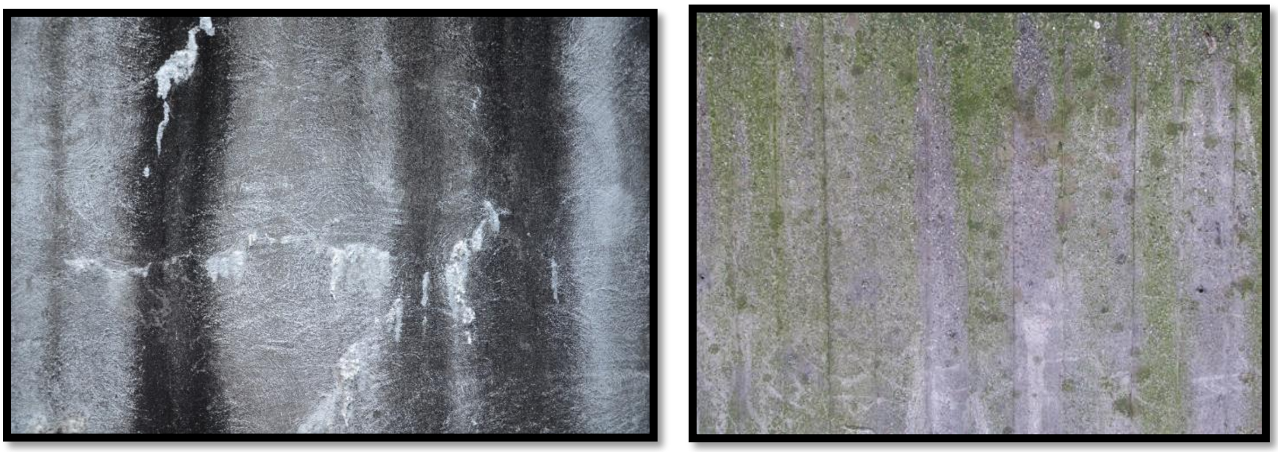


Fig 1.9: Weathering

4. CRAZING

- *Crazing is the development of fine random cracks on the surface of the concrete caused by shrinkage of the surface layer.*
- These cracks do not affect the structural integrity of concrete but may lead to subsequent deterioration of the concrete.
- The cracks are shaped like irregular hexagon and are typically not more than 50 to 100 mm across. They are rarely more than few millimeters deep and are more noticeable on steel troweled surfaces.
- They generally occur in the over floated or over troweled surface layers of concrete slabs and in the formed surfaces of concrete.
- craze cracks develop at an early age and are apparent the day after placement. The crazing is more prominently seen when the surface is wet.

The generally observed reasons for appearance of Crazing cracks are

• Poor or inadequate curing.

• Too wet a mix, excessive floating, the use of a jitterbug or any other procedure which depresses the coarse aggregate and produces an excessive concentration of cement paste and fines at the surface.

• Sprinkling cement on the surface to dry up bleed water. This concentrates fines on the surface.

• Occasionally carbonation of the surface can cause crazing.

• Finishing while there is bleed water present on the surface or the use of steel trowel at a time when the smooth surface brings up too much water and cement fines. The use of a darby or bull float while bleed water is present will produce a high water-cement ratio at the surface, which makes the slab more susceptible to crazing.

Preventive Measures

- ✓ *Damping the sub grade before placing concrete.*
- ✓ *Avoiding over-finishing of the surface.*
- ✓ *Delaying trowelling until the surface moisture has disappeared.*
- ✓ *Avoiding sprinkling of dry cement or water on the surface during finishing operation.*
- ✓ *Curing as soon as possible.*
- ✓ *Avoiding high temperature differentials between the concrete and curing water.*

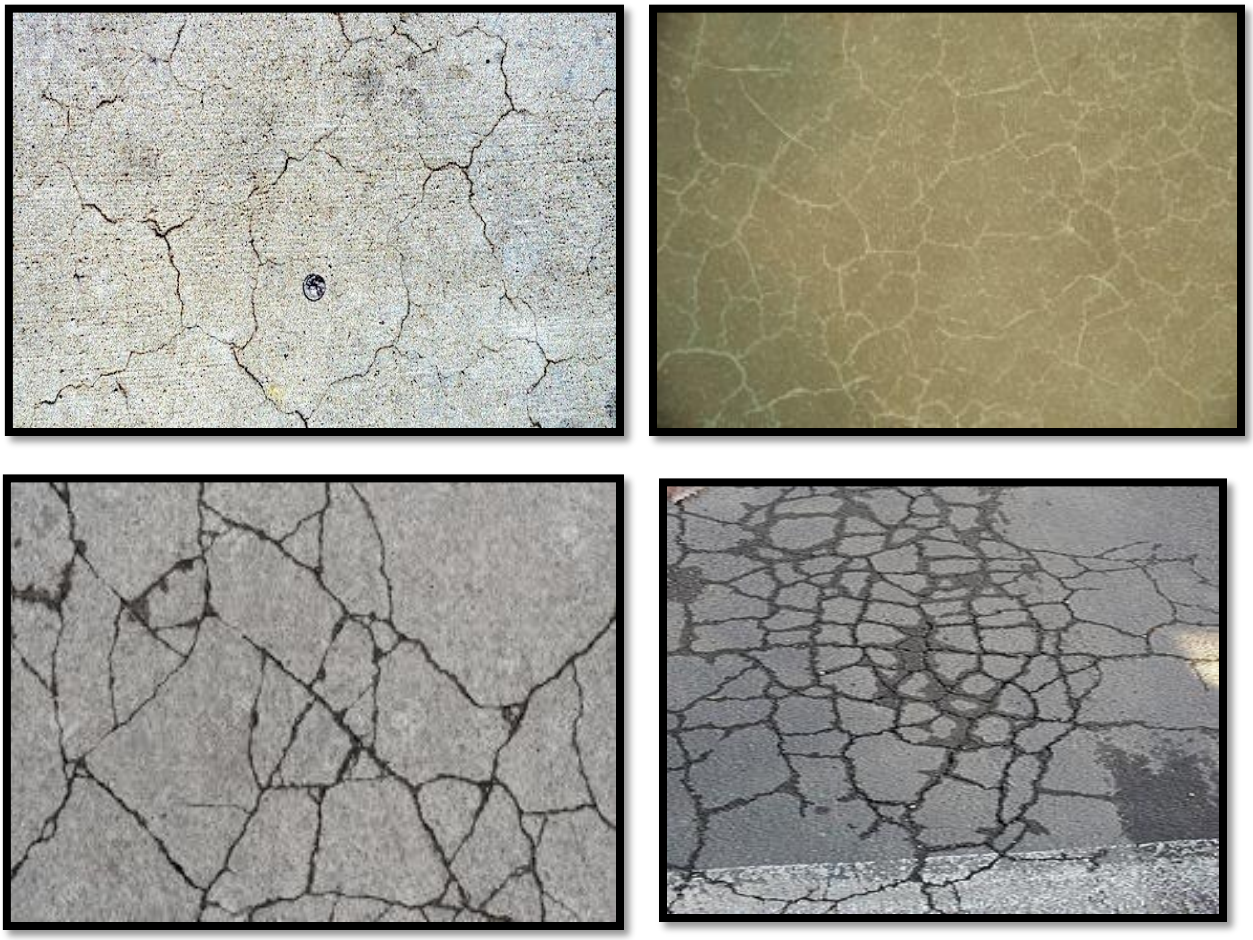


Fig 1.10: Crazing Cracks

5. HONEYCOMBING ON CONCRETE

- *Honeycomb consists of exposed pockets of coarse aggregates not covered by a surface layer of mortar.*
- *It may also be defined as the hollow spaces and cavities left in the concrete mass on surface or inside the concrete which is caused by mortar not filling the space between coarse aggregates*
- This may be caused by inadequate compaction.
- Presence of excess water in concrete or by leaky forms, which allow the water to escape.

Fig 1.11: Honeycombing

Types of Honeycomb

- ***Small size honeycomb*** *– Depth is less than 25mm*
- ***Moderate size honeycomb****- Deeper than 25mm but steel bars have not exposed.*
- ***Larger size honeycomb****- Deeper than 25mm and bars have come out*

Causes of Honeycomb

1. Poor workability
2. Poor grading of aggregate
3. Grout leak.
4. Movement of formwork.
5. Improper compaction.
6. Improper cover and placement of rebar

Preventive measures

- *To follow good construction practice.*
- *To use workable concrete.*
- *To provide good forms.*

- *To give proper vibration.*
- *To be planned sequence of placing*

Repair of honeycombs

- Hack and remove the loose particles in order to appear sound surface.
- Surface is cleaned by water jet to obtain dust free surface
- Construction grout is applied.
- Texture and colour should be matched for aesthetic finish
- Curing is done.

6. POPOUTS ON CONCRETE

- *A popout is a small, cone shaped cavity or hole in a horizontal concrete surface left after a near surface aggregate particle has expanded and fractured.*
- The cavity may range from 6mm to few mm diameter

Causes

- They are caused by freezing of water in the aggregate particles that have internal pore structure which causes to expand.
- pop outs do not appear during construction but they start to appear during the first winter and may continue to form for several years

Fig 1.12: Popouts

FOLLOW THESE RULES FOR POPOUTS:

1. *Use durable aggregate from a proven source. A limit of 1% deleterious material by mass of dry aggregate has been found to minimize difficulties with popouts.*
2. *Use concrete with the lowest water content and slump possible for the application.*

3. *Use air entrained concrete.*
4. *Do not finish concrete when bleed water is on the surface.*
5. *Avoid over finishing or hardsteel troweling where not needed, such as most exterior and garage slabs.*
6. *Reduce concrete temperature to 10C to 21C.*
7. *Impervious floor coverings or membranes should be avoided for slabs on grade as they can aggravate popouts.*
8. *Provide proper drainage. Slope the slab surface to provide good drainage. Basements slabs should be provided with a free draining granular base in areas with high groundwater conditions.*

REPAIR OF POPOUTS

- ✓ *Surfaces with pop outs can be repaired.*
- ✓ *A small patch can be made by drilling out the spalled particle and filling the void with a damp pack mortar, or other appropriate patching material.*
- ✓ *If pop outs are too numerous to patch individually, a thin bonded overlay or surfaces grinding may be used to restore serviceability.*

7. CREEP ON CONCRETE

Concrete undergoes instantaneous elastic deformation when subjected to sustained loads with respect to time known as ***creep***

Factors affecting

1. *W/C ratio.*
2. *Type of aggregate.*
3. *Admixture*
4. *Age of concrete*
5. *Type of cement and cement content*
6. *Mix proportions.*
7. *Mixing Time.*
8. *Humidity.*
9. *Temperature.*
10. *Size of the specimen.*

Creep Coefficient

The ratio of the ultimate creep strain to the elastic strain at the age of loading is termed as creep coefficient.

The assumed data of creep coefficient are given below

Age of Loading	Creep coefficient
7 Days	2.2
28 Days	1.6
1 year	1.1

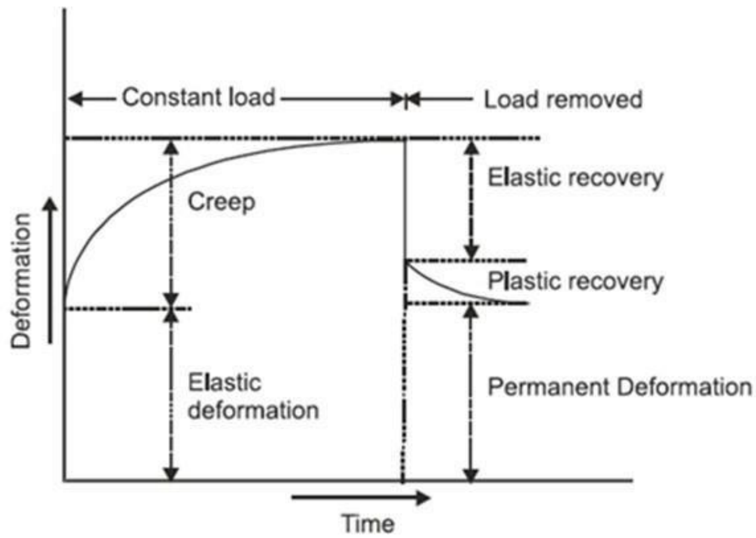


Fig 1.13: Deformation of hardened concrete

8. THERMAL MOVEMENT IN CONCRETE

- *Thermal movement is defined as concrete expands or contracts when change in temperature.*

Causes

- Thermal movement due to considerable amount of heat due to heat of hydration, atmospheric temperature and external fire.
- Due to thermal movement, changes in shape and volume of concrete causes cracks on the concrete structure.
- The extent of temperature rise depends on the properties of cement used and the shape and size of the component.

- The heat of hydration may not be significant but in mass concrete works it is an important factor to be considered.

- In load bearing structures, horizontal cracks may appear in the cross walls as shown in figure.

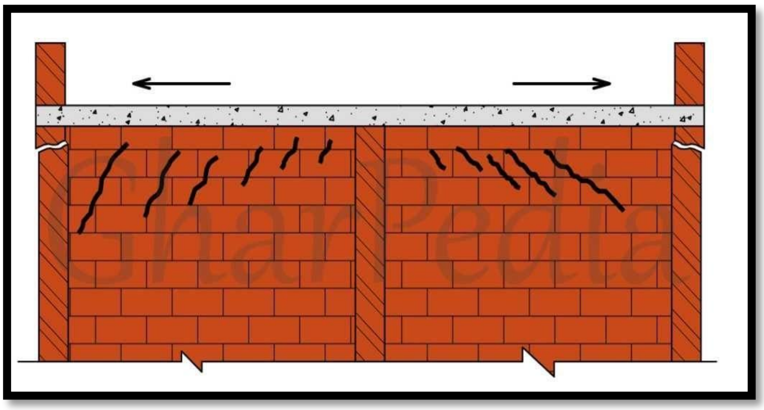


Fig 1.14: Thermal movement in load bearing structures

- In frame structures, roof slab along with beams and columns moves jointly causes diagonal cracks in walls which are located parallel to movement and horizontal cracks below beams in walls which are right angles to movement as shown in fig.

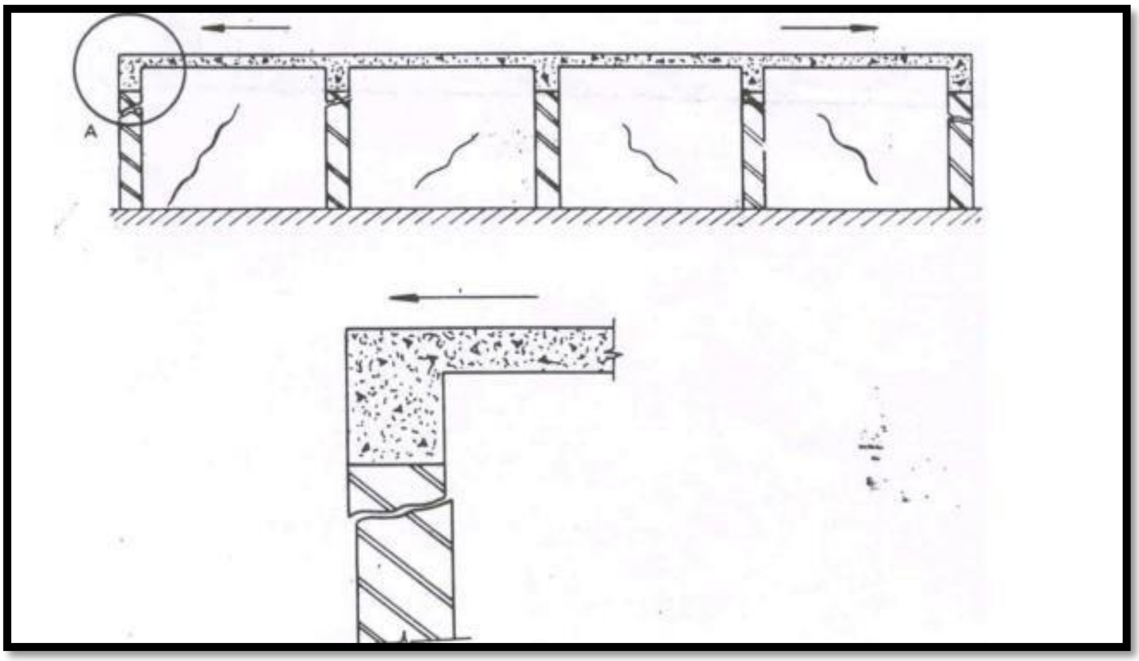


Fig 1.15: Thermal movement in framed structures

- Horizontal cracks may also appear at the support of a brick parapet wall or brick-cum-iron railing over RCC cantilever slabs as shown in fig. due to differential thermal movement.

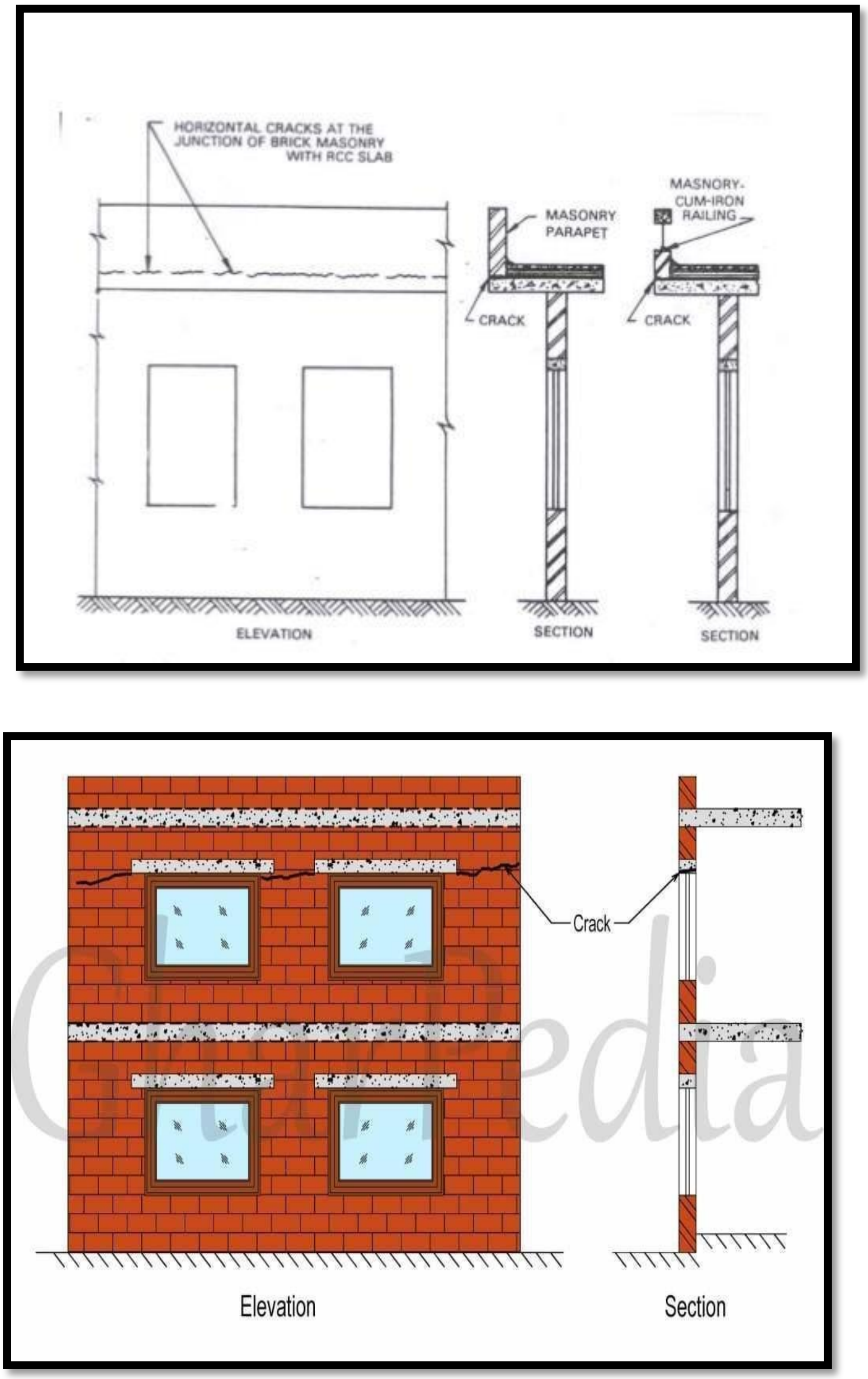
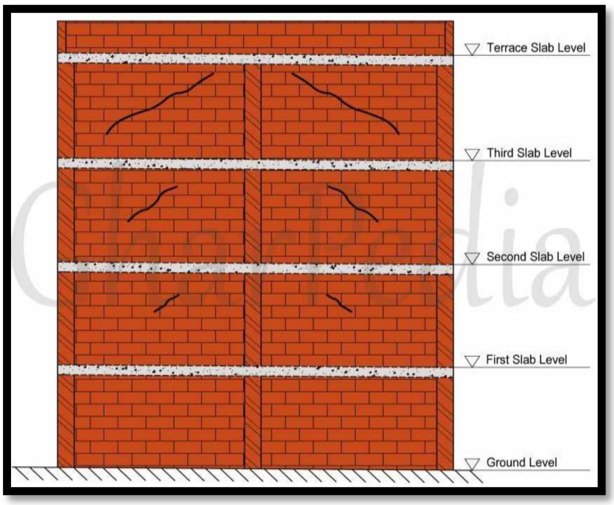
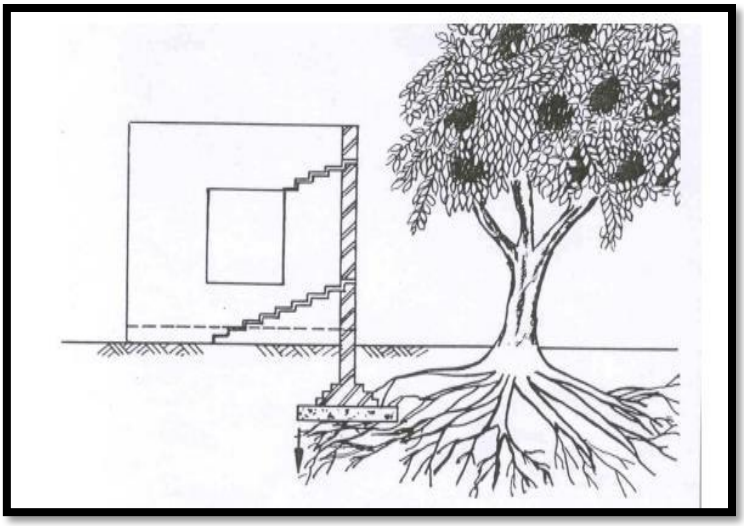


Fig 1.16: Thermal movement in parapet wall





PREVENTIVE MEASURES

- ✓ *Use of pozzolana.*
- ✓ *Use of low heat cement.*
- ✓ *Pre-cooling of aggregates and mixing water.*
- ✓ *Post cooling of concrete by refrigerated water through pipes embedded in the body of concrete.*
- ✓ *Providing joints to relieve the restraints in the structure.*
- ✓ *Providing adequate reinforcement to distribute the stresses.*
- ✓ *Providing suitable cover.*

9. FIRE ON CONCRETE

- Concrete is considered fireproof on account of its incombustibility and low thermal diffusivity.
- Concrete can also experience explosive spalling and deterioration during heating which need to be understood and designed against either at the materials level and/or at the structural level.
- The extent of fire depends upon the intensity and duration of fire.
- The principal types of damages are
  - Reduction in strength of concrete
  - Cracking and spalling of concrete
  - Deflection and deformation of members
  - Discolouration
  - other miscellaneous functional failures.
- Fire resistance of concrete is determined by 3 factors

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

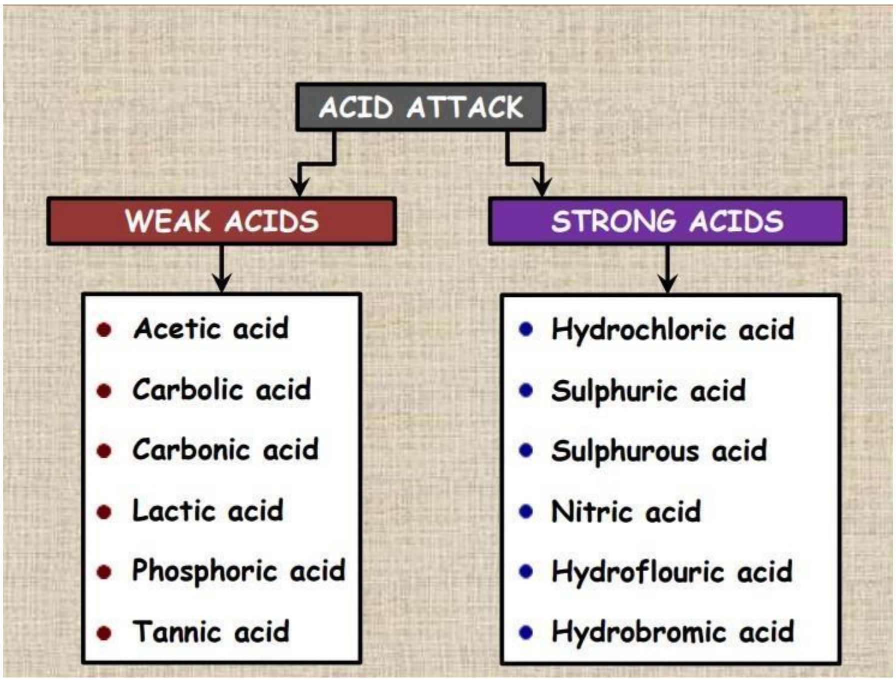
- The effect of increase in temp. on the strength of concrete is not much up to a temp. of about 250o C but above 350o C, definite loss of strength takes place.
- In mortar or concrete, the aggregates undergo a progressive expansion on heating while the hydrated products of the set cement, beyond the point of maximum expansion shrinks. These two opposing actions progressively weaken and crack the concrete.
- The test results indicated that even the best fire resistant concrete found to fail if concrete is exposed for a considerable period to a temp. exceeding 900 C, while reduction in strength occurs at a temp of about 600C.

Fig 1.17: Fire damage on concrete structure

CHEMICAL CAUSES

Acid Attack

- Concretes made of Portland cement (OPC) are highly alkaline with pH values normally above 12.5 and are not easily attacked by acidic solutions.
- As the pH of the solution decreases the equilibrium in the cement matrix is being disturbed, and the hydrated cement compounds are essentially altered by hydrolytic decomposition which leads to the severe degradation of the technical properties of the material.
- At pH values lower than 12.5 portlandite is the first constituent starting dissolution.
- If pH decreases to values lower than stability limits of cement hydrates, then the corresponding hydrate loses calcium and decomposes to amorphous hydrogel.
- The final reaction products of acid attack are the corresponding calcium salts of the acid as well as hydrogels of silicium, aluminum, and ferric oxides.
- The solubility of Al2O3 and Fe2O3 depends on the pH value of the acting solution, while SiO2 is insoluble in acidic solutions except in HF



1. SULPHURIC ACID ATTACK

- Sulphuric acid attack causes extensive formation of gypsum in the regions close to the surfaces, and tends to cause disintegrating mechanical stresses which ultimately lead to spalling and exposure of the fresh surface.

- Owing to the poor penetration of sulphuric acid, the chemical changes of the cement matrix are restricted to the regions close to the surfaces
- The chemical reactions involved in sulphuric acid attack on cement based materials can be given as follows:

$$Ca(OH)_2 + H2SO4 \longrightarrow CaSO4\ .2H2O$$

$$3CaO.2SiO2\ .3H2O + H2SO4 \longrightarrow CaSO4\ .2H2O + Si(OH)_4$$

STAGES OF ATTACK

pH Range	Effect
12.5 - 12	• Calcium hydroxide and calcium aluminate hydrate dissolve and ettringite is formed • CSH phase is subjected to cycles of dissolution and re-precipitation
11.6 - 10.6	• Gypsum is formed
< 10.6	• Ettringite is no longer stable and decomposes into aluminum hydroxide and gypsum
< 8.8	• CSH becomes unstable

- Source water has high sulphur content, both as sulphate or sulphide, and form hydrogen sulphide, H2S.
- The hydrogen sulphide gas comes out of the solution and forms sulphuric acid in the air space.
- Sulphuric acid is highly reactive and reacts with calcium compounds to form gypsum which causes the concrete to soften, ultimately leading to roof collapse.

$$\text{Organic matter} + SO_4\,2^- \longrightarrow S2^- + H_2O + CO_2$$

$$S_2^- + 2H^+ \longrightarrow H2S$$

$$H_2S + 2O_2 \longrightarrow H_2SO_4$$

2. HYDROCHLORIC ACID ATTACK

- The chemicals formed as the products of reaction between hydrochloric acid and hydrated cement phases are some soluble salts and some insoluble salts.
- Soluble salts, mostly with calcium, are subsequently leached out, whereas insoluble salts along with amorphous hydrogels, remain in the corroded layer.
- Besides dissolution, the interaction between hydro gels may also result in the formation of some Fe-Si, Al-Si, Ca-Al-Si complexes which appear to be stable in pH range above 3.5.

$$Ca(OH)_2 + 2HCl \longrightarrow CaCl_2 + 2H_2O$$

- The reaction essentially causes leaching of $Ca(OH)_2$ from the set cement.
- After leaching out of Ca (OH)2 , C-S-H and ettringite start to decompose, with release of Ca2+ to counteract the loss in Ca(OH)2 and the set cement starts to disintegrate accelerating the dissolution.

$$Ca_6Al_2(SO_4)3(OH)_{12}.26H_2O \longrightarrow 3Ca_2^{+} + 2[Al(OH)_4]^{-} + 4OH^{-} + 26H_2O$$

$$3Ca_2^{+} + 2[Al(OH)_4]^{-} + 4OH^{-} + 12HCL \longrightarrow 3CaCl_2 + 2ALCL_3 + 12H_2O$$

- There are few indications through experiments about the formation of Friedel's salt, C3A.CaCl2 .10H2O, by the action of CaCl2 , formed due to reaction of HCL with CH and C3A
- Hydrochloric acid attack is a typical acidic corrosion which can be characterized by the formation of layer structure.
- Chandra divided the cross section of damaged prisms into three main zones; undamaged zone, hydroxide mixture zone or brown ring, and attacked zone. By hydroxide mixture zone, he referred to a layer formed by undissolved salts seen as a dark brown ring.

Preventive Measures

- ✓ *By increasing cement content and reducing W/C ratio.*
- ✓ *By improving quality of cover concrete.*
- ✓ *By treating the surface with sodium silicate known as water glass.*
- ✓ *By surface treatment with coal, tar, bituminous paints, epoxy resins etc*

3. AGGRESSIVE WATER ATTACK

- Water has been reported to have extremely low concentrations of dissolved minerals.
- This soft or aggressive water will leach calcium from cement paste or aggregates and this attack take places very slowly.

- Aggressive water attack to have a serious effect on hydraulic structures, the attack must occur in flowing water. This keeps a constant supply of aggressive water in contact with the concrete and washes away aggregates particles that become loosened as a result of leaching of the paste
- Visual examination will show concrete surfaces that are very rough in areas where the paste has been leached.
- If the aggregate is susceptible to leaching, holes where the coarse aggregate has been dissolved will be evident.
- Water samples from structures where aggressive water attack is suspected may be analyzed to calculate the langlier index, which is a measure of the aggressiveness of the water.

Preventive Measures

- ✓ *Assessing the nature of water at the site before construction.*
- ✓ *Water quality evaluation in structures to monitor the aggressiveness of water at the structure Coating with an non Portland-cement based coating*

4. ALKALI REACTION ON CONCRETE

- The reaction of silica and carbonates in aggregates with the alkalis(Sodium or potassium hydroxide) in cement produces a gel, which causes expansion and cracks is called alkali reaction
- Sodium hydroxide penetrates concrete and becomes concentrated at an evaporating face, physical damage would result from crystallisation of sodium carbonate.

(A) Alkali-aggregate reaction (AAR)

- This is also called alkali carbonate reaction. Carbonate rock aggregates have been reactive in concrete.
- This reaction is apparently limited to reactions with impure dolomitic aggregates and are a result of either dedolomitization or rim-silicification reactions.

Causes

- 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 is swelling.
- A distinguishing feature which differentiates alkali-carbonate rock reaction from alkali-silica reaction is the lack of silica gel exudations at cracks.
- Petrographic examination in accordance with ASTM C295 may be used to confirm the presence of alkali-carbonate reaction.

Influencing Factors

- ✓ Size of aggregate.
- ✓ Porosity of aggregate.
- ✓ Alkali content in cement.
- ✓ Fineness of cement particles.
- ✓ Availability of non evaporable water in the paste.

Fig 1.18: Alkali aggregate reaction on concrete

(B) Alkali-Silica reaction(ASR)

- ➢ The sodium and pottasium alkalis released during the hydration of OPC and siliceous constituent in aggregate.

- The alkali-silica gel formed, imbibes pore fluid causing expansion. Expansion of gel induces stresses and these stresses may be ocassionaly base enough to cause cracking and expansion of concrete

Causes

- 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 is swelling.
- Petrographic examination may be used to confirm the presence of alkali-silica reaction.
- Apart from cracking, the major effect of ASR is a reduction in comp. strength, tensile strength and modulus of elasticity.
- The resulting damage due to ASR depends upon the amount of moisture of available for the ASR gel to expand.
- Unconfined concrete undergoing AAR exhibits tell-tale signs of surface map cracking on exposed surfaces.
- The new method called Uranyl (Uranium) acetate fluorescence technique and is rapid and economical.

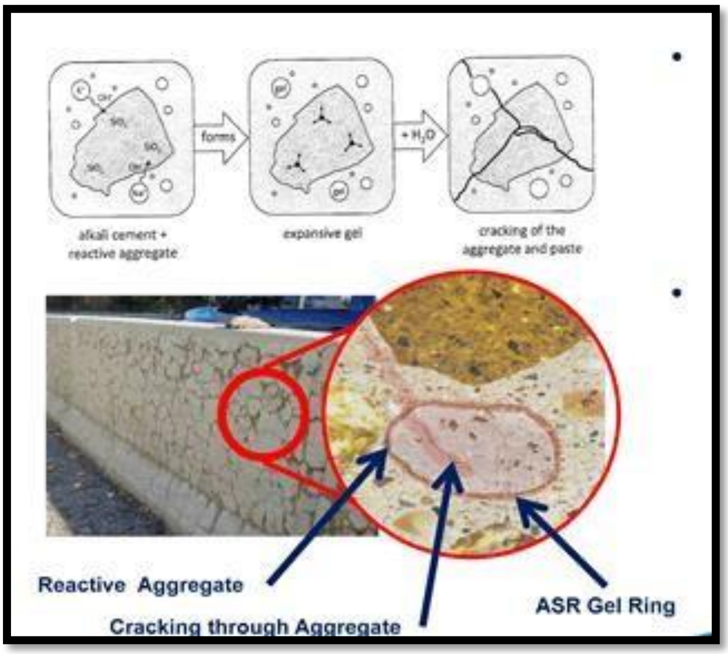


Fig 1.19: Alkali silica reaction mechanism

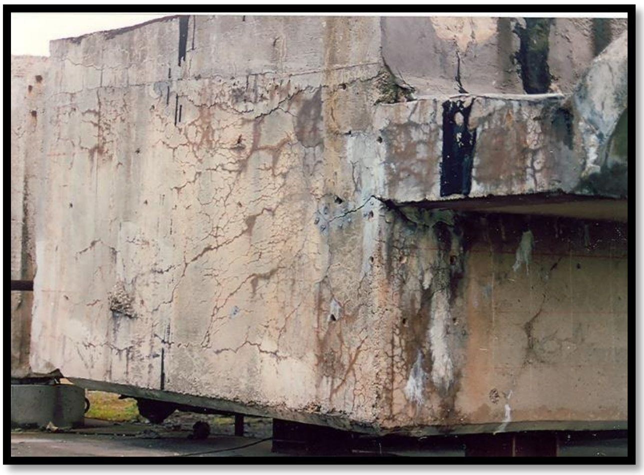


Fig 1.19: Alkali silica reaction on concrete

Preventive Measures

- ✓ *Use of low alkali content.*
- ✓ *use of slag cement*
- ✓ *Use of non-reactive aggregates*
- ✓ *Use of silica in concrete mix*

5. SULPHATE ATTACK

- ➢ Sulphates found in most of the soils as calcium, potassium, sodium and magenisum.
- ➢ Solid salts do not attack concrete, but when present is solution they can react with hardened cement paste.
- ➢ Sulphate attack occurs when pore system in concrete is penetrated by solution of sulphates.
- ➢ Sulphate reaction depends upon
    - Concentration of sulphate ions.
    - Cations present in the suplhate solution
    - C3A content in cement

- Density, Permeability of concrete.

- The second hydration product, tricalcium aluminate hydrate reacts with sulphate solution form sulpho aluminate hydrate(ettringite), which has greater volume than that of the original compound.
- Due to this, the resultant internal expansive stress may be great enough to cause deformation, cracking and eventually loss of cohesion.
- When concrete cracks, its permeability increases and the aggressive water penetrates more easily in to the interior, thus accelerating the process of deterioration

Physical Mechanism

- In addition to two chemical reactions, there may also be a purely physical phenomenon in which the growth of crystals of sulphate salts disrupts the concrete.
- The damage starts at the egdes and corners and is followed by progressive cracking and spalling which reduces the concrete to a friable or even soft state.
- The rate of sulphate attack increases with increase in strength of the solution.
- The rate of sulphate attack can be reduced by the use of cement low in tricalcium acuminate and by the addition of pozzolanic materials

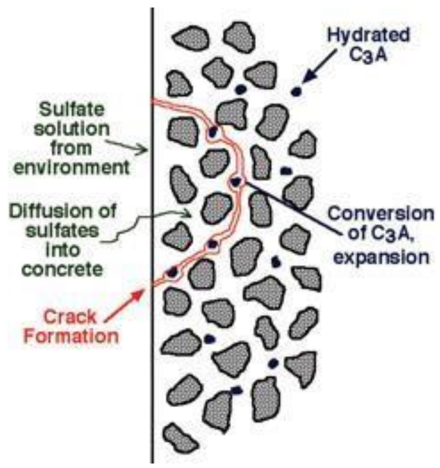


Fig 1.20: Sulphate attack mechanism

Preventive Measures

- *Using dense concrete with a low water cement ratio.*
- *Using sulphate resisting cement/super sulphated cement.*
- *Minimum cement content and max W/C ratio.*
- *Provision for expansion through joints.*

Fig 1.21: Sulphate attack on concrete

6. CHLORIDE ATTACK

- Chloride can be introduced in to the concrete by coming into contact with environment containing chlorides, such as sea water or deicing salts.
- Penetration of the chlorides starts at the surface and then moves inward.
- Chlorides may enter in to concrete from following sources

  Cement of the concrete

  Water mixed in concrete

  Aggregates

  Admixtures added

  Chloride difussion from atmosphere

Mechanism

- The concentration of chlorides in contact with the reinforcing steel will cause corrosion when moisture and oxygen are present.

- As the rust layer builds, tensile forces generated by the expansion of the oxide cause the concrete to crack and delaminate.
- the concentration of chlorides necessary to promote corrosion, among other factors, is greatly affected by the concrete's pH.
- It was known that a threshold level of 8000ppm of chloride ions was required to initiate corrosion when the pH was 13.2.

Use of Concrete	Max. chloride content in kg/m3
Concrete containing metal and steam cured at high temp. and prestressed concrete	0.4
R.C.C or plain concrete containing steel	0.6
Concrete not containing embedded metal or any materialrequiring protection from chlorides	3.0

- As the pH was lowered in to 11.6, corrosion was initiated with only 71ppm of chloride ions.
- The IS 456-2000 has specified the chloride content as chlorine, in concrete at the time of placing as shown in table

7. SEA WATER ATTACK

- The marine environment is characterized by wave action, which imposes shock loads and causes the erosion of concrete structures by abrasion.
- In addition, the concrete is exposed to the aggressive constituents of sea water and subjected to repeated freeze-thaw and wet-dry cycles.
- The deterioration of concrete structures in such an environment is both chemical and physical in nature and the type of the attack may be demarcated into 3 zones depending on the tidal lines as shown in fig.

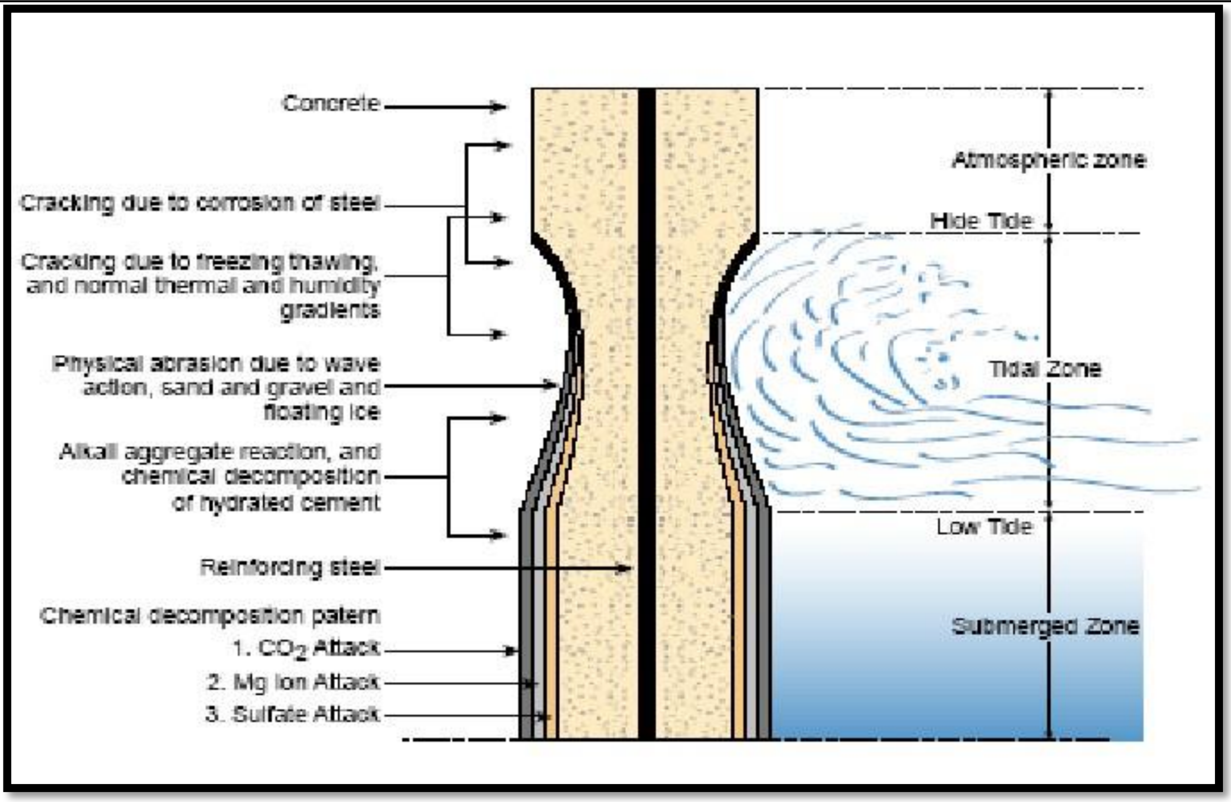


Fig 1.22: Sea water attack on concrete

- The upper part above the high tide line is not directly exposed to sea water. However, it is opposed to atmospheric air, frost action, and windblown sea salts. Consequently, cracking due to reinforcement corrosion and/or freeze-thaw cycles is the main deterioration phenomena in this zone.
- In the tidal zone, the structure is subjected to alternate wet and dry cycles, freeze and thaw cycles, impact of waves, and floating ice, abrasion by sand and gravel, and reinforcement corrosion.
- The lower zone, submerged in water, is a relatively stable environment, where freeze-thaw action and reinforcement corrosion does not occur.

Preventive Measures

- *Concrete density, cement type and cement content play a vital role in the resistance of concrete to sea water.*
- *Concrete made with calcium aluminates, super sulfate cements and other supplementary cementitious materials.*
- *Sufficient cover to reinforcement.*
- *Low W/C and high cement content.*
- *Well compacted concrete and good workmanship.*

9.2 EVALUATION OF STRUCTURAL DAMAGES TO THE CONCRETE STRUCTURAL ELEMENT DUE TO EARTHQUAKE

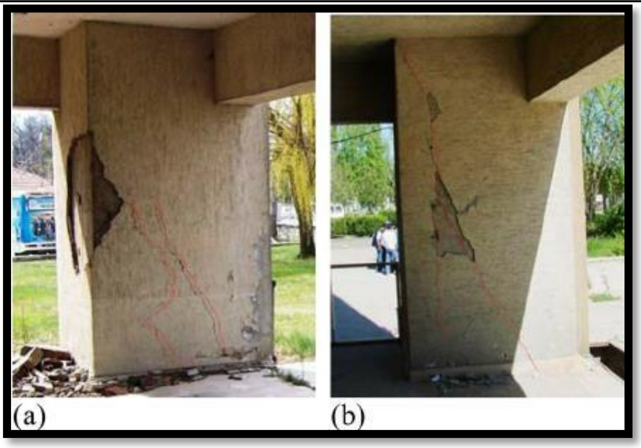
The proposed evaluation methodology is divided in to 3 components.

1. **Condition Assessment.**
2. **Visual Inspection.**
3. **Non-Destructive Evaluation(NDE)**

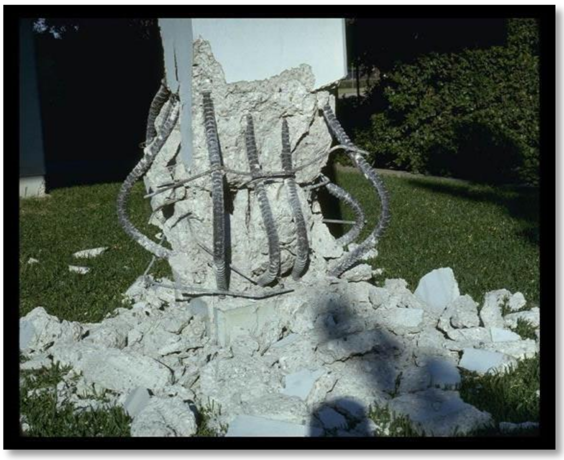
Failure of Reinforced Concrete Column

1. Formation of plastic hinge at the base of ground level column

2. Diagonal shear crack in midspan of columns

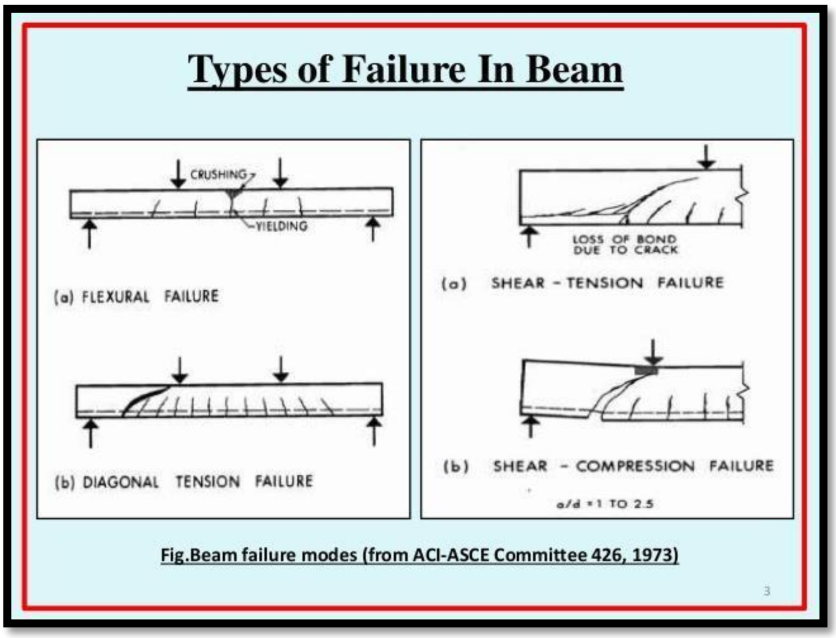


3. Shear and splice failure of longitudinal reinforcement

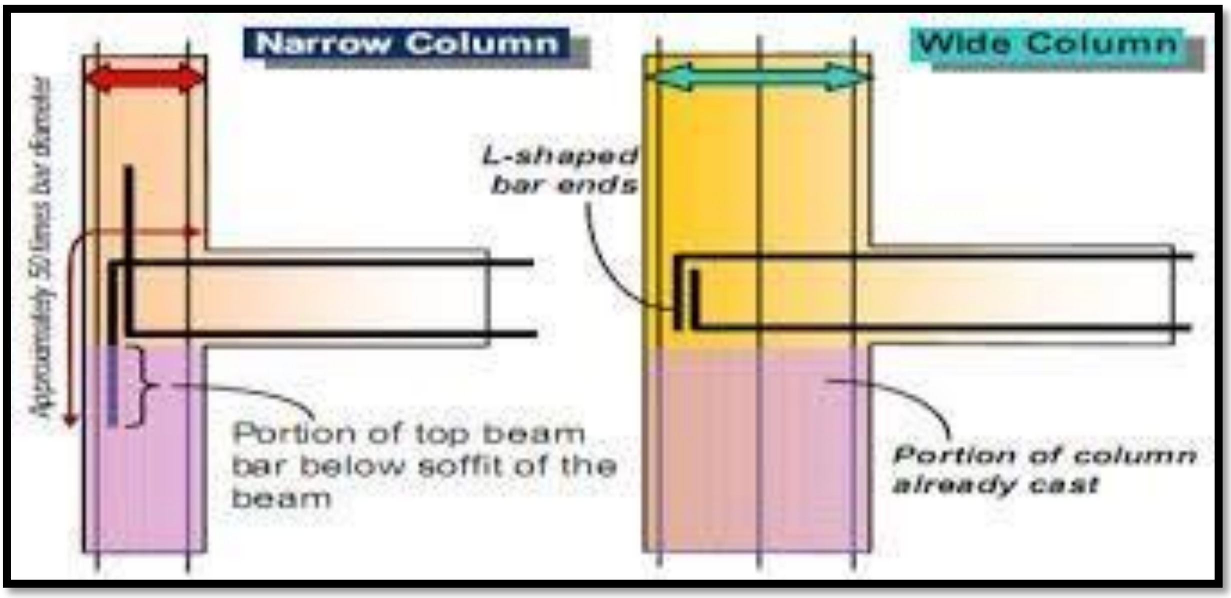


Failure of Reinforced Concrete Beam

1. Shear-Flexure Failure

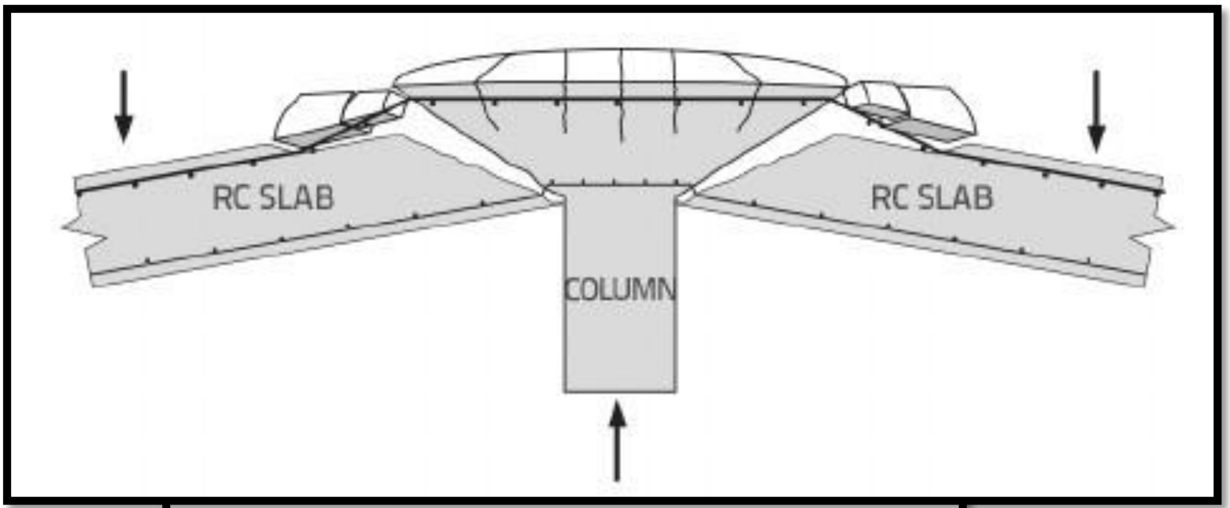


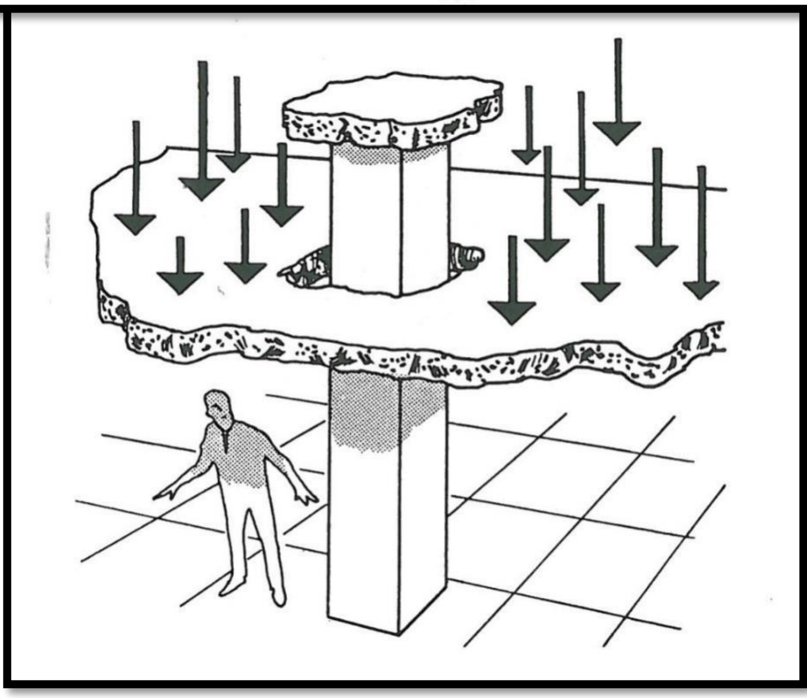
2. Shear Failure in beam - column joint



3. Failure of Reinforced Concrete Slab

1. Punching Shear Failure





1. <u>Condition Assessment</u>

The aim of condition assessment of the structure is the collection of information about the structure and its past performance characteristics to similar type of structure during past earthquakes and the qualitative evaluation of structure for decision making.

1. Data collection/information gathering

The information required for the evaluated building can be divided as

Building Data

- Architectural, structural and construction drawings.
- Vulnerability parameters : number of stories, year of construction
- Specifications, soil reports and design calculations

Construction Data

- Identifications of gravity load resisting system.
- Identification of lateral load resisting system
- Field survey of the structures existing condition.

Structural Data

- Materials
- Structural Concept: Vertical and horizontal irregularities.
- Ductile detailing
- Foundations
- Non-structural Elements

2. Past Performance Data

Past performance of similar type of structure during the earthquake provides considerable amount of information for the building, which is under evaluation process.

Materials Concerns

- Low grade of concrete.
- Deterioration in concrete
- High cement-sand ratio
- Corrosion in reinforcement
- Spalling of concrete

Structural Concerns

- The relativity low stiffness of the frames.
- Pounding-column distress, possibly local collapse
- Unsymmetrical Buildings in plan
- Unsymmetrical Buildings in elevation

Detailing Concerns

- Large tie spacing in columns lack of confinement of concrete-shear failure
- Insufficient columns lengths-concrete to spall
- Insufficient column strength for full moment hinge capacity-brittle failure
- Inadequate reinforcing of beam column joints or location

3. Seismic Evaluation Data

Seismic evaluation of data will provide a general idea about the building performance during an earthquake.

Materials Evaluation

- Building height > 3 stories, min grade of concrete, M 30 to M 40 particularly in columns of lower stories.
- Maximum grade of steel should be Fe415 due to inadequate ductility
- No siginficant deterioration in reinforcement
- No evidence of corrosion or spalling of concrete

Structural Components

- Evaluation of column shear strength and drift
- Evaluation of plan irregularities
- Evaluation of Vertical irregularities
- Evaluation of beam-column joints.
- Evaluation of pounding
- Evaluation of interaction between frame and infill

Structural Detailing should comply with IS: 13920-1993

- Flexural members
- Columns
- Foundation
- Non-structural components

2. Visual Inspection/Field Evaluation

Visual Inspection is an integral part of evaluation, and in fact, is the most widely used.

Procedures for Visual Inspection are

1. Description

- Perform a walk through visual inspection to become familiar
- Gather information on the design, construction, maintenance and operation of the structure.
- Plan the complete investigation
- Perform a detailed visual inspection and observe type of damages
- Observe damage documented on sketches

2 Equipments

- Optical magnification- detailed view of local distress
- Stereo microscope- 3 dimensional view of surface.
- Fiberscope and bore scopes- inspection of regions inaccessible to naked eye.
- Tape
- Flashlight- To aid in lighting the area to be inspected
- Crack comparator- To measure width of cracks
- Pencil- To draw sketches of cracks
- Camera-For photographs or video tape

3 Execution

- To identify the location of vertical structural elements
- To sketch the elevation with sufficient details.
- To take photo graphs of cracks
- Observation of the non-structural elements.

4 Limitations

- Applicable to surface damage
- No identification of inner damage

3. Non-destructive Evaluation

Non- destructive evaluation is discussed in MODULE-2 same thing can be incorporated here.

MODULE-2

DAMAGE ASSESSMENT

2.1 Purpose of Assessment

- Reinforced concrete is comprised of two basic materials, steel and concrete. The two materials work in a synergetic fashion when constructed properly to provide composite components which have very strong structural characteristics.
- Concrete is strong in compression but weak in tension but steel is strong in tension and little in compression. Therefore, in order to construct structural elements which are long lasting, economical, and have both compressive and tensile capacity, steel is combined with concrete to harness the compressive strength of concrete and tensile strength of steel.
- Beams are horizontal structural components that support floors, ceilings, roofs or decks and carries load perpendicular to the longitudinal axis of the beam and load tends to cause the bending of the beam. This bending creates compressive forces in upper depth of the beam carried by concrete and tensile force in the lower depth of the beam carried by the steel.
- Columns are vertical structural components that support beams and other structural elements. The compressive loads carried by columns are primarily parallel to the vertical or longitudinal axis of the column. Uniform concentric load is applied, comp. load occurs within the columns cross section and are distributed between the concrete and steel reinforcement
- Eccentric load is applied to a column, bending will occur in column, with outer section of column in tension and inner section being in compression. The tension load within the column carried by steel and compression load carried by concrete.
- Cast-in-place buildings are erected using temporary forms that concrete is placed into and then forms removed and failure will occur throughout the concrete member and/or its connections.
- Precast buildings elements generally formed off-site and then shipped to be assembled on-site using some type of anchoring device and failure will typically occurs at the joints and/or connections

2.2 Rapid Assessment

The rapid structural safety assessment should performed in the following ways

1. Review the entire outside of the structure.
2. Enter the building only if necessary to determine the extent of damage.
3. Determine what extent of damage found in the structural and non-structural elements.
4. Secure all areas that need to be isolated and post UNSAFE signage.

- The objectives of rapid structural safety assessment is to quickly inspect and evaluate the concrete structure and determine if the damage structure is unsafe for personnel within the building and rescue personnel accessing the building.
- Two primary concerns need to be considered when performing this assessment of the structure that has sustained structural damage.
- Assessment includes quick evaluation of the building structural components (eg. Beams, columns, slabs etc.) and non-structural components (Eg. Structural debris, partition walls, ceilings, glass, pipe anchoring etc)
- If there are any visual signs of structural and/or non-structural damage, then the specific building area needs to be isolated, secured, and marked as **UNSAFE**.
- The rapid structural damage assessment would note the major failures within the structure including major structural elements of beams, columns, and roof and floor decks. The on-scene commander should be notified immediately of the risk, and the area secured and marked **UNSAFE.**
- The rapid non-structural damage assessment would note the major failure within the building structure such as structural debris, partitions, ceilings, glass and piping.
- Concrete is a brittle material and, therefore, has a tendency to fragment into small. Dense, hard pieces with rough edges. Settlement or shifting of damaged structure may cause fragments to fall resulting in serious harm to personnel and/or additional damage to remaining structure
- Depending on the structural and non structural elements within the building matrix and their relation to rescue/recovery activities, there may be varying importance on the ability of these elements to provide adequate support. For ex. Failure of a column at ground level may cause failure of the remaining structure above that columns, or failure of beam above an area where rescure/ recovery workers are operating may cause collapse of floor
- The ability to perform a rapid structural safety assessment is likely to require a good flashlight(or headlamp), because adequate lightening is not available in or around the remaining structure. In addition, a note book, pen or pencil, spray paint and camera will be needed for the assessment.
- Personnel performing the rapid structural safety assessment in and around the remaining structure should wear appropriate personal protective equipment (PPE). At a minimum PPE should include a hardhat, steel-toed boots, gloves and respiratory protection from dust.

2.3 Investigation of Damage

The investigation of reasons for damage to structures is largely a matter of gathering information by observation, studying records and asking questions, supplemented if necessary by a certain amount of testing, and then interpreting the information thus obtained.

The general procedure for an investigation can be briefly summarized as given below

1. Documentation of damage.

2. Visual observation.
3. Measurements on geometrical parameters such as deflections and deformations
4. Experimentation for evaluating the material properties and behaviour
5. Interpretation and analysis of test results
6. Analysis of the building its damaged state taking in to account the test results obtained during investigation.
7. Formulation of repair measures.
8. Post-repair evaluation.

1. Observation

Texture of concrete surface may suggest possibility of chemical attack, leaching of the matrix or in the case of sulphate attack, whitening of the concrete. Rust stains often indicate corrosion of reinforcement but they may caused by contamination of aggregates. Relatively straight cracks usually indicate excessive but fairly uniform tensile strain. Cracks caused by unidirectional bending will be widest in the zone of max. tensile stress and will taper along the length, while cracks caused by direct tension will be of roughly uniform width.

2. Questioning

Record of mix proportions, sources of materials, cube test results, weather conditions etc may be available, particularly for recent built structures. It is always useful to ask questions of as many as possible of the people who were concerned with the design or construction

2.4 Damage Assessment Procedure

The first key step of investigation is to make a diagnosis of the defect or the failure of the building.

The important steps are

1. Visual Inspection.
2. Study of available documentation
3. Estimation of actual loads and environmental effects
4. Diagnosis.

1. Visual Inspection

Any damaged structure, as a first step, requires an extensive visual inspection followed by documentation of the details. A perusal of the documentation, supported by photographs.

2. Study of available documentation

Study of available documentation will give some idea on the history of construction. Original quality, analysis and design methods with assumption made, and the type of materials used. A comparison of adjacent buildings also helps in proper diagnosis.

3. Estimation of actual loads and environmental effects

- It is generally found that there is, in majority of the cases, the load acting on the structure will be much different from the load assumed in design calculations.

- cracking or any other damage may, sometimes attributed to the fact that these loads or certain load combinations were not considered in the analysis and design.
- Effect of temperature changes a hostile atmosphere would impose serviceability and durability problems and also result in undesirable effects in foundations.

4. Diagnosis

- In any investigation, diagnosis of the cause or causes of damage is of prime of importance and difficult too.
- A proper and reliable diagnosis can be made only by the conducting a systematic investigation using proven test methods and experienced personnel.

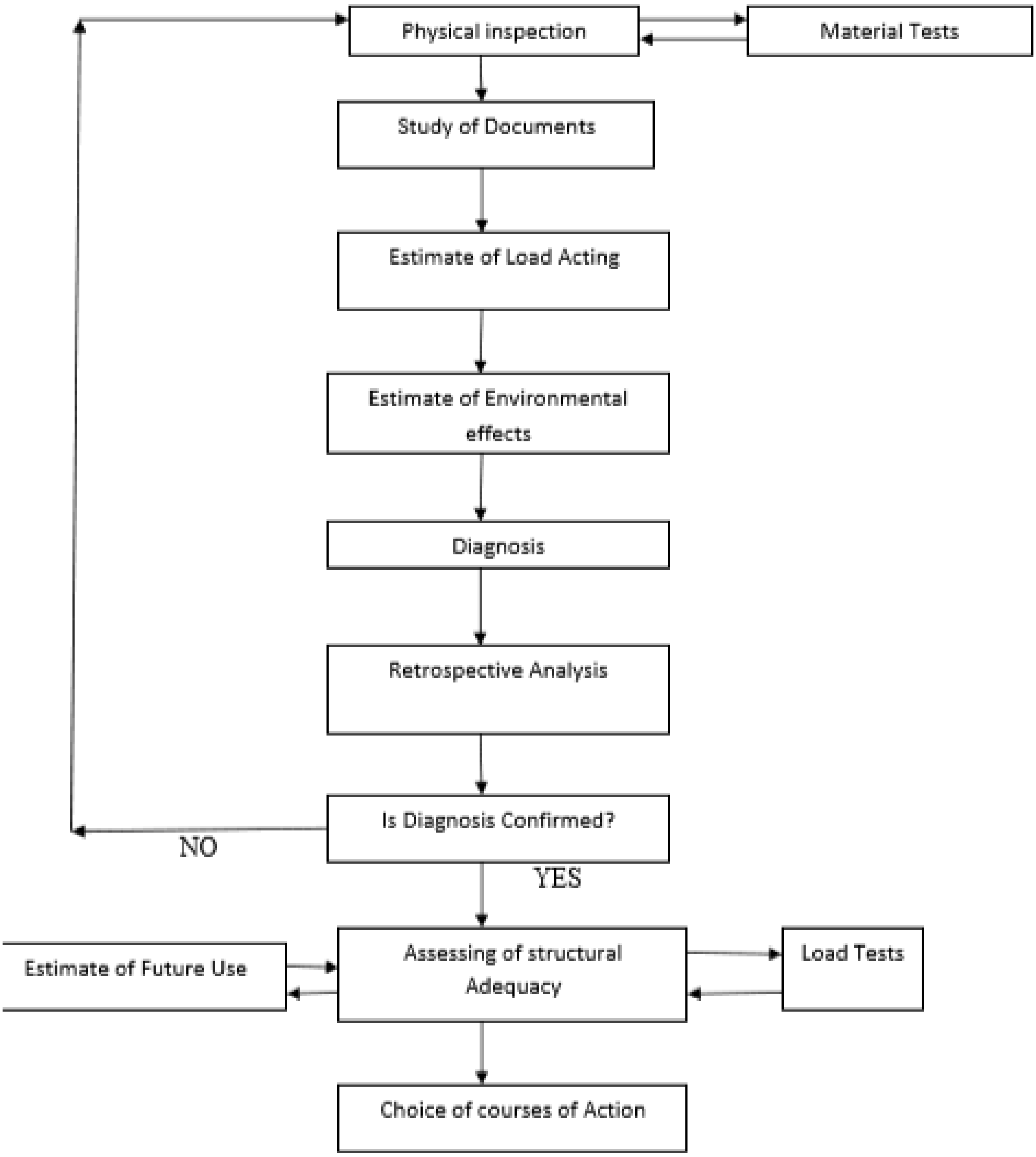


Fig 2.1: Flow chart for damage assessment

2.5 Evaluation of surface and structural cracks

- The cracks in a structure are broadly classified in to two categories:
  - Superficial cracks.
  - Structural cracks.
- The structural cracks may be active and dormant.
- A crack where a movement is observed to continue is termed **active**, whereas the crack where no movement occurs is termed **dormant or static**.
- The following information may help in diagnosing the cracks
  1. Whether the crack is new or old.
  2. Type of crack, i.e., whether it is active or dormant.
  3. Whether it appears on the opposite face of the member also, pattern of the cracks.
  4. Soil condition, type of foundation used, sign of movement of ground, if any,
  5. Observations on the similar structures in the same locality,
  6. Study of specifications, method of construction used and test results at the site, if any,
  7. Views of designer, builder, occupants of the building, if any
  8. Weather during which the structure has been constructed
- The evaluation of cracks is necessary for the following purposes
  1. To identify the cause of cracking.
  2. To assess the structure for its safety and serviceability.
  3. To establish the extent of cracking
  4. To establish the likely extent of further deterioration
  5. To study the suitability of various remedial measures,
  6. To make a final assessment for serviceability after repairs.
- Apart from visual inspection, tapping the surface and listening to the sound for hollow areas may be one of the simplest methods of identifying the weak spots.
- The suspected areas are then opened up by chipping the weak concrete for further assessment.
- The comparative strength of concrete in the structure may be assessed to a reasonable accuracy by non-destructive testing and by tests on the cores extracted from the concrete.

2.6 Testing systems of hardened concrete

There are number of testing systems available and they could be used on structures to assess the quality of concrete and steel.

Testing system of hardened concrete can be divided in to three categories

1. **Non-Destructive Testing System(NDTS)**
2. **Semi Destructive Testing Systems(SDTS)**
3. **Destructive Testing Systems(DTS)**

1. **Non-Destructive Testing System (NDTS):** To assess the quality of concrete in its damaged state without any disturbance of surrounding concrete.
2. **Semi Destructive Testing Systems (SDTS):** To assess the quality of concrete in its damaged state with partial disturbance of surrounding concrete.
3. **Destructive Testing Systems (DTS):** To assess the quality of concrete with complete disturbance of surrounding concrete (loaded up to failure).

2.6.1 Destructive Testing System (DTS)

- The most common destructive test is load test and is used to assess the strength of concrete. Load testing is sometimes used as an alternative method of assessing structural capacity.
- Load tests are usually carried out for one of the following reasons
  - *There are still doubts about the satisfactory performance of the structure under load after a survey and local testing.*
  - *It is difficult or impossible to determine inadequate information about the structure and its materials.*
  - *Verification of structural analysis in cases where the complexity of structural forms does not lend itself to analysis*
- The following aspects were set for during the testing programme
  - *To conduct the load test on the beam up to 1.25 times the designed live load.*
  - *To monitor the deflections and recovery of the beams during incremental loading and unloading.*
  - *To compare the actual deflections with that of theoretical deflections*

(a) Assessment of existing concrete structures

- It has been learnt that concrete structures requires a closer inspection, not only after construction but also periodically at regularly interval.
- The quality control measures during construction are

  Workability test on concrete

  Compressive strength of concrete samples.
- It is well known fact the results of the above tests do not reflect on true quality of concrete, existing in concrete structures because the quality of concrete depends on many factors such as mixing, transporting, placing, compacting and curing of concrete
- Assessment of quality of concrete is necessary to ensure that the quality of execution is satisfactory and to identify any deficiency so that they can be rectified. This can be achieved by conducting some in-situ tests like non-destructive and partially destructive on the structures besides visual inspection.

(b) Load test on structures

- This is a method of assessing the strength of the in-situ of concrete member. In most cases, this test is performed for the proof of structure capacity, not for suspect or critical location.
- The principle aim of this test is to demonstrate satisfactory performance under an over load, above the design working value. This is usually judged by measurement of deflections under this load which may be sustained for a specified period.

Procedure

- A live load of 1t/sqm was taken for imposed load calculation plus dead load as Floor finishing load and partition wall load were also considered. Thus imposed load was taken as 1.25times live load as per *IS:456-2000 clause 17.6 page no.30*
- The load was imposed on the beam as UDL spreads over an area of 55.5 sqm. Thus a total load of 84t was arrived at and imposed in 12 stages of 7t each at an interval of 15 minutes.
- The load of 7t was imposed with the help of 200 sand bags weighing 35kg as first step and increased in steps up to 84t.
- Dial gauges and electric strain gauges were fixed at different locations.
- Separate platform was provided to read and record the deflections from dial gauges, strain from strain indicator during loading and unloading.
- Total time for maximum load was 26hrs and the maximum load was kept for more than 43hrs during which creep effect was monitored and the time taken for unloading was 32 hrs during which deflection recovery was monitored.
- The recorded and theoretical deflections were compared.
- As per IS:456-2000, the deflections due to imposed load only shall be recorded. If within 24hrs of removal of imposed load, the structure doesnot recover at least 75% of the deflection under superimposed load, the test may be repeated after a lapse of 72hrs.
- If recovery is less than 80%, the structure shall be unacceptable.
- *As per clause 17.6.3.1, the maximum deflection in mm shown during 24hrs under load is less than 40l2/D*

  Where l – effective span

  D – Over all depth

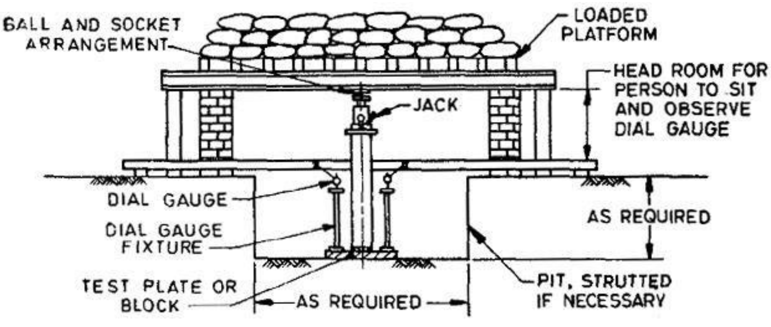


Fig 2.2: Load test on structures

2.6.2 Non-Destructive Testing System (NDTS)

The non-destructive testing tests carried out on hardened concrete are

1. Surface Hardness Method.
2. Ultrasonic pulse velocity method.
3. Resonant Frequency Method.
4. Dynamic or vibration method.
5. Pulse Attenuation Method.
6. Pulse echo Method.
7. Radioactive Methods.
8. Nuclear Methods
9. Magnetic Methods

1. Surface Hardness Method(Rebound Hammer Test)

Fundamental Principle

The Schmidt rebound hammer is principally a surface hardness tester. It works on the principle that the rebound of an elastic mass depends on the hardness of the surface against which the mass impinges. There is little apparent theoretical relationship between the strength of concrete and the rebound number of the hammer. However, within limits, empirical correlations have been established between strength properties and the rebound number.

Equipment Details

The Schmidt rebound hammer is shown in Fig. 4.1. The hammer weighs about 1.8 kg and is suitable for use both in a laboratory and in the field. A schematic cutaway view of the rebound hammer is shown in Fig. . The main components include the outer body, the plunger, the hammer mass, and the main spring. Other features include a latching mechanism that locks the hammer mass to the plunger rod and a sliding rider to measure the rebound of the hammer mass. The rebound distance is measured on an arbitrary scale marked from 10 to 100. The rebound distance is recorded as a "rebound number" corresponding to the position of the rider on the scale.

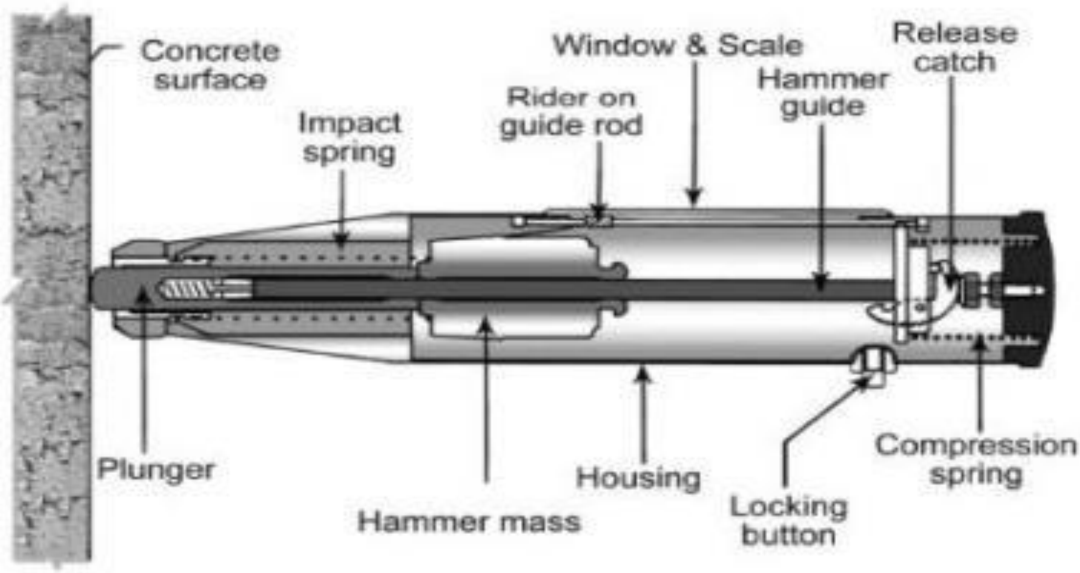


Fig 2.3: Schematic representation of rebound hammer

Procedure

- The method of using the hammer is explained using Fig.
- With the hammer pushed hard against the concrete, the body is allowed to move away from the concrete until the latch connects the hammer mass to the plunger, Fig.a.
- The plunger is then held perpendicular to the concrete surface and the body pushed towards the concrete, Fig.b. This movement extends the spring holding the mass to the body.
- When the maximum extension of the spring is reached, the latch releases and the mass is pulled towards the surface by the spring, Fig.c.
- The mass hits the shoulder of the plunger rod and rebounds because the rod is pushed hard against the concrete, Fig.d.
- During rebound the slide indicator travels with the hammer mass and stops at the maximum distance the mass reaches after rebounding. A button on the side of the body is pushed to lock the plunger into the retracted position and the rebound number is read from a scale on the body.

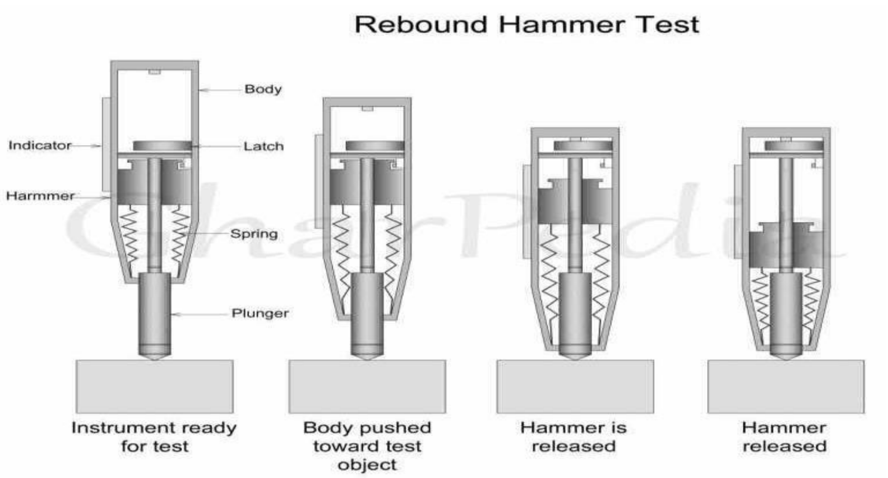
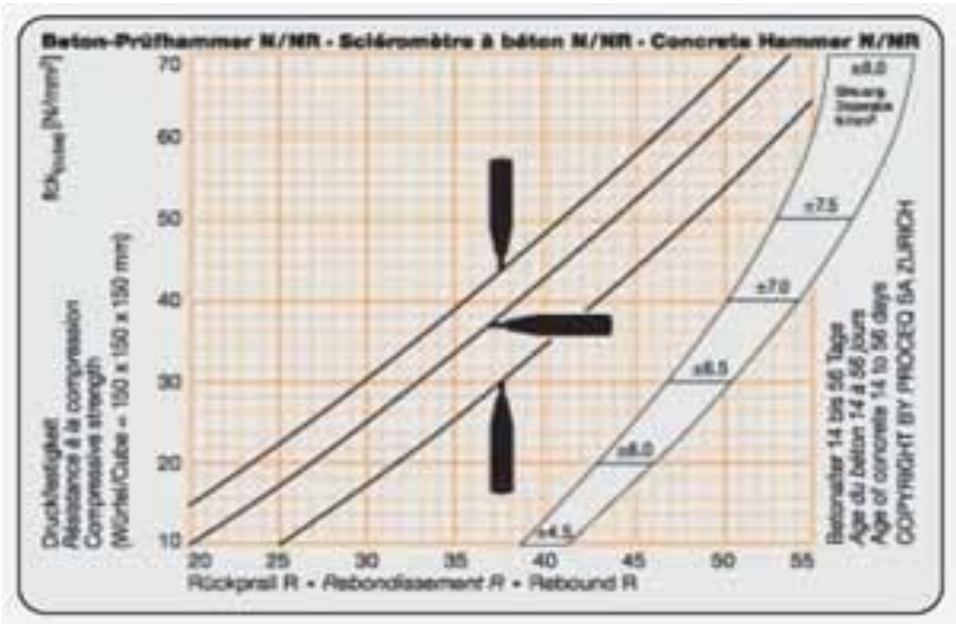


Fig 2.4: Working principle of rebound hammer

Interpretation of results

Average Rebound Number	Quality of concrete
>40	Very good hard layer
30 to 40	Good layer
20 to 30	Fair
< 20	Poor concrete
0	Delaminated



2. Ultrasonic pulse velocity(UPV) test

Fundamental Principle

- A pulse of longitudinal vibrations is produced by an electro-acoustical transducer, which is held in contact with one surface of the concrete under test.
- When the pulse generated is transmitted into the concrete from the transducer using a liquid coupling material such as grease or cellulose paste, it undergoes multiple reflections at the boundaries of the different material phases within the concrete.
- A complex system of stress waves develops, which include both longitudinal and shear waves, and propagates through the concrete. The first waves to reach the receiving transducer are the longitudinal waves, which are converted into an electrical signal by a second transducer.
- Electronic timing circuits enable the transit time T of the pulse to be measured.
- Longitudinal pulse velocity (in km/s or m/s) is given by:

$$V = L/T$$

where v is the longitudinal pulse velocity, L is the path length, T is the time taken by the pulse to traverse that length.

Equipment for pulse velocity test

The equipment consists essentially of an electrical pulse generator; a pair of transducers used should be in the range of 20 to 150 kHz, an amplifier and an electronic timing device for measuring the time interval between the initiation of a pulse generated at the transmitting transducer and its arrival at the receiving transducer. Two forms of electronic timing apparatus and display are available, one of which uses a cathode ray tube on which the received pulse is displayed in relation to a suitable time scale, the other uses an interval timer with a direct reading digital display

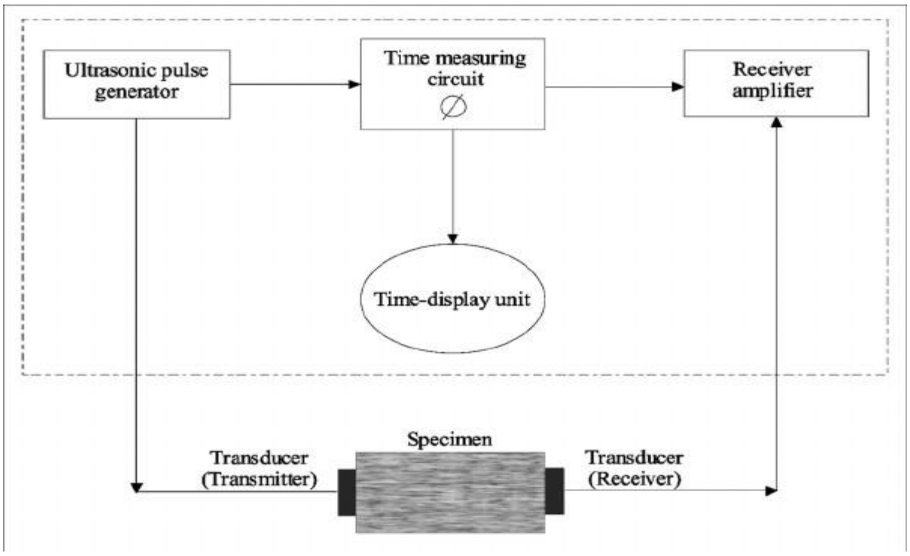


Fig 2.5: Component of Ultrasonic pulse velocity

Determination of pulse velocity

Transducer arrangement

The receiving transducer detects the arrival of that component of the pulse, which arrives earliest. This is generally the leading edge of the longitudinal vibration. Although the direction in which the maximum energy is propagated is at right angles to the face of the transmitting transducer, it is possible to detect pulses, which have travelled through the concrete in some other direction. It is possible, therefore, to make measurements of pulse velocity by placing the two transducers on either:

- **Opposite faces (direct transmission)**
- **Adjacent faces (semi-direct transmission): or**
- **Same face (indirect or surface transmission).**

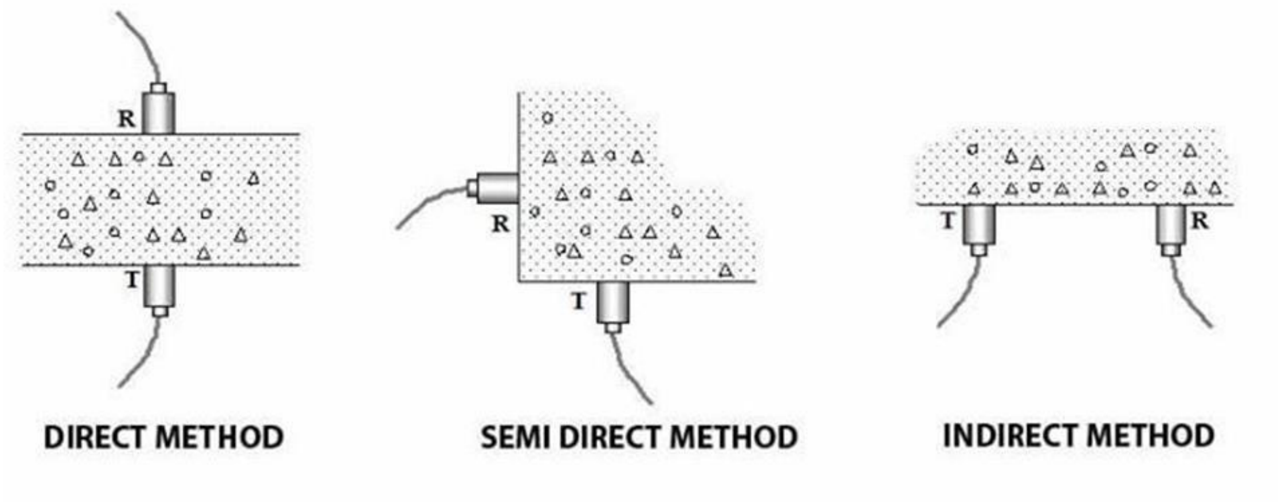


Fig 2.6: Measurement of Ultrasonic pulse velocity

Determination of pulse velocity by direct transmission

Where possible the direct transmission arrangement should be used since the transfer of energy between transducers is at its maximum and the accuracy of velocity determination is therefore governed principally by the accuracy of the path length measurement. The couplant used should be spread as thinly as possible to avoid any end effects resulting from the different velocities in couplant and concrete.

Determination of pulse velocity by semi-direct transmission

The semi-direct transmission arrangement has a sensitivity intermediate between those of the other two arrangements and, although there may be some reduction in the accuracy of measurement of the path length, it is generally found to be sufficiently accurate to take this as the distance measured from centre to centre of the transducer faces. This arrangement is otherwise similar to direct transmission.

Determination of pulse velocity by indirect or surface transmission

Indirect transmission should be used when only one face of the concrete is accessible, when the depth of a surface crack is to be determined or when the quality of the surface concrete relative to the overall quality is of interest. It is the least sensitive of the arrangements and, for a given path length, produces at the receiving transducer a signal which has an amplitude of only about 2% or 3% of that produced by direct transmission.

Interpretation of results

Longitudinal Pulse Velocity(km/sec)	Quality of concrete
>4.5	Excellent
3.5 – 4.5	Good
3.0 – 3.5	Doubtful

2.0 -3.0	Poor
< 2.0	Very poor

3. Resonant Frequency method

- This method is based up on the determination of the fundamental resonant frequency of vibration of a specimen.
- The equipment used usually known as SONOMETER.
- This method can be used in laboratory.
- The size of specimen in these tests is limited to 150mmX300mm cylinder or 75mmx 75mm x 300mm prisms
- Resonant frequency test is used for following purpose
    - For studying deterioration effects of concrete
    - To study the effects due to acid and alkali reactions.
    - For determining the damage due to fire
    - To calculate the dynamic modulus of elasticity of concrete

Fig 2.7: Resonant frequency equipments

4. Dynamic or vibration method

- These methods are important non-destructive methods used for testing concrete strength and other properties.
- The fundamental principle of this method is in the propagation of sound velocity through a solid material
- A mathematical relationship could be established between the velocity of sound through the specimen and its resonant frequency. From this relationship, the modulus of elasticity of the material is determined. For deriving this relationship, the solid medium are considered to be homogeneous, isotropic and perfectly elastic.
- The velocity of sound V in a solid material is a function of the square root of the ratio of its modulus of elasticity E and its density ρ

$V = f [g E / \rho]^{1/2}$

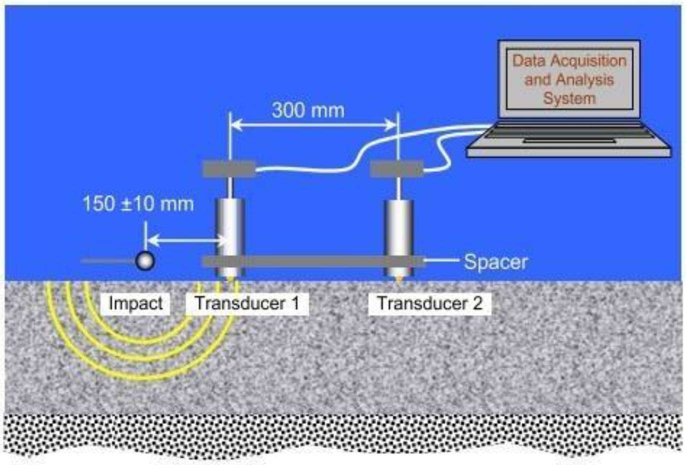
where g is acceleration due to gravity

5. Pulse Attenuation method

- This is a wave propagation method in which the electromagnetic waves, typically in the frequency ranged 500 MHz to 1000MHz are allowed to propagate through solids.
- The methodology is used for subsurface investigation in civil engineering structures and in particular concrete structures.
- The basic principle is that the attenuation properties of the electromagnetic waves are influenced by the electrical properties of the solid material tested.
- The dominant properties are the electrical permittivity, which determines the signal velocity, and the electrical conductivity, which determines the signal attenuation.
- Reflection and refraction of the radar waves will occur at interfaces between different materials and the signal returning to the surface antenna can be interpreted to provide an evaluation of properties and geometry of subsurface features.

6. Pulse echo method

- Pulse echo technique was developed for pile integrity testing and now it is popular for concrete structures and structural elements.
- An instrument commercially known as DOCTER marked in Denmark is available with a field computer, related softwares and transducers.
- The system found to be useful for
  - Testing for thickness and flaws in concrete.
  - Testing for wave speed on the surface.
  - Testing for depth of surface opening cracks.



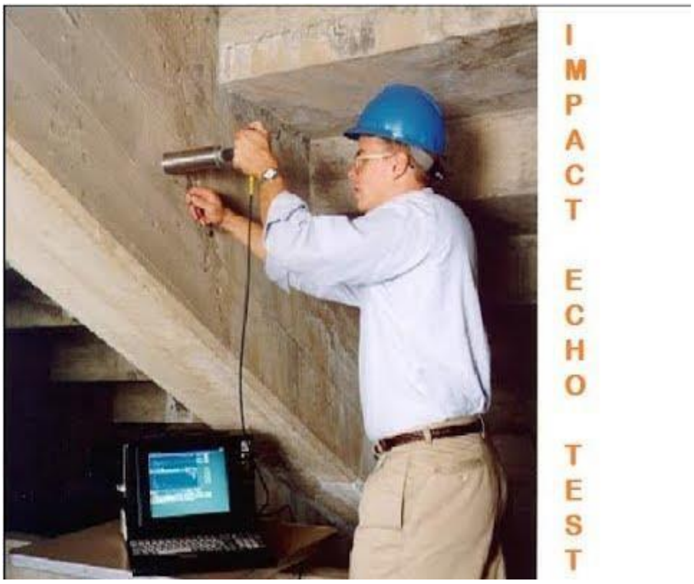


Fig 2.8: Component of Ultrasonic pulse echo equipment

7. Radioactive method

- The use of X-rays and gamma rays as non-destructive method for testing properties of concrete.
- The degree of attenuation depends on the kind of matter traversed, its thickness, and the wavelength of the radiation.
- The intensity of the incident gamma rays and the emerging gamma rays after passing through the specimen are measured. These two values are made use for calculating the density of structural concrete members.
- Gamma radiation source of known intensity is made to pass and penetrate through the concrete. The intensity of other face is measured and thickness of concrete is calculated

2.6.3 Semi-Destructive Testing System (NDTS)

The semi-destructive tests are

1. Penetration Techniques.
2. Pull-out and Pull-off Tests.
3. Core sampling and testing.
4. Break off test
5. Half-cell potential survey
6. Carbonation and pH value test
7. Chloride content test

1. Windsor probe or Penetration resistance test

In 1964 and 1966, a technique known as Windsor Probes was advanced for testing concrete in lab and in situ.

Fundamental principle

The Windsor probe, like the rebound hammer, is a hardness tester, and its inventors' claim that the penetration of the probe reflects the precise compressive strength in a localized area is not strictly true. However, the probe penetration does relate to some property of the concrete below the surface, and, within limits, it has been possible to develop empirical correlations between strength properties and the penetration of the probe.

Equipment

The Windsor probe consists of a ***powder-actuated gun*** or **driver**, ***hardened alloy steel probes***, ***loaded cartridges***, a ***depth gauge*** for measuring the penetration of probes, and ***other related equipment***.

As the device looks like a firearm it may be necessary to obtain official approval for its use in some countries. The probes have a tip diameter of 6.3 mm, a length of 79.5 mm, and a conical point. Probes of 7.9 mm diameter are also available for the testing of concrete made with lightweight aggregates. The rear of the probe is threaded and screws into a probe driving head, which is 12.7 mm in diameter and fits snugly into the bore of the driver. The probe is driven into the concrete by the firing of a precision powder charge that develops energy of 79.5 m kg. For the testing of relatively low strength concrete, the power level can be reduced by pushing the driver head further into the barrel.

Fig 2.9: Component of Windsor probe equipment

Procedure (AS PER ASTM C 803)

- The area to be tested must have a brush finish or a smooth surface.
- To test structures with coarse finishes, the surface first must be ground smooth in the area of the test. Briefly, the powder-actuated driver is used to drive a probe into the concrete.
- If flat surfaces are to be tested a suitable locating template to provide 178 mm equilateral triangular pattern is used, and three probes are driven into the concrete, one at each corner.
- A depth gauge measures the exposed lengths of the individual probes.

- The manufacturer also supplies a mechanical averaging device for measuring the average exposed length of the three probes fired in a triangular pattern. The mechanical averaging device consists of two triangular plates. The reference plate with three legs slips over the three probes and rests on the surface of the concrete.
- The other triangular plate rests against the tops of the three probes.
- The distance between the two plates, giving the mechanical average of exposed lengths of the three probes, is measured by a depth gauge inserted through a hole in the centre of the top plate.
- For testing structures with curved surfaces, three probes are driven individually using the single probe locating template. In either case, the measured average value of exposed probe length may then be used to estimate the compressive strength of concrete by means of appropriate correlation data.

2. Pull out and pull off test

- A pullout test measures the force required to pullout from concrete a specially shaped rod which enlarged end has been cast into that concrete.
- The stronger the concrete more is the force required to pullout.
- The ideal way to use pullout test in the field would be to incorporate assemblies in the structure. The standard specimens could then be pulled out at any point of time.
- The force required denotes the strength of concrete.
- ***Internal Fracture Test***

  The Capo Test

  Limpet Test
- **Internal Fracture Test**
  - It is the pullout test, which has been most widely used in the field. It was first developed for testing high alumina cement concrete components but further work has been carried out to produce correlation curves for concrete.
  - To carry out the test 6mm hole is drilled to a depth of 30-35 mm and the hole is blown out and each holes should be at least 100mm apart and drilled away from reinforcement
  - It is usually to carry out six tests on a member and the average of six max readings is used to read off the mean comp. strength from calibration curve

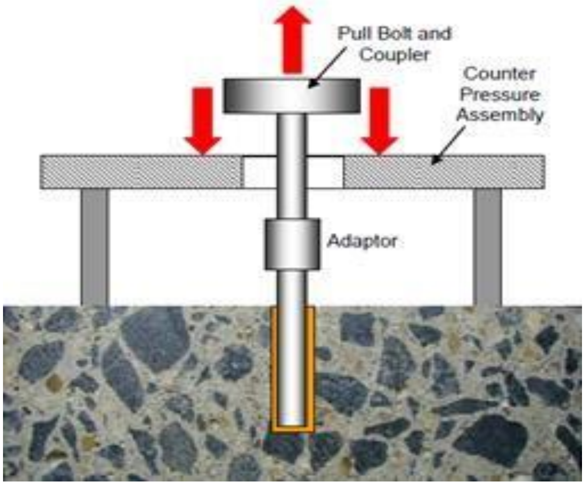


Fig 2.10: Component of pull out test equipment

3. *Carbonation test*

- Carbonation test is carried out using simple Phenolpthalein test.
- Phenolphthalein spray is an indicator of pH value and as carbonation has its effect on pH of concrete, the change in colour indicates the extent of carbonation.
- The test is conducted by drilling hole on the concrete surface to different depths up to cover concrete, spraying with phenolphthalein, and observing the colour change.
- Uncarbonated surface exhibits pink colour while carbonated concrete exhibits no change in colour.
- The depth of carbonation is estimated based on the change in colour profile.

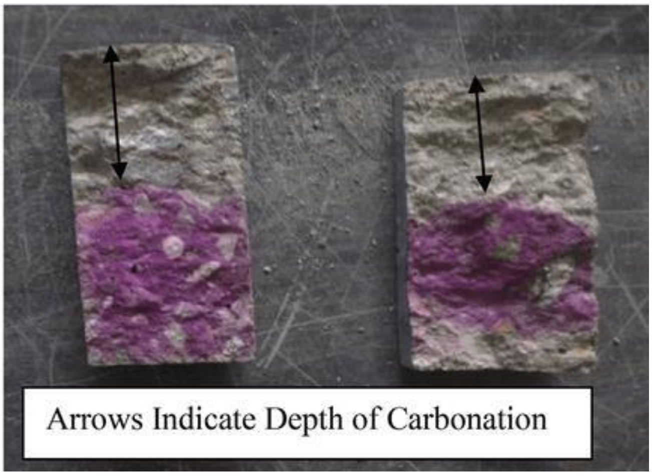


Fig 2.11: carbonation tested sample

4. *Core test*

- Concrete cores are used for testing of actual properties of concrete in existing structures such as strength, permeability, chemical analysis, carbonation etc.

Core Sampling and Testing of Concrete

- Concrete cores are usually cut by means of a rotary cutting tool with diamond bits. In this manner, a cylindrical specimen is obtained usually with its ends being uneven, parallel and square and sometimes with embedded pieces of reinforcement.

- The cores are visually described and photographed, giving specific attention to compaction, distribution of aggregates, presence of steel etc.

Fig 2.12: Core test equipment and sample extrusion of core

- **Capping of concrete core**
  - The ends of the specimen shall be capped before testing. The material used for the capping shall be such that its compressive strength is greater than that of the concrete in the core. Caps shall be made as thin as practicable and shall not flow or fracture before the concrete fails when the specimen is tested. The capped surfaces shall be at right angles to the axis of the specimen and shall not depart from a plane by more than 0·05 mm.
  - After checking for irregularities) the core shall be placed in water at a temperature of 24° to 3O°C for 48 hours before testing. The overall height of the specimens, with capping shall be measured to the nearest millimetre.

Fig 2.13: Capping of concrete Core

As per IS: 516-1959

- **Neat Cement** - Test cylinders may be capped with a thin layer of stiff, neat Portland cement paste' after the concrete has ceased settling in the moulds, generally for two to four hours or more after moulding. The cap shall be formed by means of glass plate not less than '6·5 mm in thickness or a machined metal plate not less than 13 mm in thickness and having a minimum surface dimension at least 25 mm larger than the diameter of the mould. It shall he worked on the cement paste until its lower surface rests on the top of the mould, The cement for capping shall be mixed to a stiff paste for about two to four hours before it is to be used in order to avoid the tendency of the cap to shrink. Adhesion of paste to the capping plate may be avoided by coating the plate with a thin coat of oil or grease.

- **Curing** - The test specimen- shall be stored in a place, free from vibration, in moist air of at least 90 percent relative humidity and at a temperature of 27° ± 2°e for 24 hours ± l hour from the time of addition of water to the dry ingredients, After this period, the specimens shall be marked and removed from the moulds and, unless required for test within 24 hours, immediately submerged in clean, fresh water or saturated lime solution and kept there until taken out just prior to test. The water or solution in which the specimens are submerged shall be renewed every seven days and shall be maintained at a temperature of 27° ± 2°C. The specimens shall not be allowed to become dry at any time until they have been tested.

➢ **Testing of concrete core**

- Test the specimen within 7 days after coring.

➢ **Calculation of Compressive Strength of Concrete Core**

- Calculate the compressive test of the specimen using the computed cross sectional area based on average diameter of the specimen. If the L /D ratio is 1.75 or less, correct the results obtained by multiplying with correction factors as given below.
- The value obtained after multiplying with correction factor is called corrected compressive strength, this being equivalent strength of a cylinder having L/D ratio of 2. The equivalent cube strength can be calculated by multiplying the corrected cylinder strength by 5/4.

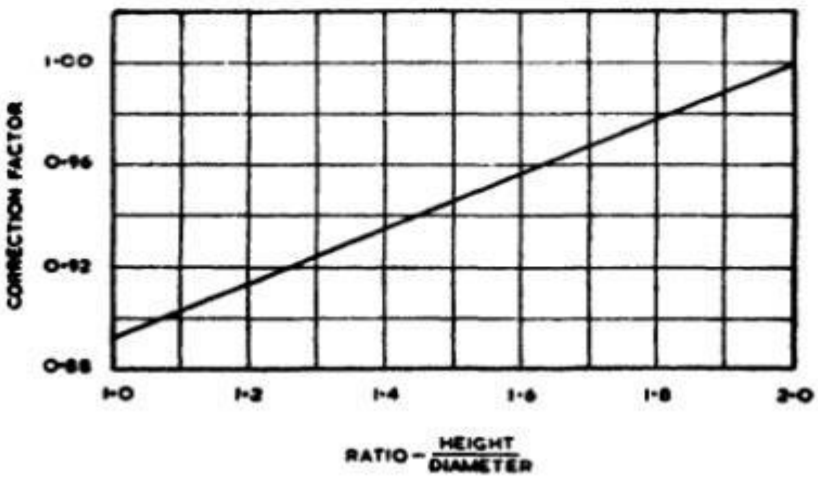


FIG 1 CORRECTION FACTOR FOR HEIGHT/DIAMETER RATIO OF A CORE

- **Calculation of Concrete Core compressive strength template**

Sl. No	Sample No.	Core Height H (cm)	Core Diameter D (cm)	Failure Load (KN)	Core Comp. Strength (MPa)	H/D Ratio	Correction Factor for H/D ratio	Corrected Cylinder Compressive strength(MPa)	Equivalent cube Compressive Strength (MPa)
As per IS:516-1959 & IS:456-2000 Cl.17.4.3 concrete in the member represented by a core test shall be considered acceptable if the average equivalent cube strength of the cores is equal to 85% of the cube strength of the grade of concrete specified for the corresponding age and no individual core has a strength less than 75%.									

- **Factors Affecting Strength of Concrete Cores**

Size of stone aggregate

If the ratio of diameter of core to maximum size of stone aggregate is less than 3, a reduction in strength is reported. For concrete with 20mm size aggregate, 50mm dia core has been tested to give 10% lower results than with 10mm dia cores.

Presence of transverse reinforcement steel

It is reported that the presence of transverse steel causes a 5 to 15% reduction in compressive strength of core. The effect of embedded steel is higher on stronger concrete and as its location moves away from ends, i.e. towards the middle. However presence of steel parallel to the axis of the core is not desirable.

H/D ratio

This has been already discussed above. However its value should be minimum 0.95 and maximum 2. *Higher ratio would cause a reduction in strength*

Age of concrete

No age allowance is recommended by the Concrete Society as some evidence is reported to suggest that in-situ concrete gains little strength after 28 days. Whereas others suggest that under average conditions, the increase over 28 days' strength is 10% after 3 months, 15% after 6 months. Hence it is not easy to deal the effect of age on core strength.

Strength of concrete

The effect in reducing the core strength appears to be higher in stronger concretes and reduction has been reported as 15% for 40 MPa concrete. However a reduction of 5 50 7% is considered reasonable.

MODULE-3

Influence on serviceability and durability

3.1 Effect due to temperature

- Change in temperature cause a corresponding change in volume of concrete.
- Two types of temp. change
  - ***Temperature change internally by the heat of hydration of cement.***
  - ***Temperature change generated by variation in climatic conditions.***

(a) Internally generated temperature differences

Mechanism

- Hydration of Portland cement is an exothermic reaction.
- In large volume placements, significant amount of heat may be generated and the temp. of concrete may be raised above 38^{o}C over the concrete temp. at placement.
- Temp. rise is not uniform throughout the mass of concrete, and steep temp. Gradients may develop. This temp. gradients give rise to a situation known as internal restraint-the outer portion of concrete may be losing heat while the inner portion are gaining heat.
- If the differential is great, cracking may occur. Simultaneously with the development of this internal restraint condition, as the concrete mass begins to cool, a reduction in volume take place.
- If the reduction in volume is prevented by external conditions such as by chemical bonding, mechanical interlock or by piles, the concrete is externally restrained

Symptoms

- Cracking resulting from internal restraint will be relatively shallow and isolated.
- Cracking resulting from external restraint will usually extend through the full section.

Prevention

- *Low heat content or combination of cement and pozzolana*
- *Placing the concrete at minimum practical temp.*
- *Aggregates with low modulus of elasticity and low coefficient of thermal expansion.*
- *Cooling internally appropriate to minimizing temp. difference*

(b) Externally generated temperature differences

Mechanism

- The basic failure mechanism in this case is same as that for internally generated temp. Differences-the tensile strength of concrete is exceeded.
- The temp. Change in this case leading to the concrete volume change is caused by external factors, usually change in climatic conditions.

Symptoms

- Visual examination will show regularly spaced cracking in the case of restrained contraction.
- Spalling at expansion joints will be seen in the case of restrained expansion

Prevention

- *Provision for the use of expansion and contraction joint*
- *Providing reinforcing steel (temp. steel) will help to distribute cracks and minimize the size of those occur.*

3.2 Effect due to Wear and Erosion

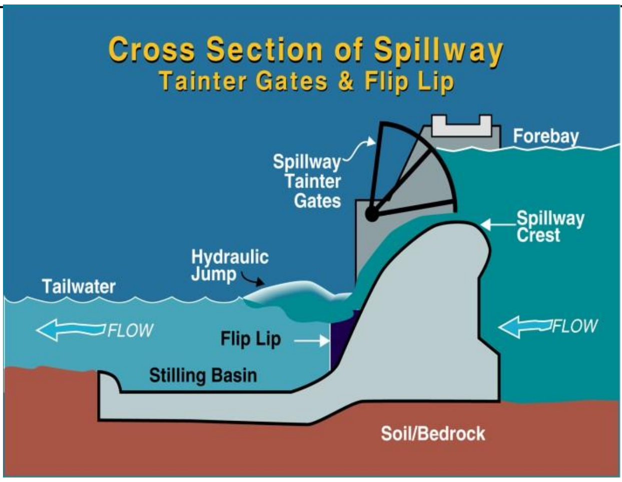
- *Wear refers to wearing away of the surface by friction.*
- *Erosion refers to wearing away of the surface by fluids.*
- Concrete used in roads, floors, the pavements and the concrete used in the hydraulic structures should exhibit resistance against wear and erosion.

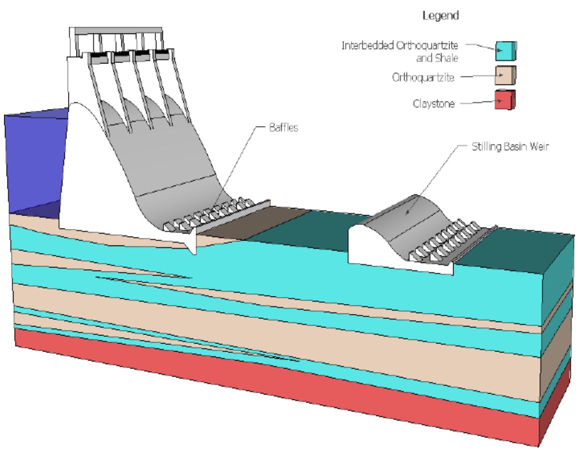
Mechanism

- Abrasion-erosion damage is caused by the action of debris rolling and grinding against a concrete surface.
- In hydraulic structures, the area's most likely to damage are spillway, aprons, stilling basin slabs, and culverts.
- The sources of debris include construction trash left in a structure, riprap brought back into a basin by eddy currents because of poor hydraulic design or asymmetrical discharge, and riprap or debris thrown into a basin by public.
- As the outer paste of concrete wears, the fine and coarse aggregate are exposed and abrasion and impact will cause additional degradation that is related to aggregate-to-paste bond strength and hardness of the aggregate.

Symptoms

- Concrete surfaces abraded by waterborne debris are generally smooth and may contain localised depressions; debris remaining in the structure will be spherical and smooth.
- Mechanical abrasion is usually characterized by long shallow grooves in the concrete surface and spelling along monolith joints.





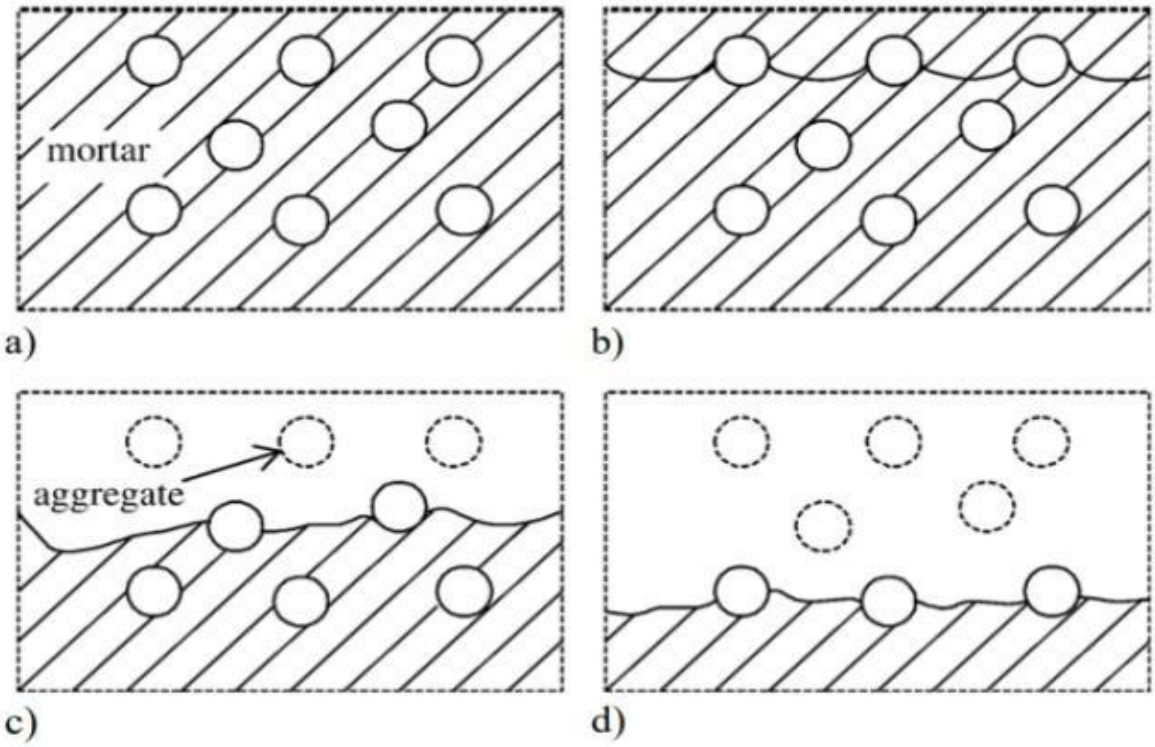


Figure 1. Sequence of abrading concrete surface in hydraulic structures [11] [a) initial stage, b) concrete surface under abrasive action, c) loss of coarse aggregate and mortar from concrete surface, d) further loss of coarse aggregate and mortar from concrete surface].

Prevention

- *Design*
- *Operation.*
- *Use of steel fibres in concrete matrix improves abrasion resistance of concrete.*
- *Polymer based systems*
- *Aggregate in concrete should be wear resistant.*
- *The shape and texture of aggregate plays an important role in abrasion resistance of the concrete.*
- *More the compressive strength of concrete higher is the resistance to wear and erosion.*

3.3 Effect due to Chemicals

This is same as effect due to chemical attack which has been discussed in Module -1

3.4 Effect due to Climate

This is same as effect due to freezing and thawing which has been discussed in Module -1

3.5 Design and construction error

Design Errors

Design errors may be divided into two general types:

1. Inadequate structural design

2. Lack of attention to relatively minor design details.

1. Inadequate structural design

Mechanism

The failure mechanism is simple – the concrete is exposed to greater stress than it is capable of carrying or it sustains greater strain than its strain capacity.

Symptoms

Visual examinations of failures resulting from inadequate structural design will usually show one of two symptoms.

First, errors in design resulting in excessively high compressive stresses will result in spalling. Similarly, high torsion or shear stresses may also result in spalling or cracking.

Second, high tensile stresses will result in cracking.

Prevention

Inadequate design in prevented by thorough and careful review of all design calculations. Any rehabilitation method that makes use of existing concrete structural members must be carefully reviewed.

2. Poor design details

- A structure may be adequately designed to meet loadings and other overall requirements, poor detailing may result in localized concentrations of high stresses in otherwise satisfactory concrete. These high stresses may result in cracking that allows water or chemicals access to the concrete.
- Poor design detailing may simply allow water to pond on a structure, resulting in saturated concrete.
- poor detailing does not lead directly to concrete failure; rather, it contributes to the action of one of the other causes of concrete deterioration

(a) Abrupt changes in section

Abrupt changes in section may cause stress concentrations that may result in cracking. Typical examples would include the use of relatively thin sections such as bridge decks rigidly tied into massive abutments or patches and replacement concrete that are not uniform in plan dimensions.

(b) Insufficient reinforcement at reentrant corners and openings.

Reentrant corners and openings also tend to cause stress concentrations that may cause cracking. In this case, the best prevention is to provide additional reinforcement in areas where stress concentrations are expected to occur.

(c) Inadequate provision for deflection

Deflection in excess of those anticipated may result in loading of members or sections beyond the capacities for which they were designed. Typically, these loadings will be induced in walls or partitions, resulting in cracking.

(d) Inadequate provision for drainage

Poor attention to the details of draining a structure may result in the ponding of water. This ponding may result in leakage or saturation of concrete. Leakage may result in damage to the interior of the structure. Saturation may result in severely damaged concrete if the structure is in an area that is subjected to freezing and thawing.

(e) Insufficient travel in expansion joints:

Inadequately designed expansion joints may result in spalling of concrete adjacent to the joints. The full range of possible temperature differentials that a concrete may be expected to experience should be taken into account in the specification for expansion joints. There is no single expansion joint that will work for all cases of temperature differential.

(f) Incompatibility of materials: The use of materials with different properties (modulus of elasticity or coefficient of thermal expansion) adjacent to one another may result in cracking or spalling as the structure is loaded or as it is subjected to daily or annual temperature variations.

(g) Neglect of creep effect:

Neglect of creep may have similar effects as noted earlier for inadequate provision for deflections. Additionally, neglect of creep in prestressed concrete members may lead to excessive prestress loss that in turn results in cracking as loads are applied.

(h) Rigid joints between precast units:

Designs utilizing precast elements must provide for movement between adjacent precast elements or between the precast elements and the supporting frame. Failure to provide for this movement can result in cracking or spalling.

Construction Errors

- Fail to follow specified procedures and good practice or outright carelessness may lead to a number of conditions that may be grouped together as construction errors.
- Most of these errors do not lead directly to failure or deterioration of concrete. Instead, they enhance the adverse impacts of other mechanisms.

(a) Adding water to concrete :

Water is usually added to concrete in one or both of the following circumstances:

1. First, water is added to the concrete in a delivery truck to increase slump and decrease emplacement effort. This practice will generally lead to concrete with lowered strength and reduced durability. As the w/c of the concrete increases, the strength and durability will decrease.
2. In the second case, water is commonly added during finishing of flatwork. This practice leads to scaling, crazing, and dusting of the concrete in service

(b) Improper alignment of formwork

Improper alignment of the formwork will lead to discontinuities on the surface of the concrete. While these discontinuities are unsightly in all circumstances, their occurrence may be more critical in areas that are subjected to high-velocity flow of water, where cavitations erosion may be induced, or in lock chambers where the "rubbing" surfaces must be straight.

(c) Improper consolidation:

Improper consolidation of concrete may result in a variety of defects, the most common being bugholes, honeycombing, and cold joints.

"Bugholes" are formed when small pockets of air or water are trapped against the forms. A change in the mixture to make it less "sticky" or the use of small vibrators worked near the form has been used to help eliminate bugholes.

Honeycombing can be reduced by inserting the vibrator more frequently, inserting the vibrator as close as possible to the form face without touching the form, and slower withdrawal of the vibrator.

(d) Improper curing:

Curing is probably the most abused aspect of the concrete construction process. Unless concrete is given adequate time to cure at a proper humidity and temperature, it will not develop the characteristics that are expected and that are necessary to provide durability. Symptoms of improperly cured concrete can include various types of cracking and surface disintegration. In extreme cases where poor curing leads to failure to achieve anticipated concrete strengths, structural cracking may occur.

(e) Improper location of reinforcing steel:

This section refers to reinforcing steel that is improperly located or is not adequately secured in the proper location. Either of these faults may lead to two general types of problems.

1. First, the steel may not function structurally as intended, resulting in structural cracking or failure. A particularly prevalent example is the placement of welded wire mesh in floor slabs. In many case, the mesh ends up on the bottom of the slab which will subsequently crack because the steel is not in the proper location.

2. The second type of problem stemming from improperly located or tied reinforcing steel is one of durability. The tendency seems to be for the steel to end up near the surface of the concrete. As the concrete cover over the steel is reduced, it is much easier for corrosion to begin.

(f) Movement of formwork: Movement of formwork during the period while the concrete is going from fluid to a rigid material may induce cracking and separation within the concrete. A crack open to the surface will allow access of water to the interior of the concrete. An internal void may give rise to freezing or corrosion problems if the void becomes saturated.

(g) Premature removal of shores or reshores: If shores or reshores are removed too soon, the concrete affected may become overstressed and cracked. In extreme cases there may be major failures.

(h) Settling of the concrete: During the period between placing and initial setting of the concrete, the heavier components of the concrete will settle under the influence of gravity. This situation may be aggravated by the use of highly fluid concretes. If any restraint tends to prevent this settling, cracking or separations may result. These cracks or separations may also develop problems of corrosion or freezing if saturated.

(j) Vibration of freshly placed concrete: Most construction sites are subjected to vibration from various sources, such as blasting, pile driving, and form the operation of construction equipment. Freshly placed concrete is vulnerable to weakening of its properties if subjected to forces which disrupt the concrete matrix during setting.

(k) Improper finishing of flat work: The most common improper finishing procedures which are detrimental to the durability of flat work are discussed below.

(1) Adding water to the surface. Evidence that water is being added to the surface is the presence of a large paint brush, along with other finishing tools. The brush is dipped in water and water is “slung” onto the surface being finished.

(2) Timing and finishing. Final finishing operations must be done after the concrete has taken its initial set and bleeding has stopped. The waiting period depends on the amounts of water, cement, and admixtures in the mixture but primarily on the temperatures of the concrete surface.

(3) Adding cement to the surface. This practice is often done to dry up bleed water to allow finishing to proceed and will result in a thin cement-rich coating which will craze or flake off easily.

3.6 CORROSION

Corrosion is the conversion of iron in to its oxides and hydroxides in the presence of oxygen and water.

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".*

The nature of reinforcement corrosion mechanism can be attributed to three predominant process

1. ***Chemical Process*** *: In this the alkalinity of concrete can get reduced to a pH < 10 by the ingress of carbon dioxide or the passivity of steel can be destroyed by the ingress of chloride*
2. ***Electrochemical Process*** *: In this the galvanic cells get established by forming locally or generally cathodic and anodic sites resulting in a flow of current with moist concrete serving as the electrolyte.*
3. ***Physical Process****: In this the corrosion product (rust) experiences a volume growth as high as six to 7 times the corroding metal. This volume growth exerts physical expansive forces to the concrete surrounding the steel.*

3.6.1 Corrosion Mechanism

The corrosion process of reinforcement embedded in concrete has two distinct periods namely,

1. **Initiation Period**: This is the time taken to initiate corrosion which can be caused either by ingress of carbon dioxide or chloride ions.

2. **Propagation Period:** the propagation period, during which begins at the moment of depassivation and involves the propagation of corrosion at a significant rate, until a final state is reached

- 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.
- A moist concrete matrix forms an acceptable electrolyte and the steel reinforcement provides anode and cathode. Electric current flows between the anode and cathode, and the reaction results in an increase in metal volume as Fe(Iron) is oxidised in to Fe(OH)2 and Fe(OH)3 and precipitates as FeOH(rust)

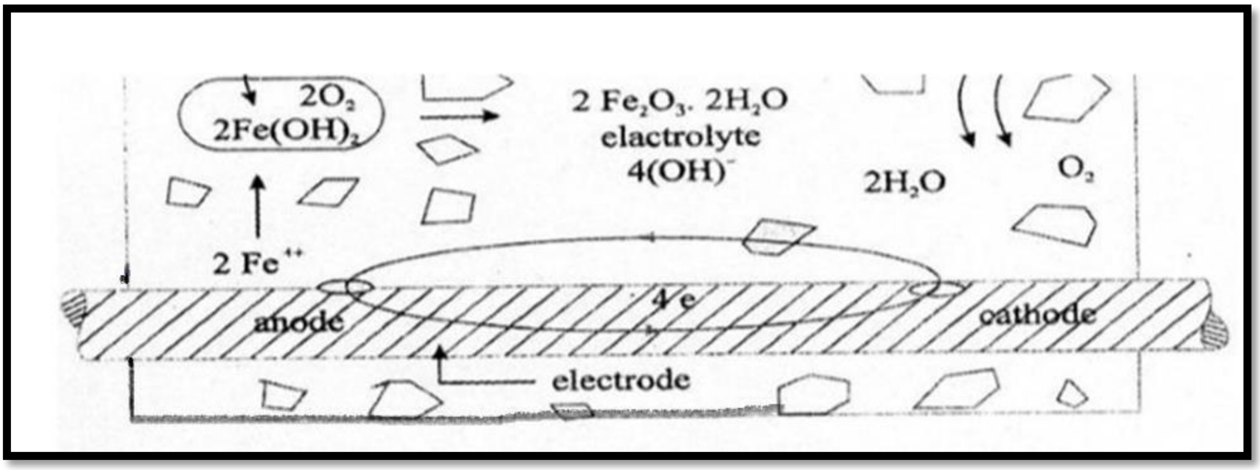


Fig 3.1: Simplified model representing corrosion mechanism

$$Fe \rightleftharpoons 2e^- + Fe \quad \text{(ANODE)}$$

$$\rightarrow Fe(OH_2)$$

$$\tfrac{1}{2}O_2 + H_2O + 2e^- \rightleftharpoons 2(OH^-) \quad \text{(CATHODE)}$$

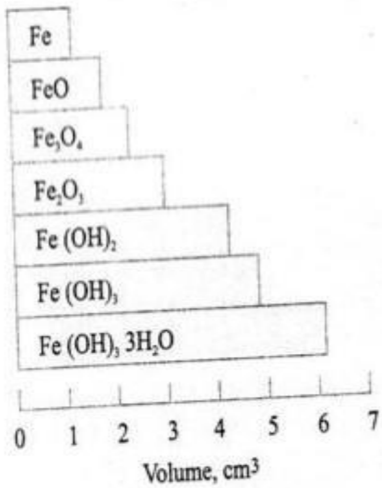
$$4\ Fe(OH)_2 + 2H_2O + O_2 \longrightarrow 4\ Fe(OH)_3\ \text{(RED RUST)}$$

$$3Fe + 8OH^- \longrightarrow Fe_3O_4 + 8e^- + 4H_2O \quad \text{(BLACK RUST)}$$

- 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, if 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 Fe and OH originate iron the anode and cathode respectively, their combination occurs more commonly at the cathode, because the Smaller 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.

3.6.2 CORROSION PROTECTION TECHNIQUES

1. Coatings to Reinforcement: The objective of coating to steel bar is to provide a sufficiently durable barrier to aggressive materials such as chlorides. The epoxy coating is done. The bar is heated to controlled temperature before passing through a spray booth. Hence, electro-statically charged powder particles are deposited evenly on the surface of the bar. The coating thickness typically varies from 130 micron to 300 micron.

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

b. 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:

ü **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.

ü **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.

c. 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 insite curing effect. The second coat of slurry is then applied and the bars are air dried.

d. Sealing

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

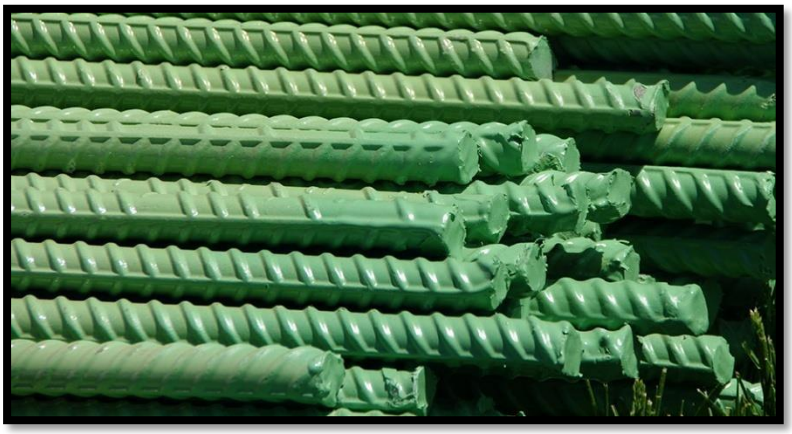


Fig 3.2: Epoxy coated rods

2. Galvanized Reinforcement: Galvanized reinforcement consists of standard black bar, hot dipped in molten zinc. This process forms a coating which is metallurgically bonded to the surface of the metal. The surface of the zinc reacts with calcium hydroxide in the concrete to form a passive layer, preventing corrosion. It is expensive.

3. Improve metallurgically by adding metals

The bars can be improved for its corrosion resistance by adding certain elements such as chromium and copper during the formation or process itself

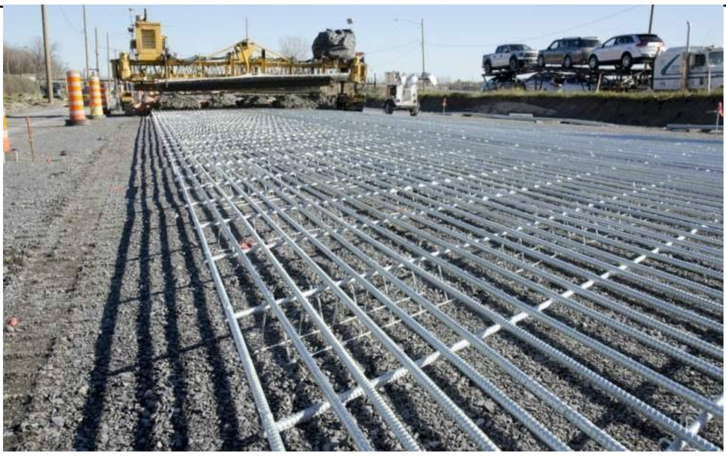


Fig 3.3: Galvanized rods

4. Stainless steel Reinforcement

Stainless steel is the name given to a family of corrosion resistant steels containing a minimum of 12% chromium. On contact with air, chromium forms a thin oxide layer on the surface of steel. This is passive and resists corrosion.

5. Non-ferrous reinforcement

Non- ferrous reinforcement is an alternative to the conventional reinforcement in traditional structures currently being developed by manufacturers. The most commonly used man-made fibres are glass, carbon and aramid. The fibres are used either in the form of ropes or combined with suitable resins to form rods.

Fig 3.4: Glass fibre reinforcement

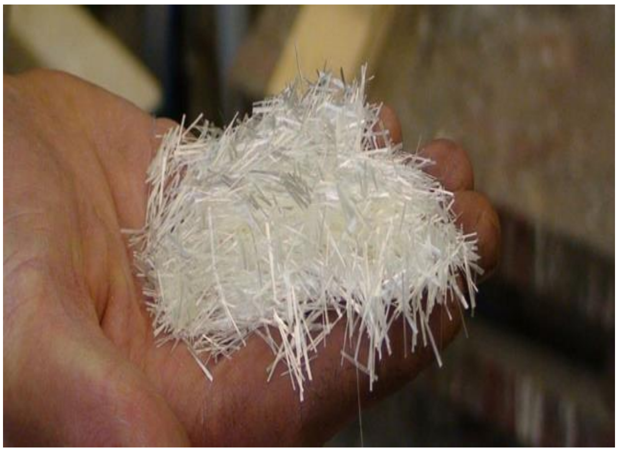


Fig 3.5: Glass fibres

Fig 3.6: Aramid fibre reinforcement

Fig 3.7: Carbon fibre reinforcement

Fig 3.8: Carbon fibre wrappings

Fig 3.9: Placing of carbon fibre to the beams

6. Concrete Coatings

A concrete surface coating of silane-siloxane type was evaluated for its corrosion performance.

7. Improving the concrete

Low W/C

High cement content

Minimum cover

Careful curing

8. Corrosion Inhibitors

A corrosion inhibitor is a substance which, when added to an environment in a small concentration, effectively reduces the corrosion rate of a metal exposed to that environment.

There are three types of corrosion inhibitors

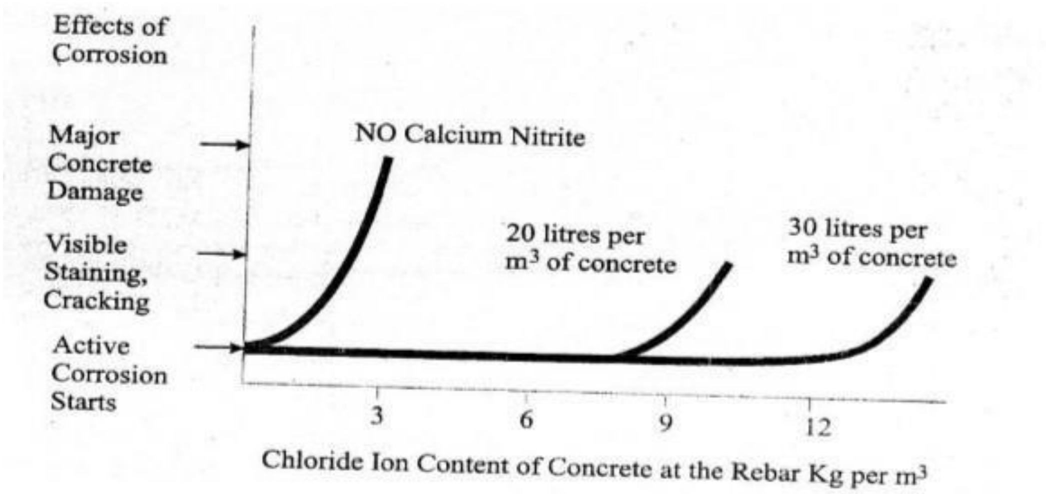
Anodic inhibitors

Cathodic inhibitors

Mixed inhibitors

- 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 is of the order of 10-30 litres per m3 of concrete, depending on the chloride levels in concrete.

- 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 finer. 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.
- 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 level of about 7 Kg of chloride iron per m3 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.



9. Cathodic 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.

3.7 EFFECT OF COVER THICKNESS AND CRACKING

In reinforced concrete structures, sufficient cover of concrete has to be provided to avoid exposure of reinforcement to aggressive environmental conditions and consequent rusting and deterioration of the cross sectional area in the structural elements. The most common construction defect, particularly in buildings, is lack of adequate thickness of cover.

It provides the nominal cover requirements to meet

- The durability requirements
- Specified period of fire resistance

Requirements of concrete cover

The protection of the steel in concrete against corrosion depends upon an adequate thickness of good quality of concrete

- ***Refer Table 16 of IS: 456-2000 which gives clear information about nominal or clear cover to be given based on exposure conditions.***
- ***Clear cover is also given based on type of structures i.e., footings, columns, beams and slabs.***

MODULE-4

Maintenance and Retrofitting Techniques

4.1 Definition

Maintenance 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.

The maintenance of structure is done to meet the following **objectives**

- Prevention of damages due to natural agencies and to keep them in good appearance and working condition.
- Repair of the defects occurred in the structure and strengthen them, if necessary.

4.2 Types of Maintenance

The Maintenance work is broadly classifies as

a) Preventive Maintenance

b) Remedial Maintenance

c) Routine Maintenance

d) Special Maintenance

a) Preventive Maintenance

- The maintenance work done before the defects occurred or damage developed in the structure is called preventive maintenance.
- It includes thorough inspection, planning the programs of maintenance and executing the work
- It depends upon the specifications, condition and use of structure.

b) Remedial Maintenance

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

- Finding the deterioration
- Determining the causes
- Evaluating the strength of the existing structure
- Evaluating the need of the structure
- Selecting and implementing the repair procedure

c) Routine Maintenance

- It is the service maintenance attended to the structure periodically.
- The nature of work done and interval of time at which it is done depends upon specifications and materials of structure, purpose, intensity and condition of use.

- It includes white washing, patch repair to plaster, replacement of fittings and fixtures, binding of road surface.

d) Special Maintenance

- It is the work done under special condition and requires sanction and performed to rectify heavy damage.
- It may be done for strengthening and updating of the structure to meet the new condition of usage or to increase its serviceability.
- It may include particular or complete renewal occurring at long interval, such as floors, roofs etc.

4.3 Necessity of Maintenance

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

a) Atmospheric agencies

b) Normal wear and tear

c) Failure of structure

a) Atmospheric agencies

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

Physical:

- Dissolving and carrying away minerals as it is universal solvent.
- Expansion and contraction – The materials is subjected to repetitive expansion and contraction while they become wet and dry and develops the stresses.
- Expansion of water – The variation of temperature causes the expansion and contraction absorbed water and affects the micro-structures of the materials.
- Erosion – Transportation, attrition and abrasion of the materials is quite evident effect of the water.

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

- **Wind:** It is the agent, which transports the abrasive material and assists the physical weathering Its action is aggravated during rains and, When it is moving with high speed, it may contains acidic gases like CO2 fumes which may act over the material and penetrates quite deeply in materials and structure.
- **Temperatur**e: The seasonal and annual variation of the temperature, difference in temperature in two parts of the materials and the surface of material causes expansion and contraction, this movement of the material bond and adhesion between them is lost when it is repeated. This responsible for the development of cracks and the rocks may break away into small units.

b) ***Normal Wear and tear: During*** the use of structure it is subjected to abrasion and thereby it loses appearance and serviceability.

c) ***Failure of structure: Failure*** is defined as the behavior of structure not in agreement with expected condition of stability or lacking freedom from necessary repair or non-compliance with desired use of and occupancy of the completed structure.

The causes of failure may be broadly grouped as:

- ✓ ***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 for which they are not designed such as deteriorating environment due to impurities from industrial fuel burning, sea water minerals, chemicals, storage of chemicals etc.
- ✓ ***Lack of maintenance***: Lack of upkeep, proper protection, precaution and preservation, deteriorated the structure, which may result in the failure.

4.4 Facts of Maintenance

Maintenance operations have many facets such as

a) **Emergency maintenance**: Necessitated by unforeseen breakdown drainage or damage caused by natural calamity like fire, floods, cyclone earthquake etc.

b) **Condition Based maintenance**: Work initiated after due inspection

c) **Fixed time maintenance**: Activities repeated at predetermined intervals of time.

d) **Preventive maintenance**: This is intended to preserve by preventing failure and detecting incipient faults (Work is done before failure takes place)

e) **Opportunity maintenance**: Work did as and when possible within the limits of operation demand.

f) Day-to-Day care and maintenance

g) **Shut down maintenance**: Thorough overhaul and maintenance after closing a facility.

h) **Improvement plans**: This is essentially maintenance operation wherein the weak links in the original construction are either replaced by new parts or strengthened.

4.5 Importance of Maintenance

- ➢ *Improves the life of structure*
- ➢ *Improved life period gives better return on investment*
- ➢ *Better appearance and aesthetically appealing*
- ➢ *Better serviceability of elements and components*
- ➢ *Leads to quicker detection of defects and hence remedial measures*
- ➢ *Prevents major deterioration and leading to collapse*
- ➢ *Ensures safety to occupants*
- ➢ *Ensures feeling of confidence on the user*

- *Maintenance is a continuous cycle involves every element of building science namely Structural, Electrical wiring Plumbing-water-supply-sanitation, Finishes in floors and walls, Roof terrace, Service platform/verandah, Lifts, Doors windows and other elements.*

4.6 Various aspects of inspection

The following are the various maintenance aspects,

a) Daily Routine Maintenance

b) Weekly Routine Maintenance

c) Monthly Routine Maintenance

d) Yearly Routine Maintenance

a) 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*

b) Weekly Routing Maintenance

- ✓ *Electrical accessories*
- ✓ *Cob webs cleaning*
- ✓ *Flushing sewer line*
- ✓ *Leakage of water line*

c) Monthly Routing Maintenance

- ✓ *Cleaning doors, windows" latches etc*
- ✓ *Checking septic tank/ sewer*
- ✓ *Observation for cracks in the elements*
- ✓ *Cleaning of overhead tanks*
- ✓ *Peeling of plaster, dampness, floor cracks*

d) Yearly Routing Maintenance

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

RETROFITTING TECHNIQUES

4.7 Need for retrofitting

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

4.8 Retrofitting of structural members

1. COLUMNS AND BEAMS BY JACKETING TECHNIQUE

- One of the simplest and most effective methods for strengthening a column is an existing building is to partially loaded the column by jacketing between floors and then insert two or more props to carry portion of the axial load.
- The props are usually rolled steel sections which may subsequently be encased in concrete to improve fire protection and appearance.

JACKETING

- Jacketing is the process of fastening a durable material over concrete and filling the gap with a grout that provides needed performance characteristics.
- Jacketing is the most popularly used method for strengthening of building columns.
- The most common types of jackets are **steel jacket, reinforced concrete jacket, fibre reinforced polymer composite jacket, jacket with high tension materials like carbon fibre, glass fibre** etc
- This restores structural values, protects the reinforcements from exposure to the harmful elements and improves the appearance of the original concrete.
- The main purposes of jacketing are:
  1. To increase concrete confinement by transverse fibre reinforcement, especially for circular Cross-sectional columns,
  2. To increase shear strength by transverse fibre reinforcement,
  3. To increase flexural strength by longitudinal fibre reinforcement provided.
- Jacketing of columns consists of added concrete with longitudinal and transverse reinforcement around the existing columns. This type of strengthening improves the axial and shear strength of

columns while the flexural strength of column and strength of the beam-column joints remain the same.

- A major advantage of column jacketing is that it improves the lateral load capacity of the building in a reasonably uniform and distributed way and hence avoiding the concentration of stiffness as in the case of shear walls.
- The jacketing of columns is generally carried out by two methods: (i) reinforced concrete jacketing and (ii) steel jacketing.
- Jacketing materials may also be secured to concrete by means of bolts, screws, nails or adhesive by bond with the existing concrete or by gravity.
- 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 or shear keys has a disadvantage in that they required drilling of holes for dowels or cutting shear keys which are costly and time consuming, and can damage the existing column.
- The expansion of collar as it slides along the roughened surfaces causes the tensioning of circular reinforcement resulting in radial compression, which provides 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.

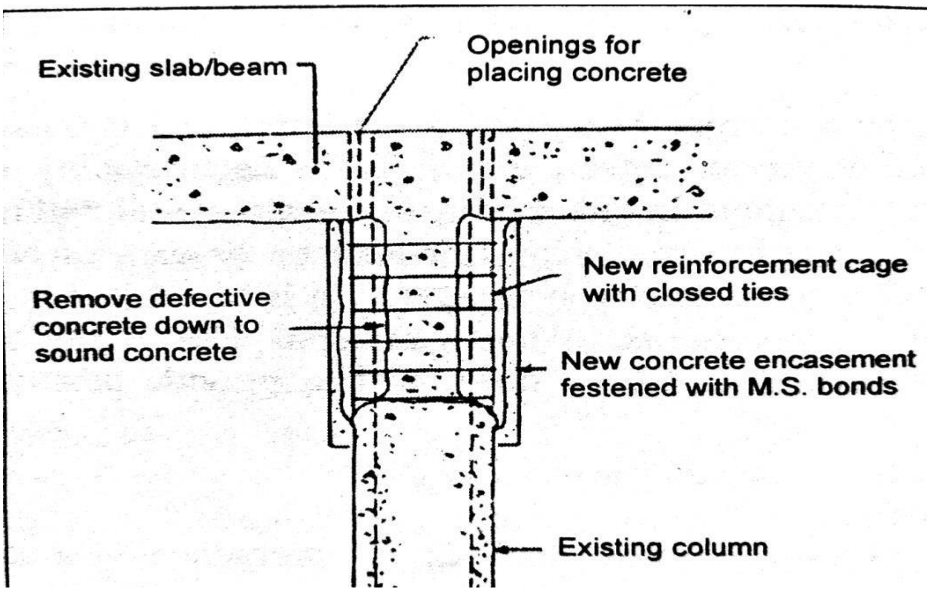


Fig 4.1: Column Jacketing

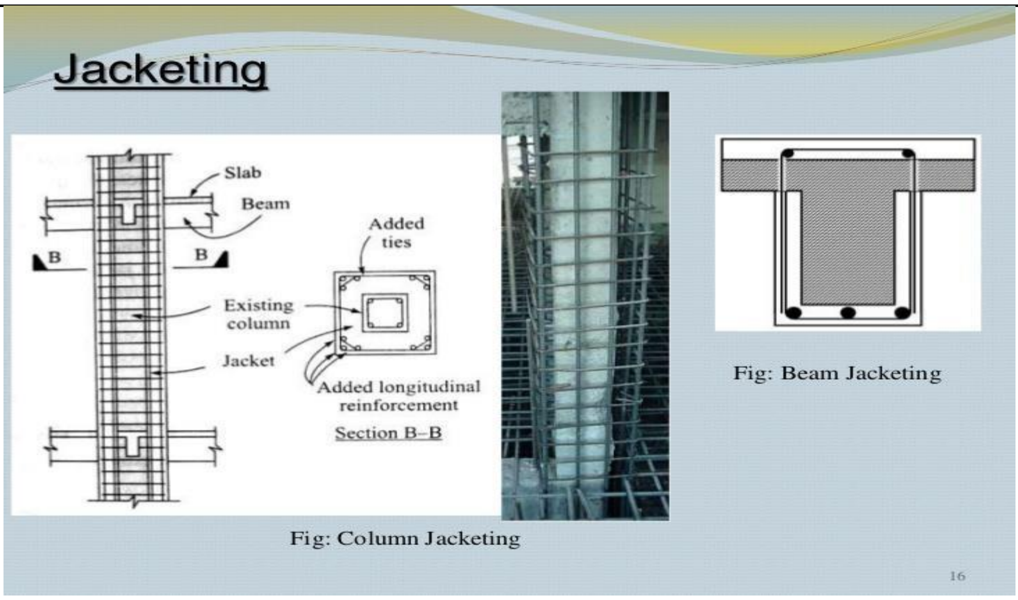


Fig: Column Jacketing

2. EXTERNAL BONDING TECHNIQUE

- Suitable laminates are pasted externally in the flexural zone to improve upon the strength and deformation characteristics of distressed structural members.
- The laminates may be fabricated from any one of the following material: Steel, Stainless steel, FRP, Ferro cement and SIFCON and SIMCON.
- The laminates are bonded to the distressed structural elements using epoxy resin.
- Design criteria suggested by researchers worked in plate bending techniques:
  - The plate or laminates width to thickness ratio should not be greater than 50.
  - The central axis depth should not be greater then 0.4 times the effective depth of member.
- **Strengthening with Externally Bonding of plates has the following limitations**
  - Difficulty in manipulating the plates in field conditions
  - Deterioration of the bend steel concrete interface
  - Lack of proper formation of joints

(a) Externally bonded mild steel plates

- The technique of gluing mild steel plates to the soffit of reinforced concrete beams and slabs can be applied to improve the structural performance of the existing structures.
- It increases the strength and rigidity and also reduces the flexural crack width in the concrete.
- The technique can be used to enhance the load carrying capacity either due to increase in load requirements or design or construction deficiencies.
- This technique has many advantages when applied to bridges.
- The plates can be easily handled and placed, this allowing the procedure to be carried out relatively quickly with minimal disruption to traffic.
- However, this technique is not recommended for application to bridges with unformed concrete or those affected by corrosion unless the source of problem is rectified.

Fig 4.2: External bonding by mils steel plates

(b) Bonded Steel Elements

- Strengthening concrete members by using bonded steel plates was developed in the 1960s.
- With this method, steel elements are glued to the concrete surface by two-component epoxy adhesive to create a composite system and improve shear or flexural strength.
- The steel elements can be steel plates, channels, angles, or built up members.
- In addition to epoxy adhesive, mechanical anchors typically are used to ensure that the steel element will share external loads in case of adhesive failure.
- The exposed steel elements must be protected with a suitable system immediately following installation and regardless of the specified corrosion protection system, its long term durability properties and maintenance requirements must be considered fully.

(c) Strengthening with FRP composites

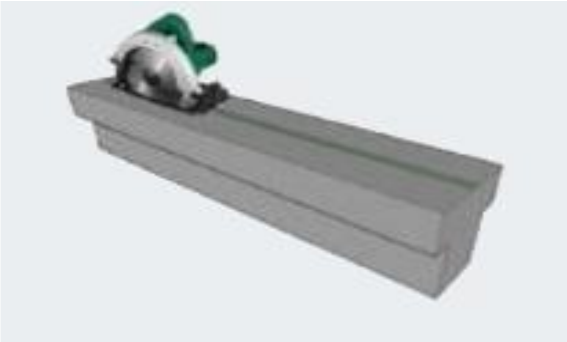
- Fiber reinforced polymer (FRP) systems are high-strength, light weight reinforcement in the form of paper thin fabric sheets, thin laminates, or bars that are bonded to concrete members with epoxy adhesive to increase their load carrying capacity.
- These systems have been used extensively in the aerospace, automotive and sport-equipment industries, and now are becoming a technology for the structural upgrade of concrete structures.
- Important characteristics of FRP's for structural repair and strengthening applications include their non-corrosive properties, speed and ease of installation, lower cost and aesthetic appeal.
- with any other externally bonded system, the bond between the FRP system and the existing concrete is critical and surface preparation is very important.

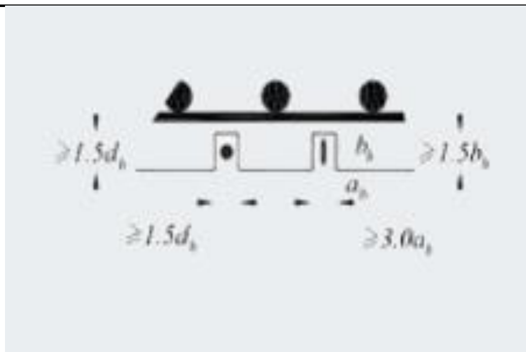
Fig 4.3: Strengthening with FRP laminates

3. NEAR SURFACE MOUNTED REINFORCEMENT

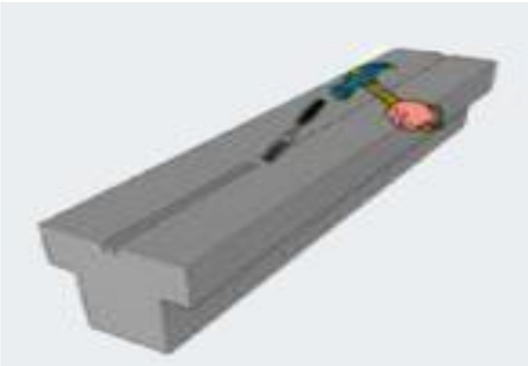
- The technique of near-surface mounted reinforcement for strengthening concrete structures is currently being developed as an alternative to externally bonded fibre composite materials.
- The process involves cutting a series of shallow grooves in the concrete surface in the required direction. (The depth of the groove must obviously be less than the cover so that the existing reinforcement is not damaged.)
- The grooves are partially filled with epoxy mortar into which pultruded carbon fibre composite rods or strips are pressed.
- The remainder of the groove is then filled with epoxy mortar and the surface levelled.
- The approach can be used to increase the flexural (bending) of beams and slabs, or the shear capacity of beams. It can also be used for strengthening concrete masonry walls.
- As the fibre composite material is embedded in the concrete, it is less susceptible to damage, for example by fire or vandalism, than material bonded to the surface.
- It is obviously very appropriate for strengthening the top surfaces of slabs, where externally bonded fibre composites would require a protective layer; damage may be caused to the composite if it is necessary to remove the protective layer at a later date.
- A further potential advantage of the technique over the use of externally bonded fibre composite is that no preparation of the concrete surface is required.
- Clearly one limitation on the technique is the need to have sufficient cover to the existing reinforcement to allow the grooves to be cut without the risk of damaging the steel.

Step 1: Grooves are cut after marking the layout as per the Engineer of Records' specifications. Generally the final groove dimension is 1.5 times the bar diameter in depth and width. Dado cuts are also effective if possible.





Step 2: Chisel any remaining concrete between cut paths.

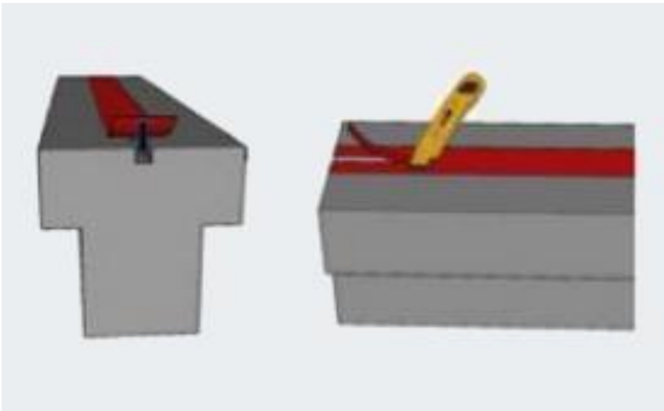


Step 3: Clean the groove and eliminate any residual dust with compressed air or vacuum.

Note: It is not necessary to roughen the interior of the groove with additional abrasion, or brushing.

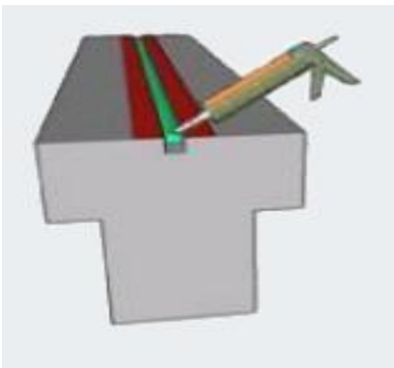
Step 4: For a clean appearance, mask the concrete adjacent to the groove.

Note: A time saving tip is to mask over the groove and then trim the masking to each edge.



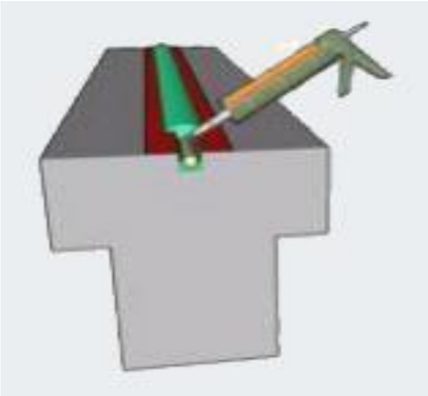
Step 5: Fill the groove approximately half way with adhesive.

Note: Consider bulk dispensing of adhesive when making your choice of adhesive for the project.

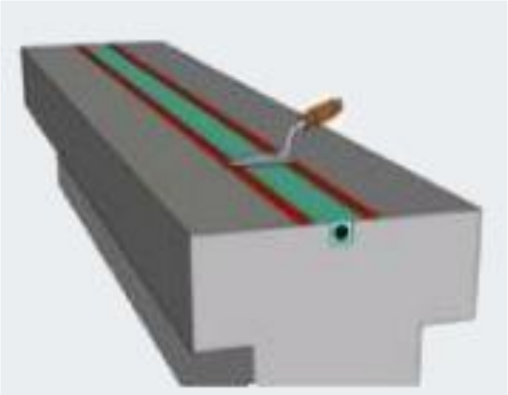


Step 6: Press bar or tape into the groove partially filled with adhesive. The objective is to ensure adhesive is well consolidated around the bar without air pockets.

Note: Some contractors have developed their own system based on epoxy crack injection methods using a low viscosity epoxy crack injection resin.

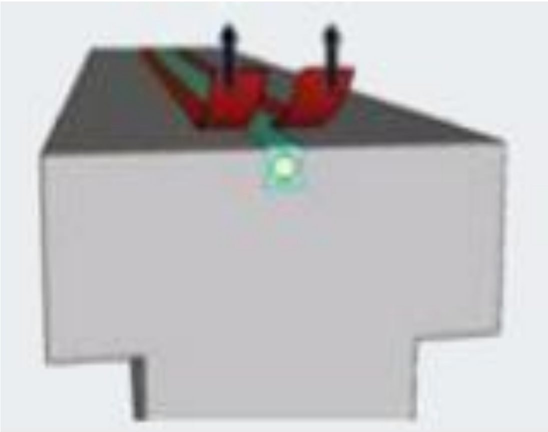


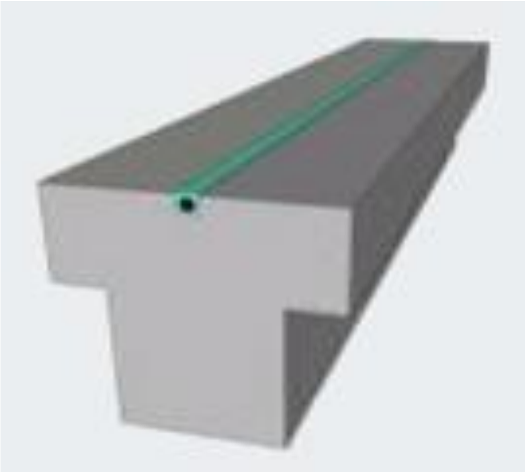
Step 7: Completely fill the groove with adhesive ensuring the bar is fully covered.



Step 9: Remove masking.

Note: pull the masking off before adhesive is fully cured.





4. EXTERNAL POST-TENSIONING

- The external post-tensioning technique has been used effectively to increase the flexural and shear capacity of both reinforced and prestressed concrete members

- With this type of upgrading, active external forces are applied to the structural member using post-tensioned cables to resist new loads.
- Because of the minimal, additional weight of the repair system, this technique is effective and economical, and has been employed with great success to correct excessive deflections and cracking in beams and slabs, parking structures and cantilevered members.
- The post-tensioning forces are delivered by means of standard prestressing tendons or high strength steel rods, usually located outside the original section.
- The tendons are connected to the structure at anchor points, typically located at the ends of the member.
- End anchors can be made of steel fixtures bolted to the structural member, or reinforced concrete blocks that are cast into place.
- The desired uplift force is provided by deviation blocks, fastened at the high or low points of the structural element.
- Prior to external prestressing, all existing cracks are epoxy injected and spalls are patched to ensure that prestressing forces are distributed uniformly across the section of the member.
- An external post-tensioning system used to strengthen prestressed double tees damaged by vehicular impact.
- Four double tee stems on an overpass located were damaged when the driver of an over-height truck failed to observe the posted height restriction.
- The four stems suffered excessive concrete cracking and spalling, and damaged occurred to some of the internal prestressing steel.
- Proposed solutions included replacing the damaged double tees with ones and installing a steel frame underneath for support.

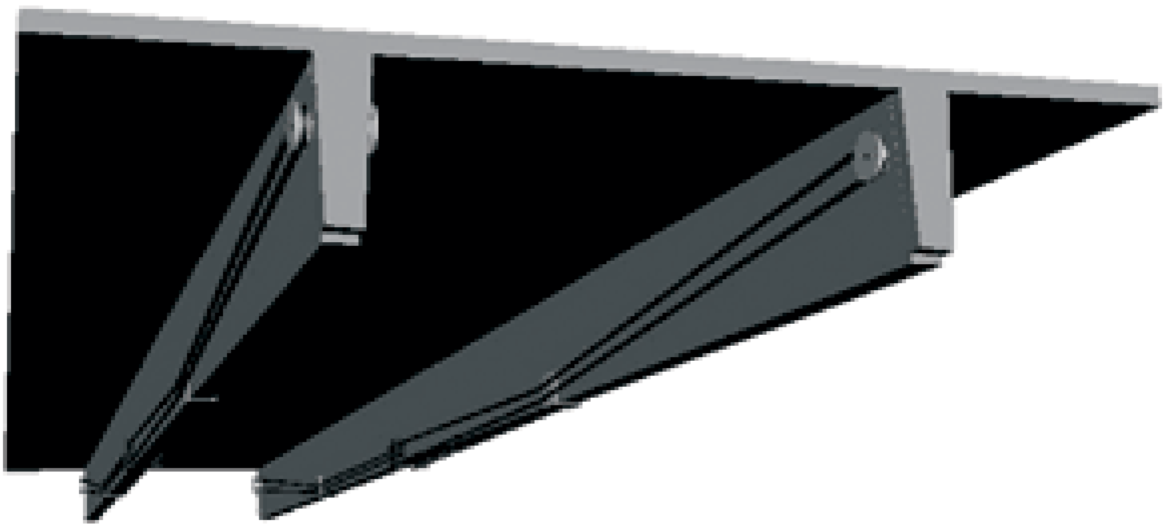


Fig 4.4: External post tensioning

5. SECTION ENLARGEMENT

- This method of strengthening involves placing additional bonded reinforced concrete to an existing structural member in the form of an overlay or a jacket.
- With section enlargement, columns, beams, slabs and walls can be enlarged to increase their load carrying capacity or stiffness.
- A typical enlargement is approximately 2 to 3 inches for slabs and 3 to 5 inches for beams and columns.
- Section enlargement used to increase the capacity of a main girder.The girder was re-evaluated because of a change in the required loading and found to be deficient in flexure and shear.
- To correct the deficiency, additional flexural and shear steel were added.
- The entire beam then was formed and a 4inch jacket of concrete was cast to enlarge the section.

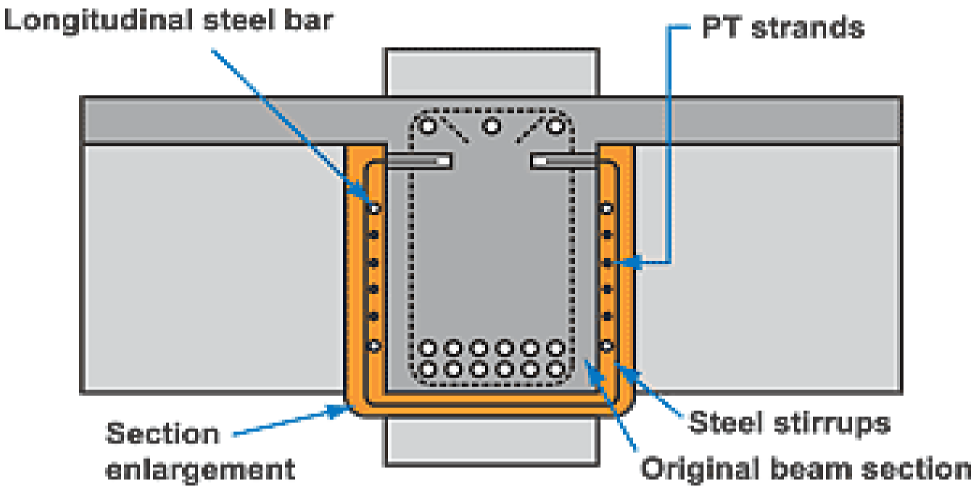


Fig 4.5: Section enlargement

4.8 Guidelines for seismic rehabilitation of existing building

1. Seismic vulnerability
2. Common seismic deficiencies
3. Strategies for rehabilitation schemes
4. Rehabilitation techniques

1. Seismic Vulnerability

- The vulnerability of a building subjected to an earthquake is dependent on seismic deficiency of that building relative to a required performance objective.
- The seismic deficiency is defined as a condition that will prevent a building from meeting the required performance objective.
- Thus, a building evaluated to provide full occupancy immediately after an event may have significantly more deficiencies than the same building evaluated to prevent collapse.
- Depending on the vulnerability assessment, a building can be condemned and demolished, rehabilitated to increase its capacity, or modified so that the seismic demand on the building can be reduced.

- Thus, structural rehabilitation of a building can be accomplished in variety of ways, each with specific merits and limitations related to improving seismic deficiencies.

2. **Common seismic deficiencies**

- Global strength
- Global stiffness
- Configuration
- Load path
- Inadequate component detailing
- Diaphragm deficiencies
- Foundation deficiencies
- Other deficiencies

Global Strength

- Global strength typically refers to the lateral strength of the vertically lateral force resisting system.
- For degrading structural systems characterized by a negative post yield slope on the pushover curve, a minimum strength requirement may apply.
- In certain cases, the strength will also affect the total expected inelastic displacement and added strength may reduce nonlinear demands into acceptable ranges.
- A deficiency in global strength is common in older buildings either due to a complete lack of seismic design or a design to an early building code with inadequate strength requirements.
- If prescriptive equivalent lateral force methods or linear static procedures have been used for evaluation, inadequate strength will directly relate to unacceptable demand to capacity ratios within elements of the lateral force resisting system.

Global stiffness

- Global stiffness refers to the stiffness of the entire lateral force resisting system although the lack of stiffness may not be critical at all levels.
- For example, in buildings with narrow walls, critical drift levels occur in the upper floors.
- Conversely, critical drifts most often occur in the lowest levels in frame buildings.
- Stiffness must be added in such a way that drifts are efficiently reduced in the critical levels.
- Although strength and stiffness are often controlled by the same existing elements or the same retrofit techniques, the two deficiencies are typically considered separately.
- Failure to meet evaluation standards is often the result of a building placing excess drift demands on existing poorly detailed components.

Load path

- A discontinuity in the load path, or inadequate strength in the load path, may be considered overarching because this deficiency will prevent the positive attributes of the seismic system from being effective.
- The load path is typically considered to extend from each mass in the building to the supporting soil.
- For example, for a panel of cladding, this path would include its connection to the supporting floor or floors, the diaphragm and collectors that deliver the load to the components of the primary lateral force resisting system (walls, frames etc.), continuity of these components to the foundation, and finally the transfer of loads between foundation and soil.

Inadequate component detailing

- Detailing, in this context, refers to design decisions that affect a component's or system's behavior beyond the strength determined by nominal demand, often in the nonlinear range.
- An example of a detailing deficiency is poor confinement in concrete gravity columns.
- Often in older concrete buildings, the expected drifts from the design event will exceed the deformation capacity of such columns, potentially leading to degradation and collapse.
- Although the primary gravity load design is adequate, the post elastic behavior is not, most often due to inadequate configuration and spacing of ties.
- Identification of detailing deficiencies is significant in selection of mitigation strategies because acceptable performance often may be achieved by local adjustment of detailing rather then by adding new lateral force-resisting elements.

Diaphragm deficiencies

- The primary purpose of diaphragms in the overall seismic system is to act as a horizontal beam spanning between lateral force resisting elements.
- Diaphragm deficiencies include such factors as inadequate shear or bending strength, stiffness or reinforcing around openings or corners.

Foundation deficiencies

- Foundations deficiencies can occur within the foundation element itself, or due to inadequate transfer mechanisms between foundation and soil.
- Element deficiencies include inadequate bending or shear strength foundations and grade beams, inadequate axial capacity or detailing of piers, and weak and degrading connections between piles, piers and caps.

- *Technical considerations*
- *Non-technical considerations*
- *Cost*

- *Seismic performance*
- *Short-term disruption of occupant*
- *Effects on long term functionality of building*
- *Aesthetics*

4. Rehabilitation techniques

- *Wood light frames*
- *Multi story, multi unit residential wood frames*
- *Steel moment frames*
- *Steel braced frames*
- *Steel frames with infill masonry shear wall*
- *Concrete moment frames*
- *Concrete shear wall buildings (Bearing wall system)*

MODULE-5

Materials for Repair and Retrofitting

5.1 FRP Composites

An FRP composite is defined as a polymer matrix which is reinforced with a fibre.

- The primary function of fibre reinforcement is to carry load along the length of the fiber and to provide strength and stiffness in one direction.
- FRP represents a class of materials that falls into a category referred to as composite materials. Composite materials consist of two or more materials that retain their respective chemical and physical characteristics when combined together.
- FRP composites are different from traditional construction materials like steel or aluminium. FRP composites are anisotropic (properties apparent in the direction of applied load) whereas steel or aluminium is isotropic (uniform properties in all directions, independent of applied load).

5.1.1 Constituents of FRP

1. Fibres

- The composite's properties are mainly influenced by the choice of fibres. In civil engineering three types of fibres are dominate. They are carbon, glass, and aramid fibres and the composite is often named by the reinforcing fibre, e.g.CFRP for Carbon Fibre Reinforced Polymer. They have different properties.
- For strengthening purposes, carbon fibres are the most suitable.
- All fibres have generally higher stress capacity than the ordinary steel and are linear elastic until failure.
- The most important properties that differ between the fibre types are stiffness and tensile strain.
- The three fibre types are schematically presented in figure in comparison with an ordinary steel bar and a steel tendon.

Types of Fibres

Artificial Fibres

1. Glass Fibre or mineral fibre
2. Aramid Fibre
3. Carbon Fibre

Natural Fibres

1. Sisal Fibre
2. Jute Fibre

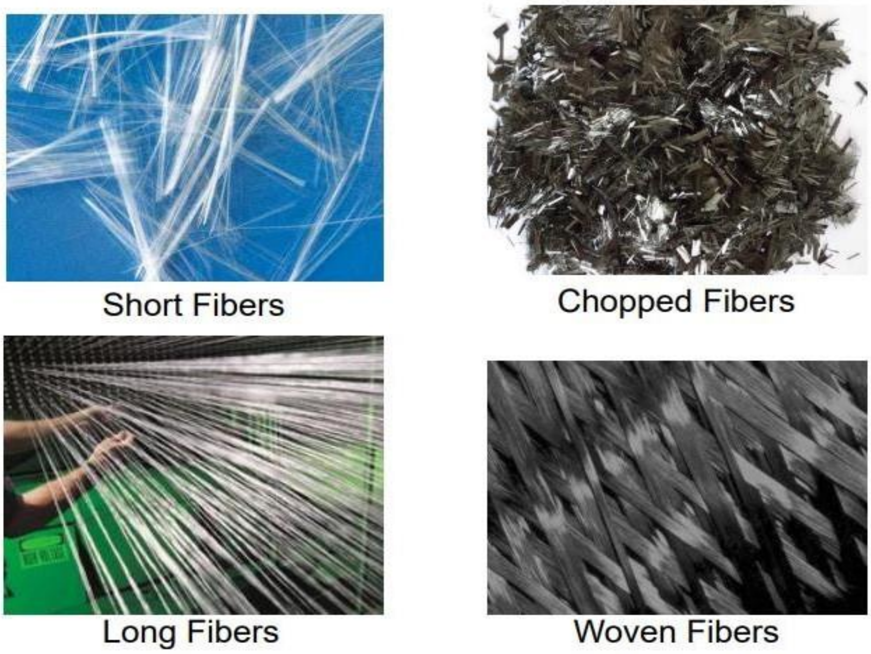


Fig 5.1: Types of fibres

2. Matrices

The matrix should transfer forces between the fibres and protect the fibres from the environment. In civil engineering, thermosetting resins (thermosets) are almost exclusively used. Of the thermo sets vinyl ester and epoxy are the most common matrices. Epoxy is mostly favoured above vinyl ester but is also more costly. Epoxy has a pot life around 30 minutes at 20degree Celsius but can be changed with different formulations. The curing goes faster with increased temperature. Material properties for polyester and epoxy are shown in table 2. Epoxies have good strength, bond, creep properties and chemical resistance.

Table 5.1: Properties of matrix materials

Resin Type	Density (kg/m^3)	Tensile Str. (MPa)	Elong. (%)	E-Mod. (GPa)
Polyester	1.2	50-65	2-3	3
Vinyl ester	1.15	70-80	4-6	3.5
Epoxy	1.1-1.4	50-90	2-8	3
Phenolic	1.2	40-50	1-2	3

TYPES OF FIBRE REINFORCED POLYMERS

The different types of fibre reinforced polymer are: glass fibre, carbon, aramid, ultra high molecular weight polyethylene, polypropylene, polyester and nylon. The change in properties of these fibres is due to the raw materials and the temperature at which the fibre is formed.

1. Glass fibre reinforced polymer

Glass fibres are basically made by mixing silica sand, limestone, folic acid and other minor ingredients. The mix is heated until it melts at about 1260°C. The molten glass is then allowed to flow through fine holes in a platinum plate. The glass strands are cooled, gathered and wound. The fibres are drawn to increase the directional strength. The fibres are then woven into various forms for use in composites.

Fig. 5.2: Glass fiber reinforced polymer sheet

Based on an aluminium lime borosilicate composition glass produced fibres are considered the predominant reinforcement for polymer matrix composites due to their high electrical insulating properties, low susceptibility to moisture and high mechanical properties. Glass is generally a good impact resistant fibre but weighs more than carbon or aramid. Glass fibres have excellent characteristics equal to or better than steel in certain forms.

2. Carbon Fibre Reinforced Polymer

Carbon fibres have a high modulus of elasticity, 200-800 GPa. The ultimate elongation is 0.3-2.5 % where the lower elongation corresponds to the higher stiffness and vice versa. Carbon fibres do not absorb water and are resistant to many chemical solutions. They with stand fatigue excellently, do not stress corrode and do not show any creep or relaxation, having less relaxation compared to low relaxation high tensile prestressing steel strands.

Carbon fibre is electrically conductive and, therefore might give galvanic corrosion in direct contact with steel.

Fig 5.3: Carbon Fibre Reinforced Polymer

3. Aramid Fibre Reinforced Polymer

Aramid is the short form for aromatic polyamide. A well known trademark of aramid fibres is Kevlar but there exists other brands too, e.g Twaron, Technora and SVM.The modulli of the fibres are 70-200 GPa with ultimate elongation of 1.5-5% depending on the quality. Aramid has a high fracture energy and is therefore used for helmets and bullet-proof garments. Aramid fibres are sensitive to elevated temperatures, moisture and ultraviolet radiation and therefore not widely used in civil engineering applications. Further aramid fibres do have problems with relaxation and stress corrosion.

ADVANTAGES OF FIBRE REINFORCED POLYMERS

The advantages of FRP are

- FRP can provide a maximum material stiffness to density ratio of 3.5 to 5 times that of aluminum or steel.
- It has high fatigue endurance limits
- It can absorb impact energies
- The material properties can be strengthened where required
- The corrosion potential is reduced
- Joints and fasteners are eliminated or simplified.

Natural Fibres

Natural fibres such as sisal, bamboo, coir and jute can be used successfully in composite components in order to realise reduction of weight and cost. These fibres are renewable, non-abrasive to Process equipment, and can be incinerated at the end of their life cycle for energy recovery as they possess a good deal of calorific value. They are also very safe during handling, processing and use. The distinctive properties of natural fibre reinforced polymers are improved tensile and bending strength, greater ductility and greater resistance to cracking and hence improved impact strength and toughness. By changing the direction of the fibres in the resin, the material properties can be tailored to the external loads.

1. Sisal

The plants look like giant pineapples, and during harvest the leaves are cut as close to the ground as possible. The soft tissue is scraped from the fibres by hand or machine. The fibres are dried and brushes remove the remaining dirt, resulting in a clean fibre. Sisal produces sturdy and strong fibres. Sisal fibre is one of the prospective reinforcing materials that its use has been more experiential than technical until now. The use of 0.2% volume fraction of 25mm sisal fibres leads to free plastic shrinkage reduction. Sisal fibres conditioned in a sodium hydroxide solution retained respectively 72.7% and 60.9% of their initial strength after 420 days. As for the immersion of the fibres in a calcium hydroxide solution, it was noticed that original strength was completely lost after 300 days. The composition of Sisal fibre is basically of cellulose, lignin and hemicelluloses. The failure strength and the modulus of elasticity, besides the lengthening of rupture, depend on the amount of cellulose and the orientation of the micro-fibres. As a natural product these characteristics have a wide variation from one plant to another. The Sisal fibres are found commercially in several formats: fabric, cords, strips, wire, rolls, etc.

Fig 5.4: Sisal Fibres production process

Properties of this fibre are as follows:

Specific gravity [Kg/m3] 1370

Water absorption [%] 110

Tensile strength [M Pa] 347-378

Modulus of elasticity [G Pa] 15

Available countries: - East Africa, Bahamas, Antiqua, Kenya, Tanzania, India

Advantages

a) They are very well resistant against moist.

b) These fibres have a good tension resistance or tensile strength.

c) They are very well resistant against heat.

d) Sisal short fibres delay restrained plastic shrinkage controlling crack development at early ages.

e) Sisal fibres conditioned in a sodium hydroxide solution retained respectively 72.7% and 60.9% of their initial strength.

Disadvantages

a) Decomposition in alkaline environments or in biological attack

Applications

a) It is mainly used for ropes, mats, carpets. and cement reinforcement

b) It is also used cement reinforcement.

c) In developing countries, sisal fibres are used as reinforcement in houses.

2. Jute Fibre

The fibres are extracted from the ribbon of the stem. When harvested the plants are cut near the ground with a sickle shaped knife. The small fibres, 5 mm, are obtained by successively retting in water, beating, stripping the fibre from the core and drying. A single jute fibre is a three dimensional composite composed mainly of cellulose, hemicelluloses, and lignin with minor amounts of protein, extractives and inorganics. These fibres were designed, after millions of years of evolution, to perform, in nature, in a wet environment. To achieve better wet ability of jute with resin and to improve strength properties, fibre pre-treatment is necessary. Simple pre-treatment is done with low-condensed resins like melamine resin, phenolic resin and CNSL modified phenol formaldehyde resin. Jute as other lignocellulosic fibres consists of –OH group which causes it susceptible to moisture and directly impairs the properties of jute composite specially dimensional stability.

Fig 5.5: Jute Fibres production process

Properties of the fibre are as follows:

Specific gravity [kg/m3] 1460

Water absorption [%] 13

Tensile strength [MPa] 400-800

Stiffness [KN/mm2] 10-30

Available countries:- India, Egypt, Guyana, Jamaica, Ghana, Malawi, Sudan, Tanzania

Advantages

a) It can withstand rotting very easily.

b) Lignocellulosic fibres are favorably bonded with phenolic resin to have better water resistance.

c) The fibres can easily withstand heat.

d) It has high tensile strength.

Disadvantages

a) Due to its short fibre length, Jute is the weakest stem fibre than other fibres.

b) Jute fibre based composites involve reactions with acetic anhydride (acetylation).

c) The fibres are biodegradable.

Applications

a) It is used as packaging material (bags).

b) It is used as carpet backing, ropes, yarns.

c) It is used for wall decoration.

5.2 ADHESIVE-Epoxy Resin

- The various adhesives used are ***epoxy, polyester, acrylic, polyurethane*** etc.
- Epoxy resin possesses very high mechanical and adhesive strength properties most desirable for civil engineering applications.
- Epoxy resin when cured with different hardness it offers a wide range of properties such as
    - High adhesive strength.
    - Low shrinkage during curing.
    - Exceptional dimensional stability.
    - Natural gap filling properties.
    - Thermosetting
    - Resistance to chemical and environment.

5.2.1 Epoxy for crack repair

- The most appropriate method of crack depends on whether crack is still actively moving or not.
- Active cracks may be due to inadequate provision of movement joint in the structure.
- The injection of low-viscosity epoxy is a possible repair method for cracks between 0.02mm to 6mm in width.

- There are wide range of low-viscosity epoxy systems and which depends upon temperature of application, capability of bonding to moist concrete, shrinkage, thermal & elastic properties of the hardened resin.

5.2.2 Epoxy mortars/Concrete

- Epoxy resin systems are superior in almost all properties to concrete. The adhesive strength of the epoxy resin is 50 times more than that of cement concrete.
- The use of epoxy in mortar is recommended only in emergency repair, since they have low modulus of elasticity and high creep than most portland cement products.
- Fillers such as flyash or silica fume are must when workability is to be improved and to minimise the use of resin.

5.3 Concrete Chemicals

An admixture is defined as a material other than water, aggregate, hydraulic cements and others, used as an ingredient of concrete or mortar and added to the batch immediately before or during mixing.

Types of chemical admixtures

1. Water Reducers- Plasticizers and superplasticizers
2. Retarders.
3. Accelerators.
4. Air entraining agents

1. Water Reducer

- Water-reducing admixtures are used to reduce the quantity of mixing water required to produce concrete of a certain slump, reduce water-cement ratio, reduce cement content, or increase slump.
- Typical water reducers reduce the water content by approximately 5% to 10%. Adding a water-reducing admixture to concrete without reducing the water content can produce a mixture with a higher slump.
- An increase in strength is generally obtained with water-reducing admixtures as the water-cement ratio is reduced.

2. Retarders

- A retarder is an admixture that slows down the chemical process of hydration so that concrete remains plastic and workable for a longer time than concrete without the retarder.
- Retarders are the chemicals that delay the setting of concrete by an hour or more.
- These are used in hot weather to counter the rapid setting caused by high temperature.
- An increase in strength is generally obtained with water-reducing admixtures as the water-cement ratio is reduced.
- The most common known retarder is calcium sulphate. It is interground to retard the setting of cement.

- Sugar is also one of the retarder.

3. Accelerators

- Accelerating admixtures are added to concrete to increase the rate of early strength development in concrete to

  · Permit earlier removal of formwork;

  · Reduce the required period of curing;

  · Advance the time that a structure can be placed in service;

  · Partially compensate for the retarding effect of low temperature during cold weather concreting;

  · Emergency repair work

- The commonly used materials as an accelerator were calcium chloride. But, now a day it is used. Instead, some of the soluble carbonates, silicates fluosilicates and some of the organic compounds such as triethnolamine are used.

4. Air entraining agents

- Air entraining agents are liquid are added during batching to produce microscopic bubbles, called entrained air
- These air bubbles improve the resistance to damage caused by freezing & thawing and deicing salt application.
- It reduces bleeding and segregation and improves workability.
- It is not necessary for interior structural concrete.
- In high cement content concretes, entrained air will reduce strength by about 5% for each 1% added but in low cement content concrete adding air has less effect and may even cause modest increase in strength.

5.4 Special Elements for Strength Gain

- In repairs of certain structures, particularly roadways and bridges, it may be desired that early strength gain should be as rapid as possible.
- Formerly high doses of 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 aluminate cement. Because of problems associated with the conversion, under hot humid conditions, of the calcium aluminate hydrates from one form 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 fluoro-aluminate. The cement meal contains a substantial amount of fluorite as a substitute for limestone. The burning process has a problem due to the release of small amounts 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 to 45 minutes.

- 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 aluminium –phosphate cements, which when used for concrete patching for pavements allow traffic flow after only 45 minutes.

5.5 Special Mortar

1. ***Cement-clay mortar:*** Here clay is introduced as an effective finely ground additive in quantities ensuring a cement-clay proportion of not over 1:1. The addition of clay improves the grain composition, the water retaining ability and the workability of mortar and also increases the density of mortar.
2. ***Lightweight and Heavy mortars***

   Light weight mortars: These are prepared form light porous sands from pumice and other fine aggregates. They are also prepared by mixing wood powder, wood shavings or saw dust with cement mortar or lime mortar. In such mortars, fibres of jute coir and hair, cut into pieces of suitable size, or asbestos fibres can also be used. These mortars have bulk density less than 15KN/m3.

   Heavy weight mortars: These are prepared from heavy quartz or other sands. They have bulk density of 15 KN/m3 or more. They are used in load bearing capacity.
3. ***Decorative mortars:*** These mortars are obtained by using- Colour cements or pigments and Fine aggregate of appropriate color, texture and surface.
4. ***Air-entrained Mortar:*** The working qualities of lean cement-sand mortar can be improved by entraining air in it(air serves as a plasticizer producing minute air bubbles which helps in flow characteristics and workability)/ The air bubbles increase the volume of the binder paste and help to fill the voids in the sand. The air entraining also makes the mortar weight and a better heat and sound insulator.
5. ***Gypsum Mortar:*** These mortars are prepared from gypsum binding materials such as building gypsum and anhydrite binding materials.
6. ***Fire Resistant Mortar:*** It is prepared by adding aluminous cement to a finely crushed power of firebricks (Usually proportion being one part of aluminous cement to two parts of powder of fire-bricks).
7. ***Sound Absorbing mortar***: These mortars may have binding materials such as cement, lime, gypsum slag etc and aggregate(light weight porous materials(such as pumice, cinders etc. The bulk density of such a mortar varies from 6 to 12KN/m3. Noise level can be reduced by using sound absorbing plaster formed with the help of sound absorbing mortar.

5.6 TECHNIQUES FOR REPAIR

1. Rust Eliminators

- Cement paste normally provides a highly alkaline environment that projects embedded steel against corrosion.
- Concrete with a low water/cement ratio, well compacted and well cured, has a low permeability and hence minimizes the penetration of atmospheric moisture as well as other components such as oxygen, chloride ion, carbon dioxide and water, which encourage corrosion of steel bar.
- In very aggressive environments, the bars may be coated with special materials developed for this purpose.
- Coating on reinforcing steel, therefore, servers as a means of isolating the steel from the surrounding environment.
- Common metallic coatings galvanizing zinc.
- High chloride concentration around the embedded steel corrodes the zinc coating, followed by corrosion of steel.
- Hence, this treatment used for moderately aggressive environments.
- For high corrosive atmospheres caused by chloride ions from the de-icing salts applied to protect against sodium chloride and calcium chloride, usually near seashores, epoxy coating is applied to protect the steel reinforcing bars from corrosion.
- Such bars have acceptable bond and creep characteristics.
- The coat normally applied is 150 mm thick.
- The reinforcement is epoxied in the factory itself, where the steel rods are manufactured. Such reinforcement is known as fusion-bonded epoxy coated steel.
- Steel manufactures also manufacture CTD bars with better corrosion resistance, termed as Corrosion resistance steel (CRS).
- The performance of the CRS CTD bars is better in resisting corrosion compared to plain CTD bars. However, the use of CRS CTD bars will only delay the process of corrosion.

2. Polymer based coating

- These are generally of two types
  - Resins blended with organic solvents
  - Solvent free coating
- Solvent based coatings are subdivided into single and two component coatings.
- The coatings on drying produce a smooth dense continuous film that provides a barrier to moisture and mild chemical attack of the concrete.
- Because of the resistance to moisture penetration, staining, and ease of cleaning, they are preferred for locations of high humidity and those in which a lot of soiling occurs.

- Most products are low solids content materials which require multiple coats to produce a continuous film over concrete, since materials are thermoplastic, and have a significant degree of extensibility they are capable of bridging minor cracks which may be develop in the concrete surface if they are applied in sufficient thickness.
- The number of coats required depends on the surface texture, porosity and the targeted dry film thickness.
- Although some of the newer products have some moisture tolerance, enabling them to be applied over damp surfaces, in normal usage they should be applied over dry surfaces.
- Due their relative in permeability to water vapor, they could blister when applied to concrete surfaces with high moisture content or where the opposite surface of the concrete is in constant contact with moisture.
- Careful control of wet film thickness is therefore necessary during application.
- Two component polymer coatings consist of a solution of a compounded polymer with or without solvent and a reactive chemical component called the curing agent hardener or catalyst.
- The materials are usually mixed just prior to use in accordance with the manufacturer's instructions.
- When using two components polymer based coatings the following items are of importance to the application of the materials.

  1. Most produces are supplied as a kit containing the two components in the required proportions. Therefore, in order to realize the full potential of the product the correct mix ratio of the two components must be used
  2. To ensure a complete reaction of the two components they must be mixed thoroughly.
  3. Some two component material require an induction period of 15 to 40 min after mixing. Therefore, such products cannot be used immediately after mixing
  4. Viscosity reduction by the use of thinners should be resorted to only after the manufacturers are consulted.
  5. The storage temperature of solvent based coatings is not critical. They should be stored are a temperature 16 to 32◦c just prior to use.

3. FOAM CONCRETE

- *Foam concrete is a type of lightweight concrete that is manufactured from cement, sand or fly ash, water, and the foam. Foam concrete is in the form of foamed grout or foamed mortar.*
- Foam concrete can also be defined as a cementitious material that consists of minimum 20 percent of foam that is mechanically entrained into the plastic mortar.
- The dry density of foamed concrete may vary from 300 to 1600 kg/m3. The compressive strength of foam concrete determined at 28 days, ranges from 0.2 to 10N/mm^2 or can go higher.

- Foam concrete is differentiated from air entrained concrete in terms of the volume of air that is entrained. The air entrained concrete takes in the air of 3 to 8 percent. It also differs from the retarded mortar and aerated concrete for the same reason of percentage of air entrained.

<u>Production of foam concrete</u>

- The production of foam concrete involves the dilution of surfactant in water, which is passed through a foam generator that will produce foam of stable form. The foam produced in mixed with the cementitious mortar or the grout, so that foamed quantity of required density is produced.
- Two main methods are used for production of foamed concrete

1. Inline Method

*T*he base mix of cement and sand is added to a unit. In this unit, the mix is blended with foam thoroughly. The process of mixing is carried out with proper control. This will help in mixing of larger quantities. The inline method comprises two processes;

- Wet Method- Inline System
- Dry Method -Inline System

***2.* Pre- Foam Method**

Here, the ready-mix truck brings the base material to the site. Through the other end of the truck, the pre- formed foam is injected into the truck, while the mixer is rotating. So, small quantities of foam concrete can be produced for small works, like for grouting or trench fill works.

<u>Composition of foam concrete</u>

- Foamed concrete composition varies with the density that is demand. Generally, the foamed concrete that has densities lesser than 600kg/m^3 will have cement, foam, water also some addition of fly ash or limestone dust.
- To achieve higher densities for foamed concrete, sand can be employed. The base mix is 1:1 to 1:3 for heavier foamed concrete, which is filler to portland cement ratio (CEM I).

<u>Materials for foam concrete</u>

1. **Cement**- 300-400kg/m3 (with fly ash blend)
2. **Pozzolana** – Fly ash or GGBS (30 to 70%)
3. **Sand** - The maximum size of sand used can be 5mm. Use of finer sands up to 2mm with amount passing through 600 micron sieve range from 60 to 95%.
4. **Foam** - The hydrolyzed proteins or the synthetic surfactants are the most common forms based on which foams are made. The synthetic based foam agents are easier to handle and are cheap. They can be stored for a longer period.

Table 5.2: Typical Properties of Foamed Concrete in its Hardened State

Dry Density Kg/m³	Compressive Strength N/mm²	Tensile Strength N/mm²	Water Absorption Kg/m²
400	0.5 – 1	0.05-0.1	75
600	1-1.5	0.2-0.3	33
800	1.5 -2	0.3-0.4	15
1000	2.5 -3	0.4-0.6	7
1200	4.5-5.5	0.6-1.1	5
1400	6-8	0.8-1.2	5
1600	7.5-10	1-1.6	5

The thermal conductivity of foam concrete ranges from 0.1W/mk to 0.7W/mk.

The drying shrinkage ranges from 0.3 to 0.07% at 400 and 1600kg/m3 respectively.

4. MORTAR & DRY PACK

- Dry pack is a combination of Portland cement and sand passing a No. 16 sieve(1.18mm) mixed with just enough water to hydrate the cement(low water cement ratio).
- Dry pack should be used for filling holes having a depth equal to, or great then, the least surface dimension of the repair area, for cone bolt, she hole, core holes, and grout-insert holes; for holes left by the removal of form ties; and for narrow slots cut for repair cracks.
- Dry pack should not be used for relatively shallow depressions where lateral restraint cannot be obtained, for filling behind reinforcement, or for filling holes that extend completely, through a concrete section.
- For the dry-pack, method of concrete repair, holes should be sharp and square at the surface edges, but corners within the holes should be rounded, especially when water tightness is required.

Preparation and Application

- Application of dry-pack mortar should be preceded by a careful inspection of the hole, which should be thoroughly cleaned and free from mechanically held loose pieces of aggregate.

- **One of three methods** should be used to ensure good bond of the dry-pack repair.
- **The first method** is the application of a stiff mortar or grout bond coat immediately before applying the dry-pack mortar. The mix for the bonding grout is 1:1 cement and fine sand mixed with water to a fluid paste consistency.
- All surfaces of the hole are thoroughly brushed with the grout, and dry packing is done quickly before the bonding grout can dry. Under no circumstances should be bonding coat be so wet or applied so heavily that the dry-pack material becomes more has slightly rubbery.
- **The second method** of ensuring good bond starts with presoaking the hole overnight with wet rags or burlap. The hole is left slightly wet with a small amount of free water on the inside surfaces. The surfaces have been covered and the free water absorbed. Any dry cement in the hole should be removed using a jet of air before packing begins. The hole should not be painted with neat cement grout because it could make the dry-pack material too wet and because high shrinkage would prevent development of the bond that is essential to a good repair.
- **A third method** of ensuring good bond is use of an epoxy bonding resin. Epoxies bond best to dry concrete. It may be necessary to dry the hole immediately prior to dry packing using hot air, a propane torch, or other appropriate method.
- The concrete temperature however should not be high enough to cause instant setting of the epoxy or to burn the epoxy when it is applied. After being mixed, the epoxy is thoroughly brushed to cover all surfaces, but any excess epoxy is removed. Dry-pack mortar is then applied immediately, before the epoxy starts to harden.

4. VACUUM CONCRETE

- *Vacuum concrete is the type of concrete in which the excess water is removed for improving concrete strength. The water is removed by use of vacuum mats connected to a vacuum pump.*
- All the water used in mixing concrete is not required for hydration. Therefore, removal of excess water before hardening take place improves concrete strength.

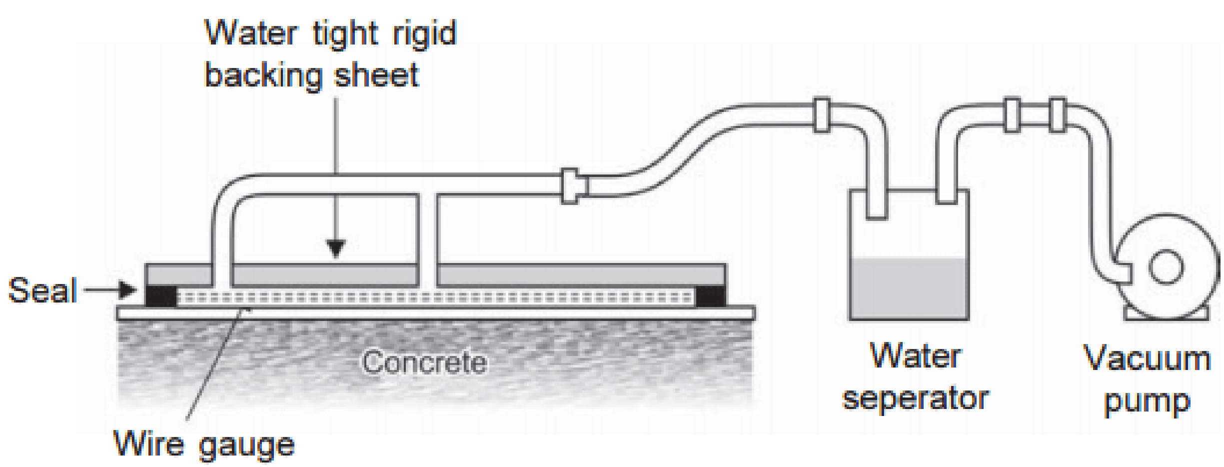


Fig 5.6: Vacuum concrete process

Procedure

In the usual manner, a concrete mix with good workability is pace in the form-works. As fresh concrete contains continues the system of water-filled channels, the application of a vacuum to the surface concrete results in a large amount of a vacuum to the surface of the concrete. This results in a large amount of water being extracted from a certain depth of the concrete. The vacuum is applied through porous mats connected to a vacuum pump. The final water cement ratio before setting is thus reduced and as this ration largely controls the strength, vacuum concrete has a higher strength and also density a lower permeability and a greater durability.

Advantages

- ✓ The final strength of concrete is increased by about 25%.
- ✓ Sufficient decrease in The permeability of concrete is sufficiently decreased.
- ✓ Vacuum concrete stiffens very rapidly so that the form-works can be removed within 30 minutes of casting even on columns of 20 ft. high.
- ✓ This is of considerable economic value, particularly in a precast factory as the forms can be reused at frequent intervals.
- ✓ The bond strength of vacuum concrete is about 20% higher.
- ✓ The density of vacuum concrete is higher.
- ✓ The surface of vacuum concrete is entirely free from pitting and the uppermost 1/16 inch is highly resistant to abrasion.
- ✓ These characteristics are of special importance in the construction of concrete structures which are to be in contact with flowing water at a high velocity.
- ✓ It bonds well to old concrete and can, therefore, be used for resurfacing road slabs and other repair works.

5. EPOXY INJECTION

- ➢ Epoxy injection is an economical method of repairing non-moving cracks in concrete walls, slabs, columns and piers and is capable of restoring the concrete to its pre-cracked strength.
- ➢ Two basic types of resin and injection techniques are used to repair concrete: epoxy resins and polyurethane resins.
- ➢ Injection of epoxies under pressure may be used to bond the **cracks having greater than or equal to 0.05mm opening**. This method is not applicable if the crack is active, the cracks are large in number, or when the water leakage can not be controlled.
- ➢ Epoxy injection is commonly used to restore the pre-cracking condition of the member without increasing its strength.

Steps

The general steps involved are as follows.

1. **Preparation of the surface:** The contaminated cracks are cleaned by removing all oil, grease, dirt and fine particles of concrete which prevent the epoxy penetration and bonding. The contaminants should preferably be removed by flushing the surface with water or a solvent. The solvent is then blown out using compressed air, or by air drying. The surface cracks should be sealed to keep the epoxy from leaking out before it has cured or gelled. A surface can be sealed by brushing an epoxy along, the surface of cracks and allowing it to harden. If extremely high injection pressures are needed, the crack should be routed to a depth of about 12mm and width of about 20mm in V-shape, filled with an epoxy, and stuck off flush with the surface.
2. **Installation of entry ports:** The entry port or nipple is an opening to allow the injection of adhesive directly into the crack without leaking. The spacing of injection ports depends upon a number of factors such as depth of crack, width or crack and its variation with depth, viscosity of epoxy, injection pressure etc. and choice must be based on experience.
3. **Mixing of epoxy:** The mixing can be done either by batch or continuous methods. **In batch mixing**, the adhesive components are premixed in specified proportions with a mechanical stirrer, in amounts that can be used prior to the commencement of curing of the material. **In the continuous mixing system**, the two liquid adhesive components pass through metering and driving pumps prior to passing through an automatic mixing head. The continuous mixing system allows the use of fast-setting adhesives that have short working life.
4. **Injection of epoxy:** In its simplest form, the injection equipment consists of a small reservoir or funnel attached to a length of flexible tubing, so as to provide a gravity head. For small quantities of repair material small hand-held guns are usually the most economical. They can maintain a steady pressure which reduces chances of damage to the surface seal. For big jobs power-driven pumps are often used for injection. It is preferable to inject fine cracks under low pressure in order to allow the material to be drawn into the concrete by capillary action and it is a common practice to increase the injection pressure during the course of work to overcome the increase in resistance against flow as crack is filled with material.
5. **Removal of surface seal:** After the injected epoxy has occurred; the surface seal may be removed by grinding or other means as appropriate. Fittings and holes at the entry ports should be painted with an epoxy patching compound.

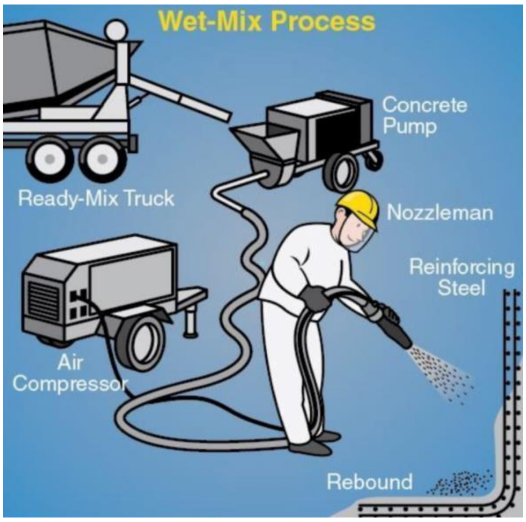
6. GUNITE or SHOTCRETE

- *Gunite can be defined as mortar conveyed through a hose and pneumatically projected at a high velocity onto a surface.*
- Recently this 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 to make the process economical by reducing the cement content.
- There is not much difference between guniting and shotcreting. Gunite was first used in the early 1900 and this process is mostly used for pneumatical application of mortar of less thickness, whereas shotcrete is a recent development on the similar principle 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.**

  1 Dry-mix Process: The dry mix process consists of number of stages and calls for some specialized plan. A typical small plant set-up is shown. 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. The wet mortar is jetted from the nozzle at high velocity onto the surface to gunited.

  2 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 a compressed air, onto the work in the same way, as that of dry-mix process.

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



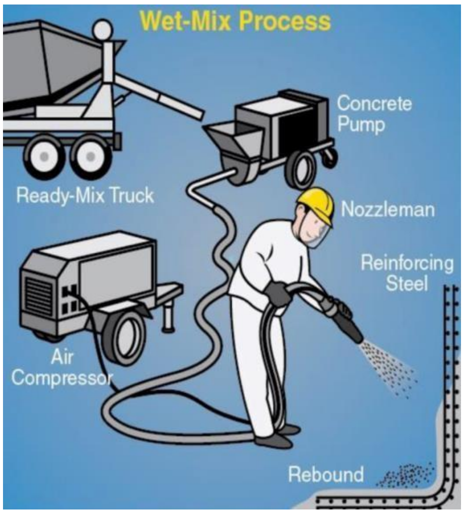


Fig 5.7: Wet and dry mix process

7. SHORING & UNDERPINING

- **Shoring** is a general term used in construction to describe the process of supporting a structure in order to prevent collapse so that construction can proceed.
- Shoring is used to support the beams and floors in a building while a column or wall is removed. In this situation vertical supports are used as a temporary replacement for the building columns or walls.
- Trenches – During excavation, shoring systems provide safety for workers in a trench and speed excavation. In this case, shoring should not be confused with shielding.
- Shoring is designed to prevent collapse where shielding is only designed to protect workers when collapses occur. concrete structures shoring, in this case also referred to as false work, provides temporary support until the concrete becomes hard and achieves the desired strength to support loads.

Shoring Techniques in Building Construction

Raking Shore

Raking Shores consist of one or more timbers sloping between the face of the structure to be supported and the ground. The most effective support is given if the raker meets the wall at an angle of 60 to 70 degrees. A wall-plate is typically used to increase the area of support.

Hydraulic Shoring

Hydraulic shoring is the use of hydraulic pistons that can be pumped outward until they press up against the trench walls. They are typically combined with steel plate or plywood, either being 1-1/8″ thick plywood, or special heavy Finland Form (FINFORM) 7/8″ thick.

Beam and Plate

Beam and Plate steel I-beams are driven into the ground and steel plates are slid in amongst them. A similar method that uses wood planks is called soldier boarding. Hydraulics tend to be faster and easier; the other methods tend to be used for longer term applications or larger excavations.

Soil Nailing

Soil nailing is a technique in which soil slopes, excavations or retaining walls are reinforced by the insertion of relatively slender elements – normally steel reinforcing bars. The bars are usually installed into a pre-drilled hole and then grouted into place or drilled and grouted simultaneously.

They are usually installed untensioned at a slight downward inclination. A rigid or flexible facing (often sprayed concrete) or isolated soil nail heads may be used at the surface.

Continuous Flight Augering

Continuous Flight Augering (CFA) is a method used to create concrete piles to support soil so that excavation can take place nearby. A Continuous Flight Augering drill is used to excavate a hole and concrete is injected through a hollow shaft under pressure as the auger is extracted. This creates a continuous pile without ever leaving an open hole.

Underpinning

Underpinning is the process of strengthening and stabilizing the foundation of an existing building or other structure.

Underpinning may be necessary for a variety of reasons:

- The original foundation is simply not strong or stable enough, e.g. due to decay of wooden piles under the foundation.
- The usage of the structure has changed.
- The properties of the soil supporting the foundation may have changed (possibly through subsidence) or were mischaracterized during planning.
- The construction of nearby structures necessitates the excavation of soil supporting existing foundations.It is more economical, due to land price or otherwise, to work on the present structure's foundation than to build a new one.
- Underpinning is accomplished by extending the foundation in depth or in breadth so it either rests on a stronger soil stratum or distributes its load across a greater area. Use of micropiles and jet grouting are common methods in underpinning.
- An alternative to underpinning is the strengthening of the soil by the introduction of a grout. All of these processes are generally expensive and elaborate.

Methods of Underpinning

Following are the different underpinning methods used for foundation strengthening:

1. Mass concrete underpinning method (pit method)
2. Underpinning by cantilever needle beam method
3. Pier and beam underpinning method
4. Mini piled underpinning
5. Pile method of underpinning
6. Pre-test method of underpinning

1. Mass Concrete Underpinning Method (Pit Method)

Mass concrete underpinning method is the traditional method of underpinning, as it has been followed by centuries. The method involves extending the old foundation till it reaches a stable stratum.

The soil below the existing foundation is excavated in a controlled manner through stages or pins. When strata suitable are reached, the excavation is filled with concrete and kept for curing, before next excavation starts.

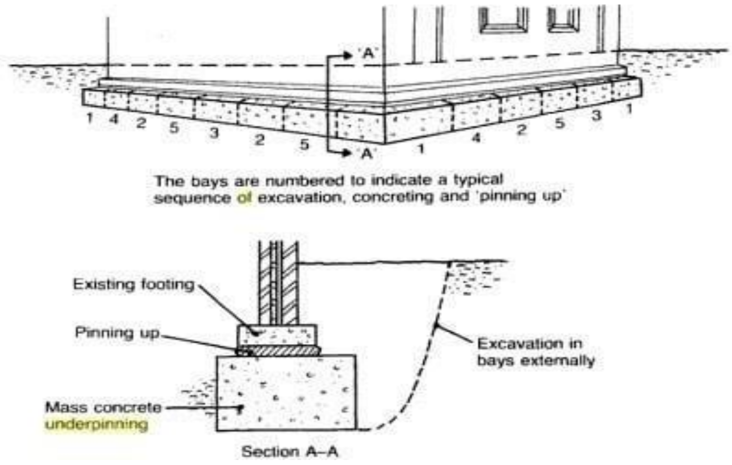


Fig 5.8: Mass concreting

2. Underpinning by Cantilever Needle Beam Method

Figure-2 represents the arrangement of cantilever pit method of underpinning, which is an extension of pit method. If the foundation has to be extended only to one side and the plan possess a stronger interior column, this method can be used for underpinning.

Advantages of Cantilever Needle Beam Method:

Faster than traditional method

One side access only

High load carrying capability

Disadvantages:

Digging found uneconomical when existing foundation is deep

Constraint in access restricts the use of needle beams

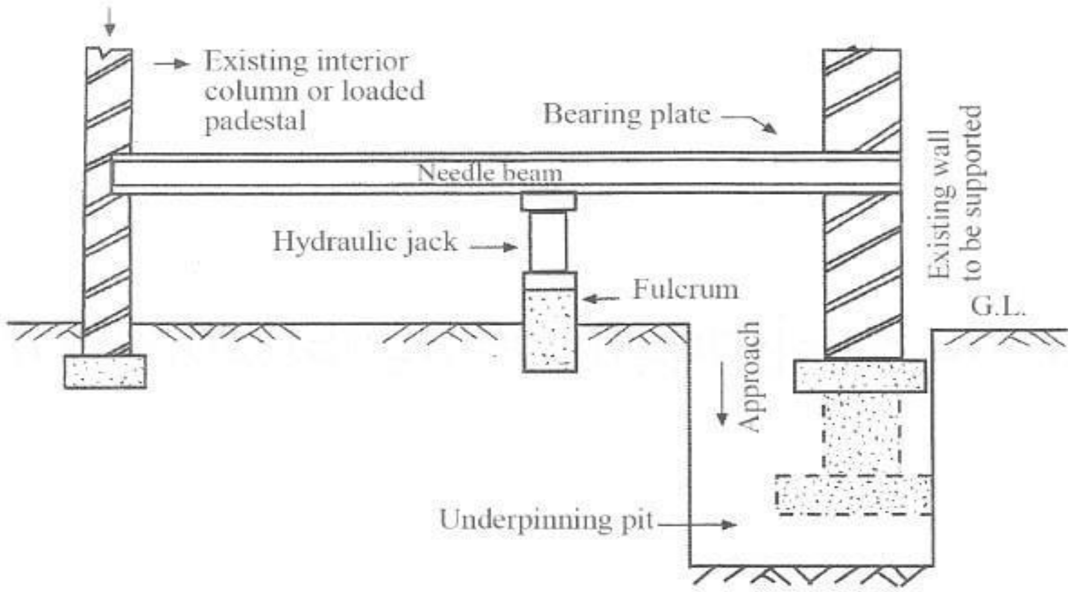


Fig 5.9: cantilever needle beam

3. Pier and Beam Underpinning Method

It is also termed as base and beam method which was implemented after the Second World War. This method progressed because the mass concrete method couldn't work well for a huge depth of foundation.

It is found feasible for most of the ground conditions. Here reinforced concrete beams are placed to transfer the load to mass concrete bases or piers as shown in figure 2.

The size and depth of the beams are based on the ground conditions and applied loads. It is found economical for depth shallower than 6m.

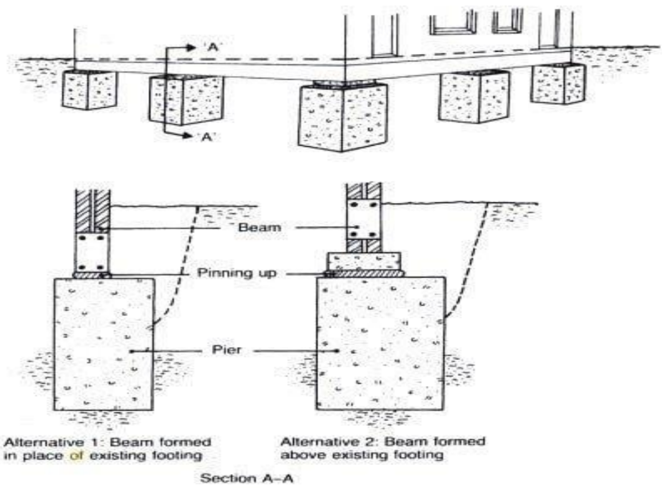


Fig 5.10: Pier method

4. Mini Piled Underpinning

This method can be implemented where the loads from the foundation have to transferred to strata located at a distance greater than 5m. This method is adaptable for soil that has variable nature, access is restrictive and causes environmental pollution problems.

Piles of diameter between 150 to 300mm in diameter is driven which may be either augured or driven steel cased ones.

5. Pile Method of Underpinning

In this method, piles are driven on adjacent sides of the wall that supports the weak foundation. A needle or pin penetrates through the wall that is in turn connected to the piles as shown in figure.

These needles behave like pile caps. Settlement in soil due to water clogging or clayey nature can be treated by this method

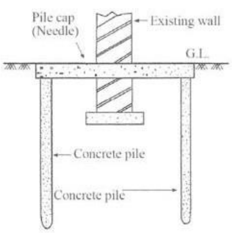


Fig 5.11: Pile method