UNIT-I

Assessment, Maintenance and Repair Strategies

Maintenance, repair and rehabilitation, Facets of Maintenance, importance of Maintenance, various aspects Inspection, Assessment procedure for evaluating a damaged structure, causes of deterioration.

1. **Maintenance:**

Maintenance is preventive in nature. Activities include inspection and works necessary to fulfil the intended function or to sustain original standard of service. The maintenance of structure is done to meet the following objective

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.

1.0.1 The Maintenance work is broadly classified 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, parch 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.

1.0.2 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 are 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 contain acidic gases like CO2 fumes which may act over the material and penetrates quite deeply in materials and structure.

Temperature: 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.

Exploitation or peeling off the shell takes place if exterior layer are heated externally with respect to internal layers. The temperature variation may also cause change in the structure and chemical composition of the material.

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. In field it may result in visual collapse of the structure or even suspension of the services e.g., the collapse of towers, sliding or over turning of dam, settlement of foundation, crushing of columns etc.

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.

1.0.3 Facets 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.

1.0.4 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

1.1 Various aspects

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 Routine Maintenance

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

c) Monthly Routine 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 Routine Maintenance

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

1.2 Repair

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

1.2.1 Stages of repair

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

a. Removal of damaged concrete
b. Pre-treatment of surfaces and reinforcement
c. Application of repair materials
d. Restoring the integrity of individual sections and strengthening of structure as a whole.

a) **Removal of damaged concrete**

1. Prior to the execution of any repair, one essential and common requirement is that the deteriorated or damaged concrete should be removed.
2. Removal of defective concrete can be carried out using tools and equipment the types of which depend on the damage.
3. Normally, removal of concrete can be accomplished by hand tools, or when that is impractical because of the extent of repair, it can be done with a light or medium weight air hammer fitted with a spade shaped bit.
4. Care should be taken not to damage the unaffected concrete portions.
5. For cracks and other narrow defects, a saw-toothed bit will help achieve sharp edges and a suitable under cut.

b) **Pre-treatment of surfaces and reinforcement**

1. The preparation of a surface/pre-treatment for repair involved the following steps: Complete removal of unsound material.
2. Undercutting along with the formation of smooth edges.
3. Removal of the cracks from the surface.
4. Formation of a well-defined cavity geometry with rounded inside corners. Providing, rough but uniform surface for repair.
5. The cleaning of all loose particles and oil and dirt out of the cavity should be carried out shortly before the repair. This cleaning can be achieved by blowing with compressed air, hosing with water, acid etching, wire brushing, scarifying or a combination. Brooms or brushes will also help to remove loose material.

c) **Application of repair materials**

1. After the concrete surface has been prepared, a bonding coat should be applied to the entire cleaned exposed surface.
2. It should be done with minimum delay.
3. The bonding coat may consist of bonding agents such ass cement slurry, cement sand mortar, epoxy, epoxy mortar, resin materials etc.
4. Adequate preparation of surface and good workmanship are the ingredients of efficient and economical repairs.

d) **Repair procedure:**

The repair of cracked or damaged structure is discussed under two distinct categories, namely, ordinary or conventional procedures; and special procedures using the latest techniques and newer materials such as polymers, epoxy resins etc.

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

1. To increase strength or restore load carrying capacity.
2. To restore or increase stiffness.
3. To improve functional performance.
4. To provide water tightness.
5. To improve appearance of concrete surface.
6. To improve durability.
7. To prevent access of corrosive materials to reinforcement.

1.2.2 Durability of concrete Repair

The objective of any repair should be to produce rehabilitation – which means a repair carried out relatively low cost, with a limited and predictable degree of change with time and without premature deterioration and/or distress throughout its intended life and purpose.

To achieve this goal, it is necessary to consider the factors affecting the durability of a repaired structural system as part of a whole, or a component of composite system. Summarized some of the findings and recommendations may be grouped into three categories:

1. Durable Repair Design
2. Durable repair application and
3. Evaluation of the repairs

1. **Durable Repair Design**

Modulus of elasticity and strength of repair material:

The modulus of elasticity of the repair material not only affects the resultant flexural stiffness of the repair members, but also the tensile stress present within the repair material and the de-bonding stress at the interface when differential movement occurs between the repair material and substance. A higher difference in modulus of elasticity between the repair material and substrate may adversely affect the stress distribution within the repaired composite materials cross section and may lead to considerable stress concentration. Therefore, the repair material selected should have as similar modulus of elasticity as the substrate as possible. Thus, considering the strength of material alone seems less fact, an overemphasis on strength may cause repairs to experience cracking arising from drying shrinkage, creep and heat of hydration.

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Coefficient of thermal expansion of repair material:

Tensile stresses in the repair material caused by changes in the temperature of the surround environment are proportional to the differences in the coefficient of thermal expansion and the change temperature. Therefore, the repair material selected should have as similar as coefficient of then expansion as the substrate as possible.

Thickness of Repair:

The internal stresses within the repair material and substrate are affected not only by differential movements, but also by the relative thickness. A thinner repair layer is more easily cracks or de-bonded by the higher tensile stress which occurs in the repair material. For most available repair materials, there seemed to be an optimum thickness of repair material which results in the lowest tense stress occurring within the repair material for a given amount of differential movement between the repair material and substrate. This optimum value is affected by the ratio of the modulus of elasticity the repair material to substrate and thickness of repair material to substrate.

Shrinkage and creep of repair material:

Differential shrinkage of the repair material and substrate is another important consideration a durable repair. The most common damages in concrete between substrate and repair materials and it proportional to the differential shrinkage. Therefore, the repair material selected should have fi shrinkage properties that are as low as possible. For the repair material under tension, creep mitigate against the tensile stresses caused by differential shrinkage. However, for the repair material under compression, creep may decrease the compressive stress within the repair material and aggravate the compressive stress in the substrate caused by the different shrinkage. The creep of the repair material should be controlled based on the state of stress that the repair material will be subjected to service.

2. **Durable Repair Application:**

Preparation of the repaired surface

The most important surface characteristics of the receiving substrate are its roughness soundness, cleanliness and moisture condition prior to application of the repair material. The first step in the repair to be carried out is the removal of the damaged concrete. It is very important to select a method most appropriate for the specific in-situ condition. Any method that weakness the sound concretes and create micro cracking should be avoided. Otherwise, the durability and bond will be decreased by these defects. Commonly used methods in-situ include: sand blasting, chipping with jack hammers, and hydro demolition among which, the last is highly recommended. A sound surface if adequate roughness can be created by this method.

Higher plastic shrinkage of the repair material near the interface should be avoided. This requires that the substrate be pre wetted for at least 7 hours prior to the application of the repair material in order to decrease the absorption and expansion of substrate caused by the uptake of moisture from the repair material. Otherwise, the higher uptake of moisture by the substrate after the repair material is cast may lead to higher plastic shrinkage of the repair material near the interface and higher expansion of the substrate, and there by resulting in the possible de-bonding of the repair material at an early age.

The application method and surface preparation are equally important considerations with regards to the performance of the repaired structures. The repair method adopted not only affects the resultant quality of the repair material, but also the quality of the interfacial transition zone, shotcrete seems to be an ideal method because it has good compatibility with the substrate concrete. Further ore, good compaction with a relatively lower water/cement ratio of the repair material can be achieved using the shotcreting process. This ensures good/high mechanical properties of the component parts and durability of the repair structure.

Bonding agents:

Use of polymer bonding agents is not recommended as their modulus of elasticity is substantially different from that of the substrate. However, use of a cementitious bonding agent with a low water/cement ratio may be considered. This type of bonding agents not only has good compatibility with the substrate and repair material, but can also alleviate the effects of differential shrinkage and thermal movement between the repair material and concrete substrate thus enhancing the bond strength and durability.

Curing of Repair Material:

Excessive loss of water may result in higher shrinkage (Plastic and drying) and cause de-bonding failure of the repair material at an earlier age. Therefore, specification of proper curing after completion of the repair is very important. Curing time should be at least the same as that adopted for usual concrete practice or in accordance to manufacturers recommendations if a commercially available material is used due to the restraint afforded by the substrate.

3. Evaluation of the Repairs

Behavior of the interfacial transition phase

The formation of the interfacial transition phase is affected by many factors. Defects such as micro-cracks and pores may be formed within this phase caused by the differential movements between the substrate and repair material and a lack of aggregate interlock action between the two materials. Its mechanical behavior and durability affect directly the performance of the repaired members in service. Thus, the mechanical properties and durability of this phase should be evaluated after the completion of the repair work.

Behavior of the repaired structure:

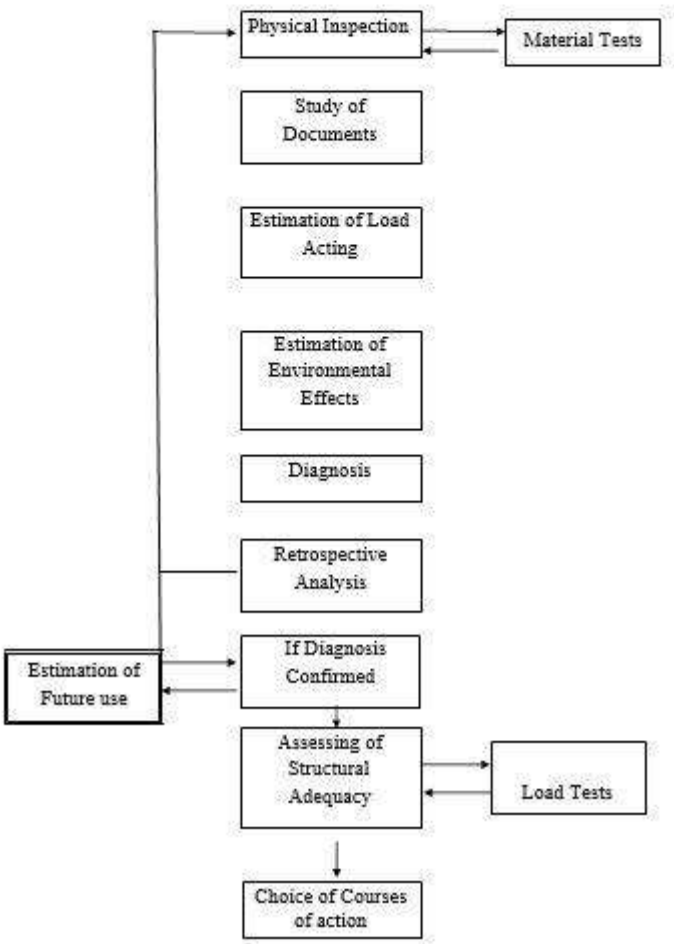
Differential movements between the repair material and they may result in the cracking of the repair material and thereby decrease the flexural stiffness and durability of the repaired members. The degradation in flexural stiffness of the required beams under static and cyclic loading was related to the appearances and development of cracks. However, the presence of steel fibers within the repair materials may improve resistance against cracking and fatigue resistance. Therefore, the flexural stiffness can be enhanced and the deflection of the repaired members reduced. At the same time, the fatigue resistance of the interface between the repair material and substrate may also be evaluated by cyclic loading test of representative samples. The test results can also form a database for the formulation of guidelines for use in practice.

1.3 Assessment Procedure for Evaluating Damages in Structure and Repair techniques:

For assessment of damage of a structure the following general considerations have to be take account.

1) Physical inspection of damaged structure.
2) Presentation and documenting the damage.
3) Collection of samples and carrying out tests both in situ and in lab.
4) Studying the documents including structural aspects.
5) Estimation of loads acting on the structure.
6) Estimate of environmental effects including soil structure interaction.
7) Diagnosis.
8) Taking preventive steps not to cause further damage.
9) Retrospective analysis to get the diagnosis confirmed.
10) Assessment of structural adequacy.
11) Estimation of future use.
12) Remedial measures necessary to strengthen and repairing the structure.
13) Post repair evaluation through tests.
14) Load test to study the behavior.

15) Choice of course of action for the restoration of structure.



Assessment Procedure of Damage

1.3.1. Testing Techniques

A number of non-destructive, partially destructive and destructive techniques for assessment of concrete structure and to predict the cause of deterioration of the concrete in the existing structures are available. Interest in the field of Non-Destructive Testing (NDT) of structure is increasing worldwide. These NDT techniques can be broadly classified into following four groups:

1.3.1.1. Strength Tests

- Schmidt Hammer Test
- Ultrasonic Pulse Velocity Pull out and Pull off Tests Break off
- Core Test
- Windsor Probe
- Pulse Eco Technique

1.3.1.2 Durability Tests

- Corrosion Tests
- Absorption and Permeability
- Test for Alkali Aggregate Reaction
- Abrasion Resistance Tests
- Rebar Locator Test

1.3.1.3 Performance and Integrity Tests

- Infrared Thermography Test
- Radar Test
- Radiography and Radiometry Tests
- Acoustic Emission
- Optical Fibre Test
- Impact Echo Tests
- Load Testing test
- Dynamic Response
- X-Ray Diffraction

1.3.1.2 Chemical Tests

Carbonation test
Sulphate Determination Test
Chloride Determination Test
Thermoluminescence Test
Thermo gravimetric analysis Test
Differential Thermal analysis

Dilatometric Test

With these tests it would be possible to know in-situ strength/quality of concrete to precise identify the damage and causes of the deterioration of the structure, to predict the residual life measures to enhance the life of the structure.

Details of few of the tests, which are commonly used in practice, are described below,

1. Schmidt Hammer Test

Schmidt Hammer Test is a quick method for assessing the quality of concrete based on hardness indicated by the rebound number. If the strength of concrete is high, then the rebound number is also high.

The principal of this test is that when the plunger of rebound hammer is pressed against surface of the concrete the spring-controlled mass rebounds and the extent of such rebound depends upon the surface hardness of the concrete. The surface hardness and therefore the rebound number is taken to be related to compressive strength of the concrete. Rebound number values also depend on angle of measurement.

2. Ultrasonic Pulse Velocity test

Ultrasonic Pulse Velocity (USPV) method is being extensively used to assess the quality concrete. This test is generally used for measurement of concrete uniformity, determination of cracking and honeycombing, and assessment of concrete deterioration. Strength estimation is qualitative assessed.

The principal of USPV measurement involves sending electro-acoustic pulse through a concrete path and measuring the transit time taken, for a known distance. Pulse velocity is then, computed. Tn pulse velocity depends mainly on elastic modulus of concrete. Any factor, which influences the modulus of elasticity of concrete, will also affect its pulse velocity. The direct method of testing is the more reliable from the point of view of transmittance measurement, as maximum pulse energy is transmitting at right angles to the face of transmitter.

3. Carbonation Test

Concrete is having micro-pores and these pores are filled with liquid, having PH –value as high 12.5. Thus, concrete is alkaline in nature. This alkaline of the concrete is due to (OH) ions in pore water, which are produced by the dissolution of $Ca(OH)_2$ from the solid phase of the cement gel into pore water and from the caustic alkalis present namely potassium and sodium oxides. Carbonation of the concrete is the reaction of $Ca(OH)_2$ with the atmospheric CO_2, and its conversion into $CaCO_3$. The reaction lowers the pH-value of the pore water to about 8.3. The outer zone of concrete is affected first out due to the passage of time; carbonation proceeds deeper into the mass as carbon dioxide diffuses inwards from the surface. If carbonation depth becomes equal to cover of concrete, steel reinforcement is then prone to corrosion damage.

By carbonation test, we measure the carbonated depth of concrete. To determine the depth of carbonation drilling of a hole is done in stages and the phenolphalein solution is sprayed in it after every stage. As soon as the color of the concrete becomes pink, drilling is stopped and the depth of the hole measured.

4. Core Test

Core test is one of the best methods to assess the strength of the concrete in reinforced concrete construction. Compression testing and petrographic examination of cores, cut from hardened concrete, is a well-established and most reliable method enabling visual inspection of the interior regions and direct estimation of the strength. The results obtained from the other nondestructive tests are generally verified using core test.

5. Rebar Locator Test

By this test, bar diameter, cover to reinforcement, spacing of reinforcement, number of reinforcing bars and any discontinuity in the reinforcing bars can be detected. This test is performed using cover meter which is based on electro-magnetic theory.

6. Chloride Determination Test

Small amount of chlorides will normally be present in the concrete. Higher amount of chlorides may give rise to potential of corrosion risk. Quantity of chlorides in the concrete is generally determined chemically and is expressed in terms of percentage of chlorides by weight of concretes.

Thermo gravimetric and Dilatometric test, differential thermal analysis tests, Thermolumine scene test etc. are some of the sophisticated tests for assessment of the residual concrete strength.

7. Thermo gravimetric and Dilatometric Tests

Thermo gravimetric and Dilatometry may be used to assess temperature attained by concrete. As the concrete undergoes irreversible chemical changes during fire there would be weight loss at about 500^0C. Using thermogravity curves the temperature attained during fire can be obtained. In dilatometric test, shrinkage of concrete due to process of dehydration is detected. By compaction expansion with temperature lines that represents dilatometric curves for fire damaged concrete and unaffected concrete, the probable temperature to which concrete was subjected can be established.

8. Thermoluminescene Test

Thermoluminescene test was proposed by placid and elaborated by chew. This method is useful in finding out the temperature history of concrete exposed to a temperature range from 300^0C to 500 ^{0}C. This method utilizes the concept that the intensity of emission of visible light on heating versus temperature curve for a particular material depends on its thermal and radiation history. Temperature versus thermoluminescence curve of the fire affected sample may be compared with that of unaffected sample for comparison of exposures to the given temperature.

9. Differential thermal Analysis Tests

Differential thermal Analysis test is based on measurement of temperature curve of the concrete samples accompanying the irreversible physic, chemical transformation at a temperature, heated in surface. This method consists of heating of sample in platinum crucible with a thermocol embedded in it. The time temperature curve of sample is compared with that of crucible containing in material or without my samples. The differential thermal analysis of concrete samples is conducted pulverized sample of mortar obtained from sound and unsound concrete with granular size of the concrete passing a sieve of 150 microns and retained on 75 microns' sieve.

Causes of Deterioration:

The following are the causes of failure of structure:

a. Occurrences incidental to construction stage. This could be attributed to
1. Local settlement of sub grade.
2. Movement of formwork.
3. Vibrations.
4. Internal settlement of concrete suspension.
5. Setting Shrinkage.
6. Premature removal forms.

b. Drying Shrinkage

c. Temperature stresses – This may be due to
1. Difference in temperatures between the inside of the building with its environment.
2. Variation in internal temperature of the building or structure.

d. Absorption of moisture by concrete

e. Corrosion of reinforcement – This could be caused by
1. Entry of moisture through cracks or pores.
2. Electrolytic action

f. Aggressive action of chemical
g. Weathering action
h. Action of shock waves
i. Erosion
j. Poor design details at
1. Re-entrant corners
2. Changes in cross section
3. Rigid joints in precast elements
4. Deflections

This lead to

1. Leakage through joints
2. Inadequate drainage
3. Inefficient drainage slopes
4. Unanticipated shear stresses in piers, columns and abutments etc.

5. Incompatibility of materials of sections

k. Errors in design
l. Errors in earlier repairs
m. Overloading
n. External influences such as
1. Earthquake
2. Wind
3. Fire
4. Cyclones etc.

Some of the major causes of deterioration of concrete structure are discussed in detail here.

Design and construction flows

Design of the concrete structures governs the performance of concrete structures. Well designed and detailed concrete structure will show less deterioration in comparison with poorly designed and detailed concrete, in the similar condition. The beam-column joints are particularly prone to defective concrete, if detailing and placing of reinforcement is not done properly. Inadequate concrete cover may lead to carbonation depth reaching upto the reinforcement, thus increasing the risk of corrosion of reinforcement.

Environmental Effects

Micro-cracks present in the concrete are the source of ingress of moisture and atmospheric carbon dioxide into the concrete which attack reinforcement and react with various ingredients of concrete. In aggressive environment concrete structures will deteriorate faster and strength life of concrete structure will be severely reduced.

Poor Quality materials

Quality of material to be used in construction, should be ensured by means of various tests as specified by the IS codes. Alkali-aggregate reaction and sulphate attack results in early deterioration. Clayey materials in the fine aggregate may weaken the mortar aggregate bond and reduce the strength. Salinity causes corrosion of reinforcement bars as well as deterioration of concrete.

Quality of supervision

Construction work should be carried out as per the standard specification. Adherence to specified water/cement ratio controls strength, permeability and durability of concrete. Insufficient vibration may result in porous and honey combed concrete, whereas excess vibration may cause segregation.

Deterioration due to corrosion

- Spalling of concrete cover
- Cracks parallel to the reinforcement
- Spalling at edges
- Swelling of concrete
- Dislocation
- Internal cracking and reduction in area of steel of reinforcement

Rehabilitation

Rehabilitation consists of restoring the structure to service level; it once had and now lost. Strengthening consists in endowing the structure with a service level higher than that initially planned by modifying the structure not necessarily damaged.

UNIT-II

SERVICEBILITY AND DURABILITY OF CONCRETE

Quality assurance for concrete – Strength, Durability and Thermal properties, of concrete Cracks, different types, causes – Effects due to climate, temperature, Sustained elevated temperature, Corrosion - Effects of cover thickness and cracking.

Quality assurances for concrete construction

Quality management ensures that every component of the structure keeps performing throughout its life span. In fact, quality is a measure of the degree of excellence and is indeed related to fulfillment enjoyed by the user. In concrete construction, even if rigid quality is not followed, the material performs for a short while without loss of strength. On account of this forgiving property of concrete, many in the construction industry have been operating under the illusion that rigid quality management, which is essential for mechanical industries, is not so important for concrete manufacture. This is not correct. The quality management in the current day context is based on the fact that the probability of failure of structure must be as low as possible and definitely lower than a prefixed accepted limit. Hence, quality management in essence is the management of uncertainties inherent in the construction industry.

Need for Quality Assurance

1. All involved with the construction and use of a concrete structure are concerned that the quality is necessary to give good performance and appearance throughout its intended life.
2. The client requires it in promoting his next engineering scheme.
3. The designer depends on it for his reputation and professional satisfaction.
4. The material producer is influenced by the quality of work in his future sales.
5. The building contractor also relies on it to promote his organization in procuring future contracts, but his task is often considerably complicated by the problems of time scheduling and costs.
6. Finally, the user is rewarded by a functionally efficient structure of good appearance. It would seem to follow therefore that since all responsible parties gain by quality it should be automatically achieved.
7. Yet this is not so, and a considerable positive effort must be employed to achieve it.
8. This effort can best be expanded by instituting a quality assurances scheme which involves each of the above parties.

   The quality management system in a true sense should have the following three components

   1) Quality assurance plan (QAP)
   2) Quality control process (QC)
   3) Quality Audit (QA)

Quality assurance plan

The following aspects should be addressed by any QAP:

- Organizational Set-up
- Responsibilities of personnel
- Coordinating personnel
- Quality control measure

- Control norms and limit
- Acceptance/rejection criteria
- Inspection program
- Sampling, testing and documentation
- Material specification and qualification
- Corrective measure for noncompliance
- Resolution of disputed/difficulties
- Preparation of maintenance record

The quality assurance plan starts right from the planning and design stage itself, and it can be defined as a procedure for selecting a level of quality required for a project.

Quality Control Plan

1. It is a system of procedures and standards by which the contractor, the product manufacture and the engineer monitor the properties of the product.
2. Generally, the contracting agency is responsible for the QC process
3. A contractor responsible for quality control incurs a cost for it, which is less than the uncontrolled cost for correcting the defective workmanship or replacing the defective material. Hence it is prudent to introduce effective quality control.

Quality Audit

1. This is the system of tracing and documentation of quality assurance and quality control program.
2. It is the responsibility of the process owner.
3. Both design and construction processes comes under this process.
4. The concept of QA encompasses the project as a whole.
5. Each element of the project comes under the preview of quality audit.

Concrete properties

Strength

Strength of concrete is one of the most important factors. Concrete is used as a structural element, and all structural uses are associated with its compressive strength. Strength of concrete is defined as the resistance that concrete provides against load so as to avoid failure. It depends on the water-cement ratio, quality of aggregates, compaction, curing etc. The primary factor that affects the strength of concrete is the quality of cement paste, which in turn, depends on the quality of water and cement used.

Sometimes it is economical to add pozzolana or use Portland pozzolana cement instead of ordinary cement concrete. Pozzolanas are materials that have little cementing value but rich with calcium hydroxide to form compounds that are cementitious. This reaction contributes to the ultimate strength and water tightness of concrete. Pozzolanas also increases the plasticity and workability of concrete. Excessive addition of pozzolanas affects durability. So, it should be used along with cement as a partial replacement or in small percentage.

Generally, construction industry needs faster development of strength in concrete so that the projects can be completed in time or before time. This demand is catered by high early strength cement, use of very low W/C ratio through the use of increased cement concrete and reduced water content. But this result in higher thermal shrinkage, drying shrinkage, modulus of elasticity and lower creep coefficients. With higher quantity of cement content, the concrete

exhibits greater cracking tendencies because of increase in thermal and during shrinkage. As the creep coefficient is low in such concrete there will not be much slope for relaxation of stresses. Therefore, high early strength concretes are more prone to cracking than moderate or low strength concrete.
Of course, the structural cracks in high strength concrete can be controlled by use of sufficient steel reinforcement. But this practice does not help the concrete durability, as provision of more steel reinforcement; will only results in conversion of the bigger cracks to smaller cracks. And these smaller cracks are sufficient to allow oxygen, carbon dioxide and moisture get into the concrete to affect the long-term durability of concrete.
Field experience have also corroborated that high early strength concrete are more cracks-prone. According to a recent report, the cracks in pier caps have been attributed to use of high cement content in concrete. Contractors apparently thought that a higher than the desired strength would speed up the construction time, and therefore used high cement content.
Similarly, report submitted by National Cooperative Highway Research Programme (NCHRP) of USA during 1995, based on their survey showed that more than, 100000 concrete bridge decks in USA showed full depth transverse cracks even before structures were less than one month old. The reasons given are that combination of thermal shrinkage and drying shrinkage caused most of the cracks. It is to be noted that deck concrete is made of high strength concrete. These concretes have a high elastic modulus at an early age. Therefore, they develop high stresses for a given temperature change or amount of drying shrinkage. The most important point is that such concrete creeps little to relieve the stresses.

Permeability

- Concrete is a permeable and a porous material. The rates at which liquids and gases can move in the concrete are determined by its permeability.
- Permeability affects the way in which concrete resists external attack and the extent to which a concrete structure can be free of leaks.
- The permeability is much affected by the nature of the pores, both their size and the extent to which they are interconnected.
- There can therefore be no one measure of porosity which fully describes the way in which the properties of concrete or of hardened cement paste are affected.
- If a material were judged, the decision would rest primarily on the choice of medium used for testing.
- For (ex) Vulcanized rubber would be found impervious and nonporous if tested with mercury, but if tested with hydrogen it would be found to be highly porous.
- Early work on the permeability of concrete was generally related to its use in dam construction.
- In 1946 Powers and Brownyard examined the permeability of cement pastes and came to the conclusion that well-cured neat paste of low w/c ratio is practically impermeable and that the permeability of cement pastes depends almost entirely on the amount of capillary water present, since the gel pores are extremely small.
- Earlier work of Ruettgers resulted that the permeability of concrete is generally much higher than the theoretical permeability owing to the fissures under the aggregate that permit the flow partially to bypass the paste and owing to the capillaries in the paste that permit the flow in the paste to bypass the gel.

The coefficient of permeability K_1 is obtained from applying Darcy's law for low velocity flow,
$(dr/dt).\ (1/A) = K_1.\ (h/L)$

dr/dt= The rate of volume flow (m^3s^{-1})
A= Area of porous medium normal to the direction of flow (M^2)
h= Drop in hydraulic head across the thickness of the medium (m).
L= Thickness of the medium (m).
K_1=Coefficient of permeability depending on the properties of the medium and of fluid (ms^{-1})

- For any set of tests, the value of K_1 depends on both the medium and the fluid and therefore represents the permeability of the medium to a specified fluid at specified temperature.
- As pointed out by the concrete society working party, a number of factors can account for widespread of permeability results for a specific w/c ratio concrete, due primarily to aspects of the test method for ex:

a) Varying and continuing hydration of the specimen.
b) Incomplete and variable initial saturation.
c) Lack of absolute water cleanliness.
d) Chemical reaction of specimen with the test fluid
e) Effect of dissolved gases where high-pressure air is used to pressurize the water.
f) Silting due to movement of fines.
g) Micro structural collapse and macroscopic instability when very high flow pressures are used.
h) Lack of attainment of steady state condition.

- The composition of the water and the presence of dissolved materials can also have a substantial effect.
- The drying was found to increase the permeability and for the particular specimens examined, drying at 79% relative humidity increased the permeability about 70-told.
- The flow tests are appropriate for testing material which has a high permeability but for concrete of low permeability a method in which the depth of penetration is measured is usually a core practical proposition.
- The water tightness of a concrete structure is not determined by the permeability of the hardened cement paste or even by the measure permeability of laboratory specimens of the concrete.

- The permeability of concrete, both to moisture and to gas is important in relation to the protection afforded to embedded steel.
- The initial surface absorption test measures the rate at which water is absorbed in to the surface of the concrete for a brief period under a head of 200 mm.
- The Figg test subsequent modifications of its measure the permeability of the concrete at the bottom of a fine hole drilled to some depth below the concrete surface.
- The depth to which water which is absorbed into concrete under little head has been shown to be initially a linear function of the square-root of time.
- The slope of this function is called Sorptivity. The sorptivity is a measure for assessing the protection that will be an afforded to embedded reinforcing steel, particularly after it has become activated.
- Penetration of concrete by materials in solution may adversely affect its durability.
- For instance, when $Ca(OH)_2$ is being leaching out or an attack by aggressive liquids takes place.
- This penetration depends on the permeability of the concrete. Since permeability determines the relative ease, with which concrete can become saturated with water, permeability has an important bearing on the vulnerability of concrete to frost.

- Furthermore, in case of reinforced concrete, the ingress of moisture and of air will result in the corrosion of steel. Since this leads to an increase in the volume of the steel, cracking and spalling of the concrete cover may well follow.
- The high permeability of concrete in actual structures is due to the following reasons:
- The large micro cracks with generated time in the transition zone. Cracks generated through higher structural stresses.
- Due to volume change and cracks produced on account of various minor reasons.
- Existence of entrapped air due to insufficient compaction.

Thermal Properties

- Concrete is a material used in all climatic regions for all kinds of structures.
- Thermal properties are important in structures in which temperature differentials occur including those due to solar radiation during casting and the inherent heat of hydration.
- Knowledge of thermal expansion is required in long span bridge girders, high rise buildings subjected to variation of temperatures, in calculating thermal strains in chimneys, blast furnace and pressure vessels, in dealing with pavements and construction joints, in dealing with design of concrete dams and in host of other structures where concrete will be subjected to higher temperatures such as fire, subsequent cooling, resulting in cracks, loss of serviceability and durability.
- The thermal properties of concrete are more complex than those of most other materials because these are affect ted by moisture content and porosity.
- Three types of tests are commonly used to study the effect of transient high temperature on the stress-strain properties of concrete under compression. These are the following,
- Unstressed Tests: Where specimens are heated under no initial stress and then loaded until the point of failure.
- Stressed Tests: Where a fraction of the compressive strength capacity at room temperature is applied and sustained during heating. When the target temperature is reached, the load is increased until the point of failure.
- Residual Unstressed Tests: Where the specimens are heated without any load, cooled to room temperature, and then loaded until the point of failure.

To study about the thermal properties of concrete the following properties needs to be known,

- Thermal conductivity
- Thermal diffusivity
- Specific heat
- Coefficient of thermal expansion

Thermal Conductivity:

•This measures the ability of material to conduct heat.

•Thermal conductivity is measured in joules per second per square meter of area of body when the temperature deference is 1^0C per meter thickness of the body.

•The conductivity of concrete depends on type of aggregate, moisture content, density and temperature of concrete. When the concrete is saturated, the conductivity ranges generally between about 1.4 and 3.4 j/m^2s ^{0}C/m.

Thermal Diffusivity:

•Diffusivity represents the rate at which temperature changes within the concrete mass.

•Diffusivity is simply related to the conductivity by the following equation.

Diffusivity = Conductivity/CP

•Where C is the specified heat and P is the density of concrete. The range of diffusivity of concrete is between 0.002 to 0.006 m^2/h.

Specific Heat:

•It is defined as the quantity of heat required to raise the temperature of a unit mass of a material by one degree centigrade. The common range of values for concrete is between 840 and 1170 j/kg per ^{0}C.

Coefficient of thermal expansion:

•Coefficient of thermal expansion is defined as the change in length per degree change of temperature.

•In concrete it depends upon the mix proportions. The coefficient of thermal expansion of hydrated cement paste varies between $11*10^{-6}$ and $20*10^{-6}$ per ^{0}C.

•Coefficient of thermal expansion of aggregate varies between $5*10^{-6}$ and $12*10^{-6}$ per ^{0}C.

•Limestone and gabbors will have low values and quartzite will have high values of coefficient of thermal expansion.

•Therefore, the kind of aggregate and content of aggregate influences the coefficients of thermal expansion of concrete.

Cracking

Plastic shrinkage cracks

•Water from fresh concrete can be lost by evaporation, absorption of sub grade, formwork and in hydration process.

•When the loss of water from the surface of concrete is faster than the migration of water from interior to the surface dries up.

• This creates moisture gradient which results in surface cracking while concrete is still in plastic condition.

•The magnitude of plastic shrinkage and plastic shrinkage cracks are depending upon ambient temperature, relative humidity and wind velocity.

Rate of evaporation of water in excess of 1 kg/m^2 per hour is considered critical. In such a situation the following measures could be taken to reduce or eliminate plastic shrinkage cracks.

- Moisten the sub grade and formwork
- Erect temporary wind breakers to reduce the wind velocity over concrete.
- Erect temporary roof to protect concrete from hot sun.
- Reduce the time between placing and finishing. If there is delay cover the concrete with polyethylene sheets.
- Minimize evaporation by covering concrete with burlap, fog spray and curing compound.

- Plastic shrinkage cracks are very common in hot weather conditions in pavements floor and roof slab concrete.
- Once they are forms it's difficult to rectify. In case of prefabricated units, they can be heated by controlled revibration, if the concrete is in plastic condition.
- In roof and floor slab it is difficult to repair. However, sometimes, thick slurry is poured over the cracks and well worked by trowel after striking each side of the cracks to seal the same.
- The best way is to take all precautions to prevent evaporation of water from the wet concrete, finish it fast, and cure it as early as feasible.
- In Mumbai – Pune express highway, the fresh concrete is protected by 100-meter-long low tent erected on wheel to break the wind and also to protect the green concrete from hot sun.
- In addition, curing compound is sprayed immediately after finishing operations.

Settlement Cracks

•If the concrete is free to settle uniformly, then there is no crack. If there is any obstruction to uniform settlement by way of reinforcement or larger piece of aggregate, then it creates some voids or cracks.

•This is called settlement cracks. This generally happens in a deep beam.

•Concrete should be poured in layers and each layer should be properly compacted.

•Building up of large quantity of concrete over a beam should be avoided.

•Sometimes, the settlement cracks and voids are so severe it needs grouting operators to seal them off.

•Re-vibration, if possible is an effective step. Otherwise, they affect the structural integrity of the beam or any other member and badly affect the durability.

Bleeding

•Shrinkage of concrete is one of the important factors contributing to lack of durability of concrete.

•Shrinkage is mainly responsible for causing cracks of larger magnitude or minor micro cracks.

•The aspect of cracking in concrete is very complex, involving many factors such as magnitude of shrinkage, degree of restraint, extensibility of concrete, extent of stress relaxation by creep and at what age the shrinkage is appearing etc.

•Cracks can be avoided only if the stress induced by shrinkage strain, after relaxation by creep, is at all-time less than the tensile strength of concrete.

•The above situation is not happening in most of the cases and as such generally shrinkage causes cracks in concrete.

Durability:

•Durability of concrete may be defined as the ability of concrete to resist weathering action, chemical attack, and abrasion while maintaining its desired engineering properties.

•Different concretes require different degrees of durability depending on the exposures environment and properties desired.

•For example, concrete exposed to tidal seawater will have different requirements than an indoor concrete floor.

•Concrete ingredients, their proportioning, interactions between them, placing and curing practices, and the service environment determine the ultimate durability and life of concrete.

Some important degradation mechanisms in concrete structures include the following:

1. Freeze-thaw damage (physical effects, weathering).
2. Alkali-aggregate reactions (chemical effects).
3. Sulphate attack (chemical effects).
4. Microbiological induced attack (chemical effects).
5. Corrosion of reinforcing steel embedded in concrete (chemical effects). a) carbonation of concrete
b) chloride induced.
6. Abrasion (physical effects).
7. Mechanical loads (physical effects).

Effect of freezing and thawing:

The most severe climate attack on concrete occurs when concrete containing moisture is subjected to cycles of freezing and thawing.

The capillary pores in the cement are of such a size that water in them will freeze when the ambient temperatures is below 0^0C.

The gel pores are so small that water in them does not freeze at normal winter temperatures.

As water when freezing expands by 9% of its volume, excess water in the capillaries has to move.

Since the cement paste is relatively impermeable, high pressures are necessary to move the excess water even over quite small distance.

For normal strength concrete it has been found that movement of the order of 0.2mm is sufficient to require pressures which approach the tensile strength of the paste.

Concrete can be protected from freeze – thaw damage, by the entrainment of appropriate quantities of air distributed through the cement paste with spacing between bubbles of not more than about 0.4mm.

The air bubbles must remain partially empty so that they can accommodate the excess water moved to them.

This will generally be the case since the bubbles constitute the coarsest pore system and are therefore the first to lost moisture as the concrete dries.

Fully saturated concrete, if permanently submerged, will not need protection against freezing, but concrete which as been saturated and is exposed to freezing, as for example in the tidal range, may not be effectively protected by air-entrainment.

Effect of Temperature:

The temperature difference within a concrete structure, result in differential volume change.

When the tensile strain due to differential volume change exceeds the tensile strain capacity of concrete, it will crack.

The temperature differentials associated with the hydration of cement, affect the mass concrete such as in large columns, piers, footings, dams etc. Whereas the temperature differentials due to changes in the ambient temperature can affect the whole structure.

The liberation of the heat of hydration of cement causes the internal temperature of concrete to rise during the initial curing period, so that is is usually slightly warmer than its surroundings.

In thick sections and with rich mixes the temperature differential may be considerable. As the concrete cools it will try to contract.

Any restraint on the free contraction during cooling will result in tensile stresses which are proportional to the temperature change, coefficient of thermal expansion, effective modulus of elasticity and degree of restraint.

The more massive the structure, the greater is the potential for temperature differential and degree of restraint.

Thermally induced cracking can be reduced by controlling the maximum internal temperature, delaying the onset of cooling by insulating the formwork and exposed surfaces, controlling the rate of cooling, and increasing the tensile strain capacity of the concrete.

Special precautions need to be taken in the design of structures in which some portions are exposed to temperature changes while the other portions of structures are either partially or completely protected.

A drop in temperature may result in the cracking of the exposed element while increase in temperature may cause cracking in the protected portion of the structure.

Temperature gradients cause deflection and rotation in structural members; if these are restrained serious stresses can result.

Allowing for movement by using properly designed contraction joints and correct detailing will help alleviate these problems. If the cracks do form.

Remedial measures are similar to those for cracks that form after a structure in service.

Effect of chemical:

The most important constituent of concrete namely cement is alkaline; so it will react with acids or acidic compounds in presence of moisture, and in consequence the matrix becomes weakened and its constituents may be leached out. The concrete may crack, as a result of expansive reactions between aggregate containing active silica and alkalies derived from cement hydration, admixture or external sources (e.g. curing water, ground water, alkaline solutions stored). The alkali – silica reaction results in the formation of a swelling gel, which tends to draw water from other portions of concrete. This causes local expansion nd accompanying tensile stresses which if large may eventually result in the complete deterioration of the structure. Control measures include proper selection of aggregate, use of low-alkali cement and use of pozzolana.

Typical symptoms in unreinforced and highly reinforced concrete are *map cracking*, usually in a rough hexagonal mesh pattern and gel excluding from cracks.

The alkali-carbonate reactions occur with certain limestone aggregate and usually results in the formation of alkali-silica product between aggregate particiles and the surrounding cement paste. The problem may be minimized by avoiding reactive aggregate, use of smaller size aggregate and use of low-alkali cement.

When the sulphate bearing waters come in contact with the concrete, the sulphate penetrates the hydrated paste and reacts with hydrated calcium aluminate to form calcium suphoaluminate with a subsequent large increase in volume, resulting in high tensile stresses causing the deterioration of concrete. The blended or pozzolana cements impart additional resistance to sulphate attacks.

The calcium hydroxide in hydrated cement paste will combine with carbon dioxide in the air to form calcium carbonate which occupies smaller volume tan the calcium hydroxide resulting called *carbonation shrinkage*. This situation may result in significant surface grazing and ay be especially serious on freshly placed concrete surface kept warm during winter by improperly vented combustion heaters.

Factors which increase concrete vulnerability to external chemical attacks are,

1. High porosity
2. High permeability and absorption resulting from too high W/C ratio.
3. Unsatisfactory grading of aggregate.
4. Cement compaction.
5. Improper choice of cement type for condition of exposure.
6. Inadequate curing period.
7. Exposure to alternate cycles of wetting and drying and to the lesser extended of heating and cooling.
8. Increased fluid velocity which may bring about both replenishment of the aggressive species and increases in the rate of leaching.
9. Suction forces which may cause by drying on one or more faces of a section.
10. Unsatisfactory choice of shape and surface to volume ratio of concrete structure.

Effect of Corrosion:

Formation of white patches

CO_2 reacts with $Ca(OH)_2$ in the cement paste to form $CaCO_3$. The free movement of water carries the unstable $CaCO_3$ towards the surface and forms white patches. It indicates the occurrences of carbonation.

Brown patches along reinforcement

When reinforcement starts corroding, a layer a ferric oxide is formed. This brown product resulting from corrosion may permeate along with moisture to the concrete surface without cracking of the concrete.

Occurrence of cracks

The increase in volume exerts considerable bursting pressure on the surrounding concrete resulting in cracking. The hair line crack in the concrete surface lying directly above the reinforcement and running parallel to it is the positive visible indication that reinforcement is corroding. These cracks indicate that the expanding rust had grown enough to split the concrete.

Formation of multiple cracks

As corrosion progresses, formation of multiple layers of rust on the reinforcement which in turn exert considerable pressure on the surrounding concrete resulting in widening of hair cracks. In addition, a number of new hair cracks are also formed. The bond between concrete and the reinforcement is considerably reduced. There will be a hollow sound when the concrete is tapped at the surface with a light hammer.

Snapping of bars

The continued reduction in the size of bars results in snapping of the bars. This will occur in ties/stirrups first. At this stage, size of the main bars is reduced.

Buckling of bars and bulging of concrete

The spalling of the cover concrete and snapping of ties causes the main bars to buckle. This results in bulging of concrete in that region. This follows collapse of the structure. When corrosion of reinforcement starts, the deterioration is usually slow but advances in geometrical progression. Corrosion can also cause structural failure due to reduced C/S and hence reduced load carrying capacity. It is possible to arrest the process of corrosion at any stage by altering the corrosive environment in the vicinity of the reinforcement.

Design Errors and Construction Errors:

Design Errors

Design errors may be divided into two general types:

1. Those resulting from inadequate structural design
2. Those resulting from lack of attention to relatively minor design details. Each of the two types of design errors is discussed below.

(1) Inadequate structural design.

a. **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.

b. **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.

To identify inadequate design as a cause of damage, the locations of the damage should be compared to the types of stresses that should be present in the concrete. For example, if spalls are present on the underside of a simple-supported beam, high compressive stresses are not present and inadequate design may be eliminated as a cause. However, if the type and location of the damage and the probable stress are in agreement, a detailed stress analysis will be required to determine whether inadequate design is the cause. Laboratory analysis is generally not applicable in the case of suspected inadequate design. However, for rehabilitation projects, thorough petro graphic analysis and strength testing of concrete from elements to be reused will be necessary.

c. **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. In other cases, poor design detailing may simply allow water to pond on a structure, resulting in saturated concrete. In general, poor detailing does not lead directly to concrete failure; rather, it contributes to the action of one of the other causes of concrete deterioration described in this chapter. Several specific types of poor detailing and their possible effects on a structure are described in the following paragraphs. In general, all of these problems can be prevented by a thorough and careful review of plans and specifications for the project. In the case of existing structures, problems resulting from poor detailing should be handled by correcting the detailing and not by simply responding to the symptoms.

(a) Abrupt changes in section.

Abrupt changes n 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 or in staining and encrustations on 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.

(i) Unanticipated shear stresses in piers, columns, or abutments.

Through lack of maintenance, expansion bearing assembles are allowed to become frozen, horizon-tal loading may be transferred to the concrete elements supporting the bearings. The result will be cracking in the concrete, usually compounded by other problems which will be caused by the entry of water into the concrete.

Construction Errors:

Failure 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. Each error will be briefly described along with preventative methods. In general, the best preventive measure is a thorough knowledge of what these construction errors are, plus an aggressive inspection program. It should be noted that errors of the type described in this section are equally as likely to occur during repair or rehabilitation projects as they are likely to occur during new construction.

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 cavitation's 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. Obviously, all of these defects make it much easier for any damage-causing mechanism to initiate deterioration of the concrete.

Frequently, a fear of “over-consolidation” is used to justify a lack of effort in consolidating concrete. Over-consolidation is usually defined as a situation in which the consolidation effort causes all of the coarse aggregate to settle to the bottom while the paste rises to the surface. If this situation occurs, it is reasonable to conclude that there is a problem of a poorly proportioned concrete rather than too much consolidation.

(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.

(i) Settling of subgrade.

If there is any settling of the subgrade during the period after the concrete begins to become rigid but before it gains enough strength to support its own weight, cracking may also occur.

(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 amouts of water, cement, and admixtures in the mixture but primarily on the temperatures of the concrete surface. On a partially shaded slab, the part in the sun will usually be ready to finish before the part in the shade.
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.

Effect of Cover Thickness

There is a substantial experience which relates durability and the amount of water. The thicker the cover over the steel is, the longer it will take the chloride ions to reach the steel and reduce the pH and passivity provided by the cement. However, excessive cover can led to the development of a few wide cracks under overstress, whereas a thinner cover results in many small cracks.

As opposed to the above mentioned facts, which appear to justify the rigid rules on cover, are the fallowing facts.

Ships built during World War I and II had covers of only about 20mm, yet they did not suffer corrosion steel.

In the erstwhile USSR, many floating dry-docks have been built with covers of 15 and 20mm with highly successful durability over many years of adverse exposure.

It is confirmed opinion that the impermeability of the cover is of major importance. The thickness should be related to the steel bar diameter and the maximum size of the coarse aggregate.

The general factors affecting permeability, such as cement content, water/cement ratio, compaction and consolidation of the concrete, and curing are important. While many fee that pre-stressing steel should have a greater cover than non-stressed steel, because of the more serious consequences of corrosion. Pre-stressed concrete pilling by hundreds of thousands are rendering completely successful service with only 4-6cm of cover. Other factors affecting cover are the tolerances of placement of steel and forms, and the depths of honeycombs and bug holes and other surface defects.

Lack of adequate cover contributes much to corrosion in an aggressive environment. A well compacted and continuous, even if thin, cover of good quality concrete on reinforcement is sufficient to protect it from corrosion. The following are the reinforcement thickness of covers for various levels of exposure.

For normal exposure: At least 50mm thickness
For moderate exposure: At least 40mm thickness
For mild exposure: At least 30mm thickness
For normal exposure: At least 20mm thickness

Cover Meter

When a metallic object is placed in the varying magnetic field of coil, the field induces eddy currents in the object. These eddy currents in turn produce an additional magnetic field in the vicinity of the magnetic object. A magnetic field gets superimposed and the magnetic field near the coil also gets modified in the presence of metal. This modification has the same effect as would be obtained if the characteristic of the coil itself had been changed. The change depends upon the electrical conductivity, dimension, magnetic permeability, presence of discontinuity such as crack, frequency of the field of the coil, size and shape of the coil, and the distance of the coil from the metallic object.

It is possible to measure the cover thickness for a known diameter by keeping all other parameters constant. By placing the soil at two different distances from the rebar, both the cover thickness and the diameter of the rebar can be found.

2.6 Effect of Cracking

The formation of cracks is dangerous for protection against corrosion. Once concrete cracks, the external depassivating agents can penetrate deep into concrete and set off the process of corrosion. Cracks running transversely to the reinforcement are less harmful than the longitudinal cracks along the reinforcement.

Thus in the order to induce the process of corrosion and to keep it going, at least one of the following conditions must exist in any RC structure.

- Chloride ion concentration in excess of the threshold value at the interface of the reinforcement and concrete or sufficient advancement of the carbonation front to destroy the passivity of the ferric oxide surface layer of the reinforcement.
- Adequate moisture in the concrete to facilitate the movement of chloride ions and provide a conduction path between the anodic and the cathodic areas on the steel.
- Sufficient oxygen supply to the cathodic areas in order to maintain such areas in a depolarized condition.
- Difference in electrochemical potentials at the surface of the reinforcement. Low values of electrical resistivity of concrete.
- Relative humidity in the range 50-70%.
- Higher ambient temperature.

UNIT - III

Materials for Repair

Special concretes and mortar, concrete chemicals, special elements for accelerated strength gain, Expansive cement, polymer concrete, Sulphur infiltrated concrete, Ferro cement, Fiber reinforced concrete

Special concretes

Special concretes are the concrete prepared for specific purpose like light weight, high density, fire protection, radiation shielding etc. concrete is a versatile material possessing good compressive strength. But it suffers from many drawbacks like low tensile strength, permeability to liquids, corrosion of reinforcement, susceptibility to chemical attack and low durability. Modification have been made from time to time to overcome the above deficiencies of cement concrete. The recent developments in the material and construction technology have led to significant changes resulting in improved performance, wider and more economical use.

Research work is going on in various concrete research laboratories to get improvement in the performance of concrete. Attempts are being made for improvements in the following areas. Improvement in mechanical properties like compressive strength, tensile strength, impact resistance. Improvement in durability in terms of increased chemical and freezing resistances. Improvements in impermeability, thermal insulation, abrasion, skid resistance etc.

Types of Special Concrete

- Light Weight Concrete
- High Density Concrete
- No Fines Concrete
- Aerated Concrete
- Fiber Reinforced Concrete (FRC)
- Polymer Concrete
- High Strength Concrete
- High Performance Concrete

Light Weight Concrete

- The density of conventional concrete is in the order of 2200 to 2600 kg/m^3.
- This heavy self-weight will make it uneconomical structural material. The dead weight of the structure made up of this concrete is large compared to the imposed load to be carried.
- A small reduction in dead weight for structural members like slab, beam and column in high-rise buildings, results in considerable saving in money and manpower.
- Attempts have been made in the past to reduce the self-weight of the concrete to increase the efficiency of concrete as a structural material.
- The light weight concrete with density in the range of 300 to 1900 kg/m^3 have been successfully developed.

No Fines Concrete

- When conventional aggregate are used, no-fines concrete show a density of about 1600 to 2000 kg/m^3, but by using light weight aggregate, the density may reduce to about 350 kg/m^3.
- Though the strength of no fines concrete is lower than ordinary concrete, the strength is sufficient for use in structural members and load bearing wall in normal buildings up to 3 stories high.
- Strengths of the order of 15 N/mm^2 have been attained with no fines concrete.
- The bond strength of no-fines concrete is very low and therefore, reinforcement is not used in no-fines concrete.

High density concrete

- High density concrete is also known as ‘heavy weight concrete’.
- High density concrete is produced by replacing the ordinary aggregate by a material of very much higher specific gravity, usually over 4.0, compared with the specific gravity of ordinary aggregate of about 2.6.
- One of the more common natural aggregate is barium sulphate.
- It has a specific gravity of 4.1, and occurs as a natural rock with a purity of about 95 %.
- Barytes behaves rather like ordinary crushed aggregate and does not present any special problems as far as proportioning of mixes is concerned.
- The aggregate tends to break up and dust so that care must be taken in handling and processing and over mixing should be avoided.

High strength concrete

- Based on the compressive strength; concrete is normally classified as normal strength concrete, high strength concrete and ultra-strength concrete.
- Indian standard recommended methods of mix design denotes the boundary at 35 MPa between normal strength and high strength concrete.
- The advent of pre-stressed concrete techniques has given impetus for making concrete of higher strength.
- High strength concrete is necessary for the construction of high rise building and long span bridges.
- To achieve high strength, it necessary to use high cement content with the lowest possible W/C ratio which invariable affect the workability of the mix.
- It should be remembered that high cement content may liberate large heat of hydration causing rise in temperature which may affect setting and may result in excessive shrinkage.

High performance concrete

- The development of high-performance concrete (HPC) is a giant step in making concrete a high-tech material with enhanced characteristics and durability.
- High performance concrete is an engineered concrete obtained through a careful selection and proportioning of its constituents.
- The concrete is with the same basic ingredients but has a totally different microstructure than ordinary concrete.
- The low water cement ratio of HPC results in a very dense microstructure having a very fine and more or less well-connected capillary system.
- The dense microstructure of HPC, makes the migration of aggressive ions more difficult, consequently HPC is more durable when exposed to aggregate environment conditions.
- High performance concrete can hence be defined as an engineered concrete with low water/ binder ratio to control its dimensional stability and when receive an adequate curing.

Special mortars

- Cement-clay mortar
- Light-weight and heavy mortars
- Decorative mortar
- Air-entrained mortar
- Gypsum mortar
- Fire-resistance mortar
- Packing mortar
- Sound absorbing mortar
- X-ray shielding mortar

Cement Clay Mortar

- In this 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.
- This type of mortar has better covering power and can be used in thin layers.

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 15 kN/m^3.

Heavy weight mortars:

•These are prepared from heavy quartz or other sands.
•They have bulk density of 15 kN/m^3 or more.
•They are used in load bearing capacity.

Decorative mortars:

These mortars are obtained by using-
•Color cements or pigments and
•Fine aggregate of appropriate color, texture and surface.

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.

Gypsum Mortar

These mortars are prepared from gypsum binding materials such as building gypsum and anhydrite binding materials.

Fire Resistant Mortar

- It is prepared by adding aluminous cement to a finely crushed power of fire- bricks (Usually proportion being one part of aluminous cement to two parts of powder of fire-bricks).
- This mortar being fire resistance, is used with fire-bricks for lining furnaces, fire places, ovens etc.

Sound Absorbing mortar

- These mortars may have binging materials such as cement, lime, gypsum slag etc. and aggregate (light weight porous materials such as pumice, cinders etc.).
- The bulk density of such mortar varies from 6 to 12 kN/m^3.
- Noise level can be reduced by using sound absorbing plaster formed with the help of sound absorbing mortar.

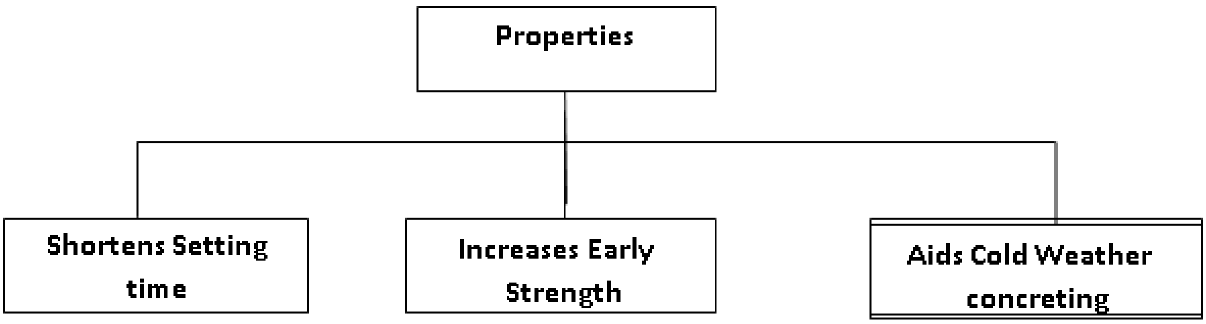
Concrete chemicals

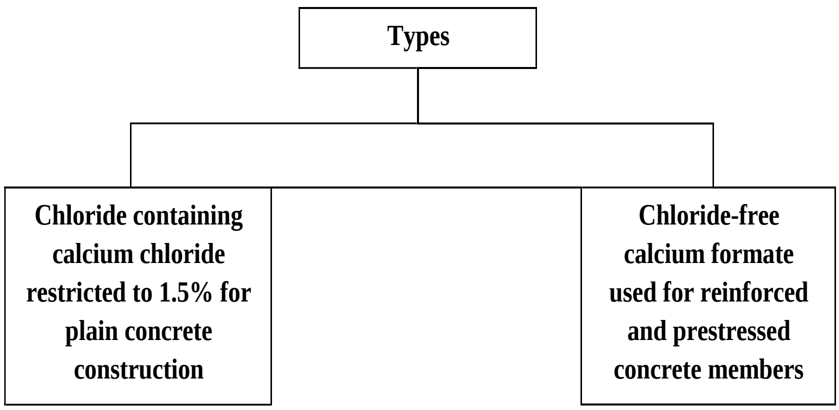
Admixtures are used to modify the properties of fresh and hardened concrete. They are classified as chemical and mineral admixtures. Chemical admixtures are used in construction industry for building strong, durable and waterproof structures.
Depending on their use, chemical admixtures are used for the following four main purposes.

1.Some chemicals are mixed with concrete ingredients and spread throughout the body of concrete to favorably modify the moulding and setting properties of the concrete mix. Such chemicals are generally known as chemical admixtures. Admixtures are added to concrete to give it certain desirable properties in either the fresh or the hardened state.
2. Some chemicals are applied on the surfaces of moulds used to form concrete to effect easy mould-releasing operation.
3. Some chemicals are applied on the surfaces of concrete to protect it during or after its setting.
4. Some chemicals are applied to bond or repair broken or chipped concrete.

Accelerators

- Accelerators increases the setting time, generally produce early removal of form work and early setting of concrete repair, and patch work.
- They are helpful in cold weather concreting. The most common accelerator for plain concrete work is calcium chloride ($CaCl_2$).
- Its quantity in the concrete mix is limited to 1-2% by weight of cement.
- The presence of $CaCl_2$ can cause corrosion of embedded steel. It reduces resistance against Sulphate attack and may cause an alkali-aggregate reaction.
- For pre-stressed and reinforced concrete $CaCl_2$ cannot be used. Instead, Calcium Formate is preferred as an accelerating admixture for such concretes.

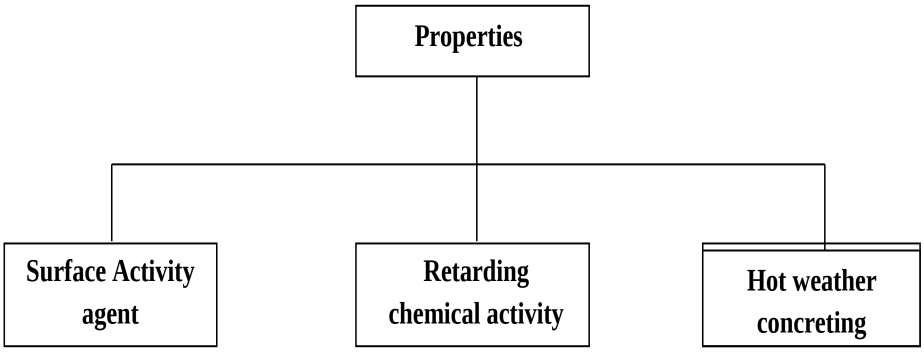




Retarders

- Retarders reduces the setting time of the concrete mix and reduce the water-cement ratio.
- Usually up to 10% water reduction can be achieved. A wide range of water-reducing and set retarding admixtures are used in ready mixed concrete.
- Usually, these chemicals are derived from lignosulphonic acids and their salts, Hydroxylated Carboxylic acid and their salts and Sulphonated melamine or naphthalene formaldehyde.

- They have a detergent like property. They work on the principle that water-reducing agent migrate to the surface of water.
- This increases the surface activity and hence imparts a soapy property to the mix and delays setting.



Plasticizers

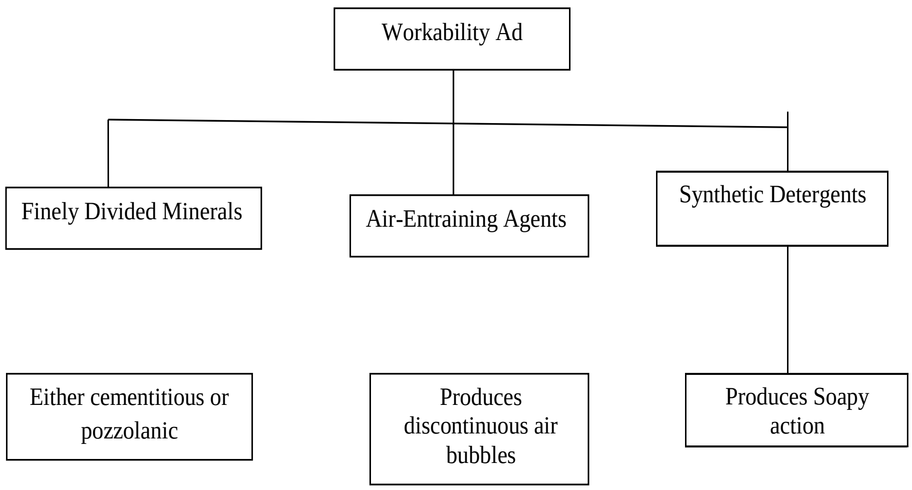
A plasticizers is defined as an admixture added to wet concrete mix to impart adequate workability properties.

As shown in figure plasticizers can be of the following three types.

1. finely divided minerals
2. air-entraining agents
3. Synthetic derivatives

Finely divided minerals

They are either cementitious or pozzolanic. Natural cements, hydraulic lime and slag cement belong to the former category, whereas fly ash and heat-treated clays belong to the latter. They are used as workability aids. They help in reducing bleeding by way of adding finer particles to the mix.



Air-entraining agents

These help in protecting concrete subjected to repeated freeze thaw cycles. Concrete with entrained air has higher workability and cohesiveness. Segregation and bleeding are reduced by using air-entraining agents. These agents are generally used to ensure durability against frost. Air-entraining agents are derived from synthetic detergents, salts of sulphonated lignin, fatty acids, organic salts of sulphonated hydrocarbons or salts of wood resins. These agents create millions of tiny air bubbles which relieve the expansion pressure. They result in 9% increase in the volume of water, and osmotic pressure develops as water diffuses from gel pores into the capillaries. Some air-entraining agents react and produce adverse effects when used along with accelerating or set-retarding admixtures.

Synthetic Derivatives

Synthetic derivatives introduce soapy into the mix. These are surface-active agents and are primarily added to increase workability. The best example of a synthetic derivative is benezene sulphonate. Chemically they comprise the same chemicals as found in retarders and hence they also generally retard the setting time. These derivatives may react differently with different types of cement. Hence, a careful study of the type of cement is required before choosing a particular synthetic derivative.

Superplasticizers

Superplasticizers produce extreme workability and thus flowing concrete. They achieve reduction in the water content without loss of workability. Their use generally leads to an overall reduction in the cost. Superplasticizers molecules and cement grains are oppositely charged and hence repel each other. This increases the mobility and hence makes the concrete flow. Superplasticizers enables savings in cement for a given strength and are ideal for pumping concrete, casting heavily reinforced concrete members, and the precast elements of concrete.

Special Cements for accelerated 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. The engineer may, as a first approach, consider admixtures so that ordinary types of Portland cement can be used. The chief chemical admixture now used for this purpose is superplasticizer. 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. The strength level is adjusted by controlling the amount of calcium fluoro aluminate in the cement. The time of set is reduced and the compressive strength gain increased in regulated cement mortars and concrete by an increase in the cement content of the mix, reduction of the water/cement ratio, increases temperature of the mix and increase in curing temperature.

The chemical reactions of this type of cement are much more energetic than those of Portland cements. For that reason, retardation is necessary. Conventional retarders for Portland cement are not effective in controlling the set of regulated set cement. However, citric acid is used in the mix as a retarder. Where practical, the setting action can be effectively controlled by reducing the mix temperature. Such reductions in the temperature of the mix is also advantageous, as the heat of hydration is considerably higher than that of Portland cement concrete. 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 are used for concrete patching for pavements allow traffic flow after only 45 minutes.

Expansion cement

Concrete made with ordinary Portland cement shrinks while setting due to loss of free water. Concrete also shrinks continuously for long time. This is known as drying shrinkage. Cement used for grouting anchor bolts or grouting machine foundations or the cement used in grouting the pre-stress concrete ducts, if shrinks, the purpose for which the grout is used will be some extent defeated. There has been a search for such type of cement which will not shrink while hardening and thereafter. As a matter of fact, a slight expansion with time will prove to be advantageous for grouting purpose. This type of cement which suffers no overall change in volume on drying is known as expansion cement. Cement of this type has been developed by using an expanding agent and a stabilizer very carefully.

Proper material and controlled proportioning are necessary in order to obtain the desired expansion. Generally, about 8-20 parts of the sulphoaluminate clinker are mixed with 100 parts of the Portland cement and 15 parts of the stabilizer.

Since expansion takes place only so long as concrete is moist, curing must be carefully controlled. The use of expanding cement requires skill and experience. One type of expansive cement is known as shrinkage compensating cement. This cement when used in concrete, with restrained expansion, induces compressive stresses which approximately offset the tensile stress induced by shrinkage. Another similar type of cement is known as self-stressing cement.

This cement when used in concrete induces significant compressive stresses after the drying shrinkage has occurred. The induced compressive stresses not only compensate the shrinkage but also give some sort of pre-stressing effects in the tensile zone of the flexural member.

Polymer Concrete

Cement concrete is an inherently porous material and as such, it has a low tensile strength. It exhibits a tendency to cracks and can deteriorate under the influence of severe chemicals in the atmosphere or in solution. Concrete polymer materials have been developed during the last fifteen years in a number of laboratories around the world. For applications as a constructional material offering the potential advantages of a higher strength, water tightness, and improved durability and resistance to freeze-thaw cycles over normal Portland cement concrete. The production of polymer-concrete involves the introduction of chemicals within the pores of the concrete and their polymerization.

Definition: Polymer concrete is a part of group of concretes that use polymers to supplement or replace cement as a binder.

Types of Polymer concrete

- Polymer concrete (PC), when the binder is a polymer that replaces the cement paste.
- Polymer modified concrete (PMC), when the polymer is mixed along with cement.
- Polymer impregnated concrete (PIC), when the cement concrete is treated by soaking and polymerization.
- Partially Impregnated and Surface coated polymer concrete.

Polymer concrete (PC)

Polymer concrete is a composite material which results from polymerization of a monomer and aggregate mixture. The polymerized monomer acts as binder for the aggregates and the resulting composite is called "Polymer Concrete". Two techniques are used to mix monomer with aggregate. The first is the conventi onal method of adding monomer to dry aggregate and stirring until a uniform blend is achiev ed. The second technique consists of placing the monomer in the specimen mould and then gradually adding aggregate to the monomer. The mixture is consolidated by mechanical vibration.

Advantages

•Rapid curing at ambient temperatures
•Good long-term durability with respect to freeze and thaw cycles
•Low permeability to water and aggressive solutions
•Good resistance against corrosion

Disadvantages

•It tends to be brittle in nature i.e. if fiber reinforcement is not provided in some polymer concrete cases they tend to develop cracks.
•Among the disadvantages is their high cost.

Polymer modified concrete

It is also known as polymer cement concrete. Polymer modified concrete is gaining popularity because of its ease of handling, economy and satisfactory results. Low water absorption and permeability make it an effective material for use in hydraulic structures as well. It has the property of setting quickly.

Advantages

- The most impressive characteristics of PMC are its ability to bond strongly with old concrete, and to resist the entry of water and aggressive solutions.
- Epoxy resin produced a concrete that showed some superior characteristics over ordinary Portland cement.

Disadvantage

- Modest improvement of strength and durability

Polymer-Impregnated Concrete

Polymer-Impregnated Concrete (PIC) is generally, a precast and hydrated Portland cement concrete, which has been cleaned, dried (eventually evacuated) and impregnated with a low viscosity monomer (eventually soaked under pressure) before being polymerized. The most appreciable improvements in the structural and durability properties have been obtained with

PIC. The unique feature of impregnating concrete is that a large part of the voids volume in the capillary pores is filled with the polymer and forms a continuous internal reinforcing structure which is thus responsible for the remarkable improvement in strength and durability.

Properties of PIC

- The mechanical and chemical resistant properties of PIC composites are superior to the conventional cement mortar.
- Porosity of the conventional cement mortar is greatly reduced when it is impregnated with polymers thereby increasing its durability.
- The presence of the polymer in a PIC not only envelopes the cement mortar but also seals the voids formed during the cement hydration.
- Compressive strength increases and is different for different composition and on type of polymers used.
- Tensile strength increases and is different for different composition and on type of polymers used.

Partially Polymer impregnated and surface coated concrete

The partially impregnated concrete can be easily produced by initially soaking the dried specimens in the liquid monomer, then sealing them by keeping them under hot water at 70°c to prevent or minimize loss due to evaporation. Partial impregnation may be sufficient in situations where the major requirement is surface resistance against chemical and mechanical attack in addition to increase in its strength. The depth of monomer penetration depends upon

- Pore structure
- Duration of soaking
- Viscosity of the monomer

Advantages

•It reduces freeze thaw deterioration, corrosion
•Increase in tensile strength
•Increase in compressive strength
•Increase in modulus of elasticity
•Resistance to acid attack
•It improves the durability of concrete
•Less pores

Places of Application

•Structural Floors
•Swimming Pools
•Pipes
•Storage Tanks for Distilled Water
•Anti-abrasive Surface
•Marine Structures
•Tunnel Liners
•Telephone Cable Ducts

Sulphur infiltrated concrete

New type of composites has been produced by the recently developed techniques of impregnating porous materials like concrete with Sulphur. Sulphur impregnation has shown great improvements in strength. Physical properties have been found to improve by more than 100% and large improvements in water impermeability and resistance to corrosion have also been achieved. In the past, some attempts have been made to use sulphur as a building material instead of cement. Sulphur is heated to bring it into molten condition to which coarse and fine aggregates are pored and mixed together. On cooling, this mixture gave fairly good strength, exhibited acid resistance and also other chemical resistance, but it proved to be costlier than ordinary cement concrete.

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

The following procedure has been reported in making Sulphur-Infiltrated concrete.

- The concrete to be infiltrated should be produced using normal aggregate with aggregate-cement ratios between 3:1 to 5:1 and having water-cement ratio preferably in the range 0.60 to 0.80.
- The infiltration procedure normally used consists of moist-curing of concrete elements for 24 hours at about 23^{0}C followed by drying (at 121^{0}C) for a period of 24 hours, immersing dried element in molten Sulphur at 121^{0}C under vacuum for two hours, releasing the vacuum and soaking for an additional half an hour, and then removing the elements from molten Sulphur to cool.
- In case of low water-cement ratio, concretes which are relatively dense external pressure may be applied following the release of vacuum to force Sulphur into concrete.

The foregoing procedure may be modified to suit individual job conditions. However, the following points should be kept in mind.

i. For concretes with a water-cement ratio of the order of 0.65, the one-day-old elements must be handled with care to avoid damage.
ii. The drying temperature should be kept as high as possible but not exceeding 150^{0}C since a higher temperature may damage the gel-structure of the young hydrated cement paste. The period of drying will depend on the type and size of element.
iii. The period of vacuum, (evacuation time) appears to be less critical than the immersion time in molten Sulphur after evacuation. For concrete with water-cement ratio of about 0.55, increased immersion time is essential to achieve full infiltration.

Durability:

Generally, the performance of sulphur-Infiltrated concrete is satisfactory against freezing and thawing, seawater attack and wetting and drying. The sulphur-Infiltrated concrete is more durable than conventional concrete in higher concentrations of H_2So_4 and HCl. When left submerged in stagnant water over extended periods of time, slight leaching of sulphur may take place and concrete may eventually show undesirable expansion followed by some cracking. The instability of SIC in aqueous media is apparently related to the presence of polysulphide anions formed during infiltration and found to be highly soluble in alkaline pore solutions of wet concrete. The polysulphide and calcium ions (dissolved from concrete) form concentrated calcium polysulphide, a yellow orange leachate. Under moist aerated conditions, it reacts with oxygen to form sulphur efflorescence.

The strength properties of SIC are not significantly affected when it is exposed to short- term temperature up to 100^{0}C. at this temperature SIC exhibits certain amount of ductile behavior before failure.
The magnitude of increase in abrasion resistance of SIC depends on the sulphur loading of the test specimens. However, the sulphur filling of the pores in concrete provides an uninterrupted path for heat flow resulting in increased values of thermal conductivity over that of normal dry concrete. The Sulphur-Infiltrated concrete provides a corrosive protection to embedded steel. The sulphur loading required for a given corrosion protection depends upon water-cement ratio used in concrete. Higher the water-cement ratio, higher the sulphur loading required. The minimum sulphur loading varies from 10% for 0.70 water-cement ratio to 5% for 0.40 water-cement ratio.

Applications:

The Sulphur-Infiltrated concrete is ideally suited for precast units such as

- Patio slabs
- Sidewalks
- Kerbs and
- Sewer pipes

Ferro cement

Ferro cement is a type of thin reinforced concrete, constructed of cement mortar reinforced with closely spaced layers of continuous and small diameter wire mesh. It is well known that conventional reinforced concrete members are too heavy, brittle, which cannot be satisfactorily repaired if damaged, develop cracks and reinforcements are liable to be corroded. These disadvantages of normal concrete make it inefficient for certain types of work. Ferro cement is a relatively new material consisting of wire meshes and cement mortar. It consists of closely spaced wire meshes which are impregnated with rich cement mortar mix. The wire mesh is usually of 0.5 to 1.0 mm dia wire at 5 mm to 10 mm spacing and cement mortar is of cement sand ratio of 1:2 or 1:3 with water/cement ratio of 0.4 to 0.45. The Ferro cement elements are usually of order of 2 to 3 cm in thickness with 2 to 5 mm external cover to the reinforcement.

The steel content varies between 300 kg to 500 kg per cubic metre of mortar. The basic idea behind this material is that concrete can undergo large strains in the neighbourhood of the reinforcement and the magnitude of strains depends on the distribution and subdivision of reinforcement throughout of the mass of concrete. The main advantages are simplicity of its construction, lesser dead weight of the elements due to their small thickness, its high tensile strength, less crack widths compared to conventional concrete, easy repairability, noncorrosive nature and easier mouldability to any required shape. This material is more suitable to special structures like shells which have strength through forms and structures like roofs, silos, water tanks and pipelines.

Reinforcement

•Skeletal reinforcement with closely spaced wires is the most commonly used reinforcement in Ferro cement.
•In the Ferro cement a wire mesh is required to control the cracking and skeleton steel to support the wire mesh.
•Use of fine meshes with thin wires at closer spacings for effective crack control.
Types of Wire mesh reinforcement used in Ferro cement:
1) Hexagonal wire mesh

2) Square mesh
3) Three dimensional mesh

Hexagonal Wire Mesh:

•Meshes with hexagonal openings are called chicken wire mesh.

•Diameter of wires varies between 0.5 mm to 10 mm, the grid size varies between 10 mm to 25 mm these meshes are more flexible and easier to work with it, which means we can make it easily into desired shape.

Square Mesh:

•Square mesh is made out of straight wires in both the longitudinal and transverse directions.

•Thus welded-mesh thickness is equal to two wire diameters.

•Welded meshes are weak at welded spots. Diameter varies between 1 mm to 1.5 mm. Grid size varies between 15 to 25 mm.

Three Dimensional Mesh:

•A three dimensional mesh is also available. A crimpled keeper wire frictionally locks together three alternating layers of straight wire.

•The mesh is sufficiently thick so that in some applications, only one layer is required.

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Types of mortar for Ferro cement:

1. Ordinary Cement Mortar
2. High Performance Mortar
3. Lightweight Aggregate Mortar
4. Fiber Reinforced Mortar
5. Polymer Mortar

Ordinary Cement Mortar:

•Portland cement is used to make ordinarily cement mortar. The filter material is usually a well-graded sand capable of passing 2.36mm sieve.

•However depending upon the characteristics of the reinforcing material mortar may contain some small-size gravel.

•The mix proportion ranges of the mortar for Ferro cement are sand-cement ratio by weight 1.4 to 2.5, water-cement ratio by weight, 0.3 to 0.5.

High Performance Mortar:

•This mortar is similar to conventional cement mortar but it contains mineral admixture to produce impermeable matrix.

•This enhances the durability of Ferro cement by providing greater protection to the steel reinforcement.

•By proper selection of chemical and mineral activities and W/C ratio, FC mortar can reduce pore size considerably and thereby achieving very high strength levels, which are not possible conventionally.

•It is having comprehensive strengths in the range of 50 to 100 MPa.

Light Weight Aggregate Mortar:

•It is used to construct low-cost housing,

•Lightweight aggregate reduces the density of the mortar,

• It helps in reduction of dead load,
•Lightweight aggregate are introduced replacing the sand in the mortar,
•Lightweight aggregates reduce the thermal conductivity.

Fiber Reinforcement Mortar Composites

•Fiber reinforcement mortar composites are produced by introducing small diameter discontinuous fibers during mixing of mortar matrices.
•Fibers which have been produced from steel, carbon, glass, nylon etc. in various shapes & sizes they possess high modulus of elasticity and lead to strong and stiff composites.
•In Ferro cement applications very short length of 2 mm to 12 mm were used to increase their properties.
•The short fibers were used in the composite, with the objective of improving the crack resistance of the matrix.

•Short fibers can control micro cracking before the actual mortar cracks. The long fibers were used to improve the post cracking behavior of the composites.
•The length of these fibers allows them to bridge the cracks.
•The fibers can then transmit the loads from the cracked matrix to uncracked matrix, which results in more ductility of composite.

Polymer Mortar

•To overcome the disadvantage of cement mortars and concretes, such as delayed hardening, low tensile strength, high drying shrinkage and low chemical resistance, polymer cement or polymer modified cement mortars are being used for main industrial application in the form of protective coating for concrete.
•Polymer modified mortar is obtained by the addition of polymer material to cement mortar during resulting in a polymer modified mortar.
•The polymer fills of the capillary pores makes the concrete impermeable.

Applications of Ferro Cement

•Boats Construction
•Sun Screens
•Cylindrical shell roof
•Folded plate roof
•Water tank

Fiber reinforced concrete

FRC can be defined as a composites material, consisting of mixtures of cement mortar or concrete and discontinuous, discrete uniformly dispersed suitable fibres.
•Fibre is a small piece of reinforcing material that can be circular or flat.

Properties of FRC:

•It has more tensile strength.
•Fibres improve the impact and abrasion resistance of concrete.
•It possess high compressive strength.

•It possess low thermal and electrical conductivity.

Aspect ratio

•The fibre is often described by a convenient parameter called "aspect ratio".
•The aspect ratio of the fibre is the ratio of its length to its diameter.
•Typical aspect ratio ranges from 30 to 150.

Types of Fibres:

- Steel Fibres
- Glass Fibres
- Polypropylene Fibres
- Slurry Infiltrated Fibre Concrete (SIFCON)
- Asbestos
- Carbon

Steel Fibres

•Steel fibre is one of the most commonly used fibre.
• Generally round fibres are used. The diameter may vary from 0.25 to 0.75 mm.
•The steel fibre is likely to get rusted and lose some of its strength. But investigations have shown that the rusting of the fibres take place only at the surface.
•Use of steel fibre makes significant improvements in flexural, impact and fatigue strength of concrete.
•It has very high tensile strength of 1700 N/mm^2.
•Steel fibres are incorporated in the shotcrete to improve its crack resistance, ductility and energy absorption and impact resistance characteristics.

Applications

- Industrial Flooring
- Warehouses
- Overlays
- Tunneling

Glass Fibre

•Glass fibre is a recent introduction in making fibre concrete.
•It has very high tensile strength of 1020 to 4080 N/mm^2.
•Glass fibre which is originally used in conjunction with cement was found to be affected by alkaline condition of cement.
•Therefore, alkaline resistant glass fibre by trade name "CEM-FIL" has been developed and used.
•AR glass fibres have a density that is similar to that of concrete.
•It gives better bond between the concrete matrix and the reinforcement.
•It prevents crack.
•The fibres also have elastic modulus which is significantly higher than concrete.
•This enables the fibres to provide an effective reinforcement during the hardened stage of concrete.

Applications

- Noise Barriers
- Water ducts and channels
- Tunnel lining
- Railways.

Polypropylene fibre:

•They are having good resistance against shrinkage and temperature cracks. It is having low modulus.

•They have longer elongation under a given load, which means they can absorb more energy without fracture.

•The low modulus fibres can be combined with steel fibres which is the latest trend what we call hybrid technology.

• It is applicable for structure exposed to atmosphere. These fibres can take care of the drying shrinkage whereas steel cannot perform in wet condition.

Applications:

•Polypropylene fibres can be used for slabs on grade, airport, highways, pavement, parking areas, bridge deck overlays, sewer pipes, precast concrete products.

Slurry infiltrated fibre Concrete (SIFCON)

•SIFCON is a high-strength, high performance concrete. It contains high volume percentage of steel fibres.

•It is also called as high-volume fibrous concrete. The volume of steel varies from 4 to 20 percent.

•SIFCON has no coarse aggregates. It contains fine sand and additives such as fly ash, micro-silica and latex emulsions.

•Proportions of cement and sand generally used for making SIFCON are 1:1, 1:1.5, or 1:2.

•Cement slurry alone can also be used for some application.

•Generally, fly ash or silica fume equal to 10% to 15% by weight of cement is used in the mix.

•The water cement ratio varies between 0.3 to 0.4.

Applications:

Properties like ductility, crack resistance and penetration and impact resistance are very high for SIFCON when compared to other materials, it is best suited for application in the following areas.

- Overlays, bridge decks
- Seismic resistance structures   Precast concrete products
- Military applications such anti-missile hangers, under-ground shelters   Aerospace launching platforms
- Repair, rehabilitation and strengthening of structures
- Concrete mega-structures such as offshore and long-span structures, solar towers etc.

Compact Reinforces Concrete (CRC)

•CRC is a mixer of cementitious content and fine steel fibres and further reinforced with a high concentration of continuous and uniformly placed larger steel bars.

• CRC has structural similarities with reinforces concrete, but is much more heavily reinforced and exhibits mechanical behavior more like that of structural steel, having almost the same strength and extremely high ductility.

Applications:

•Load carrying parts in large machines.
•Special high-performance joints in conventional steel.
•

Asbestos

•Asbestos is mineral fibre and has proved to be most successful of all fibres as it can be mixed with Portland cement.
•Tensile strength of asbestos varies between 560 to 980 N/mm^2.
•The composite product called asbestos cement has considerably higher flexural strength than the Portland cement paste.
•For unimportant fibre concrete, organic fibres like coir, jute, cane splits are also used.

Applications

Sheet pipe, boards, sewer pipes, wall lining etc.

Carbon

•Carbon fibres perhaps possess very high tensile strength 2110 to 2815 N/mm^2 and young's modulus.
•It has been reported that cement composite made with carbon fibre as reinforcement will have very high modulus of elasticity and flexural strength.
•Carbon fibres concrete are used to construct structures like cladding, panels and shells.

UNIT – IV

Techniques for Repair and Protection Methods

Rust eliminators and polymers coating for rebars during repair, foamed concrete, mortar and dry pack, vacuum concrete, Gunite and Shotcrete, Expoxy injection, Mortar repair for cracks, shoring and underpinning. Methods of corrosion protection, corrosion inhibitors, corrosion resistant steels, coatings and catholic protection, Engineered demolition techniques for dilapidated structures.

Rust eliminators

•Cement paste normally provides a highly alkaline environment that protects 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, serves as a means of isolating the steel from the surrounding environment.

•Common metallic coatings contain 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 steel reinforcing bars from corrosion.
•Such bars have acceptable bond and creep characteristics.

•The coat normally applied is 150 um thick. The reinforcement is epoxied in the factory itself, where the steel rods are manufactured.
•Such reinforcements are known as fusion-bonded epoxy coated steel.
•Steel manufacturers also manufacture Cold Twisted Deformed (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. It will not prevent corrosion once for all.

Polymer resin based coating

These are generally of two types,
•Resins blended with organic solvents and
•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 the materials are thermoplastic, and have a significant degree of extensibility they are capable of bridging minor cracks which may 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 to their relative in permeability to water vapour, 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.

- Most products 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.
- To ensure a complete reaction of the two components they must be mixed thoroughly.
- Some two component material require an induction period of 15 to 40 min after mixing. Therefore, such products cannot be used immediately after mixing.
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Foam concrete

•Foam concrete, also known as Lightweight Cellular Concrete (LCC), Low Density Cellular Concrete (LDCC), and other terms is defined as a cement-based slurry, with a minimum of 20% (per volume) foam entrained into the plastic mortar.

•As mostly no coarse aggregate is used for production of foam concrete the correct term would be called mortar instead of concrete; it may be called "foamed cement" as well.

•The density of foam concrete usually varies from 400 kg/m^3 to 1600 kg/m^3.

•The density is normally controlled by substituting fully or part of the fine aggregate with foam.

Properties

•Foam concrete is a versatile building material with a simple production method that is relatively inexpensive compared to autoclave aerated concrete.

•Foam concrete compounds utilizing fly ash in the slurry mix is cheaper still, and has less environmental impact.

•Foam concrete is produced in a variety of densities from 200 kg/m^3 to 1,600 kg/m^3 depending on the application.

•Lighter density products may be cut into different sizes.

•While the product is considered a form of concrete (with air bubbles replacing aggregate), its high thermal and acoustical insulating qualities make it a very different application than conventional concrete.

Applications

- bridge approaches / embankments
- pipeline Abandonment / annular fill
- trench backfill
- precast blocks
- precast wall elements / panels
- cast-in-situ / cast-in-place walls
- insulating compensation laying
- sunken portion filling
- trench reinstatement
- sub-base in highways
- filling of hollow blocks
- prefabricated insulation boards

Advantages of foam concrete

- It imposes little vertical stress on the surrounding sub-structure.

- It has low thermal conductivity and good sound insulation properties which are not available in ordinary concrete.
- It has excellent freeze and thaws resistance.
- Foam concrete is a free-flowing concrete and can be placed without compaction.
- When placing in foundation or excavations, foam concrete conforms to every subgrade contour.
- Foam concrete can be pumped easily with relatively low pressure over a long distance.
- Foam concrete is very long-lived material. It does not decompose and it is as durable as rock.
- Foam concrete has a low coefficient of permeability.

Disadvantages

- With a decrease in the density of foam concrete, its compressive and flexural strength decrease.
- Foam concrete has a relatively high paste content and no coarse aggregate, it will shrink more than normal concrete.
- Since it has higher cement content than normal concrete. So it becomes costly.
- The durability of foam concrete mainly influenced by the ratio of the connected pore to total pore.
- Mixing time of foam concrete is longer.

If a sufficient portion of concrete is removed, it can best be replaced with concrete placed in foams. This concrete can be placed without a bonding agent and without grout on the prepared surface of the old concrete. US Bureau of reclamation suggests that this method should be used

- When the depth of the repair exceeds 150 mm,
- For holes extending right though the concrete section
- For holes in unreinforced concrete with area greater than $0.1m^2$ and over 100 mm deep, and
- For holes in reinforced concrete which have an area greater than $0.05m^2$ and which extend deeper than the reinforcement.

There are some essential requirements that apply to the use of foamed concrete as a replacement material, regardless of its location in the structure.

i. The concrete should be made from the best possible materials and with the lowest possible water/cement ratio.
ii. To keep shrinkage to a minimum, the aggregate size should be large as can be accommodated and the water content as low as possible.
iii. The mix should be designed so that no bleeding occurs in order to ensure that the replacement material remains in intimate contact with old concrete located above it.
iv. The hole to be filled must be shaped so that there are no feather edges and with a depth normal to the finished surface of at least 40 mm.
v. Foams must be robust and firmly fixed so that they withstand any applied pressure and do not allow grout leakage.
vi. Old concrete, against which new concrete is to be placed, must be sound, completely clean and saturated and the surface must be free from moisture.

Mortar and Dry pack

•Dry packing is the hand placement of a low W/C ratio mortar which is subsequently rammed in to place to produce a dense mortar plug having tight contact to the existing concrete.

•Because of the low W/C ratio, there is a patch remains little shrinkage and the patch remains tight, with good durability, strength and water tightness.

•Dry pack should be used for filling holes having a depth equal to, or greater than, the least surface dimension of the repair area; for cone bolt, she bolt, core holes and grout-insert holes; for holes left by the removal of form ties; and for narrow slots cut for repair of 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.

•The interior surfaces of holes left by cone bolts and she bolts should be roughened to develop an effective bond; this can be done with a rough stub of 7/8-inch steel wire rope, a notched tapered reamer, or a star drill.

•Other holes should be undercut slightly in several places around the perimeter.

•Holes for dry pack should have a minimum depth of 1 inch.

Vacuum concrete

•All the water used in mixing concrete is not required for hydration.

•Therefore, removal of excess water before hardening take place improves concrete strength.

•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.

Advantages

•The final strength of concrete is increased by about 25%.

•Sufficient decrease in the permeability of concrete.

•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.

•It bonds well to old concrete and can, therefore, be used for resurfacing road slabs and other repair works.

Disadvantages

•They need specific equipment.

•This needs trained labour.

•They need power connection.

•They have a high initial cost.

•The porosity of concrete allows water, oil, and grease to seep through consequently weakening the concrete.

•It is well known that high water/cement ratio is harmful to the overall quality of concrete, whereas low water/cement ratio does not give enough workability for concrete to be compacted hundred percentages.
•Generally, higher workability and higher strength or very low workability and higher strength do not go hand in hand.
•Vacuum process of concreting enables to meet this conflicting demand.
•This process helps a high workable concrete to get high strength.
•In this process, excess water used for higher workability, not required for hydration and harmful in many ways to the hardened concrete is withdrawn by means of vacuum pump, subsequent to the placing of the concrete.

•The process when properly applied produces concrete of quality. It also permits removal of formwork at an early age to be used in other repetitive work.
•It essentially consists of a vacuum pump, water separator and filtering mat.
•The filtering consists of a backing piece with a rubber seal all-round the periphery.
•A sheet of expanded metal and then a sheet of wire gauge also form part of the filtering mat.
•The top of the suction mat is connected to the vacuum pump.

•When the vacuum pump operates, suction is created within the boundary of the suction mat and the excess of water is sucked from the concrete through the fine wire gauge or muslin cloth.
•At least one face of the concrete must be open to the atmosphere to create difference of pressure.
•The contraction of concrete caused by loss of water must be vibrated.
•The vacuum processing can be carried out either from the top surface or from the side surface.
•There will be only nominal difference in the efficiency of top processing or side processing.
• It has been seen that the size of the mat should not be less than 90 cm X 60 cm. Smaller mat was not found to be effective.

Rate of extraction of water

The rate of extraction of water is depends on workability of mix, maximum size of aggregate, proportion of fines and aggregate, cement ratio.
The following general tendencies are observed.
The amount of water, which may be withdrawn, is governed by the initial workability or the amount of free water. A great reduction in the water/cement ratio can, therefore, be obtained with higher initial water/cement ratio.
If the initial water/cement ratio is kept the same, the amount of water which can be extracted is increased by increasing the maximum aggregate size or reducing the amount of fines in the mix.

- The reduction in the water/cement ratio is very slightly less with mixes leaner than 6 to 1, but little advantage is gained with mixes richer than this.
- The greater the depth of concrete processed the smaller is the depression of the average water/cement ratio.
- The ability of the concrete to stand up immediately after processing is improved if a fair amount of fine material is present, if the maximum aggregate size is restricted to 19 mm and if a continuous grading is employed.
- Little advantage is gained by prolonging the period of treatment beyond 15 to 20 minutes and a period of 30 minutes is the maximum that should be used.

Gunite and 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.
- Normally fresh material with zero slump can support itself without sagging or peeling off.
- The force of the jet impacting on the surface compact the material.
- Sometimes use of set accelerators to assist overhead placing is practiced.
- The newly developed "Rediset cement" can also be used for shotcreting process.
- 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. They dry mix process is more successful and generally used.
Dry-mix process
The dry mix process consists of a number of stages and calls for some specialized plant. A typical plant set-up is shown in Fig
The stages involved in the dry mix process is given below:
(a) Cement and sand are thoroughly mixed.

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

(c) The mixture is metered into the delivery hose by a feed wheel or distributor within the gun.
(d) This material is carried by compressed air through the delivery hose to a special nozzle. The nozzle is fitted inside with a perforated manifold through which water is sprayed under pressure and intimately mixed with the sand/cement jet.
(e) The wet mortar is jetted from the nozzle at high velocity onto the surface to be gunited.

The Wet-mix Process
In the Wet-mix process the concrete is mixed with water as for ordinary concrete before conveying through the delivery pipe line to the nozzle, at which point it is jetted by compressedzair, onto the work in the same way, as that of dry mix process.
The wet-mix process has been generally discarded in favors of the dry-mix-process, owing to the greater success of the latter. The dry-mix methods make use of high velocity or low velocity system. The high velocity gunite is produced by using a small nozzle and a high air pressure to produce a high nozzle velocity of about 90 to 120 metres per second. This results in exceptional good compaction. The lower velocity gunite is produced using large diameter hose for large for large output. The compunction will not be very high.
Advantages of Wet and Dry process
Some of the advantages and disadvantages of the wet and dry processes is discussed below.

Although it is possible to obtain more accurate control of the water/cement ratio with the wet process the fact that this ratio can be kept very low with the dry process largely overcomes the objection of the lack of accurate control.
The difficulty of pumping light-weight aggregate concrete makes dry process more suitable when this type of aggregate is used. The dry process on the other hand, is vey sensitive to the water content of the sand, too wet a sand causes difficulties through blockade of the delivery pipeline, a difficulty which does not arise with the wet process. The lower water/cement ratio obtained with the dry process probably accounts for the lesser creep and greater durability of concrete produced in this way compared with concrete deposited by the wet process, but air-entraining agents can be use to improve the durability of concrete deposited by the latter means. Admixtures generally can be used more easily with the wet process except for accelerators.
Pockets of lean mix and of rebound can occur with the dry process. It is necessary for the Nozzel man to have an area where he can dump unsatisfactory shotcrete obtained when he is adjusting the water supply or when he is having trouble with the equipment.
These troubles and the dust hazard are less with the wet process, but wet process does not normally give such a dense concrete as the dry process. Work can be continued in more windy weather with the wet process than with the dry process. Owing to the high capacities obtainable with concrete pumps, a higher rate of laying of concrete can probably be achieved in the wet process than with
the dry process.

Epoxy injection

•The Injection of polymer under pressure will ensure that the sealant penetrates to the full depth of the crack.

•The technique in general consists of drilling hole at close intervals along the length of cracks and injecting the epoxy under pressure in each hole in turn until it starts to flow out of the next one.

•The hole in use is then sealed off and injection is started at the next hole and so on until full length of the crack has been treated.

•Before injecting the sealant, it is necessary to seal the crack at surface between the holes with rapid curing resin.

•For repairs of cracks in massive structures, a series of holes (Usually 20 mm in dia and 20mm deep spaced at 150 to 300mm interval) intercepting the crack at a number of location are drilled.

•Epoxy injection can be used to bond the cracks as narrow as 0.05mm.

•It has been successfully used in the repair of cracks in buildings, bridges, dams and other similar structures.

•However, unless the cause of cracking is removed, cracks will probably recur possibly somewhere else in the structure.

•Moreover, in general this technique is not very effective if the cracks are actively leaking and cannot be dried out.

Epoxy injection is a highly specialized job requiring a high degree of skill for satisfactory execution. The general steps involved are as follows.

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.

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.
- In case of V-grooving of the cracks, a hole of 20 mm dia and 12 to 25 mm below the apex of V-grooved section, is drilled into the crack.
- In case the cracks are not V-grooved, the entry port is provided by bonding a fitting, having a hat-like cross-section with an opening at the top for adhesive to enter, flush with the concrete face over the crack.

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.
- With the curing of material, pressure injection becomes more and more difficult.
- 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.

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. The pressure used for injection must be carefully selected, as the use of excessive pressure can propagate the existing cracks, causing additional damage.
- The injection pressures are governed by the width and depth of cracks and the viscosity of resin and should not exceed 0.10 MPa.
- 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.
- For relatively wide cracks gravity head of few hundred millimeters may be enough.

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.

Mortar repair for cracks

Portland cement mortar may be used for repairing defects on surfaces not prominently exposed. where the defects are too wide for dry-pack filling or where the defects are too shallow for concrete filling, and no deeper than the far side of the reinforcement that is nearest the surface. repairs may be made either by use of shotcrete or by hand application methods, although hand application methods are generally recommended for areas subject to public view in historic preservation applications.

Replacement mortar can be used to make shallow, small-size repairs to new or green concrete, provided that the repairs are performed within 24 hours of removing the concrete forms. Accomplishing successful mortar repairs to old concrete without the use of a bonding resin is unlikely or extremely difficult. Evaporative loss of water from the surface of the repair mortar, combined with capillary water loss to the old concrete, results in un-hydrated or poorly hydrated

cement in the mortar. Additionally, repair mortar bond strength development proceeds at a slower rate than compressive strength development. This causes workers to mistakenly abandon curing procedure prematurely, when the mortar seems strong. Once the mortar dries, bond strength development stops, and bond

failure of the mortar patch results. For these reasons using cement mortar without a resin bond coat to repair old concrete is discouraged. A Portland cement mortar patch is usually darker than the surrounding concrete unless precautions are taken to match colors. A leaner mix will usually produce a lighter colour patch.

Preparation and materials

Concrete to repaired with replacement mortar should first have all the deteriorated or unsound areas removed. After preparation, the areas should be cleaned, roughened if necessary and surfacedried to a saturated surface condition. The mortar should be applied immediately thereafter. Replacement mortar contains water, Portland cement and sand. The water and sand should be suitable for use in concrete, and the same should pass through a no.16 sieves. Only enough water

should be added to the cement sand mixture to permit placing.

Curing

Failure to cure properly is the most common cause of failure of replacement mortar. It is essential that mortar repairs receive a through water cure starting immediately after initial set and continuing for 14 days. In no event should the mortar be allowed to become dry during the 14-day period following placement. Following the 14-day water cure and while the mortar is still

saturated, the surface of the mortar should be coated with two coats of a wax-base curing compound meeting reclamation specifications.

Applications

The success of this method depends on complete removal of all defective and affected concrete, good bonding of the mortar to the concrete, elimination of shrinkage of the patch after placement, and thorough curing. Replacement mortar repairs can be made using an epoxy bonding agent; this technique is highly recommended.

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Corrosion Resistant Steel

•It is found that susceptibility of mild steel to corrosion is not significantly affected by composition, grade or level of stress.
•Hence substitute steel for corrosion resistance must have a significantly different composition.
•Based on some success in atmospheric corrosion, weathering steels of the cornet type were tested in concrete.
•They did not perform will in moist concrete, containing chlorides.
•It is observed that weathering corrode in similar concrete environments, to those causing corrosion of high-yield steel.
•They noted that although the total amount of corrosion was less, than would occur on high-yield steel under similar conditions, deep localized pitting developed, which could be more structurally weakening.
•Stainless steel reinforcement has been used in special applications, especially as fitments in precast members, but is generally too expensive to use as a substitute for mild steel.
•Very high corrosion resistance was shown by austenitic stainless steel in all the environments, in which they were tested, but the observations of some very minor printing in the presence of chlorides lead to the warning that crevice corrosion susceptibility was not evaluated in the test program.
•High titanium alloy bar is being used in some countries.
•This bar is grouted into holes, drilled into the marble stabs, and the grouts are based either on Portland cement or Epoxy.

Shoring and under pinning

- Providing support to get stability of a structure temporarily under certain circumstances during construction, repair or alteration.
- Such circumstance arises when
- The stability of a structure is endangered due to removal of a defective portion of the structure.
- The stability of a structure is endangered due to unequal settlement during construction itself or in long run.
- Certain alterations are to be done in present structure itself. Eg: remodeling of walls, changing position of windows etc.
- Alterations are carried out in adjacent building for remodeling, strengthening of foundation, etc.

- For shoring, timber or steel tubes may be used. Sometimes both are used in combination. If timber is used its surface should be coated with a preservative so as to protect against wet rot.
- The shoring should be designed based on the load it has to sustain and duration of load.
- Shoring may be given internally or externally depending on the case and in certain cases they may be provided on either side of the wall to produce additional stability.

- Shoring should be installed only after getting the permission if necessary, of the local authorities.
- There is no time limit to which the shoring has to be kept, it may range from weeks to years depending on the case.

Types

- Raking or inclined shores
- Flying or horizontal shores
- Dead or vertical shores

Underpinning

•It is the method of supporting the structures while providing new foundations or carrying out repairs and alterations without disturbing the stability of existing structures. It is carried under following conditions:

- When a building with deep foundation is to be constructed adjoining a building which is built on shallow footings. Here the shallow footings should be strengthened first.
- In order to protect an existing structure from the danger of excessive or differential settlement of foundation.
- In order to improve the bearing capacity of foundation so as to sustain heavier loads for which deepening or widening of foundation is done.
- In order to provide a basement for an existing structure.

Precautionary measures

- Before implementing appropriate underpinning measures, the following important points should be carefully attended:
- The existing structure should be fully examined carefully and appropriate underpinning method should be adopted.
- All poor masonry work, such as joints, cracks, plastering should be rectified before.
- Necessary shoring and strutting should be done such that existing structure is safe.
- Urgent repair like grouting of cracks, insertion of rod between walls, etc. should be carried out before commencing underpinning.
- Adequate care should be taken to ensure that there should be no movement of structure for which levels should be marked.
- Underpinning process is not a science but an art should be exercised depending on the situation.

Methods of underpinning

- Pit method
- Pile method
- Chemical method
- Other method

Chemical method

- In this method the foundation soil is consolidated by employing chemicals.

- Perforated pipes are driven in an inclined direction beneath the foundation. The slopes are provided such that the entire area under the existing footing comes under the area used to be strengthened.
- After the pipes are installed, solution of sodium silicate in water is injected through the pipes. This is a two-injection method. The pipes are withdrawn and at the time of withdrawal
  of pipes, calcium or magnesium chloride is injected through pipes.
- Chemical reaction takes place between these two chemicals and the soil is strengthened by consolidation. This method is suitable for granular soils.

Corrosion mechanism

•Corrosion of steel reinforcement occurs by an electrochemical process which involves exchanges of electrons similar to that which occurs in a battery.
•The important part of the mechanism is the separation of negatively charged areas of metal or "anodes" where corrosion occurs and positively charged areas or "cathodes" where a harmless charge balancing reaction occurs.
•At the anode the iron dissolves and then reacts to form the solid corrosion product, rust.
•The rust is formed at the metal/oxide interface, forcing previously formed oxide away from the steel and compressing the concrete, causing it to spall.

There are two major situations in which corrosion of reinforcing steel can occur.
These include:
1. Carbonation,
2. Chloride contamination

Deterioration through Carbonation

•Carbonation is a process in which carbon dioxide from the atmosphere diffuses through the porous concrete and neutralizes the alkalinity of concrete.

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

•Carbon dioxide, which is present in air in proportions of around 0.3 percent by volume, dissolves in water to form a mildly acidic solution.
•Unlike other acids that may chemically attack and etch the surface of the concrete, this acid forms within the pores of the concrete itself where the carbon dioxide dissolves in any moisture present.
•Here it reacts with the alkaline calcium hydroxide forming insoluble calcium carbonate.
•The pH value then drops from 12.5 to about 8.5. The carbonation process moves as a front through the concrete, with a pH drop across the front.
•When it reaches the reinforcing steel, the passive layer decays when the pH value drops below 10.5. The steel is then exposed to moisture and oxygen and is susceptible to corrosion.
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•Concrete inside the building frequently carbonates totally without any sign of deterioration as the concrete dries out, leaving the steel exposed to air but not moisture.
•Problems are seen externally where concrete is exposed to the elements and in certain situations internally, such as kitchens and bathrooms, where the concrete is susceptible to condensation or water- leakage.

Deterioration due to chlorides

•Salt causes corrosion by a different mechanism. When salt is dissolved in water sodium chloride forms a versatile, highly corrosive solution of sodium ions (Na+) and chloride ions(Cl^-).

•Salt is used for de-icing roads and its presence in sea water is a major problem for reinforced concrete structures.

•The very mobile chloride ions disperse through concrete pores in solution and where they come into contact with the reinforcing steel they attack the passive layer.

•Steel oxidizes in the presence of air and water to form rust which has a volume of up to 10 times that of the steel consumed.

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•As concrete has low tensile strength it will crack when as little as a tenth of a millimetre of steel has been consumed.

•Horizontal cracks from, causing corners to "SPALL" and surfaces to "delaminate" as the reinforcement's concrete cover becomes detached and falls away in sheets.

•The consequence can be seen on the underside of road bridges and many buildings and structures beside the sea.

ACI recommends the following chloride limits in concrete for new construction, expressed as a percent by weight of cement:

- Pre-stressed concrete 0.08%
- Reinforced concrete in wet conditions 0.10%
- Reinforced concrete in dry conditions 0.20%
- But in existing structures 0.026% is enough to breakdown the Passive Layer.

Various factors initiate and sustain the process of corrosion in R.C. structures. They are broadly divided into two groups:

- General Influencing factors
- General accelerating factors

The following are the factors that generally influence corrosion of reinforcement in R.C. structures.

•pH Value
•Moisture
•Oxygen
•Carbonation
•Chlorides
•Ambient temperature
•Severity of exposure
•Quality of concrete
• Cover to the reinforcement
• Initial curing condition
•Formation of cracks
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The following are the factors which accelerates the process of corrosion in R.C. structures

•Chlorides
•Sulphates
•Chlorine
•Electrical Charges
•Methane Acids

The following are some of the methods for protecting steel from corrosion

- Protective coatings for reinforcement
- Cathodic protection
- Corrosion Resistant steel
- Corrosion inhibitors

Protective coatings for reinforcement

•This is an effective means to combat corrosion in such environment where ordinary concrete with surface coating is not able to protect reinforcement against corrosion.
•The surface coating for the reinforcement will increase the protection against corrosion.
•There are several methods of providing protective coating to the reinforcement. The important ones are:

Cement Slurry Coating

Cement Slurry Coating provides short-term protection until placement in concrete. Several methods have been developed for an effective corrosion protection using cement slurry. One such coating is a mixture of cement, condensed silica and polymer dispersion.
This mixer found to be impermeable to water, chlorides and carbon-di-oxide.

Epoxy coating

•Epoxy coating is formed by application of an epoxy resin with appropriate curing agents' catalysts, pigments and flow control agents.
•Fusion bonding using the electrostatic process is the recent development.
•Fusion bonded epoxy coating provides long-term protection against corrosion.
•Though the cost is relatively high, it is the one which is the most effective in high alkaline and chloride contaminated environment.

Plastic coating

•Similar to epoxy coating, the plastic coatings are very effective in preventing corrosion of reinforcement even in high alkaline or chloride contaminated environment.
•However, the reduction in bond between plastic coated bar and the concrete is quite substantial and hence plastic coating cannot be considered as a solution for prevention of corrosion which cannot be solved by conventional methods.

Galvanizing

•Galvanizing gives protection to the reinforcement against corrosion, by means of metallic coating such as zinc.
•However, in case of corrosion due to excessive chlorides, the effect of galvanizing protection is reducing and hence is not advisable in highly chloride contaminated environments.

Cathodic protection

•Cathodic protection interferes with the natural action of the electrochemical cells that are responsible for corrosion.
•Cathodic protection can be effectively applied to control corrosion of surfaces that are immersed in water or exposed to soil.

•Cathodic protection in its classical form cannot be used to protect surfaces exposed to the atmosphere.
•The use of anodic metallic coatings such as zinc on steel (galvanizing) is, however, a form of cathodic protection, which is effective in the atmosphere.
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There are two basic methods of supplying the electrical currents required to interfere with the electrochemical cell action. They are
1. Cathodic protection with galvanic anodes.
2. Impressed current cathodic protection

Cathodic protection with galvanic anodes
•Cathodic protection (CP) is a technique to control the corrosion of a metal surface by making it work as a cathode of an electrochemical cell.
•This is achieved by placing in contact with the metal to be protected another more easily corroded metal to act as the anode of the electrochemical cell.
•This method is also called sacrificial anode cathodic protection system, where the active metal is consumed in the process of protecting the surfaces, so that corrosion is controlled.
•In sacrificial anode systems the high energy electrons required for cathodic protection are supplied by the corrosion of an active metal.
•Sacrificial anode systems depend on the differences in corrosion potential that are established by the corrosion reactions that occur on different metals or alloys.
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Corrosion inhibitors
•Corrosion inhibitors are admixtures that either extend the time to corrosion initiation or significantly reduce the corrosion rate of embedded metal, or both, in concrete.
•There are four common type of corrosion inhibiting admixtures, and their dosage is usually dependent upon the client's expected serviceable life of the structure and on a range of factors that affect the durability of concrete.
•These include cement type, water-to-cement ratio, cover provided b/w concrete to the steel, ambient temperature and the expected level of exposure to chlorides
•Corrosion-inhibiting admixtures are effective after the concrete has hardened and give a long-term increase in the passivation state of steel reinforcement and other embedded steel in concrete structures.

•Aggressive substances such as chloride and carbonation could jeopardize passivation layer of iron hydroxides on the steel surface and corrosion would eventually occur.
•For these reasons, admixtures that mitigate the corrosion process are useful in extending the life of concrete structures such as highways, multi-storey car parks, jetties, wharves, mooring dolphins, and sea walls.

The four most common types of corrosion inhibiting admixture are:
1. Amine Carboxylate
Available as concentrated liquids or powders.
They are absorbed on to the steel bars surfaces and create protective molecular layer, as shown in Figure.
The protective layer of amine carboxylate prevents further reactions between corrosive elements and embedded reinforcement, and decline existing corrosion rates.
Retard setting times 3 to 4 hours at 20°C.
Reduce chloride-induced corrosion of any good-quality concrete from seawater, salt-laden air, and de-icing salt exposure.

•Effective in corrosion reduction due to carbonation or chloride or combination thereof.
•The standard dosage rate is 0.6 to 1 L/m^3 for liquids and 0.6 kg/m^3 for powder versions.
•It can be added to concrete at concrete plant or job site as a powder.
•Compatible with pozzolans or slag, and do not affect the finishing properties of the concrete when used in combination with them.
•Adjustment to mixture design is not needed

2. Amine-ester Organic Emulsion

Available as a milky-white emulsion.
Creates protective layer on the steel surface and a decrease chloride permeability of the concrete
The recommended dosage is 5 L/m^3 to provide effective corrosion inhibition, minimizing the impact of the inhibitor on the fresh and hardened properties of concrete such as air entrainment and compressive strength.
For severe corrosion environments, corrosion inhibitors in combination with supplementary cementitious materials, low w/c ratio equal or less than 0.40, and adequate cover over steel.

•It is used to extend the life span of reinforced concrete structures subjected to chlorides.
•It should be blended with good quality concrete with largest w/c ratio of 0.40 and adequate concrete protection over steel bars.
•It can be used in good-quality concrete with a maximum w/c ratio of 0.40 and an appropriate level of clear cover over the reinforcing steel.
•If compressive strength reduction is unacceptable, then slight lower dosage should be used to compensate for that.
•However, mixture design adjustment is not needed when compressive strength meets design requirements.

3. Calcium Nitrite

Available as a 30% solution.
It is categorized as an anodic inhibitor that interferes with the chloride complexing process by oxidizing the more easily attacked form of iron to the more stable form.
High volume (30 L/m^3) of calcium nitrite is need to achieve desired results.
Calcium nitrite is appropriate to use for reducing chloride induced corrosion of any good-quality concrete, from seawater, salt-laden air, and de-icing salt exposure.
It is not applicable for poor-quality concrete or concrete with very low clear cover over the reinforcing steel.
w/c ratio of 0.40 or smaller should be used when calcium nitrite is added to concrete. However, w/c of 0.45 in combination with pozzolan or slag can be used in case of moderate design life concrete construction.
Calcium nitrite is an accelerator of both set and strength development of concrete.
Increase the strength of concrete significantly at early ages especially at 29 days.

4. Organic Alkenyl Dicarboxylic Acid Salt

Available as a water-based solution.
The organic alkenyl dicarboxylic acid salt is also known as DSS.
It can be classified as a dual-action corrosion inhibitor, affecting the anodic reaction at the steel and restricting moisture used in the cathodic reaction.
Dosage of 5L/m^3 is adequate for chlorides in groundwater.

For more severe exposures such as bridge decks that are salted or marine applications 10 L/m^3 is recommended.
It is also appropriate for use in reducing chloride induced corrosion of properly proportioned concrete from seawater, salt-laden air, and de-icing exposure.
Properly proportioned concrete should have a maximum w/c of 0.40 and the appropriate clear cover over the reinforcing steel.

Corrosion resistant steel

It is found that susceptibility of mild steel to corrosion is not significantly affected by composition, grade or level of stress. Hence substitute steel for corrosion resistance must have a significantly different composition. Based on some success in atmospheric corrosion, weathering steels of the corten type were tested in concrete.
They did not perform will in moist concrete, containing chlorides. It is observed that weathering corrode in similar concrete environments, to those causing corrosion of high-yield steel. They noted that although the total amount of corrosion was less, than would occur on high-yield steel under similar conditions, deep localized pitting developed, which could be more structurally weakening.
Stainless steel reinforcement has been used in special applications, especially as fitments in precast members, but is generally too expensive to use as a substitute for mild steel. Very high corrosion resistance was shown by austenitic stainless steel in all the environments, in which they were tested, but the observations of some very minor printing in the presence of chlorides lead to the warning that crevice corrosion susceptibility was not evaluated in the test program. High titanium alloy bar is being used in some countries. This bar is grouted into holes,
drilled into the marble stabs, and the grouts are based either on Portland cement or Epoxy.

Demolition of structures

Demolition is the dısmantlıng, razıng, destroyıng or wreckıng any building or structure or an y part of building by pre-planned and controlled methods.

- Demolition is bringing down the building and other structures safely.
- The demolition of structure with the help of explosives is called as *implosion.*
- The main objective for demolition may be the age of the structure.
- Methods of demolition depends upon
- type of structure
- height and surrounding structures.

FACTORS AFFECTING SELECTION OF DEMOLITION METHOD
Type of structure
Different types of structure like load bearing masonry
structure, RCC framed structure, steel structure , etc.
Size of structure
If the size of structure is small, hand demolition can be sufficient. for large structures and multistoreyed buildings special like wrecking ball method, deliberate collapse, implosion technique etc. are necessary.

- Available time period
- Location of structure
- Limitation of noise, dust and vibrations
- Skill of workers

- Safety
- Availability of equipment
- Adjacent structures

Mechanical methods

- Wrecking method
- Pusher arm technique
- Thermic lance technique
- Non explosive demolition
- Concrete sawing method
- Deliberate collapse method
- Pressure jetting method
- bursting

Manual demolition

It is suitable for demolition of small buildings.

Tools required for manual demolition

- Hammers
- Picks
- Wire cutters
- Welding cutters
- Hand driven hydraulic jacks

Sequence of demolition

- Prior to demolition of internal floors, all cantilevered slabs and beams, canopies, and verandahs shall first be demolished

The structural elements, in general, shall be demolished in the following sequence:

•Slabs;

•Secondary beams; then

•Main beams

- Mechanical plant shall descend from the floor with temporary access ramp, or be lowered to the next day floor by lifting machinery or by other appropriate means;
- When a mechanical plant has just descended from the floor above, the slabs and beams, in two consecutive floors may be demolished by the mechanical plant simultaneously. The mechanical plant may work on structural elements on the same floor and breaking up the slabs on the floor above;

The wall panel, including beams and columns shall be demolished by gradually breaking down the concrete or by pulling them down in a controlled manner.

Crane and Ball method

- The ball is made from forged steel, which means the steel is not cast into a mould in a molten state. It is formed under very high pressure while the steel is red hot (soft but not molten) to compress and to strengthen it.
- Concrete members can be broken into small pieces, but secondary cutting of reinforcing may be necessary.

Advantages and Disadvantages of Ball and Crane method:

<u>Advantages:</u>

1)To demolish roofs and other horizontal spans.

2)The wrecking balls are still used when demolition may not be possible due to local environmental issues or asbestos/lead building content.

Disadvantages:

1)It demands a great deal of skill from the crane operator.

2)The height of a building that can be demolished is limited by crane size and working room; however, buildings as high as 20 stories have been demolished.

3)The breakup process can cause considerable dust, vibration and noise which may be objectionable.

- A thermal lance is created by packing a seamless mild steel tube with low carbon rods and passing oxygen through the tube.
- While this method eliminates vibration and dust problems, it creates other hazards associated with smoke and fire danger.
- Whether sawing, jetting or lancing is used to dismantle the structure or its components, each element must be safely lowered to the ground.

Hydraulic breaker

- A common piece of equipment used for demolishing bridge decks, foundations and pavements is a hydraulically or pneumatically operated, boom-mounted breaker.
- The advantages of a machine mounted breaker may include a telescoping boom for easy reach and, remote control operation and underwater demolition capabilities
- Some of the smaller remote- controlled machines can be lifted through window openings and used inside a building to demolish floors and walls.
- Productivity can vary greatly depending on hammer size, type of concrete, amount of reinforcing and working conditions.
- A hydraulic jackhammer, typically much larger than portable ones, may be fitted to mechanical excavators or backhoes and is widely used for roadwork, quarrying and general demolition or construction groundwork.
- They are used in mines where there is an explosion risk since they lack any high-power electrical circuitry that might cause a triggering spark.
- The jackhammer is connected with hydraulic hoses to a portable hydraulic power pack: either a petrol or diesel engine driving a hydraulic pump.

Pressure bursting technique

- Pressure bursting can be used in cases where relatively quiet, dust-free, controlled demolition is preferred.
- Both mechanical and chemical pressure bursting split the concrete, either with a splitting machine operating on hydraulic pressure provided by a motor in the case of mechanical bursting, or through the insertion of an expansive slurry into a pre-determined pattern of boreholes in the case of chemical bursting.
- The split concrete is then easily removed, either by hand or by crane.
- Both methods work by applying lateral forces against the inside of holes drilled into the concrete.

Explosive techniques

Introduction

In the controlled demolition industry, building implosion is the strategic placing of explosive material and timing of its detonation so that a structure collapses on itself in a matter of seconds, minimizing the physical damage to its immediate surroundings.

UNIT - V

Repair, Rehabilitation and Retrofitting of Structures

Repairs to overcome low member strength. Deflection, Cracking, Chemical disruption, weathering corrosion, wear, fire, leakage and marine exposure.

Need for Strengthening:

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

Deflection due to strengthening of Flexural members

Many situations in which flexural members, and especially bridge girders, have been found to have less than their special attention was paid to the paid to the bond between the old concrete and the new anchor blocks. The existing concrete was cut back to the depth of the cover and roughened. After the new block had been cast in-situ the contact surface was injected with low viscosity epoxy
resin under pressure, the injection being monitored ultrasonically. Some of the new tendons were deflected at existing diaphragms, reinforced required.

In view of the importance of the new anchor blocks to the success of the repair, we might have expected that dowel bars would be provided to connect the block to the existing concrete but no mention is made of this possibility and apparently what was done has been found to be successful. The basis of this success is the roughness imparted to the old concrete. Epoxy jointing between smooth concrete surfaces would be expected to deform over a period over a period of time and
relax the stressed tendons.

Strengthening of Beams

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

The bars are passed through or inserted in the supporting columns through holes of appropriate diameter drilled in the columns. The spaces between bars and surrounding holes are filled with epoxy grout to ensure a good bond. Expanded wire mesh is fixed and anchored on three sides of the beam as shown in fig. To ensure a good bond between old concrete and polymer modified mortar, an epoxy bond coat is applied to the concrete surface. While the bond coat is still fresh, a layer of polymer modified mortar is applied. The required thickness on all the three sides is achieved by application of 2 to 3 layers of mortar. While applying mortar at the bottom of beam, the thickness of mortar layers should be so adjusted that sagging is completely covered and beam looks deflected. The mortar is cured for appropriate period in water and thereafter it is allowed to cure in air. Epoxy resin should also be injected in the cracks along top of beams. If new stirrups are required for shear strength enhancements should be followed.

Deflection due to Strengthening of slabs

The strengthening of slab is taken up only after the strengthening of beams is completed. A reinforced structural concrete topping over the existing slab can be used which provides a composite construction of old and new slabs, with additional depths to slab and beam. To ensure a good bond between new and old concretes, mechanical anchorage consisting of steel bolts inserted in holes drilled into the slab at suitable intervals may be provided. The spaces surrounding the holes are filled with epoxy grout. A shear connector is embedded for half of its length in old concrete and the remaining half which is projected will subsequently b embedded in new concrete. Before applying topping, the surface of old floor slab should be thoroughly scrabbled and cleaned. Additional reinforcement may be required over the supports, because the old reinforcement at supports acquires a position which is near to the neutral axis of compositors section. After the preparation of old concrete surface, epoxy bond coat is applied on it and while this coat is still touch-dry 25 to 50mm thick M20 grade concrete topping is laid. The thickness of topping is governed by the strength and thickness of old floor slab. However, application of topping increases the dead weight on the slab. With suitable treatment the top layer of topping maybe utilized as floor finish etc., after curing the beam and slab for 14 to 21 days' props can be removed.

Deflection due to Strengthening of columns

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

The column jacket can also be used for increasing the punching shear strength of column slab connections by using it as a column capital. When the jacket is provided around the periphery of the column, it is termed a collar. In most of the applications, the main function of the collar is to transfer vertical load to the column. Circular reinforcement can be used for load transfer. The practice of transferring load through dowel bars embedded into columns or shear keys has a

disadvantage in that they require drilling of holes for dowels or cutting shear keys which are costly and time consuming, and can damage the existing column. Reinforcement encircling the column can be used to transfer the load through shear friction. The expansion of collar as it slides along the roughened surface causes the tensioning of circular reinforcement resulting in radial compression,

which provide normal force needed for load transfer. The shear transfer strength is provided by both frictional resistance to sliding and dowel action of reinforcement crossing the crack.

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

Cracking

Routing and sealing

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

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

Stitching

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

A non-shrink or an epoxy resin based adhesive should be used to anchor the legs of the dogs. Stitching is suitable when tensile strength must be reestablished across major cracks, although stitching will not close the crack, and it is way of stopping the movement of active crack and thereby preventing it from spreading. Stitching dogs should be of variable length and orientation and so located that the tension transmitted across the crack is not applied to a single plane within the section but us spread over an area.

Bonding

Cracks in concrete may be bonded by the injection of epoxy bonding compounds under pressure. A usual practice is to drill into cracks from face of the concrete at several locations. Water or a solvent is injected to flush out the defect. The surface is than allowed to dry. The epoxy is injected into the drilled holes until it flows out through the other holes. The epoxy is injected into the drilled holes until it flows out through the other holes. Bonding with epoxies-cracks as narrow as 0.0.75mm can be sealed with epoxy compounds, usually pressure injection is restored to in sealing the cracks.

Bandaging

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

Chemical disruption

Sulphate Attack

•Mechanism-sulphates are found in most of the soils as calcium, potassium, sodium and magnesium sulphates.

•Sulphate attack occurs when pore system in concrete is penetrated by solution of sulphates.

Chemical mechanism

•The effect of sulphate on concrete can be mainly, chemical and physical and they are closely related.

•The sulphate attack or reaction is indicated by the characteristic whitish appearance on the surface.

•As a result of the chemical reactions between sulphate and hydration products, change in the microstructure and pore size distribution of the cement paste takes place.

•Sulphate converts calcium hydroxide into large molecules of calcium Sulphate.

$$Na_2So_4.10H_2O + Ca(OH)_2 \longrightarrow CaSO_4.2H_2O + 2NaOH + 8H_2O$$

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

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

Salt attack/Weathering

•Solid salts do not attack concrete, but when present in solution they can react with hardened concrete.

•It is a more general problem in masonry structures. Efflorescence is a whitish crystalline deposit on the surface.

•Efflorescence is the formation of calcium carbonate precipitate on the concrete surface owing to carbonation

Prevention measures

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

Wear

•The concrete has been damaged by erosion it is almost certain that any repaired section will again be damaged unless the cause of the erosion is removed.

•The best concrete made will not withstand the forces of cavitation or severe abrasion for a prolonged period.

•It may be more economical to replace the concrete periodically rather than to reshape the structure to produce streamlined flow or to eliminate the solids which are causing abrasion.

Mechanism

•Abrasion-erosion damage is caused by the action of debris rolling and grinding against a concrete surface.

•In hydraulic structures, the areas most likely to be damaged are spillway aprons, stilling basin slabs, and lock culverts and laterals.

•The sources of the debris include construction trash left in a structure, riprap brought back into a basin by eddy currents because of poor hydraulic design and riprap or debris thrown into a basin by the public.

•Also barges and towboats impacting on lock wells can cause abrasions erosion damage.

Symptoms

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

•Mechanical abrasion is usually characterized by long shallow grooves in the concrete surface and spelling along monolith joints.

•Armour plates is often torn away or bent.

Fire

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

The principle types of damages are:

•Reduction in strength of concrete

•Cracking and spalling of concrete

•Deflection and deformation of members

•Discolouration

Concrete thermal properties are determined by three main factors:

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

•A large number of reinforced concrete structures salvaged from destruction in fires by timely firefighting operations can be put to further service after strengthening and providing some cosmetic repairs since the cost of restoration of such structures is less than that for dismantling and construction of new ones.

The fire may cause different degrees of damage to the structure:

•The structure may be completely burnt or destroyed;

•Its surface may be slightly damaged or slight deformation may occur.

•In the first case, the whole of damaged portion has to be replaced during restoration of structure while in the latter, only repair and finishing may be required.

•The extent of damage caused the structure during a fire depends on the duration of fire, and the temperature to which the structure was subjected during the fire.

•High temperature during a fire reduces the strength of reinforced concrete structures due to change in the strength and deformability of materials, reduction in cross sectional dimensions, weakening of bond between the reinforcement and concrete which determines structural action under the load.

•When assessing the effects of a fire on a building structure, it is important to recognize that the huge expansion that occurs in the members subjected to the fire temperature may cause damage in other members remote from the fire.

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

Restoration of fire Damaged Elements

•The eccentrically loaded columns fail when reinforcement bars in tension heat up.

•The fire resistance of such elements can be increased by increasing the thickness of protective layer.

•Heat transmission and temperature of bottom reinforcement are keys to the behavior of reinforced concrete slab exposed to fire.

•The reinforcing bars are assumed to retain one half of their original strength. Carrying capacity of slabs can be enhanced by increasing their thickness.
•For beams, depth and width can be increased. It should be kept in mind that in beams, weakening of bond between transverse reinforcement and concrete on account of heating reduces the residual shear load carrying capacity considerably.

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

Leakages

•Leakage in the concrete structures causes inevitable damage to the reinforcement.
•Construction joints, shrinkage and restraint cracks may form leak paths.
•The amounts of water involved vary from damp-patches which tend to evaporate as they are formed, to running –leaks which may eventually form undrained surfaces.
•Damp patches may also be formed when water passes through the voids along reinforcing bars formed due to plastic settlement.
•The other common routes for larger volume leaks are honeycombed concrete, movements joint like expansion and contraction joints.
•In case of water-retaining structures, the extent of leakage may be measured by monitoring loss of liquid from the structure.
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Techniques

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

Conventional leak-sealing methods

Some sources of minor leakage may dry up by autogenously healing which is an accumulation of calcium salts along the leak path.
This will obstruct the passage of water over period of time and reduce the leakage to negligible proportions.
•Once leak spots have been identified, the remedial action may involve the application of local or complete surface seal in the form of a coating system.

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

•The procedure may require quite extensive preparatory work including the injection of suspect joints and random shrinkage cracks with allow viscosity resin.
•Honey combed concrete if not particularly extensive may be filled out using a resin based mortar.
•Laitance and surface contaminants may be removed by sand blasting and power wire brush.

Injection Sealing

•From liquid flow and pressure considerations the simplest and most cost effective way is to seal the leakage from the water-retaining side of the structure.
•When the wet side is inaccessible, the leakage must be tackled from the dry side which is considerably more difficult.

•Successful leak sealing requires injection of sealant to fill water passages completely, and it is necessary to attain a relatively high flow velocity to achieve this, because of short pot-life or working time of the typical repair material.
•The first basic step is to restrict or confine the water flow to tubee through which the sealant any be introduced.

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

Marine exposure

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

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

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

Application of materials

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

UNIT – VI

Work Site Safety

General safety-vehicles, eye and ear protection, clothing; Tool safety-drills and bits, power saws, power mixers, ladders, screwdrivers and chisels; co-worker safety.

Introduction

worksite safety doesn't get as much attention as it should. Far too many people are injured on jobs every year. Most of the injuries could be prevented, but they are not. One of the main reasons for this is that people arc in a hurry to make a few extra bucks, so they cut corners. This happens with employees, contractors, and piece workers. It affects hourly installers who want to shave 15 minutes off their workday so they can head back to the shop early.

Based on my field experience, most accidents occur as a result of negligence. Workers try to take shortcuts, and they wind up getting hurt. This has proved true with my personal injuries. I've only suffered two serious on-the-job injuries, and both of them a direct result of my carelessness. I knew better than to do what I was doing when I was hurt, but I did it anyway. Well, sometimes you don't get a second chance, and the life you affect may not be your own. So let's look at some sensible safety procedures that you can implement in your daily activity.

Construction can be a very dangerous trade. The tools of the trade have the potential to be killers. Requirements of the job can place you in positions where a lack of concentration could result in serious injury or death. The fact that working with concrete can be dangerous is no reason to rule out the trade as your profession. Driving can be extremely dangerous, but few people never get behind the wheel out of fear. Fear is generally a result of ignorance. When you have a depth of knowledge and skill, fear begins to subside. As you become more accomplished at what you do, fear is forgotten. While it is advisable to learn to work without fear, you should never work without respect. There is a huge difference between fear and respect. If, as an installer, you are afraid to climb up high enough to set a pour form, you are not going to last long in the plumbing trade. However, if you scurry up recklessly, you could be injured severely, perhaps even killed. You must respect the position you are putting yourself in. If you are using a ladder, you must respect the outcome of what a mistake could have.

Being afraid of heights could limit or eliminate your career. Respect is the key If you respect the consequences of your actions, you are aware of what you are doing and your odds for a safe result improve. Many young installers are fearless in the beginning. They think nothing of darting around on a roof or jumping down in a trench. As their careers progress, they usually hear about or see on-the-job accidents. Someone gets buried in a cave-in of a trench. Somebody falls off a roof. A metal ladder being set up hits a power line. The list of possible job-related injuries is a long one. Millions of people are hurt every year in job-related accidents. Most of these people were not following solid safety procedures. Sure, some of them were victim’s c unavoidable accidents, but most were hurt by their own hand, in one way or another. You don't have to be one of these statistics.For example, a supervisor might tell you to break up the concrete around a pipe to allow the installation of new plumbing and never consider telling you to wear safety glasses. The supervisor will assume you know that the concrete is going to fly up in your race as it is chiselled up. However, as a rookie, you might not know about the reaction concrete has when hit with a cold chisel. One swing of the hammer could cause extreme damage to your eyesight.

Simple jobs, like the one in the example, are all it takes to ruin a career. You might be really on your toes when asked to scoot across an I-beam, but how much thought are you going to give to carrying a few bags of concrete mix to a mixer? The risk of falling off the I-beam is obvious. Hurting your back by carrying heavy loads the wrong way may not be so obvious. Either way, you can have a work-stopping injury.

Safety is a serious issue. Some job sites are very strict in the safety requirements maintained. But a lot of jobs have no written rules of safety. If you are working on a commercial job, supervisors are likely to make sure you abide by the rules of the occupational Safety and Health Administration (OSHA). Failure to comply with OSHA regulations can result in stiff financial penalties. However, if you are working residential jobs, you may never work on a job where OSHA regulations are observed.

In all cases, you are responsible for your own safety. Your employer and OSHA can help you to remain safe, but in the end, it is up to you. You are the one who has to know what to do and how to do it. And not only do you have to take it-y for your own actions, you also have to watch out for the actions of others. It is not unlikely that you could be injured by someone else's carelessness. Now that you have had the primer course, let's get down to the specifics of job-related safety.

GENERAL SAFETY

General safety covers a lot of territory. It starts from the time you get into the company vehicle and carries you right through to the end of the day. Much of the general safety recommendations involve the use of common sense. Now, let's get started.

vehicles

Many construction workers are given company trucks for their use in getting to and from jobs. You will probably spend a lot of time loading and unloading company trucks. And. of course, you will spend time cither riding in or driving them. All of these areas can threaten your safety. If you will be driving the truck, take the time to get used to how it handles. Loaded work trucks don't drive like the family car. Remember to check the vehicles fluids. tyres, lights, and related equipment. Many company trucks are old and have seen better days. Failure to check the vehicles equipment could result in unwanted headaches. Also remember to use the seat belts; they do save lives. Apprentices are normally charged with the duty of unloading the truck at the job site. There are a lot of ways to get hurt in doing this job. Many trucks use roof racks to haul supplies and ladders. If you are unloading these items, make sure they Will not come into contact low-hanging electrical wires. Aluminium ladders make good electrical conductors, and they will carry the power surge through you on the way to the ground. If you are unloading heavy items, don't put your body in awkward positions. Learn the proper ways for lifting, and never lift objects inappropriately. If the weather is wet be careful climbing on the truck. Step bumpers get slippery, and a fall can impale you on an object or bang up your knee.

When it is time to load the truck, observe the same safety precautions you did in unloading. In addition to these considerations, always make sure your load is packed evenly and well secured. Be especially careful of any load you attach to the roof rack, and double-check the cargo doors on trucks with utility bodies. If you are carrying a load of forms in the bed of your truck, make very sure that they are strapped

Eye and ear protection

Eye and ear protection is often overlooked. An inexpensive pair of safety glasses can prevent you from permanently losing your sight. Ear protection reduces the effect of loud noises, such as jackhammers and drills. You may not notice much benefit now, but in later years you will be glad you wore it. If you don't want to lose your hearing, wear ear protection when subjected to loud noises.

Clothing

Clothing is responsible for a lot of on-the-job injuries. Sometimes it is the lack of clothing that causes the accidents, and there are many times when too much clothing creates the problem. Generally, it is wise not to wear loose-fitting clothes should be tucked in, and short-sleeve shirts are safer than long-sleeved shirts when operating some types of equipment.

Caps can save you from minor inconveniences, and hard hats provide some protection from potentially damaging accidents, like having a steel fitting dropped on your head. If you have long hair, keep it up and under a hat.

Good footwear is essential in the trade. Normally a strong pair of hunting-style boots will be best. The thick soles provide some protection from nails and other sharp objects You may step on. Boots with steel toes can make a big difference in your physical wellbeing. If you are going to be climbing, wear foot gear with a flexible sole that grips well. Gloves can keep your hands warm and clean, but they can also contribute to serious accidents. Wear gloves sparingly, depending on the job you

Jewellery

On the whole, jewellery should not be worn in the workplace. Rings can inflict deep cuts in your fingers. They can also work with machinery to amputate fingers. Chains and bracelets are equally dangerous, probably more so.

Kneepads

Kneepads can make your job more comfortable, and protect your knees. Some workers spend a lot of time on their knees, and pads should be worn to ensure that they can continue to work for many years. The embarrassment factor plays a significant role in job-related injuries. People, especially young people, feel the need to fit in and to make a name for themselves. It is no secret that construction workers often consider themselves super human beings. The work can be hard, and doing it has the side benefit of making you stronger. But you can't allow safety to be pushed aside for the purpose of making yourself look invulnerable.

Too many people believe that working without safety glasses, ear protection, and so forth makes them tougher. That's just not true; it may make them dumber, and it may land them in the hospital, but it does not make them look stronger. Don't fall into the trap so many young tradespeople do. Never let people goad you into bad safety practices. Some people are going to laugh at your kneepads. Let them laugh. You will be the one with great knees when they are hobbling around on canes. I'm dead serious about this issue. There is nothing sissy about safety. Wear your gear in confidence, and don't let the few jokesters get to you.

TOOL SAFETY

Tool safety is a big issue. Anyone in the trades will work with numerous tools. All of these tools are potentially dangerous, but some of them are especially hazardous.

This section is broken down by the various tools used on the job. You cannot afford to start working the basics in tool safety. The more you can absorb on tool safety, the better of you will be. The best starting point is reading all the literature available from the manufacturers of your tools. The people who make the tools provide some good safety suggestions with them. Read and follow the manufacturers' recommendations.

The next step in working safely with your tools is to ask questions. If you don't. understand how a tool operates, ask someone to explain it to you. Don't experiment on your own, or the price you pay could be much too high. Common sense is irreplaceable in the safe operation of tools. If you see an electrical cord with cut insulation, you should have enough common sense to avoid using it. In addition to this type of simple observation, you will learn some interesting facts about tool safety.

There are some basic principles to apply to all of your work with tools. We start with the basics, and then move on to specific tools:

- Keep body parts away from moving tool parts.
- Don't work with poor lighting conditions.
- Be careful of wet areas when working with electrical tools.
- If special clothing is recommended for working with your tools, wear it.
- Use tools only for their intended purposes.
- Get to know your tools well.
- Keep your tools in good condition.

Drills and bits

Drills have been my worst enemy. The two serious injuries I have received both related to my work with a drill. The drills most construction workers use are not the little pistol-grip, handheld types of drills most people think of. The day-to-day drilling done in concrete work involves the use of large, powerful drills. These drills have enormous power when they get in a bind. Hitting an obstruction while drilling can do a lot of damage. You can break fingers, lose teeth, suffer head injuries, and a lot more. As with all electrical tools, you should always check the electrical cord before using your drill. If the cord is not in good shape, don't use the drill.

Always know what you are drilling into. If you are doing new-construction work it is fairly easy to look before you drill. However, drilling in a remodelling job can be much more difficult. You cannot always see what you are getting into. If you are unfortunate enough to drill into a hot wire, you can get a considerable electrical shock. The bits you use in a drill are part of the safe operation of the tool. If your drill bits are dull. sharpen them. Dull bits are much more dangerous than sharp ones. If you will be drilling metal, be aware that the metal shavings will be sharp and hot.

Power saws

Concrete installers don’t use power saws as much as carpenters, but they do use them. The most common types of power saws used by concrete workers are concrete saws, reciprocating saws, and circular saws. These saws are used to cut concrete, form material, pipe, plywood, floor joists, and a whole lot more. All of the saws have the potential for serious injury. Reciprocating saws are reasonably safe. Most models are insulated to help avoid electrical shocks if a hot wire is cut. The blade is typically a safe distance from the user, and the saws are pretty easy to hold and control. However, the brittle blades do break, and this could result in an eye injury. Circular saws are used by concrete workers occasionally. The blades on these saws can bind and cause the saws to kick back. If you keep your body parts out of the way and wear eye protection, you can use these saws safely. Concrete saws are heavy and noisy, and they generate a lot of dust. Protect your eyes and your respiratory system from the flying chips of concrete and dust.

Power mixers

Power mixers are often used on small jobs. These tools make the mixing of concrete simple and require far less effort than what would be needed to mix the concrete manually. Whenever there are moving parts, as there are in mixers, there are safety risks. Workers must be careful not to get body parts or clothing caught in the moving parts of tools. Also, keep your back in mind when lifting bags of material to dump into a mixer.

Air-powered tools

Air-powered tools are not used often by concrete workers. Jackhammers are probably the most used air-powered tools for individuals rehabbing concrete. When using tools with air hoses, check all connections carefully. If you experience a blowout, the hose can spiral wildly out of control. The air hose can also create a tripping hazard that must be avoided. Any type of power washer, sandblaster, or related equipment can cause injuries.

Powder-actuated tools

Powder-actuated tools are used to secure objects to hard surfaces, like concrete. If the user is properly trained, these tools are not too dangerous. However, good training, eye protection, and ear protection are all necessary, Misfires and chipping hard surfaces are the most common problems with these tools.

Ladders

Both stepladders and extension ladders arc used frequently by construction workers. Many ladder accidents are possible. You must always be aware of what is around you when handling a ladder. If you brush against a live electrical with a ladder, you are carrying, your life could be over. Ladders often fall over when the people using them arc not careful. Reaching too far from a ladder can be all it takes to fall. When you set up a ladder or a rolling scaffold, make sure it is set up Properly. The ladder should be on firm footing, and all safety braces and clamps should be in place. When using an extension ladder, many plumbers use a rope to tie rungs together where the sections overlap. The rope provides an extra guard against the ladder safety clamps failing and the ladder collapsing. When using an extension ladder, be sure to secure both the base and the top.

Screwdrivers and chisels

Eye injuries and puncture wounds are common when working with screwdrivers and chisels. When the tools are used properly and safety glasses are worn, few accidents

Types of ladders

There are many types of ladders and it is important to choose the right ladder for the task.

Here are some different types:

- Extension/Straight
- Fixed Access
- Tripod orchard (orchard use only – never use indoors or for smooth surface application)
- Stepladder

Extension/Straight

When using a straight or extension ladder, place the ladder on a firm surface. Make sure it has slip resistant feet, use secure blocking or have someone hold the ladder. When using extension ladders raise the extension ladder to the desired height and ensure both sides are locked. The top of the ladder should extend at least 3 feet above the roof line/contact point. Follow the '4 to 1' rule: one foot back for each four feet up. When you set up the ladder, count the number of rungs up to the point where the ladder touches the wall. The bottom of the ladder must be one rung's length out from the wall for every four rungs up the wall. If needed, secure the top of the ladder. Tie the top of the extension ladder to an anchor point.

Fixed Access Ladders

Fixed (permanent) platforms with access by stair or ladders are needed when regular access is required to equipment elevated either above or below floor level. When installing a fixed access ladder, ensure design requirements comply with OHSA. Regulations for Industrial Establishments, Section 18 and use appropriate safety devices/precautions, for example, a fall arrest harness and a travelling fixture. Always maintain three points of control. This is done by having two hands and one foot, or two feet and one hand on a ladder at all times. When climbing the ladder, face the ladder and place your feet firmly on each rung. Ensure your footwear is clean and free of mud, etc. If you need tools, raise or lower using a hand-line or place the tools in a pouch.

Tripod Orchard Ladders

Tripod orchard ladders are designed for use on soft and uneven surfaces; they do not have spreaders. An orchard ladder has a single back leg. This provides relatively stable support on uneven terrain. This type of ladder is meant to be used in soft soil, therefore the ladder could collapse if used on firm, smooth ground. The steps are at least 27 inches long and should have a metal angle brace. The maximum flare on the top to bottom rails (averaging 2.25 inches per foot) is required to stabilize the base. To avoid excessive penetration in soft soil, a double base on the rails is provided. An orchard ladder should be used for specific operations, such as pruning and harvesting. The top of the ladder can be made of a combination of wood or metal. Only one person should be on the ladder at a time. When using the ladder, the back of the ladder should be towards the tree centre, allowing for additional support if the worker slips. Never use the top of the ladder as a step.

Step ladder

Many of the rules for straight ladders apply to stepladders a well. Never use a step ladder as a straight ladder. Use a platform type stepladder with side rails –it provides safer support and a more stable working surface. Be sure to lock the stepladder – spread the legs to their limit and ensure the braces are locked.

Material

Ladders are made from a number of different materials, each having its own uses and limitations.

The different materials are:

- Aluminum
- Fiber Glass
- Wood
- Steel

Aluminium

Aluminium is the most common material in ladders. Ladders made from aluminium are lightweight, moisture and corrosion resistant. Aluminium conducts heat and electricity; therefore, it should not be used where either of these conditions exists such as for electrical work.

Fiberglass

Fiberglass is an engineered or man-made material that consists of strands of high-strength glass fibres that are encapsulated in a resin matrix. Fibreglass is a non-conductor of heat and electricity and is moisture and corrosion resistant. Fibreglass ladders are heavier than aluminium ladders. Fiberglass ladders should be used for all electrical work and where accidental contact with electrical wires may occur.

Wood

Wood is a natural material and was the most popular choice before the introduction of aluminium and fibreglass ladders. Wood ladders are heavier than aluminium or fibreglass ladders, and because it is a natural material, will have some variations in strength, and can also splinter, rot, warp, and absorb moisture. Wooden ladders are non-conductors of heat and electricity when kept clean and dry. Wooden step ladders do not usually come equipped with non-slip feet, and therefore should not be used in workplaces. Wood ladders must not be painted because it may hide critical flaws and cracks.

Steel

Steel ladders can be very heavy, but are designed to meet specific load requirements. They conduct heat and electricity; therefore, should not be used in these conditions. As well, steel is susceptible to rust and corrosion.

Hazards

Injury statistics show that the use of ladders presents many hazards. Injuries involving ladders frequently cause permanent disability.

The hazards associated with ladders include:

- Falls from ladders

- Struck by falling ladders
- Struck by materials falling from ladders
- Tripping over ladders (erect or lying on floor)
- Lifting heavy ladders
- Striking persons or objects when carrying ladders
- Contact with electrical equipment

General Safety Practices

- Use the right ladder for the job
- Inspect the ladder before and after use
- Get help when moving heavy or long ladders
- Ensure that portable ladders of all types are placed on a stable surface
- When climbing makes sure your shoes/boots are clear of mud, snow and grease
- Protect base of ladder from accidental contact with traffic (human or vehicle) by securing it with hazard tape or warning signs and or having someone present at the base
- Secure the top of a ladder when using it to access a platform or scaffold and ensure that the top of the ladder extends above the upper surface (see extension ladders above)

Legal requirements for health and safety

The Management of Health and Safety at Work Regulations

Main employer duties under the Regulations include:

- making 'assessments of risk' to the health and safety of its workforce, and to act upon risks they identify, so as to reduce them (Regulation 3);
- appointing competent persons to oversee workplace health and safety;
- providing workers with information and training on occupational health and safety; and
- operating a written health and safety policy.

The Workplace (Health, Safety and Welfare) Regulations

The main provisions of these Regulations require employers to provide:

- adequate lighting, heating, ventilation and workspace (and keep them in a clean condition);
- staff facilities, including toilets, washing facilities and refreshment; and
- safe passageways, i.e. to prevent slipping and tripping hazards.

The Personal Protective Equipment at Work Regulations

The main provisions require employers to:

- Ensure that suitable personal protective equipment (PPE) is provided free of charge "wherever there are risks to health and safety that cannot be adequately controlled in other ways."
- The PPE must be 'suitable' for the risk in question, and include protective face masks and goggles, safety helmets, gloves, air filters, ear defenders, overalls and protective footwear; and
- Provide information, training and instruction on the use of this equipment.

The Manual Handling Operations Regulations

The main provisions of these Regulations require employers to:

- avoid (so far as is reasonably practicable) the need for employees to undertake any manual handling activities involving risk of injury;
- make assessments of manual handling risks, and try to reduce the risk of injury. The assessment should consider the task, the load and the individual's personal characteristics (physical strength, etc.); and
- provide workers with information on the weight of each load.

The Reporting of Injuries, Diseases and Dangerous Occurrences Regulations

- Under these Regulations, employers are required to report a wide range of work-related incidents, injuries and diseases to the Health and Safety Executive (HSE), or to the nearest local authority environmental health department.
- The Regulations require an employer to record in an accident book the date and time of the incident, details of the person(s) affected, the nature of their injury or condition, their occupation, the place where the event occurred and a brief note on what happened.

The following injuries or ill health must be reported:

- the death of any person;
- specified injuries including fractures, amputations, eye injuries, injuries from electric shock, and acute illness requiring removal to hospital or immediate medical attention;
- 'over-seven-day' injuries, which involve relieving someone of their normal work for more than seven days as a result of injury caused by an accident at work;

OSHA guidelines

- Nearly 6.5 million people work at approximately 252,000 construction sites across the nation on any given day.

- The fatal injury rate for the construction industry is higher than the national average in this category for all industries.

  Potential hazards for workers in construction include:

- Falls (from heights);
- Trench collapse;
- Scaffold collapse;
- Electric shock and arc flash/arc blast;
- Failure to use proper personal protective equipment; and
- Repetitive motion injuries.

For construction, the 10 OSHA standards most frequently included.

- Scaffolding
- Fall protection (scope, application, definitions)
- Excavations (general requirements)
- Ladders
- Head protection
- Excavations (requirements for protective systems)
- Hazard communication
- Fall protection (training requirements)
- Construction (general safety and health provisions)
- Electrical (wiring methods, design and protection)

Scaffolding

- **Hazard:** When scaffolds are not erected or used properly, fall hazards can occur. About 2.3 million construction workers frequently work on scaffolds. Protecting these workers from scaffold-related accidents would prevent an estimated 4,500 injuries and 50 fatalities each year.

Solutions:

- Scaffold **must be** sound, rigid and sufficient to carry its own weight plus four times the maximum intended load without settling or displacement. It must be erected on solid footing.
- Unstable objects, such as barrels, boxes, loose bricks or concrete blocks must not be used to support scaffolds or planks.

- Scaffold must not be erected, moved, dismantled or altered except under the supervision of a competent person.
- Scaffold must be equipped with guardrails, mid-rails and toe-boards.
- Scaffold accessories such as braces, brackets, trusses, screw legs or ladders that are damaged or weakened from any cause must be immediately repaired or replaced.

Fall Protection

- **Hazard:** Each year, falls consistently account for the greatest number of fatalities in the construction industry. A number of factors are often involved in falls, including unstable working surfaces, misuse or failure to use fall protection equipment and human error. Studies have shown that using guardrails, fall arrest systems, safety nets, covers and restraint systems can prevent many deaths and injuries from falls.

Solutions:

- Consider using aerial lifts or elevated platforms to provide safer elevated working surfaces;
- Erect guardrail systems with toe-boards and warning lines or install control line systems to protect workers near the edges of floors and roofs;
- Cover floor holes; and/or
- Use safety net systems or personal fall arrest systems (body harnesses).

Hazard: Ladders and stairways are another source of injuries and fatalities among construction workers. OSHA estimates that there are 24,882 injuries and as many as 36 fatalities per year due to falls on stairways and ladders used in construction. Nearly half of these injuries were serious enough to require time off the job.

Solutions:

- Use the correct ladder for the task.
- Have a competent person visually inspect a ladder before use for any defects such as:
- Structural damage, split/bent side rails, broken or missing rungs/steps/cleats and missing or damaged safety devices;
- Grease, dirt or other contaminants that could cause slips or falls;
- Paint or stickers (except warning labels) that could hide possible defects.
- Make sure that ladders are long enough to safely reach the work area.
- Mark or tag ("Do Not Use") damaged or defective ladders for repair or replacement, or destroy them immediately.

Stairways

- Hazard: Slips, trips and falls on stairways are a major source of injuries and fatalities among construction workers.

Solutions:

- Stairway treads and walkways must be free of dangerous objects, debris and materials.
- Slippery conditions on stairways and walkways must be corrected immediately.
- Make sure that treads cover the entire step and landing.
- Stairways having four or more risers or rising more than 30 inches must have at least one handrail.

Important Safety Measures for Construction Sites

- Every employer is responsible for safeguarding the health and safety of their staff irrespective of the industry and the nature of work being performed.
- In case of construction workers, they work in a high risk environment that is subject to electrical hazards and the dangers of construction machinery.
- In fact, according to Safe Work NSW, "around 25,000 workers suffered injuries on NSW construction sites in the last 3 years due to unsafe work conditions. 23 workers were killed and 1700 were left with permanent disabilities".
- These alarming stats make it evident that it is very important to take appropriate safety measures on a construction site and protect the construction crew from fatalities.

1. Manage and Mitigate Risk with a Safety Training Program

- Due to the risk inherent in construction work, all employees must be trained and instructed to point out high risk areas for efficient emergency management.
- While it is impossible to eliminate the risk completely, training programs can educate site workers to conduct regular safety audits.
- This will enable them to assess and address potential risks and greatly minimize the possibility of injuries, thereby ensuring a safe working environment.

2. Ensure Electrical Safety at Construction Sites

- With an average of one worker being electrocuted on the job every day in the U.S., electrocution is the fourth leading cause of death on construction sites.
- The use of power and electrical transformers on construction sites is particularly hazardous due to the use of flexible extension cords and scattered power cables in damp conditions.

Tips to ensure electrical safety at construction sites:

- Overhead and underground power transmission lines can be lethal so it is important that the construction crew maintains safe distance from them, all the lines are grounded, all construction electrical products are insulated using sleeves and all heavy equipment are de-energized when not in use.
- Check that all the extension cords are adequate for the amount of current being carried to avoid fluctuations and overloading. All construction electrical products must be UL approved and have strain relief along with a three-prong grounding plug for safe usage.
- If a portable electrical product is used in a damp environment, it is essential to ensure that a transformer is used to isolate the voltage between conductors so it does not exceed 230 volts.
- Construction electrical products must be rated for heavy-duty usage and a GFCI should be employed for ground-fault protection.

3. Implement Strict Security and Safety Protocols

- Construction site access should be limited to ensure protection of heavy equipment and machinery from theft and damage.
- The safety of pedestrians from potential hazards of a construction site requires strict supervision while the work is on.
- Only authorized visitors should be allowed on site and strict safety protocols should be enforced to protect contractors from liabilities, security breach and litigation due to negligence of safety.

4. Have a Safe Work Assessment Process in Place

- An SWMS (Safe Work Method Statement) must be prepared and implemented for all high-risk projects prior to the commencement of work.
- This statement must clearly outline the scope of work and potential risks involved along with ways to avoid or manage them. Ideally, no construction work can be commenced until all the SWMS standards have been met.

5. Make Sure Chemical Storage Safety Requirements are Strictly Followed

- Chemicals can cause pollution, fire, explosion and serious injuries if not stored, handled or used with caution.
- Using high-quality and compliant storage solutions for chemicals can reduce the risk of spillage and fatalities.

6. Display Signage Clearly at the Construction Site

- The SWMS must be clearly displayed throughout the construction site so that all the safety protocols are visible at all times.
  It should also include a 24-hour emergency number along with a map that leads to the office.

- The signage should indicate the location of fire extinguishers, first aid supplies, emergency exits, and amenities available on site.

7. Plan and Prepare for Adverse Environmental Conditions

- Unfavourable weather conditions can invite serious accidents on construction sites.
- Every construction site must have a contingency plan that guides workers with clear instructions to stop work in case of extreme weather conditions and steps to handle emergencies in case of natural disasters.

8. Provide Personal Protective Equipment

- An employer is obligated to provide his staff with all the necessary PPE including safety harness, safety goggles, head protection gear, and fall protection depending on the type of work.
- These safety tips make a good starting point for implementing a safety program and for ensuring electrical safety at construction sites.