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SCHOOL OF BUILDING AND ENVIRONMENT

DEPARTMENT OF CIVIL ENGINEERING

UNIT – I – Maintenance and Repair Strategies – SCIA7003

I. Maintenance and Repair Strategies

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

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.

e) 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.

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

a) Atmospheric agencies
b) Normal wear and tear
c) Failure of structure

a) Atmospheric agencies

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

Dissolving and carrying away minerals as it is universal solvent.

Expansion and contraction – The materials is subjected to repetitive expansion and contraction while they become wet and dry and develops the stresses.

Expansion of water – The variation of temperature causes the expansion and contraction absorbed water and affects the micro-structures of the materials.

Erosion – Transportation, attrition and abrasion of the materials is quite evident effect of the water.

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

Wind: It is the agent, which transports the abrasive material and assists the physical weathering Its action is aggravated during rains and, When it is moving with high speed, it may contains acidic gases like CO2 fumes which may act over the material and penetrates quite deeply in materials and structure.

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 is 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.

Facets of maintenance: Maintenance operations have many facets such as

- Emergency maintenance: Necessitated by unforeseen breakdown drainage or damage caused by natural calamity like fire, floods, cyclone earthquake etc.
- Condition Based maintenance: Work initiated after due inspection
- Fixed time maintenance: Activities repeated at predetermined intervals of time.
- Preventive maintenance: This is intended to preserve by preventing failure and detecting incipient faults (Work is done before failure takes place)
- Opportunity maintenance: Work did as and when possible within the limits of operation demand.
- Day-to-Day care and maintenance
- Shut down maintenance: Thorough overhaul and maintenance after closing a facility.
- Improvement plans: This is essentially maintenance operation wherein the weak links in the original construction are either replaced by new parts or strengthened.

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

Various aspects Inspection: The following are the various maintenance aspects,

a) Daily Routine Maintenance

b) Weekly Routine Maintenance

c) Monthly Routine Maintenance

d) Yearly Routine Maintenance

a) Daily Routine Maintenance:

- ✓ Basically an inspection oriented and may not contain action to be taken.
- ✓ Helps 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

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

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

a) Removal of damaged concrete

b) Pretreatment 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:

- ✓ Prior to the execution of any repair, one essential and common requirement is that the deteriorated or damaged concrete should be removed.
- ✓ Removal of defective concrete can be carried out using tools and equipment the types of which depend on the damage.
- ✓ 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.
- ✓ Care should be taken not to damage the unaffected concrete portions.
- ✓ For cracks and other narrow defects, a saw-toothed bit will help achieve sharp edges and a suitable under cut.

b) Pretreatment of surfaces and reinforcement:

The preparation of a surface/pretreatment for repair involved the following steps:

- ✓ Complete removal of unsound material.
- ✓ Undercutting along with the formation of smooth edges.
- ✓ Removal of the cracks from the surface.
- ✓ Formation of a well-defined cavity geometry with rounded inside corners.
- ✓ Providing, rough but uniform surface for repair.

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:

- ✓ After the concrete surface has been prepared, a bonding coat should be applied to the entire cleaned exposed surface.
- ✓ It should be done with minimum delay.
- ✓ The bonding coat may consist of bonding agents such ass cement slurry, cement sand mortar, epoxy, epoxy mortar, resin materials etc.
- ✓ 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 objective:

a) To increase strength or restore load carrying capacity.

b) To restore or increase stiffness.

c) To improve functional performance.

d) To provide water tightness.

e) To improve appearance of concrete surface.

f) To improve durability.

g) To prevent access of corrosive materials to reinforcement.

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.

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.

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:

Strength Tests:

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

  Pulse Eco Technique

Durability Tests:

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

Performance and Integrity Tests:

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

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 surface 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. 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. 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 transmit 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 CO2, and its conversion into CaCO3. 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.
7. **Thermo gravimetric and Dilatometric test**: 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 5000C. Using thermo gravity curves the temperature attained during fire can be obtained. In dilatometric test, shrinkage of concrete due to process of dehydratrion is detected. By compaction expansion with temperature lines that represents dialometric curves for fire damaged concrete and unaffected concrete, the probable temperature to which concrete was subjected can be established.
8. **Thermo luminescence Test** :Thermo luminescence 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 3000C to 500 0C. 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.
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 are 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

- Re-entrant corners
- Changes in cross section
- Rigid joints in precast elements
- Deflections

This leads 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

6. Neglect in design

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 flaws: 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 carbondioxide 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 material used: 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 l aid sown 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.

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UNIT – II – Serviceability and Durability of Concrete – SCIA7003

II. Serviceability and Durability of Concrete

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:

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. The client requires it in promoting his next engineering scheme. The designer depends on it for his reputation and professional satisfaction. The material producer is influenced by the quality of work in his future sales. 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. 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. Yet this is not so, and a considerable positive effort must be employed to achieve it. 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: It is a system of procedures and standards by which the contractor, the product manufacture and the engineer monitor the properties of the product. Generally the contracting agency is responsible for the QC process. 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 : This is the system of tracing and documentation of quality assurance and quality control program. It is the responsibility of the process owner. Both design and construction processes comes under this process. The concept of QA encompasses the project as a whole. 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 watertightnesss 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 concrete 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.

The high permeability of concrete in actual structures is due to the following reasons:

- ✓ The large microcracks 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 affected by moisture content and porosity.

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

Coefficient of thermal expansion
Thermal conductivity
Thermal diffusivity
Specific heat

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 n 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.

Durability:

Definition: 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 degree celsius.
- ✓ 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 and 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 occurs 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.

Effect of Corrosion:

Formation of white patches:CO2 reacts with Ca(OH)2 in the cement paste to form CaCO3. The free movement of water carries the unstable CaCO3 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.

1. 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.

2. 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.

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 cavitations erosion may be induced, or in lock chambers where the “rubbing” surfaces must be straight.

(c) **Improper consolidation**.

Improper consolidation of concrete may result in a variety of defects, the most common being bugholes, honeycombing, and cold joints. “Bugholes” are formed when small pockets of air or water are trapped against the forms. A change in the mixture to make it less “sticky” or the use of small vibrators worked near the form has been used to help eliminate bugholes. Honeycombing can be reduced by inserting the vibrator more frequently, inserting the vibrator as close as possible to the form face without touching the form, and slower withdrawal of the vibrator. Obviously, all of these defects make it much easier for any damage-causing mechanism to initiate deterioration of the concrete. Frequently, a fear of “overconsolidation” is used to justify a lack of effort in consolidating concrete. Overconsolidation 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 pro-vide 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.

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

SCHOOL OF BUILDING AND ENVIRONMENT

DEPARTMENT OF CIVIL ENGINEERING

UNIT – III – Materials and Techniques for Repair – SCIA7003

III. Materials and Techniques for Repair

Special Mortar:

The following are the different types of special mortars available, they are

- 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:

Here clay is introduced as an effective finely ground additive in quantities ensuring a cement-clay proportion of not over 1:1. The addition of clay improves the grain composition, the water retaining ability and the workability of mortar and also increases the density of mortar. This type of mortar has better covering power and can be used in thin layers.

Lightweight and Heavy mortars Light weight mortars:

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

Heavy weight mortars:

These are prepared from heavy quartz or other sands. They have bulk density of 15 KN/m3 or more. They are used in load bearing capacity.

Decorative mortars:

These mortars are obtained by using Colour 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. 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 firebricks(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 mortarts 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 a mortar varies from 6 to 12KN/m3 . Noise level can be reduced by using sound absorbing plaster formed with the help of sound absorbing mortar.

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.

- 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. Most admixtures result in modifying more than one intended property.
- Some chemicals are applied on the surfaces of moulds used to form concrete to effect easy mould-releasing operation.
- Some chemicals are applied on the surfaces of concrete to protect it during or after its setting.
- Some chemicals are applied to bond or repair broken or chipped concrete.

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 are used for grouting anchor bolts or grouting machine foundations or the cement used in grouting the prestress 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.

Polymer Concrete:

Polymer concrete is an aggregate bound with a polymer binder instead of Portland cement as in conventional concrete. The main technique in producing PC is to minimize void volume in the aggregate mass so as to reach the quantity of polymer needed for binding the aggregates. This is achieved by properly grading and mixing the aggregates to attain the maximum density and minimum void volume. The graded aggregates are prepacked and vibrated in a mould. Monomer is then diffused up through the aggregates and polymerization is initiated by radiation or chemical means. A silane coupling agent is added to the monomer to improve the bond strength between the polymer and the aggregate. In case polyester resins are used no polymerization is required. An important reason for the development of this material is the advantage it offers over conventional concrete where the alkaline Portland cement on curing, forms internal voids. Water can be entrapped in these voids which on freezing can readily crack the concrete. Also the alkaline Portland cement is easily attacked by chemically aggressive materials which results in rapid deterioration, whereas polymers can be made compact with minimum voids and are hydrophobic and resistant to chemical attack. The strength obtained with PC can be as high as 140 MPa with a short curing method.

Advantages:

- Advantages of polymer concrete include:
- Rapid curing at ambient temperatures
- High tensile flexural, and compressive
- strengths Good adhesion to most surfaces
- Good long-term durability with respect to freeze and thaw
- cycles Low permeability to water and aggressive solutions
- Good chemical resistance
- Good resistance against corrosion
- Lightweight
- May be used in regular wood and steel formwork
- May be vibrated to fill voids in forms
- Allows use of regular form-release agents Dialectric.

Disadvantages:

Some safety issues arise out of the use of polymer concrete. The monomers can be volatile, combustible, and toxic. Initiators, which are used as catalysts, are combustible and harmful to human skin. The promoters and accelerators are also dangerous. Polymer concretes also cost significantly more than conventional concrete.

Sulphur-Infiltrated concrete:

New type of composites have 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 several hundred % 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 processes is made economical. It is reported that compressive strength of about 100 MPa could be achieved in about 2 day‟s time.

FerroCement:

Ferrocement 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. Ferrocement 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 1.0mm dia wire at 5mm to 10mm 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 ferrocement elements are usually of order of 2 to 3 cm in thickness with 2 to 5mm 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 stains 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 reparability, 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 ferrocement. In the ferrocement 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.

Fibre 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 have more tensile strength. Fibres improve the impact and abrasion resistance of concrete. It posses high compressive strength. It posses 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:

1. Steel Fibres

2. Glass Fibres

3. Polypropylene Fibres

4. Slurry Infiltrated Fibre Concrete (SIFCON)

5. Asbestos fibre

6. Carbon fibre

Polymer Resin based Coating:

These are generally of two types,

1. Resins blended with organic solvents

2. 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 vapor, they could blister. When applied to concrete surfaces with high moisture content or where the opposite surface of the concrete is in constant contact with moisture. Careful control of wet film thickness is therefore necessary during application. Two component polymer coatings consist of a solution of a compounded polymer with or without solvent and a reactive chemical component called the curing agent hardener or catalyst. The materials are usually mixed just prior to use in accordance with the manufacturer‟s instructions.

When using two components polymer based coatings the following items are of importance to the application of the materials.

1. Most produces are supplied as a kit containing the two components in the required proportions. Therefore, in order to realize the full potential of the product the correct mix

ratio of the two components must be used.

2. To ensure a complete reaction of the two components they must be mixed thoroughly.

3. Some two component material require an induction period of 15 to 40 min after mixing. Therefore, such products cannot be used immediately after mixing.

4. Viscosity reduction by the use of thinners should be resorted to only after the manufacturers are consulted.

5. The storage temperature of solvent based coatings is not critical. They should be stored are a temperature 16 to 32◦c just prior to use.

Vacuum 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 percentage. 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 Gunite or shotcrete:

It 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 “Redi-set 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. The dry mix process is more successful and generally used.

Dry-mix Process: The dry mix process consists of number of stages and calls for some specialized plan. A typical small plant set-up is shown. This material is carried by compressed air through the delivery hose to a special nozzle. The nozzle is fitted inside with a perforated manifold through which water is sprayed under pressure and intimately mixed with the sand/cement jet. The wet mortar is jetted from the nozzle at high velocity onto the surface to gunited.

Wet-mix process:In the wet-mix process the concrete is mixed with water as for ordinary concrete before conveying through the delivery pipe line to the nozzle, at which point it is jetted by a compressed air, onto the work in the same way, as that of dry-mix process. The wet-mix process has been generally discarded in favour of dry-mix process, owing to the greater success of the latter. The dry-mix method makes use of high velocity or low velocity system fully. The high velocity gunite is produced by using the small nozzle and a high air pressure to produce a high nozzle velocity of about 90 to 120 meters/sec. This results in exceptional good compaction. The lower velocity gunite is produced using large diameter hose for large output. The compaction will not be very high.

General use of Shotcrete

1. It is useful where considerable savings and peculiar adaptability is needed and it is more suitable than conventional placing methods.

2. Shuttering and formwork need be erected only on side of the work and hence there will be considerable saving in the shuttering costs.

3. It can be conveyed over a considerable diameter pipe, makes this process suitable for sites where access is difficult.

4. The maximum rate of deposition is about 15 m3 hr for the dry process but this can be exceeded with the wet process.

5. The low water-cement ratio, the thinness of the section deposited and the fact that normally only one side of the concrete is covered, necessitates careful attention to curing more than with normal concrete.

6. The normal specifications with respect to cement, aggregate and water, also apply for shotcrete, but it is desirable that the aggregate should be harder to allow for attrition.

7. Admixtures can be used in shotcrete to produce the same effects as in ordinary concrete.

8. The drying shrinkage will depend on the water content and may, therefore, be expected to be fairly low for the dry process. The creep of the dry shocrete is similar to that of high quality normally placed concrete but shrinkage and creep of wet shocrete is likely to be high.

9. The durability or resistance to frost action and other agencies of dry shotcrete is good.

10. About half of the entrained air is likely to be lost while spraying.

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 20mm 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 20mm dia and 12 to25mm below the apex of V-grooved section, is drilled into the crack. A tire-calue stren is bonded with an epoxy adhesive in the hole. In case the cracks are not V-grooved, the entry port is provided by bonding a fitting, having a hat-like croos-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 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 seldom exceed 0.10Mpa. 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.

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SCHOOL OF BUILDING AND ENVIRONMENT

DEPARTMENT OF CIVIL ENGINEERING

UNIT – IV – Strengthening and Stabilization Techniques – SCIA7003

IV. Strengthening and Stabilization Techniques

Introduction

Although hundreds of thousands successful reinforced concrete and masonry buildings are annually constructed worldwide, there are large number of concrete and masonry structures that deteriorate, or becomes unsafe due to changes in loading, changes in use, or changes in configuration. Also, from the experiences of earthquakes happened that old structures are designed for gravity loads and not able to withstand seismic forces and causes wide spread damages. Repair of those structures is often difficult, expensive, hazardous and disruptive to the operation of the building. The removal and transportation of large amount of concrete and masonry material causes concentration of weight, dust, excessive noise and requires long period of time to gain strength before the building can be reopened for service.

In order to repair those structures, Fibre Reinforced Composite (FRC) materials plays a vital role due to its light weight, ease of handling and rapid implementation.

Structures damage due to earthquake

Earthquake generates ground motion both in horizontal and vertical direction. Due to the inertia of the structure ground motion generates shear force and bending moments in the structure framework. The bending moments and shear are maximum at the joints, so the joints should be ductile to dissipate the earthquake forces. Most of the earthquake affected structures are observed at the joints. If the concrete lacks confinement the joints may disintegrate and the concrete may spall. If the shear reinforcement in the beam is insufficient there may be diagonal cracks near the joints.

Figure 1: Spalling of Concrete

Figure 2: Spalling of Concrete at Joints

Figure 3: Diagonal Cracks at joints

Materials for strengthening of structures

A comparison of mechanical behaviour of material is available for strengthening of structures. It is found that non-metallic fibres have strengths that are 10 times more than that of the steel. In addition, density of these materials is approximately one-third that of the steel. Due to its corrosive resistance, FRC's can be applied on the surface without worrying about its deterioration due to environmental attack. By considering steel, polyesters, glass, aramid and carbon, Carbon is considered as beneficial as compared with other composites.

FRP's can be used in concrete structures in various forms:

1. Plates: at -a face to improve the tension capacity:

   This method is more convenient and durable than epoxy bonded steel plates. It is observed that the prestressing laminates are effective in closing the crack of the damaged structure, therefore increases the serviceability of the strengthened structure. Prestress also reduces stress in steel.

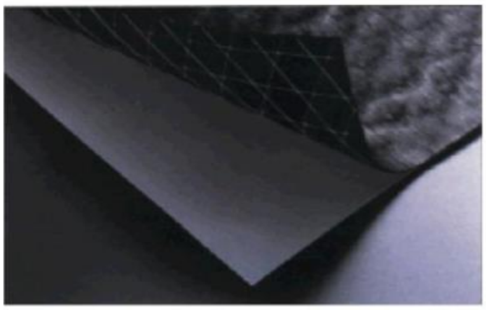

Figure 4: Fibre plates

2. Bars – as reinforcement in the beams and slabs replacing steel bars:

   The steel reinforcement in concrete structure is often largely responsible in early corrosion and deterioration of concrete structure. The steel reinforcement is susceptible to corrosion and it leads to spalling of concrete. FRC rebars are non-magnetic, non-corrosion behaviour but lower bond strength. This bond strength is improved by mechanical anchorage and coating the surface of the bar with sand.

Figure 5: Fibre reinforced bars

3. Cables – as tendons and post tension members in suspension and bridge girders: Corrosion problems are very severe in transportation structure, especially those which are exposed to marine conditions. This encourages the use of FRCs in bridges. FRC cables, post tension tendons and plating can be used to improve the durability of the bridge. Moreover, FRC cables are much lighter than the conventional steel cables leading to the lesser in self weight hence longer spans can be designed using FRCs.

Figure 6: Cables of FRCs used in bridges

4. Wraps – around concrete member to confine concrete and improve the compressive strength: The tensile strength of concrete is much less in comparison to its compressive strength. Often these structures fail due to tensile stress that develops in the perpendicular direction to that of compressive load. Such a concrete element is confined using wrapping, so that failure due to tensile cracks can be prevented.

Figure 7: Column wrapping

Repair of Structural failures in concrete structures

Techniques for Strengthening of Beam:

1. Adding new members and enlarging sections:

   If the beam span is too long, in the mid span added steel beams are bolted to the existing beams to increases its strength. On the other hand, holes are drilled on either side of the existing beams and the new rigid steel channels are attached and bolted.

Figure 8: Adding new member for Strengthening

2. Shortening the span:

   Columns are constructed in-between long beams, to avoid more sagging in the beam.

Figure 9: Shortening the Span

3. Added bolted steel tension reinforcement:

   The earlier beams are roughened and new stirrups are being drilled in adhesive anchor and the new concrete is plastered.

4. Adding bolted FRS plates and wraps:

   As the beam is susceptible to spalling to avoid these, the surface of the beam is pasted with adhesive and FRS plates are being wrapped around the beam.

5. For distress due to shear can be improved by following ways: The new plates cover the sides of the existing beams and are through bolted at least two places. Other way is by adding new stirrups. Use epoxy-bonded FRP composites to wrap the ends of the beam in thin laminates FRP plates.

Techniques for Strengthening of Column:

Column Strengthening is a process used to add or restore ultimate load capacity of reinforced concrete columns. It is used for seismic retrofitting, supporting additional live load or dead load that are included in the original design, to relieve stresses generated by design or construction errors or to restore original load capacity to damaged structural elements.

1. Section enlargement: Section can be enlarged by adding new stirrups and plastering the column with new concrete to the earlier column. By this way section are enlarged and thereby increasing the strength.
2. Adding Columns: Adding column is nothing but constructing a new column besides the older column.
3. Reinforcing with structural steel or Steel Jacketing:

   This technique is chosen when the loads applied to the column will be increased and at the same time, increasing the cross- sectional area of the column is not permitted. In this method the earlier column, plates are fixed around the surface and they are drilled with holes, the holes are filled with epoxy or grout and bolted.

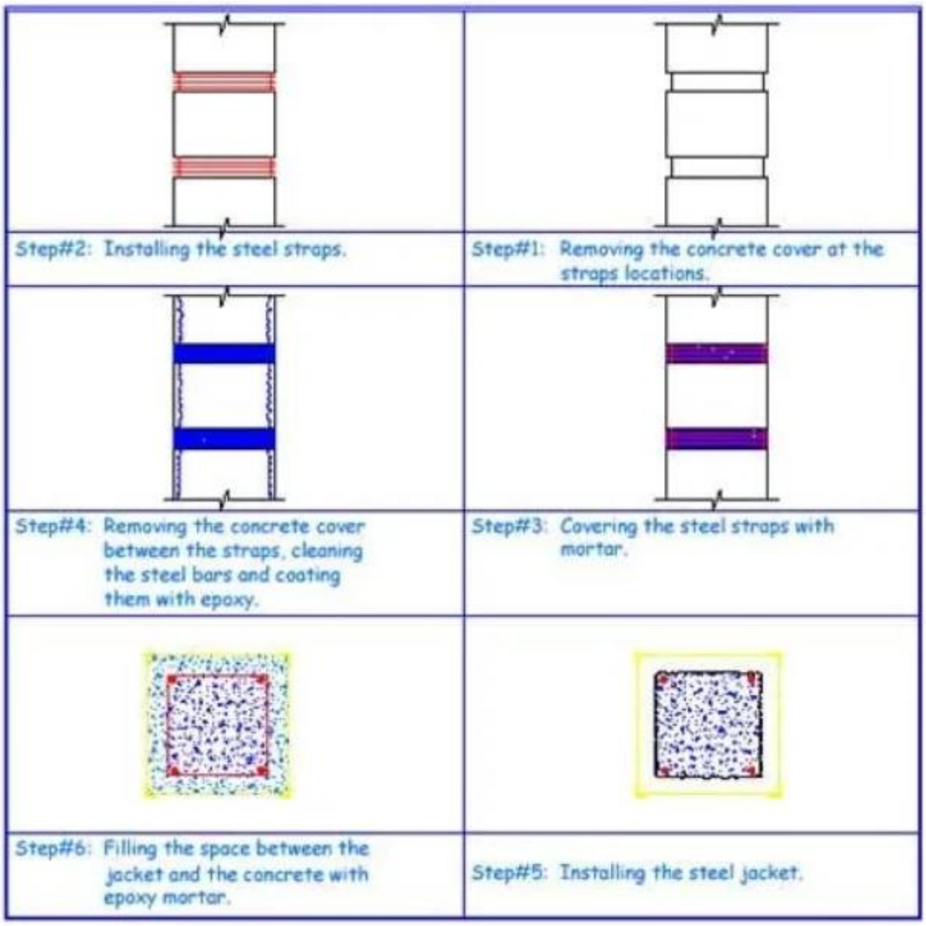

Figure 10: Process of Steel Jacketing

4. Reinforcing with FRP wraps: As similar to that beam the column is also wrapped with FRP. FRP axial strengthening systems are used to improve or enhance the capacity of reinforced concrete columns. It can be used for both circular and rectangular shaped

columns but it is effective for circular shape.

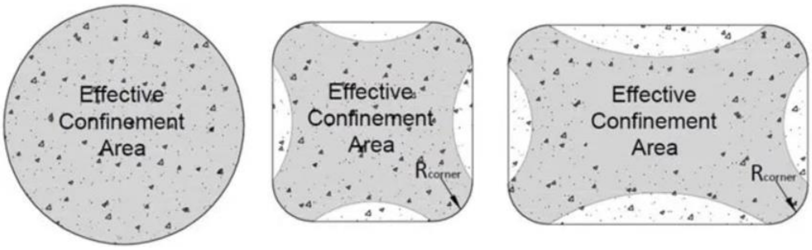

Figure 11: Comparison of Effective Confinement area for different shapes

Figure 12: Column confined with continuous FRP

5. Jacketing around: Jacketing is the method in which, the previous column is roughened and new ties and longitudinal reinforcement is assembled and concreting is done by micro concrete. And it is made into a new column of increased dimension.

Figure 13: Column Jacketing

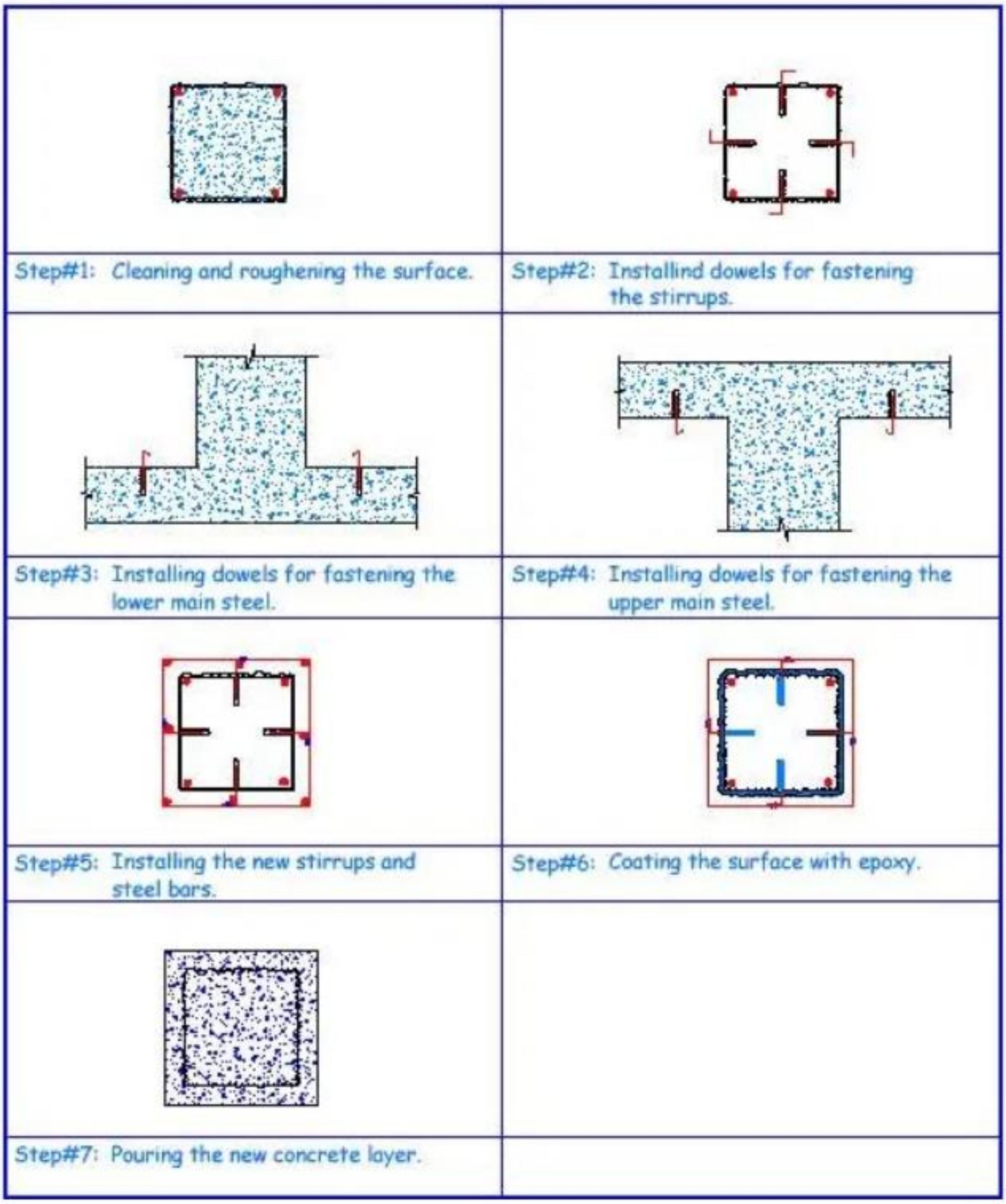

Figure 14: Process of Column Jacketing

Techniques for Strengthening of Slabs:

1. By shortening of span by introducing steel beams at the mid spans: As similar to adding new member in beams, if the slab is too long. In the mid spans steel beams are introduced in the lower part of the slab, the steel beam is fixed onto the slab by epoxy or resin.

Figure 15: Introducing Steel beams

2. By adding steel plates to improve the flexural resistance of the existing slab: In this method steel plates are being applied to the existing beams to improve flexural resistance
3. By applying various composites like CFRP: In this method, Carbon Fibre Reinforced Plastics are being popular now-a-days for repairing.

SCHOOL OF BUILDING AND ENVIRONMENT

DEPARTMENT OF CIVIL ENGINEERING

UNIT – V – NDT of Steel – SCIA7003

V. NDT of Steel

SIMPLE SURFACE NDT TESTS

Nondestructive testing (NDT) is the process of inspecting, testing, or evaluating materials, components or assemblies for discontinuities, or differences in characteristics without destroying the serviceability of the part or system. In other words, when the inspection or test is completed the part can still be used.

NDT Test Methods

Current NDT methods are:

- Acoustic Emission Testing (AE)
- Electromagnetic Testing (ET)
- Guided Wave Testing (GW)
- Ground Penetrating Radar (GPR)
- Laser Testing Methods (LM)
- Leak Testing (LT)
- Magnetic Flux Leakage (MFL)
- Microwave Testing
- Liquid Penetrant Testing (PT)
- Magnetic Particle Testing (MT)
- Neutron Radiographic Testing (NR)
- Radiographic Testing (RT)
- Thermal/Infrared Testing (IR)
- Ultrasonic Testing (UT)
- Vibration Analysis (VA)
- Visual Testing (VT)

The six most frequently used test methods are MT, PT, RT, UT, ET and VT. Each of these test methods will be described here, followed by the other, less often used test methods.

Magnetic particle inspection

- Magnetic particle Inspection (MPI) is a non-destructive testing_(NDT) process for detecting surface and slightly subsurface discontinuities in ferromagnetic materials such as_iron,_nickel,_cobalt, and some of their_alloys.
- The process puts a magnetic field into the part.
- The piece can be magnetized by direct or indirect magnetization.
- Direct magnetization occurs when the electric current is passed through the test object and a magnetic field is formed in the material.
- Indirect magnetization field is applied from an outside source.
- The magnetic lines of force occurs when no electric current is passed through the test object, but a magnetic are perpendicular to the direction of the electric current, which

may be either alternating current (AC) or some form of direct current (DC) (rectified AC).

- The presence of a surface or subsurface discontinuity in the material allows the magnetic flux to leak, since air cannot support as much magnetic field per unit volume as metals.
- Ferrous particles are then applied to the part.
- The particles may be dry or in a wet suspension.
- If an area of flux leakage is present, the particles will be attracted to this area.
- The particles will build up at the area of leakage and form what is known as an indication.
- The indication can then be evaluated to determine what it is, what may have caused it, and what action should be taken, if any.

Types of electrical current used

- Alternating current
- Full wave DC
- Half wave DC

Equipment

- A wet horizontal MPI machine is the most commonly used mass production inspection machine. The machine has a head and tail stock where the part is placed to magnetize it. In between the head and tail stock is typically an induction coil, which is used to change the orientation of the magnetic field by 90° from the head stock. Most of the equipment is built for a specific application.
- Mobile power packs are custom-built magnetizing power supplies used in wire wrapping applications.
- Magnetic yoke is a hand-held device that induces a magnetic field between two poles. Common applications are for outdoor use, remote locations, and weld inspection. The drawback of magnetic yokes is that they only induce a magnetic field between the poles, so large-scale inspections using the device can be time-consuming. For proper inspection the yoke needs to be rotated 90 degrees for every inspection area to detect horizontal and vertical discontinuities. Subsurface detection using a yoke is limited. These systems used dry magnetic powders, wet powders, or aerosols

Demagnetizing parts

- After the part has been magnetized it needs to be demagnetized.
- This requires special equipment that works the opposite way of the magnetizing equipment.
- The magnetization is normally done with a high current pulse that reaches a peak current very quickly and instantaneously turns off leaving the part magnetized.
- To demagnetize a part, the current or magnetic field needed has to be equal to or greater than the current or magnetic field used to magnetize the part.
- The current or magnetic field is then slowly reduced to zero, leaving the part demagnetized.

<u>Demagnetizing done by</u>

- Pull through AC demagnetizing coils
- AC decaying demagnetizing

- Reversing full wave demagnetizing
- Half wave DC demagnetizing

Magnetic particle powder

- A common particle used to detect cracks is iron oxide, for both dry and wet systems.
- Wet system particle range in size from less than 0.5 micrometres to 10 micrometres for use with water or oil carriers. Particles used in wet systems have pigments applied that fluoresce at 365 nm (ultraviolet A) requiring 1000 µW/cm^2 (10 W/m^2) at the surface of the part for proper inspection. If the particles do not have the correct light applied in a darkroom the particles cannot be detected /seen. It is industry practice to use UV goggles/glasses to filter the UV light and amplify the visible light spectrum (normally green and yellow) created by the fluorescing particles. Green and yellow fluorescence was chosen, because the human eye reacts best to these colors.
- After applying wet magnetic particles, a U.S. navy technician examines a bolt for cracks under ultraviolet light.
- Dry particle powders range in size from 5 to 170 micrometres, designed to be seen in white light conditions. The particles are not designed to be used in wet environments. Dry powders are normally applied using hand operated air powder applicators.
- Aerosol applied particles are similar to wet systems, sold in premixed aerosol cans similar to hair spray.

Use of coating gauges for metallic and non-metallic coating

- A coating thickness gauge (also referred to as a paint meter) is used to measure dry film thickness.
- Dry film thickness is probably the most critical measurement in the coatings industry because of its impact on the coating process, quality and cost.
- Dry film thickness measurements can be used to evaluate a coating’s expected life, the product’s appearance and performance, and ensure compliance with a host of International Standards.

How to measure Dry Film Thickness

- Dry film thickness (DFT) can be measured using two methods: destructive thickness measurement, where the coating is cut to the substrate using a cutter;
- Non-destructive coating thickness measurement, using techniques which do not damage the coating or the substrate such as magnetic, magnetic induction and eddy current thickness measurement methods.
- The non-destructive coating thickness measurements can be taken on either magnetic steel surfaces or non-magnetic metal surfaces such as stainless steel or aluminium.
- Digital coating thickness gauges are ideal to measure coating thickness on metallic substrates.
- Electromagnetic induction is used for non- magnetic coatings on ferrous substrates such as steel, whilst the eddy current principle is used for non-conductive coatings on non-ferrous metal substrates.

Figure 1: Digital Coating Thickness Gauge

- **Nondestructive examination (NDE) methods** of inspection make it possible to verify compliance to the standards on an ongoing basis by examining the surface and subsurface of the weld and surrounding base material.
- Five basic methods are commonly used to examine finished welds: visual, liquid penetrant, magnetic particle, ultra-sonic and radiographic (X-ray).
- The growing use of computerization with some methods provides added image enhancement, and allows real-time or near real-time viewing, comparative inspection and archival capabilities.
- A review of each method will help in deciding which process or combination of processes to use for a specific job and in performing the examination most effectively.

Welding is essential to the construction and fabrication of many vital components, finished products, and structures. The safety and satisfaction of consumers depends on the quality assurance of welds. Several methods of non- destructive examination are used to assure the quality of a welded part. Visual inspection is the primary method for examining the quality of a weld made by any welding process. Other methods include penetrant, magnetic, radiographic, ultrasonic, electromagnetic, and leak inspection.

Quality indicates how well a part conforms to its specifications, or "specs." Specifications are the design parameters that set the limits of acceptable deviation for a part's intended application.

Factors that can affect the quality of a welded part include the following:

- The design of a weldment
- The selection of the proper welding process
- The proper preparation of the joint prior to welding
- The verification that procedure meets the demands of fabricating the part
- The pretest of the welding process
- The attention of personnel to the quality of the part
- The in-process monitoring of quality

Liquid penetration test

- The basic principle of liquid penetrant testing is that when a very low viscosity (highly fluid) liquid (the penetrant) is applied to the surface of a part, it will penetrate into fissures and voids open to the surface.
- Once the excess penetrant is removed, the penetrant trapped in those voids will flow back out, creating an indication.
- Penetrant testing can be performed on magnetic and non-magnetic materials, but does not work well on porous materials.
- Penetrants may be "visible", meaning they can be seen in ambient light, or fluorescent, requiring the use of a "black" light. The visible dye penetrant process is shown in picture.
- When performing a PT inspection, it is imperative that the surface being tested is clean and free of any foreign materials or liquids that might block the penetrant from entering voids or fissures open to the surface of the part.
- After applying the penetrant, it is permitted to sit on the surface for a specified period of time (the "penetrant dwell time"), then the part is carefully cleaned to remove excess penetrant from the surface.
- When removing the penetrant, the operator must be careful not to remove any penetrant that has flowed into voids.
- A light coating of developer is then be applied to the surface and given time ("developer dwell time") to allow the penetrant from any voids or fissures to seep up into the developer creating a visible indication.
- Following the prescribed developer dwell time, the part is inspected visually, with the aid of a black light for fluorescent penetrants.
- Most developers are fine-grained, white talcum-like powder which provides a color contrast to the penetrant being used.

PT Techniques

Solvent Removable

- Solvent Removable penetrants are those penetrants that require a solvent other than water to remove the excess penetrant.
- These penetrants are usually visible in nature, commonly dyed a bright red color that will contrast well against a white developer.
- The penetrant is usually sprayed or brushed onto the part, then after the penetrant dwell time has expired, the part is cleaned with a cloth dampened with penetrant cleaner after which the developer is applied.
- Following the developer dwell time the part is examined to detect any penetrant bleed-out showing through the developer.

Water-washable

- Water-washable penetrants have an emulsifier included in the penetrant that allows the penetrant to be removed using a water spray.
- They are most often applied by dipping the part in a penetrant tank, but the penetrant may be applied to large parts by spraying or brushing.
- Once the part is fully covered with penetrant, the part is placed on a drain board for the penetrant dwell time, then taken to a rinse station where it is washed with a course water spray to remove the excess penetrant.

- Once the excess penetrant has been removed, the part may be placed in a warm air dryer or in front of a gentle fan until the water has been removed.
- The part can then be placed in a dry developer tank and coated with developer, or allowed to sit for the remaining dwell time then inspected.

Post-emulsifiable

- Post-emulsifiable penetrants are penetrants that do not have an emulsifier included in its chemical make-up like water-washable penetrants.
- Post-emulsifiable penetrants are applied in a similar manner, but prior to the water-washing step, emulsifier is applied to the surface for a prescribed period of time (emulsifier dwell) to remove the excess penetrant.
- When the emulsifier dwell time has elapsed, the part is subjected to the same water wash and developing process used for water-washable penetrants.
- Emulsifiers can be lipophilic (oil-based) or hydrophilic (water-based).

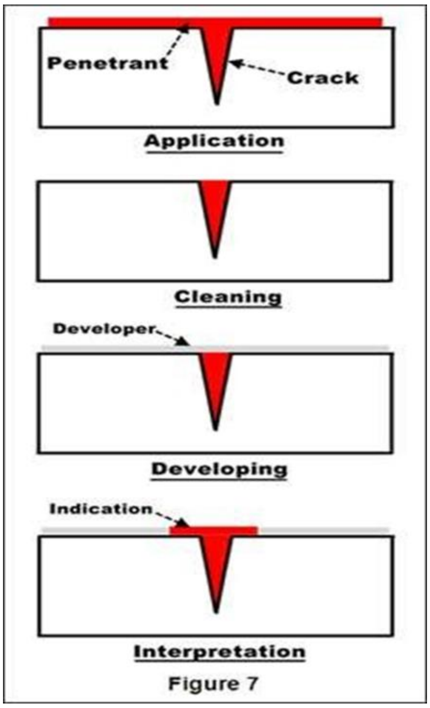

Figure 2: Process of application of Penetrant

Visual testing

- Visual testing is the most commonly used test method in industry.
- Because most test methods require that the operator look at the surface of the part being inspected, visual inspection is inherent in most of the other test methods.
- As the name implies, VT involves the visual observation of the surface of a test object to evaluate the presence of surface discontinuities.
- VT inspections may be by Direct Viewing, using line-of sight vision, or may be enhanced with the use of optical instruments such as magnifying glasses, mirrors, boroscopes, charge-coupled devices (CCDs) and computer- assisted viewing systems (Remote Viewing).
- Corrosion, misalignment of parts, physical damage and cracks are just some of the discontinuities that may be detected by visual examinations.

Magnetic particle testing

- Magnetic Particle Testing uses one or more magnetic fields to locate surface and near-surface discontinuities in ferromagnetic materials.
- The magnetic field can be applied with a permanent magnet or an electromagnet.
- When using an electromagnet, the field is present only when the current is being applied.
- When the magnetic field encounters a discontinuity transverse to the direction of the magnetic field, the flux lines produce a magnetic flux leakage field of their own.
- Because magnetic flux lines don't travel well in air, when very fine colored ferromagnetic particles ("magnetic particles") are applied to the surface of the part the particles will be drawn into the discontinuity, reducing the air gap and producing a visible indication on the surface of the part.
- The magnetic particles may be a dry powder or suspended in a liquid solution, and they may be colored with a visible dye or a fluorescent dye that fluoresces under an ultraviolet ("black") light.