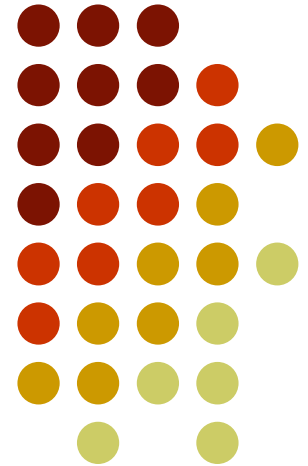


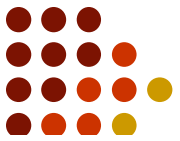
Plain & Reinforced Concrete-II

CE-413

Repair/Strengthening of Structures
Ref. Concrete Structures Part – II, 2nd Edition
Zahid Ahmad Siddiqi
(Chapter 23)



Terminology



Evaluation of an existing concrete building means that the building is studied for its future performance and expected future life by qualified engineers and staff and a comprehensive report is issued about the present safety status of the building.

Condition assessment is also a term related with evaluation of structure which perhaps is more commonly used when visual observations are prominent compared with the actual testing and structural analysis of the structure.

A strength evaluation may be required in the cases when the materials are considered to be deficient in quality based on visual observations, some evidence is present indicating faulty construction, the signs of deterioration are noticed,²

Terminology



the function of the building is modified, or there is a doubt that the structure does not satisfy some requirements of the design code.

In cases when the strength deficiency is well known and the data about the dimensions and material properties required for analysis is available and is reliable, analytical evaluations of strength are considered sufficient.

Rating of the building means the safe external load carrying capacity of a particular building at a particular age.

Serviceability refers to the capability of a structure to fulfill the functions of a structure desired by the owner, public, architects, municipal laws, specifications and codes.

Terminology



Durability is related with the life of the structure during which it is serviceable and repair / maintenance cost is within acceptable limits.

Repair is a general term related with removing a defect from within the structure, any improvement compared with the original design or a minor extension to the existing structure. According to ACI report, repair means to replace or correct deteriorated, damaged, or faulty materials, components, or elements of a concrete structure.

Terminology



Rehabilitation (retrofitting) deals with the process of sufficient repairs and subsequent structural evaluation such that the structural serviceability, safety and rating come close to the status at the time of construction. However, the future age may or may not be equal to the originally designed life of the structure

Strengthening means major repair of a freshly constructed or an old structure such that the strength, life or serviceability becomes more than the original design.

Terminology



The process of *restoration of historic structures* is a different field in which rehabilitation or strengthening is carried out by the same materials used in the past maintaining the outer surface finishes. Whatever exists at a particular point in time must not be modified or damaged during restoration.

Protection is the process of maintaining a concrete structure in its present or restored condition by reducing the chances of future damage.

Pot life is the time in which a hardening paste or epoxy remains workable and can easily be applied on a prepared surface.

23.4 STRUCTURAL EVALUATION PROCESS



This procedure is applicable for conventionally reinforced cast-in-place concrete, precast-prestressed concrete, and post-tensioned cast-in-place concrete. The evaluation of an existing concrete building is usually performed for stability, strength, safety and future expected life. Evaluation of a structure may be required in the following situations:

- Structures are subjected to excess or improper loading, vibrations, fire, etc.
- Structures having visible signs of distress / deterioration such as excessive cracking or spalling of the concrete, reinforcing bar corrosion, member deflection or rotation, etc.

23.4 STRUCTURAL EVALUATION PROCESS



- Structures with doubt about design, detail, material, or construction.
- Doubts exist about safety against future loading and the original design criteria.
- After a change in use or occupancy.
- After repair or strengthening.

Evaluation of a structure can be performed at various levels as under:

- Stability of the entire structure and the stability of individual components of the structure.
- Strength and safety of individual structural elements.
- Stiffness of the entire structure and the stiffness of individual structural elements.

23.4 STRUCTURAL EVALUATION PROCESS



- Susceptibility of individual structural elements to excess long-term deformation.
- Dynamic response of individual structural elements.
- Durability of the structure.
- Fire resistance of the structure
- Serviceability of the structure

Most common steps for structural evaluation are as follows:

- Defining the existing condition of the building, including:
 - a) Reviewing available information on the building.
 - b) Conducting a condition survey of the building.
 - c) Determining the cause and rate of progression of existing distress.
 - d) Determining the degree of repair required.

23.4 STRUCTURAL EVALUATION PROCESS



- Selecting the structural elements which require detailed evaluation.
- Assessing past, present, and future loading conditions to which the structure has and will be exposed under the anticipated use.
- Conducting the evaluation.
- Evaluating the results

The results may be reported in one of the following forms:

- a) The structure is adequate for normal use over its expected life if maintained properly
- b) The structure, although adequate for present loading and existing conditions, may not remain so in the future
- c) The structure is inadequate for its current or intended use, but may be adequate for alternative use.

23.4 STRUCTURAL EVALUATION PROCESS



- d) The structure is inadequate or unsafe, and needs remedial work
- e) The structure is unsafe and beyond repair
- f) The information or data are not sufficient to reach a definitive conclusion

The evaluation report must cover the following topics:

- Preliminary investigation
- Methods for material evaluation
- Assessment of loading
- Selection of evaluation method
- The evaluation

23.4 STRUCTURAL EVALUATION PROCESS



The strength of existing concrete buildings may be evaluated analytically or by load tests.

The observations such as type and extent of cracking, excessive deflections, deterioration of concrete, history of loading, construction record, design record, and results of evaluation are used to precisely determine why the structure has undergone distress.

The reasons and mechanisms that caused the problem may be single or multiple.

The cause, effect, and degree of influence of problems on serviceability and safety of the structure must be studied. The repair system must be as cost-effective as possible.

23.4 STRUCTURAL EVALUATION PROCESS



Before starting a repair work, the cost of repair and the expected life of the structure after repair must be compared with the cost of fresh construction and a logical conclusion as to whether repair is the solution must be made.

23.9 CAUSES OF CRACKS AND EXTENT OF CRACKING



Before discussing the repair of cracks, it is important to mention that some cracks are unavoidable in concrete structures.

They may affect appearance only, or they may indicate significant structural distress or a lack of durability. The extent of cracking may represent the total damage or it may be indication of more future damage or even collapse of the structure.

Repair should only be planned for the dangerous cracks or cracks with unacceptable opening. For water-retaining structures, it is to be decided that how much leakage prevention is needed for a particular structure.

23.9 CAUSES OF CRACKS AND EXTENT OF CRACKING



Other point that must be considered is that majority of the cracks are actually active in the sense that if the load is increased they open.

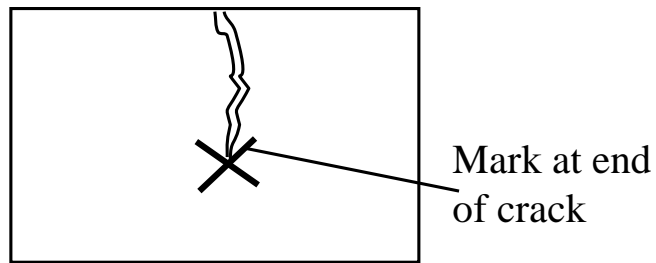
However, for repair purposes, crack openings are observed for certain fixed time (6 months or one year) with normal loading conditions to classify them as active or dormant.

Successful long-term repair procedures must try to eliminate the causes of the cracks as well as the cracks themselves.

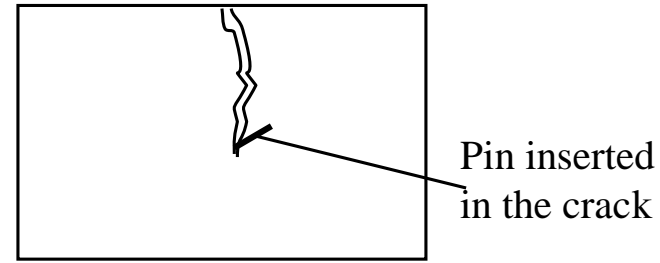
23.9 CAUSES OF CRACKS AND EXTENT OF CRACKING



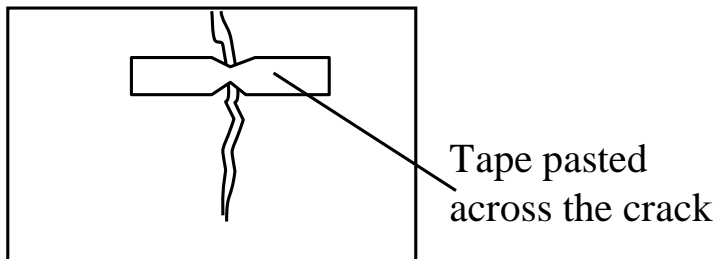
The first step to start with repair of cracks is to see that whether cracks are active or dormant. Fig. 23.3 describes various methods to observe behavior of cracks with time.



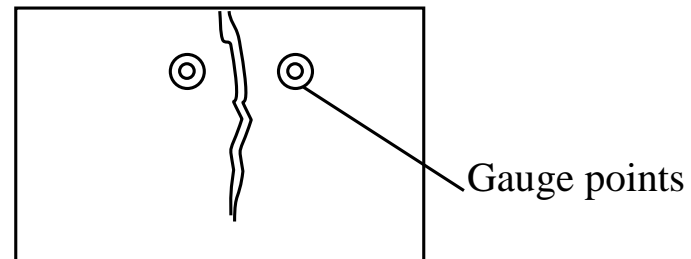
a) Mark at end of crack



b) Pin inserted near end of crack



c) Tape Pasted across crack



d) Measurement along gauge points

Fig. 23.3. Crack Measurement by Telltales.

The first method to accomplish this is to *mark the end of the crack* by ink marker. The extension of crack with time can be observed. However, this method does not provide quantitative data of the movement and the information about closing of the crack.

Another simple technique is to tightly *insert a pin near the end* of the crack. Any loosening or falling of this pin indicates opening of the crack.

Sometimes *strip of notched tape of paper, cellophane or cloth is glued to concrete surfaces on both sides of the crack*. Rectangular glass strip of less thickness may also be used. Any tearing of this strip indicates opening, while some indication of closing can also be observed. Presence of humidity can disturb the observations.

Feeler gauges can be used to measure the crack opening but successive readings may change due to a small shift in the position of the reading or due to accumulation of dirt with time.

The best method out of this category of method of telltales is to *fix gauge points* on both sides of the crack and then make measurements by using demec gage, vernier calipers or extensometer. The gauge points must be firmly fixed to the concrete after grinding and proper surface preparation.

23.9 CAUSES OF CRACKS AND EXTENT OF CRACKING



The repair method is selected based on activeness or inactiveness of cracks, pattern, type, shape and size of the cracks and magnitude and direction of expected future movements.

Primary purpose of repair depends on architectural aspects, leakage prevention or strength restoration.

If pattern cracks are active and strengthening is not required, extensible overlay can be solution. If active cracks are isolated and strengthening is required, providing expansion joints, stitching and external stressing are possible solutions.

However, in case where strengthening is not required for isolated active cracks, blanketing can be used.

For repair of dormant pattern cracks not requiring strengthening, overlay is suggested for severe water condition; rout and seal, overlay, autogenous healing or no action is recommended for minor water condition; and no action, rout and seal, autogenous healing and overlay is used for no critical water condition.

For isolated dormant cracks for which strengthening is required, external stressing plus epoxy may be used for severe water exposure; external stressing plus epoxy, autogenous healing may be used for minor water exposure; and epoxy, stitching, autogenous healing and external stressing may be used for no water exposure.

For isolated dormant cracks not requiring strengthening, blanketing may be used for severe water exposure; epoxy, rout and seal, gout, blanketing, no action and autogenous healing may be used for minor water exposure; and epoxy, rout and seal, gout, autogenous healing, no action and blanketing may be used for no water exposure.

23.9.1 Cracking Of Plastic Concrete



Plastic shrinkage cracking: The plastic shrinkage cracking produces a randomly spread hair-line or slightly wider smaller length cracks, as shown in Fig. 23.4.

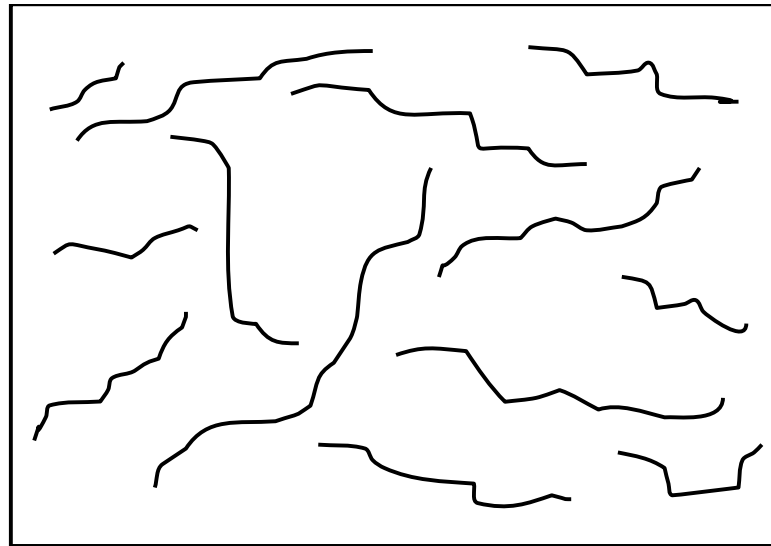


Fig. 23.4. Typical Plastic Shrinkage Cracking.

23.9.1 Cracking Of Plastic Concrete



This is caused by a very rapid loss of moisture due to high rates of surface evaporation and because some water is also consumed in the initial hydration of the cement.

The factors affecting the amount of plastic shrinkage cracking are

- Air and concrete temperatures
- Relative humidity
- Wind velocity at the surface of the concrete.

When moisture evaporates from the surface of freshly placed concrete faster than it is replaced by bleed water, the surface concrete shrinks.

23.9.1 Cracking Of Plastic Concrete



Due to the restraint provided by the concrete below the drying surface layer, tensile stresses develop in the weak outer concrete, resulting in shallow cracks of varying depth.

They range from 25 millimeters to more than meter in length and are spaced from 25 millimeters to as much as 3 m apart. Plastic shrinkage cracks begin as shallow cracks but can become full-depth cracks with time.

The use of fog nozzles to saturate the air above the surface and the use of plastic sheeting to cover the surface during construction prevent a rapid loss of moisture due to hot and dry wind. Windbreaks and sunshades are also used to reduce the drying shrinkage.

23.9.1 Cracking Of Plastic Concrete



The calcium hydroxide in hydrated cement paste will combine with carbon dioxide in the air to form calcium carbonate.

Since calcium carbonate has a smaller volume than the calcium hydroxide, shrinkage will occur (commonly known as carbonation shrinkage).

This situation may result in significant surface crazing and may especially become serious on freshly placed surfaces during the first 24 hours when improperly vented.

Combustion heaters are used to keep concrete warm during the winter months.

23.9.1 Cracking Of Plastic Concrete



Settlement cracking: After initial compaction, the concrete may consolidate and settle relative to reinforcing steel placed earlier or formwork. Hence, the voids and/or cracks may be developed adjacent to the restraining elements.

The degree of settlement cracking may be increased by insufficient vibration or by the use of leaking or highly flexible forms.

Proper form design, selection of vibration and re-vibration times, provision of suitable time interval between the placement of different layers of concrete, use of the lowest possible slump and larger concrete covers to steel bars are helpful in reducing the settlement cracking.

23.9.2 Cracking / Deterioration Of Hardened Concrete



Cracking of hardened concrete can take place due to the following reasons:

Drying shrinkage: Crazeing is the development of a series of shallow, closely spaced, fine cracks in alligator pattern on the surface of the concrete.

It usually occurs when the surface layer of concrete has higher water content than the interior concrete. Drying shrinking is caused by the loss of moisture from the cement paste constituent, which can shrink by as much as 1 percent.

Fortunately, aggregate provides internal restraint that reduces the magnitude of this volume change to about 0.06 percent.

23.9.2 Cracking / Deterioration Of Hardened Concrete



On wetting, concrete tends to expand. Shrinkage of members restrained at ends or of layers restrained by the bottom layers produces tensile stresses. When the tensile strength of concrete is exceeded, cracks will appear but will continue to progress at much lower stresses than are required to cause crack initiation.

In massive concrete elements, tensile stresses are caused by differential shrinkage between the surface and the interior concrete.

The magnitude of the tensile stresses depends on the amount of shrinkage, the degree of restraint, the modulus of elasticity, and the amount of creep.

23.9.2 Cracking / Deterioration Of Hardened Concrete



The type of aggregate and the water content of the mix usually control the amount of drying shrinkage. Larger amount of aggregate, high stiffness of the aggregates and lower water content reduce the amount of drying shrinkage.

Shrinkage cracking can be reduced by using contraction joints, better steel detailing, using shrinkage-compensating cement, and by reduction of sub-slab restraint.

23.9.2 Cracking / Deterioration Of Hardened Concrete



Thermal stresses: The temperature differences, produced either due to weather or internally by heat of hydration, result in differential volume changes.

The concrete cracks when the tensile stresses due to the differential volume changes exceed the tensile stress capacity. The tensile stresses are proportional to;

- The temperature differential
- The coefficient of thermal expansion
- The effective modulus of elasticity
- The degree of restraint

23.9.2 Cracking / Deterioration Of Hardened Concrete



The thermally-induced cracking may be reduced by

- Decreasing the maximum internal temperature
- Delaying the onset of cooling
- Controlling the rate at which the concrete cools
- Increasing the tensile strength of the concrete

Hardened concrete has a coefficient of thermal expansion that ranges from 7×10^{-6} per $^{\circ}\text{C}$ to 11×10^{-6} per $^{\circ}\text{C}$, with a typical value of 10×10^{-6} per $^{\circ}\text{C}$. Allowing for movement by using properly designed contraction joints and correct detailing reduce the amount of cracking due to the thermal stresses.

23.9.2 Cracking / Deterioration Of Hardened Concrete



Temperatures higher than about 60 °C can delay the ettringite (calcium sulfoaluminate) formation. When this compound is formed in the hardened concrete and it tries to expand, the concrete can undergo deterioration.

Chemical reaction: Deleterious chemical reactions may cause cracking of concrete. These reactions may be due to materials used to make the concrete or materials that come into contact with the concrete after it has hardened.

Concrete may crack with time as a result of slow expansive reactions between aggregate containing active silica and alkalis derived from cement hydration, admixtures, or external sources (e.g., curing water, ground water, alkaline solutions stored or used in the finished structure).

23.9.2 Cracking / Deterioration Of Hardened Concrete



The alkali-silica reaction (ASR) results in the formation of a swelling gel with local expansion and accompanying tensile stresses. The end result can be full deterioration of concrete.

This adverse reaction may be reduced by

- Proper selection of aggregates
- Use of low alkali cement
- Use of pozzolans, which themselves contain very fine, highly active silicas.
- Certain carbonate rocks (argillaceous dolomitic limestones) when react with alkalies produce expansion and cracking.

23.9.2 Cracking / Deterioration Of Hardened Concrete



A network pattern of cracks is produced without any deposits at the cracks (as in alkali-silica reaction).

The problem may be reduced by

- Avoiding reactive aggregates
- Use of a smaller maximum size aggregate
- Use of low-alkali cement

Sulfate-bearing waters are a special durability problem for concrete, causing what is commonly known as *sulfate attack*. When sulfate penetrates hydrated cement paste, it reacts with hydrated calcium aluminate (C3A) to form calcium sulfo-aluminate.

23.9.2 Cracking / Deterioration Of Hardened Concrete



This material expands producing tensile stresses and cracking.

ASTM C 150 Types II and V Portland cement (low in tricalcium aluminate), some blended cements, and addition of some pozzolans may be helpful in such cases.

Concrete subjected to water soluble salts must be sufficiently air entrained, have adequate cover of the reinforcing steel, and be made of high-quality, low permeability concrete. The sulfate attack is reduced if the cement content is more than 300 kg/m^3 .

23.9.2 Cracking / Deterioration Of Hardened Concrete



Thaumasite attack is a special type of sulfate attack in which the cement, the lime and the sulfate react in an unusual way to form a sulfate mineral called thaumasite. This causes a serious damage and softening of the exposed surfaces of concrete. Sulfate resisting cement can not stop this reaction.

Weathering: The weathering processes produce concrete disintegration on the surface which very slowly penetrates inside. The major factors contributing weathering are freezing and thawing, wetting and drying, heating and cooling and other slow chemical processes. Damage from freezing and thawing is the most common weather-related physical deterioration.

23.9.2 Cracking / Deterioration Of Hardened Concrete



A hydraulic pressure is generated by the growth of ice crystals during freezing. Effect of freezing and thawing may be reduced by the use of the lowest practical water-cement ratio, least total water content, use of durable aggregate, adequate curing and by adequate air entrainment.

Acid / other contaminants attack: In case acid, alkalies, vegetable oils, milk, lime, sugar, etc are spilled over the concrete surfaces many times, such as in factory environments, the surface concrete is deteriorated.

23.9.2 Cracking / Deterioration Of Hardened Concrete



Corrosion of reinforcement: Corrosion of a metal is an electrochemical process that requires an oxidizing agent, moisture, and electron flow within the metal.

The chemical reactions may be stopped by cutting the supplies of oxygen or moisture or by supplying excess electrons at the anodes to prevent the formation of the metal ions (called cathodic protection).

If the alkalinity of the concrete is reduced through carbonation or if the passivity of this steel is destroyed by aggressive ions (usually chlorides), corrosion of the steel may occur. This produces iron oxides and hydroxides, which have a volume much greater than the volume of the original metallic iron.

23.9.2 Cracking / Deterioration Of Hardened Concrete



This increase in volume causes high radial bursting stresses around reinforcing bars and results in local radial cracks.

If these cracks extend along the length, longitudinal splitting cracks are produced. These cracks may cause spalling of concrete or may form a general plane of separation along a row of steel. The cover along with some extra concrete is delaminated.

Cracks cause more ingress of oxygen, moisture, and chlorides, and can accelerate corrosion and cracking. Cracks transverse to reinforcement in dense concrete usually do not cause continuing corrosion of the reinforcement.

23.9.2 Cracking / Deterioration Of Hardened Concrete



In the start, the exposed portion of a bar at a crack acts as an anode but oxygen and moisture are not supplied to other portions of the same bar or bars that are electrically connected and the corrosion process stops.

Longitudinal cracks can disturb passivity of steel at many locations, and oxygen and moisture are readily available along the full length of the crack.

Longitudinal cracking, due to other reasons like high bond stresses, transverse tension, shrinkage, and settlement, can increase corrosion. Increased concrete cover over the reinforcement is effective in delaying the corrosion process and also in resisting the splitting and spalling caused by corrosion or transverse tension.

23.9.2 Cracking / Deterioration Of Hardened Concrete



In severe exposure conditions, additional protective measures, such as coated reinforcement, sealers or overlays on the concrete, corrosion-inhibiting admixtures, and cathodic protection may be needed. Any procedure that reverses the electron flow at the anode will protect the steel.

All concrete surface treatment must allow water to evaporate from the concrete.

The carbonation induced corrosion affects large areas surrounding the steel bars associated with a gradual loss of section. The indication of this type of attack is spalling of the concrete cover before such reduction in steel that produces structural failure.

23.9.2 Cracking / Deterioration Of Hardened Concrete



The chloride attack affects localized portion but causes significant loss of the cross-section without any indication on the surface. Hence, structural failure may occur without any warning.

23.9.3 Evaluation Of Cracking



During visual observations if it is found that the repair of cracks is needed, the following information is to be collected to proceed further:

- a. Identify location and extent of cracking, as well as information about condition of concrete in a structure, can be determined by both direct and indirect observations, nondestructive and destructive testing, and tests of cores taken from the structure.
- b. Whether the observed cracks are indicative of current or future structural problems.
- c. Consider the present and anticipated future loading conditions.

23.9.3 Evaluation Of Cracking



- d. The cause of the cracking should be established before repairs are specified. A detailed evaluation of observed cracking can determine which of those causes applies in a particular situation.
- e. Drawings, specifications, and construction and maintenance records must be reviewed.
- f. Field investigation and structural analysis must be completed before proceeding with repairs.
- g. Cracks need to be repaired if they reduce the strength, stiffness, or durability of the structure to an unacceptable level, or if the function of the structure is seriously impaired.

23.9.3 Evaluation Of Cracking



- h. Cracking in water-retaining structures may produce leakage for which repairs are needed, even if strength, stiffness, or appearance is satisfied.
- i. Cracks in pavements and slabs-on-grade may require repair to prevent edge spalls, migration of water to the subgrade, or to transmit loads.
- j. Sometimes, repair of cracks is required to improve the appearance of the surface of a concrete structure.

23.9.3 Evaluation Of Cracking



Direct and indirect observation: The locations and widths of cracks are noted on a sketch of the structure with accurately marked grid. Crack comparator is a small, hand-held microscope with a scale on the lens that can be used to measure crack widths to an accuracy of 0.025 mm.

A clear comparator card having lines at specified spacing marked on the card (also called monitor) may also be used to estimate the crack widths.

Observations must also be taken for spalling, exposed reinforcement, surface deterioration, and rust staining. Internal conditions at specific crack locations can be observed with the use of flexible shaft fiberscopes or rigid borescopes.

23.9.3 Evaluation Of Cracking



Crack movement can be observed with mechanical movement indicators which give a direct reading of crack displacement and rotation.

Some indicators amplify the crack movement readings for more precision. A wide range of linear variable differential transformers (or LVDT'S) and data acquisition systems are available to automatically record readings as time histories. Sketches can be supplemented by photographs.

23.9.3 Evaluation Of Cracking



Nondestructive testing: Nondestructive tests can be made to determine the presence of internal cracks and voids and the depth of penetration of cracks visible at the surface.

Tapping the surface with a hammer or using a chain drag are simple techniques to identify laminar cracking near the surface. A hollow sound indicates one or more cracks below and parallel to the surface.

The presence of reinforcement can be determined using a pachometer. Some pachometers may measure the depth, spacing and size of the reinforcement.

Sometimes, it is necessary to remove the concrete cover by drilling or chipping to identify the bar sizes.

23.9.3 Evaluation Of Cracking



The easiest way to investigate the presence and the extent of corrosion is the removal of a portion of the concrete to directly observe the steel. Corrosion potential can be detected by electrical potential measurements using a suitable reference half cell.

Ultrasonic nondestructive test equipment and radiography can also be used to detect internal discontinuities. Both x-ray and gamma-ray equipment can be used for detecting crack planes parallel to the direction of radiation.

In case of the pulse-echo technique, a single transducer is used to send and receive ultrasonic waves, but it is difficult to develop a practical pulse-echo test for concrete.

23.9.3 Evaluation Of Cracking



Tests on concrete cores: Significant information can be obtained from cores taken from selected locations within the structure.

Petrographic examination and chemical tests:

Petrographic examinations of cracked surfaces can identify alkali reactivity, cyclic freezing damage, "D" cracking, expansive aggregate particles, fire-related damage, shrinkage, corrosion, the water-to-cement ratio, relative paste volume, distribution of concrete components, the relative age of cracks and secondary deposits on fracture surfaces.

23.9.3 Evaluation Of Cracking



D-region means disturbed region due to cracking. Chemical tests for the presence of excessive chlorides indicate the potential for corrosion of embedded reinforcement.

23.10 PROTECTIVE SYSTEMS



Protective systems consist of materials and methods that provide the following protective qualities:

- a) Reduction in chances of corrosion of steel reinforcement.
- b) Less deterioration of the concrete.
- c) Less penetration of moisture, chloride ions, and other contaminants into the concrete. This can be achieved by providing surface treatments, applying electro-chemical equipment, or by modifying the PCC overlay.
- d) More abrasion or impact resistance.
- e) More resistance to other deleterious attacks.

23.10 PROTECTIVE SYSTEMS



The objective of providing a protection system is to extend the life of the structure and to reduce the number of future repairs and the rate of deterioration of the concrete structures. The following factors are considered while suggesting a protective system:

1. Life-cycle costs are compared for the various protection systems applicable for a particular situation. The protection system with the lowest initial cost may actually be the most expensive when the costs of future repairs are added over the projected life of the structure.
2. In case the protection system has a previous performance record, the confidence in its use increases.

23.10 PROTECTIVE SYSTEMS



3. Appearance can sometimes be an important factor in determining the selection of a system.
4. Thorough supervision, testing and visual observations must be made during the installation of the protection system.
5. The noise and dust levels, handling, use, and disposal of hazardous chemicals and escape of vapors into air must be considered while deciding the protective system. Further, local environmental laws must be observed.
6. The bond of the new protective system applied on existing structure or earlier repair material must be studied.

23.10 PROTECTIVE SYSTEMS



7. The expected life of a system against the exposure to prevailing atmospheric conditions must be considered.
8. There must not be any serious medical problems for the working people and chances of failure during repair work.

23.10.1 Factors Determining Need Of Protective System

The factors affecting the performance of the completed repairs and the protection system must be evaluated. The following are some of the more common factors that must be considered in a repair and protection project.

23.10.1 Factors Determining Need Of Protective System



a) Poor-quality concrete or inadequate cover:

Deteriorated concrete having excessive internal cracking, internal voids, lack of consolidation, inadequate entrained air-void system, or otherwise substandard conditions, may cause corrosion of the reinforcing steel and degradation of the structure. The deficient part of concrete is removed during a repair. A properly selected protection system can improve the long-term durability of poor-quality concrete, enhance the performance of good concrete, and extend the life of any repair.

23.10.1 Factors Determining Need Of Protective System



- b) *Misplaced reinforcing steel:*** During repair / installation of protective system, extra material or coatings are provided on misplaced steel at ends, corners and hooks and bars having less concrete cover. Cathodic protection, chloride extraction, and corrosion-inhibitor additives in repair materials can also be useful to prevent or delay future corrosion.
- c) *Water penetration:*** Water may penetrate into concrete by hydrostatic pressure, moisture vapor pressure, capillary action, and rain. Movement of water within concrete may occur due to cracks, porous concrete, lack of entrained air, structural defects, or improperly designed or functioning joints.

23.10.1 Factors Determining Need Of Protective System



- c) This moisture causes corrosion of reinforcement, freezing-and-thawing damage, leakage into the interior of the structure, and possible structural damage. It is tried while designing the protection system that the water movement is reduced and rusting of steel is directly controlled.

- d) *Carbonation:*** Carbonation is the reduction of the protective alkalinity of concrete, caused by the absorption of carbon dioxide and moisture. In normal concrete, the reinforcing steel is protected by the naturally high alkalinity (pH above 12) of the concrete around the reinforcement.

23.10.1 Factors Determining Need Of Protective System



d) A protective oxide layer is formed around the reinforcing steel that helps to prevent the reinforcing steel from corroding in the presence of high alkalinity. The absorption of carbon dioxide and water within the concrete cause reduction of the useful alkalinity of concrete by a process called carbonation. The chances of corrosion are significantly increased when pH falls below 10.

The bars close to the exterior surface are subject to the effects of carbonation and are not protected against corrosion.

23.10.1 Factors Determining Need Of Protective System



- d) Barrier coatings may provide protection against future carbonation where concrete cover is insufficient. Otherwise, cathodic protection system or re-alkalization of concrete may be used to protect steel against future corrosion.
- e) Anodic ring (halo effect):* This effect is produced when existing reinforcement extends from the parent concrete into a repair mortar or new concrete. This results in an increase of the differences in electrical potential at the bond line between the new and the parent concrete.

23.10.1 Factors Determining Need Of Protective System



- e) An anodic ring or halo effect is failure that occurs due to accelerated corrosion of the reinforcement in the parent concrete, just beyond the edge of the repair. Corrosion occurs at the anode, usually in the parent concrete, as electrons are attracted to the cathodic portion of the reinforcement in the uncontaminated repair material.

The build-up of rust produces large internal pressures at the surface of reinforcement which results in spalling of concrete. The presence of chlorides accelerates this process.

23.10.1 Factors Determining Need Of Protective System



- e) Barrier coatings on the reinforcing steel include epoxies, latex slurries, or zinc-rich coatings that can partially help to control corrosion activity; but there are field-application problems. Cathodic protection, chloride extraction and galvanic anodes can also be used to protect steel against corrosion. However, economics of these solutions are to be considered.
- f) Cracks:* Repair of cracks is usually the first step in any repair or protection job. Water present in cracks can result in corrosion and freezing-and-thawing problems in cold climates. The reason for the appearance of a crack must be investigated before the repair work.

23.10.1 Factors Determining Need Of Protective System



f) The structural cracks must be repaired in such a way that the load transfer can take place through the crack.

Epoxy injection is used to ensure sealing of the crack.

Active cracks, especially those due to thermal changes on exterior exposures, must be repaired to allow for future movements.

The cracks active for thermal movement may be repaired by providing properly designed expansion / contraction joints.

The use of caulking, chemical grouts, elastomeric coatings, and high elongation epoxies can repair moving cracks.

23.10.1 Factors Determining Need Of Protective System



f) The repair of active cracks on exterior exposures can be difficult. Most of the materials used for crack repair are temperature-sensitive and cannot be installed much below 4 °C.

It is also desirable to conduct repairs when the crack is near its maximum width, because most flexible materials used in repair of active cracks perform better in compression than in tension.

g) ***Chloride/chemical attack:*** Penetration of chemical or salt solutions through concrete contributes to the corrosion of the embedded steel. The chemical attack of acids, alkalis, and sulfates, may also have a detrimental effect on the concrete.

23.10.1 Factors Determining Need Of Protective System



- g) Barrier protection systems are commonly used to minimize the intrusion of chemicals into concrete.
- h) Surface erosion:*** Erosion of concrete at the surface is a major concern on dams, spillways, and other waterfront structures, as well as on bridge decks, ramps, parking decks, industrial floors, and other traffic-bearing structures.

Usually to a lesser extent, it can also be a concern on buildings exposed to acid rain and severe weather conditions. Concrete overlays, surface hardeners, sealers, or other treatments are often used to increase the resistance of surfaces against erosion.

23.10.2 Performance Characteristics Of Protective Systems



Although several of the available systems might provide adequate protection to the concrete and embedded reinforcing steel, there might be certain parameters for a given project that make one system more attractive than another.

A suitable protective system is selected in a particular situation that satisfies the project requirements. Following are the important parameters to be considered:

a) *Water permeability:* Water permeability is a measurement of the quantity of water that can pass through a surface treatment over a period of time.



- b) Vapor permeability:*** Moisture vapor transmission is the quantity of water vapor that can pass through a protective system over a period of time. This quality is required for the underlying concrete and other materials to dry.
- c) Resistance to reinforcement corrosion:*** Penetration of chemicals through concrete is likely to cause corrosion of reinforcing steel. One of the main functions of surface treatments is to increase the resistance to corrosion of steel reinforcement by providing a less-corrosive environment.



- d) *Crack bridging:*** The surface-treatment products are available with varying crack bridging ability. Some products have the ability to fill small dormant cracks but are not suitable to bridge moving cracks. Certain products are formulated to bridge small, moving cracks if detailed properly. Less movement of water through the cracks reduces the chances of corrosion.
- e) *Elongation characteristics:*** The capability of a material to elongate and bridge small cracks even during opening of the cracks is a useful characteristic.

- f) *Skid and slip resistance:*** Skid resistance is required if the traffic has to move over the repaired surface. Surface sealers and high build coatings may make the surface less skid resistant. The membrane systems containing aggregates and overlays provide more skid resistance.
- g) *Appearance:*** Most surface treatments alter the appearance of the concrete.
- h) *Carbonation resistance:*** Carbonated concrete loses its ability to protect the embedded reinforcement from corrosion.
- i) *Environmental regulations:*** The state regulations must be satisfied during and after the repair and protective works.



Autogenous healing



Autogenous healing is the natural process of crack repair that can occur in concrete in the presence of moisture, and the absence of tensile stress. The repair is by a combination of mechanical blocking by particles carried into the crack with the water and the deposition of calcium carbonate from the cementitious material.