REPAIR OF CORROSION AFFECTED REINFORCED CONCRETE STRUCTURES

The process of formation of rust over the surface of reinforcing bar and resulting in the depassivation of steel is known as "Corrosion".

Corrosion of reinforcing steel is one of the most important and prevalent mechanisms of deterioration for concrete structures.

Corrosion process:

In order to understand the mechanism behind corrosion of reinforcing steel in concrete, one has to know about the chemical reactions involved in it.
In concrete, the presence of abundant amount of calcium hydroxide and relatively small amount of alkali elements, such as sodium and potassium, gives concrete a very high alkalinity with pH of 12 to 13. It is widely accepted that, at the early age of the concert, this high alkalinity results in the transformation of a surface layer lf the embedded steel to a tightly adhering film, that is comprised of an inner dense spinal phase in epitaxial orientation to the steel substrate and an outer layer of ferric hydroxide. As long as this film is not disturbed, it will keep the steel passive and protected from corrosion.

When a concrete structure is often exposed to atmosphere, chloride ions from these will slowly penetrate into the concrete, mostly through the pores in the hydrated cement paste. The chloride ions will eventually reach the steel and then accumulate to beyond a certain concentration level, at which the protective film is destroyed and the steel begins to corrode, when oxygen and moisture are present in the steel concrete interface.

Once corrosion sets in on the reinforcing steel bars, it proceeds in electrochemical cells formed on the surface of the metal and the electrolyte or solution surrounding the metal, each cell is consists of a pair of electrodes (the anode and its counterpoint, the cathode) on the surface of the metal, a return circuit, and an electrolyte. Basically, on a relatively anodic spot on the metal, the metal undergoes oxidation (ionisation), which is accompanied by production of electrons, and subsequent dissolution. These electrons move through a return circuit, which is a path in the metal itself to reach a relatively catholic spot on the metal, where these electrons are consumed through reactions involving substances found in the electrolyte. In a reinforced concrete, than anode ad the cathode are located on the steel bars, which also serve as the return circuits, with the surrounding concrete acting as the electrolyte.

Corrosion: Structural effects:

In the case of concrete structures the first direct effect of the reinforcement corrosion is its section decreases due to the corroding process. Iron oxide (Rust) resulting reinforced concrete structures and their effect induces internal stresses in the concrete, which may lead to cracking or even spalling of concrete.

Induced Cracking of the concrete

Corrosion also may reduce the steel elongation at maximum load, affection the structure.

Accordingly, reduction of structural capacity of reinforced concrete elements affected by rebar corrosion is mainly due to following three main phenomena, which are direct consequence of corrosion:

a. Reduction of rebars section due to corrosion.

b. Reduction of bond strength.

c. Loss of concrete integrity due to cover cracking and spalling.

However corrosion of reinforcing steel can occur by two major situations, they include:

- Carbonation
- Chloride contamination.

Carbonation:

Carbonation is a process in which carbon dioxide from the atmosphere diffuses through the porous concrete and neutralizes the alkalinity of concrete. The carbonation process will reduce the pH to approximately 8 to 9 in which the oxide film is no longer stable. With adequate supply of oxygen and moisture, corrosion will start. The penetration of concrete structures by carbonation is a slow process, the rate of which is determined by the rate at which carbon dioxide penetrates into the concrete. The rate of penetration primarily depends on the porosity and permeability of the concrete. It is rarely a problem on structures that are built with good quality concrete with adequate depth of cover over the reinforcing steel.

Chloride contamination:

Chloride ions can enter into the concrete from the chloride containing admixtures that are used to accelerate curing or from seawater in marine environment. If the chlorides are present in sufficient quantity, they disrupt the passive film and subject reinforcing steel to corrosion. The levels of chloride required to initiate corrosion are extremely low. Field experience and research have shown that on existing structures subjected to chloride ions, a threshold concentration of about 0.026% (by weigh o concrete) is sufficient to break down the passive film and subject the reinforcing steel to corrosion. This equals to 260-ppm chloride.

The removal of the passive film from reinforcing steel leads to the corrosion process. Chloride ions within the concrete are usually not distributed uniformly. The steel areas exposed to higher concentrations of chlorides start to corrode, and breakdown of the oxide film eventually occurs. In other areas the steel remains passive.

The rate of carbonation in concrete is directly dependent on the water cement ratio of the concrete i.e., higher the ratio the greater is the depth of carbonation in the concrete

Causes for failures:

The following are the major causes for failures of structures:

- Structural deficiency due to defects in construction, use of inferior and substandard materials, poor workmanship, and negligence in quality control and supervision.
- Damages caused due to fire, foods, earthquakes, etc.

- Chemical deterioration and marine environments
- Damages caused due to abrasion, wear and tear impact, dampness, etc,
- Movements of concrete caused due to settlements of foundation, thermal expansion etc.

MATERIALS FOR REPAIR

The materials used for concert repair are generally cement based or Epoxy based. They are,

- Cement/Sand mortars
- Polymer Latex
- Epoxy Resins
- Polyester Resins

STRUCTURAL REPAIR BASED ON EXTENT OF DAMAGE

The structural repairs to be carried out in corrosion affected reinforced concrete structures to enhance its service life can be classified as follows:

1. Repairs to spallen concrete portions (steel and concrete)

- Cement based repairs
- Resin based repairs

2. Large volume repair

- Poured concrete
- Prep laced concrete

3. Sealing of cracks

- Cracks with no further movements expected
- Cracks with further movements expected

4. Surface coatings

5. Dry packing

Repair of a severely corrosion damaged member, where cover

Concrete has spallen and reinforcement (reduced in cross-sectional area) has been exposed.

Step 1

The repair process is started by cutting away all the loose and deteriorated concrete until the hard core is reached preferably behind the corroding reinforcement.

Step 2

All exposed reinforcements must be thoroughly cleaned. Loose rust or any contamination is removed by abrasive blast cleaning. Wire brushing by hand is not usually effective.

Step 3

The portions of steel bars severely corroded require replacement. This is achieved by cutting away the corroded portions and replacing with new bars of the same type and size, either welded or tied to the existing bars.

Step 4

After the corrosion affected bars are replaced in position, immediately a protective primer (Zinc, neat resin or any other suitable coating) is applied. The primer chosen should be such that it should good adhesive strength and good adhesion to subsequent repair layers.

Step 5

In order to build up the section, either cement based repair, or Resin based repair can be carried out.

Typical repair procedure for corrosion damaged concrete

Cement based repairs:

Step 6

i) The slurry (bonding coat) is applied to all concrete surfaces to which bond is required and the patching mortar (readily available in pre-weighed packets) is applied, while the slurry is still tacky. (Care should be taken to wit the concrete surface before the application of the material but there must be no standing water left on the surfaces).

ii) After the prepared surfaces have been coated with bonding agent or a coating of neat cement slurry, the repair material consisting of 1:3(cement and sand) is applied in layers not exceeding 20mm thick. Each layer is to be keyed to receive the succeeding layers. The outer layers of cement should not be thicker than the inner layers. This is required, in order to prevent failure due to shrinkage stresses.

It should be ensured that the cement-based materials used in repairs do not dry out quickly. The method is curing depends on the local conditions. Water soaked covers and curing membranes are common ways of protection.

Resin based repairs

Step 7

As usual, the priming coat is applied over the prepared surfaces to protect the surfaces. The interval between coats should not be too long; otherwise there will be bond failure.

Resin-based materials cure by exothermic chemical reaction immediately, when the constituents are mixed. It is essential that the materials should be well compacted to become impermeable, because they do not protect the steel by alkalinity.

Large volume repair

When a large volume o repair material is to be placed in members that have been extensively damaged, it becomes necessary to fix some kind o formwork and fill it with concrete or grout. The concrete is usually placed in conventional ways (poured concrete) or it may be formed by injecting grout into a mass of dry aggregate (under water work concrete).

Poured concrete

Defective concrete is first removed and loose concrete is chipped away from the face and around the reinforcement. Additional reinforcement can be provided by securely fastening it to the existing bars. It is necessary to protect the reinforcement by applying coating in the form of corrosion inhibiting paint like cement based polymer slurry or a resin based slurry. The formwork is so designed that the concrete fills it completely without leaving any air pockets. The joints in the formwork are sealed completely to avoid any leakage. Depending on the thickness to be poured, aggregate of maximum

20mm size (for thickness greater than 100mm) is adopted in the concrete mix, with suitable shrinkage compensating agent. In order to ensure good compaction of concrete, material vibration or external vibration using a mechanical hammer on the formwork can be imparted.

Replaced concrete

The technique is best suited for certain types of repair, particularly in under water work. In this method the formwork is erected in the normal way but it is first filled with clean specified (depending of thickness) coarse aggregate. Later cement grout is pumped into the forms from bottom until all the voids are filled as the air or water is vented at the top. It is essential that the formwork is watertight and is designed to withstand the full hydrostatic head of grout. This method offers quality concrete without segregation with minimum during shrinkage. This disadvantage is that the injected cement paste is prone to bleeding

Sealing of cracks

Sealing of cracks by repair materials will be effective only when proper materials are injected. For this, the cause of crack has to be determined. If the cause of the crack is such that it is unlikely to recur, then it can be filled with a rigid material. But, if the crack is caused due to movement and that is likely to continue then any attempt to seal the crack against further movement may cause a new crack along the side of the old one.

Repair of cracks (where no further movement is expected)

Such cracks can be sealed to prevent moisture penetration by simply brushing latex emulsion of low viscosity or cement paste containing fine quartz powder filler. The procedure for carrying out this type of repair is as follows:

Step 1

The crack is thoroughly cleaned using compressed air.

Step 2

Superficial seal is applied over the crack at the surface by using a fast setting polyester resin or a thermoplastic material into which injection nipples are fixed at intervals.

Step 3

Injection is started at the lowest point and when resin reaches the next higher point, the injection gun is moved up to the next and the lower point is sealed. The process is continued until the whole crack gets sealed. The pressure used is carefully controlled to avoid bursting of the seal and concrete scale work.

Repair of cracks (where further movement is expected)

When a crack is subjected to continuing movement, it is absolutely necessary to reduce the strain in it to reasonable amount. This can be easily done by widening the crack at the surface and sealing it with an elastic material such as polysulphide rubber or a performed neoprene strip.

Surface coatings

It is necessary, that after the completion of repair work, to treat both the repaired areas and the rest of the structure with some coatings, principally, to reduce the permeability of concrete, to moisture, carbon dioxide, and other aggressive agents. The coatings further can also give aesthetic look to the structure by containing the patches, discolouration and stains and match colour and textures.

Several coatings are available in the market, which can be readily used on the repaired surfaces as per the instructions of the manufacturer. Siloxene based coatings prove to be effective.

Dry packing

Dry packing or plugging is the hand placement of a low w/c ratio mortar followed by ramming or tamping of mortar into place producing a intimate contact between new and existing work. The method is applicable to dormant cracks in a structure. Shrinkage is considerably reduced. Provides good strength and water tightness increasing the durability. Care is to be taken to use well-graded sand in the mortar mix.