Methods of Rebar Protection and Repair Techniques on Concrete Structures

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Abstract: *The major factors leading to the deterioration of reinforced concrete are poor construction practice and the environment. Rebar corrosion is widely regarded as the most common cause of deterioration and premature failure of reinforced concrete (RC) structures These factors are interrelated, for example: inadequate depth of cover to rebars, or excessively porous concrete, may allow penetration of atmospheric contaminants such as carbon dioxide or chlorides to reach the steel. In the presence of oxygen and moisture, this will cause it to corrode. Sooner or later, cracking and spalling of the concrete cover will occur as the expanding rust products build up bursting stresses around the rebars. It is therefore of great importance in aggressive environments to provide a sufficient cover of high quality concrete to all embedded steel. This is particularly so in coastal and marine structures, where chloride contamination from wind-borne salt spray can be severe. The primary methods commonly used to treat concrete which is suffering, or threatened by corrosion damage to embedded steel are patch repairs or partial rebuild, Protective coatings, Cathodic protection. Cathodic protection has become accepted and widely used as a means of halting corrosion of steel in deteriorating reinforced and prestressed concrete structures. The advantage of Cathodic Cathodic Protection exhibits long-term economical advantages when discounted over the design life of the system. In many cases, the first cost may be less than a conventional patch repair, with a life four to five times longer. It is also recognized as a means of prevention of corrosion damage in new structures, where for a small percentage of the capital cost the design life expectations can be met without repeated and expensive repairs*

Keywords: Steel, Carbonation, Chloride, Corrosion, Concrete, Cracks, Spalls, CP systems

1. Introduction

The buildings constructed with reinforced concrete within the last hundred years have deteriorated rapidly in compared to the structures built with concrete thousand years ago have withstood test time. The main reason is corrosion of the reinforcing steel within reinforced concrete [4]. Concrete, by itself, is a material with high compressive strength and low tensile strength. Steel, a material that is strong in tension as well as compression, is used as tension reinforcement for concrete. By adding steel reinforcement to concrete, reinforced concrete (R/C) becomes a versatile construction material. In Compared to other construction materials, properly constructed reinforced concrete elements have a long service life. When constructed properly, high-quality concrete is an ideal environment for reinforcing steel. The cement paste within the concrete creates a passive, highly alkaline environment (pH of 12-14) that affords corrosion protection to the uncoated steel. This occurs as a surface oxide film is formed on the rebar. As long as the integrity of the protective film is maintained, the steel will remain in a passive and protected state. When uncoated steel is exposed to moisture and oxygen, corrosion will occur. The protective film, however, will protect the reinforcing steel in the presence of moisture and oxygen. Nevertheless, deterioration of R/C elements can be accelerated by defects that break down the protective layer. These defects are introduced into the concrete before or at the time of construction.

2. Design Errors

Design errors may be divided into two general types:
1) Those resulting from inadequate structural design and
2) Those resulting from lack of attention to relatively minor design details

The defects stem from design and construction faults. Design faults include a lack of adequate drainage in horizontal members, a lack of concrete cover that protects the steel reinforcement, and inappropriate concrete mixes [4]. Construction faults include failure to provide the design concrete cover (figure 1), inadequate compaction, improper placement techniques, and lack of cold joints.

The aforementioned design and construction faults allow for the ingress of harmful chemicals that break down protective film and provide conditions favorable for the corrosion of the reinforcing steel. Carbonation and chloride contamination are the two main processes that break down the protective film. Once the protective film is broken down, corrosion will commence in the presence of moisture and oxygen. As corrosion occurs, the corrosion by products expand the size of the steel and produce large stresses on the concrete.

Figure 1: Concrete Cover

These stresses are relieved in the form of cracks (Figure 2), delaminations (planes of cracking within the concrete), and spalls (Figure 3).

Figure 2: Cracks in Concrete

Figure 3: Spalls in concrete

Concrete mixes used in the past were highly permeable and allowed for the ingress of atmospheric gases, moisture, and salt. Carbonation occurs when carbon dioxide from the atmosphere diffuses through the porous concrete and neutralizes the alkalinity of the concrete. Over a period of time, the carbonation process reduces the alkalinity of the concrete to a pH of 8 or 9, where the oxide film is no longer stable. Phenolphthalein method of detecting depth of carbonation is found to be the most popular method. A lot of experimental and empirical model to estimate carbonation (Jiang et al.) have been reported in literature.

3. Depth of Carbonation

To determine depth of carbonation a phenolphthalein solution is applied to a concrete sample. The solution is colorless at and below a pH of 8.2 and pink at pH levels above 10.0 (Figure 4). A common problem occurs when the depth of carbonation is greater than the concrete cover provided for the reinforcing steel. When this occurs, the protective layer is destroyed and the reinforcing steel no longer has protection against moisture and oxygen.


Figure 4: Phenolphthalein indicator solution applied to a fresh fracture surface through a concrete slab.

Sometimes, the chloride contamination also breaks down the protective layer and initiates the corrosion process because the chlorides can be introduced to the concrete during the mixing process or in service. In the past, calcium chloride was used as an admixture to accelerate the curing time of concrete. It allowed the placing of concrete in cold conditions and provided the early-strength concrete that allowed formwork to be stripped earlier. Chlorides can also

be found in the mixing water or aggregates. In service, chloride contamination occurs because of the use of deicing salts, proximity to seawater, and ground-water salts. Parking structures also have significant deterioration because of the use of deicing salts. Chances are that salts carried in from outside have entered the concrete, and spalls or cracking have occurred there.

3.1 Acceptance

The accepted corrosion threshold for chloride content in concrete is minimal, approximately 0.025% - 0.0375% chloride ions by weight of concrete (1.0 to 1.5 lb chloride ions/yd of concrete). Generally this means that approximately two pounds of salt (NaCl) for every cubic yard of concrete (3915 lb) is needed to initiate corrosion. Furthermore, accelerated corrosion that leads to rusting of the steel and spalling of the concrete has been found to occur at 3 lb/yd and significant loss of steel has been found to occur at levels in excess of 7 lb/yd. Chloride content can be calculated by taking powder samples from the concrete [3]. These samples are then brought to the laboratory and mixed with an extraction liquid to determine the chloride content. In locations with premixed chlorides, content will be fairly uniform. In areas of service chloride contamination, a profile of chloride content vs. depth can be made by taking samples at regular intervals of depth (Figure 5).
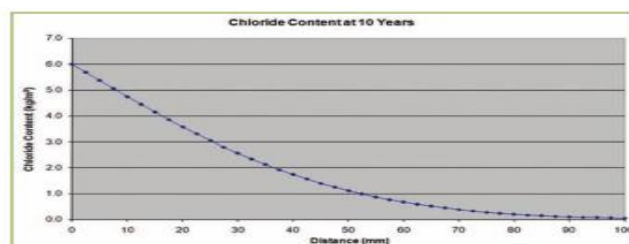
Figure 5: Profile of service chloride content vs depth.

To further complicate things, carbonation and chloride contamination can work together. As the pH of concrete is lowered through carbonation, chloride contents even lower than the threshold mentioned above can induce corrosion. Although depth of carbonation and chloride content are indicative of corrosion activity, it is not truly a measure of actual corrosion activity. Half-cell potential testing is one way to estimate the corrosion activity of the reinforcing steel. Half-cell potentials measure the difference in potential between a reference electrode (copper sulphate) [1] and the reinforcing steel (Figure 6).
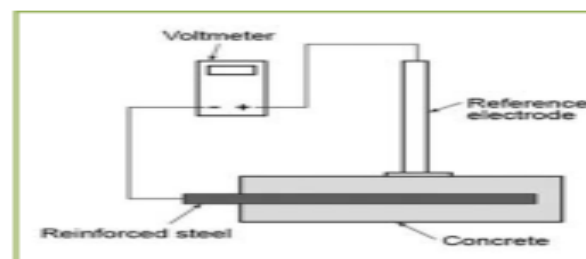
Figure 6: Schematic of half-cell potential test

Potential readings more negative than -350 mV indicate a 90% probability of corrosion activity, readings between -200 mV and -350 mV indicate an unknown probability of corrosion activity, and readings more positive than -200 mV indicate a 90% probability of no corrosion activity.

A simple way of locating areas of corroded reinforcing steel is to "sound" the concrete. This method requires the use of a rock hammer on a vertical plane or a chain on a horizontal plane. By impacting the concrete through the striking of the hammer or dragging of the chain, a tone that sounds "hollow" can be heard. Even though the area appears to be in good condition, the difference in tone reveals that areas of distress lie below the concrete surface.

4. Fixing the Problem

Once the corrosion process has begun, it is difficult to produce a long term repair to the areas of deterioration unless the underlying problem, corrosion of the reinforcing steel, is addressed.

5. Corrosion Process

Rebar corrosion is of two types, namely (i) chloride induced and (ii) carbonation induced. In the first type, chloride ions, either present in the raw materials or introduced from outside, due to insufficient cover or high permeability, lead to the breakdown of the alkaline passive film around the rebar . The second type of rebar corrosion, namely carbonation induced corrosion, results from the ingress of atmospheric carbon dioxide (CO_2) into the concrete. Corrosion is electro-chemical in nature; it is essentially a battery in which electrical current flows between an anode and a cathode (Figure 7). The anode is the site where corrosion occurs [3].
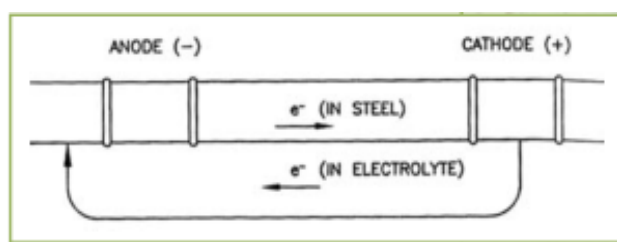

Figure 7: Corrosion Cell.

Differing electric potentials may be located on the same piece of reinforcing steel (Figure 8) because of the heterogeneous nature of steel (it is created from iron ore), depth of carbonation, chloride content, concrete imperfections, cracks, etc. The pore water in the concrete is the electrolyte that conducts the electricity.

Figure 8: Corrosion on same piece of reinforcing steel.

Conventional patch repair requires the removal of distressed concrete to a distance of approximately three-quarters of an inch behind the reinforcing steel, cleaning of the rebar, and patching of the area with new material. Although this method may work in non-chloride contaminated concrete, the same procedure has a potential to increase corrosion activity in chloride-contaminated concrete.

5.1 Approach To Apply Sealers and Coatings

While they help delay the onset of corrosion when applied before exposure to service conditions, they have limited effectiveness when applied after the onset of corrosion. Another type of product used is a corrosion inhibitor. These products are applied to the concrete surface after exposure to service conditions and seek out the reinforcing bars within the concrete. Testing and research on such products, however, has shown mixed results, as their effectiveness is dependent on the chloride content. When chloride content exceeded 0.05% chloride ions by weight of concrete [6] (two times the threshold), corrosion inhibitors were ineffective.

6. Rehabilitation Technique

The only rehabilitation technique that can prevent corrosion activity in chloride contaminated concrete is Cathodic Protection (CP) [7]. The advantages of Cathodic Protection over other rehabilitation methods can be summarized as,
- Cathodic Protection has the ability to stop the corrosion process for the extended life of the structure.
- Cathodic Protection is a long-term solution (in excess of 25 years), with minimal maintenance requirements.

By connecting the reinforcing steel to a sacrificial anode or an impressed current, the reinforcing steel effectively becomes a non-corroding cathode. Simply stated, CP reverses the corrosion process. The two types of CP systems are,
1) The galvanic (sacrificial) system and
2) The impressed current system (ICCP).
The galvanic anode system utilizes a sacrificial metal, such as zinc, to create a current flow from itself to the rebar. When attached to the reinforcing steel, the anode supplies an electric current and protects the reinforcing steel by sacrificing itself. Galvanic anodes can be attached to the rebar and embedded in the concrete (Figure 9) or sprayed on the concrete. In the latter case, a connection is made between the sprayed metal and the rebar.

**Figure 9:** Installation of an embedded sacrificial anode.

In ICCP systems (Figure 10) utilize anodes connected to an external DC power source that supply the necessary current to convert the reinforcing steel to a cathode. ICCP systems can also be embedded in the concrete or sprayed on the concrete surface.
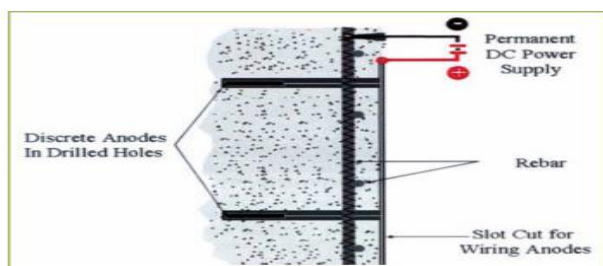
Figure 10: Schematic of an ICCP system.

Another system attaches a mesh that is covered in a concrete overlay to the concrete surface. Sacrificial CP systems, with no monitoring or maintenance, have a 15-year useful life. ICCP systems, which require monitoring and maintenance, have useful lives of 25+ years.

Another method is to use electrochemical chloride extraction (ECE) (Figure 11). This procedure applies an electric field between the reinforcing steel and an externally mounted mesh. During this short duration treatment, the chloride ions migrate away from the reinforcing steel and toward the mesh. This mesh is removed treatment. Additionally, the protective layer around the reinforcing steel is regenerated.
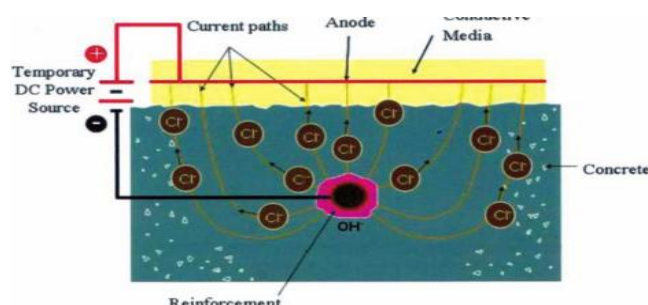
Figure 11: Schematic of an ECE system.

Although CP and ECE are effective in chloride contaminated concrete, a process called re-alkalization is effective for carbonated concrete. Similar to ECE, an electric field is applied between the reinforcing steel and the mounted mesh. The difference is that an electrolyte is transported into the concrete. This electrolyte restores the alkalinity of the concrete and reinstates a passive environment for the reinforcing steel.

7. Conclusion

Cathodic protection has become accepted and widely used as a means of halting corrosion of steel in deteriorating reinforced and prestressed concrete structures. Cathodic Protection is an economical alternative to patch repairs in chloride damaged structures, not only because it provides a long-term solution but also because it obviates the need for massive removal and replacement of contaminated concrete. Although many alternatives exist for the rehabilitation of deteriorated concrete elements, each project will have a different solution. Additionally, each repair option has its own advantages and disadvantages. Therefore, the options of repair will vary on a project by project basis.

8. Acknowledgment

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Author Profile

Dr. S. Vijaya Mohan Rao, did his B.Tech.(Civil) and M.Tech in Structural Engineering and obtained Ph.D in Retrofitting of Structures. He has 13 Years of Industrial Experience in India & Middle East and 15 Years of Teaching Experience. He has wide knowledge of RCC structures, and his articles published in various journals. At present he is working as Principal & Professor of Civil Department in "Siddhartha Institute of Engineering & Technology", Hyderabad, Telangana state, INDIA.