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SOME ENGINEERING OBJECTIONS TO USING REINFORCING STEEL AS GROUNDING ELECTRODES*

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Abstract

This paper summarizes a literature search on the corrosion of reinforcing steel and examines the ways that electrolytic action can degrade the steel. It also outlines engineering methods for mitigating such corrosion.

Introduction

This paper summarizes the results of an examination of over twenty-five documents selected from more than eighty abstracts uncovered in a literature search for the period 1955 to 1969 regarding the use of reinforcing bars vs corrosion. The paper analyzes some of the problems associated with corrosion of the reinforcing bars; particular attention is given to the use of rebar as part of an ac grounding system.

L. B. Hertzberg[1] and others have pointed out that the water system piping is no longer useful as an ac power system ground, because of the present use of insulated pipes and joints.

E. F. Fogan and R. H. Lee,[2] P. Wiener,[3] V. P. Brimerberg[13] and others have proposed the use of the reinforcing bars in concrete foundations as the grounding electrodes. H. G. Ufer[12] proposes the addition of a copper cable in the bottom of some foundations as the grounding electrode. Obviously some reliable system for grounding ac power systems is required, but each requirement must be reviewed carefully. A single system will not necessarily fulfill all the requirements in other applications.

The authors believe that there are some inherent dangers in modifying the reinforcing steel of concrete foundations to serve the dual purpose of electrical grounding and structural strength in the concrete. In some way the three separate systems, water piping, strength of foundations, and electrical grounding should be kept separate so that developments in each field will not be hazardous to some other application.

Areas of Concern

Water pipes must not carry current as this can lead to hazardous voltages being present when piping changes are made and would involve personnel not familiar with electrical problems. The currents may also pass from the pipe to the ground and cause excessive corrosion.

The reinforcing bars or joints should not be required to carry large currents that could heat the concrete or rupture the concrete because of excessive energy release during fault conditions. One recent case was brought to our attention where part of the footing of a tower carrying 115 kV was blown apart because of the 20,000 amp fault current flowing when a tower insulator flashed over. The reinforcing bars of this footing were not bonded together and the footings provided the sole ground of the tower.

The foundations of low residential buildings or single story warehouses do not seem to us to be as important as the foundations for tall structures that have narrow bases; here the steel is of very vital concern and must be always in the best of condition to resist the dynamic forces due to storm and earthquakes.

Any time that conditions are set up where currents can pass between concrete and the included reinforcing bars three destructive conditions may exist:

1. The chemistry in the concrete can be modified, weakening concrete.
2. The reinforcing bar may corrode, increasing the internal compressive forces and resulting in spallation of the concrete or forming cracks that will increase the rate of corrosion of the reinforcing bars.
3. Corrosion of the rebar will reduce the cross section of the steel and therefore weaken the structure. The corrosion rate in some old structures has been shown to be at least 0.01 inches per year which can be disastrous in prestressed applications or in designs utilizing small reinforcing bar cross sections.

There are certain practices now permitted that allow copper pipes or copper ground wires to be imbedded in the concrete. This can only lead to further dc electrolytic processes that corrode the reinforcing steel. These practices must be modified to protect the reinforcing bars.

The causes of corrosion of steel reinforcing bars in concrete may be chemical or electrical. For clarification, we will classify chemical corrosion as that caused by the interaction of the steel with the constituents of and the additives to the concrete. Foreign materials that may reach the steel through cracks or porosities in the concrete are included. We will classify corrosion resulting from the action of electric currents on the steel as electrical (or electrolytic) corrosion. The currents involved may be caused by external voltages (stray currents) or by galvanic couples involving the reinforcing steel.

What are the sources of the external currents? A few examples are: grounded power systems, cathodic protection systems and electrochemical processes. What are the sources of galvanic currents? Dissimilar metals (iron and copper), differential chemical concentration (aerated and stagnant water) and differential environments (concrete coated and bare steel) are examples. Bear in mind that a solvent is needed (in the survey at hand it is always water) to produce the electrolyte required in a galvanic source.

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Electrical corrosion occurs where positive charges leave a steel surface. They always leave as an iron ion, so the material wastes away, atom by atom. The rate is 20 pounds per ampere year, whether the source of the voltage is external to the steel structure (stray) or internal (galvanic).

This paper will not deal directly with the chemical analysis of corrosion because there are many papers available (some are listed in the bibliography with this paper) that devote many pages to these problems.[8]

The objection to using reinforcing steel for grounding electrodes lies in the inherent danger of corroding the steel. Corrosion of the steel can degrade the concrete structure in many ways: (a) Reduction of the steel cross section (b) loss of bond between the steel and the concrete (c) mechanical cracking of concrete and (d) chemical alteration of the cement.

Inasmuch as the steel provides all the tensile strength of the concrete structure, reduction of the steel area can be disastrous. Small diameter reinforcing, such as is used in prestressed and poststressed members, is particularly vulnerable to failure from corrosion. Large diameter bars may seem to be more immune to destruction, but electrolytic corrosion isn't necessarily uniform. Localized current discharge can be as effective as a hack saw.

Loss of bond between the steel and the cement may be due to changes in the steel surface or to chemical deterioration of the cement. The result is that the steel can no longer accept the tensile loading. In addition, extensive chemical alteration of the cement can destroy the concrete as a structural material.

Perhaps the worst villain is mechanical cracking of the concrete.[23] This may be due to local structural failure of the concrete or to the pressure of corrosion products. Cracks admit corrosive substances from the outside — chlorides in particular — that hasten the disintegration of the structure. The corrosion rate for steel reinforcing in a marine atmosphere has been shown to be as much as .25 mm per year in South African studies.[20] Such a corrosion may be controlled by cathodic protection[26] but care must be taken to avoid hydrogen embrittlement of the steel, as hydrogen is liberated at the steel surface.[8]

The effect of alternating current on reinforcing steel is not at all well defined. Theoretically, alternating currents cannot cause corrosion; the positive half wave removes an iron ion, the negative halfwave returns it. Much needed research remains to be done to define the relationship of current density, voltage gradient, frequency, ion movement, energy released, electrode material and surrounding electrolyte. There have been a few cases of ac corrosion observed, but no detailed measurements or analysis are available.

Tests made by Y. Kondo, Atakeda and S. Hideshima[19] and also reported by the National Bureau of Standards[23] shows that 60 Hz ground currents will not be nearly as corrosive as dc currents. A caution should be used in interpreting any controlled corrosion testing of reinforcing bars, even for tests lasting a couple of years. The NBS[23] pg. 172 points out that the passivity of iron in concrete is probably due chiefly to the calcium hydroxides present in new structures and that the resistance to corrosion may diminish in old structures. The calcium hydroxides are slowly converted to calcium carbonate which does not passivate the iron surface.

If one uses only the reinforcing steel as the grounding electrode, then particular care must be taken to isolate the steel — and the attached structures — from buried copper pipes. Insulating joints where the pipe enters the structure serve very well, but they require periodic inspection.

There is another class of troubles to consider when using reinforcing steel as a grounding electrode. This is mechanical damage to the concrete by massive currents such as lightning surges or a power ground fault. In such a situation corrosion is microscopic, the damage is caused by thermal action or high voltage arcing. Large amounts of energy released inside of a concrete structure can easily rupture the concrete. This damage may be below grade where it is not visible; the resultant cracks, if not cataclysmic, will allow corrosion of the reinforcing bar to proceed more rapidly than before. Magnetic forces between reinforcing bars are also a factor to consider. In such cases, the reactance of the grounding system determines the voltage distribution and it is quite possible to develop destructive voltages across the concrete structure.

During our investigation of these problems we inspected some old buildings in San Francisco that were being torn down. These buildings had been constructed some time after the 1906 earthquake and did not contain a great deal of reinforcing bars in concrete type construction but certain observations seem vital at this time.

Some pilings that had a thin shell of steel about 24" in diameter and poured full of concrete were in excellent shape, probably because the pilings were toward the center of the building and were isolated from adjacent metal.

Some horizontal iron beams that supported part of the sidewalks at the building wall had the bottom of the beams exposed and were badly corroded, evidently from water seepage from cracks in the sidewalk-to-wall joint. There was also evidence of excessive corrosion in the reinforcing bars in some of the sidewalks.

This brings up the concern for the strengths of reinforcement structure. The area at the bottom of the wall at the sidewalks is typically a location where a joint in the concrete pours is made because the main foundation will be constructed first. A joint at this location will be difficult to seal properly and may allow seepage into the iron where corrosion may proceed rapidly. Corrosion processes may be accelerated by the presence of chlorides used in de-icing solutions on sidewalks in cities subject to heavy snow and ice conditions.

What To Do

With all these horrors facing us when we use reinforcing steel as a grounding electrode, what shall we do? Engineer each installation to minimize the probable damage.

The worst factor is the copper-iron couple caused by using copper ground rods, a buried copper ground grid or bare copper ground wires in the concrete. Such a situation produces a continuous direct current flowing from the iron to the copper. Burying the copper conductor in the concrete only reduces the copper-iron circuit resistance and enhances the corrosive effect. The substitution of iron or stainless steel ground rods will go a long way toward minimizing the galvanic currents. Using insulated conductors to connect to the ground rods reduces the exposed area of copper and consequently reduces the galvanic current.

Considerable research has been done on the chemical corrosion of reinforcing steel. Consequently much can be done to control such corrosion by using an optimum cement content, maximum density mix, ample concrete cover over the steel and avoiding corrosive additives such as chlorides. Designs that minimize cracking reduce the entrance of corrosive solutions from the ground water.

Metallic coatings such as zinc and nickel, and chemical coatings such as benzoates seem promising as protection against chemical corrosion[8, 9, 25] but may have little value against electrical corrosion. Insulating coatings such as asphalt or epoxy on either the reinforcing bars of the outside below-ground-level walls of course destroy the grounding ability of the reinforcing steel.

Little research has been done on the effect of these measures on the control of electrical corrosion. Some benefit may be secured in reducing the effect of a galvanic source but very little may be expected in controlling external sources. Indeed, the problem of controlline external currents is the direct opposite to that of providing a satisfactory ground electrode.

Stray current discharge may best be controlled by eliminating the source or by bonding electrically to the source. The latter method is permissible only when it forces the steel to pick up current, thus affording some measure of cathodic protection. If the bonding forces the steel to discharge, the steel will corrode.

It may be risky to bond all of the reinforcing bars together to form an ac grounding system because this could increase local currents due to galvanic sources unless care has been taken to keep out all different type metals. Even the difference in the absorbed air or variable moisture[8] in the concrete structure can give rise to galvanic couples. The bonding of all of the steel together may make the application of cathodic protection impossible.

Summary

In view of all the problems associated with protecting the reinforcing bars from corrosion it seems that a separate grounding system should be used whenever possible. This grounding system should not be copper in the earth because of resultant electrolytic couples. It could be a separate system, using reinforcing bars enclosed in concrete as one choice, located between the building and the outside world. It would then intercept stray currents that might increase any incipient corrosion of the reinforcing bars of the foundations.

Care must be taken in the design of foundations and other structures to take advantage of the natural protection afforded the steel by passivation by the calcium hydroxide in concrete and not to do those things that may destroy this protection.

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