Corrosion Study of Cement-steel Casing in NaCl Solution

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Abstract: The quantification of surface corrosion and bulk corrosion of a cement-steel casing submerged in 3.5% NaCl solution for a duration of 50 days has been presented in this paper. Resistance readings were monitored using a commercial LCR device over a frequency range of 20 Hz to 300 kHz. Results show that the electrical corrosion index (*RcCc*) of the bottom two contact points (contact points #2 and #4 of cement) on the cement of the cement-steel casing both increased from 1.71E-03 ΩF to 2.10E-03 ΩF in the testing period of 50 days. This corresponds to a corrosion index change of 22.8%. This change in the corrosion index value of the two contact points on the cement is an indication that the cement is corroding. The product of interface resistance and interface capacitance (*RiCi*) for bottom probe configuration (contact #4 of cement and contact #1 of steel casing) showed a slight increase in value from 2.74E-03 ΩF to 2.76E-03 ΩF. This indicates that the steel at the interface is being protected from corrosion by the overlying cement.

1. Introduction:

Most of the civil engineering structures that surround us make use of metals such steel for construction material. Most of these structures, whether they are structures built on the ground such as buildings, bridges and roadways or underground structures such as pipelines and tunnels, require the use of metallic components that are partially or completely buried in the soil. One of the main concerns associated with such civil engineering structures is corrosion.

Corrosion is the gradual chemical attack and degradation that results in the conversion of metallic materials into oxides, salts or other compounds. Construction materials such as metals and its alloys, e.g., steel, that have undergone corrosion lose their strength, ductility and other mechanical properties. Corrosion attacks are frequently responsible for most material failures. Corrosion of underground metallic materials is a very widespread problem. Structures such as natural gas and crude oil pipelines and water pipes are some of the structures reported to have been affected by soil corrosion all around the world (Levlin, 1992; Ovri and Ofeke, 1998; Rim-ruken and Awatefe, 2006). The failure of gas, crude oil pipeline or water pipe fails, is usually accompanied by high degree of environmental, human and economic consequences (Okoroafor, 2004). Corrosion of underground metallic materials in soil is strongly dependent on the characteristics of the soil in which it is buried. There are several parameters that may affect the corrosiveness of the soil. This includes soil texture, moisture content, aeration, redox potential, pH, electrical resistivity, ionic content and bacteria (Lorena-de Arriba-Rodriguez et al., 2018).

Electrical resistivity is one of the main parameters that needs to be monitored in the field for quantification of corrosion. Electrical resistivity of a substance is the measure of the difficulty with which an electric current can be made to flow through it (McNeil J.D., 1980). In soil, it varies with depth and width due to the changes in the soil composition, moisture content and temperature. With increasing moisture, the resistivity decreases to a certain minimum value. The presence of soluble salts along with moisture also reduces the resistivity (Kar Sing Lim et al., 2013). While designing underground pipelines and similar buried structures, soil resistivity and its variation with the change in moisture content and temperature is considered. Lower values of resistivity can worsen corrosion on the outer surface of the pipelines and as a result additional costs may have to be incurred for the application of suitable protective coating on the outer surface prior to laying of the pipes.

2. Objective:

To quantify the corrosion in cement-steel casing submerged in 3.5% salinity NaCl solution

3. Methodology:

A cylindrical mold of diameter 4 inches and height 4 inches was used to prepare the cement-steel casing specimen. Circular cutouts of diameter 2 inches were made on the top and bottom surfaces of the mold for the steel pipe to be inserted. Four insertions were made on the sides of the mold to allow the wire probes to be inserted into the cement. A pictorial representation of the cement-steel casing is shown in Figure 1. The cement slurry was prepared using a water-to-cement ratio of 0.4. Commercially available oil well cement (Class-H cement) and tap water were used. The mixing method adopted was hand mixing. On demolding the specimen after one day, the specimen was placed inside a bucket containing 3.5% salinity NaCl solution. The electrical resistance readings were taken before and after immersion of the specimen in saline water. The specimen was then monitored for a period of 50 days with resistance readings being taken at an interval of every 10 days.

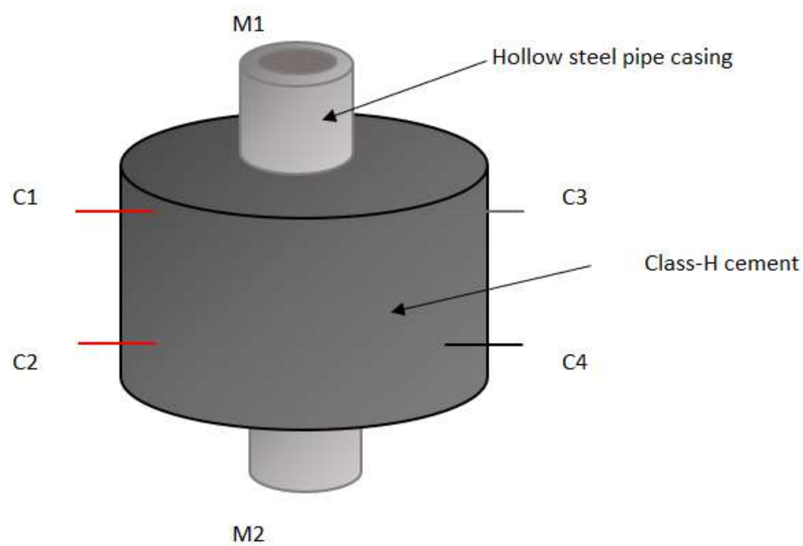


Figure 7 Cement-steel casing with wire-probe configuration (C1, C2, C3 & C4 are the cement contact points and M1 & M2 are the steel casing contact points)

4. Results:

The impedance-frequency measurements were performed over a period of 50 days at an interval of every 10 days. The frequency range used was from 20 Hz to 300 kHz. Based on the measured impedance-frequency plot a suitable equivalent circuit was chosen. The equivalent circuit is shown in Figure 2. In this the bulk material is taken as resistance only while the two contact points are taken as a resistor and capacitor in parallel. The bulk resistance, contact resistance and contact capacitance values for all the probe configurations were computed by optimizing the model impedance data points in EXCEL program.

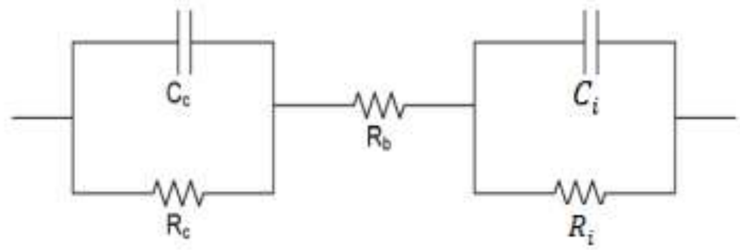


Figure 8 Vipulanandan corrosion model for two probe measurements

Figure 3 depicts the experimental impedance points versus the model impedance curve for probe configuration C2-C4 obtained on day 1 of the corrosion test.

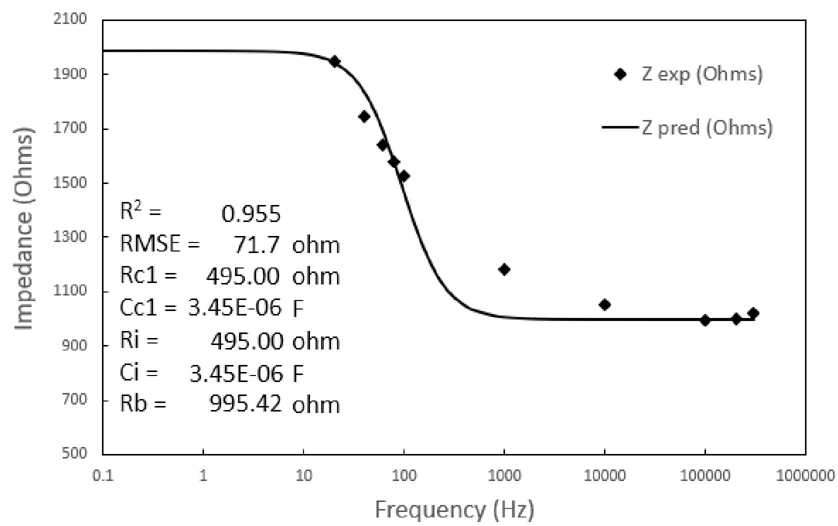


Figure 9 Impedance versus frequency plot of C2-C4 probe configuration on day 1 of corrosion test

Although resistance is not a material property, the percentage change in resistance will be directly related to the percentage change in resistivity. The bulk resistance for (1) the left-side vertical combination C1-C2 increased from 632 Ω to 959 Ω, (2) the top horizontal combination C1-C3 increased from 861 Ω to 1015 Ω, (3) the diagonal combination C1-C4 increased from 1201 Ω to 1794 Ω, (4) the diagonal combination C2-C3 increased from 691 Ω to 1128 Ω, (5) the bottom combination C2-C4 increased from 995 Ω to 1914 Ω, (6) the right-side vertical combination C3-C4 increased from 1088 Ω to 2029 Ω in 50 days. The bulk resistance for (1) combinations M1-C1 increased from 294 Ω to 414 Ω, (2) combinations M1-C2 increased from 260 Ω to 538 Ω, (3) combination M1-C3 increased from 362 Ω to 550 Ω and (4) combination M1-C4 increased from 585 Ω to 1367 Ω. All these changes indicate that the inner portion of the cement as well as the inner layer of steel casing is corroding. As rust is an oxide compound, with an increase in corrosion or rust formation, the resistance and resistivity of the material increased with time. Figure 4 depicts the variation of bulk resistance for the two probe configurations C2-C4 and M1-C4 over time.

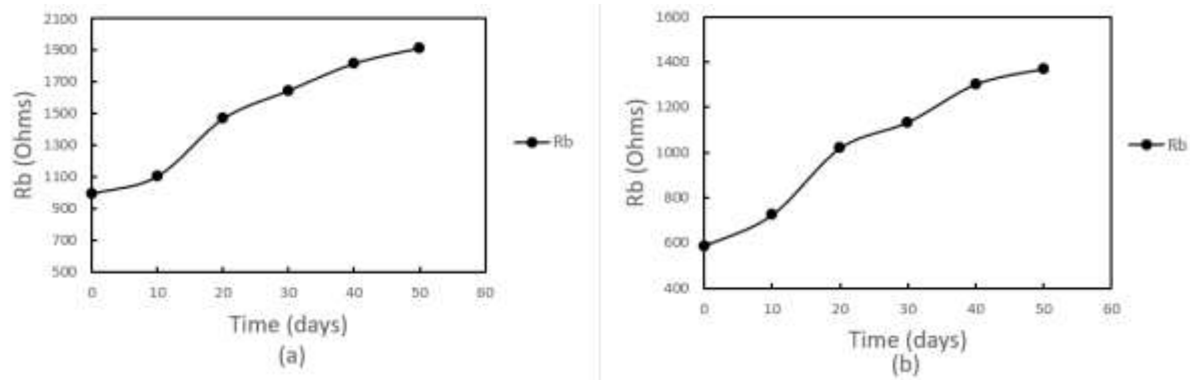
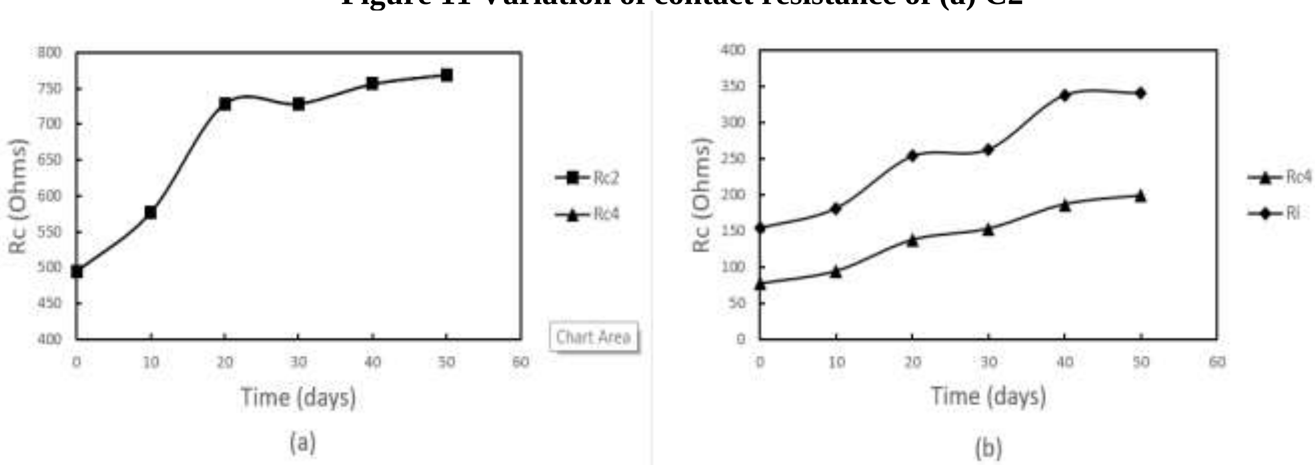


Figure 10 Variation of bulk resistance of (a) C2-C4 probe configuration and (b) M1-C4 probe configuration over time

The changes in the contact resistance (Rc) for the two probe configurations C2-C4 and M1-C4 with time are shown in Figure 5. It was observed that the contact resistance value for all the probe configurations increased over the period of 50 days. Only two results: contact resistances ($Rc2$) and ($Rc4$) for combination C2-C4 and contact resistance ($Rc4$) and interface resistance (Ri) for the combination M1-C4 are presented in this report. For C2- C4 configuration, the contact resistance (Rc) for both contacts #2 and #4 were found to increase from 495 Ω to 769.5 Ω. For M1-C4 combination the contact resistance ($Rc4$) was found to increase from 77.0 Ω to 198.4 Ω whereas the interface resistance (Ri) was found to increase from 154.0 Ω to 341.6 Ω. These changes indicate that the surface of the cement as well as the steel casing is corroding with time.

Figure 11 Variation of contact resistance of (a) C2



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C4 probe configuration and (b) M1-C4 probe configuration over time

The changes in the contact capacitance (Cc) for the two probe configurations C2-C4 and M1-C4 with time are shown in Figure 6. It was observed that the contact resistance value for all the probe configurations decreased over the period of 50 days. Only two results: contact capacitances ($Cc2$) and ($Cc4$) for combination C2-C4 and contact capacitance ($Cc4$) and interface capacitance (Ci) for the combination M1-C4 are presented in this report. For C2-C4 configuration, the contact capacitance (Cc) for contact #2 and contact #4 were both found to decrease from 3.45E-06 F to 2.72E-06 F. For M1-C4 combination the contact capacitance ($Cc4$) was found to decrease from 2.73E-07 F to 1.16E-07 F whereas the interface capacitance (Ci) was found to decrease from 1.78E-06 F to 8.09E-06 F. These changes indicate that the surface of the cement as well as the steel casing is corroding with time.

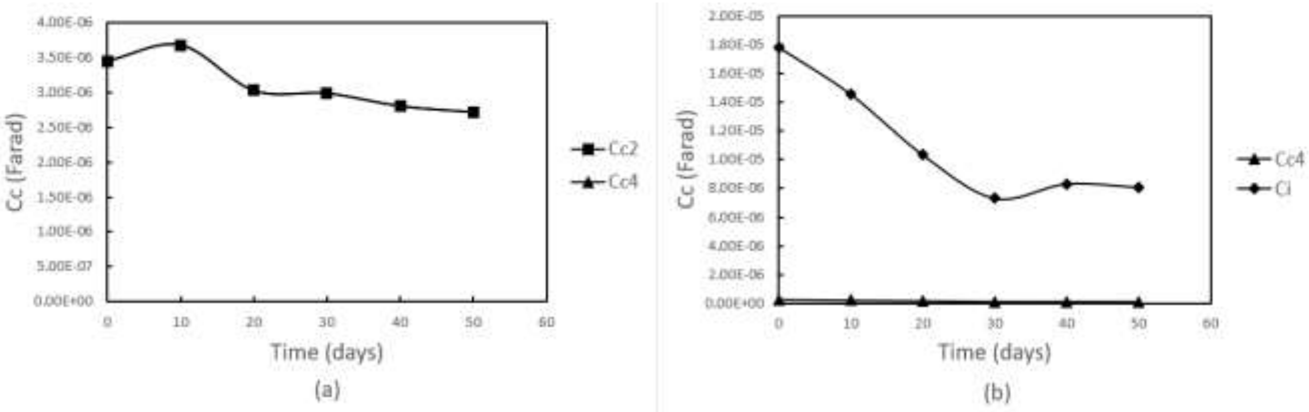

Figure 12 Variation of contact capacitance of (a) C2-C4 probe configuration and (b) M1-C4 probe configuration over time

The electrical corrosion index was defined as the product of resistance and capacitance $R \times C$, for the corroding cement-steel casing specimen in 3.5 percent sodium-chloride solution. The plot of RC $versus\ time$ for the two probe configurations C2-C4 and M1-C4 are shown in Figure 7. As rust is an oxide compound, with an increase in corrosion or rust formation, the resistance and resistivity of the material start to increase, by which we obtain this result. $Rc2Cc2$ and $Rc4Cc4$ value for probe configuration C2-C4 of the cement-steel casing specimen both increased from 1.71E-03 ΩF to 2.10E-03 ΩF in the testing period of 50 days. This corresponds to a change of 22.8% in the $RcCc$ value. $Rc4Cc4$ and $RiCi$ for probe configuration M1-C4 increased from 2.10E-05 ΩF to 2.31E-05 ΩF and 2.74E-03 ΩF to 2.76E-05 ΩF respectively in the same period. This corresponds to a change of 10% and 0.73% in the $RcCc$ and $RiCi$ value respectively.

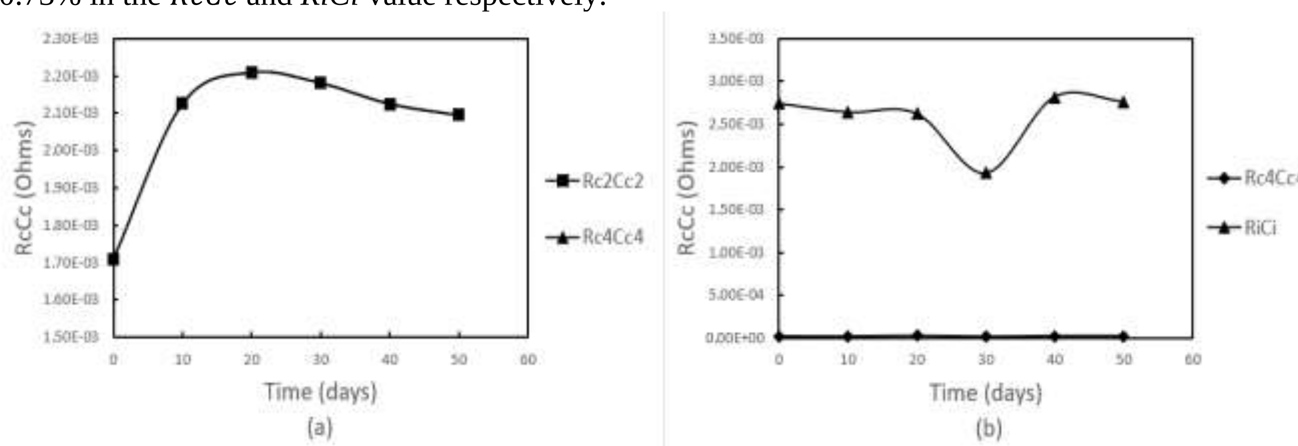

Figure 13 Variation of corrosion index of (a) C2-C4 probe configuration and (b) M1-C4 probe configuration over time

5. Conclusion:

Vipulanandan Impedance Model was used to model the impedance-frequency data from the experiments to obtain the bulk resistance, contact resistance (*Rc*) and contact capacitance (*Cc*), and the electrical corrosion index (*RcCc*). The corrosion of the cement-steel casing was monitored for 50 days in 3.5% NaCl solution. From the changes in the electrical properties, the following conclusions can be drawn:

(1) The electrical corrosion index ($R\,c\,C\,c$) of contact #2 and contact #4 increased from 1.71E-03 ΩF to 2.10E-03 ΩF in the testing period of 50 days which corresponds to a change of 22.8%. This change indicates that the cement is corroding.
(2) The electrical corrosion index at the interface ($RiCi$) increased from 2.74E-03 ΩF to 2.76E-03 ΩF in the testing period of 50 days which corresponds to a change of 0.73%. The minimal change in $RiCi$ indicates that the steel at the interface is not corroding as much. This may be due to the fact that the cement surrounding the steel casing is preventing the steel from being directly exposed to the NaCl solution.

6. Acknowledgements:

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7. References:

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