Real Time Monitoring of Short-Term Steel Corrosion in Moist Sand

S. Nandi and C. Vipulanandan, Ph.D., P.E.
Center for Innovative Grouting Material and Technology (CIGMAT)
Department of Civil and Environmental Engineering
University of Houston, Houston, Texas 77204-4003
Email: shuvam.nandi1995@gmail.com,cvipulanandan@uh.edu Phone: (713) 743-4278

ABSTRACT: The corrosion process is defined as an electrochemical reaction that causes the deterioration and loss of material which adversely affects the critical properties of a material such as its microstructure, mechanical properties, and physical appearance. Corrosion of steel is of particular interest as steel is the largest volume of metal used in the construction of most structures including buildings, bridges, storage facilities, and pipelines. Several testing methods have been used to detect and quantify corrosion such as visual inspection, weight-loss method, radiography, acoustic monitoring. However, most of these methods have limitations including field applications. In this study, the Vipulanandan Impedance Corrosion Model was used to assess and quantify the corrosion occurring in steel in moist sand in real-time.

1. INTRODUCTION:

Most civil engineering structures use metal including steel as construction material. All structures, whether built above the ground such as buildings, bridges, and roads or those built underground such as foundations, basements, and pipelines, all require the use of metallic structural components. One of the main concerns regarding the service life of such structures is corrosion. It is very important to consider corrosion as a parameter when designing such structures as it may not only affect the structural performance in the long run but also because of its economic impact. It has been seen that the costs attributed to corrosion damages of all kinds are estimated to be 3% to 5% of industrialized countries' gross national product (Roberge, 2019). In the United States, many government studies have shown that the cost due to corrosion loss is almost $300 billion annually (Corrosion: Understanding the Basics (March 19, 2000), 2021). The loss of material by corrosion is a waste not only of the steel structures, but also of the energy, water, and human effort that was used to produce and construct the structures. In addition, the replacement of the corroded steel structures requires the further investment of all these resources (Secer et al, 2016). In the present study evaluation of corrosion in real-time is of utmost importance. Using the Vipulanandan Impedance Corrosion Model the quantification of corrosion in steel subjected to moist sand has been studied.

2. OBJECTIVE:

Study and quantify the corrosion occurring in steel bar placed in 10% moist sand.

3. METHODOLOGY:

A cylindrical mold of height 4 inches and diameter 4 inches was used to prepare the corrosion specimen. Four insertions were made, two on each side of the mold, for the wire probes to pass through. A bottom cutout was made for the steel bar to go through. The pictorial representation of the specimen with the probe configurations is shown in Figure 1. A steel bar, with initial dimensions of 15 cm x 2.5 cm x 0.5 cm and density of 7.53 g/cm3, was placed in Ottawa sand with 10% moisture content. The weight of the specimen was recorded followed by measurement of the resistance and reactance values using a commercial LCR device over the frequency range of 20 Hz to 300 kHz. The electrical resistance measurements were monitored for a period of 70 days.

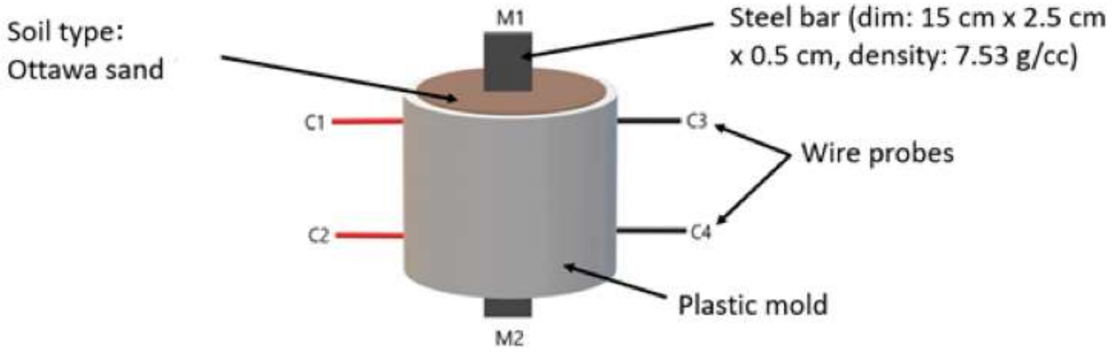


Figure 1 Probe configuration for electrical resistance measurements of steel bar in moist sand

The electrical resistance vs frequency measurements were performed over a period of 70 days. The frequency range used was from 20 Hz to 300 kHz. The measured electrical resistance vs frequency plot confirmed that the electrical response of the specimen conforms to Case 2 of the Vipulanandan Impedance Model (Vipulanandan et al, 2013). 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 equivalent circuit for Case 2 is shown in Figure 2.

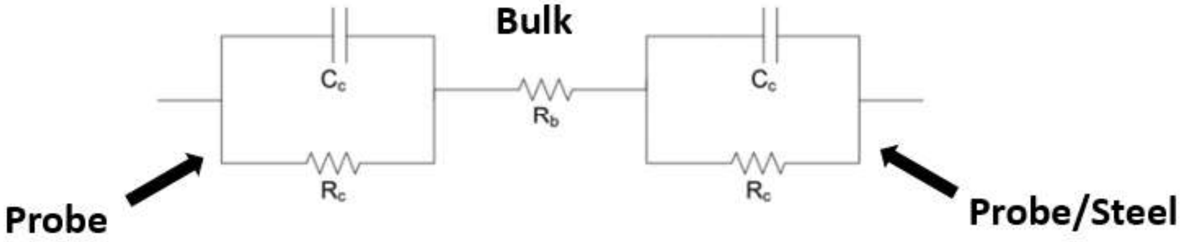


Figure 2 Equivalent circuit for case 2

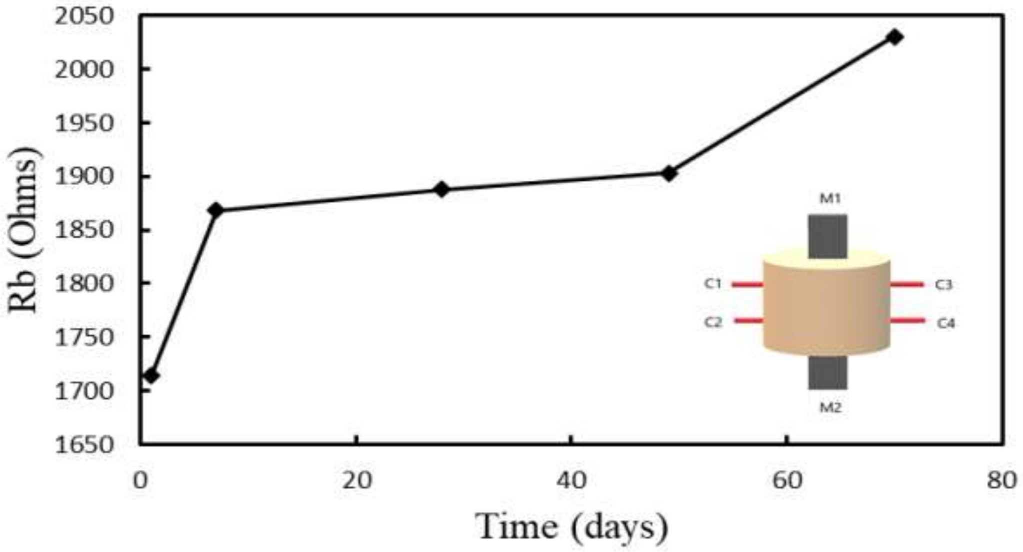
The impedance equation for the case 2 equivalent circuit is given as

$$Z_2 = R_b + \frac{2R_c}{1 + \omega^2 {R_c}^2 {C_c}^2} - j\left\{\frac{2\omega {R_c}^2 C_c}{1 + \omega^2 {R_c}^2 {C_c}^2}\right\}$$

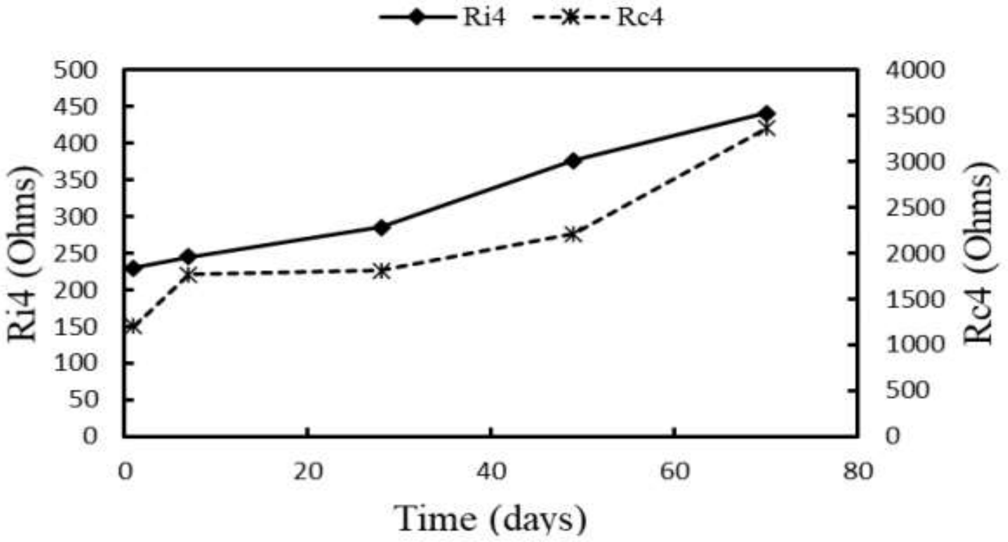
where ω is the angular frequency, R_b is the bulk resistance, R_c is the contact resistance and C_c is the contact capacitance. When the frequency of the applied signal is very low, $\omega \rightarrow 0, Z_2 = R_b + 2R_c$, and when it is very high, $\omega \to \infty$, $Z_2 = R_b$. In the case of corrosion measurement, the two contacts will have different properties.

The bulk resistance, contact resistance and contact capacitance values for all the probe configurations were computed by optimizing the model impedance data points in MS EXCEL program using the impedance equation for case 2 material.

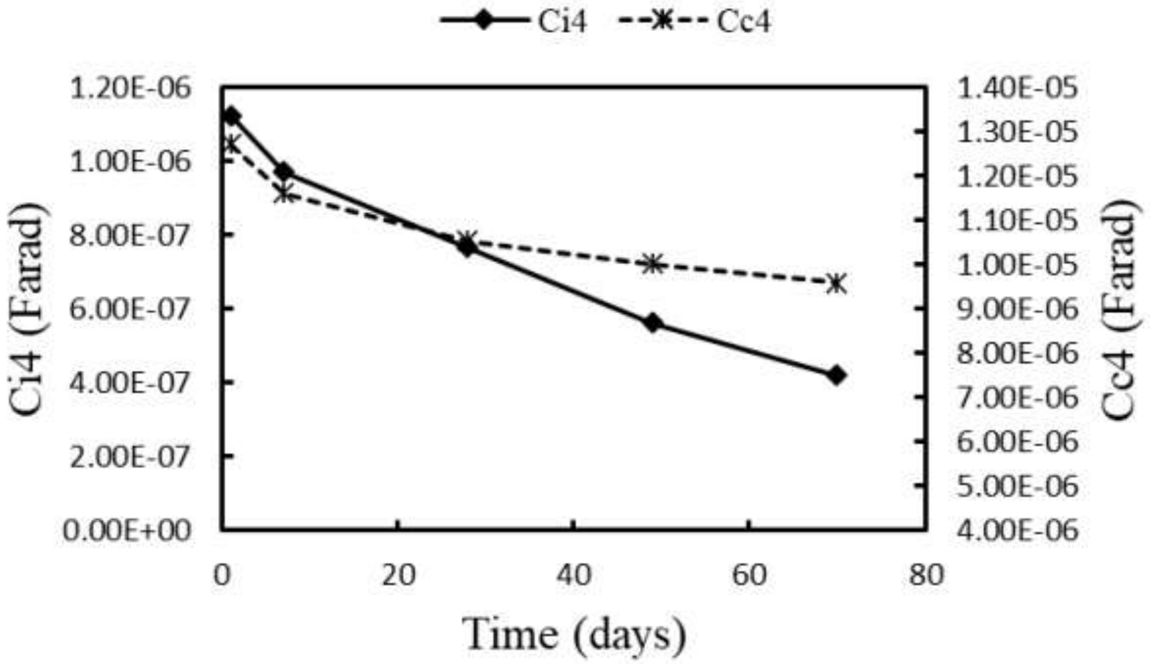
4. RESULTS:



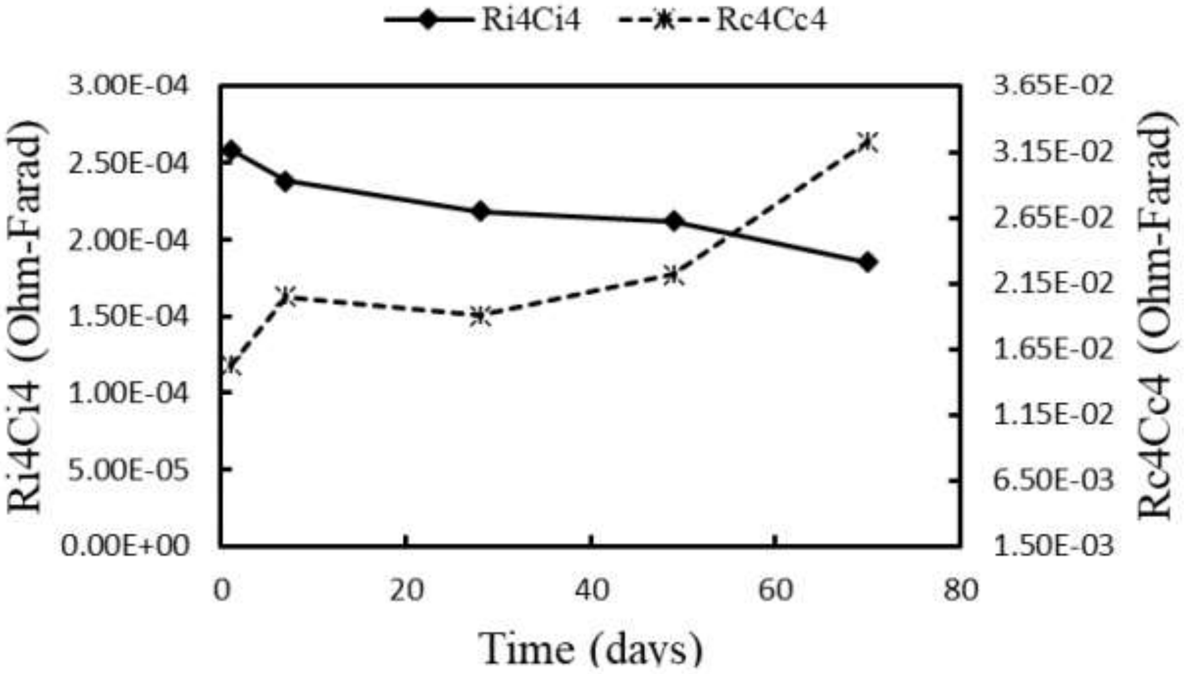
(a)



(b)



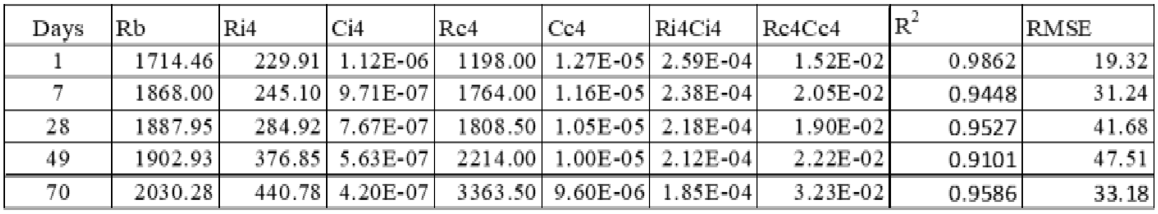
(c)



(d)

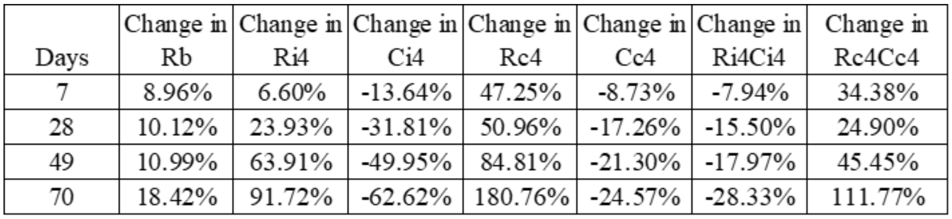
Figure 3 Change in (a) bulk resistance (Rb), (b) interface resistance (Ri) & contact resistance (Rc), (c) interface capacitance (Ci) & contact capacitance (Cc), and (d) corrosion index (RC) over time for M1-C4 configuration of moist sand specimen

Table 1 Model parameters of the equivalent circuit for M1-C4 configuration of the moist sand specimen



Days	Rb	Ri4	Ci4	Rc4	Cc4	Ri4Ci4	Rc4Cc4	R^2	RMSE
1	1714.46	229.91	1.12E-06	1198.00	1.27E-05	2.59E-04	1.52E-02	0.9862	19.32
7	1868.00	245.10	9.71E-07	1764.00	1.16E-05	2.38E-04	2.05E-02	0.9448	31.24
28	1887.95	284.92	7.67E-07	1808.50	1.05E-05	2.18E-04	1.90E-02	0.9527	41.68
49	1902.93	376.85	5.63E-07	2214.00	1.00E-05	2.12E-04	2.22E-02	0.9101	47.51
70	2030.28	440.78	4.20E-07	3363.50	9.60E-06	1.85E-04	3.23E-02	0.9586	33.18

Table 2 Change in model parameters for M1-C4 configuration of the moist sand specimen



Days	Change in Rb	Change in Ri4	Change in Ci4	Change in Rc4	Change in Cc4	Change in Ri4Ci4	Change in Rc4Cc4
7	8.96%	6.60%	-13.64%	47.25%	-8.73%	-7.94%	34.38%
28	10.12%	23.93%	-31.81%	50.96%	-17.26%	-15.50%	24.90%
49	10.99%	63.91%	-49.95%	84.81%	-21.30%	-17.97%	45.45%
70	18.42%	91.72%	-62.62%	180.76%	-24.57%	-28.33%	111.77%

The changes in the model parameters: bulk resistance, interface resistance, and contact resistance for the M1-C4 configuration can be seen in Figure 3(a) and 3(b). The bulk resistance saw an increase from 1714 ohms to 2030 ohms in 70 days which translates to an increase of 18.42%. The interface resistance and contact resistance saw an increase from 229 ohms to 440 ohms and 1198 ohms to 3363 ohms in the same duration which translates to an increase of 91 and 180%, respectively.

The change in interface capacitance and corrosion index at the interface and contacts of M-C4 configuration of the moist sand specimen over the 70 days period is shown in Figure 3(c) and 3(d). The interface capacitance decreased from 1.12E-06 F to 4.20E-07 F which translates to a decrease of 63% while the contact capacitance decreased from 1.27E-05 F to 9.60E-06 F which translates to a decrease of 25%. The corrosion index at the interface (Ri4Ci4) decreased by 28% while at the contacts (Rc4Cc4) increased by 111%. This decrease in the value of corrosion index at the interface can be seen as a result of the relatively high percentage decrease in the value of interface capacitance compared to the percentage increase in the value of the corresponding interface resistance. The increase in the Rc4Cc4 value, on the other hand, was seen because of the relatively low percentage decrease in the contact capacitance value as opposed to the percentage increase in contact resistance value.

5. CONCLUSION:

The electrical impedance method shows the corrosion kinetics and evolution of corrosion over time in the different corrosion specimens. The interface resistance of the (1) steel bar in moist sand showed an increase in almost 2 times its initial value in the 70 days period. The increase in the interface resistance and decrease in interface capacitance shows that the steel bar in moist sand is corroding over time. On comparison of the interface resistance, it can be said that the corrosion occurring in moist clay is more than the corrosion occurring in moist sand.

6. ACKNOWLEDGEMENTS:

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