Corrosion of Steel Casing in Cement Placed in Salt Solution

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Abstract
This study is on the corrosion of steel casing in cement and 3.5% saline water solution monitored for 780 days. Using the Vipulanandan Impedance model to optimize the parameters, the changes in cement resistivity with the steel and contact corrosion parameters were quantified. For the corrosion of steel casing in cement and 3.5% saline water solution the corrosion parameters were quantified. The bulk resistance and contact resistance are increasing with time.

1. Introduction

Structural failures due to corrosion not only impact the service life of the structure but also failures due to corrosion can cause economic losses. Construction industry is heavily impacted by the effects of corrosion as the corrosion of steel bars could cause deterioration of the concrete structures, thus results in failure (Kashani, et al., 2013). Corrosion of reinforcement results in fracture cracking, spalling of concrete cover, reduction of flexural and shear strength and reduction of ductility of the material (Kashani et al. 2013). As per the U.S Corrosion study conducted between 1999-2001, around $276 billion was related to the direct cost on metallic corrosion and this was 3.1% of the U.S. Gross Domestic Product (GDP) of 1998 (Koch, et al., 2002). The global cost of corrosion was estimated as US$ 2505 Billion, and this was 3.4% of global Gross Domestic Product (GDP) in 2013 (Koch, et al., 2016). This justifies the importance of monitoring and quantifying corrosion in infrastructure.

For corrosion monitoring, corrosion coupon weight loss method, electrical resistance probe method, electrochemical sensors, Ultrasonic testing of wall thickness method, magnetic flux leakage method, electromagnetic sensors, passive wireless sensors, optical fiber sensors and pipe inspection gauge are used (Wright, et al., 2019)

Non-destructive electrical methods were developed to study the degree of corrosion in the structures. The electrical properties of the materials were used to develop Vipulanandan corrosion index (Vipulanandan, 2021). The contact resistance (R) and contact capacitance (C) can be used to quantify the corrosion of the steel casing and bars.

2. Objective

The overall objective was to measure and quantify the corrosion of steel casing in cement. The specific objectives are as follows.

1. Measure the changes in the cement using the two wire probes and A/C current
2. Measure the changes in the steel and interface.

3. Methodology

A cylindrical mold of height 4 in and 4 in diameter was used. For the molds, four insertions were made for the wire probes as shown in Figure 1. A bottom cutout was made for the steel cylinder to go through. 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.

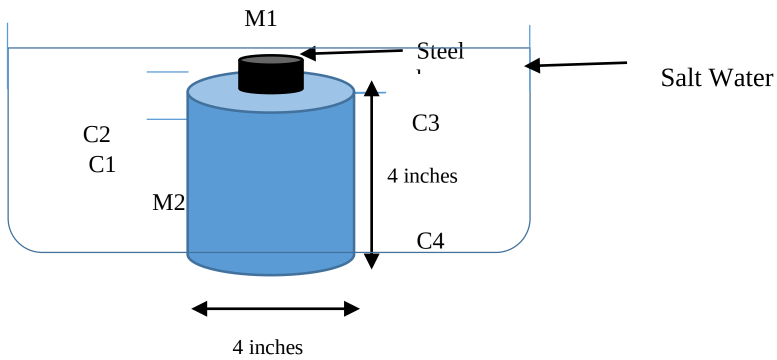

Figure 1 Cement Steel Casing wire configuration

On demolding the specimen after one day, the specimen was placed inside a bucket containing 3.5% salinity NaCl solution. The measurements of the resistance values were taken using LCR device for the frequency range of 20 Hz to 300 kHz for 540 days. The specimen was placed inside a bucket with 3.5% saline water. The resistance and reactance measurements were taken for 11 different wire probe combinations.

Based on the measured impedance-frequency plots a suitable equivalent circuit was chosen. The equivalent circuit is shown in Figure 2.

Here the bulk material is taken as resistance only while the two contact points are taken as a resistor and capacitor in parallel.

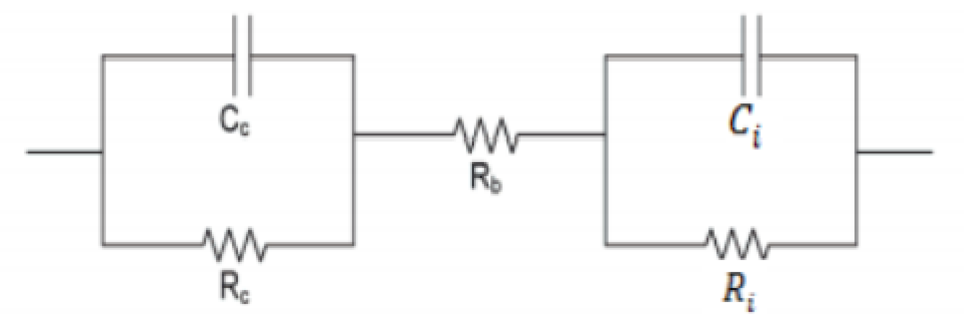

Figure 2 Equivalent circuit diagram of corrosion model

Impedance equation for given equivalent circuit diagram of corrosion model.

$$Z = R_b + \frac{R_c}{1+\omega^2 R_c^2 C_c^2} + \frac{R_i}{1+\omega^2 R_i^2 C_i^2} \quad \text{--}(1)$$

The above circuit equation can be used and the bulk resistance, contact resistance and contact capacitance values for all the probe configurations were computed by optimizing the model impedance data points using EXCEL.

4. Results

From the impedance model the collected data was optimized. The bulk resistance (Rb), contact resistance (Rc) and contact capacitance (Cc), interface Resistance (Ri) and interface capacitance (Ci) were calculated from the model optimization. The impedance curves of C1-C3 and M1-C1 configuration on day 1 and 780 are shown in Figure 3 and 4.

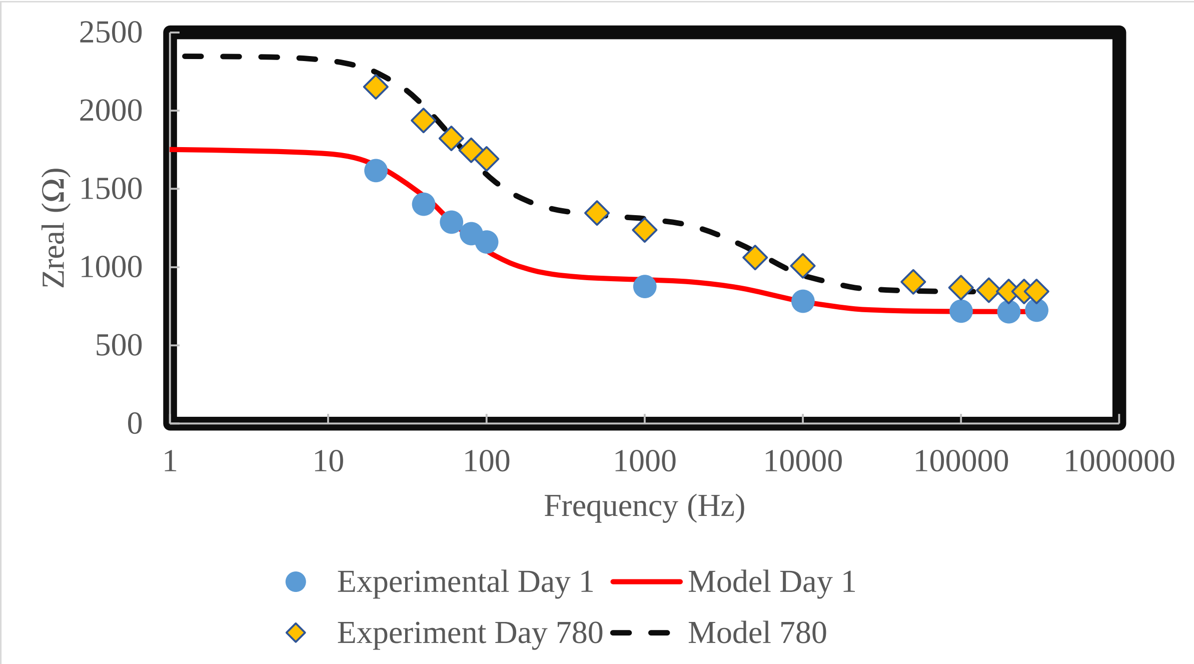

Figure 3 The impedance curve of C1-C3 on day 1 and day 780

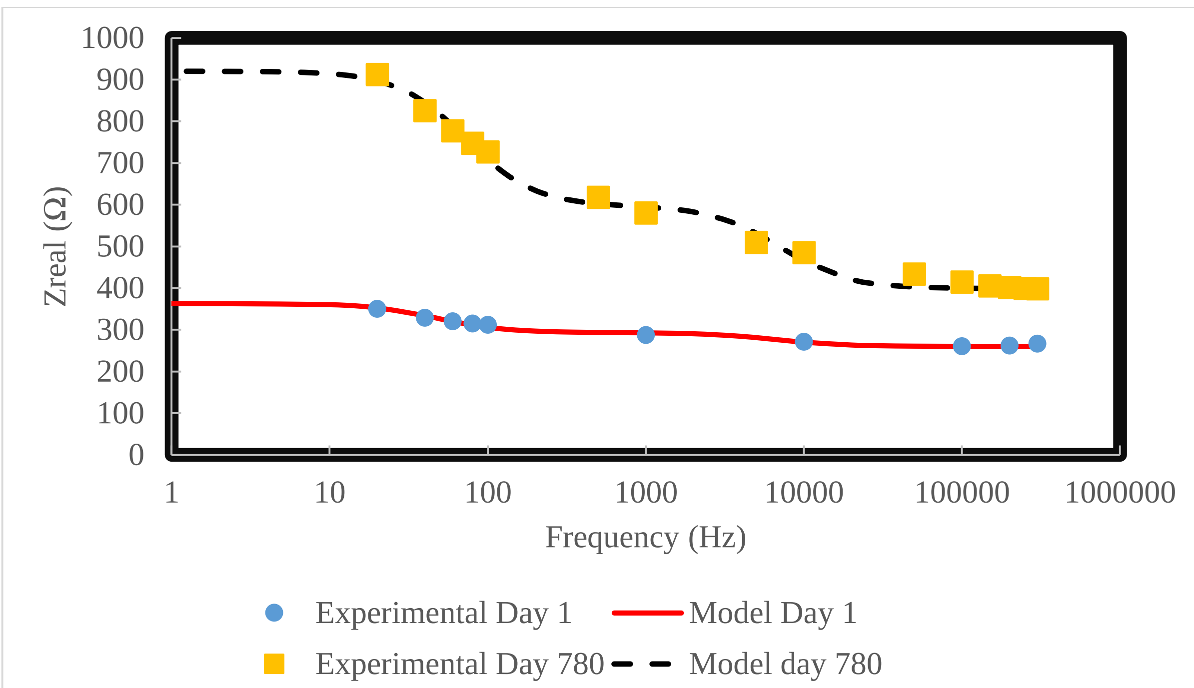

Figure 4 The impedance curve of M1-C1 configuration after 1 day and 780 days

Based on the Figure 3 and 4, contact resistance, contact capacitance, interface resistance, interface capacitance, Rbulk are tabulated for C1-C3 and M1-C1 combinations in Table 1.

Table 1 Corrosion parameters for C1-C3 and M1-C1 configurations for curing days 1 and 780days.

Curing days	Combination	R^2	RMSE (ohm)	Rc1 (ohm)	Cc1 (F)	Rc3 (ohm)	Cc3 (F)	Rb (ohm)
1	C1-C3	0.99	31.74	206	1.2E-07	830	3.5E-06	715.3
780	C1-C3	0.99	54.57	479	6.3E-08	1025	2.6E-06	842.8
Curing days	**Combination**	**R^2**	**RMSE (ohm)**	**Rc1 (ohm)**	**Cc1 (F)**	**Rci (ohm)**	**Cci (F)**	**Rb (ohm)**
1	M1-C1	0.98	4.05	70	4.8 E-05	33	7.30E-07	260.26
780	M1-C1	0.99	15.66	323	6.7 E-06	197	1.10E-07	399

The Plots for Rb change of horizontal the configuration (C1-C3) and cement-steel interface M1-C1 is given in Figure 5. For both configurations bulk resistance increased from day 1 to day 780.

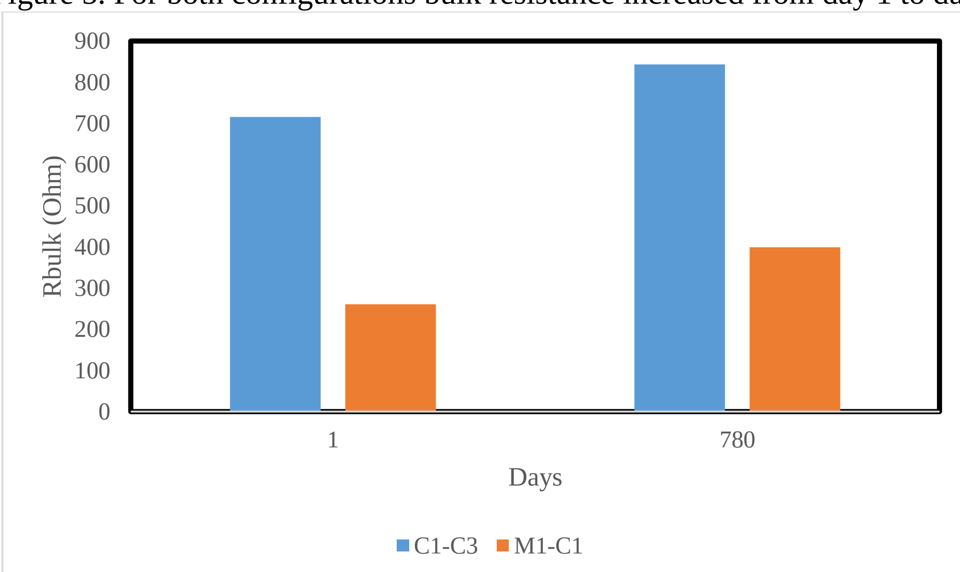

Figure 5 Bulk resistance change of C1-C3 and M1-C3 on day 1 and day 780

Contact Resistance and Contact capacitances changes of C1-C3 configuration are given in Figure 6 and 7.

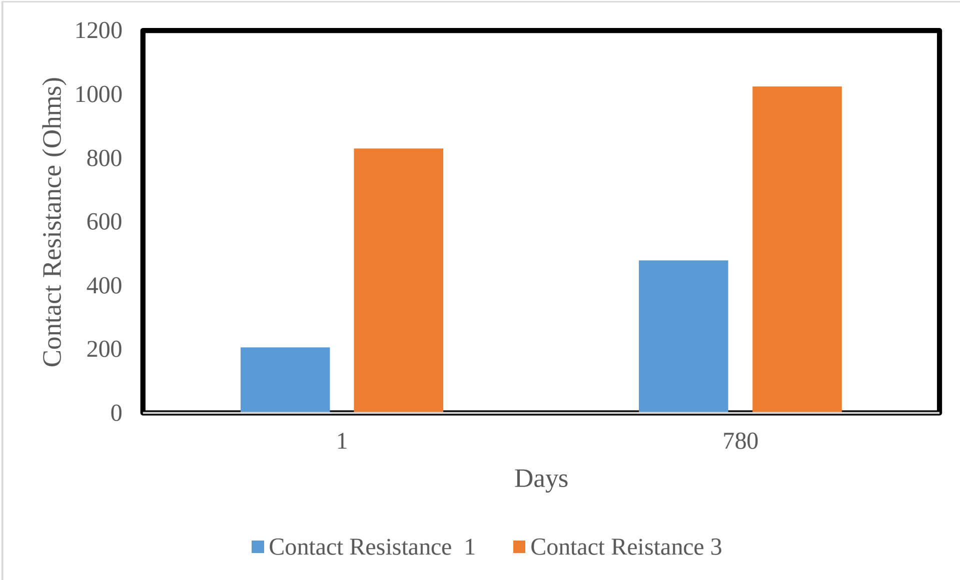

Figure 6 Contact resistance change of C1-C3 on day 1 and day 780.

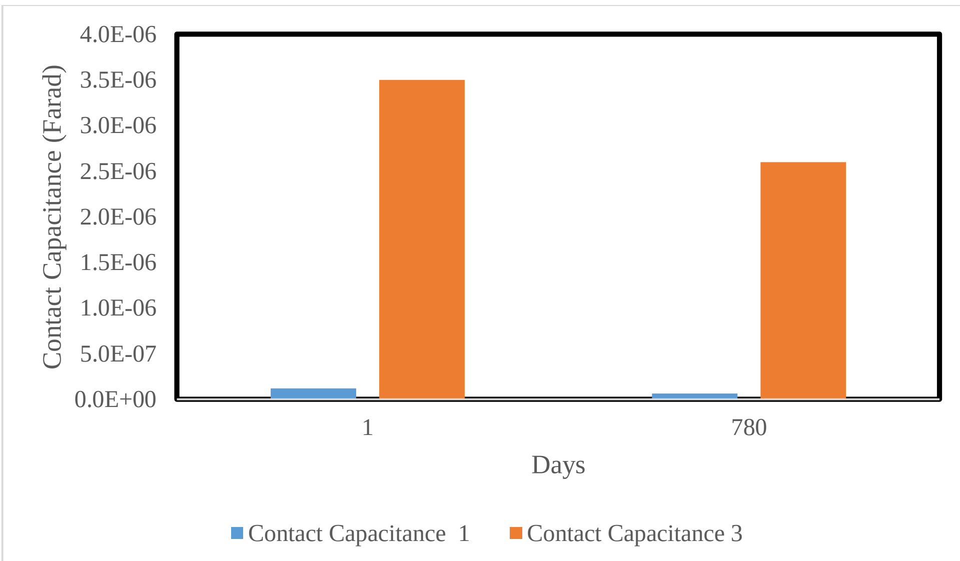

Figure 7 Contact capacitance change of C1-C3 on day 1 and day 780

From day 1 to day 780, the contact resistance has increased and contact capacitance has decreased. The interface resistance and interface capacitance change from day 1 to day 780 is given in Figure 8 and 9. Interface resistance has increased, and interface capacitance has decreased with time.

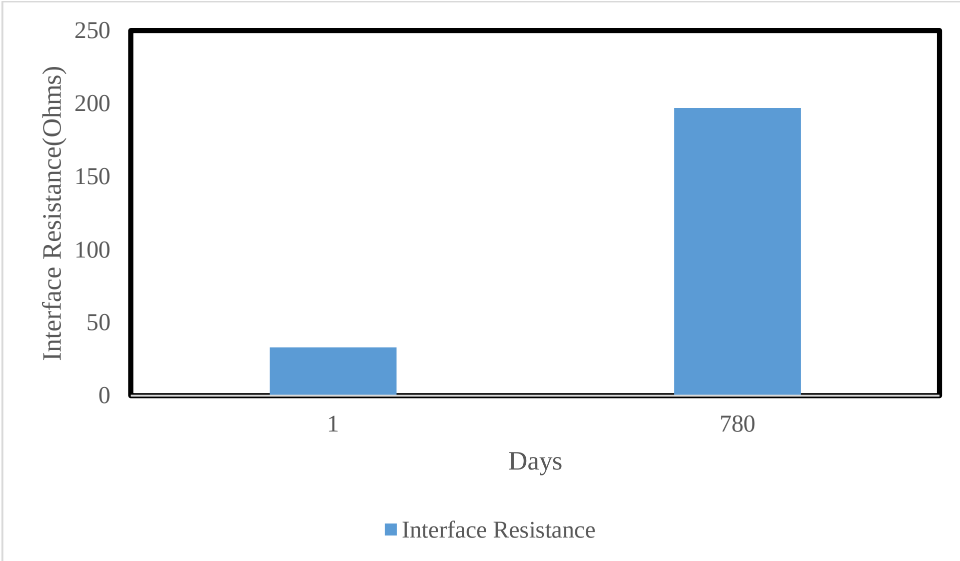

Figure 8 Interface resistance change of M1-C1 on day 1 and day 780.

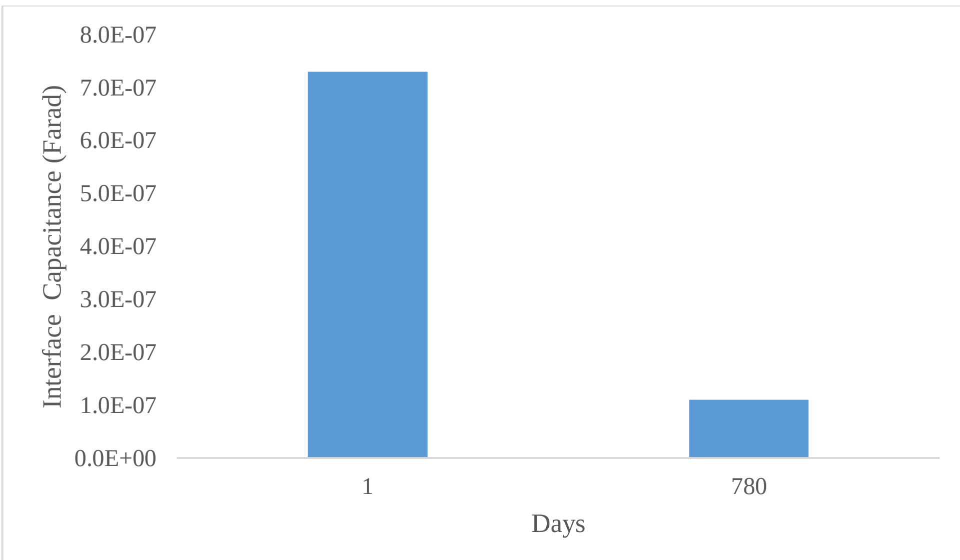

Figure 9 Interface capacity change of M1-C1 on day 1 and day 780.

5 Conclusions

1. The impedance values decrease from 20 Hz to 100 kHz. Beyond this frequency, the impedance value becomes nearly constant. This implies that the impedance value is influenced by resistance of cement. This follows case 2.
2. The same decreasing trends of impedance values were observed for cement-steel configuration.
3. The equivalent circuit for case 2 can be used for cement-steel casing, where the bulk is represented by resistor and contacts were represented by two parallelly connected resistors and capacitors.
4. The bulk resistance, contact resistance and contact capacitance of all wire configurations were determined by optimizing the circuit formula. For Steel -wire configuration, the bulk resistance, contact resistance, contact capacitance, interface resistance and interface capacitance were determined using optimization of the circuit formula.

5. From day 1 to day 780, Rbulk, was increased for all the combination. Contact resistance and interface resistance were increased while contact capacitance, and interface capacitance were decreased from day 1 to day 780.

6 Acknowledgement

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7. References

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