Development and Calibration of Low Cost Corrosion Monitoring Equipment (Dr. CORe)

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Abstract: With the passage of time, structures deteriorate exponentially causing a potential life vulnerability on residential as well as infrastructure projects. This gives rise to proper maintenance requirement and need of developing Structural Health Monitoring (SHM) techniques. The SHM is a vast topic and involves various methods and equipment which can be costly. One of the parts of SHM is monitoring Corrosion which forms the base of reinforcement failure. The paper combines a few literatures done on SHM along with developing a Corrosion Monitoring Equipment which can produce approx. electrical corrosion potential of uncoated reinforcing steel in field and laboratory concrete. The equipment works on the principle of Half Cell Potentiometer and has been calibrated successfully conforming to ASTM C876. The cost of equipment was reduced by 98.6% when compared to a state of the art equipment available in market. The name Dr.CORe stands for Doctor for Corroded Reinforcement.

Keywords: Structural Health Monitoring, Corrosion, Reinforcement, Half Cell Potentiometer, Steel, NDT.

1. Introduction

Corrosion is an inevitable phenomenon that engineers have to consider right from conceptualization, designing, to maintenance stage of a project. A premature failure of structure may well be linked with the failure of rebar which is due to plenty of reasons, but the prominent one is the corrosion of rebar which leads to durability and serviceability decrement. This effect of corrosion cannot be neglected as it accumulates to failure of entire element, or in some cases, entire structure. Corrosion of rebar cannot be tracked right from the first day as it is an activity which is initiated inside the structure. By the time, it is visually recognized with cracks, expect a major damage commenced. Therefore, considerable attention is required on the maintenance of structures. Over the recent decade, corrosion testing has been deeply researched the methods to predict corrosion have been developed. The use of the principle of Half-cell Potentiometer is to measure the probability of corrosion. The use of this method and the interpretation of its results are described in ASTM C876 [1]. Corrosion sensors have also been developed to detect corrosion of stainless steel [2]. The internal corrosion also effects the durability of concrete studied by [3].

Since 1978 Half Cell Potential mapping is in vogue for detecting corroding areas on concrete structures. The Half Cell Potential Testing method is recommended for determining the likelihood of reinforcement corrosion, which is then used to determine how long reinforced concrete will last. The reinforcement check for corrosion can be done with various methods. Non-destructive technique such as half-cell potential measurement (HCP) is a well-known technique for investigation of corrosion in steel. The use of potential mapping on reinforced concrete structures makes it easy to understand the probability of corrosion potential inside a specimen. This potential mapping phenomenon is a data representation of half-cell potential measurements and this map depends on the corrosion severity. It can be represented in either a colour plot by assigning the entire specimen area with colour depending on corrosion values specified in [1] or by creating a contour map of corrosion values which will help in simple and easy depiction of probable corrosion value [4].

2. Methodology and Materials

Corrosion of steel can be assessed by HCP measurement by an electrochemical process as per ASTM C876. Here, the electrical potential is measured with reference to a standard portable electrode in presence of a contact solution. The half-cell is made by a Copper/ Copper Sulphate or Silver/ Silver Chloride cell but other combinations are also used. In this arrangement, the concrete starts acting as an electrolyte and the potential difference value obtained is related with the risk of corrosion of reinforcement at the test location. The electrode consists of a tube, rigid in nature and made up of a dielectric material. It is non-reactive to the solution present inside it and has a porous plastic or a wooden plug which has capillary action enabled. A copper rod is also present which is immersed in the solution of $CuSO_4$. The reference electrode is connected to the positive end of the high impedance voltmeter and the steel reinforcement to the negative. The Fe^{++} ions are dissolved and electrons are set free at the anode. They form OH^- at the cathode end where they drifted the steel. This results in a potential difference which is measurable with half-cell method.

The reliability of half-cell potential measurement as an indication of corrosion potential has evolved by the good results during the bridge deck corrosion surveys. An indication of the relative probability of corrosion activity was empirically obtained through measurements during the 1970s [5].

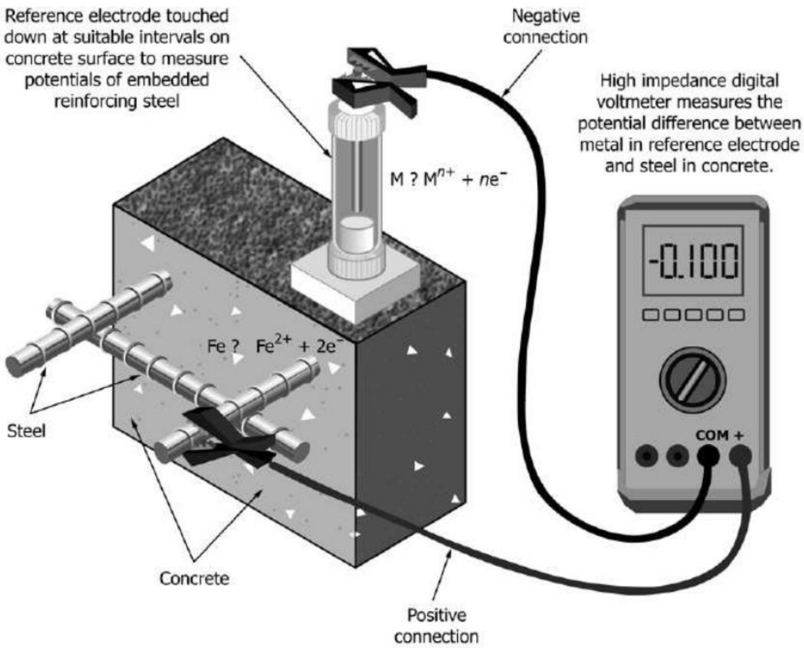

Figure 1: Reference Electrode Circuitry [1]

2.1. Materials

There are various corrosion measuring devices available in market but we decided to assemble it part by part in order to reduce cost. Following are the assembling parts used to develop this device.

- Reference Electrode – CuSo4

The electrode used for assembling the Half Cell Potentiometer device in taken with reference of CuSo4. For this equipment we used a locally available Reference electrode with a conical tip. It is to be filled with Copper Sulphate crystal and water till the top of electrode. Shown below is the image of reference electrode of FONTANA brand [Figure 2].

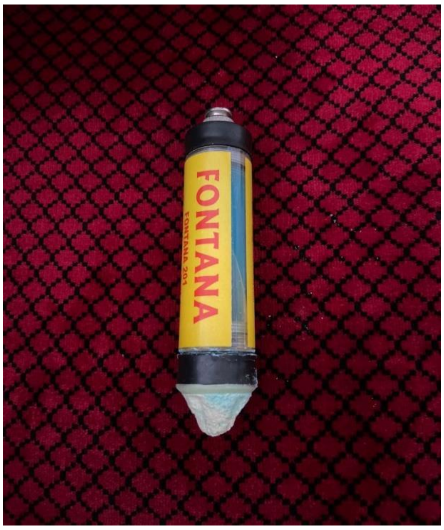

Figure 2: $CuSO_4$ Reference Electrode

Figure 3: Digital Multi-meter

- Digital Multi-meter

The voltmeter used was a digital multi-meter having DC voltage reading [Figure 3].

- Wetting Agent

The wetting agent can be of any type. For this study, we took a laundry use wetting agent. As per ASTM, the wetting agent needs to be a diluted solution of 95mL of wetting agent with 5 gallon i.e. (19L) of potable water [Figure 4].

Figure 4: Wetting Agent

Figure 5: Connecting Wires

- Connecting wires

The connecting wires include wires to be connected to the electrode and the reinforcing bar and also the extension wire in case the length of specimen is too large. Along with these, a couple of crocodile clips are also needed to connect to the electrode and reinforcing bar firmly [Figure 5].

Apart from the above mentioned, a sponge and $CuSO_4$ solution is also required. The sponge is kept at tip of electrode while the solution is filled in electrode during operation.

2.2. Procedure of working of instrument

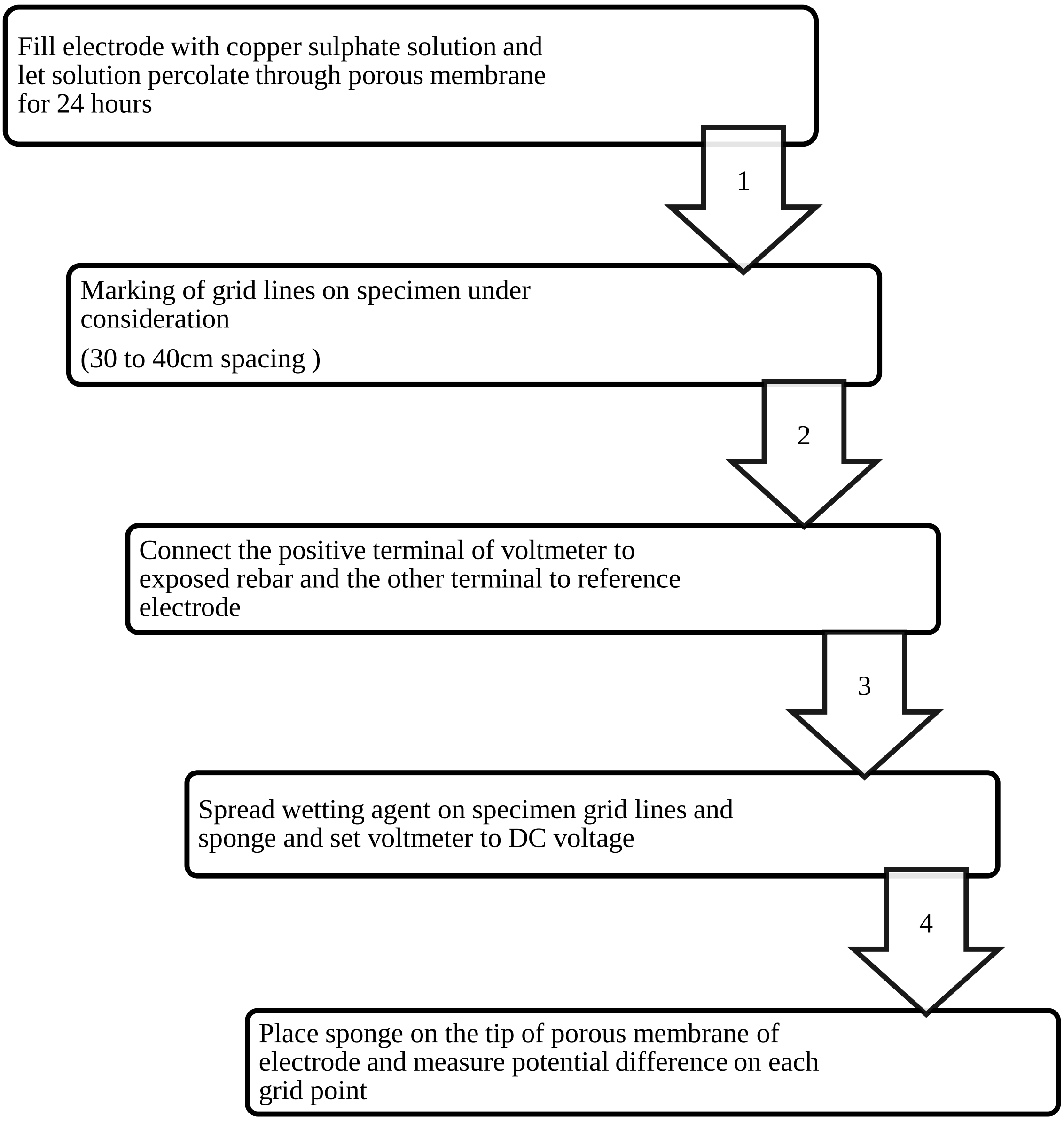

Figure 6: Flow chart of step wise procedure of testing

2.3. Calibration of the device

The assembled device can be used for determining the probability of corrosion on a RCC Structure only after it is calibrated and tested whether it is in accordance with the ASTM C876 standard values. For this purpose, a slab specimen is casted containing different types of corroded rebars. These vary from highly corroded rebar to sunlight rusted rebar to new rebar.

By doing so, we can check the potential difference for differently corroded bars and hence compare the values with the standard range of potential difference values specified in Annexure of ASTM C876 [Table 1].

The calibration was done by initially preparing a mould for slab specimen and placing reinforcement bars with different levels of corrosion. This will help in calibrating the device, whether the corroded rebars potential value matches with ASTM [Table 1] or not, to conclude the authenticity of working of the equipment.

Details of rebar are as follows –

A	First from left	New Rebar
B	Second	Rebar kept on site unexposed to sunlight
C	Third	Rebar kept on site, exposed to sunlight, not rusted
D	Fourth	Rebar kept on site, exposed to sunlight, medium rusted
E	Fifth	Rebar kept on site, exposed to sunlight, highly rusted
F	Sixth	Rebar with light corrosion
G	Seventh	Rebar with high corrosion

Figure 7: Mould Preparation

Figure 8: Laying of different types of rebar

It was followed by concreting of mould and finishing the top surface evenly.

Figure 9: Concreting of the mould

Figure 10: Finished surface of specimen

Breaking of a portion of specimen to expose the rebars. This will help in connecting one end of the clamp to the rebar firmly. The values for each rebar are measured by connecting clamp to its respectively exposed rebar portion. This way, the values for potential difference of corroded rebar and new rebar are found.

Figure 11: Specimen broken from side to exposed rebars

Figure 12: Measurement of values

Table 1. Range of Potential Diff. values to determine probability of corrosion as per ASTM C876 [1]

Potential Difference (V)	Corrosion Rate (%)
> -0.20	<10
-0.20 to -0.35	Uncertain
<-0.35	>90

3. Results and Discussion

The results obtained from the calibration data in Volts is as follows –

Table 2. Values of Potential obtained for different rebar from specimen built to calibrate device

Point of Contact on Specimen						
A	**B**	**C**	**D**	**E**	**F**	**G**
-0.210	-0.385	-0.199	-0.155	-0.480	-0.359	-0.410
-0.250	-0.388	-0.215	-0.147	-0.450	-0.400	-0.379
-0.220	-0.369	-0.217	-0.167	-0.428	0.360	-0.390
-0.240	-0.366	-0.205	-0.169	-0.443	-0.345	-0.400

Table 3. Range Table from ASTM C876 with Code

Potential Difference (V)	Corrosion Rate (%)	Code
> -0.20	<10	
-0.20 to -0.35	Uncertain	
<-0.35	>90	

Table 4. Result values from testing with Code

Point of Contact on Specimen						
A	B	C	D	E	F	G
-0.210	-0.285	-0.199	-0.155	-0.480	-0.359	-0.410
-0.250	-0.288	-0.215	-0.147	-0.450	-0.400	-0.379
-0.220	-0.269	-0.217	-0.167	-0.428	0.360	-0.390
-0.240	-0.266	-0.205	-0.169	-0.443	-0.345	-0.400

The above reading obtained show that Bar D is totally free of corrosion, whereas bar A, B and C are uncertain, whether there is corrosion occurring or not. The Bars E, F and G are having a 90% chance of being corroded which can be regarded as true due to the very physical appearance of bar.

3.1. Equipment costing

The cost of equipment part by part is given below –

- Fontana Reference Electrode - ₹1,770
- Digital Multi-Meter and Wires - ₹1,500
- Wetting Agent - ₹120
- Sponge - ₹50

The total cost of developing the equipment was under ₹3,500/-

3.2. Comparison with other devices available in market

On the other hand, price for a new equipment for different brands are mentioned below

- James Half-Cell Potentiometer Instrument - ₹250,000
- Giatech Half-Cell Potentiometer Instrument - ₹200,000
- Avantech Half-Cell Potentiometer Instrument - ₹35,000

3.3. Conclusions

The paper described the concept of Half-cell potentiometer and development of a corrosion monitoring device based on same principle. The device was assembled part by part and costed relatively cheap when compared with a market equipment. The instrument did lack the result in the form of potential map but the same can be drawn manually which definitely is not a big task. Based on the work carried out above we can conclude that

- The assembled device was calibrated and successfully tested to match with the ASTM C876 range of values.
- The device is therefore ready to use for detecting corrosion potential values.
- With the help of this instrument, the corrosion probability inside concrete can be successfully measured and hence, the maintenance work can be done accordingly.
- The repair cost estimation can be fairly estimated by the use of this device.
- The cost of equipment can be drastically reduced if assembled properly. Compared to a top model device available in market, the price is reduced by 98.6%
- The device has been submitted in the college model laboratory for use.

References

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