



HALF-CELL POTENTIALS OF EMBEDDED STEEL IN CONCRETE

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ABSTRACT

Protection of marine structures against corrosion has become a challenging task for corrosion engineers. Marine structures like jetties, sheet piles, etc. which come in contact with sea water are subjected to the action of aggressive chloride ions in addition to oxygen and moisture. These corrosive species cause severe damage to the reinforced steel when they come in contact with it.

Among the techniques available for the corrosion monitoring of the reinforced concrete structures half cell potential method is widely used. This method has been standardised by ASTM vide ASTM C876. The half cell potentials measured with reference to a reference electrode define the zones of corrosion activity on the reinforced concrete structures. Additionally the pattern of iso-potential contour lines can differentiate between the general and localised corrosion. Thus by identifying the zones of severe corrosion activity on the concrete structures preventive measures could be undertaken to enhance the life of the structure.

The paper presents a brief review on half cell potential method as applied to reinforced concrete structures. A detailed discussion on the instrumentation used and interpretation of the data is also included. The merits and demerits of the method are discussed.

1. INTRODUCTION

In the past, early stages of concrete deterioration due to reinforcement corrosion of indication that the conditions for concrete deterioration existed could not be determined. Concrete deterioration as a result of reinforcement corrosion could be discovered only after the delamination of the concrete had reached its advanced state. At this point of advanced deterioration it was too late to apply any preventive measures. Thus, the need existed to develop new techniques to evaluate the condition of reinforced concrete structures especially concrete bridge decks prior to an advanced stage of deterioration.

The present day research in the field of corrosion engineering lays more emphasis on monitoring and diagnosis of corrosion related deterioration in reinforced concrete structures. The *insitu* monitoring of reinforcement corrosion falls into two broad regimes, the perturbative and the non-perturbative monitoring methods. In the perturbative monitoring methods an externally generated AC or DC signal is fed to the steel-concrete system and its response to the signal is measured. This technique is essentially perturbative since the equilibrium of the system is disturbed due to the external signal. Examples of this technique are AC impedance method, polar-

sation resistance method etc. The non-perturbative monitoring method measures the self-generated signal of the corroding reinforcement steel within the concrete. This technique includes half-cell potential, electrical resistance, and potential-noise measurement. In all these non-perturbative monitoring methods no external AC or DC signal is applied to the concrete-steel system.

2. HALF-CELL POTENTIAL TECHNIQUE AS A MONITORING TOOL

This technique was developed in 1950's in the USA where there was concern over the rapid deterioration of a number of concrete bridge decks due to de-icing salts. As this technique was developed, a good correlation was found between the results of electrical potential measurements and the actual condition of the steel reinforcement in concrete. Later in 1970, Jonathan R. Vandaveer of Federal Highway Administration (FHWA), USA, measured half-cell potentials of many bridge decks subjected to severe deterioration due to corrosion of reinforcement. In 1980, American Society for Testing and Materials (ASTM) issued a standard vide ASTM C876 covering the test procedures and interpretation of results. At present this technique of monitoring reinforced concrete is popular in USA and Europe.

2.1 Principle of the technique

Whenever a metal is exposed to an ionically conducting electrolyte ex. reinforced steel in wet concrete it attains an electrical potential related to the ease with which the metal can be dissolved in the surrounding electrolyte. Consequently, an equilibrium is set up between the metal ions in solution and the solid metal electrode surface. This potential is related by Nernst equation as given below:

$$E_{eq} = E_O + \frac{RT}{NF} \ln \frac{a(\text{oxidised ions})}{a(\text{reduced ions})}$$

where,

- E_{eq} = Metal potential at equilibrium
- E_O = Standard electrode potential for the reaction
- R = Gas constant
- T = Absolute temperature
- F = Faraday's constant
- N = Number of electrons transferred

$a_{\text{oxidised ions}}$ = Activity of oxidised ions

$a_{\text{reduced ions}}$ = Activity of reduced ions

Hence, E_{eq} or E_{corr} may be measured with respect to a standard reference electrode.

2.2 Apparatus and circuitry

The method essentially consists of measuring potentials between the standard electrode and a desired location on the surface of the reinforced concrete. The three reference electrodes common in use for potential monitoring are,

- a) the saturated calomel electrode (SCE);
- b) the silver/silver chloride electrode (SSCE);
- c) and the copper/copper sulphate electrode (CSE).

ASTM C876 recommends saturated copper/copper sulphate electrode for monitoring the potential of reinforced concrete structures. It also gives the standard configuration of the Cu/CuSO half-cell for field and laboratory monitoring applications. Although not specified in ASTM procedure, reproducible potentials may be obtained from 1M silver nitrate or saturated potassium chloride electrolytes.

Fig.1 depicts circuit diagram for potential measurement with single Cu/CuSO half-cell. The negative terminal of the voltmeter is connected directly to the reinforcing steel by means of a compression type ground clamp or by brazing or welding a protruding reinforcement rod. The positive terminal is connected to the reference electrode. To ensure a low electrical resistance connection, the reinforcing bar surface should be cleaned with an abrasive paper before making the electrical connections. The voltmeter shall have the capability of being

battery operated and have $\pm 3\%$ end of scale accuracy at the voltage ranges in use. The input impedance of the voltmeter shall be no less than 10 Mega Ohms in the potential measurement range. The resolution should be at least 20 mv or less. The digital hand held and battery operated millivoltmeters are the most suitable for this type of applications. The electrical lead wire should be at least of AWG No. 24 wire with length not exceeding 150 meters.

2.3 Monitoring procedure

Before starting the potential measurements the concrete surface to be subjected to test needs to be made wet uniformly. For this purpose, electrical contact solutions can be used. One such contact solution is a liquid household detergent thoroughly mixed in potable water.

Before the commencement of potential measurement, it should be ensured that all contact points are firm and correct polarity relation is maintained. There is no pre-defined minimum spacing between measurements on the surface of the concrete member. The grid space may vary from 100mm for small structural elements to about 0.6 m for bridges or similar structures and possibly 1m for rapid survey of large areas. From these measurements, lines of equal potentials (iso-potential lines) are plotted either manually or by computer. Fig.2 shows typical isopotential lines plotted for a bridge deck surface.

Much of the work carried out in America and Europe has been concerned with the measurement of absolute potential at the concrete surface with respect to the reference electrode. This indeed is the requirement of ASTM method, and needs a direct electrical connection to the reinforcement steel. The absolute potential is considered to be the best criterion for assessing the corrosion status of the reinforcement rods. However, comparison of potential measurements with the actual condition of the steel suggests that the rate of change of potential, as shown by the spacing of the isopotential lines is a better indicator of corrosion activity. Based on this potential measurements with two standard electrodes as shown in figure 3 is proposed in recent publications. In this case, the electrical connection to the reinforcement steel is not necessary. One of the standard electrode is kept stationary while the other electrode is moved to different sites on the concrete surface.

2.4 Data presentation and interpretation of results

ASTM prescribes two methods of presentation of test measurements. The first one, the equipotential contour map, provides a graphical delineation of areas in the member where corrosion activity may be occurring. As shown in fig.2 on a suitably scaled plan view of the concrete member, the locations of the half cell potential values of the steel in concrete are plotted. A contour is drawn through the equal potential locations or interpolated equal values. The maximum contour interval shall be 0.10 volts. The second method, the cumulative frequency distribution, as shown in fig.4 provides the distribution of the measured half cell potentials for the concrete in different corrosion activity zones.

This technique has been used by many investigators for laboratory based accelerated tests on test concrete beams. Fig.5 shows a typical plot of the maximum potentials recorded vs number of days. Some investigators (Hansmann,G. Grimaldi et al) have carried out studies to correlate the measured potentials to the actual condition of the steel. For this purpose, maximum value of the potentials is recorded zonewise on the surface of the concrete test beams. Table 1 shows a typical data recording format for such laboratory based studies.

ASTM specifies the following regarding the significance of the numerical values of the potentials measured. Voltages listed are referenced to copper/copper sulphate (CSE) half-cell.

E_{corr} (Vs CSE) volts	Probability of corrosion
More negative than -0.35	95%
More positive than -0.20	5%
-0.2 to -0.35	Uncertain

3. MERITS AND DEMERITS OF THE METHOD

Half-cell potential monitoring is a qualitative method of corrosion estimation. The technique of measurement of potential is relatively simple but it is time consuming. One significant factor affecting accuracy is the condition of the concrete surface, particularly if some degree of carbonation has occurred prior to test causing a skin of high resistance. In such case, chemical etching or mechanical chipping is required on the surface of the concrete. Potential measurements detect corrosion activity but not necessarily the location of corrosion activity. The

precise location of corrosion activity requires knowledge of the electrical resistance of the material between the reference cell and the corroding steel. Underwater potential measurements are possible but the potentials along the member appear to be uniform. However, the magnitude of readings does serve to indicate whether or not active corrosion is occurring.

4. CONCLUSIONS

The following conclusions are drawn based on the literature survey.

1. Electrical potential method is currently the only practicable non-destructive test for locating corroding steel in the splash and atmospheric zone of the concrete structures. It can also be applied for the submerged structures, but the location of corrosion must be interpreted carefully.

2. At present, it is most popularly used in USA and Europe. This technique of monitoring is regarded as an aid to the designers. More experience with the use of the equipment and the methodology is required before reliable corrosion assessment is made. Recommendations for further studies include,

- effect of various parameters on the reliability of the technique;
- the correlation of potential and resistivity measurements in field conditions;
- extension of this technique to submerged concrete structures.

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TABLE 1. A TYPICAL POTENTIAL MONITORING CHART.

REINFORCEMENT TYPE : D 1
 CONCRETE PARAMETERS M 150, W/C = 0.8, 18 mm. COVER THICKNESS
 ZONE OF EXPOSURE: SPLASH ZONE
 DATE AND TIME OF EXPOSURE TO SEA : 9-7-1987.

S. NO.	DATE	TIME IN HRS.	TEMP IN °C	RELATIVE HUMIDITY	MAX POTENTIALS W.R. TO SCE IN ANODIC ZONES CM. FROM EXPOSED END (IN MV.)				REMARKS
					0	0-18 Cm.	18-36 Cm.	36-53.6 Cm.	
	9-7-87	1000 hrs.	28 °C	96 %	-298	-290	-308	-252	
					-296	-295	-289	-282	INITIAL
					-284	-289	-275	-263	READINGS
					-316	-270	-243	-235	AFTER
									CURING

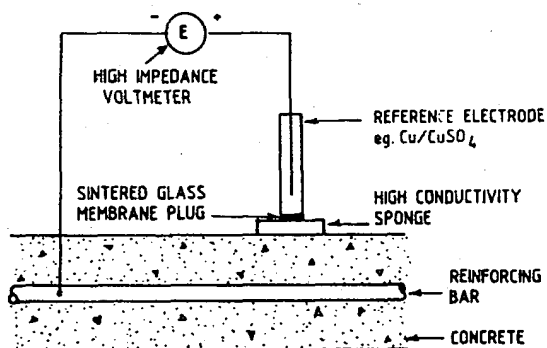


Fig. 1. SINGLE HALF CELL ELECTRODE MEASUREMENTS

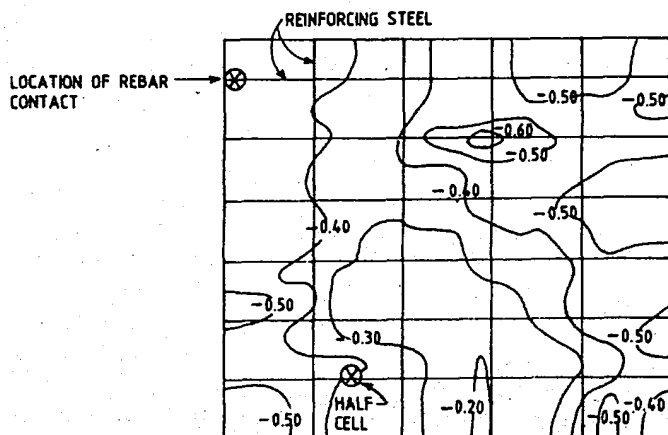


Fig. 2. A TYPICAL EQUIPOTENTIAL CONTOUR MAP

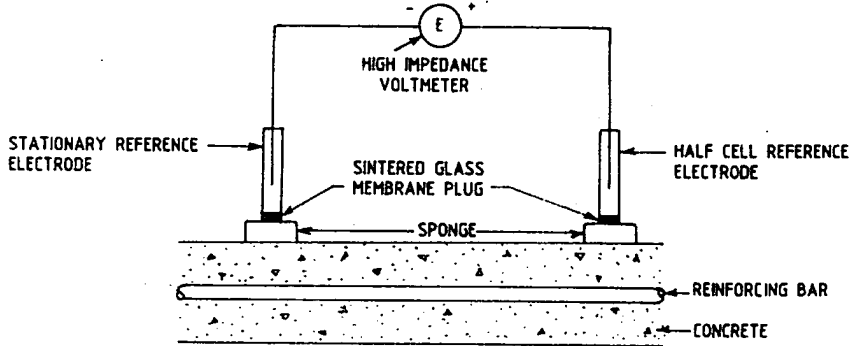


Fig. 3. TWO HALF-CELL ELECTRODE MEASUREMENT

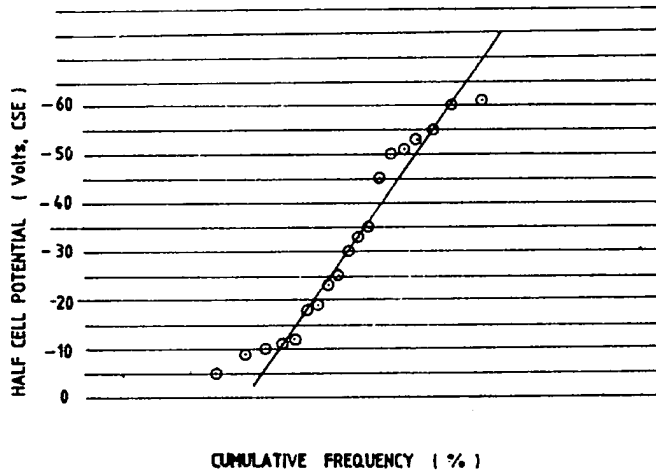


Fig. 4. CUMULATIVE FREQUENCY DIAGRAM

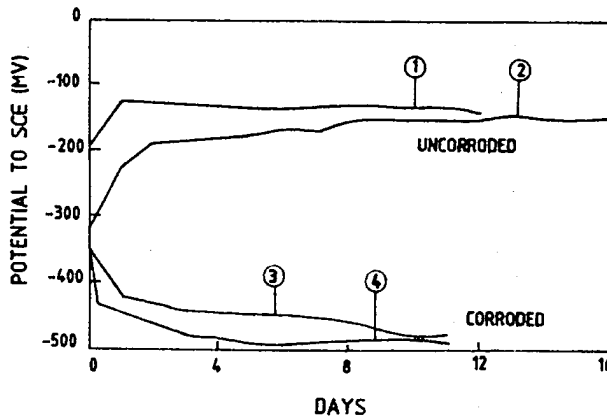


Fig 5 TYPICAL CURVES FOR STEEL RODS IN SATURATED LIME SOLUTIONS WITH FREE OXYGEN PRESENT. CURVE (1) FOR NO CHLORIDES, (2) FOR 0.02 M. Nacl , (3) FOR 0.08 M Nacl. , (4) FOR 0.10 M. Nacl.