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The lineal Polarization Method for Corrosion Rate Measurement of Reinforcing Bar of Concrete in Situ

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Abstract A linear polarization method was applied to measure corrosion rate of reinforcing bar of concrete in situ.

Generally in the experiment, the area and shape of the reinforcing bar as a working electrode can be changed and adjusted according to our needs. But polarization area cannot be defined when reinforcing bar is polarized in situ, so that a real R_p can't be obtained. Thus the purpose of present work is to improve the measurement system.

We used the double-ring auxiliary electrodes made by ourselves. The size of the double-ring auxiliary electrodes was adjusted repeatedly until the real polarization area was equivalent to one of the auxiliary electrodes. Using such an auxiliary electrode to measure R_p, we obtained the result that the measurement error of R_p is about 2.5%. This result can meet the need of measurement in situ.

Key words Reinforcing bar, Linear polarization, Corrosion rate, Concrete

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1 Introduction

Corrosion measurement methods of embedded reinforcing bar in concrete generally are divided into three categories. They are determining corrosion state, which is called half-cell method in ASTM[1,2]; estimating corrosion amount and measuring rate of corrosion. The last type of methods has been studied in this paper. It will be very useful in estimating service life of concrete structure.

Corrosion of reinforcing bar in concrete is an electrochemical process. The corrosion rate of reinforcing bar is a rate of electrochemical reaction shown as below:

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$Fe \rightarrow Fe^{2+} + 2e$

$O_2 + 2H_2O + 4e \rightarrow 4OH^-$

Thus, it is desirable to use an electrochemical method to measure rate of corrosion. In laboratory, there are many ways to do it, for example, Tafel Slope method, impedance measurement technology, measurement of weak polarization range, and so on.

However, because concrete reinforcing bars are sealed or enlaced together, these ways are not suitable to measure corrosion rate of reinforcing bar embedded in concrete in situ. Therefore, we attempted to apply an improved linear polarization technology, in order to have evaluations of corrosion rate directly.

2 The Principle of Improved Linear Polarization Method

2.1 Advantages and disadvantages of linear polarization

Generally, linear polarization equations are:

$$R_p = \eta / i \tag{1}$$

$$i_{corr} = B / R_p \tag{2}$$

As is well known, linear polarization method has some advantages as follows:

1) $|\eta| \leq 20$ mV. Thus the changes of electrode surface condition and IR drop are very small, which causes very small errors of measure and potential control.

2) Linear polarization technology could be used to many different kinds of electrode process with different control steps. This can meet the needs of complicated condition of reinforced concrete.

3) Measure time of linear polarization method is short, its measure system is simple. Therefore, it is convenient to use this method in situ.

However, in the first place the two important problems must be solved to obtain corrosion rate of reinforcing bar:

1) If R_p has been known, how to calculate the rate of corrosion according to the equation (2), that is, how to obtain B. This problem was supposed to be solved[3].

2) How to get a real R_p. Generally, measure instruments show an apparent polarization resistance R_{ap} rather than real one. The relation between R_p and R_{ap} is:

$$R_{ap} = \eta / I = \eta / (i \cdot S) = R_p / S \tag{3}$$

In an electrochemical experiment, area and shape of working electrode can be changed according to the test requirement and can be calculated accurately. But reinforcing bars of concrete are bundled or welded together to form a network. When a point of the network was polarized, it is difficult to determine polarized area S. The measured data is R_{ap} instead of R_p. Thus, we must improve measure system in order to obtain R_p.

2.2 Principle of the improvement

When using a linear polarization method to measure, the working electrode (reinforcing bar) is polarized by the aid of auxiliary electrode. If auxiliary electrode is a point electrode, the polarization distribution, as shown in Fig. 1, will be obtained, which is symmetrical around the point electrode.

The characteristic of this distribution is: the farther the distance from auxiliary electrode, the less the polarization value η; the thicker the coating of concrete, the larger the range of polarization distribution. The distribution range decreases as concrete resistivity increases. In order to determine area of polarization, a mathematic simulation has been studied to single reinforcing bar[4], but it is difficult to apply this simulation for actual reinforced concrete structure.

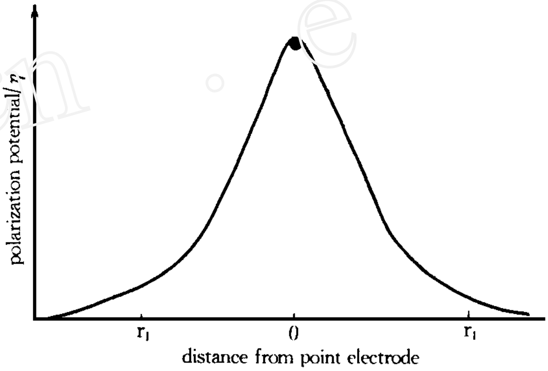


Fig. 1 Polarization potential distribution of point auxiliary electrode

According to the analysis above, if a double-ring auxiliary electrode, as shown in Fig. 2, is adopted, the polarization distribution will be similar to Fig. 3. By adjusting r_1, r_2, r_3, we can make such double-ring auxiliary electrode that its polarization action is equivalent to a disc-shaped auxiliary electrode with radius r_1, which the polarization occurred even in $r < r_1$ and it may be neglected if $r > r_1$. So that $2r_1$ will be the diameter of polarization distribution range. The polarization area S can be known. Then, R_p is:

$$R_p = R_{ap} S = R_{ap} \pi \sum_i \Phi_i l_i$$

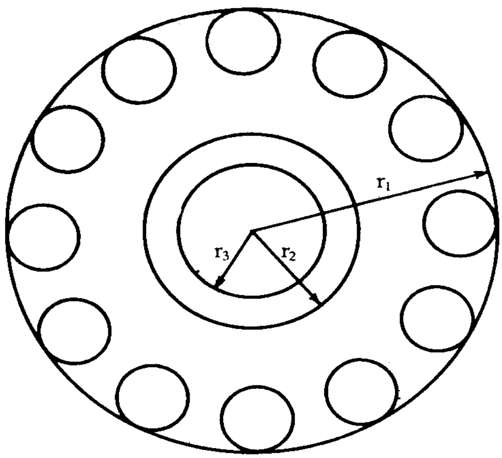


Fig. 2 Double-ring auxiliary electrode system (used method was shown in Fig. 4)

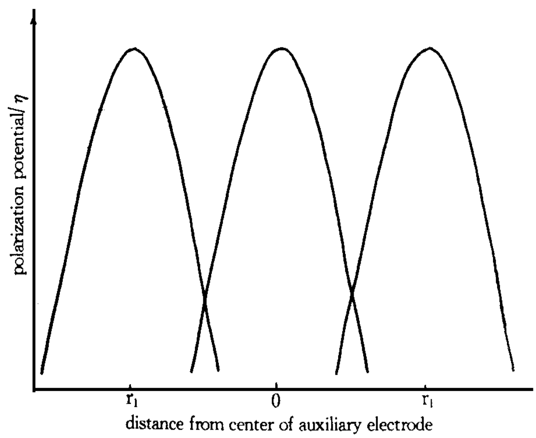


Fig. 3 The polarization distribution of double-ring auxiliary electrode

Φ_i is diameter of a measured reinforcing bar, l_i is its length covered by the double-ring auxiliary electrode.

3 Experiments and Results

3.1 Design of the double-ring auxiliary electrode

According to mentioned analysis, three types of auxiliary electrodes had been designed and made. Their section diagram is shown in Fig. 2. The data of r_1, r_2, and r_3 are listed in Tab. 1.

Tab. 1 size of auxiliary electrode (mm)

No.	$2r_1$	$2r_2$	$2r_3$
1	150	50	31
2	100	43	31
3	50	33	25

The center of auxiliary electrode was a circle, which has a diameter of $2r_3$. Cu-$CuSO_4$ reference electrode was fixed in the center of the ring.

3.2 Preparation of reinforced concrete samples

Tab. 2 Size of concrete samples

length of sample / mm	50			100			150			250			350			500		
thickness of coating / cm	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
numbers of sample	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4

The lengths of sample were 50 mm, 100 mm, 150 mm, 250 mm, 350 mm and 500 mm. The thickness of coating was 10 mm, 20 mm and 30 mm. The diameter of reinforcing bar is 6.7 mm. The different length samples were prepared for different purposes. The samples that have the lengths of 50 mm, 100 mm and 150 mm were the same length to the three kinds of double-ring auxiliary electrode respectively. Making use of the three kinds of samples, a real R_p, eliminating outer polarization distribution, could be measured. Therefore, we must use the auxiliary electrode that the diameter $2r_1$ was equal to the length of sample to measure real polarization resistance R_p. For example, the electrode, which had diameter of 50 mm, had to be used with the sample having a length of 50 mm. This was our first purpose. The second purpose was measuring R_{ap} and analyzing the effect of polarization distribution on polarization resistance. In this case, a sample had to be longer than the diameter of used auxiliary electrode.

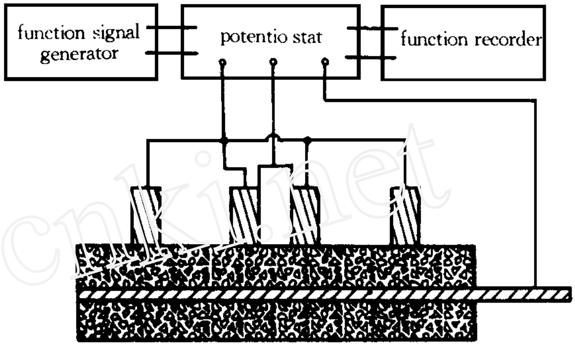
After being blended, ordinary 1:2.5:4 reinforced concrete, with a water to cement ratio of 5 to 10, was drawn from pattern. By 28 days curing, samples of reinforced concrete had been prepared.

3.3 Selection of measure parameters

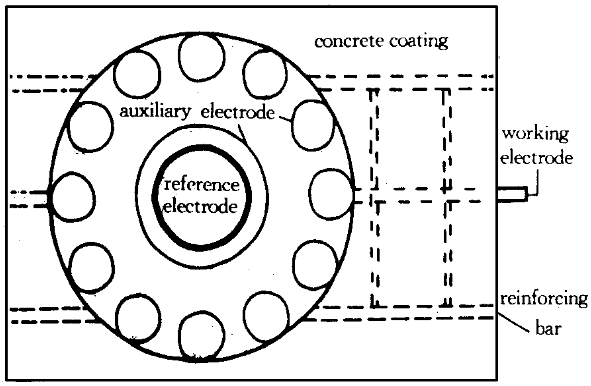
Fig. 4 showed the measure system. A square wave method of control polentential was used[5]. The frequency of square wave was 0.014 Hz. The polarization voltage η was 15 mV.

3.4 Results

Some typical experimental results of R_p or R_{ap} were shown in Tab. 3. There are two different kinds of polarization resistances in the table. R_p was derived from the experiment when the diameter of auxiliary electrode was equal to the length of sample. R_{ap} was derived from the experiment when the diameter was less than the length of sample. When r_1 was constant, the values of R_{ap} changed according to the lengths of sample, because an indefinite polarization range outside the ring existed in the latter case. We tried to find right values of the r_1, r_2, r_3 to make $R_{ap} = R_p$.



(a) section diagram



(b) plane diagram

Fig. 4　Connection diagram of measurement system

Tab. 3　measured polarization resistances (kΩ. cm²)

diameter $2r_1$/ mm	50				100			150	
length of sample / mm	50	100	150	500	100	150	500	150	500
10 mm coating	51.81	44.13	30.26	25.57	56.70	53.52	46.11	62.43	47.27
20 mm coating	53.63	33.37	26.98	22.12	56.23	45.50	42.98	50.20	52.70
30 mm coating	43.59	33.91	25.06	21.47	46.40	42.96	36.54	54.25	62.50
R_p average value/ kΩ. cm²	49.67	37.14	27.43	23.65	53.11	47.86	41.88	55.66	54.16

4 Discussion

4.1 The effect of coating

Usually, the increase of thickness of concrete coating acts on two opposite hands. As the layer thickness increases, the IR drop of concrete increases, so that polarization voltages η applied to reinforcing bar are smaller than the controlled one. The decrease of η results in descending of polarization current. Accordingly polarization resistance is up. But, at the same time outer polarization range is also enlarged, which results in polarization resistance going down. The two acts are contrary.

According to the data in Tab. 3, when the diameter of auxiliary electrode $2r_1$ is equal to the length of sample, effect of IR drop has not been proved. In other words, this effect is so small that can be neglected. However, when the sample is longer than $2r_1$, it is very obvious that outer polarization distribution affects polarization resistance. For example, using the electrode in diameter of 50 mm, the polarization resistance changes from 51.81 to 25.57 as the length of sample varies from 50 mm to 500 mm. Therefore if we adjust r_1, r_2 and r_3 auxiliary electrode reasonably, the effect of IR drop from coating can be minimal.

4.2 The effects of length of sample and auxiliary electrode radius r_1

In order to understand the effect of polarization distribution more clearly, R_p of different thickness of coating are averaged and listed in Tab. 3.

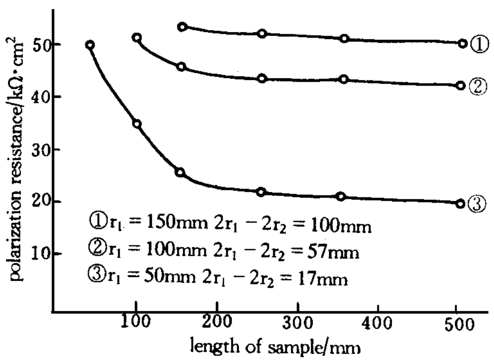


Fig. 5 Relation between polarization resistance and length of sample

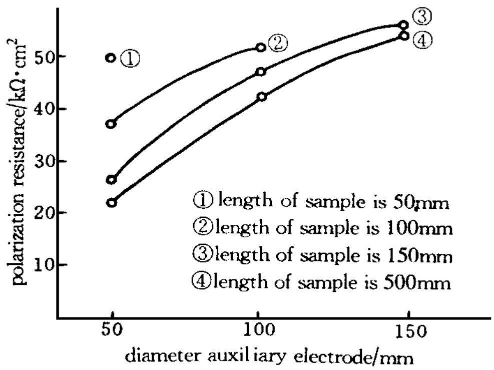


Fig. 6 Relation between polarization resistance and diameter of auxiliary electrode

The relation between polarization resistance and length of sample is shown in Fig. 5. Fig. 6 shows the relation between polarization resistance and $2r_1$.

1) From Fig. 5, one sees that if $2r_1$ is equal to the length of sample, the polarization resistances are 49.67, 53.11, 55.66 $K\Omega \cdot cm^2$ respectively. These three values are almost identical except a small change as difference of $r_1 - r_2$.

It also showed that the larger the difference of $r_1 - r_2$ is, the larger the polarization resistance is. This result is important. It has been proved that the reduplication of polarization distribution inside of the ring exists surely. It is shown in Fig. 3.

2) There is a polarization distribution out of electrode ring. The range of the distribution can be obtained by curve 3 of Fig. 5. As length of sample increases, polarization area extends, so that R_{ap} decreases. When length of sample increases to 250 mm, polarization resistance reaches steady. Therefore, an outer polarization distribution also exists around auxiliary electrode. The radius of distribution range is about 125 mm.

3) As r_1 increases, the proportion of outer polarization to total polarization decreases. This can be demonstrated by comparing the three curves in Fig. 6. When r_1 is 25 mm, the effect of outer polarization is very obvious(R_{ap} is from 49.67 to 23.05 $K\Omega \cdot cm^2$). But the effect can be neglected when r_1 is 75 mm(R_{ap} is from 55.66 to 54.16 $K\Omega \cdot mm^2$). Consequently, using larger double-ring auxiliary electrode to measure corrosion rate is feasible. The relative error is 17.9 % when diameter of auxiliary electrode is 100 mm. The relative error is 2.5 % when the diameter is 150 mm. These two errors are all acceptable for measure of corrosion rate in situ.

5 Conclusion

1) The improved linear polarization method can be applied to measure the rate of corrosion of reinforcing bar in concrete in situ.

2) The polarization distribution exists on reinforcing bar of outer auxiliary electrode. If we use ordinary auxiliary electrode, the result will deviate extremely from real polarization resistance R_p.

3) Using double-ring auxiliary electrode and enlarging its area properly is a feasible way. The difficulty that we cannot determine range and distribution of polarization in situ may be overcome by this way. The two different size auxiliary electrodes have been made and can be used in the measurement.

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线性极化方法测量混凝土中钢筋的腐蚀速度

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摘要 本文尝试用线性极化的方法对埋置于混凝土内部的钢筋的腐蚀速度进行测量. 自行设计了一组特殊结构的辅助电极 ,制备了不同尺寸和保护层厚度的混凝土试样. 通过改变辅助电极 ,调整电位的分布 ,使线性极化方法的测量误差降低到腐蚀速度测量允许的误差范围内. 确定了两种适用于混凝土中钢筋腐蚀速度测量的辅助电极.

关键词 钢筋 ,线性极化 ,腐蚀速度 , 混凝土 A