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CORROSION SURVEY OF REINFORCED AND PRESTRESSED CONCRETE STRUCTURES — METHODOLOGY OF APPROACH

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Oflate, many of the strategic reinforced and prestressed concrete structures have started showing signs of distress within a short period. Usually the condition of the structures is monitored by visual inspection and remedial measures are resorted to only when the condition becomes very serious by way of heavy rusting of steel reinforcements followed by cracking and spalling of concrete. It is desirable to, monitor the condition of such strategic structures right from the construction stage by carrying out periodic corrosion surveys and maintaining a record of data. In this paper, an integrated approach to such a corrosion survey is presented with some typical examples.

Key words : Signs of distress, monitoring, remedial measures

INTRODUCTION

When a reinforced/prestressed concrete bridge is suspected to be under distress particularly due to corrosion of steel, a corrosion survey is often required to be carried out for understanding the phenomenon and taking necessary remedial steps. Often such surveys are carried out amidst limited accessibility, non-availability of proven non-destructive techniques and other practical difficulties experienced at site. However, the data obtained are fairly reliable and interpretations based on logical scientific reasoning. Measurements are based on sound principles. However, these are indirect non-destructive techniques and are to be viewed as such. Most of them are qualitative in nature. Limitations of these techniques are also to be understood properly and appreciated.

Usefulness of such corrosion survey has already been discussed [1]. Central Electrochemical Research Institute has adopted an integrated approach to such surveys. In this paper, the methodology of approach, criteria for evaluation etc. are presented along with the limitations. Monitoring of corrosion of prestressing cables is not included in this paper.

INVESTIGATION METHODOLOGY

Aggressivity of the environment :

The chloride and sulphate pollution level in the atmosphere at the bridge site is first estimated by exposing salinity and lead-di-oxide candles. The water sample at the bridge site is also collected and analysed. Often this is made as one time measurement, though it is desirable to collect data on seasonal variations of these values.

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Concrete cover :

The actual cover of concrete provided to the embedded steel reinforcement is assessed in a non-destructive way using an instrument called "Profometer" which works on eddy current principle. The measurements will indicate the uniformity or otherwise in cover thickness, minimum cover provided and the adequacy of the minimum cover in giving satisfactory protection against the prevailing atmosphere.

Visual examination :

The various structural parts like girders, deckslabs, diaphragms, hand-rails, piers, piles etc. are identified and carefully examined for cracking of concrete, spalling of concrete, appearance of rust stains, exposure of reinforcements and their condition. If any portions appear to have been patch repaired, they are also noted. The concrete samples adjoining the spalled portions are carefully removed, collected and identified for chemical analysis. In case of rusted bars. the rust is carefully removed and the existing diameter of the base metal is measured as accurately as possible. Comparison of the original diameter with the existing diameter gives the approximate corrosion rate in millimeter per year.

Loss of alkalinity and chloride contamination:

The collected concrete samples are later analysed at the laboratory for alkalinity, and soluble chloride content. Concrete samples for this purposes are crushed and powdered and aqueous extract is prepared by adding equal quantity of double distilled water. The results will indicate the environmental condition obtained around the steel reinforcement in terms of loss in alkalinity level of chloride contamination.

Probability of reinforcement corrosion :

The tendency of steel reinforcement to corrode is assessed by measuring the open circuit potential of the embedded steel reinforcements with respect to a standard reference electrode. For this measurement, the steel reinforcement should be accessible atleast in few locations for giving electrical connections. Usually the steel rebars exposed due to normal spalling of concrete due to corrosion are made use of. Suitable locations are selected at the stage of visual examination A high impedance voltmeter is used for this study. The concrete is divided into number of grids and the measurements are taken at nodal points. The reference electrode is moved along the nodal points and the corresponding potential is noted and recorded.

The limitations of open circuit potential :

This gives only a qualitative data. This measurement is influenced by the moisture content in the concrete. The criteria of evaluation is therefore applicable only to an apparently dry surface and not applicable to the submerged portions which are saturated with moisture. Open circuit potential as it is a thermodynamic quantity and as such will not indicate the extent and rate of corrosion.

Surface potential measurement :

Two reference electrodes are used for surface potential measurements. In this measurement, there is no need for connection to the embedded steel rebar. One electrode is kept fixed at a suitable place on the structure or on the ground and is known as fixed electrode. The other electrode called moving electrode is moved along the nodal points as in the case of open circuit potential. The potential of the movable electrode, when placed at these points, is measured against the fixed electrode using a high impedance voltmeter. Making use of these data, equipotential contours (as in the case of contour levelling) are plotted. A relatively more positive potential readings represent anodic areas where corrosion is possible. The potential difference between the anodic and cathodic areas indicates the gradient for the corrosion process. The greater the potential difference between the anodic and cathodic regions, the greater is the probability of corrosion. However, it is to be emphasised that the surface potential by itself will not be indicating corrosion rate.

Resistivity of concrete cover :

A four probe resistivity meter is used to get the resistivity values directly. This meter gives the average resistivity of the concrete in the cover portion only is needed for calculation of the corrosion current. The resistivity values are measured along the nodal points, which will be helpful in two ways. When made on unpainted natural concrete surfaces they will be useful for calculation of corrosion current. When made on painted surfaces comparison of the resistivity values between painted and unpainted surfaces will indicate the effectiveness of the paint system.

Corrosion cell ratio :

Corrosion cell ratio is calculated using the surface potential data and the resistivity data obtained on unpainted concrete surfaces. It is the ratio of the maximum potential difference between the anodic and cathodic regions to the average resistivity in the anodic region.

CRITERIA OF EVALUATION

Environmental factor :

If the water sample contains more than 500 ppm of chloride and 1000 ppm of sulphate it is to be termed aggressive towards concrete.

A salinity value of more than 100 mg/m²/day of chloride and even trace amount of sulphate will make the atmosphere aggressive. An alkalinity value of less than 0.04N and a chloride contamination of more than 1000 ppm in the concrete samples indicate favourable conditions for reinforcement corrosion.

Probability of corrosion :

As per ASTM standards [2] the probability of reinforcement corrosion is as follows :

OCP Values (mV vs Calomel Electrode)	*Probability (Percentage)*
More -ve than - 275	90
Between - 275 and - 125	50
More +ve than - 125	Less than 10

Corrosion cell ratio :

If the ratio is more than 5, then spalling is to be expected at the anodic regions. However this is to be treated as a guide line based on literature information [3].

ILLUSTRATION

The typical data for a bridge which is apparently affected by severe corrosion is given in Table I. It can be seen that the water sample contain considerable amount of chloride and sulphate. Atmosphere is contaminated with considerable amount of sulphate. Concrete samples show considerable loss in alkalinity and chloride contamination in the range of 2000 to 3000 ppm. Electrochemical data show that OCP is highly negative, resistivity values are very much on the lower side (13 to 36 KΩ cm), corrosion cell ratios are in the range 10 to 20. The minimum cover is less than 6mm.

Table II gives the typical data for a bridge which is apparently in good condition. It can be seen that chloride and sulphate contents are very low in water (less than 100 ppm) and correspondingly chloride and sulphate pollution in the atmosphere are also very low. Concrete samples generally contain less than 1000 ppm of chloride. However, there is loss in alkalinity. The most negative OCP in 3 out of 4 locations indicate only less than 10% as probability of corrosion. Resistivity values are generally on high side (700 to 800 KΩ cm). The cell ratios are generally less than 1. Minimum cover is around 20 mm.

TABLE I

TYPICAL DATA FOR BRIDGE 'A' WHICH IS APPARENTLY UNDER DISTRESS

1	Chloride in the water sample (ppm)	20,000			
2	Sulphate in the water sample (ppm)	2,400			
3	Sulphate in atmosphere (mg/m²/day)	5,600			
4	Analysis of concrete samples	Sample 1	Sample 2	Sample 3	Sample 4
	Chloride (ppm)	2000	2300	2450	3200
	pH	9.73	11.15	11.25	10.75
5	Electrochemical data	Location 1	Location 2	Location 3	Location
	Most -ve O. C. P. (mv)	-303	-279	-209	-680
	Max. surface potential difference (mV)	360	278	268	398
	Resistivity (KΩcm)	36	17	13	24
	Cell ratio	10	16.35	20.60	16.55
	Minimum cover (cm)	0	0.4	0.60	0.5

TABLE II

TYPICAL DATA FOR BRIDGE 'B' WHICH IS APPARENTLY IN GOOD CONDITION

1	Chloride in water sample (ppm)	80			
2	Sulphate in water sample (ppm)	10			
3	Chloride in atmosphere (mg/m²/day)	20			
4	Sulphate in the atmosphere (mg/m²/day)	32			
5	Analysis of concrete samples	Sample 1	Sample 2	Sample 3	Sample 4
	Chloride (ppm)	800	300	700	100
	pH	11.45	11.5	12.10	11.30
6	Electrochemical data	Location 1	Location 2	Location 3	Location 4
	Most-ve OCP (mV)	-198	-41	-26	-40
	Max. surface potential (mV)	285	150	148	262
	Resistivity (KΩcm)	870	835	718	239
	Cell Ratio	0.33	0.18	0.21	1.09
	Minimum cover (cm)	2	2	2	2

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2 Standard test method for half cell potentials of reinforced steel in concrete ANSI/ASTM C 876-80, Annual Book of ASTM standards

3 R F Stratful, *Corrosion* 13 (1957) 173

DISCUSSION

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Q : The resistivity measurement depends on the moisture content in the concrete.

How reliable are the resistivity values in field?

A : No doubt resistivity values depend on moisture content of concrete, particularly at the initial stages of hardening. However measurements are taken only during dry season. Moreover the relative values are taken for interpretation along with surface potential values.

Q : Can you correlate resistivity with concrete strength under different percentage of moisture content?

A : We have not carried out such studies. However studies have shown that correlation between 28 days cube strength and resistivity of concrete under moisture saturated condition.