Cathodic Protection of Steel in Concrete Using Conductive Polymer Overlays

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This paper presents the results of a study of the effectiveness of sacrificial anodes in preventing the onset of pitting corrosion in chloride contaminated concrete using zinc overlay and a conductive coating in cathodically protected chloride contaminated slabs. Experimental tests were carried out on reinforced concrete slabs with steel embedded both in chloride free concrete and chloride contaminated concrete in order to compare the effects of sacrificial anodes on passive steel and on corroding steel. Results have shown, that sacrificial anodes may be more effective in preventing corrosion initiation (i.e. in providing cathodic prevention) than in controlling ongoing pitting corrosion (i.e. in guaranteeing cathodic protection). Monitoring criteria for this type of prevention are also discussed.

1. INTRODUCTION

Corrosion of steel induced by chlorides is the major cause of damage of reinforced concrete structures exposed to seawater. Chlorides penetrate the concrete cover and lead to the onset of pitting corrosion when their concentration near the steel surface reaches a critical threshold [1,2]. This threshold is not easy to evaluate, since it depends on several factors related both to the concrete and the environment [3,4]. In any case, it has been well established that the critical value increases if the potential of steel is lowered [5]. For this reason, corrosion hardly ever initiates in the parts of reinforced concrete structures that are permanently immersed in seawater, since lack of oxygen leads to very negative values of potential. Furthermore, even when corrosion initiates, the corrosion rate is negligible because of the small amount of oxygen that can reach the steel surface [2,6]. Critical conditions for corrosion initiation and subsequent propagation are usually found in the emerged part of

structures (tidal and splash zones), where wetting and drying cycles favor the presence of both oxygen and chlorides. In calm seas with low tides (such as the Mediterranean sea), the most severe attacks are usually found within a couple of metres above the sea level; conversely, in agitated seas with high tides, serious corrosion attacks can occur at over 10 m above the sea level [3,7].

Once pitting corrosion has initiated in the emerged part of a structure, cathodic protection can be applied to control the corrosion rate [5,8,9]. This is usually achieved using an extended anode laid on the surface of the concrete, either an inert anode (i.e. activated titanium) connected to a current feeder or a sacrificial anode (i.e. sprayed zinc). The use of submerged sacrificial anodes has also been studied to provide cathodic protection to corroding steel in the emerged part of marine piles [10,11,12]. Nevertheless, it was shown that, unless the concrete electrical resistivity is very low, protection provided by submerged anodes is of limited effectiveness above the waterline, so that other above-surface systems are required [11,12].

Since the early nineties, a technique called cathodic prevention has been developed to prevent the onset of pitting corrosion in new structures when, in time, chloride penetration from the environment takes place [13,14]. It consists in the application of a cathodic current to the passive reinforcement in uncarbonated and chloride free concrete. This current can delay the initiation time for corrosion by increasing the critical chloride content, inasmuch as it lowers the steel potential and increases pH at the steel/concrete interface as the cathodic reaction takes place at the steel surface [5]. Laboratory and field experiences [15,16,17,18] have suggested that even impressed current densities lower than 2 mA/m^2 can maintain steel at potential values where pitting corrosion cannot initiate when the chloride content exceeds 3% by weight of cement.

Such current densities are sufficient for cathodic prevention, i.e. when current is applied before corrosion initiates and is maintained throughout the entire service life of the structure, but not for the cathodic protection normally used which, being aimed at protection of already corroding steel, requires current densities of the order of 10–20 mA/m^2 [9,19].

Cathodic prevention also differs from cathodic protection with regards to its throwing power. In fact, it has been shown that, in spite of the high resistivity of concrete, the beneficial effects of cathodic prevention can extend to rebars at remarkable distances from the anode [20]. This is a consequence of the higher cathodic polarizability of passive steel compared with corroding steel [19]. Conversely, effects of cathodic protection are usually limited to distances of a few tens of centimetres [20].

In this paper an attempt was made using magnesium anode and also conductive overlays to show the effectiveness of cathodic protection using sacrificial anode in chloride contaminated concrete with very low cement content.

2. EXPERIMENTAL PART

Tests were carried out on reinforced concrete slab of size 1mx1mx0.1m were cast with 3% sodium chloride by weight of cement by varying the parameters as follows:

Slab - 1: Cast without chloride and without cathodic protection

Slab - 2: Cast with chloride and without cathodic protection

Slab - 3: With chloride and with cathodic protection

Slab - 4: With chloride with cathodic protection and with zinc overlay.

Slab - 5: With chloride, with cathodic protection and with conductive coating.

Rebar skeleton arrangement before placing concrete
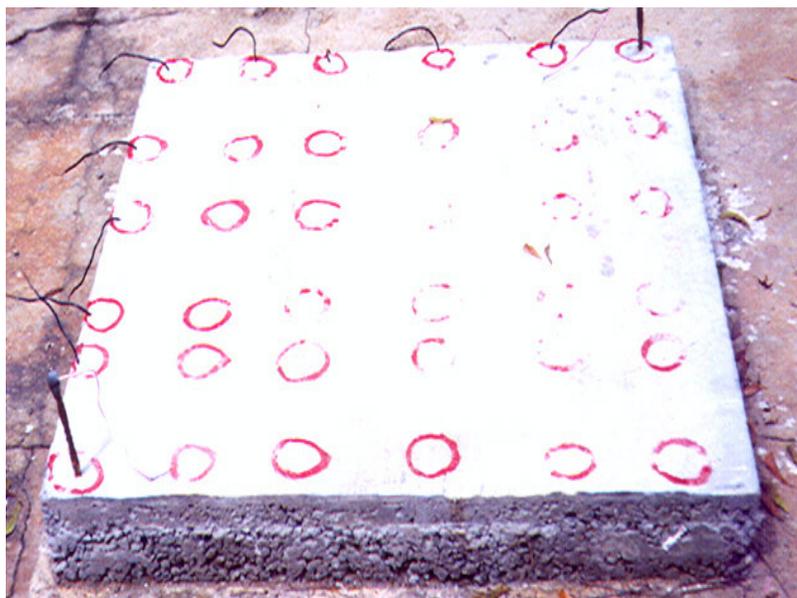
Slab with chloride and without cathodic protection

Slab with chloride and zinc overlay with cathodic protection
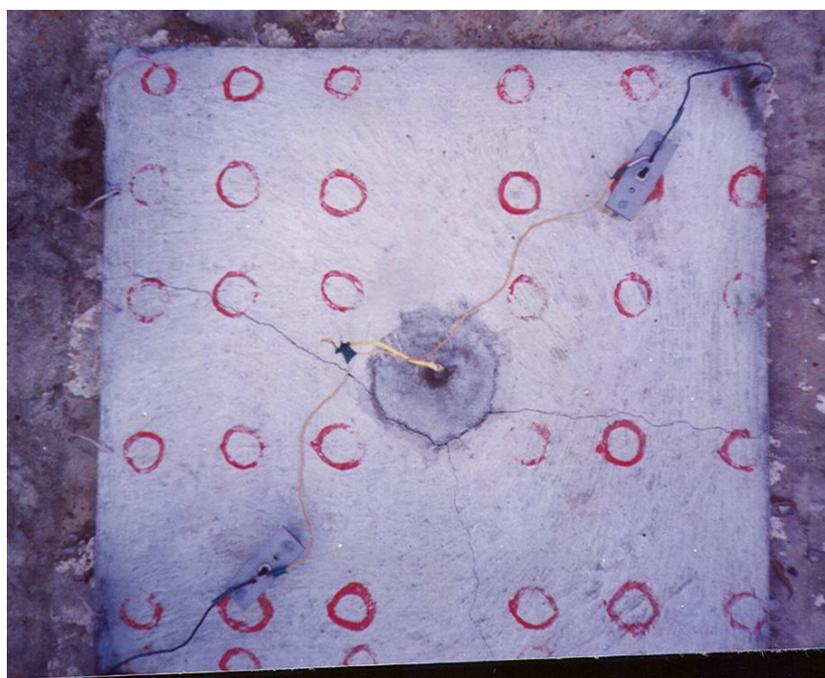
Slab with chloride and conductive polymer overlay with cathodic protection

Steel rebars were electrically connected outside the concrete as shown in the above slab: shunt resistances were used to measure the current circulating in each bar. Saturated Calomel Electrode (SCE) was used as a reference electrode for measurements of potential [21]. A mixture of cement, sand and stone ballast in the ratio 1:3:6 and a water/cement ratio of 0.62 were used for casting the slab. Chlorides were added as NaCl to the mixing water. After curing the slabs for 28days, the Magnesium

anode was placed centrally using the backfill of 75% gypsum, 20% bentonite, 5% Na_2SO_4 by weight of the anode and the ratio of anode to backfill being 1:2. The top surface of the anode is covered by cement mortar having the lead wire projecting from anode. The anode is electrically connected to the steel reinforcement (cathode) assembly at the two diagonal opposite points.

2.1. Preparation of backfill

Backfill enables the uniform distribution of electrons and retains moisture

a) 75% gypsum, 20% benonite, 5% Na2SO4 by weight of the anode is taken the ratio of anode to backfill being 1:2

b) The backfill is mixed well.

c) A cloth bag is made accurately to hold the anode with uniform distribution of Backfill around it.

2.2. Embedding the anode

a) A magnesium anode is placed inside the bag such that it remains exactly in-between the top and bottom mesh of reinforcement. The bag is tied on the top.

b) The top surface of the cloth bag is covered by cement mortar, leaving the lead wire projecting from anode.

c) The anode is electrically connected to the steel reinforcement (cathode) assembly at the two diagonal opposite points.

2.3. Preparation of zinc overlay

A mixture of cement and zinc in the ratio 3:1 (1.5 kg cement and 0.5kg zinc dust) is mixed with water, with water cement ratio as 0.62 and placed over the slab at 2mm thickness .

2.4. Conductive paint overlay

A coating of conductive paint (polymer coating) is coated on the concrete surface at a distance of 7cm from the base of the slab. The coating is allowed to dry for 6 hours and the remaining cover is laid over it.

Corrosion rate is monitored by non-destructive method of testing, using electrical methods of measuring potential and resistivity.

Ohms Law: V=IR

The interpretation is that, greater the voltage greater is the current and lower the resistance greater is the current.

3. RESULTS AND DISCUSSION

Corrosion of the embedded steel was monitored by measuring the potential of steel, resistivity of concrete and cathodic protection current.

The Figures 1-5 relate potential and resistivity with time. In the slab 1, cast without chloride and without cathodic protection, the potential of steel is found to be around -200 mV. Comparing that with the slab 2, which is cast with chloride and without cathodic protection, the potential of steel has become more –ve, in the order of -500mV. This is attributed to the effect of chloride, which is negatively charged and has promoted the corrosion current. Further in slab 2, rust stains were noticed after a period of 1806 hrs (75days).
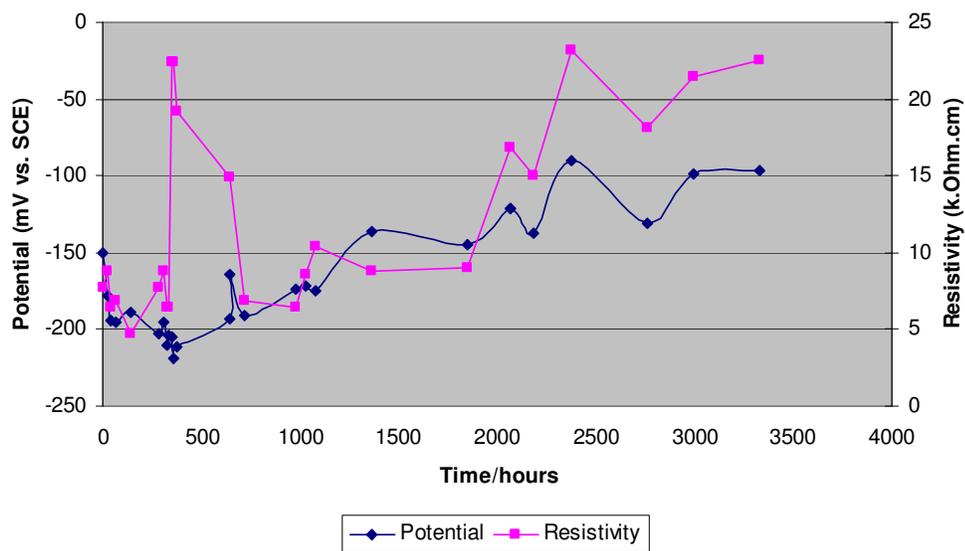
Figure 1. Effect of time and resistivity on the potential of embedded steel in chloride free concrete
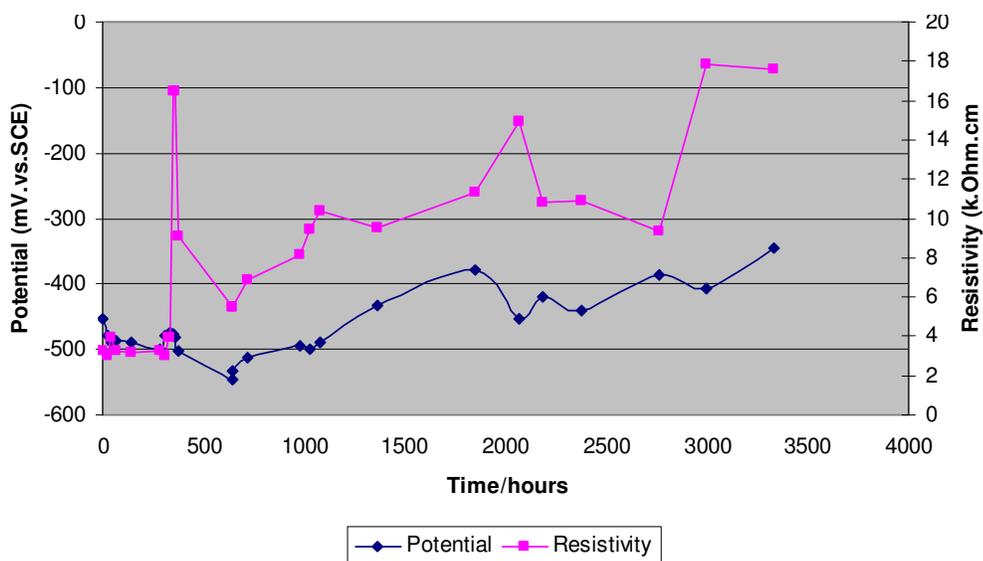
Figure 2. Effect of time on resistivity and potential of embedded steel in chloride contaminated concrete
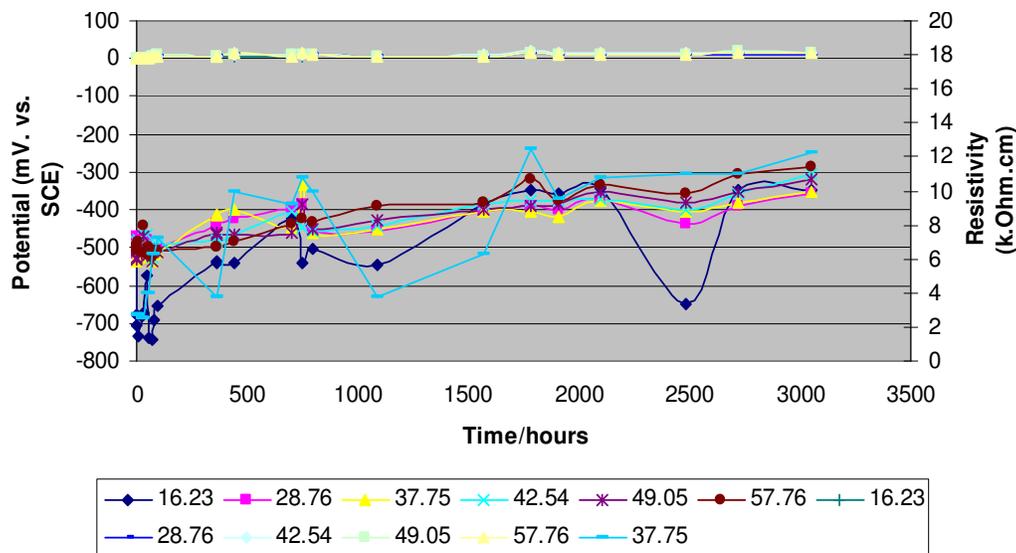
Figure 3. Effect of time on potential and resistivity of embedded steel in chloride contaminated concrete with CP for various distances from the anode
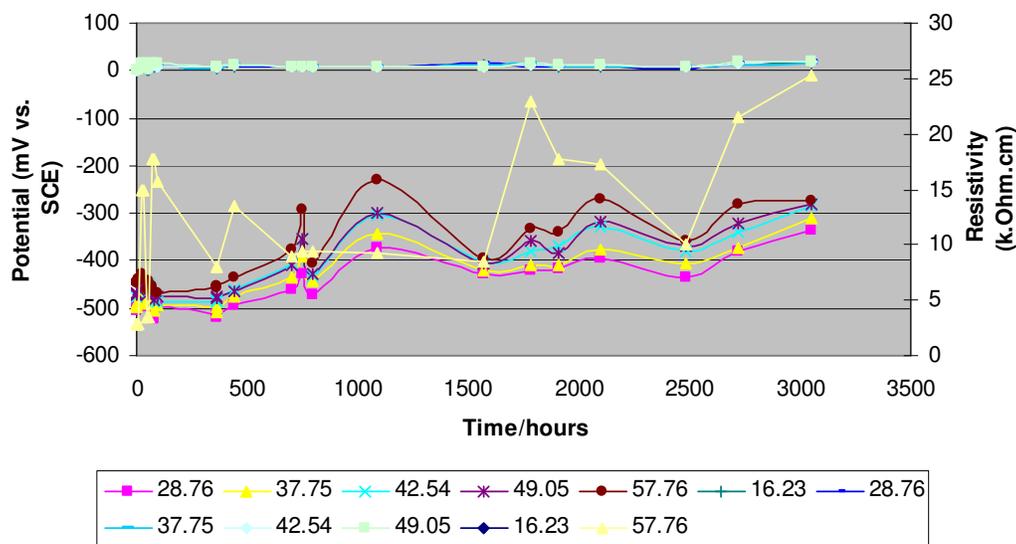
Figure 4. Effect of cathodic protection on the potential of steel in slab coated with mortar containing zinc in chloride contaminated concrete

In Fig.3, relating potential and time for various distances from the anode which is cast with chloride and with cathodic protection. In the region very close to the anode (i.e, 16.23cms from the anode), it is observed that the potential of the steel has become more negative to around -700mV. This is attributed to the cathodic protection, which has shifted the potential of steel by about 200mV. From the figure it is observed that, the distance increases the potential shift is found to be very less with time.
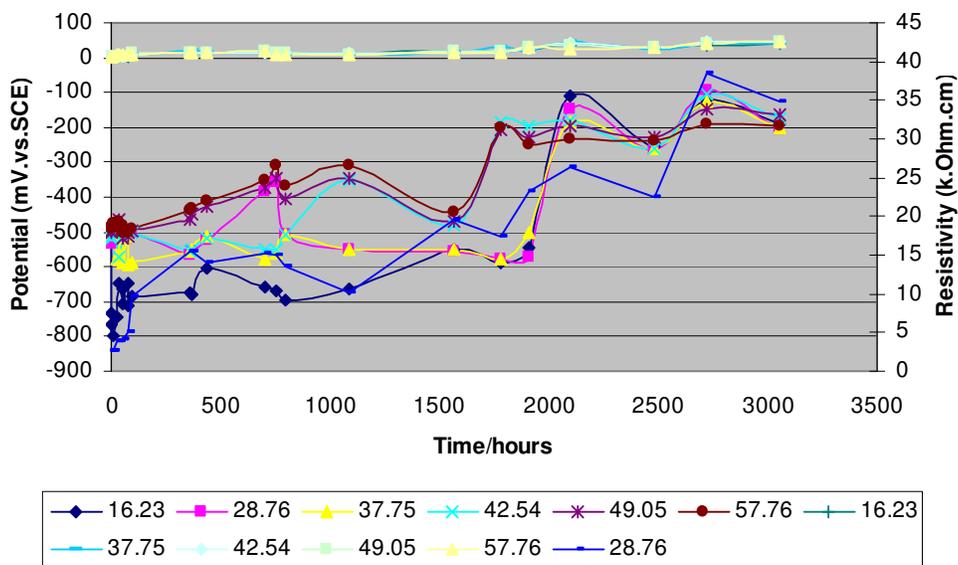
Figure 5. Effect of cathodic protection on the potential of steel in slab coated with conductive paint in the middle of the cover in chloride contaminated concrete
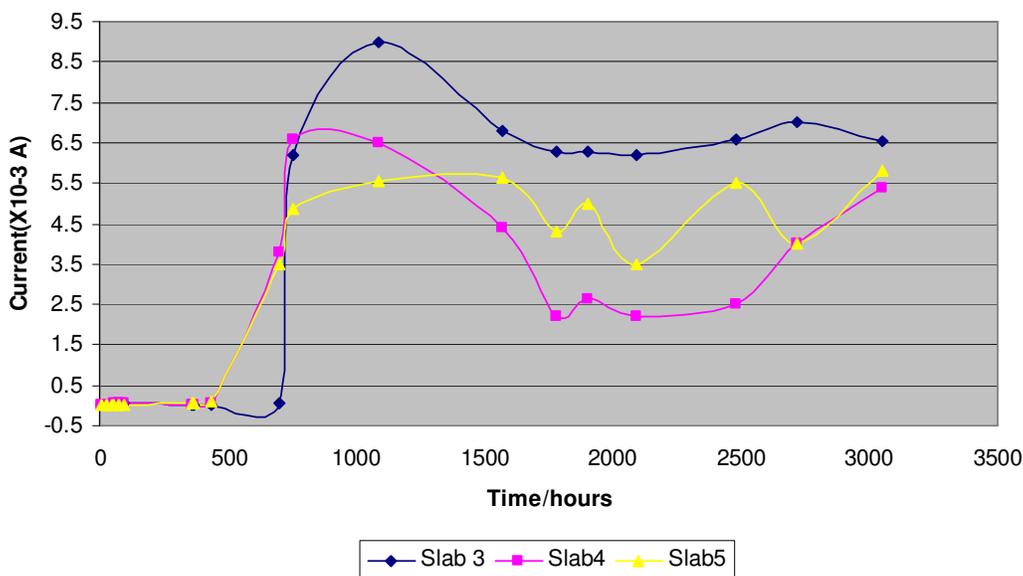
Figure 6. Effect of time on the current flowing in slabs with cathodic protection

In the slab which is cast with chloride, with cathodic protection and with zinc overlay, the potential value of steel at various distances from the anode follow a similar profile. From Fig.4 it is observed that, near the anode the potential shift is found to be around 200mV and if the distance increases the shift is found to be negligible near the edge of the slab. This implies that the addition of zinc does not have any influence on shift in potential or uniform distribution of current.

In the slab 5, which is cast with chloride, with cathodic protection and with a conductive coating, a significant observation is noted. Fig.5 relating potential and resistivity has also shown the same observation as the previous system. The concrete cover laid over the conductive coating started

to separate to after a period of 1507 hrs,(I,e, 65 days), Subsequently, minute cracks originating from the region of anode assembly and propagating outwards were noticed. The reason for this could be that, although the conductive coating had aided in the distribution of protection potential, it had initiated in the disbondment leading to unexpected but significant failure of the slab. The failure of this type of conductive coating is incompatible to concrete structures.

Fig.6 shows the variation of cathodic protection current with respect to time in slabs 3, 4 and 5. From the graph it is observed that the cathodic protection current in the slabs 4 & 5 is active an earlier time and has reached significant and stable values also after 1900 hours.

Cathodic protection applied to steel in concrete is normally considered effective if the 100 mV decay criterion is fulfilled, i.e. if a decay of at least 100 mV is achieved during a certain period (usually 4 or 24 h). This criterion, which was developed empirically has shown to be effective in practical applications, and is also recommended by standards [9]. Recently, it has been suggested that the achievement of a decay of 100 mV should imply that a near passive state has been induced on the protected steel [22].

The 100 mV decay criterion has shown to be applicable to cathodic prevention as well. Tests with very low cathodic current densities applied to passive steel in chloride contaminated concrete showed that this criterion is also reliable in evaluating the effectiveness of this technique. In fact, current densities able to achieve a 4-h decay higher than 100 mV were sufficient to maintain passivity on steel bars even when a chloride content up to 3% by weight of cement was reached near the steel surface [15,16, 17].

Therefore, the 100 mV decay criterion can be applied to both cathodic protection (i.e. application of a cathodic current in order to control corrosion rate of already corroding steel) and to cathodic prevention (i.e. application of a cathodic current to passive steel in chloride contaminated concrete in order to prevent the onset of pitting corrosion). Hence, it can be assumed that submerged sacrificial anodes are able to control corrosion only on the reinforcement in the emerged part of a pile that experiences values of 4-h decay steadily higher than 100 mV. In chloride contaminated concrete such decay can guarantee a cathodic polarization sufficient to provide protection to corroding steel, while in chloride free concrete it can guarantee a cathodic polarization sufficient to induce a remarkable increase in the critical chloride content (and thus to contrast pitting corrosion initiation even when chlorides penetrate the concrete in contact with the steel surface).

The observation is observed in the present investigation. In this investigation potential shift of 200mV is observed in conducting polymer overlay and zinc overlay applied systems. Another interesting observation is that the points very near to the anode have the potential shift of 200mV and the farther points has very low shift in potential even in chloride contaminated concrete. This may be due to the poor throwing capacity of the anode.

4. CONCLUSIONS

The following conclusions can be drawn from the above investigations:

- The chloride ions significantly contribute to the corrosion of steel rebars in concrete structures.
- Zinc overlay is found to have an initial cathodic protection current density distribution effect.
- Sealed conductive coatings as adopted in slab 5 have to be modified to suit concrete structures.
- The sacrificial anode system is found to protect the steel rebars against corrosion. The shift in potential is found to be significant near the anode.

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