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CATHODIC PROTECTION CRITERIA AND PRACTICAL COMPLETION ISSUES FOR CP OF REINFORCED CONCRETE STRUCTURES

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ABSTRACT

Cathodic protection of steel in concrete has emerged in the last 10-15 years from being an experimental method to a well-established technique to combat reinforcement corrosion, particularly chloride-induced corrosion.

Various organisations have produced sets of criteria against which the performance of a cathodic protection (CP) system can be monitored and judged.

In some cases, the rigid adherence to specific criteria requested by some consulting engineers to judge the performance of CP systems has led to contractual conflicts and has contributed to setbacks in the growth and development of this technique.

The aim of this paper is to outline various practical issues related to the applicability of cathodic protection criteria under different circumstances.

Keywords: Cathodic protection (CP), corrosion, monitoring, potential, protection, chloride, concrete, steel, potential, criteria.

INTRODUCTION

Various empirical criteria have evolved over the years in the area of cathodic protection in reinforced concrete structures. Most of these criteria have been empirically determined by evaluating data obtained from successfully operated CP installations or have been developed based on laboratory experiments and in some cases they have developed for situations other than reinforced concrete. These criteria are now being globally accepted and form the basis of international and national standards.

This paper will present various practical issues related to the general applicability of these criteria under different circumstances.

PRACTICAL ISSUES

Application of Cathodic Protection

The decision to apply cathodic protection to a particular structure can be in many cases based on the results of a preliminary investigation that shows some high levels of chloride contamination in some elements of the structure. The structure receiving cathodic protection may have certain elements or even some regions of certain elements that in practice require CP as a preventative measure only. The steel in these elements is passive and the response of these elements to CP application can vary substantially depending on a combination of issues mainly related to concrete characteristics. The reduction in the corrosion rate that can be brought about by the CP application will be very minimal and achieving the 100mV decay criterion is not possible. In some cases, it is possible to achieve a particular criterion during commissioning. However, afterwards, due to combinations of conditions such as drying out of the concrete, initial low chloride level, low corrosion activity and passive steel, the voltage required to pass a given current will become high and only minimal or no current can be impressed. Under such circumstances, it is important to consider various factors such as the value of the decayed off potential and to consider the protection criteria applicability if such value is less negative than −150mV with respect to an Ag/AgCl reference electrode.

The rigid adherence to CP criteria in this case is not appropriate. Careful consideration of the special conditions of the structure and engineering judgement should be applied to determine the appropriate assessment technique for the structure.

Current Density

The initial step for the design of a CP system is to determine the area of reinforcement to be protected. It is generally specified to base the design on a current density of 20mA/m2 of steel based on the area of the greatest steel density within the CP zone in order to ensure that anode design is adequate.

In some structures, it is impractical to fully adhere to the above requirements to select the design current density based on the greatest steel density due to the existence of small areas of high steel density in a particular CP zone, or the existence of many layers of reinforcement within the CP zone.

A combination of engineering judgement, experience, and in some circumstances trial applications, is needed in order to determine the optimum current density required with regard to steel density, especially allowing for the appropriate current required for the layers of steel located away from the anode but still within the CP zone. Also it is important to bear in mind that the current density that is required to maintain a given reduction in the corrosion rate will decrease with time, and it is possible to impress a higher current for a short period if necessary to polarise the steel.

The full adherence to 20mA/m2 requirements based on the areas of greatest steel density is not justified especially for heavily reinforced structures. Trial applications to obtain the optimum current density required to achieve the appropriate performance criteria or limited variations of anode spacing or capacity of anode in the heavily reinforcement areas should be considered.

Uniformity of Concrete

An essential part of the design of a CP system is to divide the system into different cathodic protection zones. Various considerations are taken into account for the zoning of the CP system during the design process. These considerations include the geometry of the structure, the proposed control system, (capacities of power supply units), the corroding conditions of reinforcement, the steel density, etc. Ideally, one electrical zone should incorporate concrete with similar characteristics such as resistivity, chloride content, steel density, etc. In practice, this cannot be achieved. Generally, one electrical CP zone is likely to have repaired and unrepaired areas, variations in steel densities, variations of chloride content and variations of corroding conditions of reinforcement. Dividing a CP system into a large number of zones may optimise the level of protection provided to reinforcement, however this will require more reference electrodes, more power supply units, more cabling and more complicated monitoring and adjustment of the system. The justification for using large numbers of small zones is not practical and may render cathodic protection as a costly method of repair.

Under such circumstances, it is likely that the reinforcing bars will respond differently to the applied cathodic protection current and these differences will be measured with respect to the embedded reference electrodes. Such conditions cannot be compared to a bridge deck suffering from a uniform chloride attack or to a submerged structure where the electrolyte has the same resistivity at all reference locations. Subject to the number of reference electrodes installed in a particular CP zone, the 24h decay for the embedded electrodes may range from 400mV to say 70mV. The adjustment of such systems is not a straightforward activity described in existing textbooks or standards. Adjusting the system to avoid overprotection and underprotection in various locations should only be based on the experience and judgement of the CP engineer who should take note of all the performance assessment techniques available and have a full understanding of the specific conditions of the structure.

Reference Electrode Locations

The assessment of a cathodic protection system is mainly related to the performance of reference electrodes embedded in concrete in the cathodic protection zones. The location of the reference electrodes is normally selected on site based on certain criteria and generally subject to the results of potential mapping in the cathodic protection area. It is very likely that the location of these electrodes has a major influence on the achievement of CP criteria. The selection of reference electrode locations in passive areas, corrosive areas, repaired areas and unrepaired areas may yield very large variations in regard to the achievement of criteria for these reference electrodes. It is logical to assume that the rigid requirement to achieve 100% protection criteria may encourage selecting convenient locations for the reference electrodes. For this reason, it is vital that the criteria for selecting the reference electrode locations be determined as a part of the design and based on the size and special conditions of the CP system installed.

Interpretation of Readings

It is quite common to see reports from consulting engineers reviewing CP installation data in such a way that, say, a 95mV decay is not acceptable, whilst a decay of say 400 mV is acceptable because the values fit within the criteria figures regardless of the obvious overprotection. The danger of adopting such an assessment reflects poor engineering judgement and basic misunderstanding of the various practical considerations during any installation, starting from the calibration of reference electrodes and the acceptable tolerance allowed in this calibration, to the accuracy of the measurements of the "Instant Off" potential. The ability to reproduce the "Instant Off" readings using a hand held multimeter is very questionable. Some engineers use the first reading displayed on the multimeter as the "Instant Off " reading whilst others prefer to use the second reading. The difference between the first and second readings can be in some cases very substantial. Even with this condition some engineers still consider 95mV decay as not an acceptable decay value. It is reasonable to say that issues like "Instant Off" reading should be more clearly defined in the standards. Alternatively, the convenient "Instant Off" reading is recorded and used for system assessment and adjustment rather than the actual reading.

Achievement of Criteria at Commissioning

It is a common practice in a typical Contractor/Consultant CP contract to demonstrate to the Consultant during commissioning that at least one of the CP criteria adopted for the system is achieved in order to obtain practical completion.

It is the author's experience that CP criteria can be achieved in some structures during commissioning whilst in others it takes a longer time. In some cases it is necessary for structures to apply slow polarization for the CP system. Under these circumstances, the achievement of criteria during commissioning is not possible and the CP system cannot be judged during commissioning or even say after a fixed short period of operating the CP system.

On the other hand, under some circumstances, it is possible to achieve the criteria during commissioning. However, thereafter in some structures, because of circumstances related to passivation of the steel, some of the criteria cannot be achieved at all locations.

Cathodic Protection Zoning

In some reinforced concrete structures with submerged, tidal and atmospheric sections, the submerged sections of the structure and the tidal sections can be protected by the water anode system or by a combination of 2 systems, the water anode system and the system being installed in the lower region of the atmospheric zone.

In the tidal zone, the concrete may be submerged for between 0% and 100% twice a day. Because of the reduction of current delivery during low tide, the potential criteria adopted for the submerged part of the structure (say "Instant Off" potential more negative than –720mV to Ag/AgCl) cannot be achieved 100% of the time.

Other criteria such as the 100mV decay criterion (a potential decay over a maximum period of 24h of at least 100mV) are unachievable because the pores of the concrete are soaked with sea water and the oxygen diffusion is slow. In this case, it is impossible to estimate the time that should be allowed for the potential decay.

Under such circumstances, and in the absence of any clear applicable criteria in this particular section of the structure, the rigid demand to achieve one of the CP criteria, which mainly apply to the submerged and atmospheric areas, is totally inappropriate.

CONCLUSIONS

Without any doubt, there is a need to have standards for the assessment of cathodic protection systems. However, it is vital to acknowledge that it is impossible to have a standard that can be applicable to all CP systems under all circumstances.

Cathodic protection has not reached a stage of development that allows definitive global criteria to be used. For this reason, it is suggested that the assessment of whether a given CP system is providing adequate protection to the structure for which it is designed should not be based on a rigid adherence to specific criteria. The achievement of given criteria does not represent a pass or a fail. These criteria have been developed based on empirical grounds and on experience from previous CP installations. The assessment of the performance of a cathodic protection system should be based on the judgement of a skilled CP Engineer who can make a full assessment of the condition of the CP system using all of the relevant and latest performance assessment techniques that are available and considering all the variables and the circumstances related to the particular CP system.

REFERENCES

1 NACE Standard RP0290-90, "Cathodic Protection of Reinforced Steel in Atmospherically Exposed Concrete Structures."

2 PrEN 12696 –1, "Cathodic protection of steel in concrete Part 1: Atmospherically exposed concrete."