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New Installation Technique of Linear Anode for Cathodic Protection -Test and Project-

Toshiyuki AOYAMA[1*], Tatsuya KAWAYOKE[1*], Masahiro ASADA[2*], Toshihide DAN[3*], Hideki NAKAMURA[3*] and Kazuyuki TORII[4*]

[1]*P.S Mitsubishi Construction Co.,Ltd., JAPAN*
[2]*ARS CONSULTANTS Co.,Ltd., JAPAN*
[3]*ISHIKAWA Prefecture, JAPAN*
[4]*KANAZAWA UNIVERSITY, JAPAN*
[*]*t-aoyama@psmic.co.jp, yoke@psmic.co.jp, asada@ars-c.co.jp,dan@pref.ishikawa.lg.jp, h.naka@pref.ishikawa.lg.jp, torii@t.kanazawa-u.ac.jp*

ABSTRACT

Cathodic protection is one of the most effective countermeasures for corrosion of steel in concrete. This method is to surpress corrosion of steel by applying weak electric current flow from the anode installed on or near the concrete surface to the steel in concrete. In Japan, cost reduction of execution and improvement of quality is demanded to apply widely. So, this paper discusses the efficient arrangement method of linear anode for cathodic protection of impressed current method. Through laboratory test and application to a structure. As a result, this titanium-based linear anode for cathodic protection has enabled a 15% reduction compared with the conventional method, by virtue of improved setting position of anodes, number of anode strips for a single groove and width of the anode strips, while keeping proper rust preventive effect.

Keywords. Cathodic protection, Linear anode, Cost reduction, PC girder, Salt damege

INTRODUCTION

One remedial measure for salt-damaged concrete is cathodic protection. Through this type of cathodic protection, embedded steel is electro-chemically prevented from corroding, by conducting DC power current from the anode provided near the surface of structure to the embedded steel in the concrete. Various methods are available, differing in supply system of electric current and anode installation method [Concrete Library 107. (2001)]. Among these methods, an cathodic protection method using a linear anode of titanium has many positive features, such as high durability of the anode strip, the ability to place the anode arbitrarily and high adaptability to combined use with another supplementary system, and its use is increasing. A major challenge in selecting this type of protection is its large initial cost compared with other types of chloride protection systems, such as a surface treatment method or section repair method. Out of various work elements for this type of cathodic protection, major costs are anode construction involving groove cutting and anode installation, together comprising 75% of the total construction costs. In view of this, the present paper introduces certain proposals to reduce the anode construction costs and practical application to an existing structure.

PROPOSAL FOR COST REDUCTION

For the setting location, the anode is moved to a perpendicular point as shown in **Fig. 1(b)** from horizontal points in the conventional practice as shown in **Fig. 1(a)**. By so doing, cost reduction is expected in groove cutting and installation of anode strips. This setting approach has been verified as effective in performance by conducting an electrification test of a test specimen modelled after a PC girder [Ikeya, K. et al. (2009)].

In a linear anode system, anode strips are frequently set at not more than 300mm intervals to ensure a uniform supply of corrosion-preventive current to the embedded steel. In actual practice, if more steel elements are embedded in the concrete and if corrosion is further developed, the size of the anode strips used becomes larger and the abutting anode strips are located closer together. For portions where large steel elements are used or where corrosion is largely developed, two anode strips are set per groove as shown in **Fig. 1(c)**, thereby effecting a cost reduction.

In addition to a titanium grid anode 15 or 20mm wide, 10mm wide strips are used. This will enable cost reduction in anode strips and yet minimal damage to an existing structure where the corrosion is slight and amount of embedded steel is small. In addition, cost reduction will be ensured in both anode strips and groove cutting by properly selecting the number of anode strips and width of anodes depending on the steel strips used and development of corrosion at anode setting.

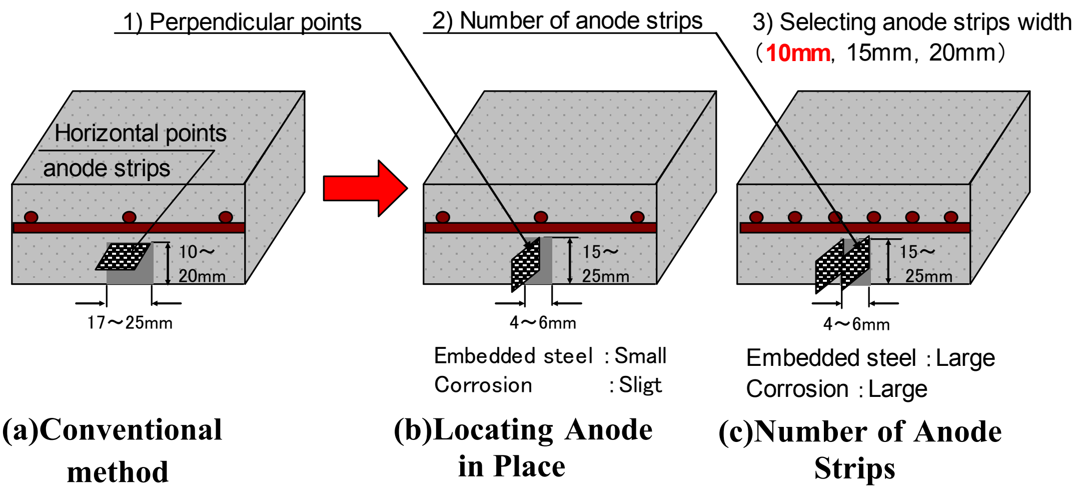

Figure 1. Proposal for Cost Reduction

VERIFICATION TEST

Outline of test method. Where two anode strips are used in a single groove, it should be verified that power current runs in each of the strips. For the purpose of this research work, specimens were prepared in such a way that embedded steel was different in quantity according to anode setting planes, so that the most efficient anode setting could be verified on an experimental basis when different anode strips were used according to the quantity of steel. **Fig. 2** shows the shapes and dimensions of the specimens, and **Table 1** lists the kinds of specimens. These specimens are 310×210×200 mm in the rectangle section and have embedded eight 13mm dia. polished plain steel bars. The experiment was designed so that different anode strips were set in a plane, A2, where plenty of embedded steel is provided, specifically, a single strip is provided for No. 1 and two strips for No. 2. These strips of linear shape, 10mm wide, were set in the groove, 6mm wide and 15mm deep on average, and filled with a cement-based cover of high fluidity. Where two anodes were provided, it was successfully checked that there was no contact between these two anodes. The electrification test was conducted in an indoor space exposed to outdoor climate conditions, except for water supply, in order to avoid, wherever practicable, electric current from being influenced by different water contents in the anode setting plane. The electrification was continued for about 130 days at a constant current flow of 0.98mA. During the test, the amperage running in the anode and steel elements was measured approximately once a month by using an ammeter with zero internal resistance.

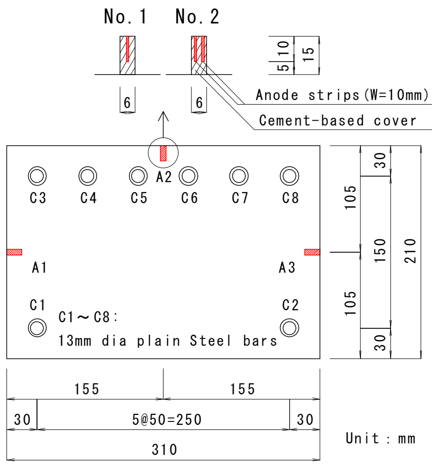

Figure 2. Specimens

Table 1. Kinds of specimens

	Anode strips A1	Anode strips A2	Anode strips A3
No.1	single	single	single
No.2	single	two	single

Outline of test result. **Fig. 3** shows test values of current distribution ratios as affected at the anode A1 through A3 of each specimen. Here, the current distribution ratios at the anodes are calculated as amperage flowing out of each anode as divided by total amperage. As viewed from the results shown in **Fig. 3**, it was judged that there was a tendency of roughly uniform current flowing out from each anode, though a slight surplus current flow was observed from the anodes A3 of Specimen No. 1 and A1 of Specimen No. 2. Also, the current distribution ratios at anode strips A2-1 and A2-2, both of which were set in a single groove, were much the same; therefore, it was judged that variance in the current distribution ratios due to prolonged electrification periods was small as a tendency. Consequently, it was judged that each anode was functioning effectively where two anode strips were set in a single groove. Also, reasonableness of setting plural anode strips was confirmed through a specimen modeled after a post-tensioned PC girder [Aoyama, T. et al. (2012)].

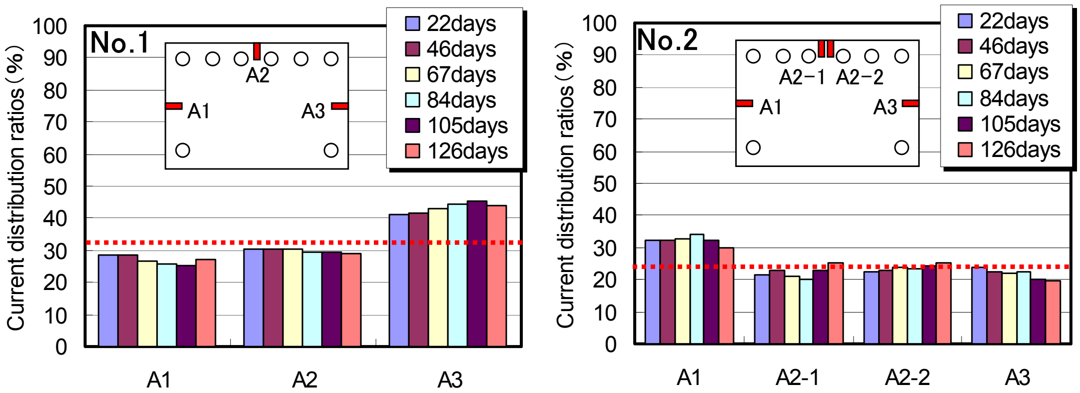

Figure 3. Test values of current distribution ratios(Anode A1 through A3)

APPLICATION TO A STRUCTURE

Outline of a bridge. The present model bridge is a post-tension type of PC simple T-girder bridge, 36m long, which spans Route 249, facing the *Sotoura* Coast of the *Noto* Peninsula, in *Ishikawa* Prefecture, as shown in **Photo 1**. It was erected in 1980. Since then, the main girders and horizontal girders in the superstructure have been protected with concrete paint coating to prevent salt damage; however, as shown in **Photo 2**, re-deterioration has become noticeable including delamination of concrete, and rust stains are present due to the corrosion of embedded steel. Coupled with this, another type of deterioration has developed due to ASR. As shown in **Photo 2**, cracks have developed on the order of 0.1mm along PC strand in the main girders. To cope with the re-deterioration of the superstructure, electric corrosion prevention with linear anodes was considered to be most suitable remedy from the standpoint of the comparative study on reliable workability, maintenance and influence on surroundings.

Table 2. Specifications of a bridge

Route Number	Route 249
Location	Fukami,Wajima City,Ishikawa Prefecture
Structure form	Post-tensioning PC simple T-girder (five girders)
bridge length, width	length 36.0m, width 8.9m
Angle of skew	60°00’00″
Distance of coast line	160m from the Sea of Japan

Photo 1. Outline of a bridge

Photo 2. The degradation situation of concrete

Design of cathodic protection. With an eye toward insuring long time load-carrying capacity of the superstructure, the corrosion preventive treatment by way of electric process was employed for the remedy portion where PC steel elements are embedded in the main girders including bend risers. The electric circuit system consists of a single circuit and the treatment area is 496m^2. For this bridge, since the corrosion of steel elements was slight, the spacing intervals of the anodes were set at 300mm in webs and 250mm in the lower flanges, and the anode strips were changed to those of 10mm in width from the previous 15mm width. In addition, two anode strips were set in one groove at the bottom of the lower flanges as shown in **Fig. 4**; thus anode sources were enlarged to optimize the corrosion prevention function as well as ensure cost reduction in the materials and groove preparation in the remedial work. To attempt to check for proper supply of corrosion prevention current and corrosion effect, an embedding type of reference electrode serving as a monitoring circuit was provided at three points as shown in **Fig. 5**. On this bridge, any change in crack width due to ASR was to be measured with a crack displacement meter to observe the trend of expansion due to ASR.

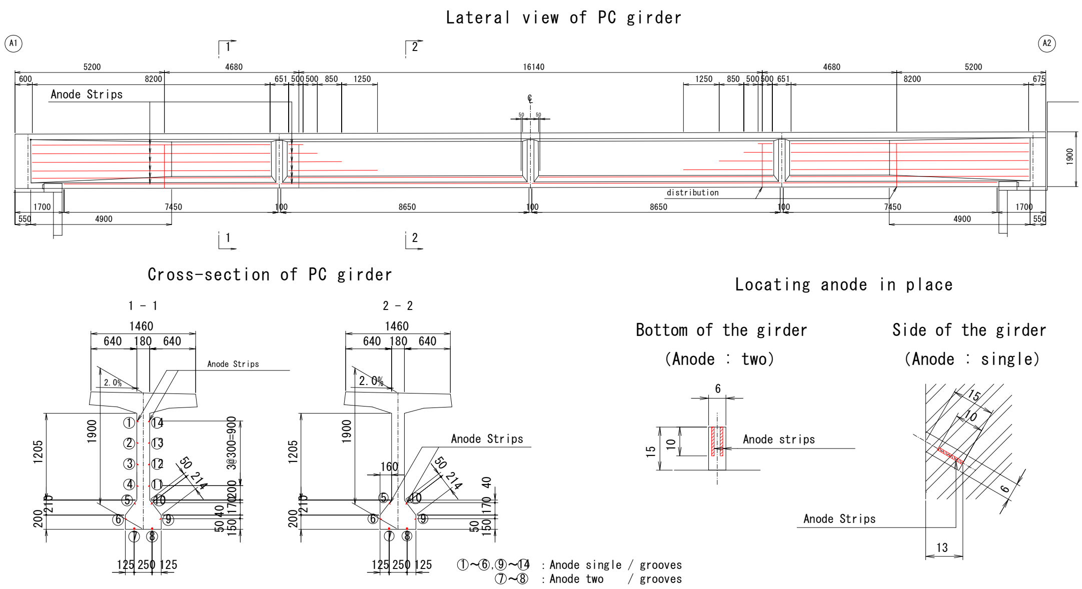

Figure 4. Locating anode in place of PC girder

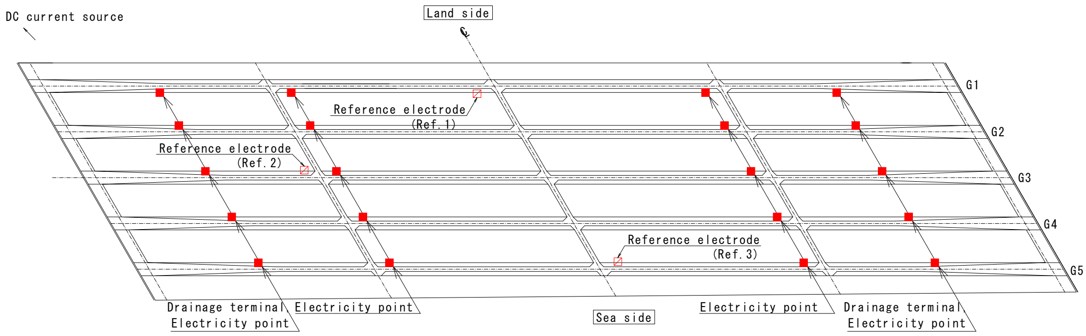

Figure 5. The place of reference electrode, drainage terminal and electricity point

Construction of cathodic protection. The grooves were cut 6mm in width and 15mm in depth using a concrete cutter, as shown in **Photo 3**. Upon the completion of groove cutting and clearing, in-groove metal detection was carried out, as shown in **Photo 4**, to prevent any short-circuit from occurring between steel and the anodes. This electrification check was to detect any spot of electrification through steel embedded in concrete by moving a metal brush connected to a DC voltmeter inside the groove by taking advantage of the fact that there is electrification between exposed metal and a drainage terminal fixed in the concrete.
Photo 5 shows anode fixing conditions at the bottom of a girder. Where two anode strips were provided, rubber spacers were embedded between adjacent anodes at approx. 300mm pitches to prevent those anodes from contacting each other. **Photos 6(a)** and **(b)** show anode coating on the side of the girder side plane and at the bottom of the girder respectively. For the anode coating, such material as cement-based inorganic substance having high fluidity was used. To fill grooves on the girder side plane, the material was forced to flow into them after the bottom side of the groove was encased with simplified formwork. Also, on the bottom side of a girder, simplified formwork was provided and the material was pressurized to flow inside. On the completion of the anode coating, an electrification point and a drainage terminal were connected, following which the standardized value[1)] was ascertained to be not smaller than 10mV, denoting that steel and anode were isolated from each other. **Photo 7** shows the DC current source apparatus used for this project. Included in the power source box are measuring units for taking various measurements pertinent to electric rust prevention; DC power source; remote observation units to send measurement data via electronic mail; and a measurement terminal to measure width of cracks due to ASR. After piping, wiring and DC power source installation were completed, the polarization test was made to set amperage through which a potential variation of not smaller than 100mV is secured as a rust prevention standard[1)]. The results are shown in **Fig. 6**. Figure indicates the relationship between current density and polarization. The polarization is differences between self potential and instant off potential. Instant off potential energized a predetermined electric current and assumed it the measurements five minutes later. For this bridge, the amperage was set at 5mA/m^2 for the concrete surface so as to meet the rust prevention standard. About one week later, a depolarization test was conducted, and it was

Photo3. Cutting of grooves

Photo4. In-groove metal detection

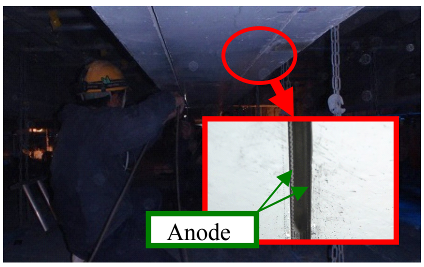

Photo5. Anode fixing conditions

(a) side of the girder **(b) Bottom of the girder**

Photo6. Anode coating

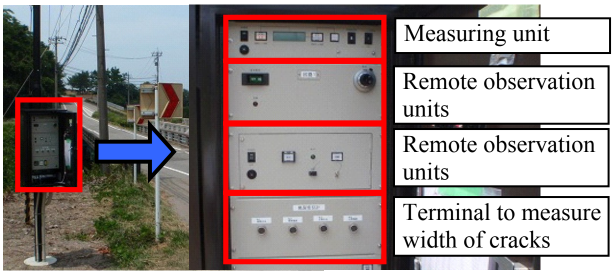

Photo7. DC current source

Photo8. Completion

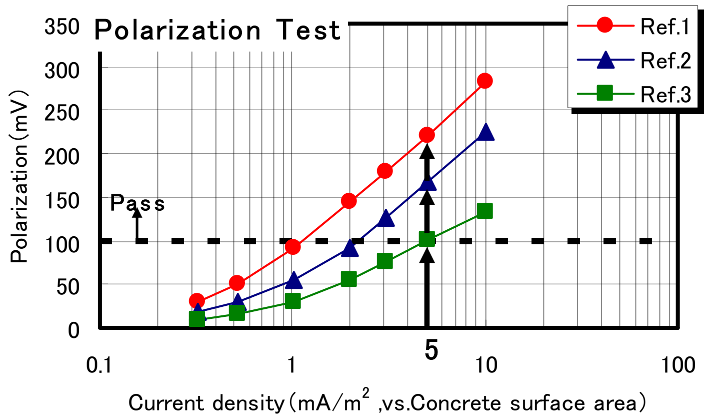

Figure 6. Polarization Test Result

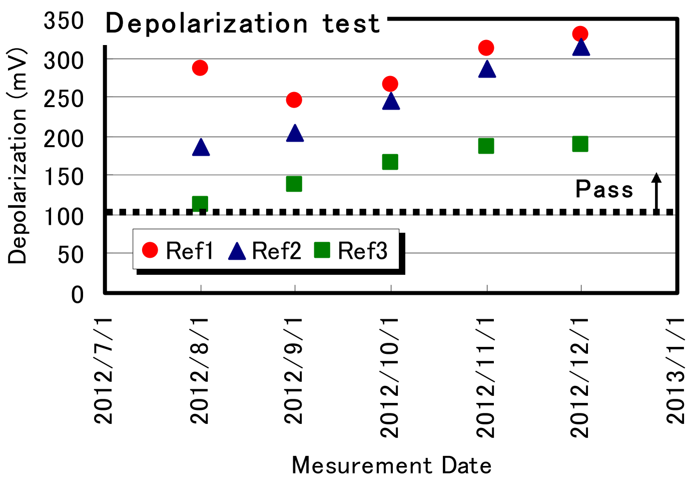

Figure 7. Depolarization Test Result

consequently confirmed that the rust prevention standard was met, and the project was completed. The scene of the project completion is shown in **Photo 8**.

Maintenance of cathodic protection. As the electric rust prevention method is of value only when the electrification is continued, it is important to monitor the continuance of the electrification. On this bridge, utilizing the measuring units and remote observation units housed in the power source apparatus, the amperage is automatically measured daily and the depolarization test is likewise measured monthly. The measurement results on the

Table 3. The Construction cost ratio of the conventional construction method and a proposal construction method

	Conventional method	Proposal method
The construction cost of anode installation of anode strips and anode coating	1	0.82
Total construction cost of cathodic protection	1	0.86

polarization resumption test are shown in **Fig.7.** Figure indicates the relationship between measurement date and depolarization. The depolarization is differences between instant of potential and self potential. The measurements of self potential stop an electric current and are the value 24 hours later. The Since every measurement in the depolarization tests records 100mV or larger as a rust prevention standard, the projected rust prevention standard, the projected rust prevention is considered to be fully functional.

Effect of cost reduction. Table 3 shows the cost ratio at the time of using the method proposed the conventional method and this time. Table shows a ratio when based on the construction cost of the conventional construction method. Anode fixing conditons of the conventional method was horizontal points. And titanium grid anode used 15mm wide. As a result, anode fixing conditions and anode coating has enabled a 20% reduction compared with the conventional method. And total construction cost of cathodic protection has enabled a 20% reduction compared with the conventional method.

CONCLUSIONS

As for the cost reduction, this titanium-based linear anode for cathodic protection has enabled a 15% reduction compared with the conventional method, by virtue of improved setting position of anodes, number of anode strips for a single groove and width of the anode strips, while keeping proper rust preventive effect. In the future, the author will strive for further improvement in rust-preventive construction technology and cost reduction, while keeping the best quality assurance.

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