INVESTIGATION OF A CATHODIC PROTECTION CONFIGURATION FOR THE STEEL CASING PIPES IN REINFORCED CONCRETE BRIDGE IN THE NIGER DELTA

ABSTRACT

This paper details the Design of a Cathodic Protection System on the steel casing pipes of the 60m reinforced concrete bridge projectin the Niger Delta, Nigeria. Galvanic anode cathodic protection system was provided for the submerged steel support piles on the newly reinforced concrete bridge to ensure adequate corrosion protection of the structures. A total of fifty-six (56) Aluminum Anodes (32 kg) were used.Two of the Aluminum anodes were installed on each of the twenty-eight (28) steel casing piles. The anode installation was achieved by means of clamping at the predetermined water depth of 37.2 m with purpose made carbon steel clamps. The bonding of the anode to the pile structure to make electrical contact was achieved through welding of the pre-installed anode steel core extension bar against the steel pile at the water splash zone area of the river. A pre- and post-installation test and survey activities were conducted on each of the steel piles to ascertain the integrity of the installation and degree of corrosion protection of the steel casing piles. The field test and measurement results indicated mean values of open circuit potential of 0.600 Volts and polarized corrosion potential of 0.850 Volts. The recorded corrosion potential for the installed cathodic protection system confirmed adequate corrosion protection for ten (10) years from anode life for the steel casing supports of the 60 m reinforced concrete bridge.

Keywords—anode; cathodic protection; casing piles; bridge; corrosion

1. INTRODUCTION

Corrosion refers to a chemical or electrochemical process between alloys, metallic or even nonmetallic materialsin a corrosive environment, which can triggerthe deterioration of the integrity of such components in a system that lacks adequate protection [1]. It is undesirable in engineering projects because it reduces structural lifespan, amplify safety concerns which can result in fatalities if neglected,promote pollution in the affected environment, and financial losses associated with downtime required for repairs and maintenance. [1, 2]. Prevention of the negative consequences of corrosion is preferred to the prohibitive cost of components or systems replacement.

Corrosion prevention techniques conventionally practiced include intentional materials selection to safeguard stability and durability, appropriate design based on peculiarity of the project, optimal application of coatings to prevent rapid deterioration of rust-prone components, electrochemical techniques i.e. cathodic and anodic protection, and tailored adjustment in the environmental condition[3, 4, 5]. The practicable ways of environmental conditioning referred to here include introduction of corrosion inhibitors, adjusting aggressive species content e.g. O_2, or adjustment of other physical parameters like flow rate or temperature choice between these possibilities hinges on economic considerations. It is not uncommon for a couple or more of these concepts to be applied simultaneously [6, 7]].

Many concrete structures with embedded reinforcement develop corrosion due to long exposure to adverse environment such as chlorides from sea water [8]. Cracking and spalling of concrete and steel cross section loss are as a result of reinforcement corrosion, which compromise serviceability and eventually structural safety [9];

Conventional methods of concrete repair of many cases have been found not to be effective or durable [10,11], but Cathodic protection (CP), which was introduced in the Europe in the 80s [12], has shown to be an effective and durable method for protecting steel in concrete.

Cathodic protection (CP) is the willful reconfiguration of the electrochemical system such that a possible metallic anode is made to function as the cathode to prevent corrosion.This can be achieved by two methods, namely: - impressed current cathodic protection and galvanic or sacrificial cathodic protection [8]. The later technique requiresDC current sourceto force the current flow from an installed anode(s) to the structure causing the entire structure to be a cathode. The DC source can be a solar cell, rectifier, generator, anaccumulator, or some other DC power supply source which can be installed in the circuit. The anodic electrode is selected based on economic consideration or the rate of weight loss per ampere year of current regardless of its position in the galvanic series [13]. The current required for cathodic protection depends upon the metal being protected and the environment.Whereas, the formermethod involves the consideration of the galvanic series in metal selection. The chosen active metal (anode) can be installed in the electrolyte solution to provide the conductive pathway for the electrons as it sacrifices itself to protect the cathode which is the corrodible component of the structure. Presently, alloys of magnesium, zinc and aluminium can be adapted as sacrificial anodes in cathodic protection projects in the marine or water environment, e.g. steel, storage tanks, fuel pipelines, steel pier piles, water-based vessels including yachts and powerboats, offshore oil platforms and onshore oil well casings. The electrochemical potential, current capacity and consumption rate of these alloys are superior for CP than iron [14].

In this report, the second approach being the galvanicanode cathodic protection system was provided for the submerged steel support piles on the newly reinforced concrete bridge located in the Niger Delta part of Nigeriato ensure adequate corrosion protection of the structuresand to achieve safety and serviceability – meeting the fundamental objectives of bridge design [15]. A total of fifty-six (56) Aluminum Anodes (32 kg) were used. Two of the Aluminum anodes were installed on each of the twenty-eight (28) steel casing piles.

Fig. 1. Image of the 60 m reinforced concrete bridge structure

The “installation of cathodic protection on the steel casing pipes of the 60m reinforced concrete bridge was carried out in line with the work specification provided by the client. The objective of the project was to provide galvanic anode cathodic protection system for the submerged steel support piles on the new reinforced concrete bridge to ensure adequate corrosion protection of the structures.

2. METHODOLOGY

A. Basis of Design

The factors considered that have resulted in the design decisions taken to ensure that the submerged steel piles supporting the new reinforced concrete bridge is given cathodic protection for a 20-year design life are as follows:

Environmental Conditions and External Influences- The new reinforced concrete bridge steel support piles are submerged in river water with intermittent high tidal currents and constantly changing salinity level all of which possesses the potential to create circumstances capable of adversely affecting the structure to steel pile. The combination of these factors makes it imperative to provide cathodic protection to the steel piles in addition to the external fusion bonded epoxy (FBE) coating.

Soil Resistivity - River water resistivity values used herein are based on the Engineering and geotechnical judgment of the river and laboratory analysis of the water, sampled at the general area of the steel piles, we conducted. The approximate relationship between the medium resistivity and the medium corrosivity is highlighted Table 1.

TABLE 1.Resistivity and Corrosivity relationship

Resistivity, Ω.cm	Corrosivity
Under 1500	Very Corrosive
1500 to 5000	Moderately Corrosive
Above 5000	Slightly Corrosive

The average river water resistivity value of 20Ω.cm extrapolated from the conductivity value obtained from the water analysis is used to size the galvanic anode CP system.

Protection Current Density - Current demands for coated structure are usually lower for coated structures however, in this Sacrificial Anode Cathodic Protection (SACP) design, the current density of $100mA/m^2$ for bare steel was deliberately adopted for over-design purposes in order to make provisions for unexpected conditions and errors of judgment.

Protection Potential Criteria - The cathodic Protection potential measurement is used as the criterion for assessment of effective cathodic protection. The following potential limits with respect to $Ag/AgCl_2$ reference electrode is used in this design: Protection potential of 800 mV (- 0.800Volts).

B. Sizing of the Sacrificial Anode Protection

The entire length of the steel piles is considered for the galvanic cathodic protection using Aluminum sacrificial anodes. Average soil resistivity value of 20 Ω.cm is used for the calculations. The steel casing pipe data are as follows: Pipe Length (L), 30 m; Pipe Diameter (D), 24 in; Type of Coating, FBE; Coating Breakdown factor: 0.15.

Data for the Aluminum Anode are summarized as follows: Weight, 32kg; Length, 0.55m; Breath, 0.07m; Height, 0.07m; Capacity, 2651 Ah/kg; Consumption, 3.3kg/A.yr; Potential, -1100mV.

Design Calculations – The structure current demand (I_{pipe}) was estimated using (1).

$$I_{pipe} = S_A I_{cd} K \quad (1)$$

where, I_{pipe} is the structure current demand, A; S_A, surface area of steel to be protected in m^2, estimated by πDL; I_{cd}, Current density of bare steel in A/m^2 = 100mA/m^2; K, Coating breakdown Factor= 0.15; D, diameter of individual steel pile in m = 0.6069m; L, total length of the individual steel pile in m = 30 m.

The calculated structure current demand was therefore, **0.933 A**

The anode maximum current output (I_{anode}) was estimated as follows;

$$I_{anode} = \Delta V/Ra \quad (2)$$

where, ΔV is the potential difference between Anode Closed Circuit Potential and Protection Potential for Steel, Volts. For this study, it is 1050mV – 800mV = 250mV or 0.25V; Ra, anode resistance, ohms, estimated by $Ra = \rho/2S$; ρ is the resistivity of the medium in Ω-m; S is the geometry of the anode in m; (L*B*H/ 3) = 0.345.

From the Equation (2), the estimated anode maximum current output was **0.86 A**

The number of aluminum anode required (N_{anode}) for this design is estimated by;

$$N_{anode} = I_{pipe} / I_{anode} \quad (3)$$

N_{anode} = 2 Anodes approximately per pile.

Hence, the total number of anodes required for the 28piles was calculated to be 56 anodes.

The anode life by mass is calculated using;

$$M = \text{etq} I_{c(mean)} / uE \quad (4)$$

where, M is the total mass of anode in kg; e, Anode consumption rate = 3.3kg/A.yr; t, design life = 10yrs; q, Immersion factor =1; $I_{c(mean)}$, mean current demand = 0.933A; u, utilization factor = 0.95; E, Efficiency factor = 0.5.

M = 64.81kg

Therefore, mass of each anode = 64.81/2 = 32.4Kg

C. Fabrication of the Anode-Clamp Assembly

A total of Fifty-six (56) circular steel clamps with 112 pieces of 24 mm steel bolts were procured for the installation of the fifty-six Aluminum anodes. In line with the installation procedure, the anodes were welded on the clamps. The exposed steel core at each end of the anode was welded to a half-moon segment of the clamps in a way that two (2) complete clamps will carry two anodes, see Fig. 2 showing images of the fabricated anode-clamp assemblies. Continuity test was conducted between the anode material and the steel clamps to confirm the effective contact between the two materials thereafter the exposed metal of the clamp and the anode core were properly coated with epoxy coating for added insulation. The anode/clamp assemblies were inspected by the authorized representative of quality control personnel before installation. Great care was taken during this exercise while handling the anodes to avoid damage to the anode structure.

Fig. 2. Images of the fabrication of the anode-clamp assembly

D. Installation, welding and potential measurement of the Galvanic Anodes

The methodology adopted for the installation, welding and potential measurement of galvanic cathodic protection system on the steel casing pipes of the reinforced concrete bridge was carried out professionally with strict adherence to safe work procedures. The work activities are enumerated in the various job categories as follows:

Clamping and Termination of the Anodes on the Casing Pipes - Two (2) fibre re-inforced plastic (FRP) boats were deployed in the anode installation exercise for the purpose of moving the personnel, equipment and material between the shore and the work location and for use as a working platform respectively.

Due to the exposed nature of the site and the anodes were transported to site in batches of two (2) pairs of the anode-clamp assembly so as to avoid damage to the anode structure. Each anode-clamp assembly comprising two anodes and two prefabricated circular clamps was installed on each of the 28no steel piles by wrapping the half-moon segments of the clamps around the piles and locking the fastening bolts. The Depth of the anode installation was predetermined and delineated during the preliminary site survey by logging the water depth at different times during the high and low tide and information on the tidal behavior obtained from some local fisher men. Using the FRP boats as means to transport the personnel, equipment and materials were moved to the surface working platform, the work procedure use for the anode installation at each pile is stated as follows:

- Confirmation of the anode installation depth by logging is first carried out prior to each installation as the depth of the river between each pile.
- A universal clamp, with purpose made hooks on either half of the clamp is provided as support the two chain hoists needed for lowering the anodes safely to the required depth.
- At each pile during the anode installation exercise, the universal clamp is first positioned and secured on the highest point on the steel pile, to provide enough room for maneuvering the anode/clamp assembly during the installation, before hooking on the two chain hoists on the opposite sides of the steel pile.
- Each half of the anode/clamp assembly is lifted off the FRP boat with the aid chain hoist and the lifting belts, the dangling halves of the anode-clamp assembly are wrapped around the steel pile and brought together and by working the chain blocks, the face of the four (4) clamp flanges are aligned and bolted together using the 24mm steel bolts.

- The complete anode-clamp assembly now wrapped around the steel pile is gradually hoisted down along the trunk of the steel pile to the pre-determined depth which the aid of the chain hoists supported by the divers under the water.
- While at the desired depth, the divers finally lock the bolts on the clamps firmly against the steel piles and releases the lifting belts. TheInstallation is tested for mechanical integrity by the divers for confirmation before moving to the next installation.

Fig. 3 shows images of the installation exercises of the galvanic anodes.

Fig. 3. Images of the installation exercises of the galvanic anodes

Welding of the Anodes on the Casing Pipes - Welding of the anode steel core extension bar on to the steel pile commenced after all the anodes had been installed, see Fig. 4. The exercise involved the following activities:

- Surface preparation of the selected point on the piles and the tip of the extended anode steel core were carried out using a power grinding machine to ensure a low impedance terminal drain point.
- The welding of the anode steel bar on the prepared point on the steel pile. The exercise at each turn was done properly and carefully.
- Testing of the welding for mechanical and electrical integrity was carried out by hitting with hammer and by conducting electrical continuity test between the bar and a remote point on the steel pile respectively.
- At the conclusion of the welding and confirmation of the weld integrity, the welded points and all the exposed metal around the vicinity were coated with splash zone compound.

Fig. 4. Images of welding exercise of the anodes on the casing pipes

Conduction of Potential Measurement – The FRP boat and the floaters shall form the working surfaces for this job category. The polarized cathodic protection potential measurement was conducted on each of the twenty (28) steel piles 48 hours after the installation of the anodes, to ascertain and ensure the corrosion protection of the casing pipes and the integrity of the installation. The methodology used in the exercise, which is a standard procedure, is highlighted below.

- Expose the steel at a point above the maximum water level on the casing pipes by wire brushing.
- Put on the Digital multimeter and ensure that the probe and electrode terminals are correct. Drop the $Ag/AgCl_2$ half-cell in the water very close to the casing pipe under test and allow the electrode to get saturated for 7 minutes before conducting the test.
- Place the probe terminal on the exposed steel of the casing pipe and record the reading in milli-Volts. This measurement is repeated on other points on the casing pipe to confirm the data obtained. The data obtained was properly recorded.

E. *CP Potential Survey Data*

After installation, welding of the anodes on the casing pipes and preliminary potential measurement have been carried out, corrosion survey was then performed. The steel casing piles supporting the new reinforced concrete bridge were arranged in two (2) rows with each row bearing fourteen (14) of these 24-inch Outer Diameter (OD) steel pipe piles. Theschematic representation of the layout of the steel piles is shown in Fig. 5. The steel piles were numbered in the diagram for reference and clarity purposes only, as the numbers were not inscribed on the steel piles.Table 2 Shows the technical data and Criteria for the Cathode Survey Reading.

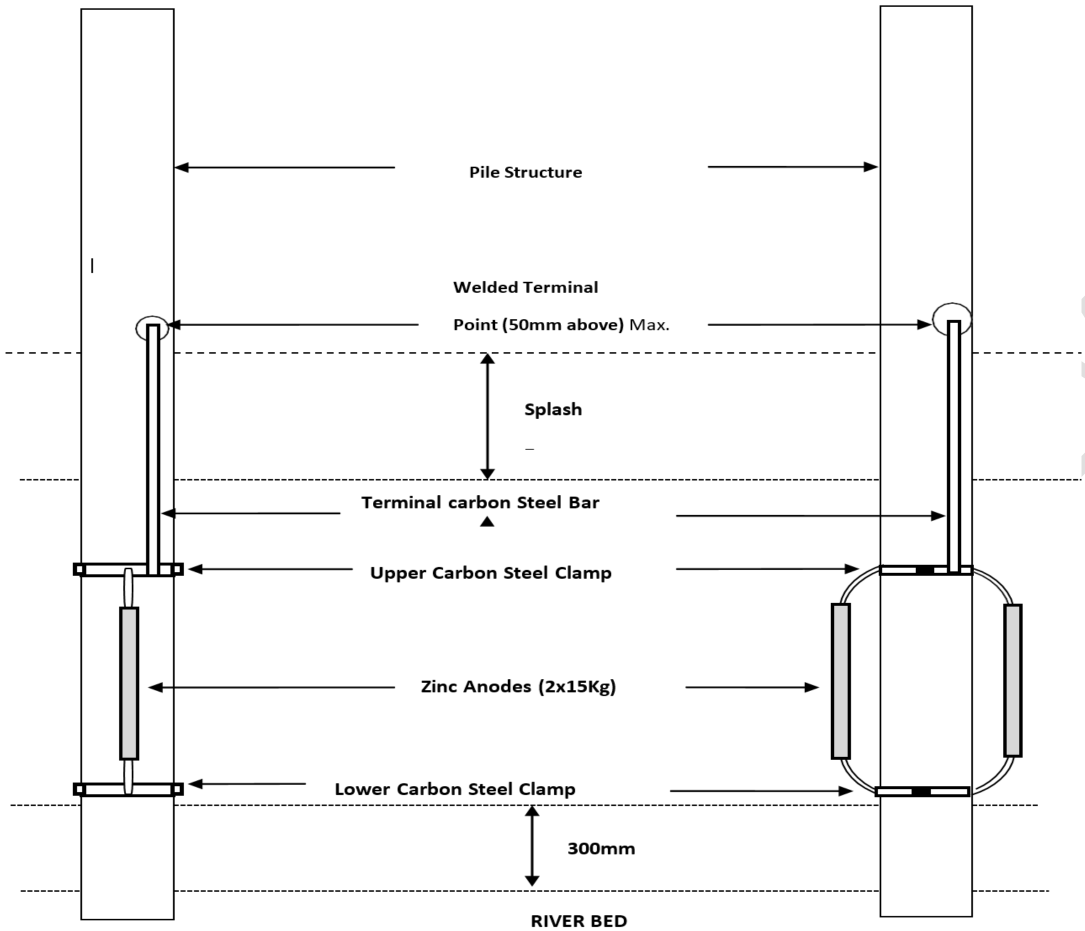

Fig. 5. Layout/Configuration of Anodes on Steel Casing Piles for the 60 m Reinforced Concrete Bridge

TABLE 2. Anode type and criteria data for the cathodic survey reading

Technical Data	Value
Anode size	2x15kg
Anode dimensions	Diameter = 300mm/Thickness = 12mm
Anode make/composition	Aluminium alloy
Anode Installation life	10years
Reference cell	$Ag/AgCl_2$
Pile composition	Carbon steel
Coating type	Red oxide (anti rust) and coal tar
Criteria	- 0.800 Volts (Protection Limit) / -1.050Volts (Overprotection Limit)
Mean river depth	37.5m
Anode installation depth	37.2m

The readings for the corrosion potential survey for the steel pipes in the two rows are presented in Tables 3 and 4.

TABLE 3.Corrosion potential survey for row no. 1 steel pile casings

Corrosion Potential Survey for Row No. 1 Steel Pile Casings		
No. of Steel Pile Casings	**Open Circuit Potential (Volts)**	**Polarized Corrosion Potential (Volts)**
1	-0.601	-0.809
2	-0.611	-0.860
3	-0.616	-0.889
4	-0.606	-0.843
5	-0.600	-0.805
6	-0.601	-0.805
7	-0.605	-0.822
8	-0.605	-0.842
9	-0.610	-0.851
10	-0.608	-0.850
11	-0.600	-0.801
12	-0.607	-0.828
13	-0.600	-0.808
14	-0.602	-0.812

TABLE 4.Corrosion potential survey for row no. 2 steel pile casings

Corrosion Potential Survey for Row No. 2 Steel Pile Casings		
No. of Steel Pile Casings	**Open Circuit Potential (Volts)**	**Polarized Corrosion Potential (Volts)**
1	-0.611	-0.860
2	-0.603	-0.825
3	-0.599	-0.802
4	-0.604	-0.836
5	-0.608	-0.850
6	-0.602	-0.827
7	-0.606	-0.845
8	-0.604	-0.832
9	-0.603	-0.838
10	-0.607	-0.849
11	-0.604	-0.832
12	-0.602	-0.822
13	-0.605	-0.834
14	-0.601	-0.814

3. RESULTS DISCUSSION

The reference cell (Ag/AgCl$_2$) was calibrated for measurement of the potential readings before and after installation of the sacrificial anode cathodic protection (SACP) on the steel casing piles. As can be seen in Tables 3 and 4, the polarized cathodic protection potential readings recorded for the two rows of the steel casing piles range from -0.889 to -0.801 Volts for the steel pile casings in row 1, and from -0.860 Volts to -0.814 Volts. These are within the recommended protection criteria of -800milli-Volts to -1050milli-Volts.The readings are generally homogenous mostly because the steel piles were electrically bonded together through the steel reinforcement in the bridge concrete structure and submerged in the same river water medium.

Figures 6 and 7 show the comparisons between the native and the polarized corrosion potentials for the steel pile casings in row 1 and row 2, respectively.

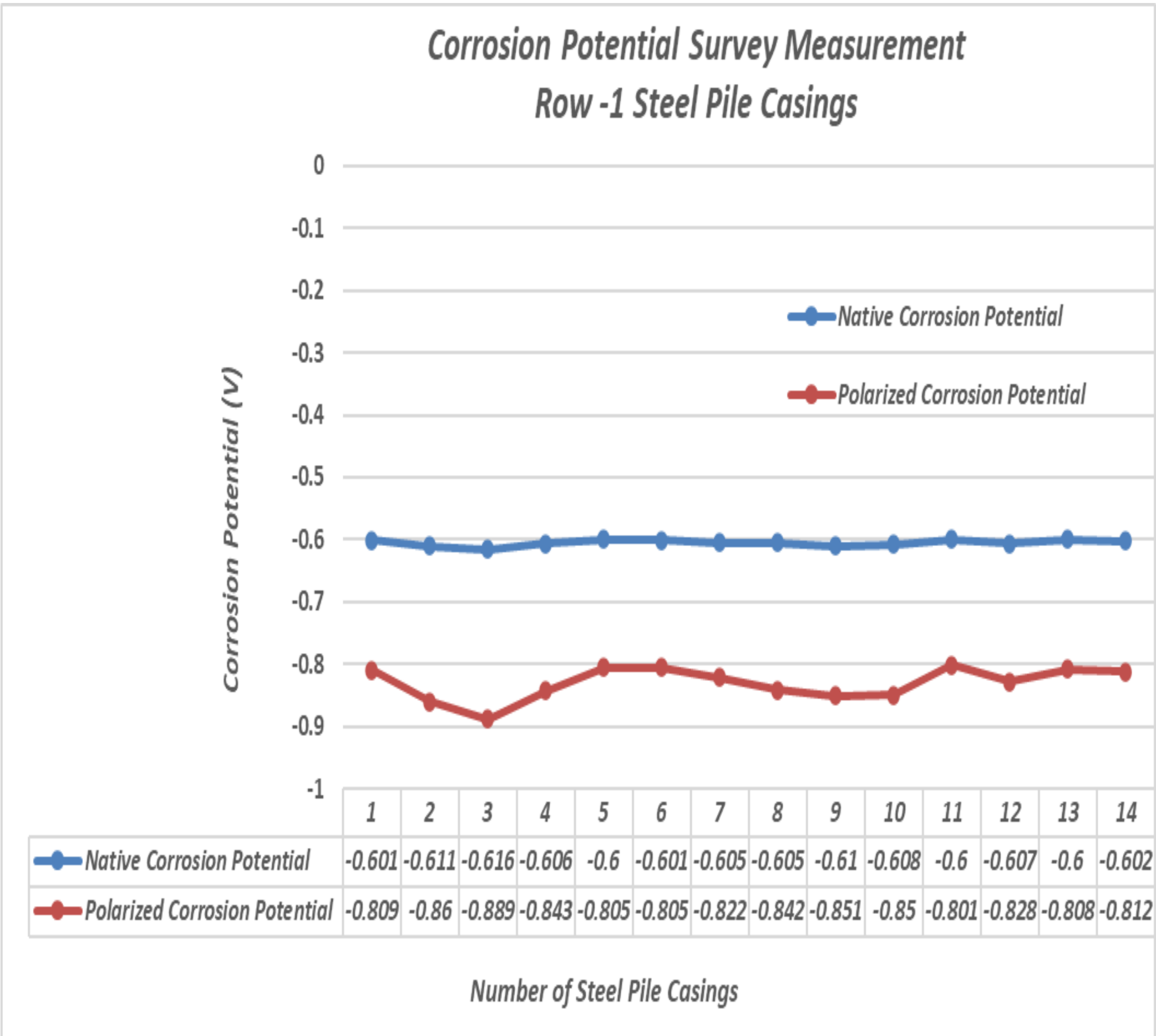

Fig. 6. Native and polarised corrosion potential survey readings for row 1 steel pile casings

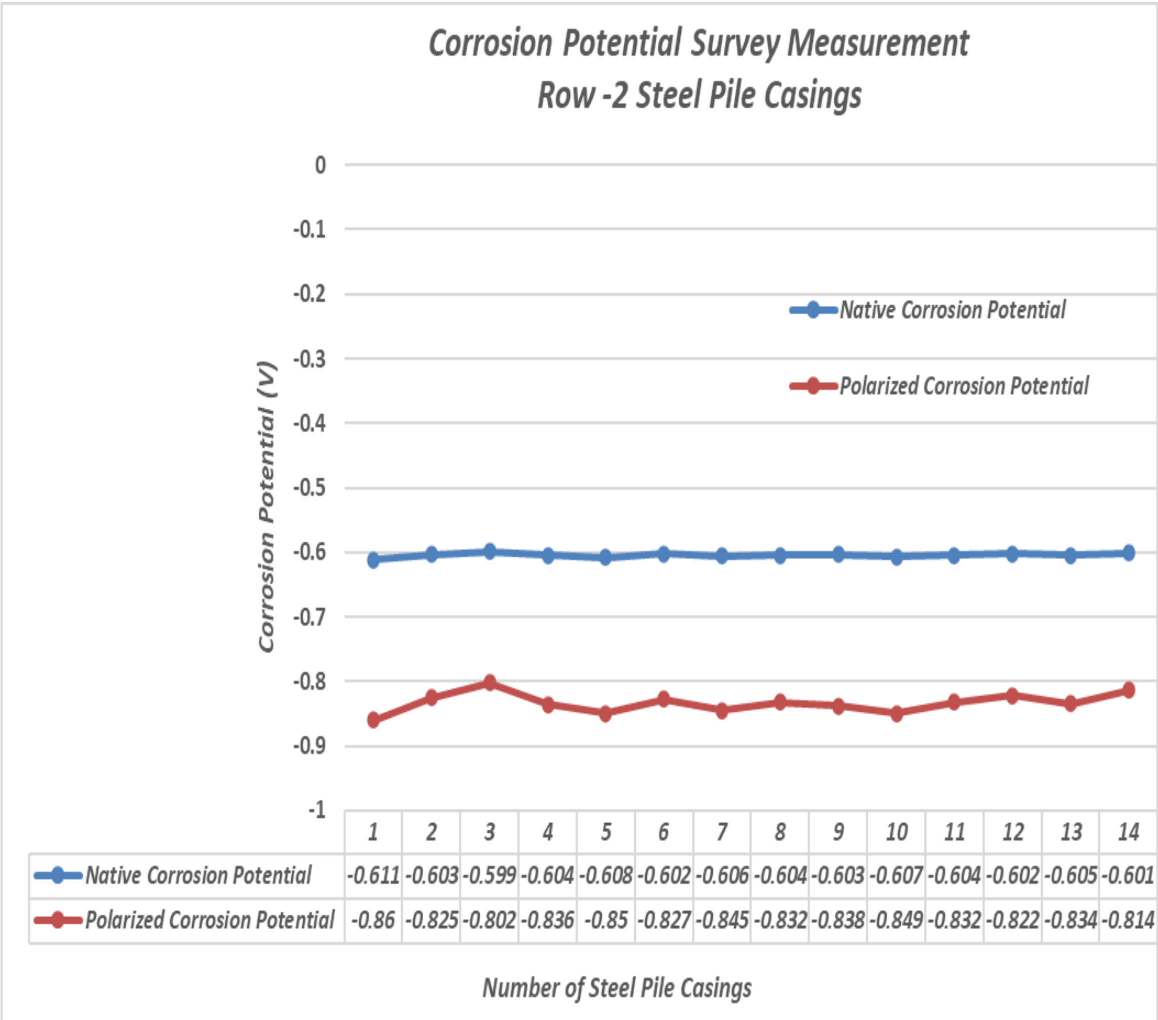

Fig. 7. Native and polarised corrosion potential survey readings for row 2 steel pile casings

The natural potential readings give indication on the corrosion potential of the piles prior to cathodic protection with respect to the environmental factors acting on the structures, such as; changing salinity level of the water, changing tidal current, $_{P}$H of the water and the soil structure in which the piles are embedded.

4. CONCLUSION

A total of fifty-six (56) 32kg Aluminum Anodes were installed in the project with two (2) Aluminum anodes installed on each of the twenty-eight (28) steel casing piles. The anode installation was achieved by means of clamping at the predetermined water depth with purpose made carbon steel clamps. Bonding of the anode to the pile structure to make electrical contact was achieved through welding of the pre-installed anode steel core extension bar against the steel pile at the splash zone area. All the welded points were coated with splash-zone epoxy compound for insulation. After the successful installation and termination of all the anodes, a cathodic protection potential survey was conducted on each of the steel piles to ascertain the functionality of the installation. The recorded potential readings fall within protection criteria of -800milli-Volts indicating effective protection of the steel casing piles from corrosion.

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