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GEOELELECTRIC MEASUREMENTS FOR DESIGN OF CATHODIC PROTECTION SYSTEM TO PROLONG THE LIFE SPAN OF JETTY.

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ABSTRACT: Geoelectric measurements have been carried out at the Jetty of Maritime Academy of Nigeria, Oron. The result of the measurements identified five geoelectric layers (Table 1) with relatively low resistivity of 272Ωm at the first layer. This resistivity value and the relatively shallow depth of the layer permit the planting of protective galvanic anode for the metallic piles supporting the Jetty. The passive geoelectric method (pile-to-soil potential) shows that the piles are extensively corroding (the potential result falls below the protection level of -0.85v). The galvanic protection system design indicates that with one standard magnesium anode, the piles can be protected for a period of 16years before thinking of replacement of the anode. From the design, it is cheaper to install and maintain a cathodic protection system for the jetty than re-construction or rehabilitation of the jetty.

INTRODUCTION

In Nigeria, external corrosion mitigation had been and still remains the act of coating except in multi-national companies. The process of coating involves painting with anti-rust (anti-corrosive) paints which are often formulated as oil paints. The application of paints on metal surfaces will surely isolate the metal from its surrounding electrolyte, thereby minimizing the level of electrochemical reaction between the metal and the surrounding electrolyte. However, coating cannot guarantee absolute protection of metals from corrosion due to formation of holes referred to as holidays during coating. These holidays have been seen as corrosion initiation site, which in most cases result in pitting type of corrosion (Mishra *et al*, 2002 and Tsuru and Nsihkata, 2000). Such site does not only threaten the life span of metals but increases the risk level at which metallic ions leave the metals to the environment. Therefore, if coating is not supported by a well designed and installed cathodic protection system, metal rods used for construction of bridges, pipelines and tanks used for construction of ships and iron pipes used as support for jetties will not only pose threat to assets but also collapse of such structure.

Corrosion is an electrochemical process that involves the transfer of ions from anode to cathode across a conducting path (electrolyte). Corrosion can take place at room temperature and with or without oxygen. In the absence of oxygen, the presence of anaerobic bacterial in the electrolyte (soil) will initiate corrosion. Therefore, the way out is supplementing coating with cathodic protection system (ANSI/ASME, 1986; Mishra *et al*, 2000; Atkins and Paula, 2004 and Obi *et al*, 2008). Although, West (1986) advocates the use of anodic protection as substitude for cathodic protection. The principle of anodic protection is based on the formation of films on the metal by externally applied current. The method is relatively new as opposed to cathodic protection and has not gained enough confidence in the field of corrosion protection. Besides, it is limited to metals and alloys that are capable of undergoing passivation. The limitations of anodic protection system give room for wider application of cathodic system as the best technical option used to supplement coating in offering solutions to corrosion problems.

Cathodic Protection (CP) system can be applied in two ways: galvanic cathodic protection system and impressed current cathodic protection system. The galvanic CP system uses current naturally generated between the anode and its environment. Whereas, impressed current CP system uses direct current from external power source, which is impressed on the anode. For an impressed current CP system to be effective there should be uninterrupted power supply. A renewable power (photovoltaic) source has been suggested by Obi *et al* (2008) for this. Some of the advantages of photovoltaic source over national grid in Nigeria include cost effectiveness in installation as well as maintenance, reliability, ability to exist independent of national grid, its applicability to protect metals in the rural areas even when there is no power supply from the national grid.

LOCATION OF THE JETTY

The jetty investigated is located globally within latitude 4.668^0N and longitude 8.261^0E in the Maritime Academy of Nigeria, Oron, Akwa Ibom State. The jetty is constructed in one of the rivers that empty into the Atlantic Ocean. Hence, the surface water at the jetty is saline in nature. The salinity increases from the wet season to the dry season. This saline water is absorbed into the pores of the surrounding soil and it poses serious threats to metallic structures within the area. Consequently, metallic piles used to support the Jetty are at a risk of corrosion. Structurally, the Jetty is supported by 57 metallic piles, with half of their lengths driven into the ground. These piles are considered to be exposed to two different environments (fresh water and saline water). Besides, within the ground the piles cut across layers of Benin Formations of different resistivities, which also increase the chance of their corrosive degradation**.** Ogden (2001) noted that pitting type of corrosion has been a primary cause of degradation and failure of unprotected ductile iron pipes in different soil environments. However, cathodic protection system was used to safe-guard the piles from corrosion attack.

MATERIALS AND METHODS

To design a working galvanic cathodic protection system for the metallic piles that can prolong the life span of the Jetty, several investigations were carried-out. These investigations aimed at determining the subsurface conditions that favour corrosion, the subsurface layer(s) suitable for planting sacrificial anodes and the extent of corrosion of the piles at the Jetty. The materials used for the study were McOhm Terrameter and its accessories, Copper-copper Sulphate Electrode (CSE), high impedance digital multimeter and coated copper wire uncoiled from a spool.

The Terrameter and its accessories were connected to form the Schlumberger array (Fig. 1). This was used to perform a vertical electrical sounding, which generated data for the resistivity of the subsurface at various depths within the limit of penetration of the injected current. The impressed current sent into the ground created a potential which was divided by the current displayed by the Terrameter as resistance (R) and with the electrode configuration, the resistivity was determined by multiplying the resistance with the geometric factor of the electrode separations. To mechanically pre-analyse the data, log-log graph was used to plot the apparent resistivity against the $^{AB}/_2$ and the smoothened apparent resistivities were used to generate electronically the final models of resistivities, thicknesses and depths shown in Table1 with the use of Resist software.

For the result in Table 1 to be relied upon, drilled borehole data within the sounding station shown in Fig. 2 was used to correlate the geoelectric result with geology and they all agreed Fig.2. This was done to ensure that there is a strong reliability in the interpretation of the data and the geomaterials are true representation of the geology within the environment.

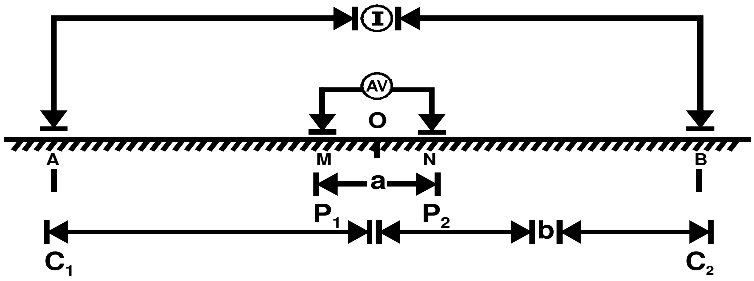

Fig. 1 Sketch diagram of Schlumberger array used in data acquisition

Again, the copper-copper Sulphate electrode and the digital multimater were used to conduct pile-to-soil potential test. Ten of the fifty-seven piles were tested. Apart from this test, visual inspections of all the fifty-seven piles were conducted and there was a clear evidence of corrosion seriously taking place at the jetty.

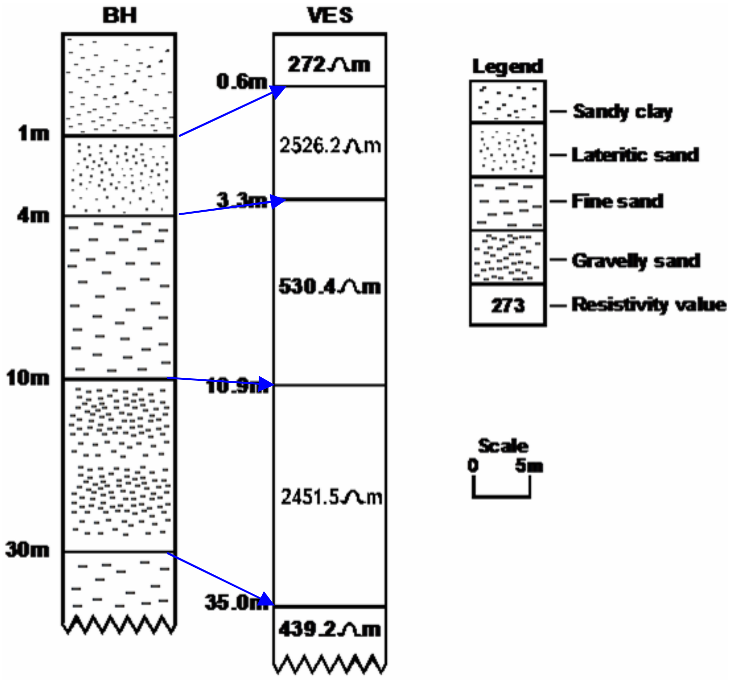

Fig. 2: Correlation of the geoelectric layer with lithologic units within the jetty environment

Galvanic anode Cathodic Protection System Design

The galvanic anode cathodic protection system deliberately sacrifices the anode (magnesium or zinc) to protect the cathode. To ensure continuous and effective protection, the life span of the anode sacrificed should be determined to aid anodic inspections and replacement. Atkins and Paula 2004) reports that a block of magnesium replaced occasionally is much cheaper than the cost of buying ship, construction of pipelines and building of metallic structures for which it is sacrificed to protect.

Generally, galvanic anode protection system is used for protection of underground installations that require small amount of current and in contact with soil of low resistivity. The two types of galvanic anode materials frequently in use are magnesium and zinc. However, magnesium anode is more popular than zinc.

The galvanic protection design admits some fundamental data of the material(s) to be protected such as length (L), diameter (D), coating thickness (tc) and the average potential of the material. For the piles considered in this study:

Length (L)	=	12m
Diameter (D)	=	8" = 0.20m
Coating thickness (tc)	=	0 (bare material).
Average potential	=	-0.67v

The total surface area (A) of a pile can be calculated using the formula in equation 1(Tsuru and Nsihkata,2000);

$$A = \pi (D + 2tc)L \quad (1)$$

$$A = 3.142\,(0.20 + 0)12 = 7.54m^2$$

By Corrosion Engineers Standard, the current density (J) needed to protect a metallic material is 0.1 mA/m^2

Thus, the protection current (I_p) required per pile (Owate *et al*; 2000) is

$$I_p = J \times A \quad (2)$$

which gives $I_p = 0.1\ mA/m^2 \times 7.54m^2$

$I_p = 0.8mA$

Therefore, the total current needed to protect all the piles (57) is 45.6mA.

Assuming a magnesium anode is to be used to protect the piles, the magnesium anode from manufacturer's manual provides that a standard 14.5kg high-potential anode with a length of 0.5m, diameter of 0.12m and potential of -1.75v should be used. Therefore, the net driving potential (E_n) between the anode and the pile (cathode) (Atkins and Paula 2004) is

$$E_n = -1.75v - (-0.67v) = -1.08v \quad (3)$$

This potential is usually influenced by the resistance of the galvanic anode in a soil. Such resistance is determined from the Dwight's formula of a vertically installed anode in a given soil of known resistivity. From Table 1, it could be inferred that the layers of low resistivity are 1, 3 and 5. The first layer was considered to be favourable for planting of the anode not only because it has the lowest resistivity but its depth to bottom permits easy replacement of anode. The anode resistance is given by equation 4(Klechka, 2004).

$$R_a = \frac{0.00521}{L}\rho_S\left[\ln\left(\frac{18L}{d}\right) - 1\right] \quad (4)$$

Where:

ρ_S is the soil resistivity where the anode is to be planted, L the length of the anode and d is the diameter of the anode.

Hence, $R_a = \left(\frac{0.00521}{0.5}\right)272\left[In\left(\frac{18\,(0.5)}{0.12}\right) - 1\right]$

$$R_a = 9.403\,\Omega / anode$$

The current output from the anode can be computed in accordance with ohm's law.

$$I_A = \frac{E_n}{R_a} \quad (5)$$

$$I_A = \frac{1.08}{9.403} = 114.9mA$$

The number of galvanic anode required to protect the Jetty is given by $N = {}^{I_t}\!/_{I_a}$ (6)

Where: I_t = Total current required (45.6mA)
I_a = Single anode current (114.9mA)

$$N = \frac{45.6mA}{114.9mA} = 0.4$$

N is less than one. This shows that one anode can do the job.

Comparing the total current needed by the piles to the current produced by an anode (I_A), it could be seen that one 14.5kg magnesium anode is capable of protecting the whole piles for a specific period of time known as anode life span (T) given by equation 7(Tsuru and Nsihkata, 2000) as;

$$T = F_u \,.\, C_a \,.\, {}^{W}\!/_{I} \quad (7)$$

Where:
F_u is utilization factor which is 85% for magnesium.
C_a is anode capacity (given as 0.125A-yr/kg at 50% efficiency), W is the anode weight (14.5kg) and I is the anode current calculated with respect to polarized potential of the cathode (0.85V) by Atkins and Paula (2004) as;

$$I = \frac{E_A - E_p}{R_a} \quad (8)$$

Therefore, $I = \dfrac{-1.75 - (-0.85)}{R_a}$ (9)

$$I = \frac{0.90}{9.403} = 0.0957A$$

Hence $T = (0.85)\,.\,(0.125)\,.\,\dfrac{14.5}{0.0957} = 16\,years$

RESULTS AND DISCUSSION

The result obtained from pile-to-soil potential survey shows that the piles were undergoing appreciable corrosion. This is evidence of the potential drop below the level of protection (-850mV with respect to CSE) for all the piles (Fig. 3). This was confirmed by physical inspections of the exposed segments of the piles. High corrosivity is observed from piles 8 down when the same depth of penetration was considered (Fig. 3).

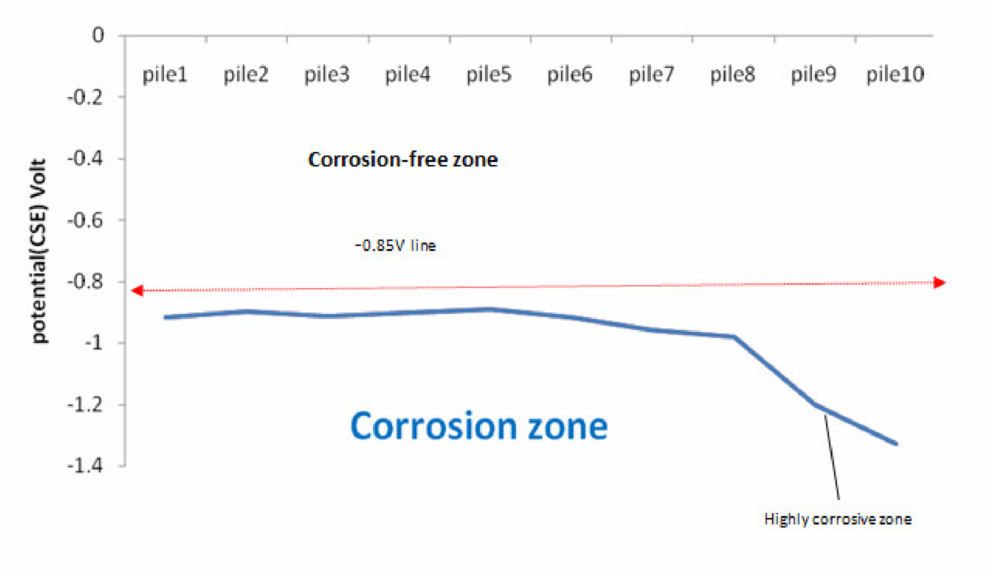

Fig.3: Potential-pile plot for the ten representative piles showing corrosivity below safe potential drop of -0.85V at the jetty

The result of the resistivity survey is as presented on Table 1. Five geoelectric layers were delineated as well as their resistivity values, thicknesses and depths. Within the limit of penetration of injected current, the deepest layer lies below 35m. This result shows that piles are buried within geomaterials of diverse resistivity values. Thus, the environment is favourable for corrosion of the piles and that is why protection is paramount.

Table 1: Results of geoelectric resistivity soundings conducted at the Jetty's environment.

Layer	$\rho\,\Omega m$	Depth (m)	Thickness (m)
1	272	0.6	0.6
2	2526.2	3.3	2.7
3	530.4	10.9	7.6
4	2451.5	35.0	24.6
5	439.23	-	-

The design of the cathodic protection was based on the field measurement, pile parameters and the sacrificed anode parameters which were obtained in the manufacturer's manual. From the design, anode current, I_a was found to be 114.9mA which is greater than the cathodic current I_p (0.8mA). By calculation, the number of anode is less than unity and this suggests that one anode can comfortably be sacrificed to protect the piles. The design also shows that the sacrificial anode to be used can be replaced after sixteen years of installation. This will prolong the life of the Jetty and make it safe for use.

The implication is that if a magnesium anode of weight 14.5kg is considered to be used to protect the jetty, the anode should be due for replacement after 16years.

CONCLUSION

Cathodic protection system if used to supplement coating can enhance the life span of metallic structure in contact with a conductive environment such as saline soil and water. The protection system discussed here, if installed and maintained will prolong the life span of the Jetty. This is more economical when compared with the cost of reconstruction of a new Jetty or rehabilitation of the existing one.

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