A New Monitoring Method for Evaluation Cathodically Protected Large Diameterprestressed Concrete Cylinder Pipe Using Real Size Coupons

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Abstract:

The effectiveness of the cathodic protection (CP) system for large diameter prestressed concrete cylinder pipe (PCCP) system is monitored only by indirect methods, known as "criteria for protection". However for large diameter PCCP their exist t a problem on PCCP cathodic protection system including, difficulty to gasp corrosion condition of PCCP, whether it is in progress or not, and hard to evaluate the effectiveness and adequacy *of the cathodic protection system. The principle causes for these problems is due to the large size of PCCP pipe and inaccessibility of the pipe and prestressing wire makes evaluation difficult, costly and impractical to determine steel potential at the circumferential positions of the pipe..No reference electrodes are installed on the surface of PCCP and the overland surveys (CIPS) can only measure some form of weighted mean steel potential. Also the variation in soil resistivity along the PCCP pipeline route will have a noticeable effect on the performance of cathodic protection system and the interpretation of the performance monitoring result. The mixed nature of the pipeline that may exist, i.e., combination of coal tar epoxy coated PCCP pipe and non-coated pipeline sections. Such problems associated with data measurement and interpretations of the CP system are usually overcome by using corrosion coupons (small size test piece). Whereas coupons have provided sterling service in the process industry on the whole, an application to large and very long PCCP pipeline is deemed impractical and non-productive. We propose in this paper to install real scale coupons which consist of actual size PCCP pipes. The aim of this new monitoring technique is to confirm the effectiveness and adequacy using zinc anodes on the performance of passivated, corroded and coal tar coated PCCPs which are buried in various soil resistivity ranges.*

1.Introduction:

The North Africa State of Libya water project is one of the largest in the Middle East, in which total length over 4000 km of pre-stressed concrete cylinder pipe lines (4.0 m diameter) were installed. In August

1999 and early 2000 four bursts and water leakage accident have occurred. And it was observed that many sections of pre-stressed wire on the burst PCCPs were attacked by heavy corrosion (chloride induced corrosion) and failed in their duty as reinforcement. After the accident, the Libyan water authority has decided to install two types of galvanic anode cathodic protection (CP) systems namely: retrofit for already installed conveyance system and ribbon anodes for newly installation of conveyance lines. Galvanic anode was selected for two technical reasons, firstly its output in harmony can increase or decrease with changing of corrosion potential, and secondly the risk of overprotection leading to hydrogen embrittlement is almost negligible.

Evaluating the effectiveness and adequacy of galvanic anode system is very hard, and time consuming due to the large size of PCCP pip and very long conveyance system, which make it impractical to determine the steel potential at the circumferential position of the pipe, the mixed nature of pipeline i.e. combination of "black" (coal tar epoxy coated) and "white" (non-coated mortar) un-corroded and corroded pipe line sections, and seasonal and climatic variation. In this paper we propose to install several real size PCCP pipe as the test coupons, rather than using conventional small size coupon in different soil resistivity areas, near and parallel with existing PCCP pipeline. Furthermore, galvanic anode around the coupon PCCP to be applied in the same manner with main PCCP pipeline to replicate the same condition of the cathodic protection system. The coupon PCCP pipes shall be instrumented with resistivity sensors, corrosion monitoring probes and permanent reference electrodes to monitor and to confirm the adequacy of cathodic protection system.

Outline of Real Size Coupon :

The real size coupon system aims to confirm the effectiveness and adequacy of the Libyan water present cathodic system using zinc alloy anodes on the performance of passivated, corroded and coal tar coated PCCPs which are buried in various soil resistivity ranges.

One real size coupon consists of three (3) actual PCCP pipes which shall be removed from the existing PCCP conveyance system. The PCCP pipes shall have clear data for own manufactured and previous installation details including detailed specification of the pre-stressed wire. The real size coupon shall be installed at four different locations along the cathodically protected conveyance line. Those four locations shall be decided to simulate a particular soil resistivity range in according to environmental criteria as shown in Table (1).

Table (1) Environmental Criteria or Test Location

Location No.	Resistivity Range (Ωcm)	Degree of Aggressiveness
A	0 – 3,000	Highly aggressive
B	3,000 -10,000	Aggressive
C	10,000 – 30,000	Moderate
D	>30,000	Low

Advantages of Real Size Coupon:

By using actual PCCP pipe as corrosion coupon, it would be possible to allow corrosion engineer to achieve the following goals:

1- Isolating electrically enable to measure/calculate the current density (Current demand)

2- Reproducing similar conditions to the prestressed wires.

3- Replicating conditions in soil variation.
4- Installing monitoring probes at different circumferential locations as close as possible to the pre-stressed wires embedded in mortar to minimize IR drop.
5- Switching off the cathodic protection system instantly without interfering and/or interruption on the main PCCP conveyance line.
6- Investigating and evaluating the effect of the variation on water table depths and moisture level of the soil/ backfill i.e. soil resistivity, on the potential and current low from the anode.
7- Permitting execution the instant off technique to obtain true potential measurements without any interference.
8- Confirming visually the adequacy of cathodic protection on stopping corrosion of previously corroded areas and determines the optimum required current and/or potential to achieve full protection.

Basic Design O Real Size Coupon:

1- Real size coupon:

One (1) set of the real size coupon consist of three (3) actual sized PCCP (4.5 m diameter x 7.5 m length pipe), which shall be removed from existing PCCP conveyance system. First pipe (No.1) of those three should be coal tar epoxy coated "black" and two pin holes should presented on the pipe surface to resemble coating damage. Pipe No. (2) and No. (3),shall have no additional protection beyond the alkaline cement mortar slurry and mortar coating. Pipe No. (2) Should have previously existing corroded areas/areas. No. (3) Pipe should be selected as free of corrosion. These three real size pipes shall be connected to each other electrically and mechanically. Figure (1) shows the concept of the real size.

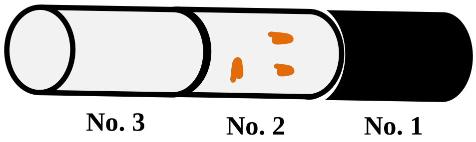

Figure (1) Concept of Real Size Coupon

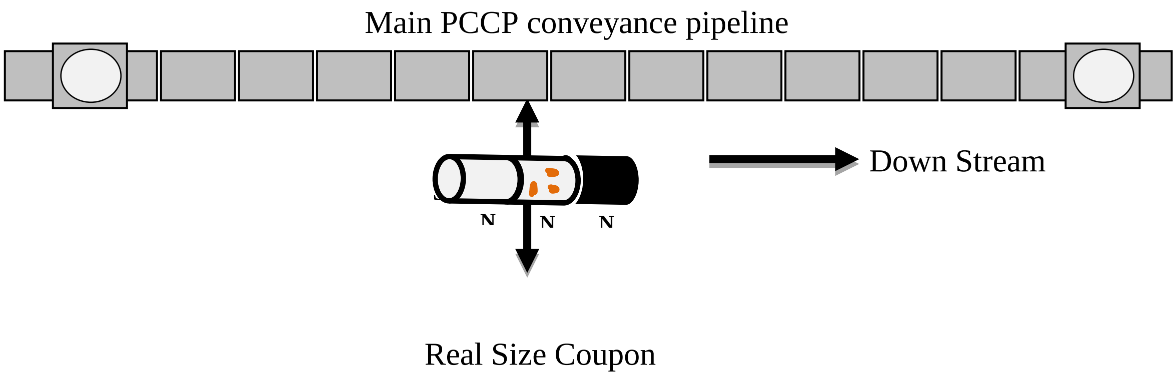

Figure (2) Concept of Real Size Coupon

2- Coupon Setting:

The real size coupon shall be installed at four (4) locations where have different soil resistivity ranges. The coupon consisting of three pipes should be buried 30 meter distance from the main PCCP conveyance pipeline to avoid any interference with other CP system.

Prior to excavation the soil resistivity on the undisrupted soil shall be confirmed in details. Full chemical and physical geotechnical analysis of the excavated soil should be carried out at every one meter depth during both excavation and backfilling.

These tests should include and not limited to soil resistivity measurement, wet and dry conditions, pH, chloride and sulfate content. After backfilling Soil resistivity shall be continuously measured after excavation using special sensor furnished at every one (1) meter depth on both side each PCCP pipe i.e. 6 pieces x 2 sides x 3 = 36 sensor/ coupon. The soil sampling position and the arrangement of the resistivity sensors are shown in Figure (3)

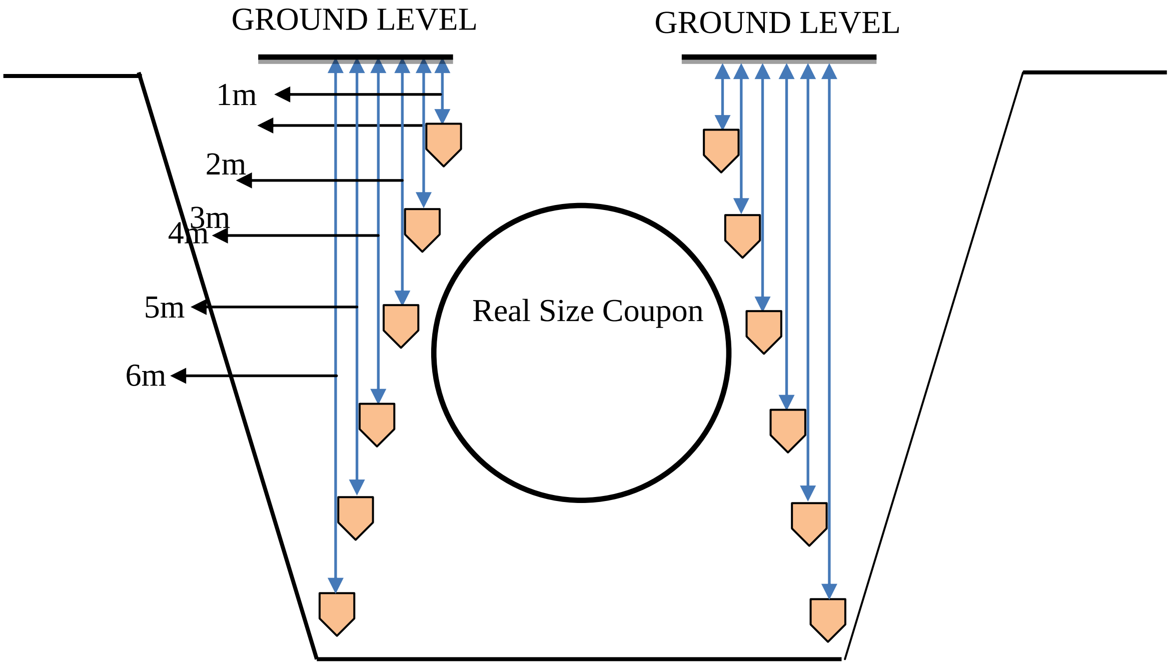

Figure (3) Soil Sampling Position and Arrangement of Soil Resistivity Sensors

Instrumentation :

(1) Soil Resistivity sensors: Arrangement and numbers as shown in Figure(3).

(2) Soil moisture probe: No soil moisture probe will be provided and the moisture will be monitored by soil resistivity sensors.

(3) Reference Electrodes: Potential monitoring of embedded structure is necessary to presume the potential current distribution surrounding the structure and to confirm the effectiveness of cathodic protection. In general, the nature potential of steel would be between -50 mV and 250mV vs. a copper/copper sulfate reference electrode (CSE) that is nobler than the potential of bare steel.

The potential in the range above usually indicates that steel material are passivated and protected from corrosion. However in case of a sudden negative shift is observed in potential, although still within -50 to 250 mV rang. It indicates that corrosion is occurring. Potential more negative than 300 mV (CSE) are generally accepted as an indication or high probability of corrosion taken place.

In order to measure consciously the pipe to soil potential around the real size coupon during and after the backfilling. Permanent type copper/copper sulfate reference electrode (CSE) should be installed at the circumferential positions of the coupon. The installation positions of the CSE reference electrodes are shown on Figure (4).

Seven permanent Copper/Copper Sulfate Reference Electrode (CSE) shall be provided at 1, 3,5,7,9 and 11 o'clock positions and at the ground surface above 12 o'clock position for one circumferential band around the PCCP as shown in Figure (4) left. The last reference electrode is used for comparing the value with the Closed Potential Interval Survey (CIPS) data. Three circumferential bands shall be applied to one PCCP, so that 21 reference cells (7x3x21) are furnished to the pipes.

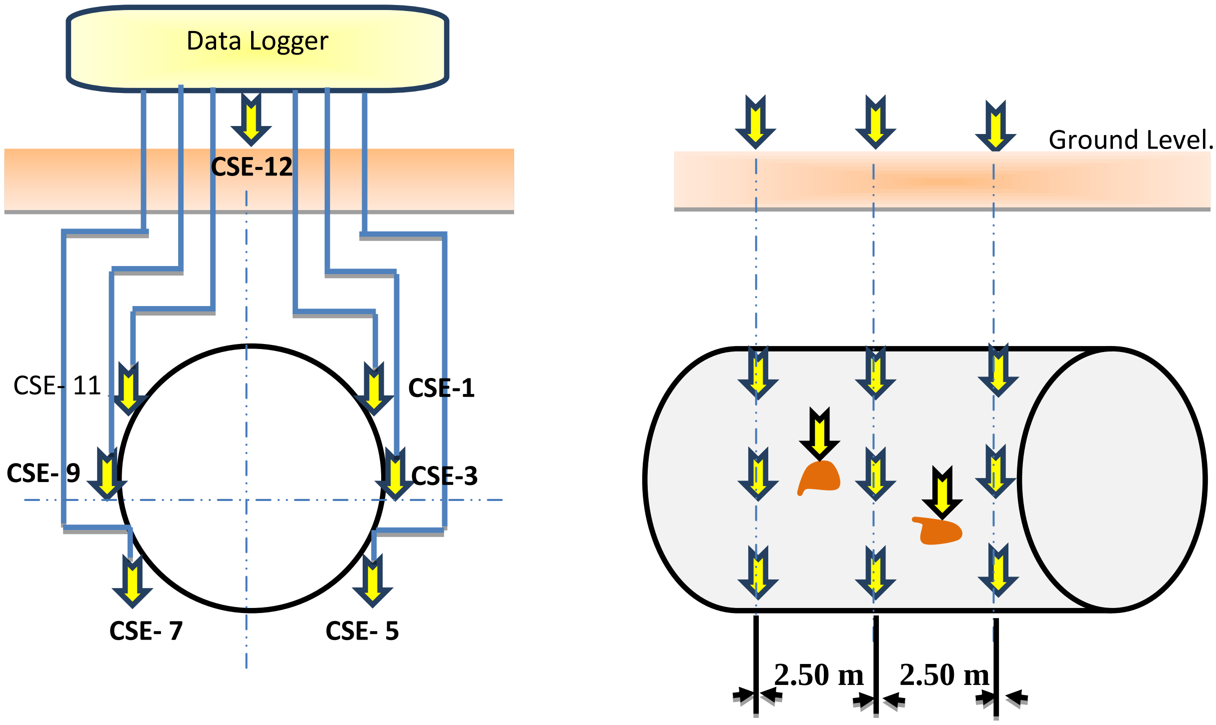

Figure (4) Copper/Copper Sulfate Reference Electrode (CSE) Arrangement

Further two additional CSE reference electrodes should be installed at the corroded areas. In total 78 pieces (21x3x12=78) of the CSE reference electrode are necessary for a coupon. The reference electrode would not be necessary to install inside the mortar coating due to negligible IR as comparing inside the mortar and in the soil near PCCP. The measured potential data shall be recorded in a data logger interrogator through lead wires. Potential measurement at every second shall be possible to collect the decay/development and instant-off potential.

(4) Closed potential survey (CIPS) is one of the common conventional methods that are available to corrosion engineers to collect the formation potential of PCCP. The CIPS technique would apply to the coupon to compare the potential data measured by CIPS with data measured by the reference electrodes (CSE) probe.

Cathodic Protection System:

Protection method: Galvanic anode system

Sacrificial anode: Zinc ally anode

Design Protective current density: life25 years

Protection criteria: On soil resistivity greater than 1500 ohm-cm, the aim of cathodic protection is to obtain a potential shift (instant-off potential – minus natural potential) more negative than -250 mV with respect to a Copper/copper sulfate reference electrode. The protection criteria for pre-stressed concrete cylinder pipe (PCCP) shall be in accordance with most recent issued criteria by NACE No. RP0100-2000 which specifies a minimum of 100 mV polarization development/decay.

The same specification with actual PCCP conveyance pipeline shall be applied to the cathodic protection system for the real size coupon as follows: Installation of the cathodic protection system or each coupon including tests and inspection should also be carried out according to the same manner with the existing installation for the actual PCCP conveyance pipes as shown in Figure (5) below.

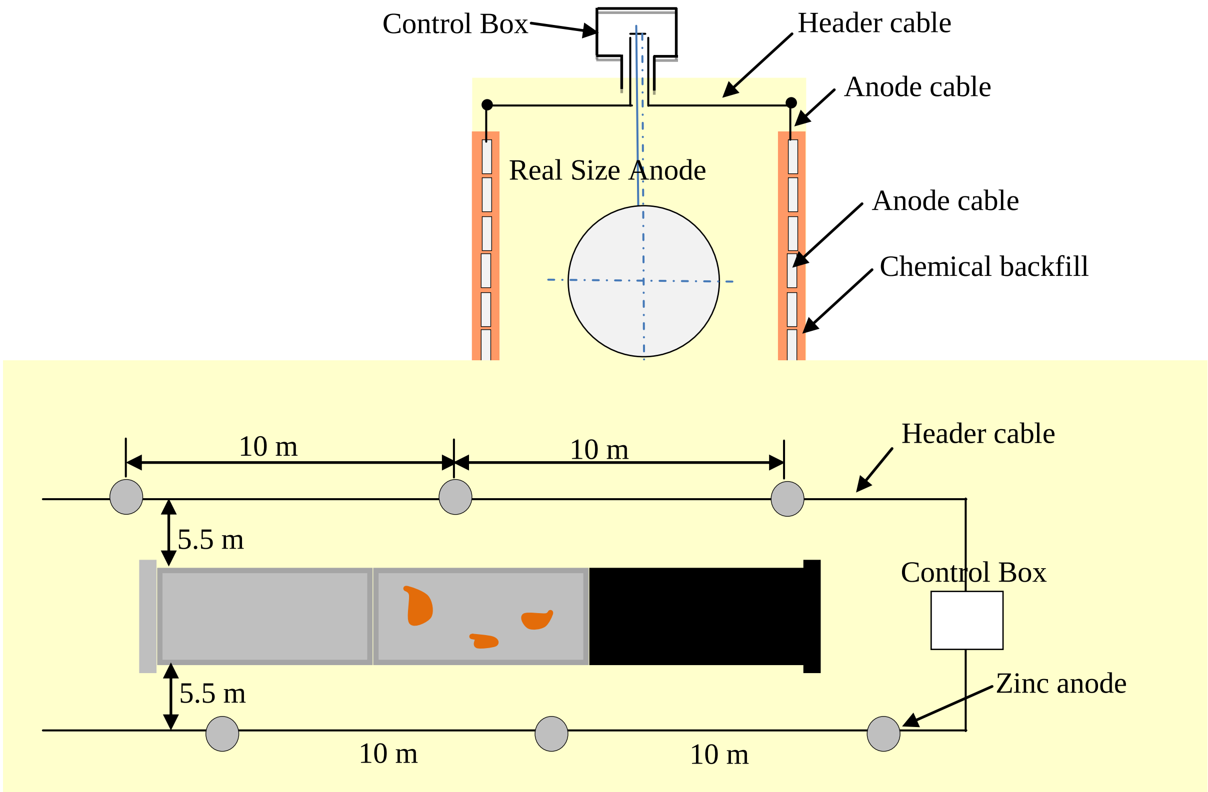

Figure (5) Typical Anode Installation Layout

Monitoring Procedure:

1) Purposes of Monitoring:

- Measurement of the natural potential at each predetermined location
- Measurement of potential shifts before and after CP installation.
- Measurement of polarization decay and development for CP performance.

- Effectiveness and adequacy of the Present CP in various soil resistivities.
- Comparison between the CIPS and fixed potential measurement by CSE) reference electrode installed around the coupon.
- Effect of various soil resistivities on the effectiveness of CP and usefulness of potential survey.
- Potential distribution patterns on the circumferential of PCCP pipe.
- Verification of design current density used at various soil resistivities.
- The minimum required potential shift to achieve full protection on corroded steel (confirmation of the criteria mentioned in NACE standard).

2) Measurement Prior to Installation of CP:

The following measurement shall be conducted prior to installation CP system:

- Soil resistivity measurement prior to excavation on the top of the proposed location.
- Corrosion conditions of the PCCP pipes by portable rebar corrosion meter.
- Soil resistivity measurement after the excavation and during the backfilling.
- Chemical and physical analysis during the excavation and backfilling.
- Pipe to soil potential measurement during the backfilling.
- Soil reistivity after completion of backfilling using Resistivity sensors.

After the backfilling, each coupon PCCP shall be monitored periodically under the absence of CP for sixteen (16) weeks to establish the sound basic information (base line) of the pipe-to soil potential data. After the said monitoring period is finished, all the PCCP coupons shall be carefully re-excavated, inspected thoroughly.

3) Measurement During Installation of CP:

- Resistivity measurement of chemical backfilling material for the anode
- Open potential measurement of the individual zinc anode.
- Cable continuity test.

4) Measurement After Installation of CP:

Following measurement shall be made after installation and commissioning of CP by means of remote monitoring system.

- Soil resistivity measurement at all locations and depth surrounding the coupons.
- Pipe-to soil potential using the permanent reference electrodes and CIPS.
- Ground bed current measurement.
- On/off potential measurement.
- Measurement of depolarization criteria

Confirming Adequacy of Cathodic Protection:

Using 100 mV Development/Decay Criteria:

The effectiveness of CP prestressed concrete structure is best conducted using 100 mV shit criterion, as using the -850 mV criterion has serious disadvantages, since the voltage drop by application of CP current is not necessary contribute to corrosion control. In addition the -850 mV criterion may give a total change in potential including IR drop. Figure (7) shows a typical potential change when cathodic protection is applied to PCCP pipe.

When the CP current is applied at point "A“ where the natural potential was about -50 mV vs Cu/CuO_4reference electrode potential of the specimen increases in negative direction to point "B". This change (shift) is caused by IR drop which contribute nothing to CP system. As the CP current increases in the negative direction from point "B" To "C" this final shit at "C" is called the polarization potential (True Potential). If we measure the potential while the CP system "ON" using Cu/CuO_4reference electrode the measured potential will include the IR drop, which will result in misinterpretation of the protection criteria. In this work the depolarization criteria shall be conducted using a reference electrodes (Cu/CuO_4) buried close to PCCP pipe plus the reference electrode positioned near corroded area. The polarization is measured by interrupting the CP current and watching polarization decay from the time immediately after removing the current (instant -off value) and for a period of four hours later. Potential reading taken one second after the potential spike is usually considered the true polarized P/S potential (IR free potential) and is used as a base reading from which to measure potential decay. Using this permanent will give clear indication of whether the entire surface area of the pipe has been protected satisfactory or under protection.

Once the potential depolarization is completed a total of 40 decaying graphs similar to the one shown in Figure **(7)** should be achieved to represent protection levels around the entire circumferences of each tested pipes. Similar measurement shall be conducted at each test sites to show the cathodic protection behavior and effectiveness for all soil reistivity ranges.

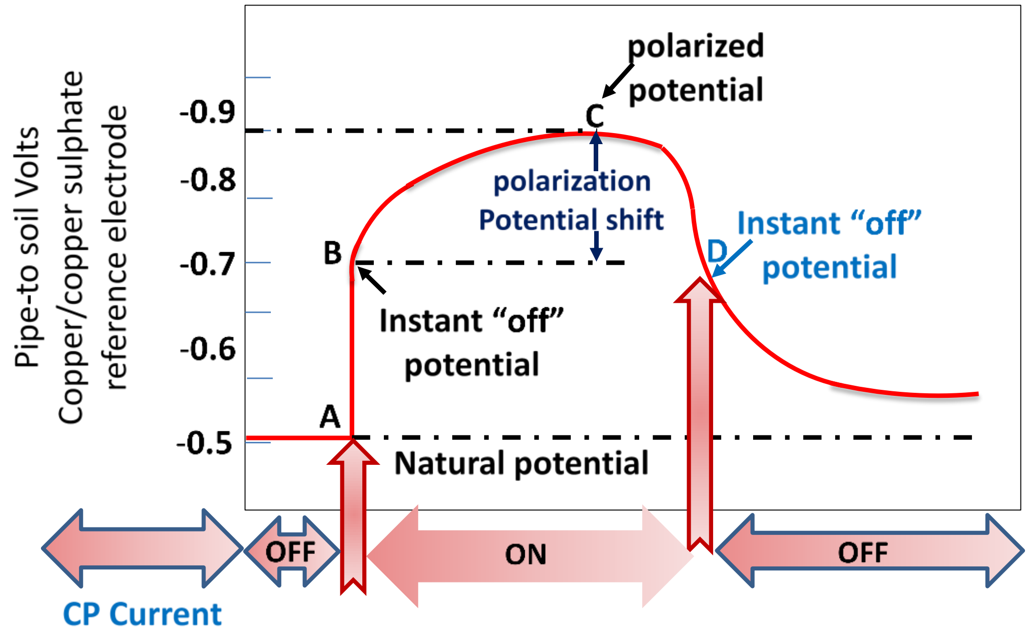

Figure (7) Potential shift at specimen

Guaging Adequacy of Cathodic Protection:

Using Inductive Scan Imaging Techniques:

The main purpose of cathodic protection is to keep the lines safe, reliable and viable for their design life. A sacrificial zinc anode cathodic protection system was installed, both to prevent corrosion and to minimize embrittlement damage to the prestressed wires. In this paper we shall introduce Inductive Scan Imaging (ISI) technique to confirm the adequacy of galvanic anodes CP system. This technique is new to market, and can successfully image both bars and prestressed wires at the external surface of the PCCP pipes. It can obtain qualitative information with regards to the presence of surface corrosion at various degree of severity Figure (6) photos "B" and "C" depict the resulting images at low and high respectively of a bar shown in (Figure 6 photo "A"). This technique may be new alternative to all indirect criteria (Such as the 100 mV Criteria). It can be conducted to confirm the adequacy of the protected coupon system for confirming the effectiveness of CP system in concrete structure.

The ISI technique can be used to inspect the external surface of the tested PCCP samples to obtain the following information successfully:

- Verify results obtained by other techniques related wire break.
- Locate the size extent of both wire breaks and corrosion.
- Estimate the remaining life of the pipes.
- Exactly determine the surface condition of inner wrap ends of PCCP pipes.
- Gauge the performance and effectiveness of CP.

Data To Be Collected To Monitor Cp:

The data for monitoring cathodic protection on PCCP coupon to be transmitted to the data control center is tabulated in Table (2).

Table (2) List of Data

Particulate	Specification of Signal (Q'ty)	Transmission frequency	Measurement Duration	Remarks
Soil resistivity (ohm-cm	36 channels/coupon	3 times/day(*)	124 months	Before and after CP energizing
P/S potential (mV) without CP	65 channels/coupon	3 times/day(*)	4 months	Before CP energizing
P/S potential (mV) with CP	65 channels/coupon	3 times/day(*)	120 months (10 years)	after CP energizing
Protection Current (mA)	1 channels/coupon	3 times/day(*)	120 months (10 years)	after CP energizing
On/off potential (mV)	65 channels/coupon	1 times/second	48 hours	Once a month after CP energizing
On/off condition of switch	1channels/coupon	3 times/day(*)	120 months (10 years)	after CP energizing

(*) Day time, night time and morning time (Highest temp., lowest temp. and higher humidity

Data shown in Table (2) will be monitored and transmitted to the data control center of Libyan water authority by remote monitoring equipment.

Conclusions:

Prestressed Concrete Cylinder Pipe (PCCP) is used all over the world to distribute circulating, cooling and service water. In recent years a number of catastrophic failures have occurred throughout North America, North Africa (LIBYA), china and Canada. These failures are of concern for owners and operators of these pipelines because of the consequent interruption in service, property damage and repair cost. The general inaccessibility of the pipe and prestressing wire makes evaluation difficult, costly and often inconclusive. Random examination of prestressing wires by excavating or internal inspection of the pipe wall gives only a much localized knowledge of the prestressing wire condition. Other technique such as eddy current and acoustic system is limited to wire break, it can neither identify corrosion active sites nor determine it severity and/or location around the circumferential of the PCCP pipes. In addition inspection techniques is give only a "snapshot" of corrosion conditions at a specific point in time. It is concluded that no single monitoring or inspection technique can provide comprehensive information on corrosion conditions or effectiveness of cathodic protection over time (through time, as a function of time). Using Real Size Coupons and utilizing various measurement and inspection techniques, instrumentation, rules and regulations, standards, logistical support, data analysis, communication and information management allow corrosion engineers to conduct a real-time monitoring, which can be helpful in understanding "where, when and why" corrosion damage takes place and hence allow to obtain effective corrosion control.

Acknowledgement: The authors would like to express his deepest thanks and gratitude to the Japan Bank or International Cooperation for financing this work and for their kind and unlimited support

References:

1- Abdullah, A.A., M.E. Reafat, and M.E. Khalifa. 2003. Rehabilitation Management of PreStressed Concrete Cylinder Pipe Using Remote Field Current/Transformer Coupling (RFEC/TC) and Other Technologies. In *Proceedings of the ASCE International Pipelines Conference 2003: New Pipeline Technologies, Security, and Safety*. Reston, VA: ASCE.

2- Almughery, A, P. Gaydcki, M. Zaid, B. Fernandes, G. Miller, F. Elmadaani, H. Hussin, and O.B. Wojuola. 2005. Inductive Scan Imaging Technique in Detecting and Visualizing Corrosion for Large Scale Pre-Stressed Concrete Cylinder Pipes. In *Proceedings of the ASCE International Pipelines Conference 2005: Optimizing Pipeline Design, Operations, and Maintenance in Today's Economy*. Reston, VA: ASCE.

3- Amaitik, N. M., and S.M. Amaitik. 2008. Development of PCCP Wire Breaks Prediction Model Using Artificial Neural Networks. In *Proceedings of the ASCE International Pipelines Conference 2008: Pipeline Asset Management: Maximizing Performance of Our Pipeline Infrastructure*. Reston, VA: ASCE.

4- Atherton, D.L., K. Morton, and B.J. Mergelas. 2000. *Detecting Breaks In Prestressing Pipe Wire*. Jour. AWWA, 92(7): 50-56.

5- Bambei, J.H., Jr. and R.A. Lewis. 2005. Correlation of Wire Breaks on Prestressed Concrete Cylinder Pipe with Predictions from Electromagnetic Testing. In *Proceedings of the ASCE International*

Pipelines Conference 2005: Optimizing Pipeline Design, Operations, and Maintenance in Today's Economy. Reston, VA: ASCE.

6- Compton, K.G. 1981. Corrosion of Buried Pipes and Cables, Techniques of Study, Survey, and Mitigation. In *Underground Corrosion*, ASTM STP 741, Edward Escalante, Ed., American Society for Testing and Materials, pp. 141-155.

7- NACE No, RPO100-2000.