IDENTIFICATION OF COATING DEFECT WITH THE HELP OF CLOSE INTERVAL POTENTIAL LOGGING (CIPL) & DIRECT VOLTAGE GRADIENT (DCVG) SURVEYS TO UNDERTAKE REPAIRS

By

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May, 2008

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A thesis submitted in partial fulfillment of the requirement for the Degree of

Master of Technology

(Pipeline Engineering)

By

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CERTIFICATE

This is to certify that the work contained in this thesis titled "IDENTIFICATION OF COATING DEFECTS WITH THE HELP OF CLOSE INTERVAL POTENTIAL LOGGING (CIPL) & DIRECT CURRENT VOLTAGE GRADIENT (DCVG) SURVEYS TO UNDERTAKE REPAIRS" has been carried out by **Sachin Kumar Verma** under my supervision and has not been submitted elsewhere for a degree.

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ABSTRACT

Corrosion is being a hot issue in a pipeline industry. Every year this industry bears a huge amount of loss of money due to the corrosion. The pipeline industry is the biggest investors in the world. Adopting the fully corrosion control methods can save a high amount of money by reducing the property loss in accidents, by reducing the cost of repairs, by reducing the level of risk of catastrophic failure with the loss of property and life both. Implementation of Best practices of corrosion control methods in pipeline sector can save billions of dollars in long run.

There is a need to adopting new and improved inspection technique with regular interval of pipeline to increase the lifetime of the nation's pipeline, ensuring safe and cost effective transport of valuable energy sources. Pipeline coating is the broad answer with respect to corrosion crisis, so now coating inspection becomes a big issue to handle in industry like GAIL, IOCL etc.

'Finding Defect with the help of Close Interval Potential logging (CIPL) & Direct Current Gradient Voltage (DCVG) Surveys' are one of those inspection techniques which assess the effectiveness of pipeline coating. This helps to know about the present status of coating, locating the defects, types of defects, reasons of failure and the refurbishment of those defects. In this project, I participated in the ongoing pipeline coating integrity study of GREP pipeline (GAIL rehabilitation and expansion project). I was associated with the survey agency for collecting the field data generated during inspection with the help of CIPL and DCVG survey.

On the basis of the data collected during the survey and its analysis ascertain the exact location of defect and it's severity whether it is sever, moderate, major or minor. Thereafter in order to verify the accuracy of results it was required to carry out dig verification at select locations and carry out refurbishment of those coating defects according to the severity of defect and requirement to improve the overall coating performance. During the period I was associated with the project both the CIPL and DCVG survey for about 200kms of pipeline section under Agra region has been completed and data analysis carried out to find out the exact location and nature/ size of defects. Coating repairs at these locations has been started and completed for a few locations and being planned for balance locations. All action are being planned and taken up for implementation of suitable corrective measures at GAIL (India) Ltd. based on the recommendations.

The project has helped me to develop the basic understanding of the various types of coatings used for underground pipelines, their long terms performance, various kind of coating defects and its reasons, how to find out these defects and carry out coating repairs/ refurbishment to improve the overall performance of the pipeline coating system.

Acknowledgement

I am greatly indebted to my guides **Mr. R. P. Shriwas,** Course Co-ordinator, **UPES**, and **Mr. Ayush Gupta,** senior manager (Pipeline), *GAIL India* Ltd., Agra, for providing me an opportunity to work under their guidance. Their unflinching support, suggestions and directions have helped in smooth progress of the project work. They have been a constant source of inspiration in all possible ways for successful completion of my project work.

I acknowledge my sincere gratitude to **Mr. R. P. Shriwas,** Course Co-ordinator, **UPES**, and **Mr. Ayush Gupta,** Senior manager, *GAIL India* Ltd., for having me provided all the facilities to complete this dissertation work successfully.

I also acknowledge my sincere gratitude to employees of the pipeline department in GAIL India, Agra especially **Mr.Shushant Gautam** Dy. Manger (Pipeline) and **Mr. Gaurav Jain** Dy. Manager (Mechanical) for their support and cooperation throughout my project work.

I also acknowledge the help rendered by **HR Dept** of GAIL India especially **Mr. R.K Bhilwariya** and all other non-teaching staff of the **Department of Pipeline Engineering, UPES and Mr B.P Pandey, Dean (College of Engineering).**

Finally, I would like to thank my family for their constant support. It would have been impossible for me to accomplish this study without their support.

SACHIN VERMA

CHAPTER 1

Introduction

GAIL – An Overview

GAIL (India) Ltd. operates over 4400 Km of pipelines in all the four regions of the country, supplying about 62 million cubic meter (MMSCM) of gas per day as fuel to power plants, as feedstock for gas based fertilizer plants and other industrial units to meet their energy and process equipments. The backbone of the natural gas pipeline network is the 1900 km long HBJ pipeline. Further, GAIL is now operating the world's longest exclusive LPG pipeline from Jamnagar to Loni with a total length of 1240 kms.

GAIL today has reached new milestones with its strategic diversification into Petrochemicals, Telecom and Liquid Hydrocarbons besides gas infrastructure. The company has also extended its presence in Power, Liquified Natural Gas re-gasification, City Gas Distribution and Exploration & Production through equity and joint ventures participations. Incorporating the new-found energy into its corporate identity, Gas Authority of India was renamed GAIL (India) Limited on November 22, 2002.

The Company operates six natural gas processing plants with an installed capacity to produce a total of 9, 61,000 tones of Liquefied Petroleum Gas per year. Four of the Company's natural gas processing plants are located along the HBJ Pipeline - two at Bijaipur in Madhya Pradesh and one each at Vaghodia in Gujarat and Pata (Auraiya) in Uttar Pradesh. The other two natural gas processing plants are located at USAR near Mumbai in Maharashtra and Lakwa in Assam.

Every year new pipelines are being added to the existing infrastructure and from an era of cross country pipelines, we are entering into an era of cross border or inter continental pipelines. With the pipelines getting older, the maintenance and rehabilitation costs are increasing along with the business stakes of the various oil and natural gas companies. When the pipelines get older, maintenance and rehabilitation is the solution to enhance the availability and the reliable life of the system. However, to ensure profit maximization no company can afford high operation and maintenance costs too. What is required to keep a control over the mounting costs on maintenance and rehabilitation is not just the use of good quality material and workmanship at the time of pipeline construction but more importantly a regular and routine health check up of the system.

PURPOSE

The Basic purpose of this project is to find the information and guidance on the operation and maintenance of coating system which has been applied at GREP Pipeline of GAIL (India) Ltd. Maintenance of these systems is critical to the reduction of corrosion on exterior surfaces of buried utility pipeline. Those responsible for maintaining these systems have an important job in preserving the integrity of the various structures, enhancing safety of base personnel, and preventing the release of substances which are detrimental to the environment. The information and guidance in this report should be reviewed as the first step towards achieving the performance and effective operation of coating systems.

During my stay with GAIL (India) Ltd., I was associated with the work on system study of GAIL's GREP project along with "Identification of Coating Defects with the help of CIPL and DCVG surveys" which focused on to identify the coating defects, main causes under present working condition, their remedies and come out with the best possible option to enhance the coating performance.

CHAPTER 2

LITERATURE REVIEW

2.1 What is corrosion?

Thermodynamic reasons cause metals obtained from minerals in nature in their normal use to have a tendency to return to the combined state. The phenomenon leading to the progressive deterioration of metallic properties is known as corrosion. Corrosion is nearly always of an electrochemical nature, that is, an electrical current that circulates between determined zones of the metal surface, known as anodes and cathodes, through a solution called electrolyte, able to conduct such current. This conjunction consists of micro and macro piles in which the anodic zones suffer the effects of corrosion.

When atoms of the anode dissolve to form ions, the electrons that are freed make the anode negative with respect to the solution. It's electrons pass to the cathode through the metallic mass and neutralize the positive ions. Therefore, corrosion is supported by simultaneous anodic and cathodic processes.

Anodic reactions:

$$\underset{\text{(metal)}}{Me} \rightarrow \underset{\text{(metallic ions)}}{Me^{++}} + \underset{\text{(electrons)}}{e^-} \quad \textbf{corrosion}$$

Cathodic reactions:

$$2H^+ + 2e^- \rightarrow H_2$$

$$2H^+ + O_2 + 2e^- \rightarrow 2OH^-$$

$$2H_2O + O_2 + 4e^- \rightarrow 4OH^-$$

This corrosion of an electrochemical type, characteristic of submerged or buried structures, is highly dangerous, not for the metal loss in itself, but because it deals with localized corrosion, which could be the origins of deep punctures. This definition encompasses all materials, both naturally occurring and man-made and includes plastics, ceramics, and metals. Here we focus on the corrosion of metals, with emphasis on corrosion of carbon and low-alloy steels used in underground pipelines.

There are certain conditions which must be met before a corrosion cell can function. These are:

1) There must be an anode and a cathode.
2) There must be an electrical potential between the anode and cathode. (This potential can result from a variety of conditions on pipeline).

3) There must be a metallic path electrically connecting the anode and cathode. (Normally, this will be the pipeline itself).
4) The anode and cathode must be immersed in an electrically conductive electrolyte which is ionized-----meaning that some of the water molecules (H_2O) are broken down into positively charged hydrogen ions (H^+) and negatively charged hydroxyl ions (OH^-)

Once these conditions are met, electric current will flow and metals will be consumed at the anode.

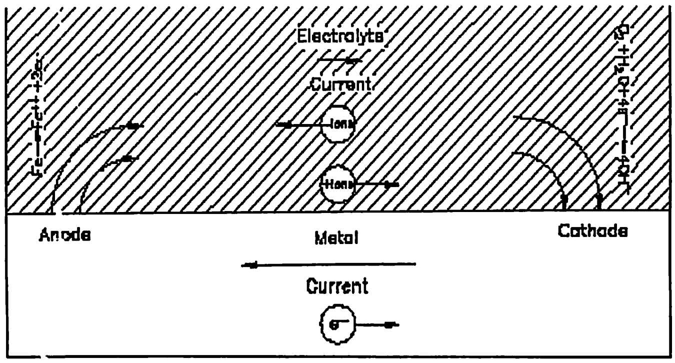

Figure 2.1 Schematic showing a differential corrosion cell

Underground corrosion of pipelines and other structures is often the result of differential corrosion cells of which a variety of different types exist. These include differential aeration cells, where different parts of a pipe are exposed to different oxygen concentrations in the soil, and cells created by differences in the nature of the pipe surface or the soil chemistry. Galvanic corrosion is a form of differential cell corrosion in which two different metals are electrically coupled and exposed in a corrosive environment.

2.2 Cost of Corrosion – Study Goals

- Determine the cost of corrosion control methods and services
- Determine the cost of corrosion for specific industry sectors
- Extrapolate individual sector costs to a national total corrosion cost
- Assess barriers to progress and effective implementation
- Develop strategies for realizing cost savings

In spite of having the total cost estimation of corrosion in various sectors, now our main concern deals with the cost of corrosion in gas and petroleum sectors.

CORROSION COST STUDY of GAS and LIQUID TRANSMISSION PIPELINES

Corrosion is the primary factor affecting the longevity and reliability of pipelines that transport crucial energy sources throughout the nation. There are more than 528,000 km (328,000miles) of natural gas transmission and gathering pipelines, 119,000 km (74,000 miles) of crude transmission and gathering pipelines, and 132,000km (82,000 miles) of hazardous liquid transmission pipelines. The average annual corrosion-related cost is estimated at $7 billion to monitor, replace, and maintain these assets. The corrosion-related cost of operation and maintenance makes up 80% of this cost.

Previous Studies

- 1950 H.H. Uhlig – US Study: 2.1% of GNP
- 1970 T.P. Hoar – UK Study: 3.5% of GNP
- 1974 Japan Study: 1.2% of GNP
- 1975 Battelle/NBS – U.S. Study: 4.5% of GNP
-

Typical Corrosion Related Costs: Gas & Liquid Transmission Pipelines

- Annual ICCP System Investment - $40 Million
- Annual Sacrificial CP Investment - $9 Million
- Annual O&M Costs - $2.4 Billion - $4.8 Billion

Total Cost of Corrosion

Estimated Cost	B$	138
Extrapolated Cost	B$	236
Actual Cost	>B$	550

2.3 NEED TO CORROSION CONTROL

Corrosion affects our society on a daily basis, causing degradation and damage to household appliances, automobiles, airplanes, highway bridges, energy production and distribution systems, and much more. The cost of controlling this naturally occurring phenomenon—and costs associated with the damage it causes—is substantial.

Public safety concerns have driven new regulations and corrosion control practices for gas and liquid transmission pipelines over the past few years, following a number of high-profile pipeline failures. Data management, system quantification through the use of global positioning systems,

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

remote monitoring, and electronic equipment documents have significantly improved several areas of pipeline corrosion maintenance.

The newest developments center on risk assessment strategies and pipeline integrity management programs. The study has determined that major cost savings can be realized by developing an optimum approach that includes both pipeline inspection and corrosion prevention strategies.

Inspection strategies should include in-line inspection, hydrostatic testing, and direct assessment—all currently available methodologies—depending on the pipeline conditions. By developing new and improved inspection techniques and corrosion prediction models, corrosion professionals will be able to determine inspection intervals more accurately, prioritize the most effective corrosion-prevention strategies, and ultimately, increase the lifetime of the nation's pipelines, ensuring safe and cost-effective transport of valuable energy sources.

Corrosion is so prevalent and takes so many forms that its occurrence and associated costs cannot be eliminated completely. Annual corrosion cost could be saved if optimum corrosion management practices were employed.

The bottom line is that the use of appropriate corrosion prevention and control methods protects public safety, prevents damage to property and the environment, and saves billions of dollars in the ASIA and worldwide.

2.4 Preventive Strategies

- Increase awareness of the large corrosion costs and potential savings.
- Change the misconception that nothing can be done about corrosion.
- Change policies, regulations, standards, and management practices to increase corrosion savings.
- Improve education and training of staff.
- Advance design practices for better corrosion management
- Advance life prediction and performance assessment methods
- Advance corrosion technology through research, development, and implementation

Application of cathodic protection should be evaluated on the basis of technical feasibility, economic analysis, and system functional requirements such as reliability and consequence of failure.

2.5 Corrosion in pipelines

The pipeline industry is confronted with a wide range of corrosion problems. External surfaces of pipelines in contact with soil, waters, or an atmospheric environment, and the interior surfaces of pipelines which are in contact with a potentially corrosive material being carried by the pipeline, are subject to most of the basic corrosion processes and most of the forms of corrosion attack.

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All new pipelines which are to carry hazardous gases or liquids must be coated and cathodically protected in order to comply with minimum Federal Safety Standards. This applies as well to existing pipelines (except that if existing pipelines are bare, they need not be excavated and coated). Where cathodic protection is to be applied in areas, where the pipeline to be protected is getting sufficient cathodic protection current to the pipeline in question can become rather acute. Whereas pipelines in open country (particularly if well coated) can be protected with cathodic protection installation is seldom effective in highly congested areas. In these areas, it is usually necessary to install distributed anode systems for either impressed current systems or galvanic anode networks. These complicated systems involve careful maintenance and testing to make certain that current from any anode is not interfering with (and causing possible damage) metallic structures adjacent to the pipeline being protected.

2.6 CORROSION CONTROL METHODS

The principal methods for mitigating corrosion on underground pipelines are coatings and Cathodic Protection. Coating is the primary method to protect the structure from external or internal corrosion. It offers protection to the surface where it is applied. However, the points where are defects created in the coating remain venerable to the attack of corrosion. For such defects CP acts as an active means of protection and thus supplements the coating.

2.6.1 COATING

Coating is the process of using an external/internal agent on the parent metal to protect it from the surrounding environment and increase the life of metal. Pipe that carries oil and gas is generally buried or exposed to external environment that may ultimately lead to corrosion, metal loss, or third-party damage. First attempt to control pipeline corrosion is the use of coating materials, with the reasoning that if the pipeline metal could be isolated from contact with the surrounding earth, no corrosion could occur. Further, a coating would be completely effective as a means to stopping corrosion if:

1. The coating material is an effective electrical insulator.
2. It can be applied with no breaks and remain so during the backfilling process.
3. It is an initially perfect film that remains so with time.

Although coatings by themselves may not be the perfect answer to corrosion control, but a properly selected and applied coating will provide all the protection necessary on most of the pipeline surface to which it is applied. Protective coatings control corrosion by providing a barrier against oxygen and water. Its effectiveness is directly related to the oxygen and water permeability coefficients. It has been calculated that an extremely small concentration of oxygen and water can start the corrosion process. Therefore, to minimize corrosion, materials those have

extremely low permeability have to be used in the formulation.
Pipelines have been coated with a variety of protective coatings with a wide performance. Whenever an existing pipeline within a system is exposed, the industry's practice is to examine the coating system and report on problem areas and record the overall condition of the pipeline system.

The most popular corrosion resistant pipeline coatings in the world are three-layer polyethylene or three-layer polypropylene, each of which offers superior resistance to damage during construction and long term corrosion protection while in service. These coatings are applied in factories under well controlled conditions with constant quality control monitoring. Field-applied coatings, however, are applied under demanding conditions and the products need to be engineered for application in some very severe climates. These highlight the need for proper specification of products which are truly compatible with the mainline coating, and proper application in the field. Product specification, qualification, installation training, applied quality and ongoing inspection are cornerstones to ensuring long term performance of field applied coatings.

2.6.2 CATHODIC PROTECTION

"Cathodic Protection" is defined as **"a reduction of the corrosion rate by shifting the potential of the structure toward a less oxidizing potential by applying an external current."** Cathodic Protection (CP) is the most useful means of corrosion control.

Basic Theory of Cathodic Protection

The basic concept of cathodic protection is that the electrical potential of the subject metal is reduced below its corrosion potential, and that it will then be incapable of going into solution, or corroding. This mechanism has been defined by many scientists and has become established beyond dispute. Indeed the principles of corrosion reactions are used in the design and construction of expendable and re-chargeable batteries and accumulators which play such a major part in modern life. A battery that is 'dead' has no energy left and does not corrode any further. Likewise a car battery on charge does not corrode, in fact in this case the reaction is reversible, and energy is 'pumped back in'. However, a battery has a very carefully composed electrolyte which has qualities to ensure a predictable reaction with the other components of the battery. We know that the corrosion within a battery can be controlled very accurately, by external electrical input, as this technique is in common use with rechargeable batteries which are nowadays controlled by computers which balance the reaction equilibrium to suit their own power demands.

CP is a technique to reduce the corrosion rate of a metal surface by making it the cathode of an electrochemical cell.

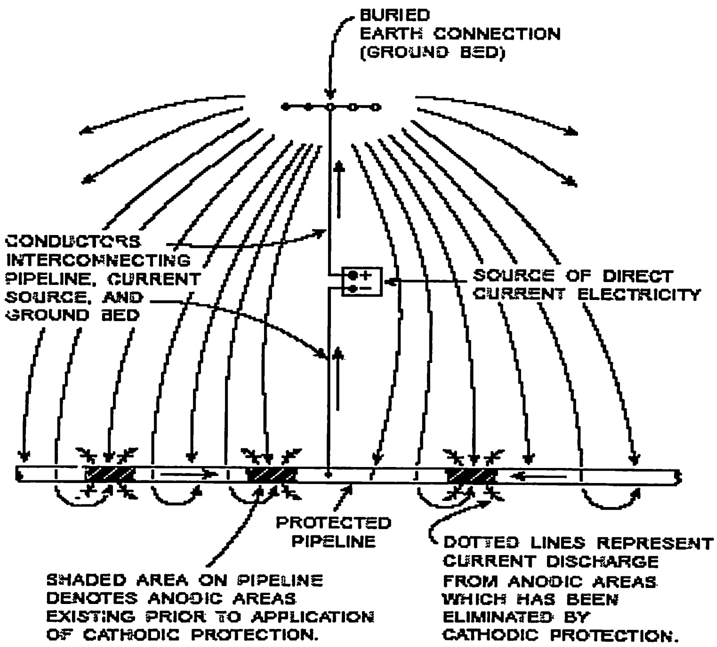

Figure 1.1

In each case of corrosion, anodic areas and cathodic areas are present on the pipe surface. At the anodic areas, current flows from the pipeline steel into the surrounding electrolyte (soil or water) and the pipeline corrodes. At the cathodic areas, current flows from the electrolyte onto the pipe surface and the rate of corrosion is reduced. In light of the above fact, it becomes obvious that the rate of corrosion could be reduced if every bit of exposed metal on the surface of the pipeline could be made to collect current.

This is exactly what CP does. Direct current is forced onto all surfaces of the pipeline. This direct current shifts the potential of the pipeline in the active (negative) direction, resulting in reduction in the corrosion rate of the metal. When the amount of current flowing is adjusted properly, it will overpower the corrosion current discharging from the anodic areas on the pipeline, and there will be a net current flow onto the pipe surface at these points. The entire surface then will be a cathode and the corrosion rate will be reduced.

Pipelines can be regarded as many interface reactions connected together in parallel. The metal element can be well defined, as this is specified to a high degree by the designers, as is the coating material.

However, it is accepted that no coating can be perfect, and the faults or 'Holidays' introduce the first indefinable variable to the system. During the construction of a pipeline all possible measures are taken to detect and repair coating faults, so it follows that those remaining are undefined. It is possible to calculate the theoretical resistance of a perfectly coated pipeline, given the specification of the coating and dimensions of the pipeline, but it is impossible to calculate the actual resistance of the total pipeline

The electrical current measurements, taken during routine cathodic protection monitoring, show that there is little resistance in the total coating (with faults) of a pipeline and this can be explained by the difficulty in quality control, during the construction period.

Undetected coating faults are the path of cathodic protection current and a perfect coating would prevent any output from the CP system. We therefore, know that there are many unspecified 'metal to electrolyte' interfaces present on an average pipeline. The electrical resistance of the pipeline metal itself can be calculated, and is found to be very low. In fact the effect that the pipeline resistance has on the complex current paths and variation in potentials is so small that it can almost be ignored. The complication is due to each interface being capable of a different reaction, electro- motive-force (EMF) which cannot be measured as it is in parallel with all other EMF's on the same section of pipeline.

The magnitude of the current from each of these reactions is dependent on the earth resistance immediately adjacent to the interface, and the direction of all the resulting currents is the result of the combined effects of all the resistances and electrical pressures caused by all the EMF's.

Although it is simple to understand each corrosion cell and the mechanism of corrosion itself, the reality of applying the science, to the field, becomes immensely complex. This becomes more obvious when the circuit has been subject to computer modeling.

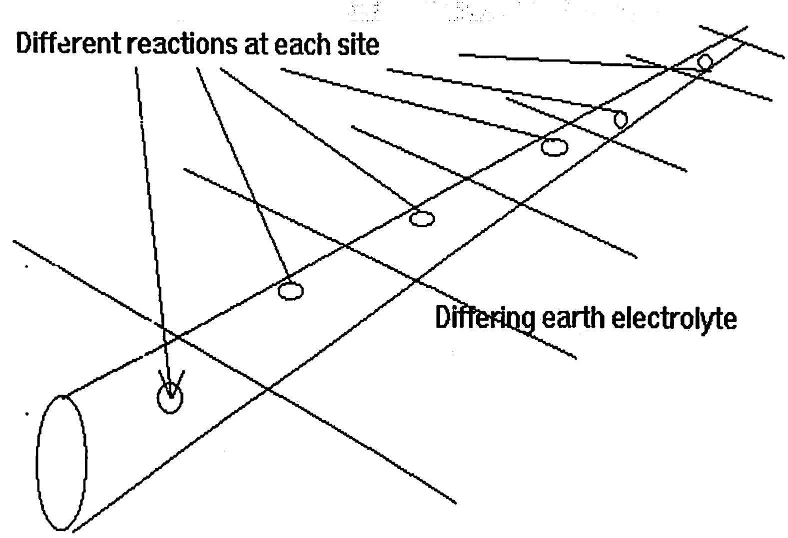

Figure 1.2

To be effective, cathodic protection must reduce the metal at each single interface, to below its corrosion potential. This is not too difficult to achieve, as each interface is part of the same metal structure, which has a very low electrical resistance. The difficulty is, knowing when all the interfaces have been reduced to below their corrosion potential in relation to the electrolyte in their reaction vicinity. (If we knew where each interface was we would repair them all!!!!).

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

2.7 WHY COATING...

..................IF CATHODIC PROTECTION IS PRESENT?

Corrosion occurs as the result of a voltage differential between two components of a system. An anode and a cathode must be present. If a complex structure of materials that are near each other in the galvanic series, then there is reduced likelihood of potential differences. Construction using materials that are not close in the galvanic series, such as steel and copper, can create a corrosion cell.

Because coating defects are unavoidable and can thus permit corrosion, pipeline surface protection is not complete with coatings alone; supplementary cathodic protection is necessary. Cathodic protection on the coated pipe is needed only on the minute areas of steel exposed to the earth at holidays rather than the whole surface of an uncoated structure. The electrical energy required to cathodically protect a bare structure may be thousands of times as great as the energy required to protect the same structure when it is well coated.

Cathodic protection can be applied by two methods: Impressed current cathodic protection and galvanic cathodic protection. Both system functions by causing flow from an anode to the pipeline. Inspite of these properties cathodic protection stands apart when compared to its application with the coating. Cathodic Protection system is in the pipeline to protect the facility from corrosion; but at the same time it does not help to reduce metal loss, erosion, etc. CP system in itself is not 100% efficient in removing corrosion. It needs continuous observation to run effectively because the soil resistivity changes from time to time. The operating cost of the cathodic protection system is also high. This is a disadvantage.

Coating material is an effective, one time investment, basically, for the end joints of the pipeline. It is available in all sizes and shapes depending on the requirement of the project.

If there is no coating and protection is given only by CP, then current requirement will be too high and it will directly affect the pipeline economy system.

2.8 Coating-CP interaction

External corrosion control on steel pipelines is achieved by the combined use of a protective coating and cathodic protection. The coating provides the first, and major, defense against corrosion and the cathodic protection serves to prevent pitting or general corrosion where the pipe steel is exposed by damage to the coating. Some degree of coating damage is to be expected on all pipelines, for example due to external interference, so this combined approach to corrosion control is essential.

Ineffective Cathodic Protection

Ineffective cathodic protection can be caused by the accelerated degradation of a coating such that the total cathodic protection current demand for full protection cannot be met. However, inaccurate monitoring of pipe to soil potentials is a common cause of under protection. Common examples include a failure to correct for the voltage drop error inherent in 'ON' potential measurements and lack of close interval survey data between fixed test points. Intelligent pig inspection data provides information on the size, depth and location of corrosion defects in a pipeline and the deepest pit depth is commonly recorded in small features. Polarization of exposed pipe steel may vary with defect size because the current distribution will be influenced by the local resistance of the soil – coating interface.

Common causes for loss of protection due to excess cathodic protection current demand include:

- Accelerated breakdown of thermoplastic coatings due to high temperature operation above the softening point of the coating.
- Progressive failure of field applied tape due to inadequate overlap and loss of adhesion to the mill applied pipe coating.

2.9 COATING AND THEIR CHARACTERIATICS

The development of the oil and gas industry has provided great challenges and needs for new for new and innovative coating technologies to address many unique applications, such as cold climates and deep water environments. The main factor affecting the fitness for purpose of a coating is the risk of failure and the modes of failure when the pipeline is in service. Here we discuss the coating selection- fitness for purpose with respect to the construction and operating conditions, coating application- essential controls to ensure fitness for purpose, and operation-coating failure modes and integrity threats to the pipeline. Each of these issues is comprised of two main components- technical and cost. Every decision made on a pipeline, whether driven by cost or technical considerations will have an impact on the long term integrity of the pipeline. Risk assessment provides a basis for assessing the long term impact of these decisions.

Coatings are applied on pipelines both externally as well as internally. For external coatings the main aim is to isolate the pipe from the surrounding earth to avoid any corrosion. Internal coatings are usually applied in sour system where level of hydrogen sulphide, moisture and temperature are high.

2.9.1 What should a coating do?

An ideal coating will stop pipeline corrosion. The minimum requirement is that a coating should stop corrosion for the design life of the pipeline but a more realistic objective is that the coating should stop corrosion for as long as the pipeline remains in service. Most pipelines are operated well beyond the original design life.

Inevitably coatings get damaged by external forces or by a number of long term degradation processes that affect the constituents of the coating. Typically this result in coating defects that expose the pipe steel to the environment around the pipeline and this corrosion risk can be controlled by cathodic protection. Many coatings also show a loss of adhesion such that water or soil penetrates between the pipe and the coating. Ideally this failure mode should not create new corrosion threats to the pipeline but in many cases it does.

For operating pipelines the key coating issues can be resolved into three questions.

- How is the coating performing?
- How does the coating impact on monitoring and maintenance costs?
- When will a coating degrade to the point at which it is no longer sustainable?

2.9.2 Properties of COATING

- ★ The coating material should be an effective electrical insulator.
- ★ It can be applied with no breaks and should remain so during backfilling.
- ★ It constitutes initially perfect film which will remain so with time.

2.9.3 What a pipeline engineer should know about coatings

Proper selection of coating

- A wrong selection of coating can cause a loss of millions of rupees.
- A proper selection will make corrosion control relatively easier.

One of the most serious problems that one usually encounters during coating process is the small defect in the coated film. These are called holidays, the main reasons for this are:

- Skips by coating machine.
- Pinholes in the coating film applied.

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

- Cracks from excessive mechanical or thermal stresses.
- Scraps or gauges caused during subsequent handling of the coated pipe.
- Penetration by rocks, clods or debris in the backfill surrounding the pipe.
- Distorting stresses exerted on the coating by certain soils having a very high shrinkage rate upon drying.
- Penetration by growing roots.
- Action of solvents in the earth surrounding pipeline- such as leaks from pipelines.
- Action of bacteria in the soil surrounding the pipeline.
- Damages from subsequent construction on other facilities making it necessary to uncover the pipeline.

Some of these damages can be prevented by:

- By following rigid application specifications.
- Care in placing backfilling.
- Painstaking inspection procedures.

2.9.4 Why pinholes are dangerous?

Corrosion is an electrochemical process. Extent of corrosion depends upon anode to cathode areas. A pinhole in a coated pipeline exactly simulates large cathode and small anode which result in excessive dissolution and hence catastrophic failure of pipe.

Sometimes even after taking a lot of care, holidays cannot be avoided. What are the solutions in such cases?

Combination of **coating** with an alternative method such as **cathodic protection.**

Actually both these controls methods are complimentary to each other. While CP takes care of continuous damage of coating with time, CP on bare pipeline consumes heavy current and hence more power. Coated pipelines reduce the current and hence make CP relatively cheaper.

Thus selection of a coating system in combination with CP must have:

- ★ A high electrical resistance after the pipeline has been installed and the backfilled stabilized.
- ★ The least reduction in electrical with time.

2.10 Specifications for coating must include:

- ★ Cleaning the pipe surface.
- ★ Priming if required.

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- ★ The coating material to be used and in case of one or more material, order in which the application has to be made, total thickness with permissible tolerances. Special specifications such as temperature (in case of hot enables), tension (for wrapper and tapes).
- ★ Handling requirements for coating materials such as storage provisions and maintenance of dry and clean conditions.
- ★ Inspection requirements.
- ★ Procedure for repair of coating defects.
- ★ Basis of rejection of unacceptable coating.
- ★ Requirements for handling and transportation of coated pipes.
- ★ Details of coated filed joints when factory coated pipe are used.
- ★ Backfilling requirements.

2.10.1 Some final points for coating selection

- The coating selected for a specific application ideally be that which will have the lowest applied coast per foot of pipeline and still have desired characteristics of good electrical and mechanical resistance and long term stability. Here are some factors which must be considered:
- Soil must be either free of rock or other matter which can mechanically damages the coating or selection of coating must be of high mechanical strength at the outer surface.
- Whether the problem of soil stress exists.
- Can the coating be used for all parts of installation such as river crossing, swampland, submarine location etc.
- The temperature of operation of pipeline.
- If coating application is over ditch,, what are the ambient temperature, humidity over installation period.
- Requirements of CCP and current requirement.
- Each coating system considered should be evaluated carefully and all performances characteristics be determined.

2.10.2 Properties of coating material

A coating material must have the following properties:

1. **Low permeability to oxygen:** Protective coatings control corrosion by providing a barrier against oxygen and water. Its effectiveness is directly related to the oxygen and water permeability coefficients. An extremely small concentration of water and oxygen can start the corrosion process. Therefore, to minimize corrosion, materials that has extremely low permeability have to be used in the formulation.

2. **Good adhesion to pipe surface:** A powder coating's ability to be in intimate contact with the metal surface is known as the wetting property. This is the most important factor that affects the success of powder coating. The adhesion property of the powder coating is integral to the coating's corrosion prevention capabilities. The adhesive strength is the sum of several components. The major portion comes from three components: mechanical polar and chemical. Mechanical adhesion is the dripping force of the coating onto the substrate (pipe surface). Polar adhesion is the force of attraction between the positive and negative poles of the coating and the substrate. Chemical adhesion is the force needed to remove the coating molecules that have chemically reacted with the metal substrate.
3. **Adequate temperature stability:** A proper temperature is good for the coating to keep healthy for a longer time. At the time of application, the temperature range at the surface of the pipe to be coated shall be determined in agreement with the manufacturer of the product. The temperature of the pipe shall be monitored using suitable means in order to make sure that the application conditions are fully satisfied. Temperature variations can cause contraction and expansion of the pipe surface under the coating.
4. **Ease of application:** Pipeline structures and miles of pipelines offer challenging conditions for coating applications. It is important that the coating be as easy as possible to apply, but it must meet the criteria and requirements of the specific application. This will help ensure that the application is done correctly. If application is difficult to accomplish, welds, bends, fittings, or even the lengths of pipe may suffer coating flaws that will invite corrosion attack.
5. **Flexibility to strain:** This is one of the most important mechanical properties of pipeline coating. It affects the construction activities expense, time and installed coating integrity. Flexibility to strain is the measure of the powder coating's ability to resist mechanical damage when stretched. This property is critical because it will decide the field bending limits of the coated pipe.
6. **Resistance to bio-degradation:** A coating should resist to biological changes around its vicinity so that it can work effectively for a longer period of time as given by the manufacturer.
7. **Resistance to cathodic disbondment:** It is defined as the ability of the coating to resist disbondment and delamination when it is subjected to electrical stress in a highly conductive electrolyte. Normally, coatings will lose adhesion and disband from the pipe surface when it is subjected to excessive current densities. Therefore, the powder coating's ability to resist disbondment when it is subjected to extensive current through voltage fluctuations is crucial.
8. **Easy to repair:** A coating should be easy to repair when the need arises
9. **Non-toxic, environment friendly:** It should be strictly environment friendly and should not cause any kind of toxic effect in the surrounding areas.
10. **Mechanical resistance:** Mechanical resistance includes the following: impact resistance, abrasion resistance, and gouge resistance. Resistance to water is probably one of the most important properties of an effective coating because water strongly affects almost all materials. Resistance to soil stress is particularly important for buried pipe. As soil contracts and expands due to pull and push at the coating surface, pulling it away from the pipe and causing cracks, voids, and thin spots. Resistance to dirt, bacteria, fungi is

important in many areas because these bacteria and fungi can settle in dirt deposits and actually attack the coating. Weather resistance is necessary for above-ground pipeline structures. Weather conditions that must be protected against include sunlight, hail, rain, snow, dew, freezing, and thawing.

11. **Ease of application:** Pipeline structure and miles of pipelines offer challenging conditions for coating applications. It is important that the coating be easy as possible to apply, but it must meet criteria and requirements of the specific application. This will help ensure that the application is done correctly. If application is difficult to accomplish, welds, bends, fittings, or even the lengths of pipe may suffer coating flaws that will invite corrosion attack.
12. **Insolubility in hydrocarbon.**
13. **Good electrical insulation.**
14. **Retention of form under soil pressures.**

If any of the above mentioned properties, fail to exist then the coating may fail and the results may be catastrophic.

2.11 Selection of coating material

The effectiveness of a coating is dependent not only on its characteristics but also on using proper application procedures and protecting the coating during and after installation. Besides having a range of properties, selection of coating material depends on the following points:

- Handling and safety characteristics
- Shop/field application and repair attributes.
- Surface preparation requirements.
- Physical performance requirements.
- Cost analysis.

If the coatings are compatible, almost any type of coating can be used on field joints or repaired sections. Proper coating application includes preparation, application, and protection.

Ensuring that the pipe is properly prepared for coating application is extremely important. The pipe surface must be free of all moisture, dirt, scale, rust, and debris. If it is not, the coating will not adhere and will not be effective. Each type of field coating has specific surface preparation requirements that must be followed. For all coatings, the surface must be clean and dry. Often this is accomplished with power tools, but in some cases, abrasive blasting and solvents are required. In the mills or the field, brushes and buffers may be used. Some coatings require a primer on the prepared surface prior to the application of the coating. Primer application must be done in accordance with the manufacturer's specifications and must be allowed to dry to the specified consistency before the outer coating is applied. The coating and wrapping must be done in accordance with manufacturer's specifications.

2.12 General procedure for coating

Specific coatings have specific application requirements and procedures. Coatings may be applied hot or cold depending on the type of coating. The common field coatings in use today are liquid epoxies, heat shrink sleeves, and various types of tape. All coatings should be applied in accordance with the manufacturer's requirements.

Because the ends of pipe to be welded are left uncoated, they must be coated in the field after welding. The same applies to parts of the pipe from which coating has been removed for repairs. The factors that pose a hazard to the coating include:

a) Moisture content of the soil.
b) Contamination of the soil.
c) Soils that vary greatly from wet to dry.
d) Extreme temperature variations.

These factors must be addressed when selecting the types of coating to use. A particular set procedure is followed while applying coating of any type. These points are explained as under:

Surface Preparation- This involves removal of both visible and non-visible contaminants such as dirt, oil, grease and other soluble contaminants. Poor surface preparation always results in poor bonding strength of the coating to the pipe. Using abrasive blast cleaning as a method of large surface preparation, abrasive media such as slag, sand or steel grit (G-40 or coarser) is recommended. Sand blast cleaning is the least expensive method of all field surface preparation. Surface preparation demands removal of all burrs, slag (iron oxide), and scruff so that the surface is flat and smooth to reduce the number of particles and thus the holidays that result due to these foreign elements. The sand is blasted on the surface at a pressure range of 5-6 kg/cm^2. Once filled, the hopper can be used for 10-12 joints in succession. The thickness of sand blasted layer has to be between 60-70 microns (for coal tar enamel coating). The cleanliness thus achieved is assessed as NACE grades.

Codes for surface preparation for various purposes are stated here under:

- All steel pipe exterior surfaces have been recommended to achieve at least an SSPC-SP 6/NACE No. 327
- Blast finish for coal-tar enamels, asphalt coatings, tape coatings, or an SSPC-SP 10/NACE No. 2
- Liquid or powder coatings such as fusion-bonded epoxy, liquid epoxy, and polyurethane require white finish.
- Interior lining application, an SSPC-SP 10/NACE No. 2

Pre-heating- Pre-heating is done in order to remove moisture, water and ice provided it is done in a uniform manner. Pre-heating is done in a temperature range of 60-80 degree Celsius. The temperature of the pre-heated surface is measured using a digital thermometer (also called as digital temperature meter) whose measuring range is 50-150 degree Celsius. It is after done sand blasting to check the surface hardness.

Application of primer-adhesive mixture- Primer (PART-A) and adhesive (PART-B) are mixed in a ratio of 3:1 respectively. This mixture is then applied on the pre-heated surface with the help of applicator and gently distributed over the surface. The primer contains **phenol/formaldehyde/glycidyl/**and other polymers. The adhesive constitutes of the following: **trimethylhexane, 1, 6-diamine**. Primer thickness has to be 90-100 microns. Corrosion inhibitors are added in primer to provide extra safety against rust etc. There are of two types of corrosion inhibitors: (a) inhibitors that alter the chemistry of the process stream, and (b) inhibitors that form passive films or enhance naturally occurring passivating films on the pipe surface. Chemical deaeration (removal of dissolved oxygen) is an example of inhibition by modifying the chemistry of the process stream.

Induction heating- It is a process where an electrically conducting work piece is placed in a copper coil through which an alternating current flows. Pipe resistance to the current flow; generate heat without radiating heat and combustion.

Application of the coating sleeve- The sleeve is wrapped around the circumference of the weld joint, heated and then pressed with rollers all over until it sticks properly and no room for air is left out. For the NSPL Project, Covalence Raychem make, coal tar enamel sheets are used. These sheets are **high tensile low pre-heat** sheets. Maximum time to apply coating after sand blasting is within one hour.

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

2.13 Different types of coating in pipeline:

Pipe Coating	Desirable characteristics	Limitations
Coal tar enamels	• 80 + Years of use • Minimum holiday susceptibility • Low current requirements • Good resistance to cathodic disbondment • Good adhesion to steel	• Limited manufacturers • Limited applicators • Health and air quality concerns • Change in allowable reinforcements
Mill-applied tape system	• 30 + years of use • Minimum holiday susceptibility • Ease of application • Good adhesion to steel • Low energy required for application	• Handling restrictions—shipping and installation • UV and thermal blistering— storage potential • Shielding CP from soil • Stress disbondment
Crosshead-extruded polyolefin with asphalt/butyl adhesive	• 40 + years of use • Minimum holiday susceptibility • Low current requirements • Ease of application • Non polluting • Low energy required for application	• Minimum adhesion to steel • Limited storage (except with carbon black) • Tendency for tear to propagate along pipe length

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

Dual-side-extruded polyolefin with butyl adhesive	• 25 years of use • Minimum holiday susceptibility • Low current requirements • Excellent resistance to cathodic disbondment • Good adhesion to steel • Ease of application • Nonpolluting • Low energy required for application	• Difficult to remove coating • Limited applicators
Fusion-bonded	• 35 + years of use • Low current requirements • Excellent resistance to cathodic disbondment • Excellent adhesion to steel • Excellent resistance to hydrocarbons	• Exacting application parameters • High application temperature • Subject to steel pipe • surface imperfections • Lower impact and abrasion resistance • High moisture absorption

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

Multi-layer epoxy/ extruded polyolefin systems	• Lowest current requirements • Highest resistance to cathodic disbondment • Excellent resistance to hydrocarbons • High impact and abrasion resistance	• Limited applicators • Exacting application parameters • Higher initial cost • Possible shielding of CP current

Table: 2.1 Different types of coating

2.14 PROPERTIES OF VARIOUS COATING

NAME	MIN.Recommended Operating Temp.	MAX.Recommended Operating Temp
Three layer polyethylene coating	-40°C (-40°F)	85°C (185°F)
Fusion bonded epoxy powder coating (FBE)	-40°C	85°C
Three layer polypropylene coating	-40°C (-40°F)	110°C (230°F)
Asphalt enamel coating	-40°C	90°C
Poly chloroprene (Neoprene rubber coating)	-40°C	95°C
High Performance Composite Coating (HPCC)	-40°C (-40°F)	85°C (185°F)
Polyurethane coating	-20°C	70°C

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

Table 2.2: for properties of coating

2.15 Coating Economics:

Here we already emphasized that the most favorable coating system for any given pipeline is the most stable of those available—that is, the coating system with electrical and mechanical characteristics that will deteriorate at the slowest rate with time under the specific installation conditions. Such a coating used with a CP system will be the most economical combination.

Even the most stable pipeline coating system selected will suffer some deterioration with time. Designing and constructing the initial CP system with sufficient reserve capacity to allow for the expected increased current requirements from anticipated coating degradation will result in overall cost savings.

This saving tends to be greater in the case of rectifier installations where the cost of providing additional current output capacity can be substantially less than in the case of galvanic anode installations.

The direct cost of the installations will be a function of the electrical resistivity of the coating used. An excellent stable coating properly applied should have a high electrical resistance. Current requirements should be so low that the cost of providing additional capacity will be minimal. On the other hand, a coating initially having a substantially lower electrical resistivity will require correspondingly greater investments for CP and the additional cost for reserve capacity becomes much more significant.

A – Asphalt/ Coal tar : 1940 to 1970	
Advantage:	Disadvantage:
• Easy to apply • Soil stress has been an issue • Limitation at low application temperatures • Environment and exposure concerns	• Subject to oxidation and cracking • Soil stress has been an issue • Limitation at low application temperatures • Environment and exposure concerns • Association with corrosion and stress crack corrosion failure
B – Tape wrap (Two layer): 1960 to Present	
Advantage:	Disadvantage:
• Simple Application	• Poor shear strength resistance. • Many documented failures related to corrosion and stress crack corrosion • Shielded of cathodic protection • Adhesives subject to biodegradation
C – Two layer extruded polyethylene: 1960 to Present	
Advantage:	Disadvantage:
• Excellent track record • Good handling	• Limited temperature range • Poor shear stress resistance • Limited pipe size (< 24in.[610mm] outside diameter)

D – Fusion-bonded epoxy: 1975 to Present	
Advantage: • Excellent adhesion and corrosion resistance • Does not shield cathodic protection	Disadvantage: • Low impact resistance • High moisture absorption and permeation
E – Three-layer polytefin: 1975 to Present	
Advantage: • Excellent combination of properties	Disadvantage: • Best suited for electrical resistance welded pipes • High thickness to eliminate weld tenting
F – Composite Coating: 1990 to Present	
Advantage: • Excellent combination properties	Disadvantage: • Suitable only for large diameter pipes and is not designed for small diameter pipes (<406mm OD) • Conforms well to external raised weld profiles

Table: 2.3 Advantage and Disadvantage of main coating types used for pipeline protection

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

2.16 ASTM Test Standards for Pipeline Coating:

ASTM Standard	Test Description
G6-88(1998)	Standard Test Method for Abrasion Resistance of Pipeline Coatings
G7-05	Standard Practice for Atmospheric Environmental Exposure Testing of Nonmetallic Materials
G8-96(2003)	Standard Test Methods for Cathodic Disbonding of Pipeline Coatings
	Standard Test Method for Water Penetration into Pipeline Coatings
G9-87(1998)	Standard Test Method for Specific Bendability of Pipeline Coatings
G10-83(2002)	Standard Test Method for Effects of Outdoor Weathering on Pipeline Coatings
G11-04	Standard Test Method for Nondestructive Measurement of Film thickness of Pipeline Coatings on Steel
G12-83(1998)	Standard Test Method for Impact Resistance of Pipeline Coatings (Falling Weight Test)
G14-04	Standard Test Method for Penetration Resistance of Pipeline Coatings (Blunt Rod)
	Standard Test Method for Joints, Fittings, and Patches in Coated Pipelines
G17-88(1998)	Standard Test Method for Disbonding Characteristics of Pipeline Coatings by Direct Soil Burial
G18-88(1998)	Standard Test Method for Chemical Resistance of Pipeline Coatings
G19-04	Standard Test Method for Cathodic Disbonding of Pipeline Coatings Subjected to Elevated Temperatures

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

	Standard Test Method for Evaluating Pipeline Coating Patch Materials
G20-88(2002)	
	Standard Test Methods for Holiday Detection in Pipeline Coatings
G42-96(2003)	Standard Test Method for Ring Bendability of Pipeline Coatings (Squeeze Test)
	Standard Test Method for Specific Cathodic Disbonding of Pipeline Coatings
G55-88(1998)	
	Standard Test Method for Jaw Crusher Gouging Abrasion Test
G62-87(1998) e1	Standard Practice for Modified Salt Spray (Fog) Testing
G70-81(1998)	Standard Practice for Performing Accelerated Outdoor Weathering of Nonmetallic Materials Using Concentrated Natural Sunlight
G80-88(1998)	Standard Test Method for Cathodic Disbondment Test of Pipeline Coatings (Attached Cell Method) Coating Qualification Test Panel Series
G81-97a(2002) e1	
G85-02e1	
G90-98	
G95-87(1998)e1	

Table 2.4: ASTM Test Standard for Coating Inspection

2.17 List of Tests performed for Coating Examination.

Abrasion	
Abrasion Test: Taber abrasimeter method	ASTM D-4060and ASTM D-1044
Abrasion resistance of pipeline coating	ASTM G-6
Rubber property: Durometer Hardness	ASTM D-2240
Rockwell Hardness of Plastics and Electrical Insulating materials.	ASTM D-785

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

Penetration Resistance of Pipeline Coatings (Blunt Rod).	ASTM G-17
Corrosion	
Salt spray test	ASTM B-117
Cathodic Disbonding (water)	ASTM G-8
Cathodic Disbonding (soil)	ASTM G-19
Electrical	
Breakdown voltage, dielectric strength.	ASTM D-149
D C Resistance, Volume resistivity.	ASTM D-257
Flexibility	
Deflection temperature under flexural load.	ASTM D-648
Tensile strength	ASTM D-638
Tensile properties of thin plastic sheeting.	ASTM D-882
Flexural properties of Plastics.	ASTM D-790 and electrical insulating material.
Flexibility cylindrical mandrel bend test	ASTM D-1737
Flexibility conical mandrel bend test.	ASTM D-553
Mandrel bend test attached organic coating.	ASTM D-522
Hardness	
Rockwell Hardness	ASTM D-785
Durometer Hardness	ASTM D-2240
Persoz pendulum hardness	
Buchloz indentation hardness	
Compressive properties of rigid Plastics.	ASTM D-695
Penetration resistance of pipeline coating	ASTM G-17
Hardness test	ASTM D-3363
Impact	
Impact resistance	ASTM G-13
Impact resistance of pipeline coating.	ASTM G-14
Impact resistance (rapid deformation).	ASTM D-2794
Pendulum type hammer impact test.	ASTM D-256
Tensile impact energy to break plastics.	ASTM D-1822
Miscellaneous	
Evaluation of level of blisters	ASTM D-714
Flame resistance.	ASTM D-635
Chemical resistance test	ASTM D-1308

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

Physical	
Melting temperature	ASTM D-789
Density and Specific gravity.	ASTM D-792
Particle size (Sieve analysis)	ASTM D-1921
Water absorption of plastics	ASTM D-570
High humidity.	ASTM D-2247
Immersion in water	ASTM D-870
Film thickness	ASTM D-1186
Adhesion test.	ASTM D-4541
Cross cut tape adhesion test.	ASTM D-3359
Apparent shear strength.	ASTM D-1002
Shear strength of plastics by punch tool.	ASTM D-732
Slant shear test	ASTM C-882
Weathering	
Accelerated weather meter	ASTM D-2565
KTA Envirotest	ASTM D-2246
Atmospheric weathering	ASTM G-7
Spectroscopic analysis of coatings	ASTM E-932
Gloss	ASTM D-523
Color visual	
Colorimetry	

Table 2.5: test performed on pipeline coating

2.18 Pipeline Coating Failure and Inspection

Coating problems may be flaws that occur if the coating is not applied correctly, improper coating is used, or the pipe is not prepared properly. Flaws can also be the result of not using the correct coating for the job. Coating damages may occur during application or installation or after the pipeline is put into service. While coating quality levels are continuously improving, there are many process steps where defects can be introduced. It's important to remember that coating defects can have a variety of causes that many defects that appear different can have similar origins, such as spots and wetting defects, and that, conversely, many defects that seem to be similar can have different causes, such as chatter and bubbles. This is why it is advantageous to use a systematic approach for identifying and defining the problem, determining its cause, eliminating the problem, and preventing its recurrence. Despite careful selection and control during coating applications, failures can and do happen. Failures may occur as a result of many factors including:

- Application defects
- Surface preparation
- Service environment (chemistry, temperature, pressure)

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

- Physical stresses
- Coating selection
- Material defects

There are only two basic causes of problems or defects in a coater: either something in the process has changed, or an underlying physical principle is being violated. Of these the former is the most typical cause of the defect. Therefore, the goal of the troubleshooting procedure is to determine what has changed and correct it. This will result in eliminating the defect and determining the underlying cause. The following six steps comprise the troubleshooting process:

1. Detect the defect, or recognize the problem
2. Define the defect or problem
3. Collect and analyze data
4. Identify potential causes
5. Eliminate the problem
6. Document the results

Detect the defect: When a defect is first detected or a need determined on the coater, the first step is to get agreement that there is a problem, and that it needs to be solved. Also, the location of the detected problem, and the part of the coating process causing it, may be far apart. The problem and its cause must not be treated as one step. Resources and responsibility must be assigned to take the next step.

Define the defect: After detection, representative samples of the defect must be obtained, ideally from a variety of locations within the coated roll. Large, clearly labeled samples including web-ark orientation are helpful for this purpose. One useful technique is to stop the coater, dry the suspect coating in place, and mark key locations on the web. If the defect is detected at a customer's plant, and our facility is no longer running the same product, obtain customer samples from the same lot in the distribution system if possible.

Naming is typically the next step in the process, and is an obvious starting point. It is also one of the first areas where troubleshooting can go astray. Initially giving the defect a descriptive name implies both a cause and a specific course of action, neither one of which may be appropriate. It can even shift the focus from the true cause of the defect and result in an ineffective troubleshooting process. The last task in this step is to formulate an agreed-to written problem statement. It should be clear, unambiguous, and state the problem and the anticipated result.

Collect and analyze data: One requirement for problem solving is to obtain the necessary information about the problem. It is helpful to formulate a series of questions that need answering, involving all functions and using creative brainstorming if appropriate. Many sources of information are at our disposal:

- historical quantitative and qualitative data
- new measurements
- anecdotal evidence
- quality-control testing

Identify potential causes: When all the data have been assembled and analyzed, you should be able to arrive at a hypothesis on the mechanism of the problem. While a number of analysis techniques can be used, the Kepner-Tregoe method is excellent for this purpose. This technique asks us to characterize what the specific problem is, and what it is not and to arrive at the distinctive difference between the two (see box). This method then leads to a number of questions that propose a specific cause. Typically, a few potential causes are identified. Therefore statistically designed experiments should be run in a lab pilot line to identify the correct cause. Computer simulations, if appropriate, can speed up analysis. One major tactical error that is often made is to make one good coating with all of the identified changes at once and then resume production. This will mask the true cause of the defect and make future troubleshooting more difficult. It is far better to evaluate the changes and use only those which can eliminate the defect.

Eliminate the problem: When the preferred solution has proven itself in the pilot line, it must be demonstrated and reproduced in the plant manufacturing facility. Again statistical experiments should be used initially to prove the solution and obtain reliable data on the effect of the variable being studied. Ensure that enough data has been obtained to prove out the solution. This may take a couple of iterations. Often the first experiments yield partial success or raise more questions, which needs to be answered. We may need to return to the previous step to obtain additional data and repeat this step.

Document results: Often overlooked, the documentation of troubleshooting process and its results is an essential part of the project. Prepare progress reports and summaries as the work is evolving.

2.19 Common coating failures

Coating failures can vary widely depending on conditions. Some common pipeline coating failures may include:

- Disbonding
- Incorrect thickness
- Wrinkles
- Foreign inclusions
- Incompatibility
- Holiday

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

2.19.1 Disbonding

A common type of coating failure is the disbonding or separation, of the coating from the pipe. Disbonding is lack of adhesion. The cause for lack of adhesion depends on the type of adhesion. The problem can usually be traced to improper application or selection of the coating or poor handling and preparation procedures. In some cases, however, the pressure differential created by a voltage imbalance between the pipe and the soil electrolyte can build to the point that water is actually forced to migrate through the coating and onto the surface of the pipe. Disbonding of the coating and the beginning of a corrosion cell is the usual result of this process.

2.19.2 Incorrect thickness

When liquid coating is applied too thinly, there may not be enough material left on the surface to effectively coat it. Coating that is too thin can give rise to pinpoint corrosion. The pinpoints will gradually become larger until the entire are is undercut in the thinnest spots. When liquid coating is applied too thickly, runs and sags in the coating can result. Thick coating may not dry properly; the surface dries much more quickly than the underlying body of the coating, and there may be an excessive retention of solvent. Retained solvents can cause blistering and poor adhesion. Internal shrinkage caused by excessive thickness can result in checks, cracks, and scaling, which leads to undercutting.

2.19.3 Wrinkles

If a liquid coating is applied too thickly, the surface and body of the coating will dry at different rates and cause wrinkles. Wrinkles can also occur when excess surface driers are used. This problem occurs most frequently with oil-based coatings. Temperature can be a major factor in wrinkling. A higher curing temperature causes the surface to dry more quickly, and cold weather application can cause a film to develop on the surface. Tape wrapping can also have wrinkles from incorrect application or from soil stress after the pipe is installed.

2.19.4 Foreign inclusions

Any foreign inclusions in the coating material form weak points in the coating integrity. Depending on the nature of the inclusion and the type of coating, the foreign matter can also degrade the coating itself. This will prevent proper adhesion and provide access to corrosive conditions.

2.19.5 Incompatibility

The coating selected for the application must be compatible with any existing coating. Mixing of different types of coating on one application can cause lack of adhesion at joints or negative effects of one material on the other. All components of the coating system must be compatible. For example, the tape wrapping must be compatible with the primer.

2.19.6 Holiday

An undesirable discontinuity or break in the anti-corrosion protection (coating) of the pipe. Electronic testing devices detect flaws in the protective coating of the pipeline and joints as the pipe is being laid. When detected, the breaks are manually coated.

2.20 Pipeline coating damages

Damage to the pipeline coating can occur as a result of handling or excavation procedures, environmental factors, or contact with other materials. Causes of pipeline coating damage may include:

- ***Soil stress*** - Moisture in the soil around the pipe can lead to soil stress in the coating. Soils that are alternately wet and dry can be abrasive against the coating surface and can stress it to the point of failure.
- ***Foreign chemicals*** – Foreign chemicals in the soil, such as hydrocarbons, can cause degradation of some coatings, particularly enamels.
- ***UV damage*** – When pipe is aboveground, ultra-violet light can be damaging to some coating surfaces.
- ***Rock damage*** – Rocks in the soil can damage the coating and the pipe. Rocks in the backfill can scrape, dent, or gouge the pipe coating when the ditch is filled. Rocks under the pipe can cause pipe bending or ruptures when the weight of the pipe and liquid presses down. Care is usually taken to remove rocks from the ditch and backfill material to avoid damage to the pipe and coating. Rock shields are also used to protect the pipe and coating from rock damage.
- ***Mechanical damage*** - Mechanical damage can be caused during excavation, handling, installation, storage, or transportation. This damage includes dents, scrapes, cuts, cracks, gouges, and tears.

2.21 Coating inspection

Premature failure of coatings can be avoided if proper techniques are used during the initial application. Coating must be inspected when it is applied and whenever the pipe is exposed during service to ensure that it is performing as it should. Coating is inspected visually and by machine. Visual coating inspections may be performed on aboveground pipe or on exposed buried pipe. Inspections must be documented on the proper company forms.

2.21.1 Aboveground Pipeline Coating Inspection

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

Visual inspection of aboveground pipeline coating requires that coating be checked for damage caused by exposure. The following steps should be taken care of while inspecting aboveground pipeline coating:

Step 1 Test the atmosphere for any hazardous gases to ensure that the area is safe for work.

Step 2 Ensure that the area is properly marked and required safety equipments is in place.

Step 3 Visually inspect the pipe for any signs of wetness or leaks.

Step 4 Inspect the soil below the pipe for any discoloration or other signs of contamination.

Step 5 Visually inspect the pipe for signs of pitting on the surface of the pipe.

Step 6 If present, determine the extent of any pitting and document the results.

Step 7 Visually inspect the pipe for signs of metal loss.

Step 8 If loss has occurred, use the appropriate instrument to measure the amount of loss, and document the results.

Step 9 Inspect the pipeline for general corrosion problems, including connections and welds.

Step10 Document any corrosion findings.

Step 11 Visually inspect the pipe for coating flaws or damage, and document any findings.

Step 12 Identify any areas of thin spots or holidays in the coating, and document any findings.

Step 13 If the coating is to be repaired or replaced; retrieve a sample of the coating and any by-products under it for analysis.

Step 14 Complete the appropriate inspection form per company procedures.

2.21.2 Exposed Buried Pipeline Coating Inspection

Buried pipeline coating is only inspected when it is exposed. Pipeline is not excavated for the purpose of inspection. The following steps should be inspected related to expose buried pipeline coating:

Step 1 Ensure that the areas of the pipeline system have been properly excavated without damage to the pipeline.

Step 2 Ensure that the atmosphere above and in the trench has been tested for hazardous gases.

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

Step 3 Ensure that the trench has been properly constructed and that safety procedures are in place.

Step 4 Visually inspect the pipe for any signs of soil discoloration, wetness, or fungus growth before cleaning the pipe.

Step 5 Take samples of any signs of contamination, and document findings.

Step 6 Visually inspect the pipe for any signs of wetness or leaks.

Step 7 Inspect the soil below the pipe for any discoloration or other signs of contamination.

Step 8 Inspect the pipeline, including connections and welds, for general external corrosion problems.

Step 9 Locate and identify any areas and signs of corrosion on the pipe, including pitting. Document any findings.

Step10 When corrosion is evident, measure the longitudinal axis of the corroded area(s) to determine the length of the corrosion.

Step 11 Note the location of the corroded area on the pipe, such as the top, bottom, or sides, and record all the information per company policy.

Step 12 Visually inspect the pipe for signs of pitting on the surface of the pipe. Determine the extent of any pitting. Using a pit depth gauge, measure the depth of the pits, and document the results.

Step 13 Visually inspect the pipe for signs of metal loss.

Step 14 If loss has occurred, use the appropriate instrument to measure the amount of loss, and document the results.

Step 15 Visually inspect the pipe for mechanical damage, such as dents, scrapes, scratches, and gouges. If found, determine the cause of the mechanical damage, document the extent of the damage, and notify those responsible for correcting damage.

Step 16 Determine the shape and depth of the physical/ mechanical damage in order to determine the method of repair.

Step 17 Determine the proximity of the dent in relationship to the seam and girth weld, measure the depth of the dent, and document any findings.

Step 18 Identify areas of the exposed pipe that have coating.

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

Step 19 Identify the type of existing coating. It is necessary to identify the correct type of coating on the pipe so that the proper selection can be made for repair to ensure compatibility, adhesion, mechanical integrity, and proper temperature range.

Step 20 Visually inspect the pipe for coating flaws, abnormalities, or damage, and document any findings. Recognizing any physical damage to the coating, such as peeling, cracking, bubbling, and disbondment, is necessary to make an accurate assessment of the coating damage.

Step 21 Identify any areas of thin spots or holidays in the coating, and document any findings.

Step 22 Remove all loose and disbonded coating. The removal of such coating enables the proper inspection and evaluation of the underlying pipe. The removal of the defective coating and subsequent surface preparation of the pipe surface ensures good adhesion of the repair coating to the pipe.

Step 23 If the coating is to be repaired or replaced; retrieve a sample of the coating and any by-products under it for analysis.

Step 24 Identify possible causes of the coating failure. Considering the geographic location of the failed coating, inspect the environment for clues and causes. Look for signs of poor surface preparation/ application, debris in the backfill, third-party encroachments, and the presence of foreign materials.

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

CHAPTER 3

THEORETICAL DEVELOPMENT

3.1 General

The management of pipelines presents challenges that are quite unique. Their long length, high value, high risk and often difficult access conditions, require continuous monitoring and an optimization of the maintenance interventions. The main concern for pipe-line owners comes from possible leakages that can have a severe impact on the environment and put the pipeline out of service for repair. Leakages can have different causes, including excessive deformations caused by earthquakes, landslides or collisions with ship anchors, corrosion, wear, material flaws or even intentional damaging.

3.2 Pipeline System Monitoring

The other tool used to validate the integrity of a pipeline is an intelligent pig survey. The intelligent pig survey measures any metal loss. The first intelligent pig survey may be done as part of the commissioning of the new pipeline. Metal loss on the pipeline is unlikely at this early stage of its life. The second intelligent pig survey is much more relevant; unfortunately, this normally occurs ~15 years later. In the meantime, corrosion may be active at the trenchless crossings and remains undetected. Corrosion rates vary but in some cases can be up to 1 mm wall thickness metal loss per year.

Maintenance Activity	Maintenance Schedule/Frequency	Requirement/Remarks
ROW Inspection	Annual	CSA Z 662: (2003) Sour gas(>10 moles H_2S/k-mole NG) required monthly/bimonthly. Sour condensate: bimonthly/weekly depending on class location.
	Monthly	Industry norm, B31 requires periodic/as required – leak and corrosion survey report kept while

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

Pipeline patrol/leak detection/corrosion (gas)		line in service.
	Bi weekly (liquids): LPG/NH_3 lines<1 week in common areas	ASME B 31.4 (1998)
Pipeline patrol (gas lines)	Class 1,2: Annual	ASME B 31.8 (1999)
	Class 3: 6 Months	
	Class 4: 3 Months	
CP Monitoring	Annual, not to exceed 15 months	ASME B 31.1 (1999)
CP: Pipe to Soil Potential and rectifier readings	Monthly, Soil survey once per year	Industry Norm
Internal corrosion Monitoring	< 6 Months	ASME B 31.4 (1998): if line internally coated, pigged, dehydrated/corrosion coupon used
Exposed pipe: External Monitoring	< 3 Years	ASME B 31.4 (1998)
Encroachment assessment	Periodic or annual	

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

Class location assessment (Gas line)	Annual	ASME B 31.8 (1999)
Valve inspection/operation	Annual	ASME B 21.4 and B 31.8, Partial operation required
Valve testing	Annual	
Remote control shutdown devices	Annual	B 31: For functionality test
Relief valve (liquid)	< 5 years	ASME B 31.4 (1999): LPG/CO2/NH3 line/Storage

Table 3.1 Maintenance Schedule of pipeline

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

3.3 Need To Monitor Coating (Indirect Method):

In case of any coating defect, the **current requirement**, the **power consumption** increases while the **pipe to soil potential (PSP)** decreases with respect to the same. This is the reason why coating monitoring is an important feature in pipeline maintenance and performance.

Coating monitoring is an important task as a part of Coating system maintenance and its operation. Coating performance monitoring at fixed regular intervals is undertaken to ensure that all the structures are receiving desired protection against corrosion and the total system is performing as intended for in design stage. Coating must be properly maintained in order to operate effectively. To accomplish this goal effectively, diligent monitoring is required.

Pipeline coating monitoring includes its operation and maintenance work, it's should be work properly and effectively.

Within the pipeline industry, operators are constantly looking for metrics that can help them accurately measure coating properties, monitor coating performance in the field, and predict long-term coating performance in specific circumstances. These areas continue to be an active area of research and development.

Although it is not practical to develop specific tests and acceptance criteria for all coating systems, the available information (from laboratory tests, field experience, and operational practices) can be used to develop strategies to maintain the integrity of the pipeline coating.

Most important factor is the type of environment which pipeline faces due to location. If the pipeline is laid in a high salt air environment, for example, pipeline require more consistent monitoring than if the pipeline is laid in a fresh air environment where corrosion occurs less rapidly. But soil condition and environment vary at every location.

Maintenance will be referred to as the Monthly, Bi-annual, Annual, or Five Years inspection, monitoring, and repair of the given coating system. The various activities that are performed for regular monitoring are broadly classified as under:

- Potential Measurements-Fixed Point Measurements, close order potential survey.
- Measurement of protective current density.
- Interference measurement wherever suspected.
- Coating Performance Tests.
- Transformer-Rectifier unit operation checks (D.C. Power Source) and its inspection.
- Individual Anode Performance Checks.
- Insulation joint checks.
- Test for casing/ carrier short.
- Junction boxes.

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

Coating faults directly can be measured by current leak from the system, so generally from different surveys we get pipe to soil potential and based on that we decide the fault severity. In general we used for this purpose different type of surveys they will measure pipe to soil potential with the help of reference electrode. These survey methods available to determine the condition of coating systems and cathodic protection systems in order that the condition of the pipeline can be evaluated either along a section or along its entire length.

3.4 Need for Specialized Surveys

Pipeline coating is the primary protection to any underground cross country pipeline In order to maintain the metal integrity of the pipeline; the foremost task is to keep the coating always in good condition.

This aspect becomes furthermore important when one deals with the old three layer polyethylene coating. To ensure the working of a healthy pipeline, it is of prime importance that the condition of coating on the line is watched closely. For this purpose technology has given us certain tools in the form of Specialized Survey techniques that ensure a sound and efficient working of the pipeline. Need for these surveys are:

- ★ Coating deteriorates with passage of time and the load on CP increases day by day.
- ★ It slowly reaches a limiting condition where any amount of additional CP protection does not improve the situation.
- ★ Therefore, identification of coating defects with highest accuracy becomes very important, so that coating repairs and subsequent line protection is achieved in shortest possible time.
- ★ These specialized surveys give accurate results with respect to a pipeline under inspection and have greater efficiency in locating the holidays in coating on the pipeline.

  Taking PSP reading does not serve the purpose of locating the defects on the line as the test lead points are located at every kilometer and so they give only one or two location of suspected points, which means that the success rate of finding out the holiday is very less. Further, the PSP gives only the ON reading for every suspected location.

  On the other hand, Specialized Surveys (like the CPL and DCVG), give the ON and OFF readings of the potential for every meter. This means that for 1 kilometer line there will be 1000 potential readings, which surely improves the success rate of these surveys, and so more defects are known. These surveys increase the operating life of a pipeline and help in keeping away defects.

Once the need for these surveys is known, we can highlight the basic requirements for the coating surveys. These are stated as under:

- ★ Accurately identify all the coating defects.
- ★ Provide accurate information regarding size and position of defects.
- ★ Whether corrosion is taking place at the defect location.
- ★ Interpretation independent of the skill of the operator.
- ★ Simple to operate and reproducible.

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

★ Results not influenced by interference from external factors.

3.5 Selection of the Type of Survey

The information required as the output of the survey defines the technique to be employed.

Close Interval Potential	To provide initial cathodic protection data for new pipelines To assess cathodic protection levels and areas of poor protection To identify major coating defects
DC Voltage Gradient	To identify specific areas of coating effect together with estimation of defect size
Pearson survey	To identify specific areas coating defects
Signal Attenuation survey	To rapidly asses the coating condition and identify the worst areas

A Signal Attenuation coating survey followed by more detailed DCVG or Pearson Survey; in this way the entire pipeline can be raised in the most effective manner. A Signal Attenuation Survey can take 10% of the time of a Pearson Survey and 30% of the time of a DC Voltage Gradient Survey.

3.6 Types of Survey:

Periodical inspections are essential to perpetuate your protection system because the environment of the installation changes during use: aggressiveness of soil, coatings damage and equipment wear, etc.

Coating survey is need of every pipeline industry to regulate pipeline for proper and safety aspect. If coating damaged then pipeline could lead to be corrosion that cause leak or rupture. So the scheduled survey for pipeline coating is carried out once in every five year.

Generally four type of survey is used to monitor or locate the coating defect, most favorably used CIPS and DCVG combination. This combination is quick, efficient and economic

The following surveys are available:

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

1. Close Interval Potential
2. DC Voltage Gradient
3. Pearson survey
4. Signal Attenuation survey

3.6.1 Close Interval Potential Survey

Close Interval Potential Survey (CIPS) refers to potential measurements along the length of buried pipelines to assess the performance of Coating systems and the condition of the cathodically protected pipeline. The potential of a buried pipeline can be obviously be measured at the permanent test posts, but considering that these may be miles apart, only a very small fraction of the overall pipeline surface can be assessed in this manner.

The principle of a CIPS is to record the potential profile of a pipeline over its entire length by taking potential readings at intervals of around 1 meter.

Cathodic Protection systems are an electrical means of mitigating corrosion on buried and submerged metallic structures (primarily steel).

One of the most common methods of testing these systems is the annual test station survey. This requires the measurement and recording of pipe to soil potentials at designated test stations each year. While this is very useful information, particularly for well-coated pipelines, the test station data only represents the potentials on less than 1% of the pipeline surface. The test station data does not provide any information on the pipe to soil potentials at a distance from the test station. On bare or poorly coated pipelines, the test station data may not represent potentials more than a few meters from the test station.

Consequently, it has become a standard practice to undertake “close interval potential surveys” (C.I.S.) on pipelines, every few years, in order to provide the data for assessing the effectiveness of the Cathodic Protection system over the full length of the pipeline. The C.I.S. measures and records the pipe to soil potential on a regular spacing of between 1 and 3 meters (spacing depending on client requirements, field conditions and pipeline physical properties).

Methodology

A reference electrode is connected to the pipeline at a test post, and this reference electrode is positioned in the ground over the pipeline at regular intervals (around 1 meter) for the measurement of the potential difference between the reference electrode and the pipeline.

In practice, a three-person crew is required to perform these measurements. One person walking ahead locates the pipeline with a pipe locator to ensure that the potential measurements are performed directly overhead the pipeline. This person also carries a tape measure and inserts a distance marker (a small flag) at regular intervals over the pipeline. The markers serve as distance calibration points in the survey.

The second person carries a pair of electrodes that are connected to the test post by means of a trailing thin copper wire and the potential measuring instrumentation. This person is also responsible for entering specific features as a function of the measuring distance. Such details (road, creek, permanent distance marker, fence, rectifier, block valve, etc) serve as a useful geographical reference points when corrective actions based on survey results have to be taken.

The third person collects the trailing wire after individual survey sections have been completed. (Strictly speaking the first person may not be required if the distance can be monitored via a counter measuring the length of the unwinding copper wire). The interrupter switch is ON and OFF for a constant time interval or it is handled by GPS satellite systems. The ohmic drop at points indicates the corroded or poor CP region.

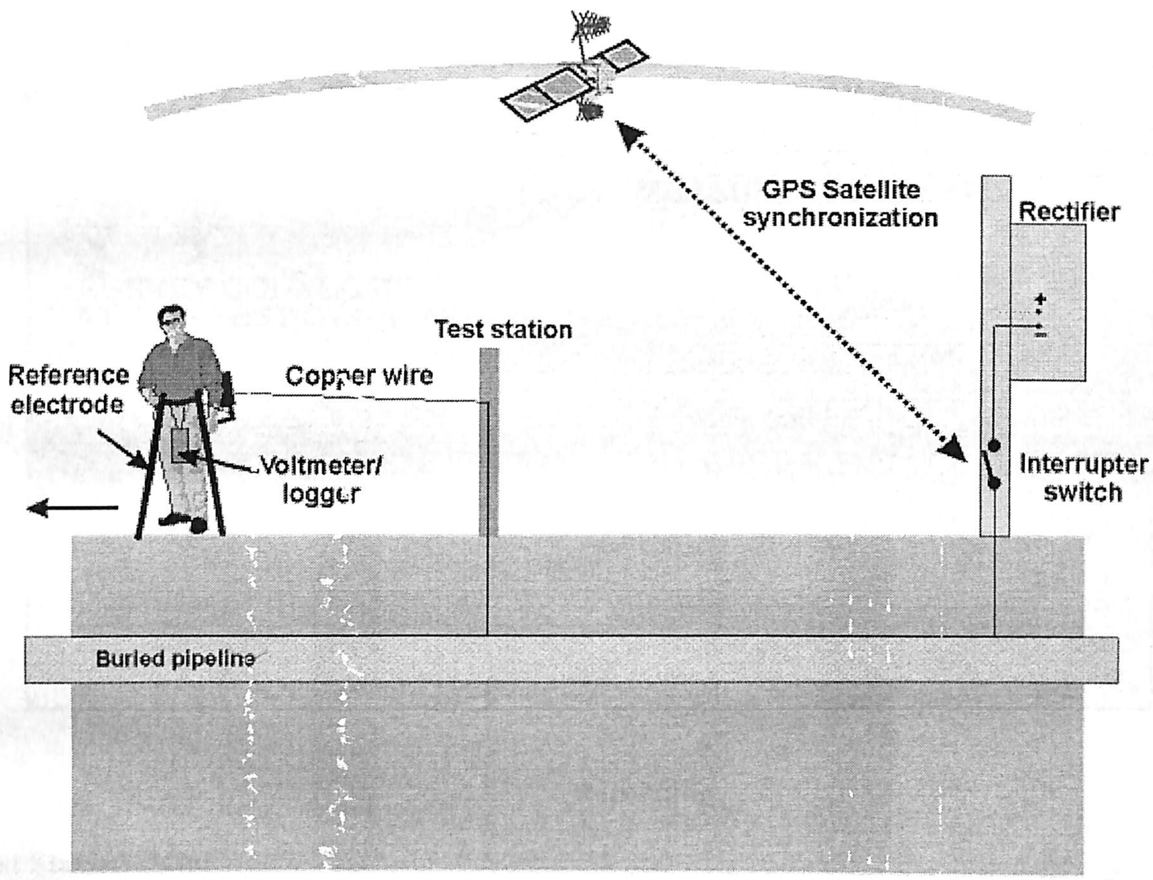


Fig 3.6.1 Pipe to Soil Potential Measurement In CIPL Survey

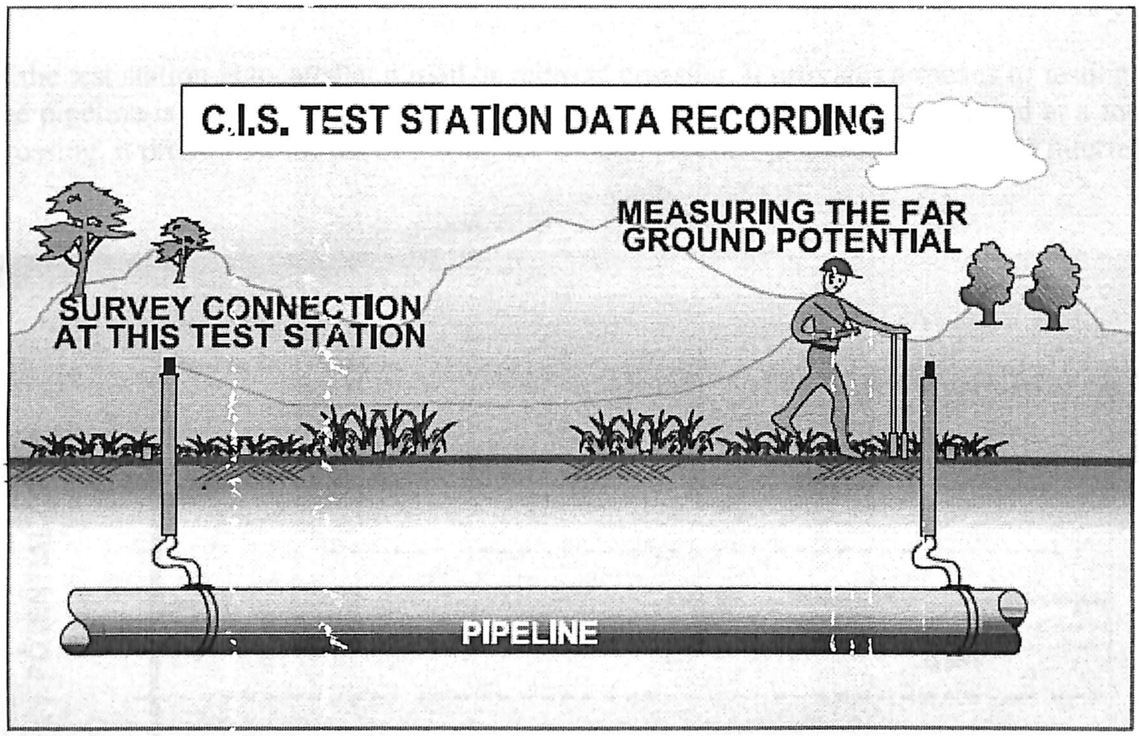
Close Interval Survey Data

During the C.I.S., most of the data collected will be pipe to soil potentials. There will also be comments relating to pipeline features and terrain features as well as special tests such as data logs or continuous logs. It is very important that the technician recording the data input as much information as possible. This can both be in the field and as extra notes in the data files.

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

Personnel who were not involved in the field survey will normally produce the C.I.S. report, and consequently, any field comments will greatly assist in the data handling and report generation.

If the ground is dry, this information needs to be input into the datalogger. If there is a wire break and the survey has to restart at a different location and proceed in the opposite direction, this must be clearly noted. In summary, the C.I.S data collection involves far more than just data collection. The field crew has the responsibility of providing all of the relevant field information so that the final report can be accurate.



Recording

Test Station Data:

Test Stations are normally located along the pipeline at locations such as roads, railroads, foreign line crossings, and at 1 to 5 Km separations in more remote areas.

The test stations provide a means of electrically contacting the pipeline for testing purposes. While a pipe to soil potential taken at a test station is not representative of more than a few meters of pipeline, it can be considered as a location for data sampling and comparison of year-to-year potentials.

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

For the C.I.S., the test station serves several functions:

- It provides a means of electrically connecting to the pipeline and a means of verifying the pipe to soil potentials being recorded from the last test station.

- The test station is a measurement point at which the voltage drop in the pipeline can be measured. The voltage drop in the pipeline will directly show if the interrupters are operating properly and if all of the rectifiers affecting that section of pipeline have been interrupted.

- If the test station is located at a road or railroad crossing, it provides a means of testing to verify that the pipeline is isolated from the casing. (If present) If the test station is located at a foreign pipeline crossing, it provides a means of testing the foreign pipeline to check for possible interference.

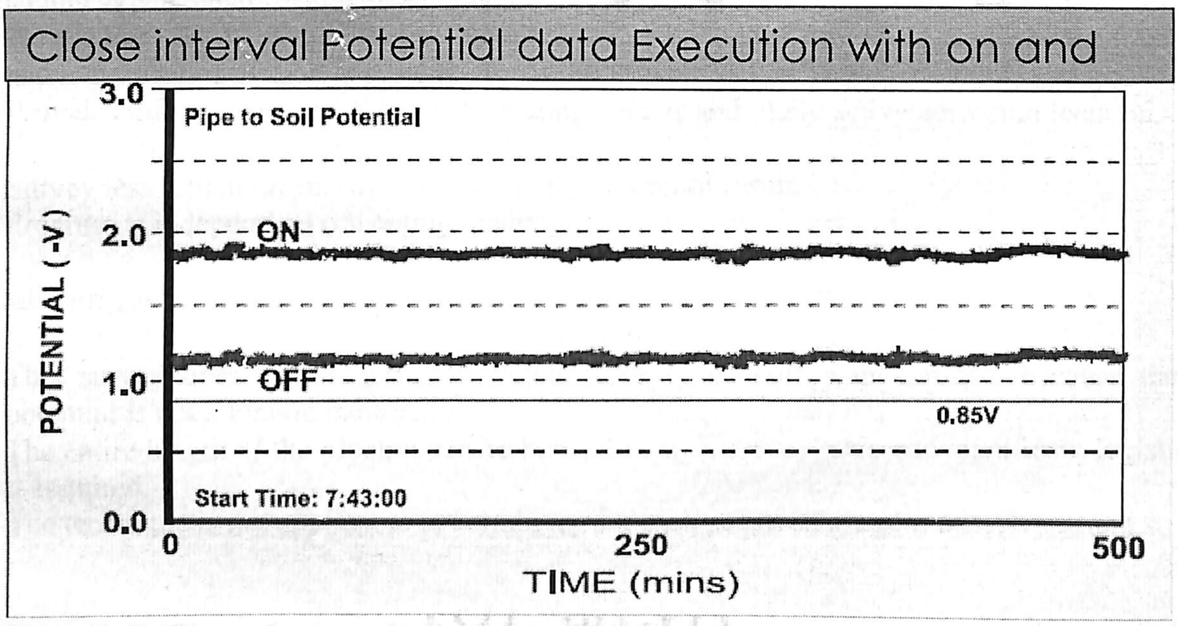


Fig.3.6.1 CIPL Data Execution

The following responsibilities of a pipeline operator in preparing for a CIPS are:

- Preparation of a detailed technical specification for the survey.
- Establishing and clearing the right of way (the path of the pipeline).
- Notification of land owners and foreign operators.
- Establishing the sphere of influence of existing rectifiers and foreign structures.
- Checking the condition and establishing functionality of rectifiers, bonds, and isolation.
- Characterizing the effectiveness of the CP systems in difficult terrain.

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

- Identification of suitable seasonal and weather windows.
- Specification of the reporting format.
- Ensuring availability of support personnel

Advantages

- The CIPS technique provides a complete pipe-to-soil potential profile, indicating the status of cathodic protection levels.
- The interpretation of results, indicating the identification of defects, is relatively straightforward.
- The rate of progress of the survey team is independent of the coating quality on the pipeline. When the entire pipeline is walked, the condition of the right-of-way and the cathodic protection equipment can be assessed together with the potential measurements.
- Provides a complete pipe to soil potential profile on the pipeline for both 'ON' and 'polarized OFF' potentials.
- The entire pipeline section is walked enabling an inspection of CP equipment and the right of way at the same time as the survey.
- A hard copy of the survey data is produced allowing easy identification of defect areas by non-technical personnel.
- A base line survey of the pipeline potentials can be obtained providing guidance for future operation and maintenance of the CP system.
- Provides information on CP levels at coating defects and likely active corrosion location.
- Identifies areas of stray current interaction.
- Survey less reliant on survey team for interpretation of result.
- Progress is independent of coating quality.

Disadvantages

- This survey does not indicate the actual severity of corrosion damage, because the corrosion potential is not a kinetic parameter.
- The entire length of the pipeline has to be walked by a survey team and significant logistical support is required.
- The technique is not applicable to certain terrain such as paved areas, roads, rivers, and so forth.

3.6.2 DCVG (Direct Current Voltage Gradient) Survey

DCVG stands for **Direct Current Voltage Gradient** and is a survey technique used for assessing the effectiveness of corrosion protection on buried steel structures. In particular, oil and natural gas pipelines are routinely monitored using this technique to help locate coating faults and highlight deficiencies in their cathodic protection (CP) strategies.

Direct Current Voltage Gradient Surveys (DCVG) is the application of a pulsed DC current either from the interruption of the cathodic protection rectifiers or the application of pulsed DC current from a temporary source. Voltage gradients are measured along the pipeline. Generally the larger the voltage gradient the larger the coating defect, but soil resistivity and current attenuation must be considered in the interpretation of the magnitude in the voltage gradient.

DCVG survey does not indicate the level of cathodic protection on the pipeline system. It's more recent methodology to locate defects on coated buried pipelines and to make an assessment of their severity. The techniques again relies on the fundamental effect of a potential gradient being established in the soil at coating defect under the application of CP current; in general, the greater the size of the defect the greater the potential gradient. The DCVG data is intricately tied to the overall performance of a CP system, because if gives an indication of current flow and its direction of soil.

Methodology:
The potential gradient is measured by an operator between two reference electrodes (usually of the saturated Cu/$CuSO_4$ type), separated by a distance of say half a meter. The appearance of these electrodes resembles a pair of cross-country ski pole. A pulsed dc signal is imposed on the pipeline for DCVG measurements. The pulsed input signal minimizes interference from other current sources (other CP systems, electrified rail transit lines). This signal can be obtained with an interrupter on an existing rectifier or through a secondary current pulse superimposed on the existing "steady" CP current.

The operator walking the pipeline observes the needle of a milli voltmeter needle to identify defect locations. It is preferable for the operator to walk directly over the pipeline, but it is not strictly necessary. The presence of a defect is indicated by a increase needle deflection as the defect is approached, no needle deflection when the operator walks away from the defect. It is claimed that defects can be located with an accuracy of 0.1 to 0.2 m. which represent a major advantage in minimizing the work of subsequent digs when corrective action has to be taken.

An additional feature of the DCVG technique is that defects can be assigned an approximately size factor. Sizing is most important for identifying the most critical defects and prioritizing repairs. An empirically based rating based on the so called %IR value has been adopted in general terms as follows:

- 0 to 15%IR ("small"): No repair required usually
- 16 to 35% ("medium"): Repair may be recommended.
- 36 to 60% ("large"): Early repair is recommended
- 61 to 100% ("extra large"): Immediate repair is recommended

Principle of the DCVG technique:

- In cathodic protection when current flows through the resistive soil to the bare steel exposed at defects. In the protective coating, voltage gradient is generated in soil. Larger the defect greater the current flow & hence the voltage gradient. This is utilized in the technique to give priority to the defects for repair.

- When the two electrodes are placed 1.5 meters apart on the soil in the voltage gradient form a coating defect, one electrode adopts a more positive potential than the other, which allows the direction of current flow to be established and defect to be located.

- The voltage gradient is monitored by measuring the out of balance between two reference electrodes using specially designed millivoltmeter, called as DCVG (Direct Current Voltage Gradient) survey meter.

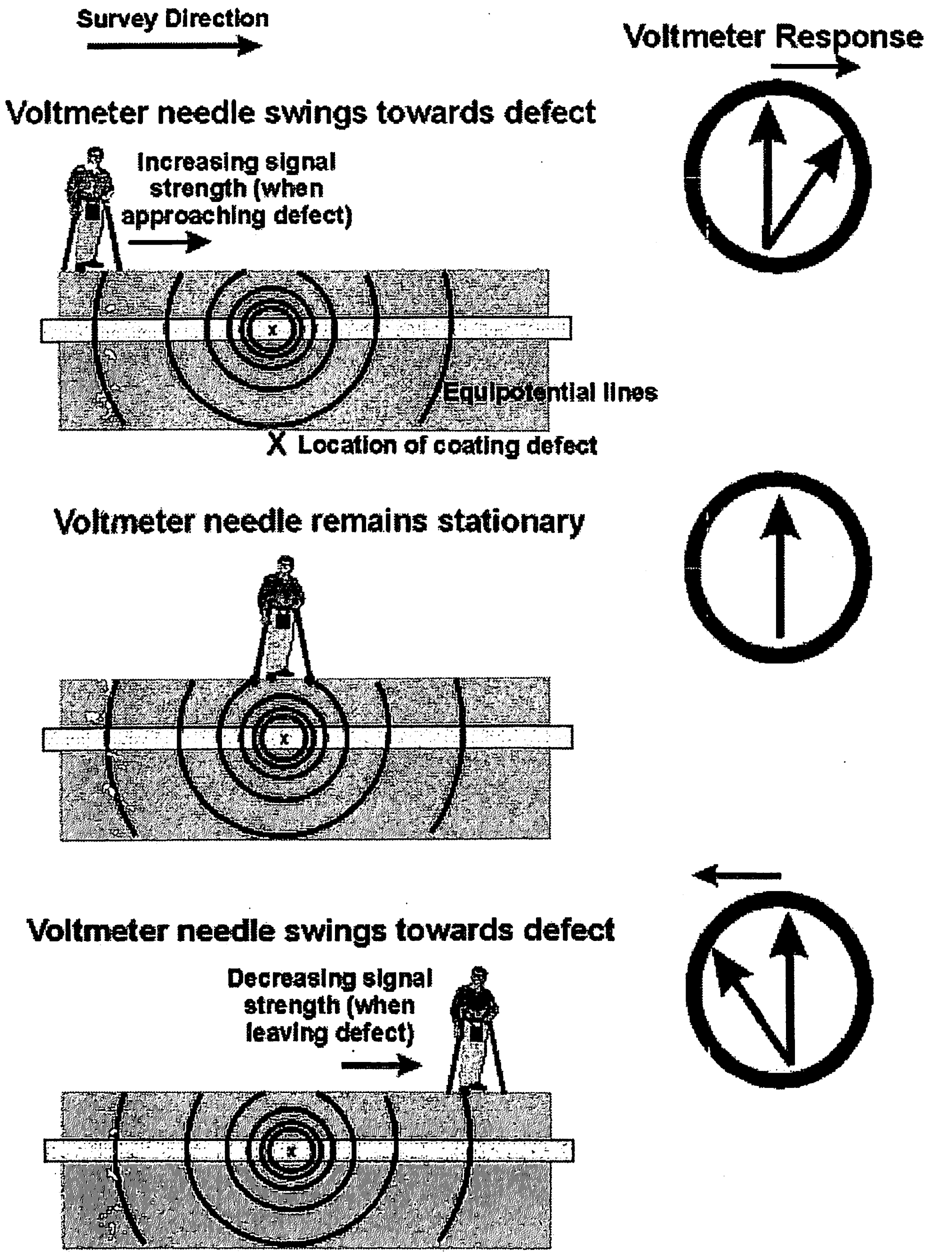


Fig 3.6.2 DCVG Surveying

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

Setting up the DCVG Signal

The most important parameter in ensuring an accurate survey and in determining the survey speed is the amplitude of the DCVG pulsed signal.

The interrupter should be connected into the electrical circuit shown in fig.

- ✓ The black terminal of the interrupter should be connected to the negative terminal of T/R unit. Keep T/R unit in Manual mode.
- ✓ The red terminal of the interrupter should be connected to the cable going to the pipeline.
- ✓ Polarity of the connection is important. If connection is wrong the interrupter will not switch the DC output. If this happen remedy is just reverse the terminal connections on the interrupter. The amplitude of signal strength is the difference between ON and OFF potential measured on the pipe using DCVG meter, whilst the interrupter is switching ON and OFF the applied source.
- ✓ The output signal from T/R unit along with interrupter should be less than 25 amperes.
- ✓ Adjustments beyond 25 amperes up to 50 amperes are possible but careful adjustment is necessary preferably using a scope meter. A pipeline requiring more than 25 amperes to get a good signal level over a 1 KM length is indicative of a very bad coating on pipeline.
- ✓ The amplitude of DCVG signal should at least 250 mV & no large than 1500 mV.
- ✓ Rapid decay of signal measured at two locations one kilometer apart would be on attenuation of signal amplitude with distance.

Adjustment to ensure a good signal level requires trial and error and patience but extra time spent in setting up the signal will give greater confidence in the quality of the survey, which usually can be achieved at greater speed than on pipelines with a poor signal.

Measurement of signal level at test posts are carried out in exactly the same way as measurements made to measure pipe-to-soil potential, except there are two measurements in this case:-

- From the copper wire or test post terminal to the soil alongside the test post.
- From the soil position alongside the test post to remote earth.

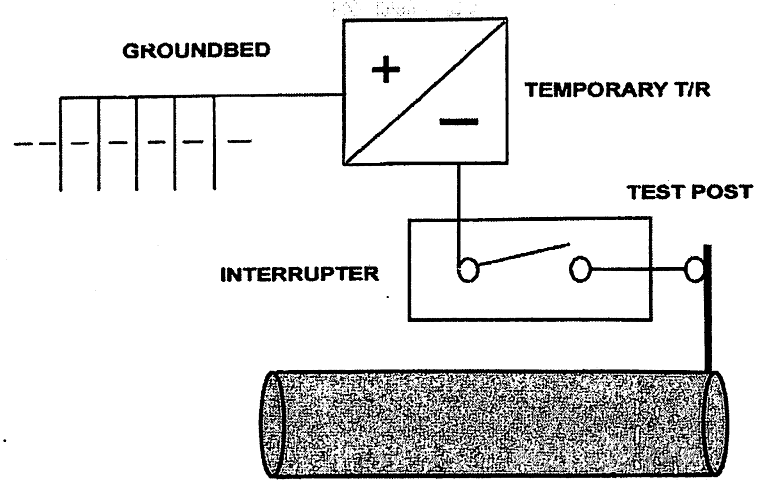


Fig 3.6.2 Temporary T/R and Ground-bed

Assembling the DCVG Equipment

- ✓ Probes are filled with copper sulphate solution.

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

- ✓ The DCVG meter is placed around the neck and waist so that the meter fits snugly on operator.
- ✓ Connecting leads are fitted into the meter and into the process to interconnect two probes with meter.
- ✓ The meter switch is then turned ON and the Range switch is adjusted.
- ✓ With the probe tips placed in the soil the bias to the right hand probe is switched ON.
- ✓ The bias to the left hand probe is not switched ON, it is a spare available if needed.

Application of DCVG Technique

- Evaluate pipeline coatings to define rehabilitation requirements
- Define weaknesses in the cathodic protection system
- Validate that the pipeline has been constructed with minimum coating faults
- Investigate Interference effects
- Establish effectiveness of insulating flanges and other methods of pipeline isolation
- Provides data for Operating License Validation
- Surveying complex pipeline networks not possible by other methods
- Capable of surveying under overhead power lines.
- Evaluation of test post integrity.

Advantages

- o This technique is particularly suited to complex CP systems in areas with a relatively high density of buried structures.
- o The DCVG equipment is relatively simple and involves no trailing wires.

Disadvantages

- The rating system is empirical and does not provide quantitative kinetic corrosion information.
- The survey team's rate of progress is dependent on the number of coating defects present

3.6.3 Pearson Survey

The Pearson Survey, named after its inventor, is an electrical method used to locate holidays in buried pipeline coating by the application of an AC signal on the pipeline and the reception of the signal by two surveyors wearing metal cleats and connected to the Pearson receiver.. Once these defects have been identified, the protection levels afforded by the CP system can be investigated at these critical locations in more detail.

Methodology:

An A C signal of around 1000 Hz is imposed onto the pipeline by means of a transmitter, which is connected to the pipeline and the earth spike. Two survey operators make earth contact either through metal studded boots or aluminum poles. A distance of several meters typically separates the operators. Essentially, the signal measured by the receiver is the potential gradient over the distance between the two operators. Defects are located by a change in the potential gradient, which translates into a change in signal intensity.

As in CIPS technique, the measurements are usually recorded by walking directly over the pipeline. As the front person moves away from the defects, the signal intensity drops and later picks up again as the rear operator approaches the defect. The interpretation of signals can obviously become confusing when several defects are located between the two operators. In this case, only one person walks directly over the pipeline, with the connecting leads at a right angle to the pipeline.

In principle, a Pearson survey can be performed with an impressed cathodic protection system remaining energized. Sacrificial anodes should be disconnected because the signal from these may otherwise mask actual coating defects. A three-person team is usually required to locate the pipeline, perform the survey measurements, place defect markers into the ground, and move the transmitters periodically. The operator carrying the receiver should be highly experienced, especially if the survey is based on audible signals and instrument sensitivity settings. Under these conditions, the results are completely dependent on this operator's judgment.

Advantage

- By walking the entire length of the pipeline, an overall inspection of the right-of-way can be made together with the measurements.
- All significant defects and metallic conductors causing a potential gradient will be detected.
- There are no trailing wires and the impressed CP current does not have to be pulsed.
- Survey technique can provide an assessment of coating condition over areas of difficult access i.e. road, rail and water crossing etc.
- Estimates defect sizes in order to prioritize excavation and repair
  Minor defect: from 0% IR => 15% IR
  Medium defect: from 16% IR => 35% IR
  Large defect: from 36% IR => 100% IR
- Has already proven in use and accuracy
- One person can conduct survey, although 2 persons are recommended (progress, & safety).
- Provide data for cathodic protection adjustment/upgrading.
- Survey can be conducted in areas affected by stray currents and telluric effects in most soil conditions.
- Involves no trailing wires.
- High accuracy in locating and pin-pointing defects.
- Can be used in combination with other techniques.

Disadvantages

The disadvantages are similar to those of CIPS because the entire pipeline has to be walked and contact established with ground. The technique is therefore unsuitable to roads, paved areas, rivers, and so forth. Fundamentally, no severity of corrosion damage is indicated and no direct measure of the performance of the CP system is obtained. The survey result can be very operator dependent, if no automated signal recording is performed.

3.6.4 Current Attenuation Survey (CAT)

Current Attenuation is the measurement of the current attenuation on a pipeline with distance from the power source. The current attenuation is indicative of the coating quality and integrity. Current attenuation does not indicate the level of cathodic protection or the effectiveness of the CP system. CAT Survey is based upon measurement of magnetic field from AC current in the pipeline. Gradient profile of AC current in the pipeline is obtained by discrete measurement along the line. Line current is monitored by a set of coils in the receiver. Ripple current from transformer-rectifier unit or signal from AC current may be used fro signal.

A coated pipeline will have a loss of AC signal along the line due to capacitance and resistance of coating, capacitance and resistance of polarization layer in coating faults, form and shape of coating holidays, thickness of coating and soil resistivity. Loss of signal due to coating capacitance and resistance is proportional to signal strength and capacitance per unit length of the pipeline. Provided a uniform coated pipeline with no coating holidays, loss of signal will decrease logarithmically with distance.

Current Attenuation can be performed with various electromagnetic tools including the Pipeline Current Mapper and Precision Pipe Locator for AC attenuation and the Stray Current Mapper for DC attenuation. The pipe is located and depth of cover is determined while simultaneously obtaining current measurement and current direction. All the data is captured and stored into a portable submeter GPS instrument for later download into a computer for data compilation and interpretation.

Advantages of current attenuation include:

- Measurements can be taken at 50 foot, 100 foot or larger intervals. Does not need to be take every 5 feet to be effective
- Measurements can be taken over many types of cover including concrete, rocks, pavement and water with no detrimental effect.
- Allows the operator a quick way to determine the overall pipeline coating condition
- Allows the operator to obtain information very quickly on the electrical CP circuit and whether there are shorts, bonds or other unknown areas of concern.
- Gives the operator a fast and reliable way to narrow down the areas of concern where more detailed and time consuming surveys can be performed.

CHAPTER 4

EXPERIMENTAL/COMPUTATIONAL/FIELD WORK ANALYSIS

GAIL India) Limited in their rehabilitation and expansion project has laid GREP pipeline and it's branch pipelines of varying diameter ranging from 36" to 8" have been laid underground to supply natural gas to various customers such as power plants, fertilizer plants, chemical plants, etc in the state of MP, Rajasthan, UP, Haryana, and Delhi through a network of 635 kms. of pipeline. The GREP pipeline and its branch lines have 3-layer polyethylene coating and impressed current system has been provided for cathodic protection of the pipelines.

Brief **features** of the pipeline network of GAIL (India) Ltd. in India are as given below:-

Sr. No.	**Description**	**HVJ pipeline**	**GREP**	**JLPL**
1.	Length of Pipeline	2456KM	505KM	1330KM
2.	Coating	3LPE-2304KM Coaltar-152KM	3LPE	3LPE
3.	Pipeline Diameter	36"-04"	36"	16"-6"
4.	Year of Commissioning	1987	1997	2000
5.	Testing Done	3LPE & SS	3LPE & SS	3LPE & SS
6.	Total num of bell hole inspected	79	36	90
7.	Ref. STD	DIN 30670	DIN 30670	DIN 30670

Various pipeline details with in GAIL India: the description and the salient feature have given for the present status of coating which has been applied for the desired condition in GAIL India Ltd.

VIZAG-SECUNDRABAD PIPELINE (VSPL)

Sr. No.	**DESCRIPTION**	**VSPL**	
		Vijag - Vijayawada	Vijayawada- Secundrabad
	Length of pipeline	343 KM	235 KM
	coating	3LPE	3LPE
	Pipeline diameter	12"	10"
	Year of commissioning	2004	2004
	Testing done on	3LPE	3LPE
	Total no. of bell holes inspected	26	15

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

	Ref. Standard	DIN 30607	DIN 30607

DAHEJ VIJAYAPUR PIPELINE (DVPL)

Total length of pipeline 610 KM

Pipeline diameter 42”

Commissioned 2004

Coating type 3LPE

Other salient features of the GREP gas-pipeline are given below:

4.1 PIPELINE DETAILS

GREP: Vijaipur to Dadri pipeline along with spur lines are being divided into six [06] regions namely, Vijaipur, Gwalior, Agra, Mathura, Faridabad and Dadri/NCR.

SR.NO.	NAME OF PIPELINE	LENGTH OF PIPELINE (km	DIAMETER (inch)
[A]	**VIJAIPUR REGION**		
1	Vijaipur - Khardhar	0.00-132.00	36”
[B]	**GWALIOR REGION**		
1	Khardhar – Chambal river	132.00-246.00	36”
[c]	**AGRA REGION**		
1	Chambal River - Bajhaera	246.00-335.85	36”
2	Bajhaera – Agra spur line	0.00-52.70	10”
3	Agra – Firozabad	0.00-34.95	8”
4	Agra – Firozabad loop line	34.30	10”
[D]	**MATHURA REGION**		
1	Bajhaera - Jatauli	334.85-425.35	36”
2	Lalpura – Mathura railway	0.00-12.53	14”
[E]	**FARIDABAD REGION**		
1	Jatauli – Yamuna River	425.35-460.00	36”
[F]	**DADRI REGION**		
	Dadri – Yamuna river	460.00-500.00	36”

Total length: 635kms. (approx.)

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

4.2 SCOPE OF THE WORK:

This project is related to finding out the locations of current drainage due to coating defect, their failures with the help of conducting surveys (CIPL & DCVG), the refurbishment of found defects locations and the activities involved with the pipeline section understudy.

4.3 OBJECTIVE:

The objective of the project is coating integrity study for GREP Pipeline system under Agra region at GAIL (India) Ltd. and to locate the defected area, the type of defect and their repair. The objective includes following:

- Identification of stretches of current drainage by plotting of PSP graph by using CIPL data.
- Identifying locations/spots of coating damages i.e. current drainage points by DCVG survey.
- DIG verification.
- Severity analysis.
- Repair Strategy.

The Coating Integrity Survey for GAIL's 1900 km. long HBJ pipe has already been completed in the year 2000 and the survey results indicated excellent system performance and coating condition and also provided useful inputs for further system improvement.

Now, GAIL has undertaken the coating performance survey for its 500 km. long Vijaipur–Dadri GREP pipeline for the year 2007-2008, for Agra region & Mathura region CIPL survey and DCVG survey has been completed and for the rest of the section, these surveys are in progress. This pipeline has been laid in 1997-98 year. At that time the main pipeline is coated with 3LPE and the city gas pipeline coated with coaltar enamel coating.

In this project I am dealing with finding out the coating defect with the help of conducting surveys on GREP pipeline for Mathura region and repair those coating defect accordingly the severity of the defect. In Mathura region, there are two branch line and spur lines which distributed through the city to transport the gas, are connected to the GREP main pipeline. Mainline pipe coated with 3LPE and those spur lines which are small in diameter, coated with coaltar enamel coating. Here I m just mentioning the detail conducting the pipeline coating surveys for specified area. The information about the pipeline coating integrity is mentioned below:

4.4 COATING DETAILS

1. Main line 3-layer polyethylene coating
2. Branch line:
   (a) Bajhaera – jathuali
   (b) Lalpura – Mathura refinery
3. Spur line coated coaltar enable coating.

Main pipelines and Branch connection pipeline are coated with 3LPE coating and city gas distribution pipelines are with coaltar coating. The disintegration of any of these pipeline coatings can be a potential threat to the integrity of the pipeline system. Whenever a pipeline coating is disintegrated at any location due to any reason, it can lead to corrosion on entire pipe slowly with time as ingress of water from surrounding soil is possible though holidays on coating. The water ingress through coating holidays shall travel along the pipeline surface, which will lead to total disbonding of the coating (including epoxy layer) from thee pipe. In such cases, the coating gets easily removed as an envelop from the pipeline even with little application of physical stress. The CP system becomes ineffective for the protection of the pipeline surface against external corrosion or SCC, if SCC occurs with in the corrosion. This means the coating material which is supposes to apply on the steel pipe should be of desirable condition. Considering the serious implication of the disbondment of coating to pipeline, it was imperative to conduct the coating integrity study for commissioned pipeline. Accordingly, the coating monitoring surveys has been conducted by the O&M department in a phase wise manner for all major pipeline networks. These reports brief us to the present condition of coating and mitigation measures to be taken.

4.5 Cathodic Protection System for GREP pipeline: ICCP (Impressed Current Cathodic Protection)

No of CP Station: 11 Nos.

- Manual test stations for current and potential measurement are installed at:

a) Approximately, 1 km interval in GREP main lines and 1 km in spur lines.
b) All HT overhead power transmission lines of 66 kV and above.
c) All railway crossings
d) All road – crossing
e) All major river crossings (with insulation joints on either bank)
f) SV/ Terminal/Scrappers/Compressor Stations
g) Foreign Pipeline crossings.

- Galvanic anodes have been provided for casing and carrier pipes at railway crossings and for river section of pipeline. But normally the river section is also protected by the ICCP system by providing links across insulating joints.
- At all above ground insulating joints, spark gap arrester have been installed across insulating joints.

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

- External corrosion sensing probes have been installed to monitor the external corrosion rate at approximately each 10 kms.
- The grounding cells have been provided near insulation joints.
- Two types of anode ground bed configuration are in use:
  a. Horizontal anode ground bed
  b. Deep well type.

4.6 Sites visited and covered in detail during the project

4.6.1 Sone Ka Gurja (Sectioning Valve (SV) & Intermediate Pigging (IP) Station)

1. **CPPSM (Cathodic Protection Power Supply Module) Unit**

DC Input Voltage	=	49- 53.2 V
Reference Voltage (PSP)	=	- 1.26 V
DC Input Current	=	0.25–5 Amps (Varies between this range to maintain the Reference voltage of -1.26 V)
DC Output Current	=	0.5 – 0.7 Amps.
DC Output Voltage	=	1.5 V

Sone Ka Gurja is a remote location, approximately 70 kms from Agra on the banks of river Chambal. Being far from Agra city, there is a problem of availability of state electricity in this place which gives rise to many domestic problems at this place. Therefore, to overcome this problem TEG (or thermo-electric generator) is used. The power source to the CPPSM Unit is this TEG (or Thermo-Electric Generator) only which is imported from Canada. Thermo-electric generators convert heat directly into electricity, using the voltage generated at the junction of two different metals. It works on the principle of See beck Effect.

At Sone Ka Gurja, it is a system of five (5) sets of Dual TEG system connected together in series parallel combination to produce 5350 Watts at 48 Volt DC nominal. Each set contains two (2) 24 volt DC generators in series to provide the 48 Volt DC nominal requirement and five (5) of these systems are wired in parallel to provide 5350 Watts. Since the TEG system naturally provides 48 volt DC nominally, no DC to DC converter is required at the output of the system.

4.6.2 Farah (Sectioning Valve (SV) Station), Mathura

Actual PSP = -1.2
Off PSP = -1.2 (Natural Potential)
Min. P/L Potential = -1.1
Max. P/L Potential = -1.8
Max. Set Potential = -1.15
Solar Charge Controller; Voltmeter = 13 V
Unlike Sone Ka Gurja station where TEG is installed, here we have solar chargers installed on the top of the station rooms to generate energy for operating the units installed. The reason for using these solar chargers is almost the same as that for Sone Ka Gurja station i.e. there is either intermittent or no power supply at this location.

4.6.3 Bhajera (Sectioning Valve (SV) & Intermediate Pigging (IP) Station)

This station is very similar to Sone Ka Gurja station in term of installation and the operations looked after from this location.
The Cathodic Protection System of GAIL (India) Ltd. initially during the construction phase of the line used galvanic anode (or sacrificial anode) system. Once the line was commissioned, a permanent cathodic protection system was used. The permanent impressed current system provide protection to the external exposed surface of trunk pipeline ranging from 36" to 18" diameter and 12" diameter branch pipelines. In addition the permanent galvanic anode system offer cathodic protection to the carrier and casing pipes at railway crossings and to the carrier pipes at river crossings. Cathodic Protection system must be properly maintained in order to operate effectively. To accomplish this goal efficiently, diligent monitoring is required.

The monitoring and maintenance routine calls for visual inspection of components and observation of system's performance whenever the station is visited, for whatever reason for cleaning and for testing systems performance, and possible re-adjustments. This approach of observing and analyzing system's performance whenever possible will result in keeping the number of unscheduled service calls to a minimum.

4.6.4 Agra City Gas Station (ACGS) & City Network

The Agra City Gas Station is situated at Teri Bagiya on the outskirts of Agra. The total gas handled at this station is 1,30000 to 1,70000 scm per day as compared to the handled at Firozabad City Gas Station (FCGS) which 10,0000 to 11,00000 scm. This huge difference is because of the industrial base (glass industry) in Firozabad which requires great quantities of gas for the purpose. Whereas in Agra, nature of industries is such that they require lesser quantity of Natural gas.
There is an inlet of 10" spur line from Bajhera which supplying gas at a pressure of 60 -70 kg/cm^2. From this 10" spur line, an 8" and a 10" line are moving to Firozabad station. Now on the exit of the 8" line a filter separator is mounted followed by Shutdown Valve (2 Nos.), and Pressure Control Valve (2 Nos.). Out of these, 1 SDV and PCV each is in operating mode while the remaining two are in standby mode.

Thereafter, from the Pressure Control Valve the gas is sent to the metering unit (turbine meter) where the amount of gas outflow is being measured. And finally, the gas is distributed to the customer in the local market at the pre-decided price.

4.6.5_Firozabad City gas Station & City Network

Firozabad city gate station is situated at Raja ka Tal in Firozabad; it's 5 km away from Firozabad. Natural gas requirements or handling is higher than Agra city gas station.

A similar installation is found at the Firozabad City Gas Station (FCGS).
The only change is handled natural gas because of higher glass industry which has higher Natural gas required to melt glass. Firozabad has large city gas network. This network contain 8" line to 2"line and valve and all facility same as Agra city gas station.
Large network required larger maintenance per year, so Firozabad city gate station has higher maintenance than Agra city gas station.

During the project work, I was associated with the CIPL and DCVG survey, which being carried out for the pipeline under AGRA-MATHURA regions.

4.7 Possible Pipeline Coating Defects & Deterioration

Pipeline coatings and their performance have developed markedly in the last three decades. However they still are subject to damage and deterioration caused by factors identified.

- Damage during handling and laying
- Failures during commissioning and operation
- Rock penetration during installation and
- Soil loading and shear failure during operation
- Lack of coating integrity at elevated temperature
- Disbonding through pipe movement and
- Disbonding due to inadequate surface cleaning
- Enhanced failure at low temperatures

4.8 Possible reason of these Failures:

- Poor coating electrical insulation properties due to improper formulation or application.
- Deteriorating coating electrical insulation due to moisture absorption and/or general breakdown of coating film.
- Characteristic failures of particular coatings (e.g. spiral corrosion and disbondment with tape coatings with inadequate properties/overlap, disbondment of fiber reinforced coal tar and asphaltic enamels at elevated temperatures particularly in moist conditions.
- Failures of inadequately designed or applied field joints and repairs
- Damage due to third party interventions (e.g. deep plough or excavation damage).

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

- Action of bacteria in the soil surrounding the pipeline. Some coating materials are relatively inert in this respect while others are sensitive to such damage.
- Damage on subsequent construction on other facilities making it necessary to uncover the pipeline.
- If PSP value becomes either too low or too high beyond the prescribed range (i.e. -0.85 to -1.5) it either leads to corrosion or coating disbondment.

4.9 Specialized Techniques & Survey for Monitoring

The main objectives of the survey were to:-

- Find out the effectiveness of CP System over the entire length of pipeline.
- Find out the current drain points/ coating defects locations.
- Find out under and over protected zones.
- Find out possible coating disbondment locations due to over protection
- Find out pin pointed location and size of coating defects.
- Find out locations prone to foreign interference.

Survey Agency: The survey has been carried out by M/s Corrtech International Pvt. Ltd., Ahmadabad.

a. Carry out CIPL (ON-OFF) Survey at every 1.0 meter along the pipeline as per the specified procedure and guidelines.
b. Determine exact location, size and magnitude of coating defect throughout the periphery of the pipeline by carrying out the DCVG survey at the probable defect locations identified by the CPL Survey. Also quantify and categorize the coating defects in the terms of severity as 'minor', 'moderate', and 'severe' and anodic/ cathodic in accordance with NACE standards.
c. To establish the existence of interference situations, if any.
d. To excavate at least 5 locations on every 100 kms of surveyed length to verify the survey results. Based on 80% accuracy of the result, the survey is continued. If results are not found proper at these locations, excavation is to be done at additional locations.

4.10 CIPL Survey

CIPL survey carry out to measure pipe to soil potential along the pipeline. This survey determines:

- Probable locations of defects in pipeline coating, and
- Status of cathodic protection system by close interval potential logging (CIPL) Survey.

Procedure: A reference electrode is connected to the pipeline at a test post, and this reference electrode is positioned in the ground over the pipeline at regular intervals (around 1 meter) for the measurement of the potential difference between the reference electrode and the pipeline.

In order to achieve measurements of both "ON" (including IR drop error) and "INSTANT OFF" potentials (in principle excluding IR drop error), the sources of cathodic protection current require to be interrupted; typically they are switched ON : OFF in a ratio of 8:2 to avoid depolarization during the survey. As most pipelines have more than one source of current (transformer-rectifiers, bonds to other networks, sacrificial anodes) it is often necessary to deploy multiple switching devices or current interrupters.

Standard ON: OFF ratio is 4: 1 which we used for CIPL PSP monitoring, reason for ON potential time is more otherwise line depolarize, so interrupter is used for this purpose.

Now project will start from here. We have inspected 10 km part of pipeline where we have monitored coating and performed coating survey. In every meter we placed electrode of $Cu/CuSO_4$ and take reading of ON potential and with the help of interrupter shut the supply and take reading of OFF potential. Here I'm including those data gathered during the surveys. This data is for 1 km from chain age 300.000 to chainage 300.100.

CHAINAGE	OFF PSP(-V)	ON PSP(-V)
300.000	0.982	1.254
300.001	0.907	1.273
300.002	0.969	1.249
300.003	1.070	1.325
300.004	1.129	1.308
300.005	1.108	1.357
300.006	1.101	1.365
300.007	1.105	1.344
300.008	1.067	1.349
300.009	1.140	1.319
300.01	1.126	1.349
300.011	1.101	1.374
300.012	1.102	1.356
300.013	1.106	1.358
300.014	1.126	1.302
300.015	1.142	1.382
300.016	1.102	1.332

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

300.017	1.108	1.364
300.018	1.108	1.313
300.019	1.108	1.378
300.02	1.104	1.376
300.021	1.104	1.355
300.022	1.112	1.354
300.023	1.108	1.368
300.024	1.103	1.328
300.025	1.103	1.364
300.026	1.129	1.324
300.027	1.150	1.351
300.028	1.107	1.379
300.029	1.101	1.330
300.03	1.109	1.354
300.031	1.147	1.317
300.032	1.163	1.360
300.033	1.098	1.376
300.034	1.108	1.352
300.035	1.113	1.366
300.036	1.185	1.313
300.037	1.165	1.391
300.038	1.108	1.308
300.039	1.103	1.386
300.04	1.118	1.366
300.041	1.154	1.363

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

300.042	1.105	1.303
300.043	1.108	1.309
300.044	1.095	1.379
300.045	1.101	1.345
300.046	1.178	1.348
300.047	1.108	1.311
300.048	1.101	1.340
300.049	1.148	1.387
300.05	1.169	1.318
300.051	1.164	1.381
300.052	1.102	1.302
300.053	1.105	1.376
300.054	1.125	1.344
300.055	1.160	1.371
300.056	1.112	1.394
300.057	1.103	1.310
300.058	1.101	1.389
300.059	1.185	1.370
300.06	1.168	1.337
300.061	1.101	1.343
300.062	1.199	1.322
300.063	1.159	1.339
300.064	1.153	1.308
300.065	1.102	1.321
300.066	1.102	1.398

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

300.067	1.168	1.359
300.068	1.149	1.321
300.069	1.103	1.318
300.07	1.109	1.315
300.071	1.158	1.301
300.072	1.140	1.328
300.073	1.115	1.348
300.074	1.153	1.369
300.075	1.104	1.323
300.076	1.108	1.334
300.077	1.104	1.328
300.078	1.140	1.350
300.079	1.106	1.329
300.08	1.101	1.393
300.081	1.129	1.376
300.082	1.116	1.313
300.083	1.106	1.321
300.084	1.088	1.335
300.085	1.150	1.308
300.086	1.133	1.354
300.087	1.114	1.328
300.088	1.109	1.342
300.089	1.084	1.320
300.09	1.120	1.359
300.091	1.101	1.333

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

300.092	1.107	1.344
300.093	1.157	1.312
300.094	1.146	1.369
300.095	1.120	1.350
300.096	1.106	1.311
300.097	1.106	1.323
300.098	1.101	1.394
300.099	1.124	1.328
300.100	1.116	1.317

Now all reading regarding to 10 km should be taken. Now graph will be plotted in respect to these reading.

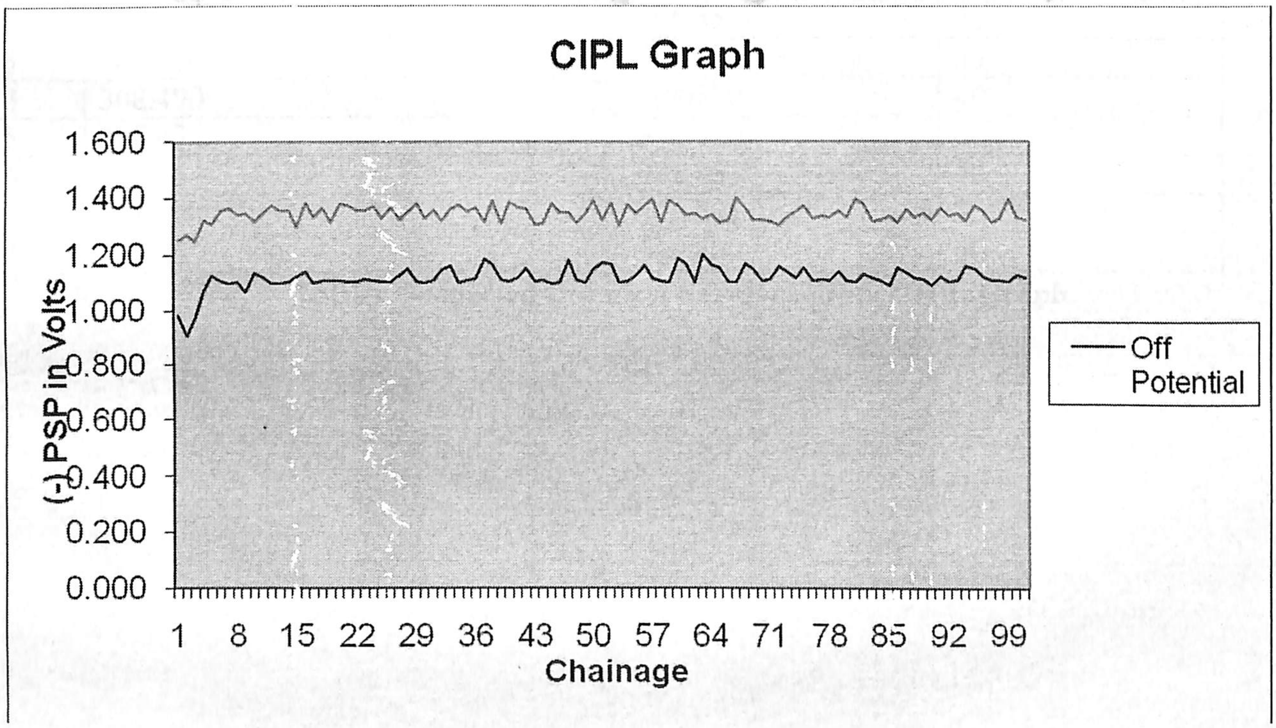


Fig.4.1 CIPL Graph

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

Based on the CIPL graphs, entire pipeline is cathodically protected within acceptable PSP range if any voltage drop in OFF reading, so that will be suspected location and monitored by DCVG survey. CIPL survey drop is to be investigated by DCVG survey for investigation of nature of coating fault for observed suspected locations.

A computerized field data logger is used for measurement of potentials and synchronisable current interrupters are connected for continuously switching ON/OFF DC power source during the survey. The selection of ON/OFF measurement cycle of current interrupter in 4:1 ratio depends on technical, economic and practical considerations.

This survey requires more time and cost but provides better and more comprehensive information then other CP surveys.
The result of the CIPL survey is shown as under:

S No.	Pipeline Chainage from (KM.)	To Chainage (KM.)	Spot Length (in mt
1	300.0	300.30	30
2	306.8	306.85	50
3	308.440	308.470	30
4	308.490	308.530	40
5	308.63	308.690	60
6	308.76	308.80	40
7	309.260	309.295	35
8	310.25	310.300	50

Table: Suspected Location Resulted From CIPL Graph

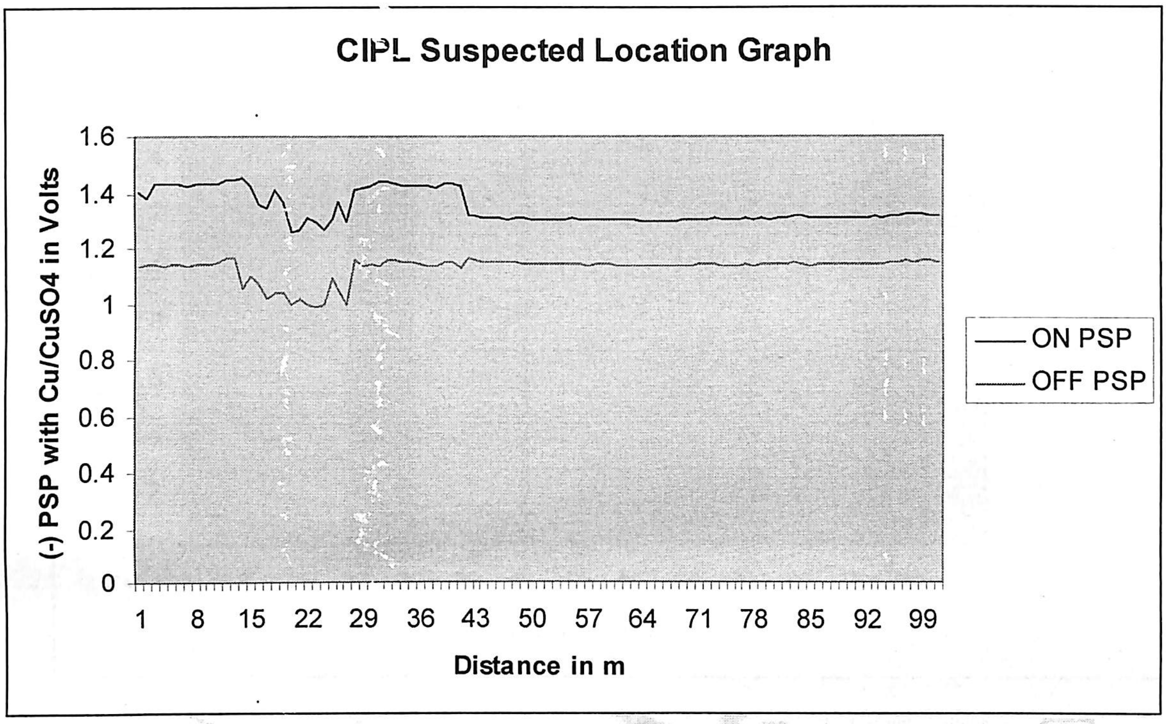


Fig 4.2 CIPL Suspected Location graph from 306.800 to 306.850m

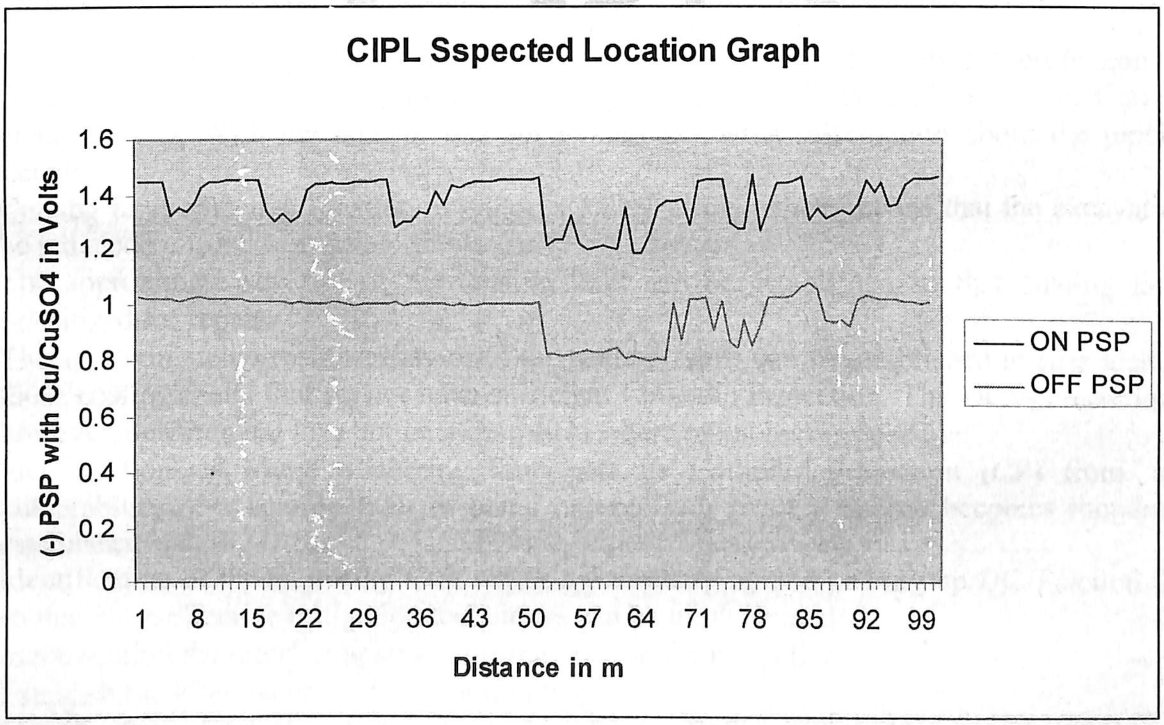


Fig 4.3 CIPL Suspected Location graph from 308.490 to 308.530m

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

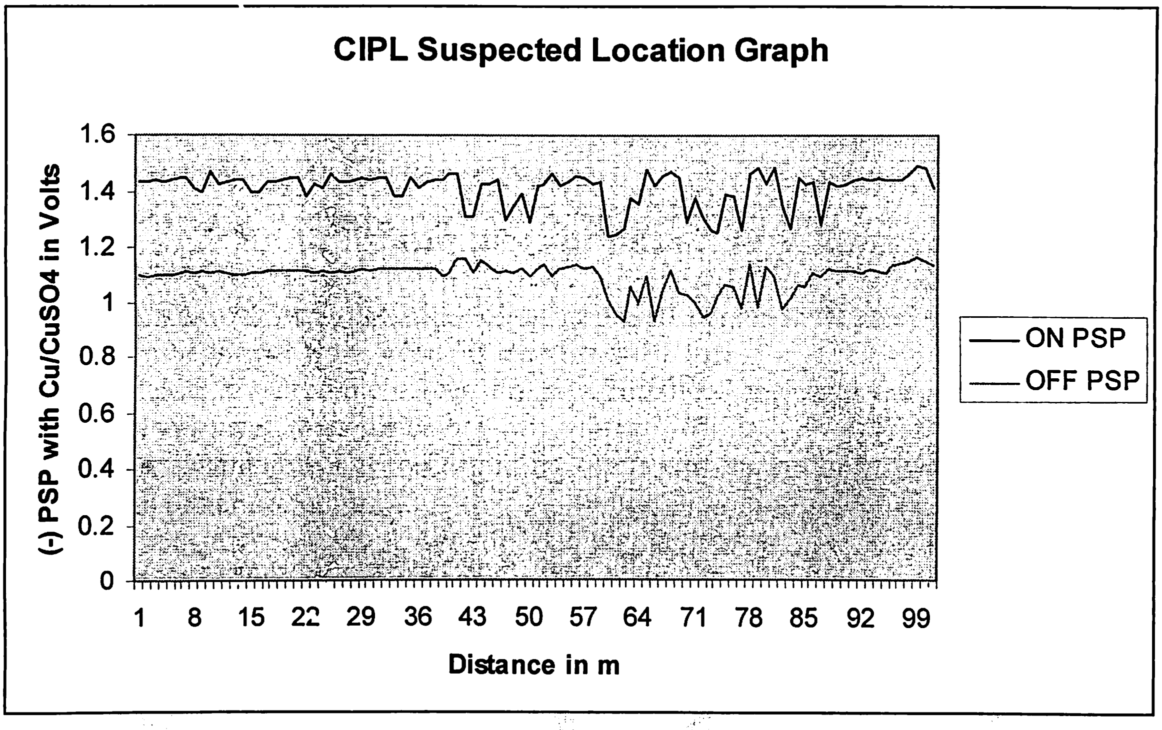


Fig 4.4 CIPL Suspected Location graph from 310.250 to 310.300m

4.11 DCVG Survey

Direct Current (dc) is applied to pipeline by existing / temporary cathodic protection system for determination of location and relative size of defects in coating by DCVG (Direct Current Voltage Gradient) Survey. With the help of this survey the following information about the pipeline can be inspected:

1. Coating fault epicenter location to within a 15 cm circle, which means that the excavation cost can be reduced.
2. The approximate severity of the coating fault can be established so that coating faults can be prioritized for repair.
3. The approximate corrosion behavior of the coating faults can be established to ease identification of those coating faults that do not have sufficient Cathodic Protection. The DCVG technique does not however, detect metal loss but identified sites where metal loss is possible.
4. Identification of where a coating fault gets its Cathodic Protection (CP) from, so that the vulnerability of a coating fault to being unprotected, if a CP source becomes inoperable can be established.
5. Identification of those coating fault which are discharging and picking up DC Traction Interference so that more effective mitigation techniques can be implemented.
6. Identification the interfering structures that rob CP from pipeline.
7. Establish the effectiveness of Insulating Flanges.
8. Identification of defective test posts at which Pipe to Soil potentials are routinely monitored.

9. Rapidly establish sections of pipeline that have a larger number of coating faults by studying the rate of decay of DCVG signal on the pipeline.

The data gathered by the DCVG technique is not absolute but relative and is not influenced by a series of parameters such as soil resistivity, depth of burial etc. whose effects must be taken into account to improve the accuracy of any data.

Survey Procedure to Locate Coating defects:

1. In surveying pipeline, the operator walks the pipeline route for testing pulsing voltage gradient at regular interval.
2. As a defect is approached, the milli voltmeter needle begins to respond to the pulse and pointing in the direction of current flow, which is towards the defect.
3. When the defect is passed the needle direction completely reverses and slowly decreases as the surveyor moves away from the defect.
4. By retracing toward defect, a position of the electrodes can be found where the needle shows no deflection in either direction.
5. The defect is then sited midway between the two electrodes.
6. This procedure is then repeated at right angles to the first set of observation.
7. Where the two midway positions cross each other is the position directly above the coating defect.

Surveying

Setting up the DCVG Signal

The most important parameter in ensuring an accurate survey and in determining the survey speed is the amplitude of the DCVG pulsed signal.

The interrupter should be connected into the electrical circuit shown in fig.

✓ The black terminal of the interrupter should be connected to the negative terminal of T/R unit. Keep T/R unit in Manual mode.

✓ The red terminal of the interrupter should be connected to the cable going to the pipeline.

✓ Polarity of the connection is important. If connection is wrong the interrupter will not switch the DC output. If this happen remedy is just reverse the terminal connections on the interrupter. The amplitude of signal strength is the difference between ON and OFF potential measured on the pipe using DCVG meter, whilst the interrupter is switching ON and OFF the applied source.

✓ The output signal from T/R unit along with interrupter should be less than 25 amperes.

✓ Adjustments beyond 25 amperes up to 50 amperes are possible but careful adjustment is necessary preferably using a scope meter. A pipeline requiring more than 25 amperes to get a good signal level over a 1 KM length is indicative of a very bad coating on pipeline.

✓ The amplitude of DCVG signal should at least 250 mV & no large than 1500 mV.

✓ Rapid decay of signal measured at two locations one kilometer apart would be on attenuation of signal amplitude with distance.

Adjustment to ensure a good signal level requires trial and error and patience but extra time spent in setting up the signal will give greater confidence in the quality of the survey, which usually can be achieved at greater speed than on pipelines with a poor signal.

Measurement of signal level at test posts are carried out in exactly the same way as measurements made to measure pipe-to-soil potential, except there are two measurements in this case:-

- From the copper wire or test post terminal to the soil alongside the test post.

- From the soil position alongside the test post to remote earth.

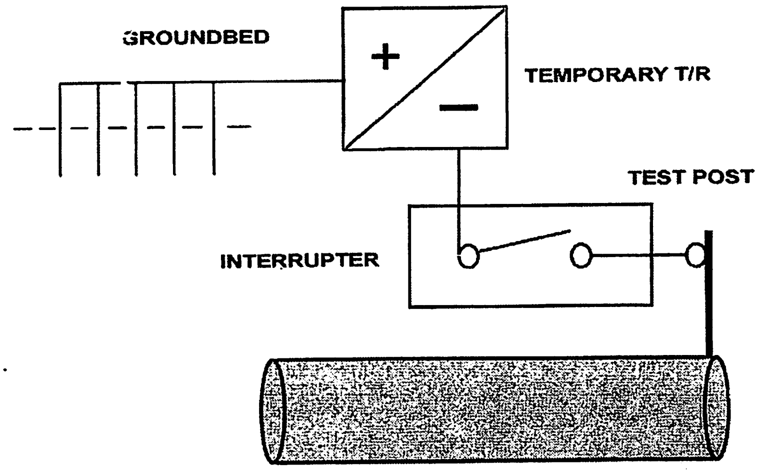


Fig 4.5 Temporary T/R and Ground-bed

Assembling the DCVG Equipment

- ✓ Probes are filled with copper sulphate solution.
- ✓ The DCVG meter is placed around the neck and waist so that the meter fits snugly on operator.
- ✓ Connecting leads are fitted into the meter and into the process to interconnect two probes with meter.
- ✓ The meter switch is then turned ON and the Range switch is adjusted.
- ✓ With the probe tips placed in the soil the bias to the right hand probe is switched ON.
- ✓ The bias to the left hand probe is not switched ON, it is a spare available if needed.

Operating Instructions

Finding a defect

Adjust the meter range switch to 100 mV range, and ensure that only one handle bias switch is ON adjusted to position 3. This is all that is necessary for normal surveying.
Place the probes, one in front of the other. Contact the soil with the probes approximately at 1.5 to 2 meter spacing. Turn the bias control potentiometer to bring the needle of the meter on to the scale. Keep the needle on the meter scale the whole time the probes are in contact with the soil. Look for the meter needle to be flicking in response to the pulsed DC. Lift the probes; step out from the test point at which the signal strength was previously measured. Move forward 2 paces and contact the ground with the probes. Use the bias if necessary to bring the meter needle on to the scale.
Look for a needle deflection. If there is no deflection then step out another two paces and then bring the needle on to the scale with the bias control. If there is a deflection, observe the needle to which direction the coating fault lies. If you are unsure either change to a lower meter scale or move the probe forward along the pipeline. The meter needle points to the probe, which is nearest to the defect.

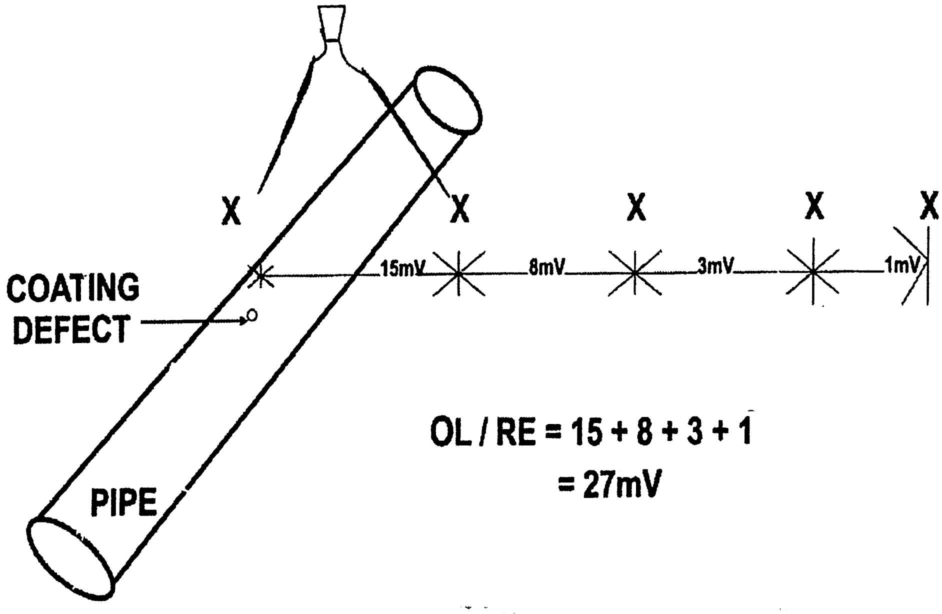


Figure 4.6 Over-line to Remote earth Potential

The Interrupter is OFF for longer than for what it is ON and when it is ON the current normally flows from the ground to towards the defect. It is the size and direction of the needle flick, or swing that we are interested in. It may be possible that the coating fault is small and lies behind us, so correct identification of the direction of the needle swing is important. Recognizing the direction of the current flow, as indicated by the needle flick will take a little time. If we have observed a deflection lift the probe which is closest to the coating fault and move it 0.5 meter towards the defect. Bring the second probe forward and place it where the first probe used to be. Keep moving forward in this manner.

As we move towards the defect, the amplitude of the deflection will increase so there may be a need to change to a higher meter range as required. When the coating fault is passed, the needle deflection is completely reverses and slowly decreases as we move away from the defect. We retrace our steps to the suspected coating fault position where the change in meter needle direction occurs. At the approximate null position, with the probes at about 1.5 meters apart observe any meter deflection. If the deflection is from left to right, move the left probe 15 cm to the right and retest. Keep doing this until there is no deflection. It may be necessary to reposition the right hand probe. At the point of no deflection, the coating fault location lies midway between the two probes locations. Scratch a mark on the ground at the midway position.

The above process of nulling the meter is to place the probe tips on the same line of equipotential around the defect. Because it is an equipotential line there is no voltage difference between the probe tips and no meter needle deflection. Now we turn through 90 degrees to work across the pipeline direction. Stand facing the mark in the ground and repeat the coating fault location process.

At the new Null position mark the midway position between the probes on the ground to cross the first mark. Recheck the first location by turning back to the original position and checking for the null. Where the two lines cross is above the center of the coating fault voltage gradient and is called the coating fault epicenter. As a final check, that the location is correct, place on probe at the epicenter and

the other about 1.5 meters away placed in turn at the four points of the compass. At each of the four locations the meter needle should indicate a direction of the coating fault epicenter. If this is not the case then the epicenter has been incorrectly located or the coating fault location is at on e end of the long crack in the pipe coating.
Place a numbered peg, or some means of indication at the coating fault location.

Determining the coating fault severity

Coating fault severity, which is related to its geometric size although there are other influencing factors is determined from electrical measurements taken at the coating fault epicenter. Place one probe tip at the coating fault epicenter and the other at arms length at 90 degrees to the pipeline direction. Adjust the meter range if necessary and the bias control so that the full meter needle deflection is on scale. Read the amplitude of the meter deflection in mill volt, in the same fashion as that for taking measurements at a test post.

For example, if on the 100 mV range and the deflection is from 10 mV in the OFF position and 95 mV in the ON position, the meter deflection is 85 mV.

Put the epicenter probe where the other probe is and move the other probe out at right angles about 2 meters. Observe the meter deflection. Add this reading to the first reading. Continue summing the deflection until the meter ceases to show any, or a small deflection, which indicates remote earth. During these measurements the bias control may need adjustment to keep the full meter needle movement on scale so that meter readings can be taken.

The total mill volt drop made by summing all the individual readings to remote earth is referred to as the "Overline to Remote Earth Potential" (OL/RE) and must be entered in the notebook against the appropriate coating fault number and distance. The Size/Importance of severity of a coating fault titled %IR is calculated by expressing the Overline to Remote Earth Potential as a percentage of the actual pipe to remote earth potential (the signal amplitude) on the pipeline at the defect.
Once all information about a coating fault has been logged continue surveying along the pipeline route. When leaving a coating fault location, keep the probe spacing at 0.5 to 1 meter, overlapping the probe locations until away from the voltage gradient and meter needle deflections cease. Close spacing is used to locate coating faults sited in close proximity to the first coating fault already located.
A special but common type of voltage gradient encountered during surveying has a long sausage shape, generated by longitudinal crown cracking in coal tar, ruffling in tapes, and micro-porosity in asphalt coatings or where many small coating faults occur in close proximity. Whilst this type of coating fault is often missed during CIPS or Pearson surveys, their presence can readily be recognized by DCVG technique because such coating faults have strong lateral voltage gradients.
The meter needles readings on the approach to a crack etc will be similar to those of a normal defect. The needle will deflect to the probe nearest the coating fault and will increase in size as the coating fault is approached. However, when past the epicenter a region of negligible needle deflection occurs before the needle swing reverses as the crack is passed. During the region of negligible needle movement, a check should be made of the voltage gradient at 90 degrees to the pipe direction, i.e. laterally, where a strong meter needle movement indicating a strong lateral gradient should be observed.

The beginning and end of the null, which indicates approximate length of the crack, should be marked and recorded. The overline to remote earth potential should be measured as normal but with readings taken at either end, if the crack is long.

Coating fault size, shape and location of the pipeline

A good indication of the coating fault size, shape and location around the circumference of the pipeline can be gained by plotting of the equipotential lines of the voltage gradient at a coating fault in the soil surface. Start by plotting at a point equivalent to 30% of the overline to remote earth potential. Track the equipotential line by nulling method around the coating fault epicenter all way back to the start point, placing markers on the way. The line will indicate the size and shape of the coating fault. The distance from the epicenter to the pipe centre line as determined by a pipe locator will determine whether a coating fault is on the bottom, side or top of the pipeline.

A small discrete coating fault on top of the pipe will appear as circular iso-potential shape. The same sized coating fault on the bottom of the pipe will appear as an ellipse, distorted to one side of the pipe center line.

Because the effect, the pipe itself has in distorting the iso-potential lines from the pipe center line, it is easier to determine the location of a coating fault around the circumference of a pipeline on large diameter pipelines than on smaller diameter pipelines.

An alternative way of determining the orientation of a coating fault is to carry out the four points of the compass readings at each location keeping the probe spacing the same for all four measurements. If the coating fault is on top of the pipe all four readings will be of similar amplitude. If the two readings to the side are much larger than those taken down the length of the pipeline then the coating fault is on the bottom segment of the pipeline. If one side reading is larger than the other then the coating fault is on that side of the pipeline.

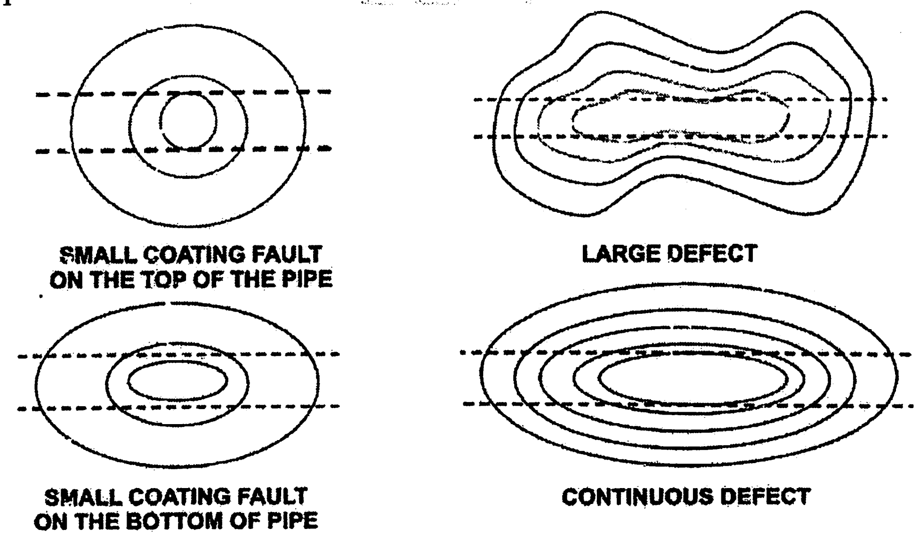


Fig 4.7 DCVG Shape Profiles

Now the project envisaged calculations to determine the coating fault severity:

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

Calculating the severity of the coating fault

The relative severity of the coating fault is expressed by the term of %IR drop, which is calculated using the formula:-

$$\text{Coating Fault Severity } \mathbf{(\%IR)} = \frac{\text{Fault Epicenter to Remote Earth } \mathbf{(OL/RE)} \times 100}{\text{Calculated Pipe to Remote Earth } \mathbf{(P/RE)}}$$

To be able to calculate the severity of the defect it is necessary to know the distance of defects and the DCVG signal strengths at test posts either side of the sector being surveyed.

The Pipe to Remote Earth Potential is calculated as follows:

$$\mathbf{P/RE = S_1 - \frac{dX\,(S_1 - S_2)}{D_2 - D_1}}$$

Where:

S_1 = Signal at upstream test post

dX = Distance between upstream test post and defect

D_2 = Distance of downstream test post

D_1 = Distance of Upstream test post

S_2 = Signal at downstream test post

Now result of CIPS is taken account here:

S. No.	Location (Chainage)		Signal at upstream (mV)	Signal at downstream (mV)	Length (m)	OL-RE at Defect location	REMARKS
	From	To					
1	300.0	300.030	1500	1500	30	-	Defects not found
2	306.8	306.085	1500	1500	50	40	Defect found at 306.813
3	308.440	308.470	1500	1500	30	320	Defects found at 308.453
4	308.490	308.530	1500	1500	40	70	Defects found at 308.498
5	308.63	308.690	1500	1500	60	35	Defects found at 308.645

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

6	308.76	308.80	1500	1500	40	-	Defects not found
7	309.260	309.295	1500	1500	35	-	Defect not found
8	310.25	310.30	1500	1500	50	-	Defect not found

Table: DCVG Survey on Suspected Locations

The Coating Fault Severity Grading is:-

0 - 5% **MINOR DEFECT**

5 – 15% **MODERATE DEFECT**

15% AND ABOVE **SEVERE DEFECT**

Now calculating the defect severity we prepare one more table:

Location (Chainage)	Signal Strength at Upstream TS (mV)	Signal Strength at Downstream TS (mV)	Distance of Upstream (d2) TS to Defect location (m)	Distance of Downstream (d1) TS to Defect location (m)	OL/RE (dx) at Defect location
306.813	1500	1500	810	154	40
308.453	1500	1500	442	568	320
308.498	1500	1500	480	512	70
308.645	1500	1500	654	467	35

Table: Coating Defect Severity Calculation

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

Location (Chainage)	Signal Strength at Upstream TS (mV)	Signal Strength at Downstream TS (mV)	Distance of Upstream (d2) TS to Defect location (m)	Distance of Downstream (d1) TS to Defect location (m)	OL/RE (dx) at Defect Location
306.813	150C	1500	810	154	40
308.453	1500	1500	442	568	320
308.498	150C	1500	480	512	70
308.645	1500	1500	654	467	35

4.12 Completion of the Survey

Upon completion of the survey all cover plates and accesses to test post wires shall be returned to their original condition. All rectifier settings shall be returned to their original settings before the survey. The ON pipe to soil potential at the nearest test post shall be measured to ensure that it has returned to that before the survey. At the end of the survey, any adjustments to rectifier settings that are not the same as those before the survey shall only be made by the Contractors Engineer under written instructions from the owner. Any damage to any pipeline right of way furniture such as test post, marker post, rectifiers, etc. either caused by contractor or by vandals or any intrusion or excavation on the right of way shall be reported to the owner in writing as soon as possible.

4.13 REFURBISHMENT OF DEFECTS FOUND DURING SURVEYS:

After completion of the survey and analysis of the report, the size and location of the defects are to be marked as Severe, Moderate & Minor for each region. All the defects are to be verified with probability of detection 80%, and rectify all defects (Severe, Moderate & Minor) by excavating the pipeline [exposing the pipe surfaces] as per the requirement to repair the defects, removal of defective coatings, cleaning & repairing using coating materials, holiday checking, backfilling & restoration, and resolving the dispute with the formers for any compensation.

Procedure for Coating Repair:

The job is to be carried out as per the stage inspection format:

A. EXCAVATION:

- Without regard the soil condition or topography of the ground, the trench shall be excavated and finished to the dimensions, a view to expose the pipeline and to provide for sufficient working space for carrying out the work of manual removal of old coat and wrapping all round the circumference of pipeline. The free movement while coating with a coating machine by coating gang and enable the gang freely removes the old coat and wrap, to carry out cleaning, new priming, coating etc. Safety of working person as well as pipeline shall be taken into consideration. The pipeline excavated length shall be such as to carry out the intended length of coat with required side overlapping to be provided.
- The site engineer is warned that while excavation job is carried out, the pipeline, which is carrying highly explosive natural gas should not be damaged by chiseling, hammering, etc. shall not be allowed on the pipeline surface in any case. The person or contractor shall be responsible for all necessary fire hazards precautions and for taking actions to prevent any damage whatsoever to the pipeline. The contractor shall be responsible for taking all preventive measures keeping adequate number of fire extinguishers duly charged and in good working condition near the worksite.

  Contractor shall exercise care to see that the fresh soil recovered from trenching operation intended to be used for backfilling over the laid pipe in the trench is not mixed with loose debris or foreign matter. The excavated earth shall be deposited sufficiently away from the trench sides, in such a manner so as not to collapse on the trench sides and also not to obstruct other operation.

- Maximum unsupported length of pipeline shall not exceed 10 meters. If the some exceeds 10mtrs, the contractor has to provide supports of every 6-8 meters, with gunny bags, sand bags, wooden bags, etc.
- In most of the sectionalizing valve stations [SV] and Radio-Repeater stations/Intermediate Pigging stations/concreting has been done. In case of any coating defect in those areas the some has to be excavated by dismantling the concreting.

B. WITNESSING OF THE DEFECT:
The "EIC/SIC" of the respective region will witness the defect with respect to the reported one of that of survey and accordingly the report will be signed jointly by the contractor. The defected area of the coating to be photographed with proper numbering of the defects and the copy of the defects and the copy of the some should be a part of final report.

4.14 Types of Coating Repair:

Generally two type of coating repair work is used in GAIL India.

1. Coating repair using cold applied tape
2. Coating repair using –PERP

Coating – Repair Using Cold Applied Tape:

[A] Surface Preparation:

1. The old/damaged coating shall be totally removed carefully with scrappers.

2. After the coating is removed, the pipe-surface shall be prepared by hand-brush/emery-paper/scrappers etc or a combination of all above with full removal of loose point, coating, rust, oil, grease, dirt, etc. to the entire satisfaction.

[B] Application of Primer:

1. Priming shall be carried within immediately after cleaning/surface-preparation of the pipeline. Before applying the primer, the pipe-surface shall be cleaned with a clean cloth ensuring that the surface is free from dust particles.

2. Stir the primer in its original container and apply a uniform coat of primer to the cleaned surface of the pipeline (and where applicable to the adjacent mill – coating) with a good quality point brush. Consumption of the primer is approximately 0.2 liters per sq. meters of surface.

3. The primer is to be allowed to dry for thirty minute, during drying time of the primer; enough precautions must be taken to ensure that no dust particles are falling on the fresh primed surface.

4. Thumb test is to be done and is found ok, wrapping may be started within 8 hours of application of primer.

[C] Wrapping:

1. **Inner Wrap:** Wrap diesoline tape S 25 HT hand – wrapping machine under proper tension and without wrinkles spirally around the pipe into the sticky primer with grey side of the tape facing the steel surface overlap on to the adjoining factory applied coating.

2. **Outer Wrap:** Wrap the densolene tape R 25 HT with under the proper tension and without wrinkles spirally around the pipe with butyl adhesive facing the inner wrap with a minimum of 50% overlap. Ensure that the outer wrap completely covers the inner wrap.

The cold applied tapes shall be kept in shade and the coated pipeline section shall also be protected from direct sunlight by using tarpolene/ polythene sheet/ gunny bags filled with soil, if not backfilled immediately.

[D] For Tees/Bends:

1. Cut the inner wrap in 50 mm width and apply in small piece of length (as required) manually with 50% overlap and with good tension.

2. Apply the outer wrap in similar manner and two cross strips of outer wrap on the final outer wrap.

Coating Repair Using PERP:

[A] Surface Preparation:

1. The loose/damaged coating shall be totally removed carefully with scrappers.

2. After the coating is removed, Clean the pipe surface and 50 mm of adjacent mill coating using – brush/emery – paper/scrappers.

[B] PERP – Patch Application:

1. Measure the holiday and cut the PERP-patch from PERP-roll consideration 50 mm overlapping from all sides.

2. Round off the edges of the PERP Patch

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

3. Pre – heat the entire repair area to approximately 60 – 70 deg cent.
4. Apply the filler mastic to fill the holiday then heat the mastic and smooth it down with a paint-scrapper.
5. The adhesive side of PERP-patch shall be flame brushed until the adhesive becomes glossy.
6. Apply the pre-cut PERP-patch over the damaged area and heat until the adhesive melts roll out.
7. Complete the installation by smoothing with gloved hand or roller to avoid air entrapments.
8. Repeat the post heating and smoothing operation three times.

4.14 Holiday Testing:

Test the coated surface with a holiday detector at 20 kV for any imperfections. The test probes of the holiday detector must touch the surface of the wrapping. The same has to be done in the presence of owner-personal.

The repaired coating areas are to be photographed

4.15 Backfilling and Final Restoration:

The backfilling operation shall be performed in such a manner as to provide firm support and avoid any injury at damage to be new coating, wrapping and pointing. Suitable soft selected earth, free from lumps, etc. shall be used for providing the soft good earth padding up to 200 mm above the top of the pipe [if soft good earth is not sufficient within the excavated soil then the supply of good earth/sand up to 200mm from the top of the pipe]. Prior to backfilling of the trench, the contractor shall insure that the trench shall be cleaned of all spills of old and new coating material which may be lying inside the trench subsequent to coating operations. The coating spills removed from trench shall be disposed off suitably outside the row. The soft earth pad for the pipe shall be neatly covered over the ditch and there on to a minimum height of 0.200 meters above the adjacent ground.

The entire field/ground shall be brought to the original level and conditions which were existing prior to taking up to the job. All fencing, bunds, and other structure shall be restored to their original condition, i.e. entire ROW shall be smoothened to a manner satisfactory to he landowner/tenant.

CHAPTER 5

RESULT & DISCUSSION

5.1 General

GAIL has been conducted the coating monitoring survey to check the health of GREP pipeline coating. During this period I was fully involved with this survey and collected the data which has been generated during this survey. Survey agency completed this survey for few locations and rest of the section of GREP pipeline is being planned. With the help of these surveys we can find out the defect location, defect severity so we can refurbish the pipe coating according to the defect nature. Corrtech is the survey agency, carried out the CIPL and DCVG surveys. These surveys have been completed for 200 km section of GREP pipeline successfully. The defects which were found during the survey are repaired. Here I'm including the result for 10 kms of pipeline section under my study (Mathura-Agra region).

CIPL results nothing but they just show the PSP reading and its execution in form of graph. On the basis of these graphs we find out the suspected locations.

5.2 Recording Data before and after survey

5.2.1 before Survey

Before these survey starts we record the data from given instrument, its PSP level is measured, line temperature, pressure these does not effect on external environment. PSP recorded quarterly, this gives the overall view of pipeline.

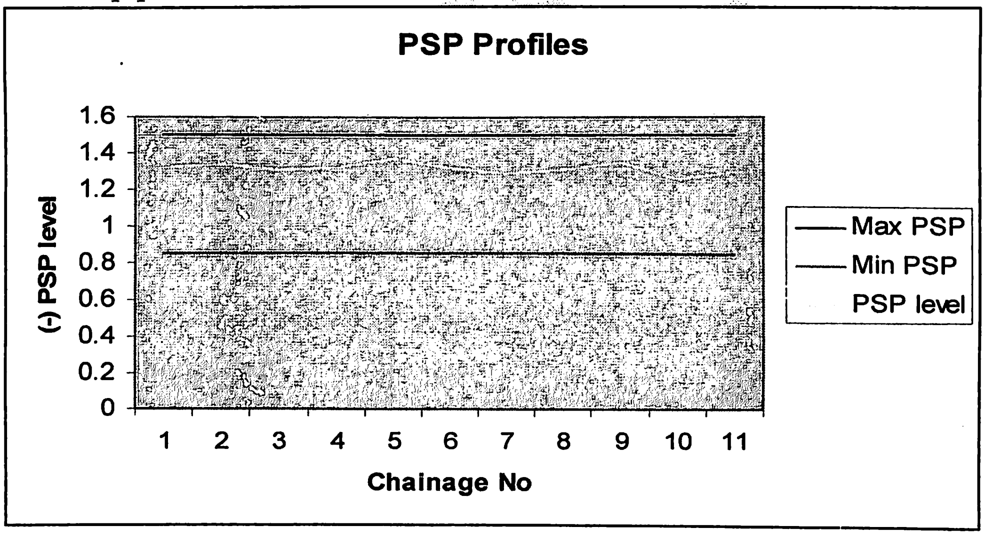


Fig 5.1 PSP profiles from 300.0 Chainage to 310.0 Chainage

These profiles give the overall information about system, but it's not able to give the defect information, so at the time of survey we check our various parameters which used to protect our pipeline, as current applied by T/R unit, level of max and minimum level.

Voltage measured at every meter distance: vary 0.85 to 1.5 (-)

Voltage gradient; check out from 2 readings of voltage

Line pressure: 18 kg/cm^2

5.2.2 after Survey

For Chainage 306.124 (after Surveying)

PSP Level 0.926 (-) V OFF reading 1.271 (-) V in ON reading

Voltage gradient 0.042(-) in OFF reading and 0.066 (-) in ON reading

5.2.3 after repairing

When survey has finished now we have already locate exact defect location, so now we will go for repair according to its severity, when once repair has complete now we record and check data is in desired limit or not, Firstly we applied holiday testing in which sound waves of 20 KV identify the defect location, if any spark will be there it means some disbonding is there, after successful completion we record data of that location where this defect has found. We take result of Chainage 306.124 and show the collected data

PSP level: 1.121 (-) V in OFF reading and 1.296 in ON reading

Voltage gradient 0.007 (-) V in OFF reading and 0.09(-) V in ON readings

5.3 RESULTS & DISCUSSION

I was associated with survey agency for 10 kms of inspection of line from **chaninage 300.000 m to chainage 310.000 m**. A result includes both CIPL and DCVG surveys data. During the CIPL surveys there are number of suspected location have been found. Those suspected locations are:

S No.	Pipeline Chainage (KM.)	Chainage to (KM.)	Spot Length (in mtr.)
1	300.0	300.030	30
2	306.8	306.085	50
3	308.440	308.470	30
4	308.490	308.530	40
5	308.63	308.690	60
6	308.76	308.80	40

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

7	309.260	309.295	35
8	310.25	310.300	50

After getting the suspected location DCVG has been conducted to locate the defect locations with the help of CIPL out put. The natures of defects found during DCVG are:

S. No	Location (Chainage)		Signal at upstream (mv)	Signal at downstream (mv)	Length (m)	OL-RE at Defect location	REMARKS
	From	To					
1	300.0	300.030	1500	1500	30	-	Defects not found
2	306.8	306.085	1500	1500	50	40	Defect found at 306.813
3	308.440	308.470	1500	1500	30	320	Defects found at 308.453
4	308.490	308.530	1500	1500	40	70	Defects found at 308.498
5	308.63	308.690	1500	1500	60	35	Defects found at 308.645

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

6	308.76	308.80	1500	1500	40	-	Defects not found
7	309.260	309.295	1500	1500	35	-	Defect not found
8	310.25	310.30	1500	1500	50	-	Defect not found

This table describes about such location wherever the defects have been found and wherever not found. Now with the help of DCVG coating severity formula, it becomes easy to find out the nature of defects whether it is sever, moderate, major or minor. Here I'm presenting the result of such location where I got some minor and sever defects.

Location (Chainage)	**P/RE = S1-{dx [(S1 – S2)/ (d2 – d1) (mv)**	**%IR = (Defect epicenter to remote Earth *100)/ calculated pipe to remote earth**	**Defect severity**
306.813	1500	2.66	Minor

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

308.453	1500	21.33	Severe
308.498	1500	4.66	Minor
308.645	1500	2.33	Minor

DISCUSSION

As far we see how to conduct CIPL and DCVG surveys and result found during these surveys. These surveys help to locate the coating defect or suspected locations, to find out the nature of the defect and their repairment. % IR drop has been recorded at 1 m interval during CIPL survey and on the basis of recorded IR drop, find out the suspected locations. After finding the suspected location DCVG has been carried out according to the procedure. Millimeter deflections help to find out the exact location of defect. Coating severity calculation has been done for these locations for finding out the nature of the defects and then those founded defects has been refurbish accordingly the need of the defects. All the work has been carried out according to the GUIDELINES and STANDARDS.

But During the analysis it was found that PSP level recorded, is above the protection level or pipe was over protected as NACE recommended keeping PSP level for protection of pipeline due to corrosion. NACE recommend to keep PSP level (-0.85) V to (-1.1V) for efficient protection of pipeline. If PSP level is too high to protect the pipeline it count as an OVER protection for pipeline which causes coating defect as cathodic disbondment of coating. For this pipeline, it appears that the PSP level is (-0.85) V to (-1.5) which is beyond the NACE recommendations for PSP level, that is why the coating disbondment problem has occurred. So at the end of the discussion it was found that PSP level to protect the pipeline should be as NACE recommends minimizing the coating problem like coating disbondment.

CHAPTER 6

CONCLUSION & RECOMMANDATIONS

6.1 Conclusion

Corrosion costs the industry billion of rupees in India. With liberalization of Indian economy, the industrial revolution sprang a surprise in the pipe industry with a great demand of pipelines. The pipe manufacturers, pipe coaters, and pipe laying companies have seen a tremendous growth in the last decade and in the near future it is going to multiply ten times. India is now a big industry in pipeline both for crude transportation and supply of natural gas.

The company like IOCL and GAIL has tremendous pipeline Network, they required more security from corrosion. The pipeline industry is confronted with a wide range of corrosion problems. External surfaces of the pipelines in contact with soils, waters, or an atmospheric environment, and the interior surfaces of pipelines which are in contact with a potentially corrosive material being carried by the pipeline, are subject to most of the basic corrosion processes and most of the forms of corrosion attack. All forms of installations need protection in order to enhance their life. Material selection is the first and foremost method of corrosion protection. A material to be selected must have lower corrosion rate in the said environment. However, cost consideration is an important factor. Thus the choice should be a relatively cheaper material with low reactivity.

Regular inspection and condition monitoring of underground Oil & Gas Pipelines is essential to ascertain the health of pipeline coating. The various monitoring techniques that can be used for health checkup of the pipeline system are installation of corrosion sensing probes, thickness survey, PSP monitoring, current drainage survey, Pearson Survey, CAT, CIPL on-off survey, DCVG survey, Intelligent Pigging etc. All these techniques provide information or data which can be utilized to assess the health of the pipeline

CIPL On-Off survey and DCVG Survey are one of the most effective techniques in achieving the above results. GAIL (India). CIPL surveys are used to identify the levels of protection that exist along pipelines and DCVG is pinpointing method which detect the exact defect location. DCVG can not used for whole pipeline because it will be time consuming, required more man power and infeasible.

CIPL and DCVG survey are not able to detect coating internal defects, means internal surface of coating which adheres with pipe surface, if any defect set up there then we can not predict with the help of available techniques.

CIPL instrument measures the gradients in both the On/Off condition allowing later calculation of DCVG Survey. As the spacing of the surveys is 1 meter and defect epicenters are not located it may be that the resultant calculations are entirely representative of the defect size, the information obtained gives a very good indication of the coating and cathodic protection conditions in a single pass survey.

Coating inspection and testing has already scheduled quarterly or half in year, but the survey including CIPL and DCVG survey has scheduled once in five years.

Once coating Fault location is find out then we started repair work according to their defect severity.

Patch Repair and Cold Applied Tape repair are practically and economically suitable approach for coating repair. For minor and moderate defect we applied patch repair and for severe Cold applied tape.

At last in this project we find out in my calculations 3 minor and one 1 severe and all defects are repair with patch applications. NACE RP 0185 standard is used for 3 layer Polyethylene Coatings.

6.2 Recommendations

The recommendations are always set up for our work it's related to material environment, processing condition, design, operations, maintenance etc. These recommendations are giving to avoid any recurrence during in operation our system. The recommendations are:

- Coating inspection and survey is carried out as per schedule.
- Coating need to be repaired at defect locations.

- It is recommended that the entire section of pipeline between Vijaipur and Sone Ka Gurja may be electrically isolated in to three independent sections at the IP stations.

- Before going on routine survey firstly pipe to soil potential (PSP) survey carried out.

- For avoiding failures in a pipeline, a company has to have a well designed inspection and maintenance programme.

- The choice of a technique shall be made after taking into consideration the pipeline operating parameters, the type of CP, pipeline characteristics, the end result and objective that is desired from a particular technique to be applied.

- Operating pressure in the pipeline should be continuously monitored and pressure surging should be avoided.

- To ensure correct interpretation of data in areas of stray current interaction, a simultaneous "static" pipe to soil potential is always recorded.

- Current interrupters are set up in synchronization with the datalogger commonly at a switching ratio of 4 : 1 On : Off to prevent pipeline depolarization. A timing cycle of 0.8 seconds On and 0.2 Off is commonly adopted.

- To check the accurate deflection of mill voltmeter at suspected location in the DCVG survey.

- Proper set up of all equipments for carrying survey.

- Extra care and vigilance is required to be taken by the personnel inspecting the pipe surface during coating re-visioning work of operating pipelines and coating of pipes to ensure that no corrosion patch goes unnoticed anywhere on the pipe surface.

- The accuracy of the instrument and the skill of the operator allow detailed investigation of the location and the collected data can be interpreted to categorize many defects along the route and prioritise on coating repairs, so operator should be experienced.

- Before repair work at coating defects, surface preparation include cleaning of surface, primer application required.

- Patch repair with mastic application is recommended generally with minor and moderate defects, and some time can be applied on severe defects.

- Cold applied tape or inner and outer wrap is recommended with serious problem as coating disbondment, and its failure.

- Different types of tapes are using for coating repair work given in Appendix C.

- Once coating repaired then Holiday inspection should be recommended to check out your repair work properly or not.

- Effective backfilling exercise care to minimize damage in the ditch, so it is recommended at the time backfilling soft clay on pipe surface.

- Standards like NACE and OISD must be strictly followed and there should be no slackness to ensure good health of the pipeline system.

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

- Coating monitoring is difficult task should be handled by experienced person, who had undergone some training programme for this purpose.

- Coating defect directly affect the performance of Cathodic Protection so it is recommended to repair coating defects as soon as possible.

- Pipeline different accessories should be monitored properly they can affect directly or indirectly on coating performance.

- Safety engineer is always allowed or posted at the excavation period when coated pipe repaired.

- The ON/OFF potential measurements methods provide good information for determination of remoteness of anode ground beds and performance of insulating joints, cased crossings and overall Cathodic protection system.

- GAIL recommended CIPL followed by DCVG survey, because this combination is time saving, economic and efficient.

- Scheduled coating inspection required as peel test, hardness, abrasion test etc has recommended knowing the exact information about coating health.

- All instrument using in inspection and survey as half cell, voltmeters etc are properly calibrated.

- All coatings to be though roughly checked for defect, regular monitoring of Cathodic protection system to be adopted.

- At last for efficient monitoring proper care of pipeline, and scheduled work being carried out.

- The PSP level should be in accordance with NACE recommendations. The recommended range should be -0.85 to -1.1 volts, in order to avoid coating defects, like Disbonding as found in previous service, due to over protection of pipeline

REFERENCES

1. Report of GREP Pipeline CIPL Survey and DCVG Survey.
2. Peabody A.W., Control of Pipeline Corrosion, published by NACE, Houston 1967.
3. John Morgan, Cathodic Protection, published by NACE, Houston, 1967.
4. GTI Manual, GAIL (India) Limited.
5. NACE Standards for Pipeline Corrosion,
6. Mo Mohitpour, Jason Szaba, "Pipeline Operation & Maintenance-A Practical Approach", published by ASME PRESS, New York, 2005
7. Protective coatings and lining for corrosion protection by NACE India section
8. Pipeline corrosion training manual by GAIL.
9. Pipeline rules of thumb handbook.
10. Google.com

APPENDIX (data gathered during surveys)

CHAINAGE	OFF PSP(-V)	ON PSP(-V)		
300	0.982	1.254	0.85	1.5
300.001	0.907	1.273	0.85	1.5
300.002	0.969	1.249	0.85	1.5
300.003	1.070	1.325	0.85	1.5
300.004	1.129	1.308	0.85	1.5
300.005	1.108	1.357	0.85	1.5
300.006	1.101	1.365	0.85	1.5
300.007	1.105	1.344	0.85	1.5
300.008	1.067	1.349	0.85	1.5
300.009	1.140	1.319	0.85	1.5
300.01	1.126	1.349	0.85	1.5
300.011	1.101	1.374	0.85	1.5
300.012	1.102	1.356	0.85	1.5
300.013	1.106	1.358	0.85	1.5
300.014	1.126	1.302	0.85	1.5
300.015	1.142	1.382	0.85	1.5
300.016	1.102	1.332	0.85	1.5
300.017	1.108	1.364	0.85	1.5
300.018	1.108	1.313	0.85	1.5
300.019	1.108	1.378	0.85	1.5
300.02	1.104	1.376	0.85	1.5
300.021	1.104	1.355	0.85	1.5
300.022	1.112	1.354	0.85	1.5
300.023	1.108	1.368	0.85	1.5
300.024	1.103	1.328	0.85	1.5
300.025	1.103	1.364	0.85	1.5
300.026	1.129	1.324	0.85	1.5
300.027	1.150	1.351	0.85	1.5

300.028	1.107	1.379	0.85	1.5
300.029	1.101	1.330	0.85	1.5
300.03	1.109	1.354	0.85	1.5
300.031	1.147	1.317	0.85	1.5
300.032	1.163	1.360	0.85	1.5
300.033	1.098	1.376	0.85	1.5
300.034	1.108	1.352	0.85	1.5
300.035	1.113	1.366	0.85	1.5
300.036	1.185	1.313	0.85	1.5
300.037	1.165	1.391	0.85	1.5
300.038	1.108	1.308	0.85	1.5
300.039	1.103	1.386	0.85	1.5
300.04	1.118	1.366	0.85	1.5
300.041	1.154	1.363	0.85	1.5
300.042	1.105	1.303	0.85	1.5
300.043	1.108	1.309	0.85	1.5
300.044	1.095	1.379	0.85	1.5
300.045	1.101	1.345	0.85	1.5
300.046	1.178	1.348	0.85	1.5
300.047	1.108	1.311	0.85	1.5
300.048	1.101	1.340	0.85	1.5
300.049	1.148	1.387	0.85	1.5
300.05	1.169	1.318	0.85	1.5
300.051	1.164	1.381	0.85	1.5
300.052	1.102	1.302	0.85	1.5
300.053	1.105	1.376	0.85	1.5
300.054	1.125	1.344	0.85	1.5
300.055	1.160	1.371	0.85	1.5
300.056	1.112	1.394	0.85	1.5
300.057	1.103	1.310	0.85	1.5

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

300.058	1.101	1.389	0.85	1.5
300.059	1.185	1.370	0.85	1.5
300.06	1.168	1.337	0.85	1.5
300.061	1.101	1.343	0.85	1.5
300.062	1.199	1.322	0.85	1.5
300.063	1.159	1.339	0.85	1.5
300.064	1.153	1.308	0.85	1.5
300.065	1.102	1.321	0.85	1.5
300.066	1.102	1.398	0.85	1.5
300.067	1.168	1.359	0.85	1.5
300.068	1.149	1.321	0.85	1.5
300.069	1.103	1.318	0.85	1.5
300.07	1.109	1.315	0.85	1.5
300.071	1.158	1.301	0.85	1.5
300.072	1.140	1.328	0.85	1.5
300.073	1.115	1.348	0.85	1.5
300.074	1.153	1.369	0.85	1.5
300.075	1.104	1.323	0.85	1.5
300.076	1.108	1.334	0.85	1.5
300.077	1.104	1.328	0.85	1.5
300.078	1.140	1.350	0.85	1.5
300.079	1.106	1.329	0.85	1.5
300.08	1.101	1.393	0.85	1.5
300.081	1.129	1.376	0.85	1.5
300.082	1.116	1.313	0.85	1.5
300.083	1.106	1.321	0.85	1.5
300.084	1.088	1.335	0.85	1.5
300.085	1.150	1.308	0.85	1.5
300.086	1.133	1.354	0.85	1.5
300.087	1.114	1.328	0.85	1.5

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

300.088	1.109	1.342	0.85	1.5
300.089	1.084	1.320	0.85	1.5
300.09	1.120	1.359	0.85	1.5
300.091	1.101	1.333	0.85	1.5
300.092	1.107	1.344	0.85	1.5
300.093	1.157	1.312	0.85	1.5
300.094	1.146	1.369	0.85	1.5
300.095	1.120	1.350	0.85	1.5
300.096	1.106	1.311	0.85	1.5
300.097	1.106	1.323	0.85	1.5
300.098	1.101	1.394	0.85	1.5
300.099	1.124	1.328	0.85	1.5
300.1	1.116	1.317	0.85	1.5
300.101	1.106	1.328	0.85	1.5
300.102	1.108	1.317	0.85	1.5
300.103	1.184	1.309	0.85	1.5
300.104	1.180	1.362	0.85	1.5
300.105	1.198	1.332	0.85	1.5
300.106	1.106	1.341	0.85	1.5
300.107	1.172	1.313	0.85	1.5
300.108	1.139	1.348	0.85	1.5
300.109	1.155	1.313	0.85	1.5
300.11	1.104	1.319	0.85	1.5
300.111	1.162	1.384	0.85	1.5
300.112	1.115	1.386	0.85	1.5
300.113	1.145	1.318	0.85	1.5
300.114	1.102	1.324	0.85	1.5
300.115	1.134	1.307	0.85	1.5
300.116	1.152	1.300	0.85	1.5
300.117	1.132	1.317	0.85	1.5

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

300.118	1.101	1.330	0.85	1.5
300.119	1.181	1.369	0.85	1.5
300.12	1.186	1.392	0.85	1.5
300.121	1.189	1.393	0.85	1.5
300.122	1.107	1.394	0.85	1.5
300.123	1.084	1.378	0.85	1.5
300.124	1.144	1.360	0.85	1.5
300.125	1.126	1.321	0.85	1.5
300.126	1.109	1.333	0.85	1.5
300.127	1.107	1.308	0.85	1.5
300.128	1.182	1.362	0.85	1.5
300.129	1.106	1.367	0.85	1.5
300.13	1.102	1.302	0.85	1.5
300.131	1.088	1.330	0.85	1.5
300.132	1.183	1.303	0.85	1.5
300.133	1.167	1.301	0.85	1.5
300.134	1.151	1.306	0.85	1.5
300.135	1.109	1.316	0.85	1.5
300.136	1.106	1.376	0.85	1.5
300.137	1.135	1.327	0.85	1.5
300.138	1.109	1.338	0.85	1.5
300.139	1.102	1.346	0.85	1.5
300.14	1.162	1.300	0.85	1.5
300.141	1.145	1.314	0.85	1.5
300.142	1.188	1.308	0.85	1.5
300.143	1.107	1.322	0.85	1.5
300.144	1.145	1.315	0.85	1.5
300.145	1.123	1.391	0.85	1.5
300.146	1.101	1.310	0.85	1.5
300.147	1.109	1.383	0.85	1.5

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

300.148	1.166	1.383	0.85	1.5
300.149	1.122	1.326	0.85	1.5
300.15	1.108	1.331	0.85	1.5
300.151	1.106	1.344	0.85	1.5
300.152	1.101	1.306	0.85	1.5
300.153	1.126	1.330	0.85	1.5
300.154	1.101	1.333	0.85	1.5
300.155	1.105	1.342	0.85	1.5
300.156	1.167	1.326	0.85	1.5
300.157	1.137	1.381	0.85	1.5
300.158	1.196	1.362	0.85	1.5
300.159	1.181	1.300	0.85	1.5
300.16	1.199	1.317	0.85	1.5
300.161	1.101	1.304	0.85	1.5
300.162	1.158	1.352	0.85	1.5
300.163	1.136	1.313	0.85	1.5
300.164	1.137	1.301	0.85	1.5
300.165	1.164	1.392	0.85	1.5
300.166	1.102	1.320	0.85	1.5
300.167	1.194	1.362	0.85	1.5
300.168	1.139	1.392	0.85	1.5
300.169	1.151	1.369	0.85	1.5
300.17	1.180	1.313	0.85	1.5
300.171	1.178	1.332	0.85	1.5
300.172	1.146	1.376	0.85	1.5
300.173	1.139	1.395	0.85	1.5
300.174	1.191	1.328	0.85	1.5
300.175	1.147	1.312	0.85	1.5
300.176	1.184	1.327	0.85	1.5
300.177	1.165	1.305	0.85	1.5

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

300.178	1.193	1.342	0.85	1.5
300.179	1.147	1.345	0.85	1.5
300.18	1.171	1.370	0.85	1.5
300.181	1.152	1.381	0.85	1.5
300.182	1.124	1.358	0.85	1.5
300.183	1.165	1.393	0.85	1.5
300.184	1.192	1.312	0.85	1.5
300.185	1.184	1.323	0.85	1.5
300.186	1.153	1.333	0.85	1.5
300.187	1.165	1.380	0.85	1.5
300.188	1.187	1.327	0.85	1.5
300.189	1.160	1.376	0.85	1.5
300.19	1.148	1.312	0.85	1.5
300.191	1.169	1.337	0.85	1.5
300.192	1.161	1.388	0.85	1.5
300.193	1.182	1.308	0.85	1.5
300.194	1.114	1.373	0.85	1.5
300.195	1.198	1.358	0.85	1.5
300.196	1.198	1.393	0.85	1.5
300.197	1.103	1.325	0.85	1.5
300.198	1.178	1.399	0.85	1.5
300.199	1.161	1.351	0.85	1.5
300.2	1.101	1.300	0.85	1.5
300.201	1.109	1.391	0.85	1.5
300.202	1.117	1.398	0.85	1.5
300.203	1.157	1.372	0.85	1.5
300.204	1.146	1.390	0.85	1.5
300.205	1.180	1.387	0.85	1.5
300.206	1.195	1.319	0.85	1.5
300.207	1.175	1.379	0.85	1.5

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

300.208	1.112	1.382	0.85	1.5
300.209	1.197	1.397	0.85	1.5
300.21	1.172	1.315	0.85	1.5
300.211	1.184	1.355	0.85	1.5
300.212	1.194	1.333	0.85	1.5
300.213	1.180	1.371	0.85	1.5
300.214	1.159	1.370	0.85	1.5
300.215	1.148	1.387	0.85	1.5
300.216	1.171	1.306	0.85	1.5
300.217	1.101	1.310	0.85	1.5
300.218	1.159	1.345	0.85	1.5
300.219	1.167	1.381	0.85	1.5
300.22	1.130	1.350	0.85	1.5
300.221	1.152	1.349	0.85	1.5
300.222	1.111	1.395	0.85	1.5
300.223	1.117	1.369	0.85	1.5
300.224	1.159	1.377	0.85	1.5
300.225	1.149	1.378	0.85	1.5
300.226	1.119	1.383	0.85	1.5
300.227	1.169	1.366	0.85	1.5
300.228	1.109	1.308	0.85	1.5
300.229	1.102	1.354	0.85	1.5
300.23	1.169	1.386	0.85	1.5
300.231	1.170	1.361	0.85	1.5
300.232	1.192	1.399	0.85	1.5
300.233	1.102	1.373	0.85	1.5
300.234	1.103	1.319	0.85	1.5
300.235	1.177	1.309	0.85	1.5
300.236	1.148	1.335	0.85	1.5
300.237	1.155	1.333	0.85	1.5

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

300.238	1.117	1.367	0.85	1.5
300.239	1.106	1.396	0.85	1.5
300.24	1.145	1.387	0.85	1.5
300.241	1.120	1.395	0.85	1.5
300.242	1.104	1.393	0.85	1.5
300.243	1.131	1.356	0.85	1.5
300.244	1.197	1.323	0.85	1.5
300.245	1.180	1.304	0.85	1.5
300.246	1.136	1.390	0.85	1.5
300.247	1.108	1.309	0.85	1.5
300.248	1.196	1.369	0.85	1.5
300.249	1.103	1.378	0.85	1.5
300.25	1.112	1.356	0.85	1.5
300.251	1.125	1.306	0.85	1.5
300.252	1.108	1.351	0.85	1.5
300.253	1.185	1.354	0.85	1.5
300.254	1.184	1.304	0.85	1.5
300.255	1.183	1.306	0.85	1.5
300.256	1.199	1.335	0.85	1.5
300.257	1.171	1.320	0.85	1.5
300.258	1.182	1.354	0.85	1.5
300.259	1.183	1.326	0.85	1.5
300.26	1.141	1.377	0.85	1.5
300.261	1.199	1.363	0.85	1.5
300.262	1.196	1.352	0.85	1.5
300.263	1.119	1.309	0.85	1.5
300.264	1.108	1.337	0.85	1.5
300.265	1.136	1.333	0.85	1.5
300.266	1.106	1.358	0.85	1.5
300.267	1.154	1.397	0.85	1.5

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

300.268	1.117	1.331	0.85	1.5
300.269	1.198	1.346	0.85	1.5
300.27	1 193	1.337	0.85	1.5
300.271	1 103	1.396	0.85	1.5
300.272	1.115	1.321	0.85	1.5
300.273	1.105	1.361	0.85	1.5
300.274	1.189	1.336	0.85	1.5
300.275	1.104	1.343	0.85	1.5
300.276	1.176	1.329	0.85	1.5
300.277	1.135	1.387	0.85	1.5
300.278	1.184	1.319	0.85	1.5
300.279	1.188	1.313	0.85	1.5
300.28	1.120	1.326	0.85	1.5
300.281	1.103	1.370	0.85	1.5
300.282	1.187	1.302	0.85	1.5
300.283	1.167	1.332	0.85	1.5
300.284	1.103	1.308	0.85	1.5
300.285	1.107	1.389	0.85	1.5
300.286	1.123	1.353	0.85	1.5
300.287	1.110	1.382	0.85	1.5
300.288	1.103	1.394	0.85	1.5
300.289	1.105	1.360	0.85	1.5
300.29	1.154	1.394	0.85	1.5
300.291	1.172	1.396	0.85	1.5
300.292	1.148	1.337	0.85	1.5
300.293	1.103	1.303	0.85	1.5
300.294	1.107	1.333	0.85	1.5
300.295	1.095	1.311	0.85	1.5
300.296	1.183	1.311	0.85	1.5
300.297	1.104	1.336	0.85	1.5

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

300.298	1.103	1.331	0.85	1.5
300.299	1.107	1.307	0.85	1.5
300.3	1.183	1.394	0.85	1.5
300.301	1.103	1.360	0.85	1.5
300.302	1.103	1.340	0.85	1.5
300.303	1.102	1.312	0.85	1.5
300.304	1.187	1.373	0.85	1.5
300.305	1.181	1.362	0.85	1.5
300.306	1.103	1.350	0.85	1.5
300.307	1.104	1.343	0.85	1.5
300.308	1.170	1.391	0.85	1.5
300.309	1.154	1.399	0.85	1.5
300.31	1.107	1.367	0.85	1.5
300.311	1.105	1.367	0.85	1.5
300.312	1.108	1.302	0.85	1.5
300.313	1.145	1.364	0.85	1.5
300.314	1.181	1.367	0.85	1.5
300.315	1.106	1.365	0.85	1.5
300.316	1.102	1.365	0.85	1.5
300.317	1.088	1.335	0.85	1.5
300.318	1.110	1.385	0.85	1.5
300.319	1.143	1.377	0.85	1.5
300.32	1.102	1.383	0.85	1.5
300.321	1.188	1.364	0.85	1.5
300.322	1.104	1.325	0.85	1.5
300.323	1.190	1.349	0.85	1.5
300.324	1.106	1.323	0.85	1.5
300.325	1.101	1.322	0.85	1.5
300.326	1.133	1.340	0.85	1.5

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

300.327	1.138	1.314	0.85	1.5
300.328	1.197	1.399	0.85	1.5
300.329	1.108	1.310	0.85	1.5
300.33	1.106	1.399	0.85	1.5
300.331	1.138	1.323	0.85	1.5
300.332	1.113	1.337	0.85	1.5
300.333	1.196	1.373	0.85	1.5
300.334	1.101	1.372	0.85	1.5
300.335	1.101	1.380	0.85	1.5
300.336	1.120	1.332	0.85	1.5
300.337	1.103	1.346	0.85	1.5
300.338	1.193	1.354	0.85	1.5
300.339	1.193	1.357	0.85	1.5
300.34	1.131	1.368	0.85	1.5
300.341	1.108	1.392	0.85	1.5
300.342	1.185	1.354	0.85	1.5
300.343	1.109	1.367	0.85	1.5
300.344	1.108	1.335	0.85	1.5
300.345	1.118	1.379	0.85	1.5
300.346	1.173	1.392	0.85	1.5
300.347	1.101	1.387	0.85	1.5
300.348	1.106	1.362	0.85	1.5
300.349	1.106	1.371	0.85	1.5
300.35	1.121	1.385	0.85	1.5
300.351	1.165	1.345	0.85	1.5
300.352	1.101	1.351	0.85	1.5
300.353	1.109	1.351	0.85	1.5
300.354	1.159	1.386	0.85	1.5
300.355	1.173	1.331	0.85	1.5
300.356	1.106	1.355	0.85	1.5

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

300.357	1.106	1.353	0.85	1.5
300.358	1.102	1.328	0.85	1.5
300.359	1.165	1.377	0.85	1.5
300.36	1.170	1.341	0.85	1.5
300.361	1.102	1.354	0.85	1.5
300.362	1.106	1.303	0.85	1.5
300.363	1.131	1.317	0.85	1.5
300.364	1.151	1.347	0.85	1.5
300.365	1.108	1.333	0.85	1.5
300.366	1.104	1.347	0.85	1.5
300.367	1.107	1.316	0.85	1.5
300.368	1.159	1.372	0.85	1.5
300.369	1.140	1.397	0.85	1.5
300.37	1.107	1.343	0.85	1.5
300.371	1.108	1.353	0.85	1.5
300.372	1.170	1.330	0.85	1.5
300.373	1.180	1.390	0.85	1.5
300.374	1.165	1.346	0.85	1.5
300.375	1.103	1.372	0.85	1.5
300.376	1.109	1.369	0.85	1.5
300.377	1.141	1.333	0.85	1.5
300.378	1.108	1.382	0.85	1.5
300.379	1.106	1.384	0.85	1.5
300.38	1.168	1.343	0.85	1.5
300.381	1.105	1.389	0.85	1.5
300.382	1.106	1.304	0.85	1.5
300.383	1.106	1.378	0.85	1.5
300.384	1.103	1.335	0.85	1.5
300.385	1.166	1.389	0.85	1.5
300.386	1.132	1.391	0.85	1.5

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

300.387	1.102	1.366	0.85	1.5
300.388	i.102	1.373	0.85	1.5
300.389	1.103	1.393	0.85	1.5
300.39	1.165	1.346	0.85	1.5
300.391	1.106	1.368	0.85	1.5
300.392	1.108	1.371	0.85	1.5
300.393	1.105	1.338	0.85	1.5
300.394	1.127	1.358	0.85	1.5
300.395	1.173	1.393	0.85	1.5
300.396	1.107	1.345	0.85	1.5
300.397	1.104	1.351	0.85	1.5
300.398	1.179	1.325	0.85	1.5
300.399	1.152	1.380	0.85	1.5
300.4	1.148	1.322	0.85	1.5
300.401	1.102	1.350	0.85	1.5
300.402	1.105	1.333	0.85	1.5
300.403	1.105	1.396	0.85	1.5
300.404	1.157	1.355	0.85	1.5
300.405	1.098	1.350	0.85	1.5
300.406	1.104	1.358	0.85	1.5
300.407	1.106	1.321	0.85	1.5
300.408	1.128	1.365	0.85	1.5
300.409	1.171	1.333	0.85	1.5
300.41	1.107	1.346	0.85	1.5
300.411	1.106	1.353	0.85	1.5
300.412	1.169	1.317	0.85	1.5
300.413	1.156	1.349	0.85	1.5
300.414	1.168	1.319	0.85	1.5
300.415	1.104	1.330	0.85	1.5
300.416	1.192	1.369	0.85	1.5

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

300.417	1.176	1.387	0.85	1.5
300.418	1.105	1.342	0.85	1.5
300.419	1.108	1.308	0.85	1.5
300.42	1.179	1.389	0.85	1.5
300.421	1.133	1.307	0.85	1.5
300.422	1.108	1.339	0.85	1.5
300.423	1.109	1.384	0.85	1.5
300.424	1.154	1.350	0.85	1.5
300.425	1.127	1.307	0.85	1.5
300.426	1.132	1.326	0.85	1.5
300.427	1.106	1.339	0.85	1.5
300.428	1.143	1.311	0.85	1.5
300.429	1.160	1.377	0.85	1.5
300.43	1.140	1.344	0.85	1.5
300.431	1.105	1.364	0.85	1.5
300.432	1.108	1.330	0.85	1.5
300.433	1.150	1.343	0.85	1.5
300.434	1.127	1.343	0.85	1.5
300.435	1.125	1.327	0.85	1.5
300.436	1.104	1.344	0.85	1.5
300.437	1.131	1.321	0.85	1.5
300.438	1.157	1.381	0.85	1.5
300.439	1.103	1.359	0.85	1.5
300.44	1.109	1.326	0.85	1.5
300.441	1.159	1.396	0.85	1.5
300.442	1.144	1.368	0.85	1.5
300.443	1.122	1.320	0.85	1.5
300.444	1.107	1.366	0.85	1.5
300.445	1.107	1.334	0.85	1.5
300.446	1.166	1.383	0.85	1.5

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

300.447	1.124	1.322	0.85	1.5
300.448	1.108	1.332	0.85	1.5
300.449	1.105	1.383	0.85	1.5
300.45	1.160	1.322	0.85	1.5
300.451	1.108	1.391	0.85	1.5
300.452	1.107	1.337	0.85	1.5
300.453	1.103	1.345	0.85	1.5
300.454	1.106	1.307	0.85	1.5
300.455	1.162	1.377	0.85	1.5
300.456	1.135	1.398	0.85	1.5
300.457	1.105	1.331	0.85	1.5
300.458	1.101	1.343	0.85	1.5
300.459	1.102	1.323	0.85	1.5
300.46	1.102	1.386	0.85	1.5
300.461	1.147	1.374	0.85	1.5
300.462	1.109	1.368	0.85	1.5
300.463	1.107	1.391	0.85	1.5
300.464	1.137	1.356	0.85	1.5
300.465	1.141	1.399	0.85	1.5
300.466	1.102	1.340	0.85	1.5
300.467	1.104	1.352	0.85	1.5
300.468	1.179	1.325	0.85	1.5
300.469	1.179	1.319	0.85	1.5
300.47	1.104	1.315	0.85	1.5
300.471	1.108	1.334	0.85	1.5
300.472	1.104	1.394	0.85	1.5
300.473	1.165	1.380	0.85	1.5
300.474	1.175	1.348	0.85	1.5
300.475	1.108	1.343	0.85	1.5
300.476	1.177	1.311	0.85	1.5

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

300.477	1.160	1.359	0.85	1.5
300.478	1.154	1.358	0.85	1.5
300.479	1.109	1.377	0.85	1.5
300.48	1.108	1.352	0.85	1.5
300.481	1.141	1.329	0.85	1.5
300.482	1.141	1.360	0.85	1.5
300.483	1.101	1.331	0.85	1.5
300.484	1.188	1.306	0.85	1.5
300.485	1.103	1.330	0.85	1.5
300.486	1.164	1.384	0.85	1.5
300.487	1.108	1.350	0.85	1.5
300.488	1.152	1.301	0.85	1.5
300.489	1.184	1.333	0.85	1.5
300.49	1.136	1.377	0.85	1.5
300.491	1.105	1.339	0.85	1.5
300.492	1.149	1.395	0.85	1.5
300.493	1.191	1.337	0.85	1.5
300.494	1.153	1.388	0.85	1.5
300.495	1.105	1.317	0.85	1.5
300.496	1.171	1.351	0.85	1.5
300.497	1.141	1.327	0.85	1.5
300.498	1.197	1.330	0.85	1.5
300.499	1.173	1.303	0.85	1.5
300.5	1.195	1.350	0.85	1.5
300.501	1.187	1.319	0.85	1.5
300.502	1.175	1.300	0.85	1.5
300.503	1.151	1.383	0.85	1.5
300.504	1.185	1.308	0.85	1.5
300.505	1.198	1.302	0.85	1.5
300.506	1.142	1.365	0.85	1.5

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

300.507	1.191	1.326	0.85	1.5
300.508	1.171	1.308	0.85	1.5
300.509	1.198	1.316	0.85	1.5
300.51	1.155	1.319	0.85	1.5
300.511	1.126	1.304	0.85	1.5
300.512	1.170	1.368	0.85	1.5
300.513	1.103	1.324	0.85	1.5
300.514	1.179	1.322	0.85	1.5
300.515	1.163	1.386	0.85	1.5
300.516	1.155	1.369	0.85	1.5
300.517	1.104	1.399	0.85	1.5
300.518	1.189	1.340	0.85	1.5
300.519	1.108	1.320	0.85	1.5
300.52	1.118	1.310	0.85	1.5
300.521	1.136	1.359	0.85	1.5
300.522	1.102	1.334	0.85	1.5
300.523	1.173	1.396	0.85	1.5
300.524	1.105	1.318	0.85	1.5
300.525	1.105	1.301	0.85	1.5
300.526	1.102	1.395	0.85	1.5
300.527	1.173	1.350	0.85	1.5
300.528	1.116	1.327	0.85	1.5
300.529	1.187	1.392	0.85	1.5
300.53	1.105	1.309	0.85	1.5
300.531	1.177	1.398	0.85	1.5
300.532	1.114	1.376	0.85	1.5
300.533	1.189	1.342	0.85	1.5
300.534	1.122	1.380	0.85	1.5
300.535	1.187	1.364	0.85	1.5
300.536	1.127	1.378	0.85	1.5

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

300.537	1.190	1.346	0.85	1.5
300.538	1.107	1.376	0.85	1.5
300.539	1.125	1.358	0.85	1.5
300.54	1.197	1.316	0.85	1.5
300.541	1.178	1.385	0.85	1.5
300.542	1.195	1.388	0.85	1.5
300.543	1.165	1.382	0.85	1.5
300.544	1.130	1.324	0.85	1.5
300.545	1.111	1.340	0.85	1.5
300.546	1.169	1.361	0.85	1.5
300.547	1.140	1.397	0.85	1.5
300.548	1.167	1.380	0.85	1.5
300.549	1.195	1.309	0.85	1.5
300.55	1.156	1.394	0.85	1.5
300.551	1.187	1.328	0.85	1.5
300.552	1.142	1.383	0.85	1.5
300.553	1.172	1.382	0.85	1.5
300.554	1.190	1.347	0.85	1.5
300.555	1.103	1.316	0.85	1.5
300.556	1.135	1.379	0.85	1.5
300.557	1.179	1.312	0.85	1.5
300.558	1.103	1.389	0.85	1.5
300.559	1.105	1.302	0.85	1.5
300.56	1.110	1.328	0.85	1.5
300.561	1.101	1.383	0.85	1.5
300.562	1.103	1.314	0.85	1.5
300.563	1.190	1.310	0.85	1.5
300.564	1.172	1.363	0.85	1.5
300.565	1.102	1.396	0.85	1.5
300.566	1.126	1.376	0.85	1.5

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

300.567	1.189	1.307	0.85	1.5
300.568	1.192	1.368	0.85	1.5
300.569	1.109	1.306	0.85	1.5
300.57	1.102	1.360	0.85	1.5
300.571	1.102	1.351	0.85	1.5
300.572	1.182	1.398	0.85	1.5
300.573	1.106	1.399	0.85	1.5
300.574	1.102	1.303	0.85	1.5
300.575	1.105	1.370	0.85	1.5
300.576	1.185	1.358	0.85	1.5
300.577	1.101	1.306	0.85	1.5
300.578	1.106	1.371	0.85	1.5
300.579	1.105	1.365	0.85	1.5
300.58	1.117	1.300	0.85	1.5
300.581	1.189	1.314	0.85	1.5
300.582	1.103	1.339	0.85	1.5
300.583	1.137	1.395	0.85	1.5
300.584	1.175	1.340	0.85	1.5
300.585	1.109	1.306	0.85	1.5
300.586	1.103	1.326	0.85	1.5
300.587	1.108	1.393	0.85	1.5
300.588	1.161	1.391	0.85	1.5
300.589	1.198	1.301	0.85	1.5
300.59	1.108	1.306	0.85	1.5
300.591	1.108	1.366	0.85	1.5
300.592	1.133	1.371	0.85	1.5
300.593	1.189	1.387	0.85	1.5
300.594	1.108	1.384	0.85	1.5
300.595	1.109	1.391	0.85	1.5
300.596	1.198	1.336	0.85	1.5

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

300.597	1.188	1.301	0.85	1.5
300.598	1.101	1.385	0.85	1.5
300.599	1.115	1.398	0.85	1.5
300.6	1.189	1.385	0.85	1.5
300.601	1.162	1.321	0.85	1.5
300.602	1.171	1.388	0.85	1.5
300.603	1.104	1.300	0.85	1.5
300.604	1.107	1.387	0.85	1.5
300.605	1.111	1.341	0.85	1.5
300.606	1.107	1.385	0.85	1.5
300.607	1.107	1.312	0.85	1.5
300.608	1.108	1.311	0.85	1.5
300.609	1.188	1.316	0.85	1.5
300.61	1.178	1.384	0.85	1.5
300.611	1.109	1.308	0.85	1.5
300.612	1.101	1.321	0.85	1.5
300.613	1.102	1.377	0.85	1.5
300.614	1.178	1.313	0.85	1.5
300.615	1.120	1.306	0.85	1.5
300.616	1.108	1.307	0.85	1.5
300.617	1.128	1.387	0.85	1.5
300.618	1.173	1.394	0.85	1.5
300.619	1.173	1.337	0.85	1.5
300.62	1.105	1.330	0.85	1.5
300.621	1.174	1.303	0.85	1.5
300.622	1.102	1.301	0.85	1.5
300.623	1.189	1.306	0.85	1.5
300.624	1.158	1.316	0.85	1.5
300.625	1.120	1.376	0.85	1.5
300.626	1.103	1.327	0.85	1.5

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

300.627	1.199	1.338	0.85	1.5
300.628	1.117	1.346	0.85	1.5
300.629	1.104	1.300	0.85	1.5
300.63	1.106	1.314	0.85	1.5
300.631	1.138	1.308	0.85	1.5
300.632	1.185	1.322	0.85	1.5
300.633	1.177	1.397	0.85	1.5
300.634	1.106	1.353	0.85	1.5
300.635	1.134	1.381	0.85	1.5
300.636	1.162	1.302	0.85	1.5
300.637	1.111	1.345	0.85	1.5
300.638	1.107	1.380	0.85	1.5
300.639	1.103	1.339	0.85	1.5
300.64	1.116	1.338	0.85	1.5
300.641	1.165	1.391	0.85	1.5
300.642	1.158	1.370	0.85	1.5
300.643	1.103	1.319	0.85	1.5
300.644	1.103	1.330	0.85	1.5
300.645	1.178	1.388	0.85	1.5
300.646	1.131	1.346	0.85	1.5
300.647	1.108	1.322	0.85	1.5
300.648	1.109	1.310	0.85	1.5
300.649	1.197	1.332	0.85	1.5
300.65	1.137	1.391	0.85	1.5
300.651	1.158	1.339	0.85	1.5
300.652	1.177	1.308	0.85	1.5
300.653	1.154	1.364	0.85	1.5
300.654	1.112	1.389	0.85	1.5
300.655	1.192	1.375	0.85	1.5
300.656	1.103	1.302	0.85	1.5

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

300.657	1.150	1.344	0.85	1.5
300.658	1.101	1.380	0.85	1.5
300.659	1.169	1.311	0.85	1.5
300.66	1.130	1.381	0.85	1.5
300.661	1.187	1.300	0.85	1.5
300.662	1.129	1.380	0.85	1.5
300.663	1.174	1.311	0.85	1.5
300.664	1.154	1.329	0.85	1.5
300.665	1.181	1.396	0.85	1.5
300.666	1.134	1.352	0.85	1.5
300.667	1.106	1.369	0.85	1.5
300.668	1.190	1.302	0.85	1.5
300.669	1.151	1.383	0.85	1.5
300.67	1.165	1.391	0.85	1.5
300.671	1.109	1.373	0.85	1.5
300.672	1.103	1.348	0.85	1.5
300.673	1.130	1.391	0.85	1.5
300.674	1.153	1.384	0.85	1.5
300.675	1.109	1.386	0.85	1.5
300.676	1.198	1.366	0.85	1.5
300.677	1.193	1.330	0.85	1.5
300.678	1.127	1.343	0.85	1.5
300.679	1.153	1.370	0.85	1.5
300.68	1.190	1.381	0.85	1.5
300.681	1.104	1.334	0.85	1.5
300.682	1.130	1.321	0.85	1.5
300.683	1.134	1.360	0.85	1.5
300.684	1.108	1.374	0.85	1.5
300.685	1.151	1.391	0.85	1.5
300.686	1.130	1.357	0.85	1.5

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

300.687	1.167	1.392	0.85	1.5
300.688	1.109	1.351	0.85	1.5
300.689	1.192	1.342	0.85	1.5
300.69	1.171	1.391	0.85	1.5
300.691	1.154	1.398	0.85	1.5
300.692	1.103	1.372	0.85	1.5
300.693	1.130	1.390	0.85	1.5
300.694	1.166	1.387	0.85	1.5
300.695	1.182	1.319	0.85	1.5
300.696	1.109	1.379	0.85	1.5
300.697	1.108	1.382	0.85	1.5
300.698	1.107	1.397	0.85	1.5
300.699	1.163	1.315	0.85	1.5
300.7	1.156	1.355	0.85	1.5
300.701	1.196	1.389	0.85	1.5
300.702	1.160	1.375	0.85	1.5
300.703	1.133	1.394	0.85	1.5
300.704	1.108	1.380	0.85	1.5
300.705	1.107	1.398	0.85	1.5
300.706	1.109	1.355	0.85	1.5
300.707	1.177	1.318	0.85	1.5
300.708	1.161	1.318	0.85	1.5
300.709	1.106	1.383	0.85	1.5
300.71	1.109	1.393	0.85	1.5
300.711	1.151	1.376	0.85	1.5
300.712	1.133	1.358	0.85	1.5
300.713	1.108	1.346	0.85	1.5
300.714	1.150	1.380	0.85	1.5
300.715	1.162	1.396	0.85	1.5
300.716	1.152	1.329	0.85	1.5

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

300.717	1.102	1.378	0.85	1.5
300.718	1.107	1.373	0.85	1.5
300.719	1.113	1.319	0.85	1.5
300.72	1.175	1.342	0.85	1.5
300.721	1.135	1.356	0.85	1.5
300.722	1.108	1.323	0.85	1.5
300.723	1.101	1.315	0.85	1.5
300.724	1.119	1.355	0.85	1.5
300.725	1.164	1.312	0.85	1.5
300.726	1.140	1.340	0.85	1.5
300.727	1.104	1.301	0.85	1.5
300.728	1.104	1.322	0.85	1.5
300.729	1.174	1.332	0.85	1.5
300.73	1.180	1.327	0.85	1.5
300.731	1.108	1.388	0.85	1.5
300.732	1.101	1.370	0.85	1.5
300.733	1.133	1.379	0.85	1.5
300.734	1.165	1.313	0.85	1.5
300.735	1.142	1.336	0.85	1.5
300.736	1.103	1.318	0.85	1.5
300.737	1.102	1.318	0.85	1.5
300.738	1.177	1.394	0.85	1.5
300.739	1.171	1.366	0.85	1.5
300.74	1.104	1.321	0.85	1.5
300.741	1.104	1.317	0.85	1.5
300.742	1.129	1.330	0.85	1.5
300.743	1.166	1.335	0.85	1.5
300.744	1.156	1.333	0.85	1.5
300.745	1.103	1.319	0.85	1.5
300.746	1.106	1.369	0.85	1.5

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

300.747	1.188	1.354	0.85	1.5
300.748	1.170	1.357	0.85	1.5
300.749	1.152	1.383	0.85	1.5
300.75	1.106	1.363	0.85	1.5
300.751	1.105	1.333	0.85	1.5
300.752	1.191	1.321	0.85	1.5
300.753	1.123	1.306	0.85	1.5
300.754	1.101	1.321	0.85	1.5
300.755	1.103	1.353	0.85	1.5
300.756	1.199	1.377	0.85	1.5
300.757	1.106	1.331	0.85	1.5
300.758	1.101	1.346	0.85	1.5
300.759	1.105	1.337	0.85	1.5
300.76	1.188	1.396	0.85	1.5
300.761	1.177	1.321	0.85	1.5
300.762	1.108	1.361	0.85	1.5
300.763	1.163	1.336	0.85	1.5
300.764	1.196	1.343	0.85	1.5
300.765	1.139	1.329	0.85	1.5
300.766	1.102	1.387	0.85	1.5
300.767	1.129	1.319	0.85	1.5
300.768	1.103	1.313	0.85	1.5
300.769	1.189	1.391	0.85	1.5
300.77	1.101	1.342	0.85	1.5
300.771	1.103	1.367	0.85	1.5
300.772	1.138	1.370	0.85	1.5
300.773	1.177	1.307	0.85	1.5
300.774	1.115	1.329	0.85	1.5
300.775	1.101	1.343	0.85	1.5
300.776	1.103	1.397	0.85	1.5

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

300.777	1.107	1.320	0.85	1.5
300.778	1.187	1.322	0.85	1.5
300.779	1.183	1.337	0.85	1.5
300.78	1.108	1.356	0.85	1.5
300.781	1.101	1.339	0.85	1.5
300.782	1.118	1.342	0.85	1.5
300.783	1.185	1.303	0.85	1.5
300.784	1.104	1.359	0.85	1.5
300.785	1.107	1.309	0.85	1.5
300.786	1.132	1.351	0.85	1.5
300.787	1.193	1.356	0.85	1.5
300.788	1.182	1.330	0.85	1.5
300.789	1.102	1.390	0.85	1.5
300.79	1.102	1.334	0.85	1.5
300.791	1.118	1.343	0.85	1.5
300.792	1.189	1.343	0.85	1.5
300.793	1.133	1.311	0.85	1.5
300.794	1.103	1.306	0.85	1.5
300.795	1.104	1.329	0.85	1.5
300.796	1.101	1.371	0.85	1.5
300.797	1.195	1.335	0.85	1.5
300.798	1.106	1.379	0.85	1.5
300.799	1.107	1.399	0.85	1.5
300.8	1.105	1.302	0.85	1.5
300.801	1.132	1.385	0.85	1.5
300.802	1.106	1.360	0.85	1.5
300.803	1.101	1.313	0.85	1.5
300.804	1.108	1.314	0.85	1.5
300.805	1.101	1.300	0.85	1.5
300.806	1.135	1.310	0.85	1.5

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

300.807	1.105	1.329	0.85	1.5
300.808	1.101	1.341	0.85	1.5
300.809	1.194	1.311	0.85	1.5
300.81	1.153	1.375	0.85	1.5
300.811	1.115	1.302	0.85	1.5
300.812	1.108	1.313	0.85	1.5
300.813	1.187	1.398	0.85	1.5
300.814	1.199	1.358	0.85	1.5
300.815	1.107	1.327	0.85	1.5
300.816	1.109	1.308	0.85	1.5
300.817	1.103	1.349	0.85	1.5
300.818	1.183	1.391	0.85	1.5
300.819	1.140	1.328	0.85	1.5
300.82	1.104	1.388	0.85	1.5
300.821	1.115	1.307	0.85	1.5
300.822	1.175	1.389	0.85	1.5
300.823	1.194	1.363	0.85	1.5
300.824	1.147	1.331	0.85	1.5
300.825	1.104	1.329	0.85	1.5
300.826	1.129	1.319	0.85	1.5
300.827	1.181	1.378	0.85	1.5
300.828	1.173	1.381	0.85	1.5
300.829	1.136	1.332	0.85	1.5
300.83	1.121	1.309	0.85	1.5
300.831	1.181	1.339	0.85	1.5
300.832	1.172	1.316	0.85	1.5
300.833	1.133	1.325	0.85	1.5
300.834	1.110	1.309	0.85	1.5
300.835	1.101	1.372	0.85	1.5

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

300.836	1.188	1.382	0.85	1.5
300.837	1.170	1.313	0.85	1.5
300.838	1.104	1.307	0.85	1.5
300.839	1.106	1.313	0.85	1.5
300.84	1.192	1.361	0.85	1.5
300.841	1.197	1.375	0.85	1.5
300.842	1.192	1.313	0.85	1.5
300.843	1.103	1.335	0.85	1.5
300.844	1.140	1.320	0.85	1.5
300.845	1.102	1.378	0.85	1.5
300.846	1.149	1.304	0.85	1.5
300.847	1.122	1.309	0.85	1.5
300.848	1.101	1.323	0.85	1.5
300.849	1.181	1.341	0.85	1.5
300.85	1.198	1.376	0.85	1.5
300.851	1.183	1.311	0.85	1.5
300.852	1.107	1.343	0.85	1.5
300.853	1.108	1.326	0.85	1.5
300.854	1.194	1.326	0.85	1.5
300.855	1.143	1.303	0.85	1.5
300.856	1.133	1.370	0.85	1.5
300.857	1.106	1.320	0.85	1.5
300.858	1.118	1.309	0.85	1.5
300.859	1.102	1.373	0.85	1.5
300.86	1.191	1.315	0.85	1.5
300.861	1.126	1.348	0.85	1.5
300.862	1.130	1.325	0.85	1.5
300.863	1.111	1.358	0.85	1.5
300.864	1.157	1.312	0.85	1.5
300.865	1.108	1.321	0.85	1.5

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

300.866	1.104	1.378	0.85	1.5
300.867	1.108	1.300	0.85	1.5
300.868	1.169	1.336	0.85	1.5
300.869	1.164	1.312	0.85	1.5
300.87	1.101	1.330	0.85	1.5
300.871	1.111	1.342	0.85	1.5
300.872	1.122	1.321	0.85	1.5
300.873	1.109	1.358	0.85	1.5
300.874	1.103	1.363	0.85	1.5
300.875	1.146	1.307	0.85	1.5
300.876	1.137	1.355	0.85	1.5
300.877	1.172	1.343	0.85	1.5
300.878	1.103	1.336	0.85	1.5
300.879	1.166	1.356	0.85	1.5
300.88	1.131	1.313	0.85	1.5
300.881	1.150	1.383	0.85	1.5
300.882	1.101	1.349	0.85	1.5
300.883	1.130	1.375	0.85	1.5
300.884	1.153	1.378	0.85	1.5
300.885	1.113	1.329	0.85	1.5
300.886	1.147	1.331	0.85	1.5
300.887	1.106	1.330	0.85	1.5
300.888	1.124	1.333	0.85	1.5
300.889	1.140	1.360	0.85	1.5
300.89	1.109	1.332	0.85	1.5
300.891	1.175	1.319	0.85	1.5
300.892	1.172	1.333	0.85	1.5
300.893	1.106	1.368	0.85	1.5
300.894	1.139	1.355	0.85	1.5
300.895	1.127	1.308	0.85	1.5

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

300.896	1.150	1.346	0.85	1.5
300.897	1.103	1.363	0.85	1.5
300.898	1.106	1.350	0.85	1.5
300.899	1.102	1.333	0.85	1.5
300.9	1.143	1.305	0.85	1.5
300.901	1.136	1.336	0.85	1.5
300.902	1.109	1.369	0.85	1.5
300.903	1.105	1.343	0.85	1.5
300.904	1.101	1.368	0.85	1.5
300.905	1.116	1.377	0.85	1.5
300.906	1.108	1.365	0.85	1.5
300.907	1.104	1.377	0.85	1.5
300.908	1.105	1.384	0.85	1.5
300.909	1.117	1.351	0.85	1.5
300.91	1.115	1.306	0.85	1.5
300.911	1.108	1.339	0.85	1.5
300.912	1.185	1.340	0.85	1.5
300.913	1.175	1.317	0.85	1.5
300.914	1.160	1.338	0.85	1.5
300.915	1.129	1.310	0.85	1.5
300.916	1.154	1.352	0.85	1.5
300.917	1.191	1.352	0.85	1.5
300.918	1.128	1.301	0.85	1.5
300.919	1.132	1.354	0.85	1.5
300.92	1.165	1.369	0.85	1.5
300.921	1.139	1.350	0.85	1.5
300.922	1.160	1.341	0.85	1.5
300.923	1.142	1.351	0.85	1.5
300.924	1.117	1.389	0.85	1.5
300.925	1.178	1.346	0.85	1.5

300.926	1 113	1.367	0.85	1.5
300.927	1.130	1.315	0.85	1.5
300.928	1.122	1.369	0.85	1.5
300.929	1.134	1.324	0.85	1.5
300.93	1.142	1.308	0.85	1.5
300.931	1.137	1.306	0.85	1.5
300.932	1.128	1.385	0.85	1.5
300.933	1.105	1.368	0.85	1.5
300.934	1.130	1.306	0.85	1.5
300.935	1.149	1.314	0.85	1.5
300.936	1.181	1.370	0.85	1.5
300.937	1.124	1.309	0.85	1.5
300.938	1.142	1.339	0.85	1.5
300.939	1.198	1.357	0.85	1.5
300.94	1.137	1.312	0.85	1.5
300.941	1.139	1.367	0.85	1.5
300.942	1.105	1.331	0.85	1.5
300.943	1.114	1.355	0.85	1.5
300.944	1.186	1.359	0.85	1.5
300.945	1.195	1.355	0.85	1.5
300.946	1.159	1.384	0.85	1.5
300.947	1.133	1.370	0.85	1.5
300.948	1.122	1.328	0.85	1.5
300.949	1.107	1.356	0.85	1.5
300.95	1.197	1.305	0.85	1.5
300.951	1.109	1.373	0.85	1.5
300.952	1.193	1.317	0.85	1.5
300.953	1.139	1.380	0.85	1.5
300.954	1.186	1.333	0.85	1.5
300.955	1.109	1.312	0.85	1.5

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

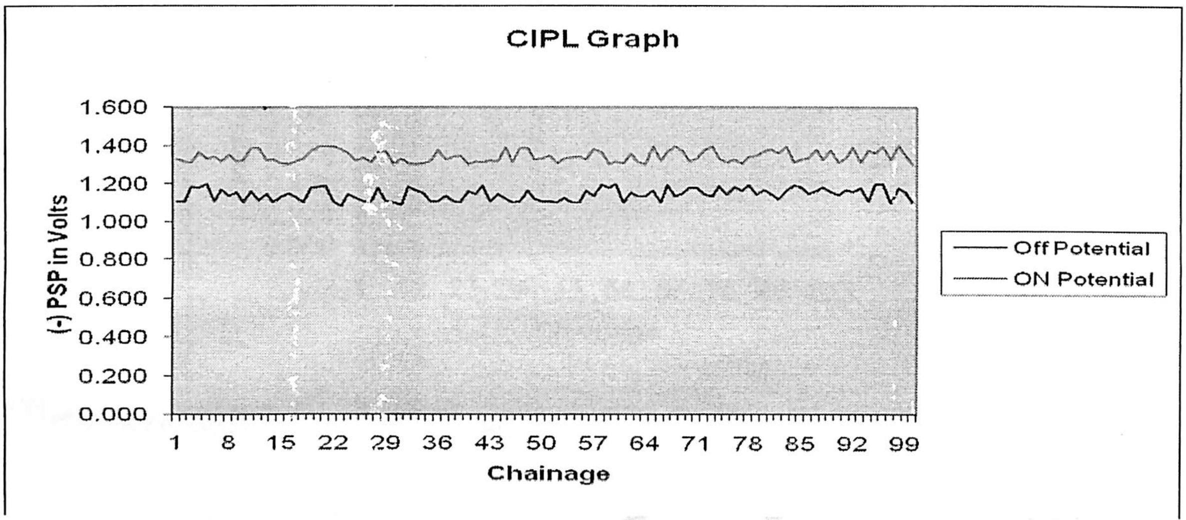
300.956	1.132	1.361	0.85	1.5
300.957	1.194	1.376	0.85	1.5
300.958	1.121	1.302	0.85	1.5
300.959	1.114	1.366	0.85	1.5
300.96	1.121	1.354	0.85	1.5
300.961	1.146	1.349	0.85	1.5
300.962	1.188	1.355	0.85	1.5
300.963	1.166	1.361	0.85	1.5
300.964	1.191	1.374	0.85	1.5
300.965	1.109	1.301	0.85	1.5
300.966	1.140	1.376	0.85	1.5
300.967	1.160	1.316	0.85	1.5
300.968	1.177	1.352	0.85	1.5
300.969	1.101	1.347	0.85	1.5
300.97	1.112	1.372	0.85	1.5
300.971	1.196	1.373	0.85	1.5
300.972	1.129	1.354	0.85	1.5
300.973	1.179	1.334	0.85	1.5
300.974	1.190	1.323	0.85	1.5
300.975	1.104	1.354	0.85	1.5
300.976	1.176	1.336	0.85	1.5
300.977	1.112	1.370	0.85	1.5
300.978	1.126	1.343	0.85	1.5
300.979	1.140	1.309	0.85	1.5
300.98	1.191	1.371	0.85	1.5
300.981	1.101	1.379	0.85	1.5
300.982	1.095	1.329	0.85	1.5
300.983	1.186	1.319	0.85	1.5
300.984	1.137	1.351	0.85	1.5
300.985	1.107	1.387	0.85	1.5

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

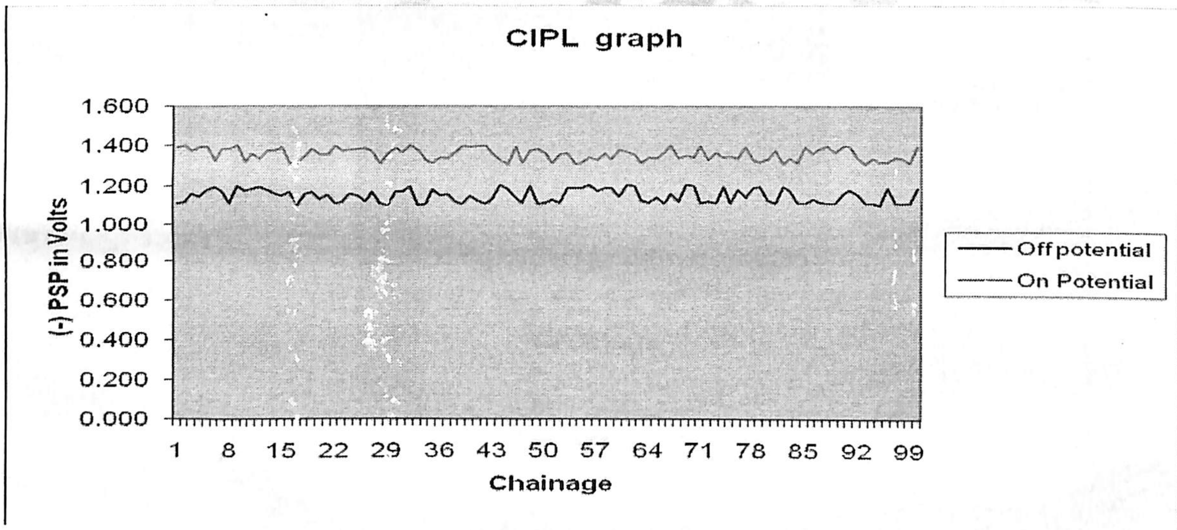
300.986	1.195	1.372	0.85	1.5
300.987	1.132	1.306	0.85	1.5
300.988	1.168	1.383	0.85	1.5
300.989	1.189	1.370	0.85	1.5
300.99	1.106	1.378	0.85	1.5
300.991	1.142	1.331	0.85	1.5
300.992	1.169	1.389	0.85	1.5
300.993	1.173	1.348	0.85	1.5
300.994	1.101	1.379	0.85	1.5
300.995	1.104	1.317	0.85	1.5
300.996	1.130	1.365	0.85	1.5
300.997	1.132	1.359	0.85	1.5
300.998	1.170	1.338	0.85	1.5
300.999	1.107	1.388	0.85	1.5
301	1.126	1.363	0.85	1.5

APPENDIX B (CIPL Graph)

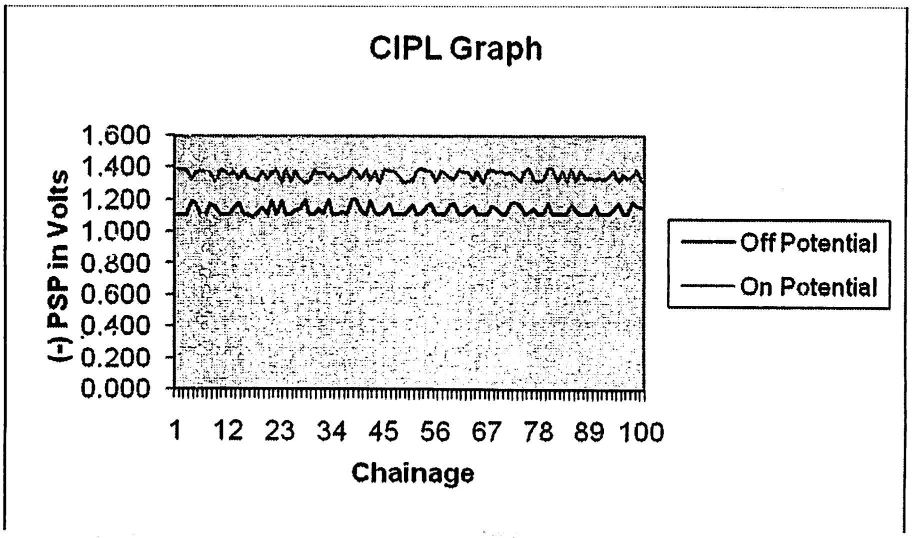
CIPL GRAPH for certain locations



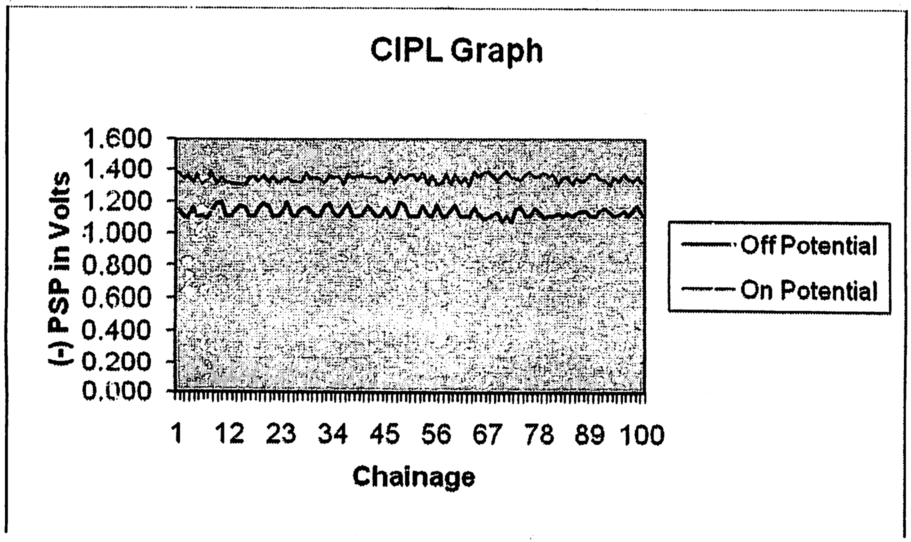
From CH.300.1 to 300.2



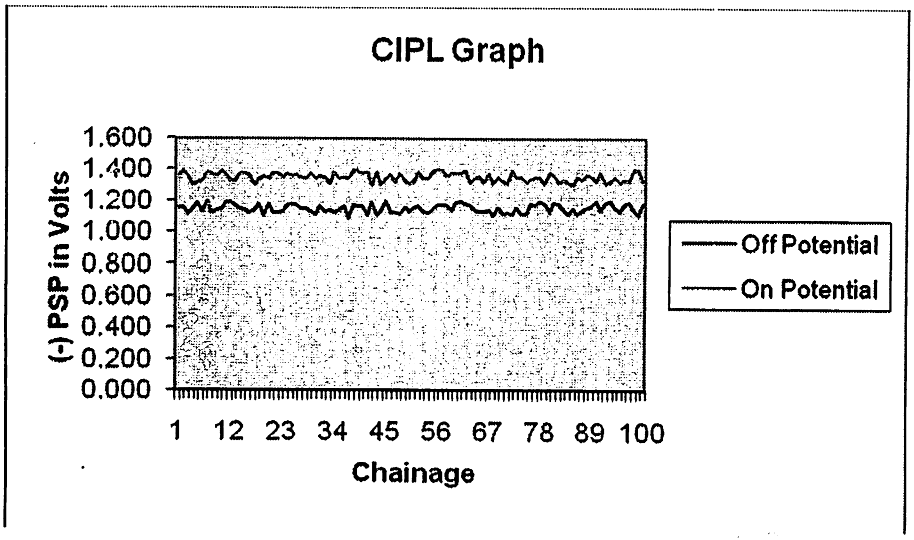
From CH.300.2 to 300.3



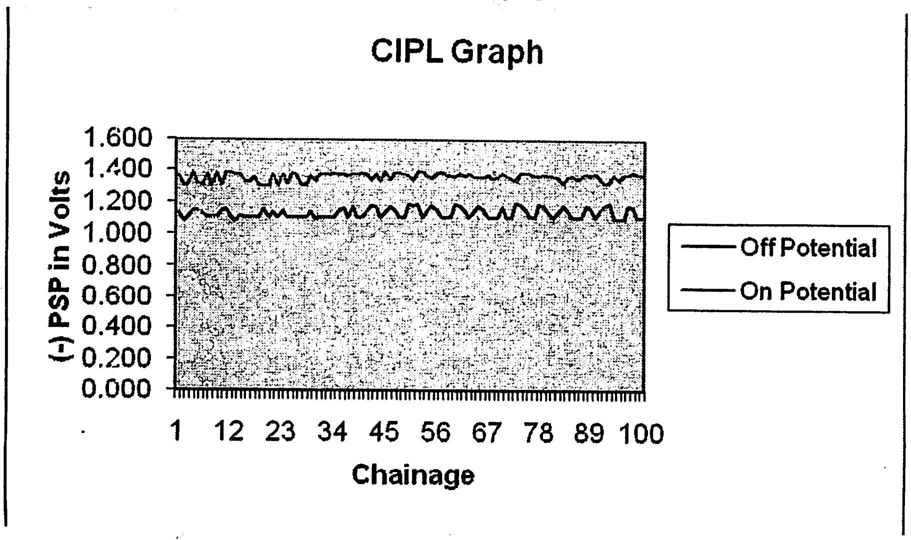
From CH.300.3 to 300.4



From CH.300.4 to 300.5

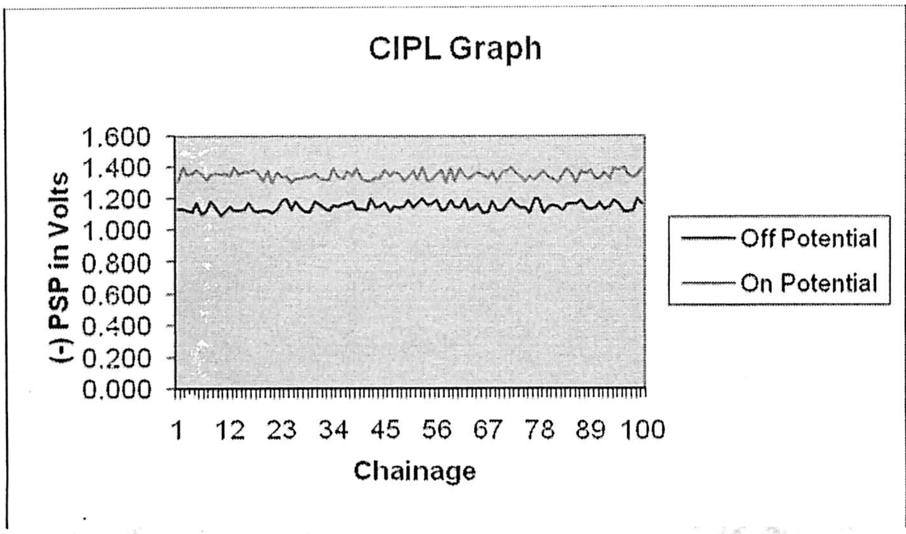


From CH.300.5 to 300.6



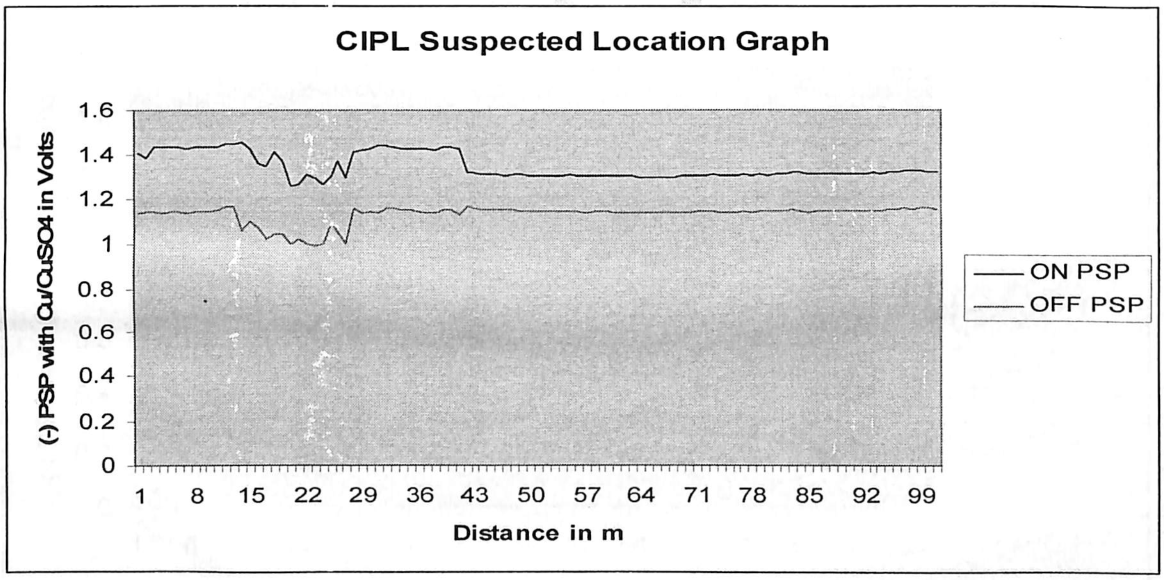
From CH.300.6 to 300.

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.



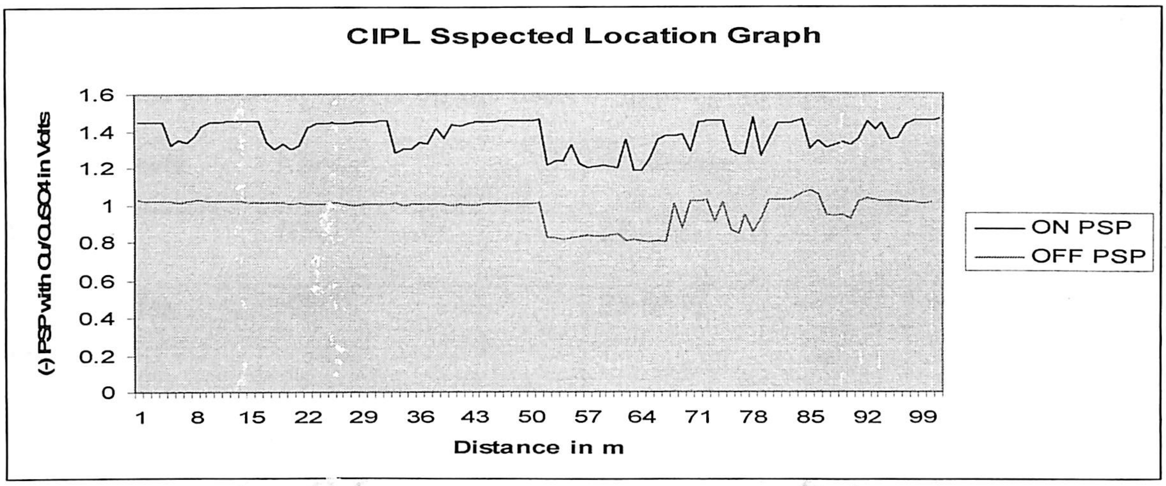
From CH.300.7 to 300.8

Defect locating GRAPHS

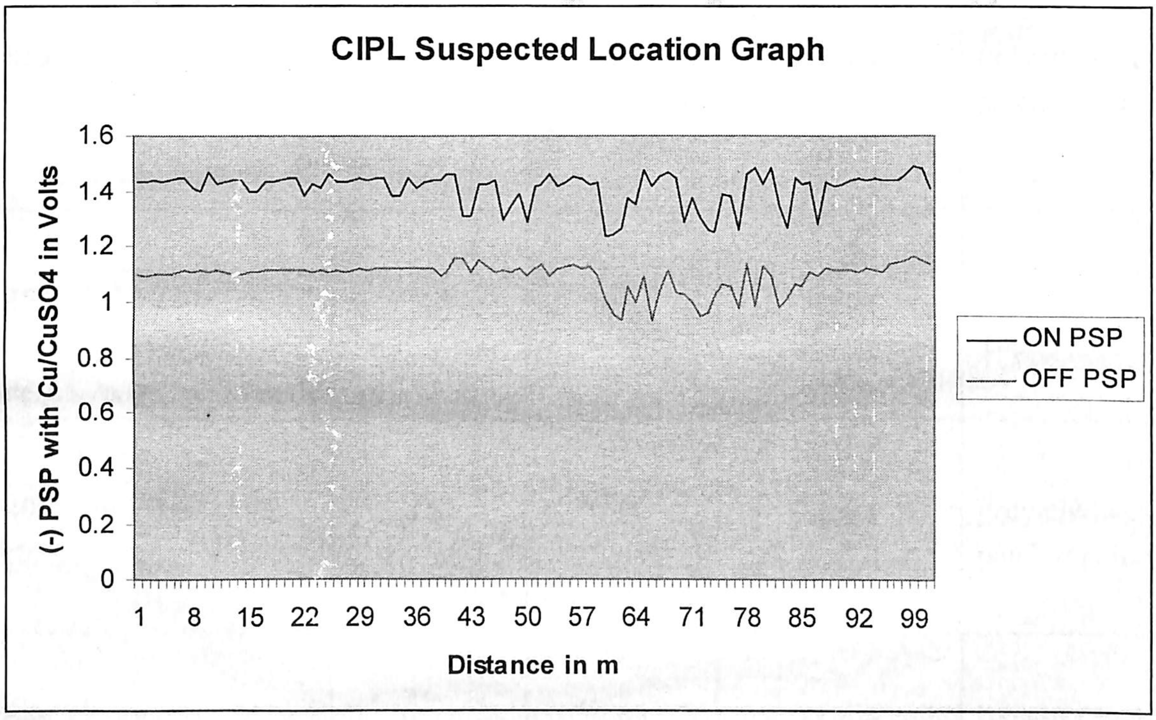


CJPL Suspected Location graph from 306.800 to 306.850m

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.



CIPL Suspected Location graph from 308.490 to 308.530m



CIPL Suspected Location graph from 310.250 to 310.300m

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

APPENDIX C (refer chapter 4, Field analysis)

1. Classification of coating defect on the basis of depth of defect.

Nature of defects	Minor	Moderate	Severe
%IR drop	00 - 05%	05-15%	>15%
Depth of coating defects(%) of std.coating	<25%	25-50%	>50%

2. Result Found at Surveyed Location & Their Type of Repair

Defect location(km)	Width(mm)	Depth(mm)	% IR Drop	Nature of Defects	Type of Repairs
306.813	100	0.72	2.66	Minor	Polyethylene patch repair
307.453	220	1.8	21.33	Severe	Cold applied Tape
308.498	150	0.67	4.66	Minor	Polyethylene patch repair
308.645	170	0.73	2.33	Minor	Polyethylene patch repair

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

3. **Photo records of defects found during DIG VARIFICATION.**

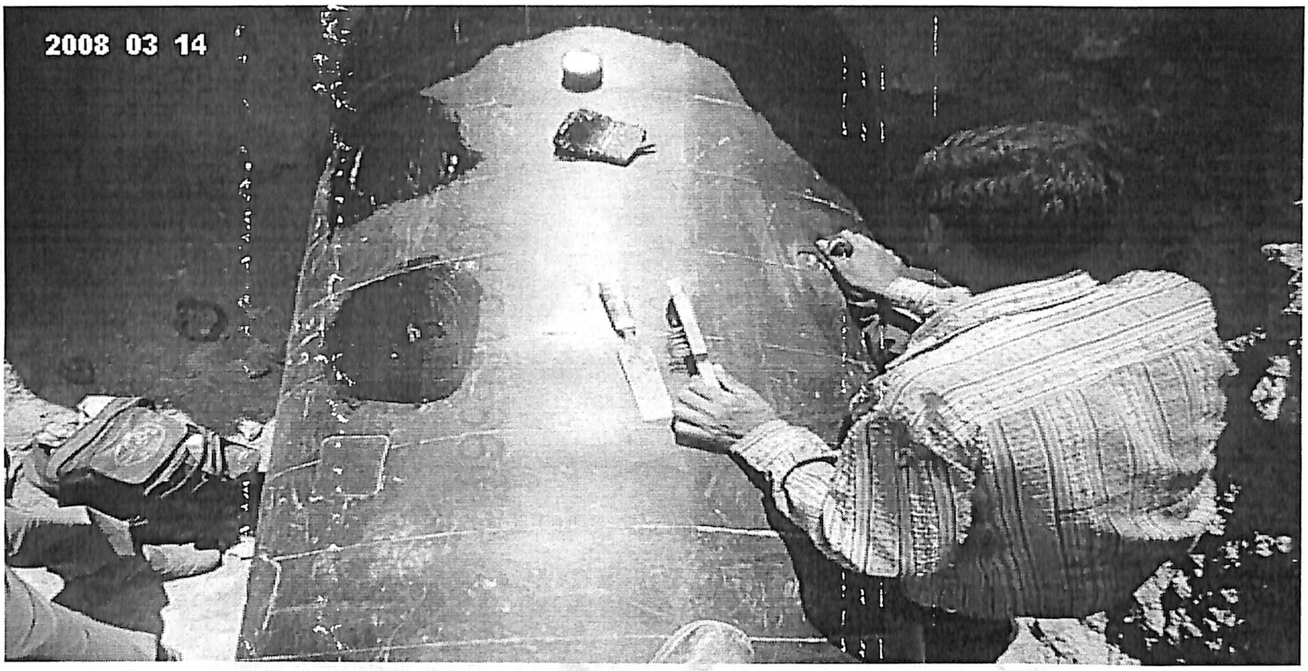


Photo1: Minor defect: chainage 306.813: Patch repair

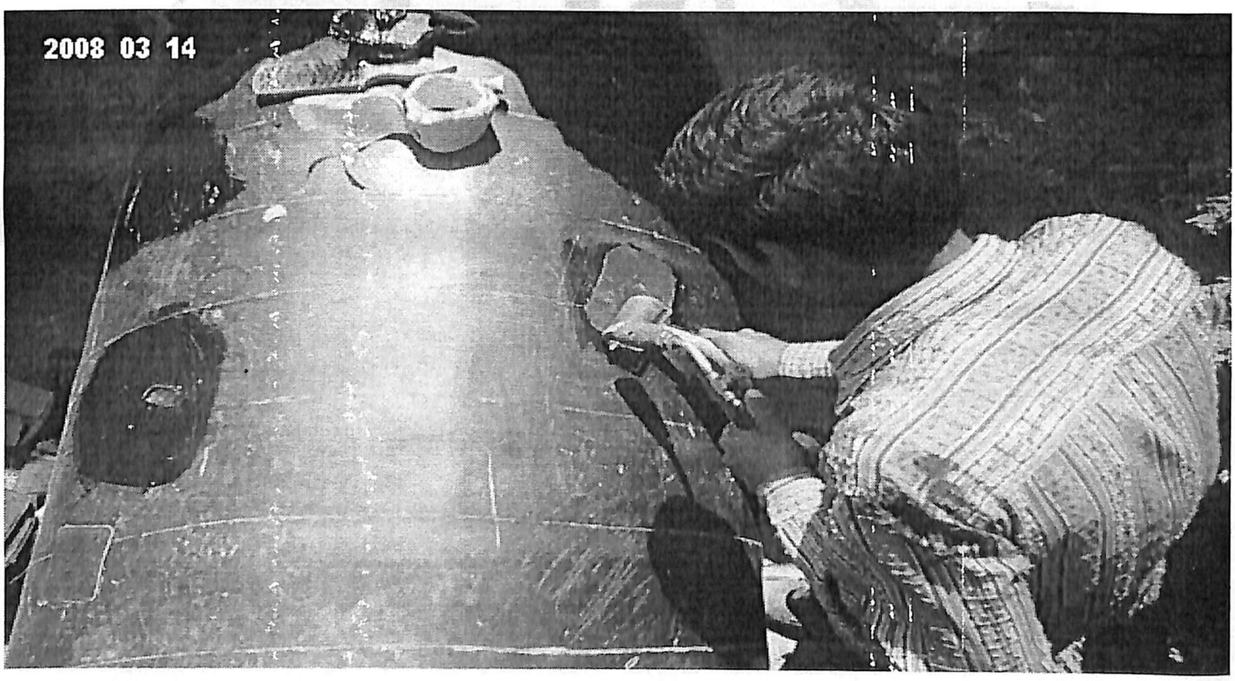


Photo2: Minor defect: chainage 308.498: Patch repair

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.

Photo3: Minor defect: chainage 308.645: Patch repair

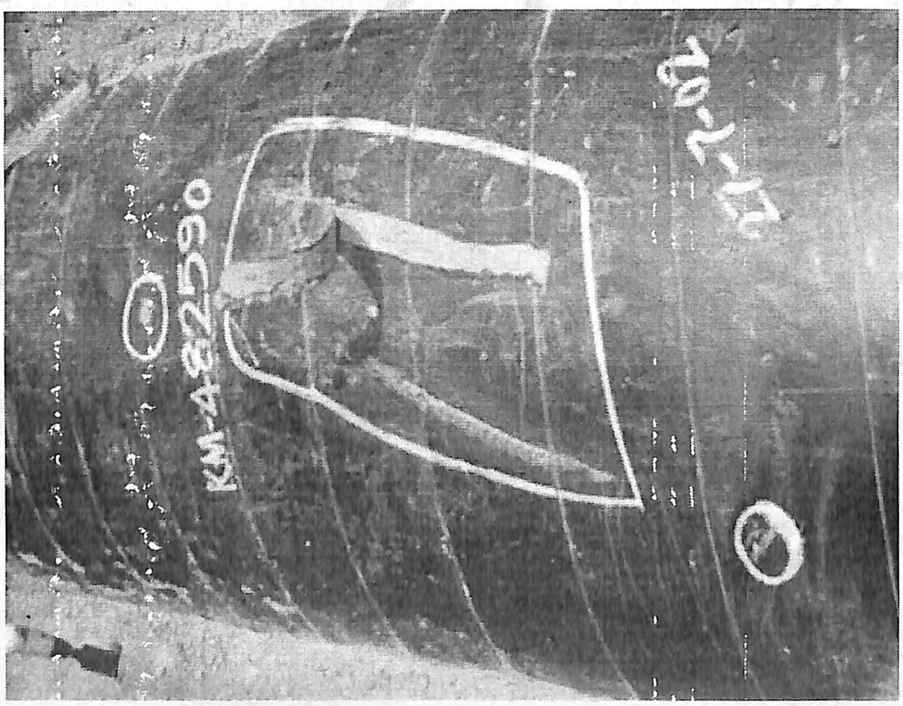


Photo4: Major defect: chainage 307.453: Cold Tape repair

Identification of coating defects with the help of Close Interval Potential Logging (CIPL) &Direct Current Voltage Gradient (DCVG) surveys to undertake Repairs.