Cathodic Protection Engineering
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Lecture – 05
Cathodic protection engineering: Assessment of pipeline condition through surveys: Part – I

Welcome back to the lectures on Cathodic Protection Engineering. In the earlier lectures, we saw two important concepts. The application of electrochemical concepts to corrosion and cathodic protection engineering, then we also saw the criteria for cathodic protection of buried structures. We shall today discuss, the concepts involved in assessing the pipeline experiencing corrosion.

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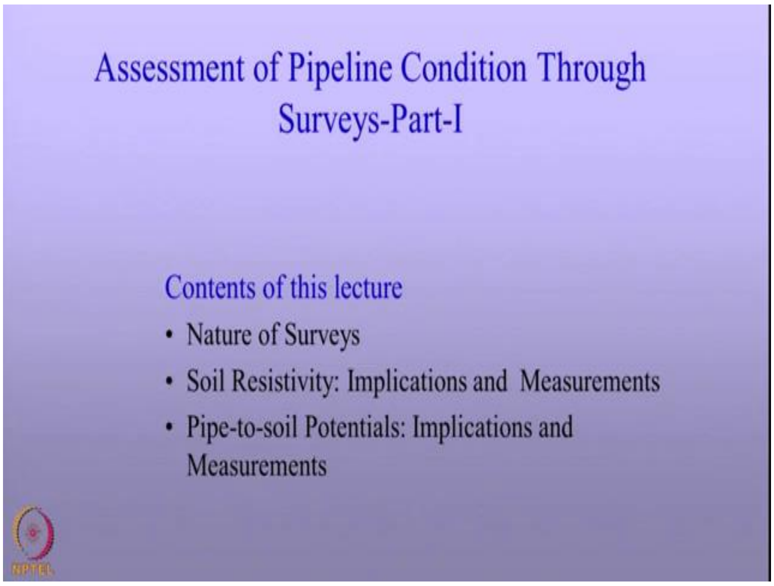

If you compare the pipelines with respect to the engineering structures in a typical plant, these pipelines undergo an unknown terrain. These pipeline also are very long in dimensions. In comparison the in comparison the structures in the plant or of small dimension, the environments these structures face are reasonably well known. And, so, assessing the buried structures especially the pipelines against corrosion is going to be more challenging.

And, more often it is indirect in nature than direct that normally you see in the plants, the operating plants. This assessment of pipeline condition through surveys this has two parts. And, today we shall look at the part one that consists of the nature of surveys, they are applicable to the buried pipelines, then we look at the two important surveys. They involve soil resistivity and the pipe to soil potentials.

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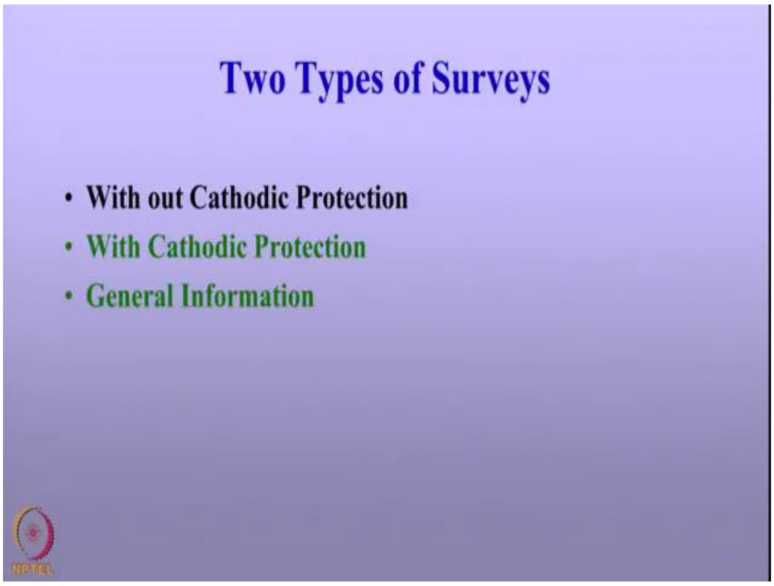

There are two types of surveys as applicable to the buried structures. Those structures, which are cathodically protected and there are other structure, which are not cathodically protected. The type of surveys that required in two cases can vary. In addition to these surveys, it is also necessary to have the information about the buried structures. We shall see a list of information that one may seek in assessing the pipelines are buried structures.

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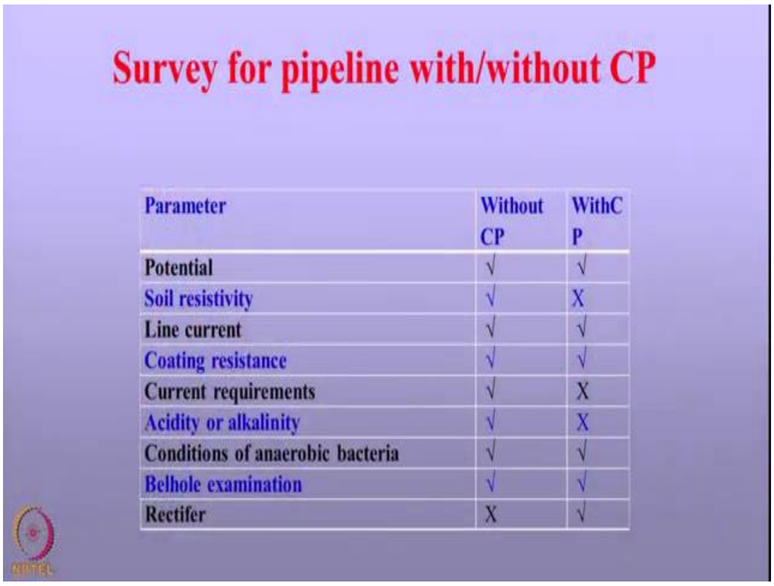

Parameter	Without CP	WithCP
Potential	√	√
Soil resistivity	√	X
Line current	√	√
Coating resistance	√	√
Current requirements	√	X
Acidity or alkalinity	√	X
Conditions of anaerobic bacteria	√	√
Belhole examination	√	√
Rectifer	X	√

So, we have seen the list of the parameters, the list of information that one would like to survey for the buried structures. They involve, potential, soil resistivity, line current measurements, coating resistance, current requirements, acidity or alkalinity of the soil, conditions of the bacteria present in the soil, and then goes last you also look excavate and look at the condition of the pipelines.

And, we need to also survey the rectifiers. In the list that are given here you will also notice in this column that all the surveys are not applicable to both the cases if it is cathodically protected.Then you will notice that the soil resistivity the current requirements the nature of the soil these information's are not required.

In fact, these information's are gathered before the pipelines are cathodically protected. On the other hand if the pipeline is not protected cathodically, you like to know the status of corrosion, then you need to have the host of information's that are given here; except of course, the rectifier which is not present in the case of pipelines or buried structures.

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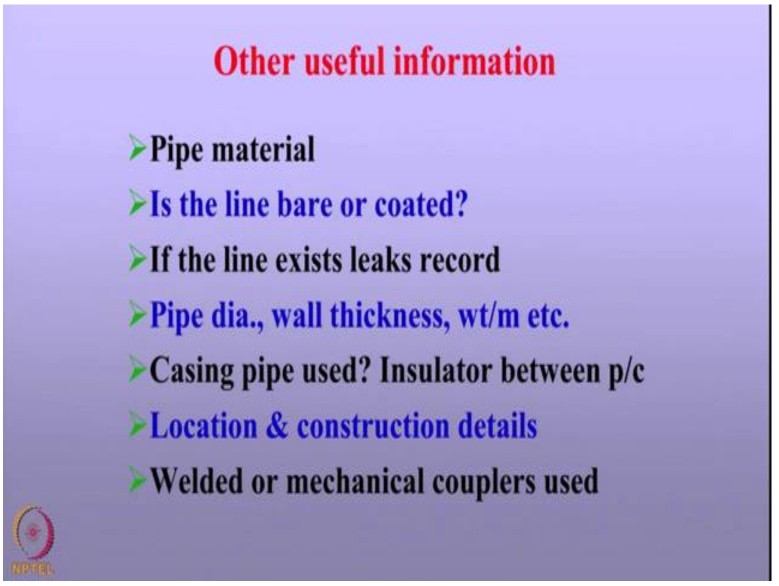

The other useful information required are you like to know the nature of the material be it a cast iron or a steel, there are different types of API grade steels are there. You like to know whether the pipeline is coated or bare. And, if the old pipeline the leak records off of importance.

About the pipeline you would like to know the dimensions such as pipe diameter, wall thickness weight per meter length or unit length of that.If, there are pipelines, if they are buried are they encased actually casing has been used if there are casings, then are there insulator between these casings.

Location and construction details of the pipelines when comes to pipelines, these pipelines may have mechanical couplers or they may be welded. It makes lot more difference to know, if there are mechanically coupled, because current needs to pass through in the cathodic protection systems. If there are mechanical couplers, it is possible that current does not pass through the pipeline.

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There are other information such as location of the branch taps, location of the insulator flanges we just saw the mechanical couplers. Sometimes you do have install the insulated flanges in order to prevent the current entering the unwanted areas.

The route maps and details of the maps actually, other pipelines which are surrounding the structures, it can be even tanks; stray current corrosion locations, if there are any parallel high tension lines are present and also like to know what is the temperature of the pipeline, what kind of products being transported or what temperature they are being transported.

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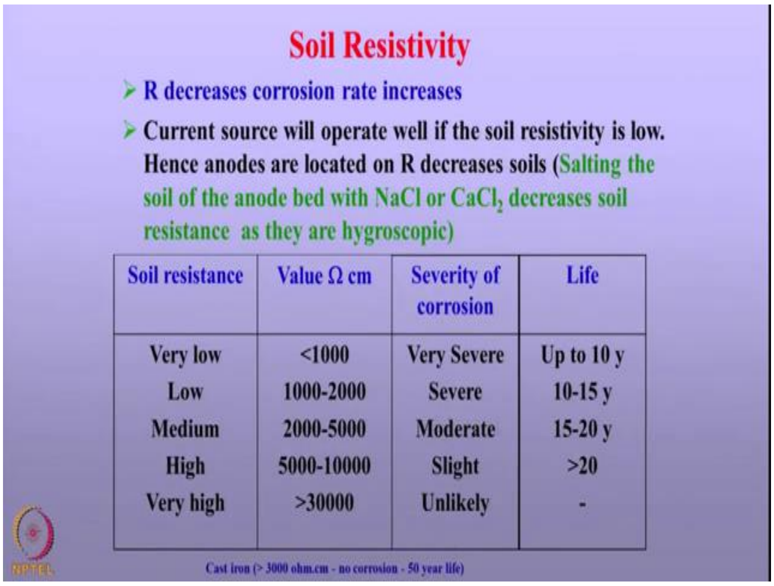

Now, let us look at the first aspect of the survey, which is soil resistivity. The soil resistivity is important on two accounts; one it influences the corrosion of the soil or put it other way around the corrosivity of the soil is related to the resistance, resistivity of the soil.

Resistivity measurement is also useful, when you install a cathodic protection system, because normally the anodes are located at a soil, where the resistance is lower. It enables the anode to discharge the current without having higher voltage applied onto the anodes.

This table gives you some kind of comparison between the soil resistivity and the extent of corrosion a steel pipeline may suffer. As you notice that when the soil resistance is lower than 1000 ohm centimeter, the soil has a very high severity in terms of corrosion, as the resistivity of the soil increases the severity of corrosion of the soil decreases.

In fact, if the soil has a resistivity greater than 30,000 ohm centimeter is very unlikely that the pipeline will suffer corrosion. The severity of the soil towards corrosion also related to the life of the pipelines. And, so, there is an indirect relation between the soil resistivity and the life of the pipelines.

In fact, you can see that if the soil resistivity exceeds 10,000 ohm centimeter ok, the life of the steel structures can be beyond 20 years. And, in fact, if it is going to be a cast iron, then the life can be even beyond 50 years of life.

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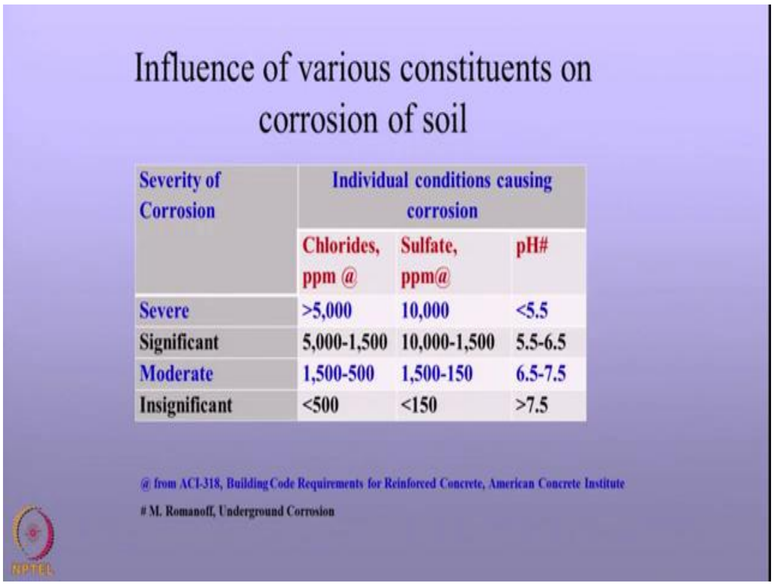

Severity of Corrosion	Individual conditions causing corrosion		
	Chlorides, ppm @	Sulfate, ppm@	pH#
Severe	>5,000	10,000	<5.5
Significant	5,000-1,500	10,000-1,500	5.5-6.5
Moderate	1,500-500	1,500-150	6.5-7.5
Insignificant	<500	<150	>7.5

Coming to the soil again the chemistry of the soil decides the corrosivity of the soil. Three factors are given here; one is the chloride content of the soil, the sulfate content of the soil, the pH of the soil. As you notice that between chlorides and sulfates, generally the chlorides are more severe.

They are more corrosive as compared to the sulfates. In both the cases; however, if the soil concentration increases, the severity of corrosion increases. So, is the case with the pH, lower pH means it is very severe and relatively neutral and alkaline pH, the corrosion becomes very insignificant. So, the soil chemistry is an important factor on the life of a buried structures.

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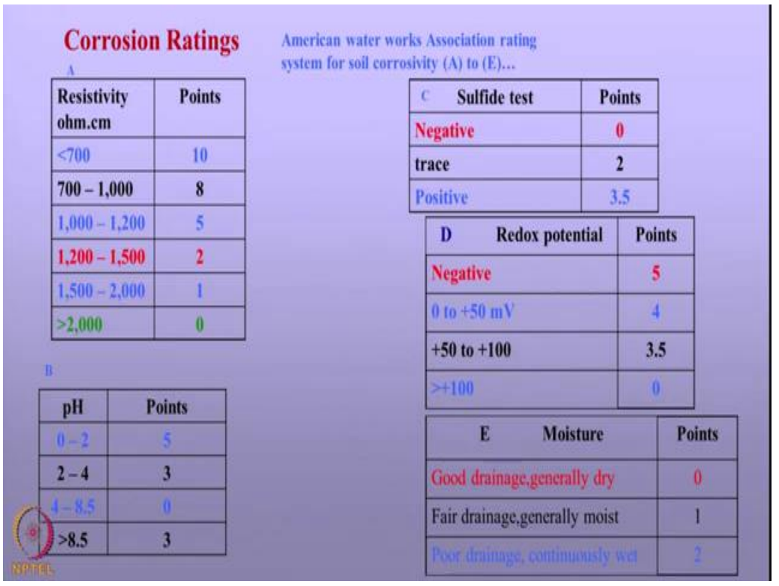

In fact, the American water works association has used some kind of rating to quantify soil corrosivity. They involved resistivity of the soil, the pH of the soil, the sulfide content of the soil, the redox potential of the soil, the moisture content of the soil. We have seen the resistivity and this relation to corrosion of the pipeline.

You can see the kind of ratings that is given here, rating starting from 0 to 10, 10 being the highest in terms of corrosivity of the soil. And, the redox potential if you notice is related basically to how aerated a soil is. If, the soil is more aerated or of course, even the nature of chemicals oxidizes present the potential will start moving towards positive direction.

So, the redox potential is also indication of the corrosivity of the soil. As you notice that when the redox potential increases, it acquires a bit of passivation tendency for the metal. And, so, the severity of the corrosion is decreasing. Moisture highly moisture content you can see that, the corrosivity increases.

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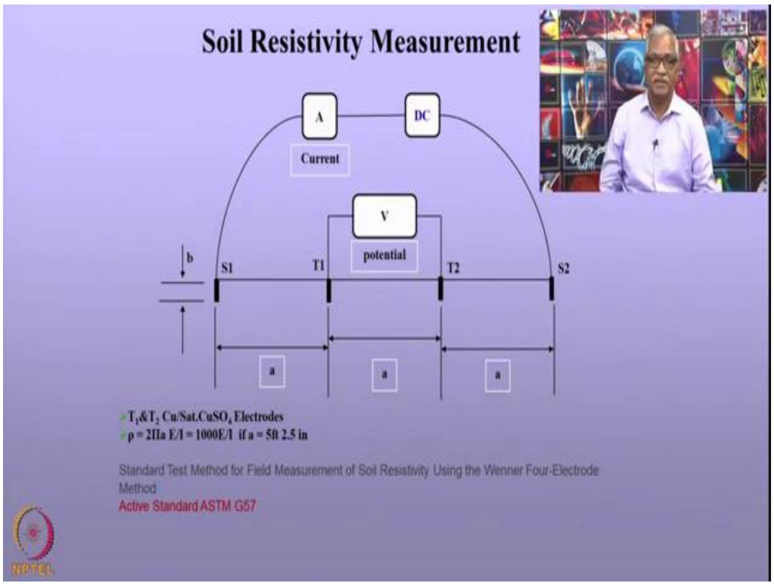

So, let us now discuss how to measure the soil resistivity on the field. One of the most important techniques is the 4 point probe technique and this is of course, well known to material scientist. In this case we use 4 pins, which are inserted in the ground at a equal distance, and between the external pins a current is being passed using A, so, a DC source a known current is passed through these pins.

Now, the inner 2 pins, which are kept at the same distance equidistance they measure the potential right, simply using the ohms law right ok. The current and voltage are related to resistance of the soil. And, this formula is used to obtain the resistivity of the soil. In order to make the calculation simple, the dimensions of these the instances are something like 5 feet and 2.5 inch distance. So, that the equation becomes simpler to determine to calculate the resistivity of the soil.

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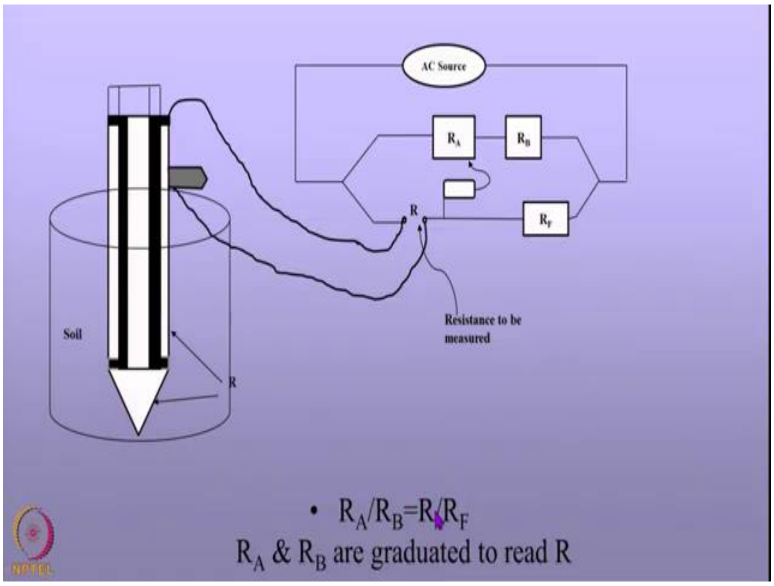

There is yet another simple method, wherein we use two electrodes. The previous case four electrodes were used, because you can also use two electrodes even for a DC measurements.

The disadvantage of using two electrodes in the DC measurements, wherein the two electrodes serve to pass the current and to measure the potential; the electrodes get polarized so, the potential of the pipeline or the potential of the electrodes keep changing. So, the accuracy of resistivity determination becomes a problem.

You can use two electrode system in which case instead of using a DC we use an AC current. And, AC current does not polarize the electrodes, they are in they are pierced in the soil or immersed in the electrolyte. So, this is a rod, that is inserted into the soil actually and the resistance between this point these 2 points are measured using a width and bridge kind of circuit.

The unknown resistance or the resistance of the soil is measured by balancing this resistance actually ok. You change these resistance values there are two resistance values R_A and R_B are known fixed values, and R of this is variable resistance you start moving actually and using this relationship R_A / R_B = R_E /R_F, it is possible to determine the R values. The advantage of this technique is very versatile, simple it can be taken to the field.

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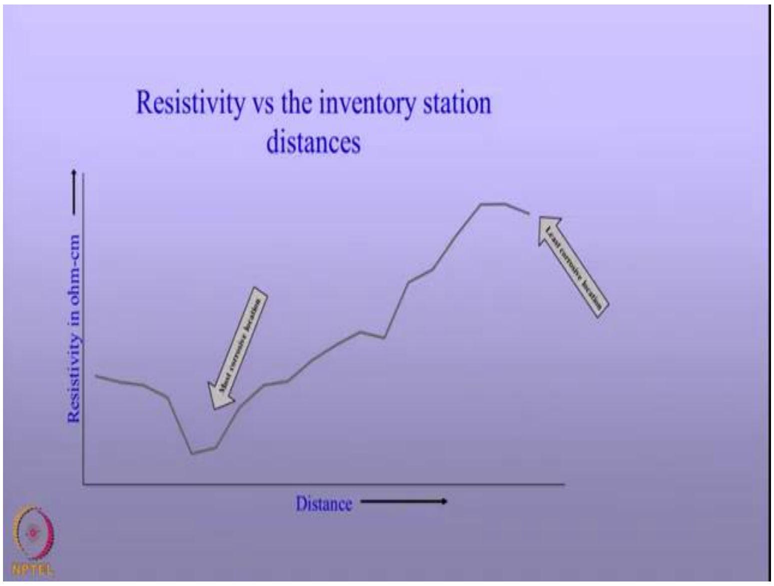

Let us look at the usefulness of the resistivity. What is given here is a plot of resistivity in ohms, versus the distance in a soil typically measured; it is a schematic of it. What you notice here is that the resistance resistivity is not uniform all through as expected the soil chemistry changes.

And, as you notice that wherever the resistivity of the soil is very low that refers to the most corrosive location. And, the resistivity is higher it implies that the soil is least corrosive. This has two important implications. Suppose for a cathodic protection if one wants to bury an anode, it is better to bury here, because the anode will function very effectively.

On the other hand, if you look at from the corrosion point of view the pipeline will experience least corrosion over here and highest corrosion over here. So, the resistivity is useful in two accounts; one to establishing an efficient ground bed anode ground bed and also to assess the corrosion of the pipeline or buried structures.

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Potential survey; potential is one of the most important parameter that one uses in the cathodic protection of buried structures.

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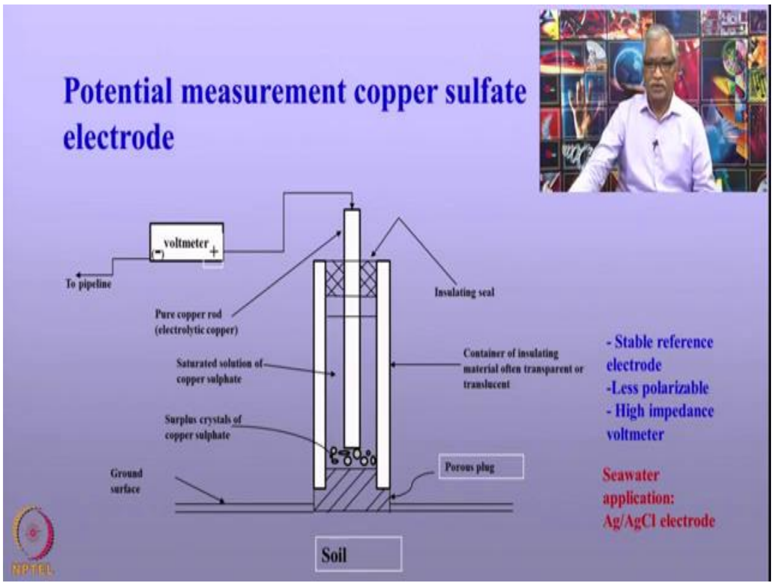

Before you go into the survey let us look at the measurement method. In order to measure the potential of the buried structures, one uses a reference electrode; a schematic of the reference electrode is given here. This refers to copper, saturated copper sulfate electrode.

And, this consists of a very simple you know arrangement, you have a transparent cylindrical container, and there is a porous plug, and into which you insert a pure copper, wire or rod. The solution inside is a saturated copper sulfate solution, that you will identify that the solution is saturated by looking at the undissolved copper sulfide crystals.

In fact, this is an advantage, because in the field by looking at this you notice that, the concentration of the copper sulfate is remained unchanged. The advantage of using a saturated copper sulfate is that, the concentration of the copper sulfate in the solution, which means the copper ions in the solution, remain unchanged.

And, so, this electrode has a potential which is not changing. For some reason, if the concentration of the copper sulfate solution changes, then the potential of this electrode changes. So, saturated copper separate solution is a versatile way of ensuring that the potential of the reference electrode remains undisturbed.

In practice there can be some kind of contamination, the electrode potential can change. It is necessary to ensure that the potential of this reference electrode is as per the requirement. The only way that you can do is you can compare with the another copper copper sulfate electrode or any other reference electrode, which is not used.

And, if you are going to use another copper copper sulfate electrode, the potential does not vary beyond 5 millivolt or 2 millivolt, then you are satisfied that this electrode is functioning. The reference electrode is connected to the pipeline, through a voltmeter which measures the potential.

The positive terminal of the voltmeter is connected to the reference electrode; the negative terminal of the reference electrode is connected to the pipeline. The other important characteristics of the reference electrode is it should be stable, it should not disintegrate, it should be less polarizable, which means that when I measure this voltage, between the pipeline and the reference electrode, small current is suspected to pass through this and that should not polarize the reference electrode.

In order to minimize the current passing between this reference electrode and the pipeline, you also use an high impedance voltmeter. The high impedance voltmeter ensures that not too much current flows between this reference electrode on the pipeline, because of the voltage difference. You can also use the other kind of reference electrode, which is silver silver chloride electrode; it is used mostly for sea water applications.

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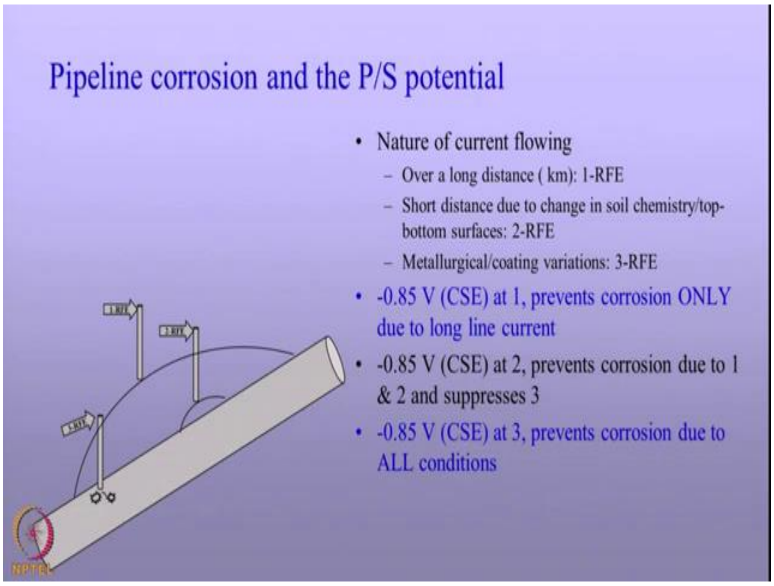

Now, let us look at the potential what we measuring and what does the measured potential really imply. You can measure the potential of a pipeline by placing the reference electrode at different locations. What is given here is the three locations? Indicating three type of information's that one would seek from a pipeline.

If the reference electrode is quite kepts quite far away, it can be kept close to the pipeline, it can be kept just above the pipeline. The potential is so, measured in all three cases give different type of information's. What are they? You notice that in a long pipeline the current travels long distance and some place becomes an anode, some place becomes a cathode, or there may be ground beds through which the current travels from one location to other location.

So, by keeping a reference electrode quite away from the pipeline, which we call as pipe to soil potential remote at remote distance, what one actually measures is the current that travels at a long distance. Maybe from the anode ground bed, or maybe two locations of the pipelines, if you are going to keep this reference electrode close to the pipeline a ball has a 4 to 5 feet or maybe a 2 3 meters.

Then, you will measure the potential that is developed because of the current that is flowing due to change in the soil chemistry. On the other hand, if the reference electrode is kept just well over the pipeline very close by then you see, that the current that is flowing between the metallurgical variations, between the coatings, that generate voltage that is measured.

So, the potential so, measured in three locations, they give three different types of information's. The potential is always measured with respect to electrolyte of course; you connect this you know reference electrode positive terminal to the voltmeter and the entire television of the voltmeter connected to the pipeline ok.

Let us look at what are the implications. Suppose, I obtain a voltage which is - 0.85 volt remote, it indicates that it prevents corrosion due to long line current. The current that flows between you know the pipelines, having different chemistry of soil is not controlled. So, if it is if one measures a potential which is - 0.85 and more negative than this, by keeping the electrode here, then the corrosion due to long line current and due to soil is suppressed.

And, if the reference electrode measures a potential kept over the pipeline and if the value is - 0.85 and more negative than that, then we can say that that corrosion due to all forms of current flow is reduced. So, it is important that we know what kind of potentials that we are really measuring.

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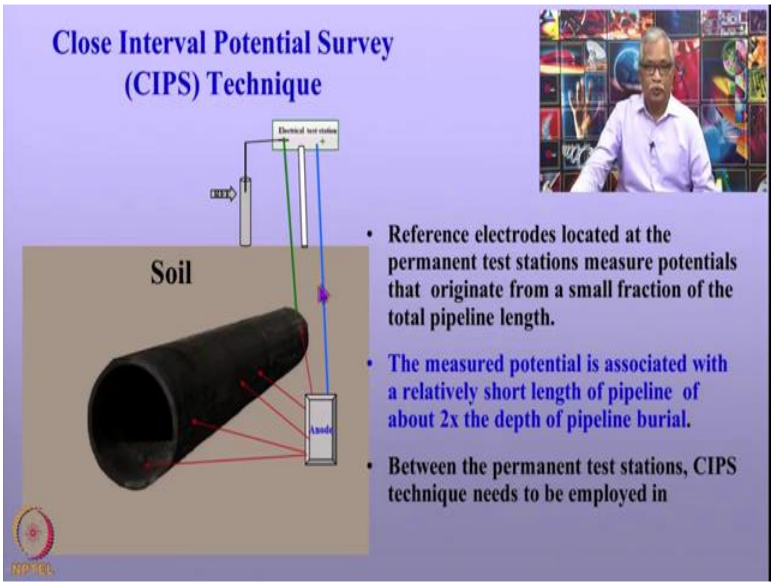

Let us go into the field applications, how the potential are measured on the field. The one type of potential measurements is called as closed interval potential survey technique; this technique is used to measure the potential of the pipeline, across the pipeline. Normally, in a cathodic protection systems a reference electrode is kept at the test station.

This potential measured by this reference electrode corresponds to the corrosion of the pipeline in the near vicinity of the pipeline ok. For example, it can be about twice the depth of the pipeline. If, there is if the pipeline is about 1 meter depth, the corrosion conditions of the pipeline about 2 meters on either side of the reference electrode is can be seen.

But, if you want to know the corrosion performance of the pipeline or a long distance between the permanent test stations, then it is required to carry out the closed interval potential survey.

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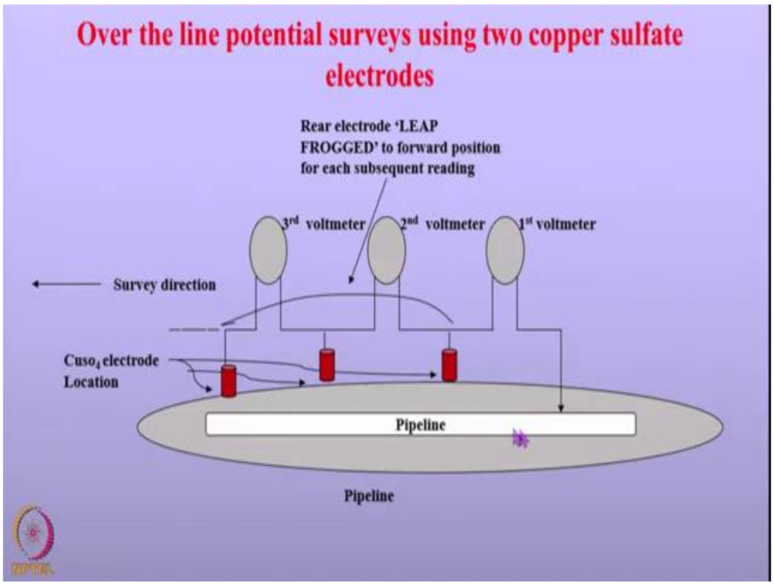

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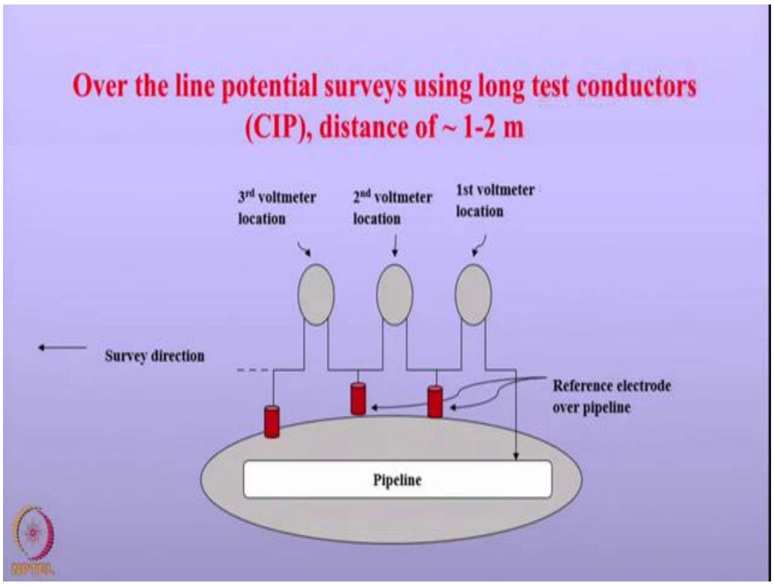

The closed interval potential survey is generally done over the pipeline. Now, the reference electrode is connected to a voltmeter, the other terminal is connected to the pipeline. And, it is moved at a distance of about 1 to 2 meters. And, each time you move over the pipeline, the potential is recorded. The only problem with respect to such a kind of measurement is that you need to have a long cable; the long cable has high resistance.

So, one has to compensate the potential with respect to resistance offered by the cables. So, in order to minimize this people use two copper sulfate electrodes. The measurement is done as follows first you measure the potential of the pipeline at a location. Subsequently place another reference electrode at a distance let us say about 1 to 2 meters.

Now the potential difference between these two reference electrodes are measured. First you measure the potential of the pipeline with respect to reference electrode by establishing electric connection here; subsequently the electrical connection is now disconnected.

Now, between the two electrodes you measure the potentials, then you leap frog this reference electrode to the front. And, you again measure the potential between two different electrodes. The algebraic sum of these potentials give you the potential of the pipeline at a given location. The advantage of this technique is that the cable is very short, but does not have to worry about the resistance offered by the cables.

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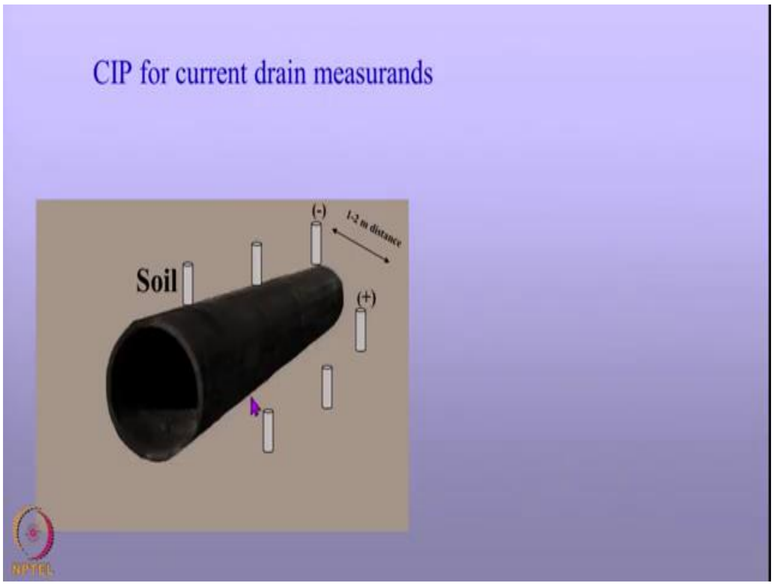

There is another kind of information; one seeks from the pipe to soil potential measurements. This again is closed interval potential measurements; the difference is that one electrode is kept well above the pipeline, the other one on either side of the pipeline at a distance of 1 to 2 meter.

The potential is measured between these two reference electrodes. And, this and if this potential between these two is positive the current enters in one directions, if it is negative the current enters in the other direction. So, the advantage of this technique is you will come to know, whether the pipeline is receiving current or the pipeline also act as a drain, wherein corrosion occurs.

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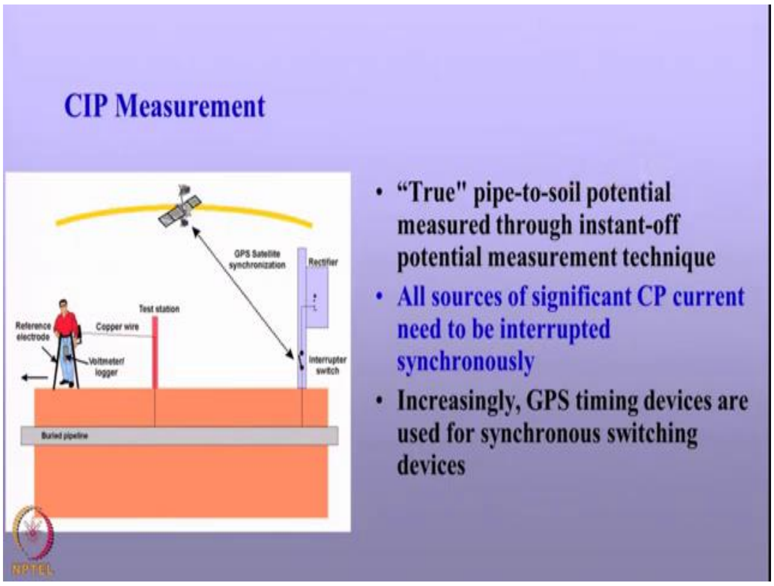

CIP Measurements we need to look at the one important factor. That is you need to measure the true potentials, that is true pipe to soil potential, you have to discount the resistance offered by the soil; that means, you use instant off potential measurement technique.

What you seen in this diagram is various features associated in measuring the instant off potential for a given pipelines. In this case you have a test station a copper wire is taken from the test station and it is connected to the voltmeter. And, the person carries voltmeter you can see here in this case and it also has got a data logger, which records the volt at a given place.

It is very important that in the instant off technique, we need to synchronize all the devices, all the CP current providing stations, in order that, the pipeline does not receive current So, this synchronization is can be done using GPS satellite synchronization. So, that the pipeline does not receive current when it is interrupted.

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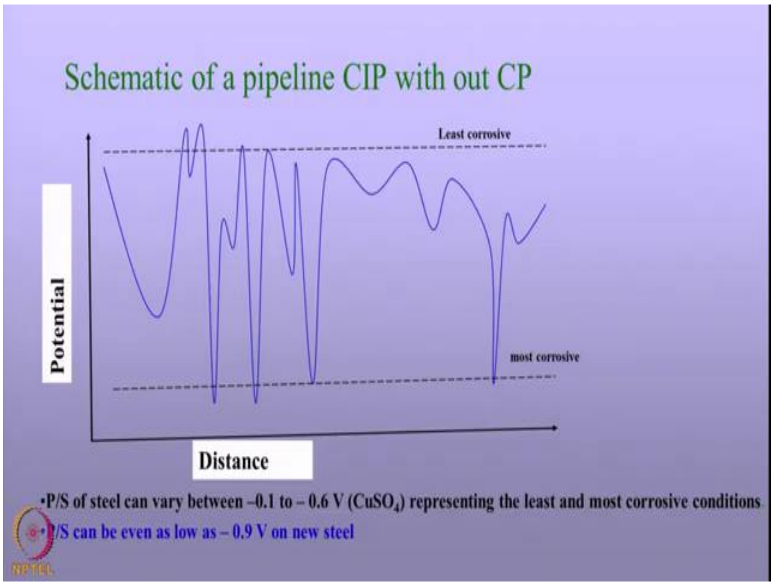

What is given is a schematic of a pipeline closed interval potential measurements without CP, without cathodic protection; as you see here the potential fluctuates quite significantly it is not a smooth. And, if the potential is more negative lower value it indicates that the pipeline suffers the corrosion. If the pipeline is (Refer Time: 33:56) in showing relatively positive potentials and it indicates that the pipeline is suffering least corrosion.

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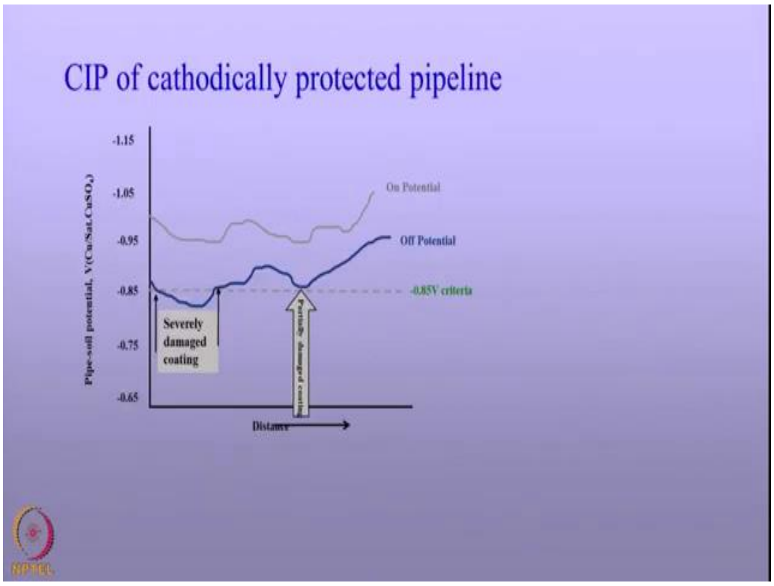

Exactly reverse is true, if the pipeline is cathodically protected ok. Wherever, it shows more negative potentials, the pipeline is protected from corrosion. But on the other hand the pipeline wherever shows less negative potentials, it indicates that the pipeline is experiencing corrosion. So, this experiencing corrosion can be due to damaged coatings or maybe some other reasons ok.

But, it is possible to know from CIP, that the corrosion of the pipelines. As compared to CIP of the unprotected pipelines, the cathodic protection pipelines the piped soil potential is very smooth, it does not have a very severe variations with respect to distance.

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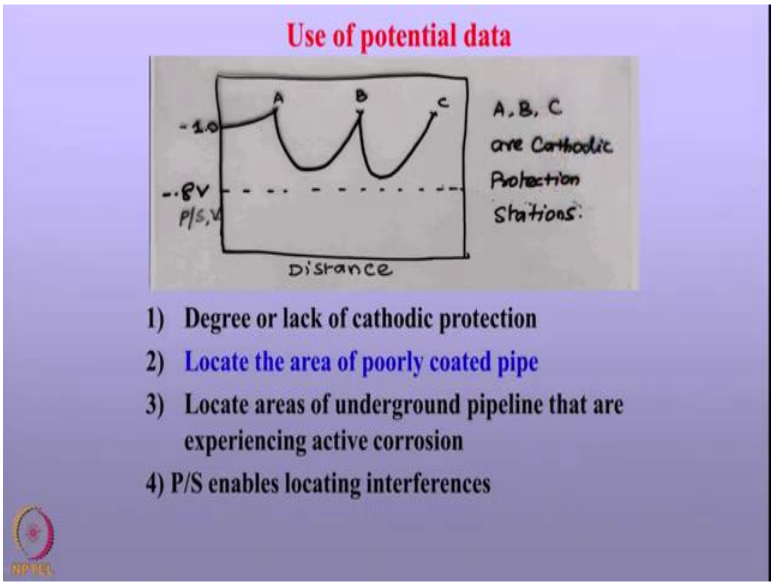

We have summarized here, how the pipe to soil potential can vary with respect to distance between the various test stations. And, A, B and C represent various cathodic protection stations here. And, you can see here this line corresponds to the cathodic protection criteria - 0.85 volts, if the potential lies above this then the pipeline is cathodically protected.

And, if the potential falls below this then pipeline is not protected against corrosion sufficiently. The potential data is very useful on several accounts; one as we discussed now, it indicates the degree and lack of cathodic protection of the pipeline. It can indicate the protection capacity of the coatings, if the coatings are damaged or degraded.

Now, you can also look at those underground pipelines which are experiencing active corrosion or suffering interferences slaker and corrosion. If, the potential you know remains below - 0.85 it indicates that any of these cases are responsible for the corrosion of the pipelines, so.

Thank you.