

AC Corrosion and Mitigation

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NACE SP0177-2007

- The initial publication of the standard, which is titled “Mitigation of Alternating Current and Lightning Effects on Metallic Structures and Corrosion Control Systems” was July 1977
- The safety concerns of AC on pipelines was established in 1947, which is now accepted as keeping AC potentials below 15 volts for safety
- Beginning in the mid 1990’s, concerns for AC corrosion mitigation began when it was identified as a cause of corrosion in Germany and Australia

What Has Caused this Now?

- The implementation of pipelines in electrical power line right of ways is not new.
- Implementing of new high dielectric coatings is new, and new constructions began using coatings like FBE in the mid 1970's, but most were in open country locations, with a small percentage in common corridors with AC lines
- Beginning in the 1980's the cost of new ROW for pipelines, separated from other lines and utilities was seen as too costly, and most new lines were installed with FBE in common corridors with AC Power lines
- Common corridors were considered a good use of expensive ROW and less of an impact on congested areas as well. So the practice has expanded over the years.

Common ROW Today



Common ROW Today



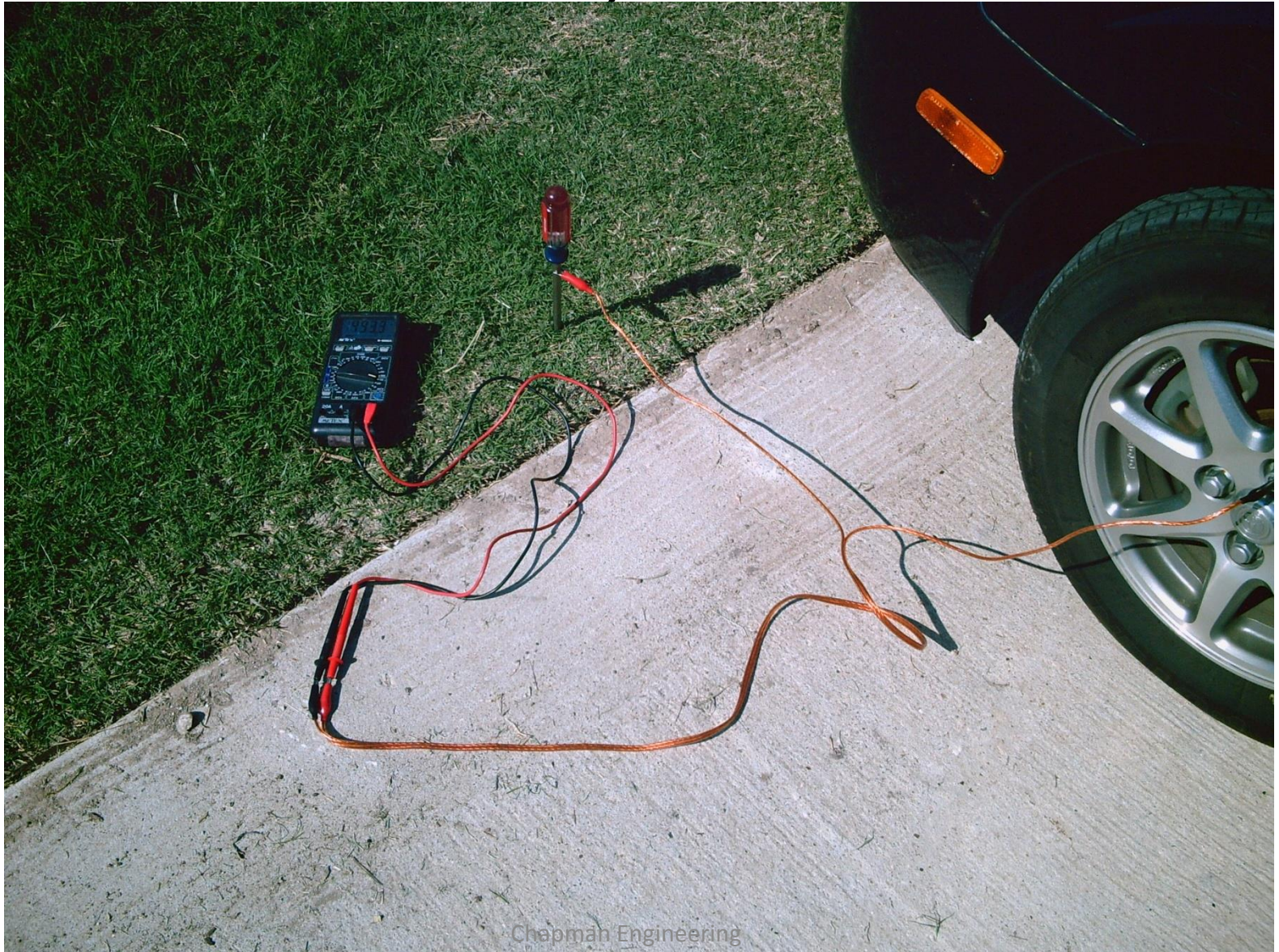
General Perspective

- The consequence of well insulated pipelines in High Voltage AC corridors resulted in pipelines suffering high current loads of AC as a byproduct of inductive, capacitive, and direct coupling issues with the power lines.
- The pipeline basically is now a secondary winding of a gigantic transformer, with the AC power line as the primary winding.
- Voltages induced into the pipeline go in the opposite direction to those in the power line.
- These voltages can build to levels that can become safety hazards, and the current values of the pipe line can result in corrosion to the pipe walls by AC Corrosion
- AC Corrosion is not yet a clearly defined process, however, it does have some characteristic indications that are commonly associated with it from field inspections.

What about a Car?



Screwdriver in Dirt, Wires to it and Car



What type of Interaction?



Types of AC Power Line/Pipeline Involvement

- Inductive Coupling

The process is one where the nearby pipeline and parallel power line orientation induces magnetic fields in the pipeline, opposite to those in the power line.

The model is a power transformer, with the power line the primary winding, the pipeline as the secondary winding, and the air and earth as the core

This process primarily causes the flow of high current levels in the pipeline, that may need to be returned to the power line to protect the pipeline.

- Capacitive Coupling

This process creates charges on the pipeline as the opposite plate of a leaky capacitor and the power line as the other capacitor.

Normally the current accompanying this coupling is low except during construction where the isolation of the pipeline can be much better than the buried pipeline, which allows the pipeline to charge to a high voltage, engendering shock hazards, and sufficient current to cause damage to people and equipment.

Auxiliary grounding is recommended for this situation during construction.

Normally when buried there is much less capacitive coupling.

Pipeline/Power Line Interaction

- Resistive Coupling/Faults

A rare condition normally associated with a short from the power line to the ground, or to the pipeline directly.

The coupling can happen from a power line contacting a tree, a bad insulator allowing contact between the tower and a phase line, a line falling to equipment in the area or to ground.

The currents coupled to the pipeline can be very large, and normally of short duration as switchgear is oriented to disconnect lines that have this situation.

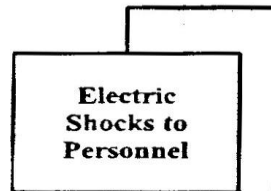
The major issue of this type of coupling may be significant coating damage from the high voltages and currents involved

- Power Arc, and Lightning

Power arcs can happen during fault currents, where the soil is ionized to allow an arc to the pipeline or soil near the pipeline. Lightning can be similar but is normally of less an issue on coating damage than arcs and faults may be.

Lightning can ionize the soil and penetrate to the pipeline, even to the point of burning holes in the pipe wall. Normally this would be in an area of higher soil resistivity with an area of less cover over the line. Lightning can also cause coating damage, but may be less of an area of damage than an arc or fault.

HVAC/Pipeline Interactions



AC Safety Issues

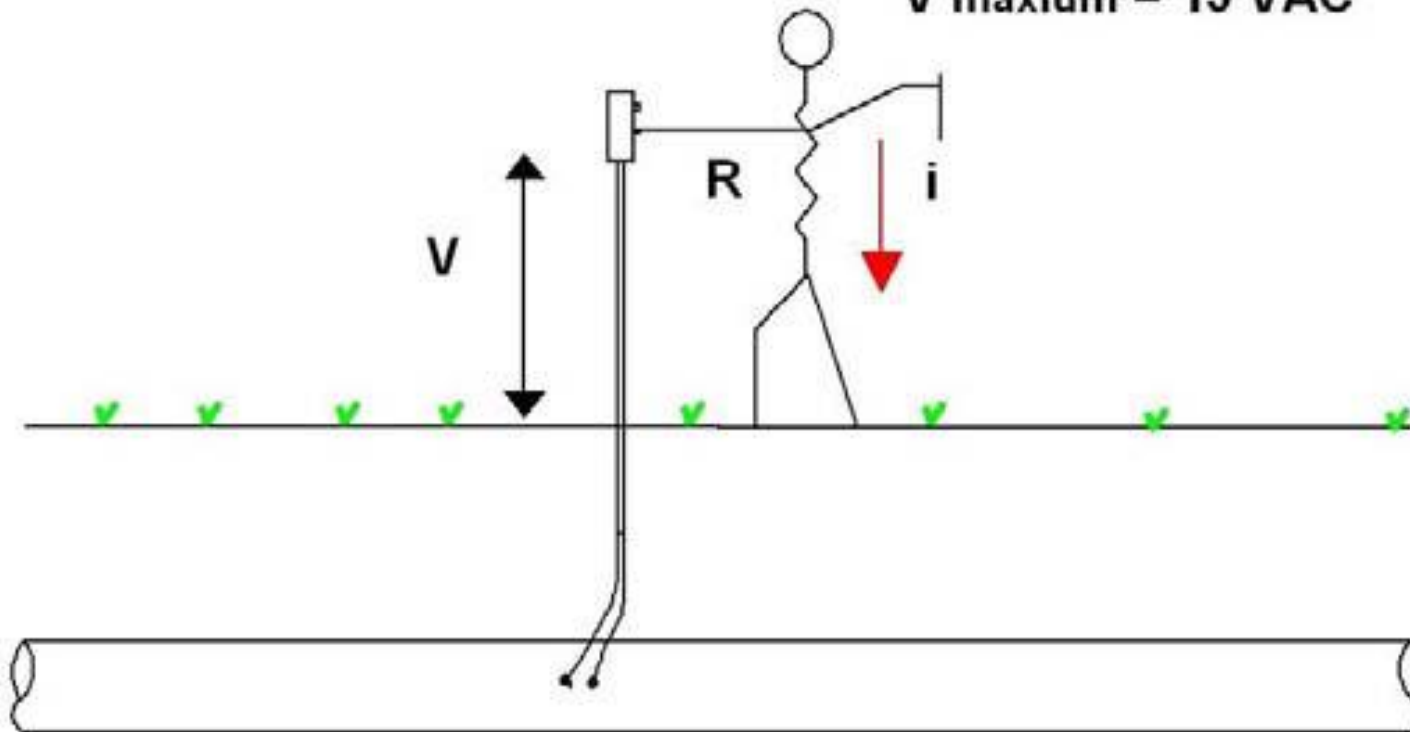
- The threshold of 15 volts AC can be achieved by a well insulated pipeline in fairly low voltage situations due to inductive coupling. Faults, lightning, and arcing can also be implicated only if of a very short time. Capacitive coupling often causes high voltage on pipelines when on insulating blocks during construction.
- AC safety levels can be achieved with modest additional grounding elements and materials at reasonable costs, even during construction.
- A construction zone grounding element would be about 20' long and 2' wide with 3 bags of solid conductive media (conducrete) for a ground resistance of 1.2 ohms in 1000 ohm cm soil for instance. This would be an effective safety ground connected to pipe or equipment in HIVAC ROW's.

Touch Potentials

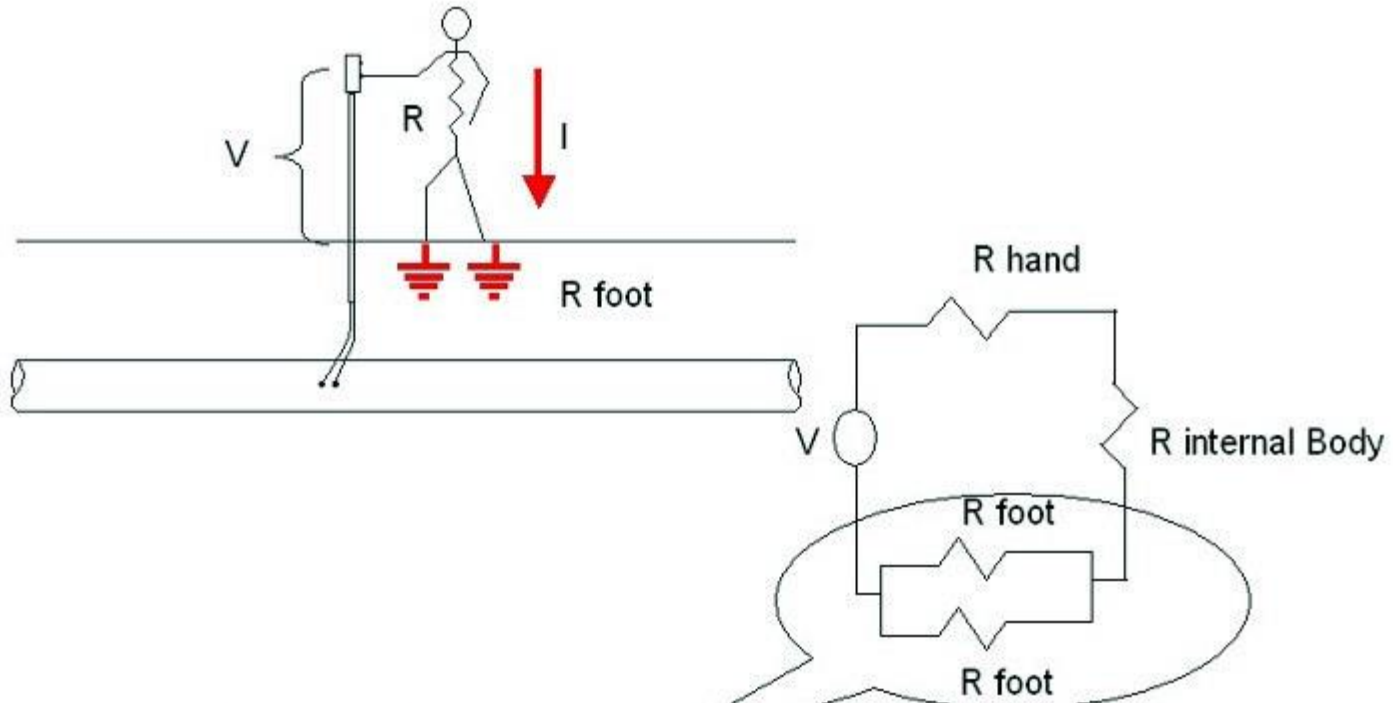
$i =$ Let go current = **10 mA**

$R = 1500$ Ohms

$V_{\text{maxium}} = 15$ VAC

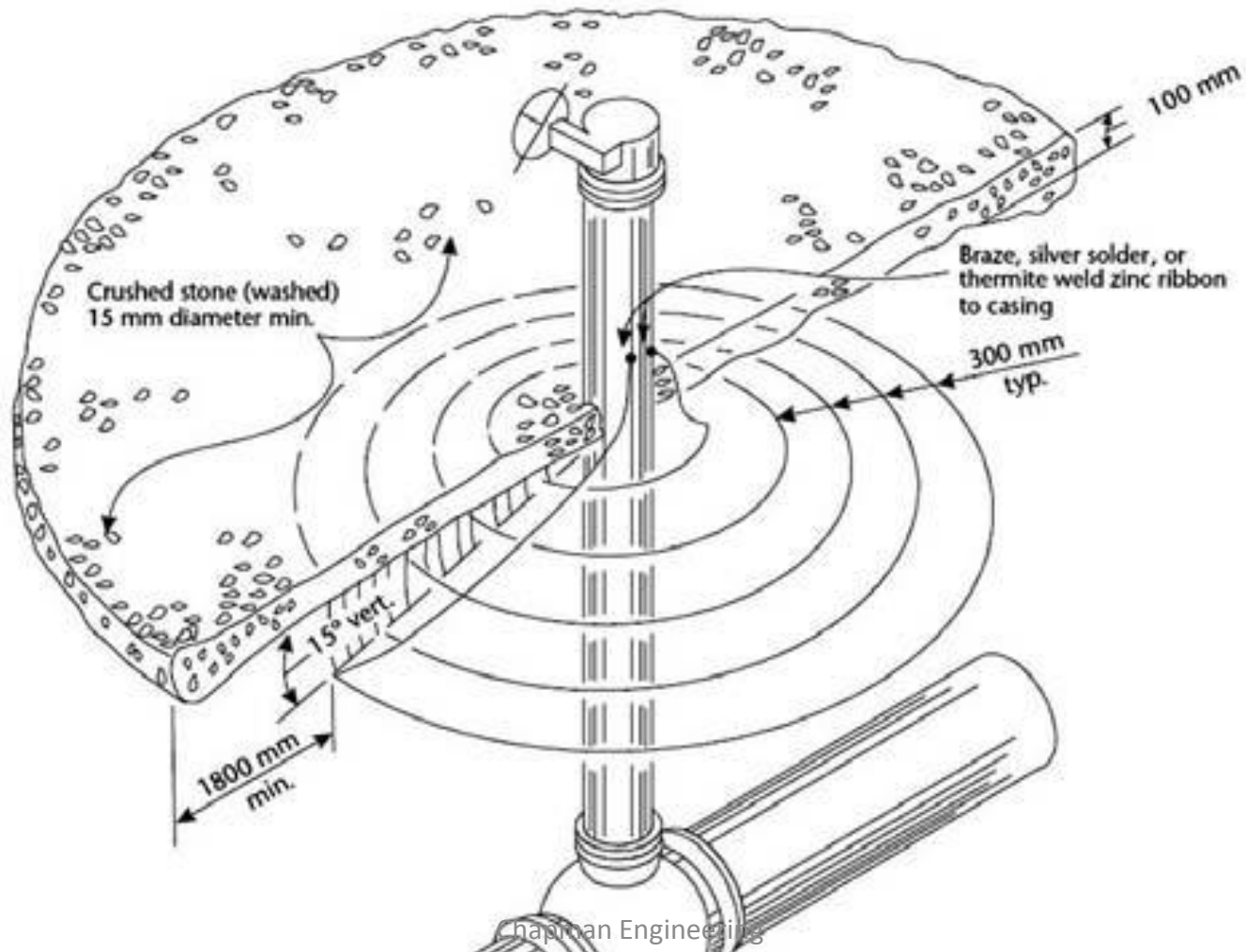


Step Potentials



Here the parallel resistance of the two feet to ground is calculated as
 $R (2 \text{ feet parallel}) = 1/2 (\rho)$
Where ρ = Soil Resistivity in Ohm-Meters

Step Potential Mats



Safety Hazard Voltages Very High



Temporary Grounding/Construction



Power Line Fault Example



AC Corrosion Characteristics

- AC corrosion is possible mainly due to inductive coupling which applies the higher current values to the line for long distances.
- Where the induced AC finds an opportunity to leave the pipe, through an opening in the coating to the soil, low soil resistivity usually is needed to have AC corrosion.
- The main culprit is the AC Current Density.
- The lower the soil resistivity and the smaller the coating anomaly, the higher current density and the higher the probability of corrosion issues.

What is Meant by AC Current Density?

- The current density level is important, not necessarily in the pipeline itself, but at the point of discharge from the pipeline into the soil.
- Reported data from field inspections have shown a range of AC current densities of 0 to 20A/m² are not involved with AC corrosion. From 20A/m² to 100A/m² there may be an involvement, while levels over 100A/m² are strongly indicated to have AC corrosion active.

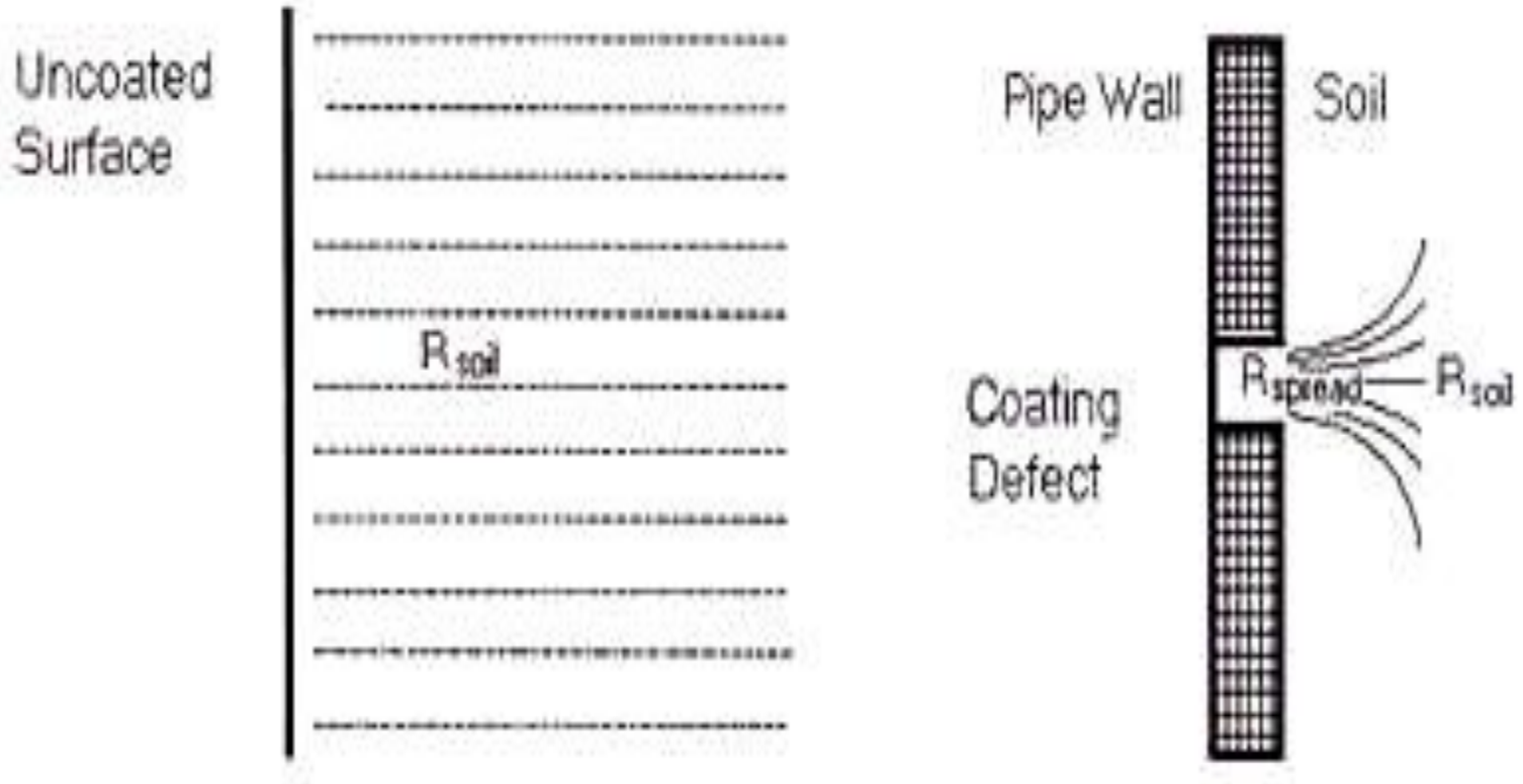
What affects the AC Current Density?

- High soil resistivities are an enhancement to protect the pipeline by lowering the current density.
- Low soil resistivities allow higher current densities as the current flow away from the coating anomaly is enhanced.
- The size of the defect is critically important. Densities of current from a scrape of several inches in length will have lower current densities. While a small defect in the coating, such as made by a grain of sand in the coating will have much higher current densities as the current is being pushed from a much smaller cross sectional area.

Further AC Current Density

- The availability of the current in the pipeline is also a major factor. If the pipeline is in a corridor with low AC current power lines, the critical current densities may be too low induced in the pipeline to be an issue, while large tower like lines with high voltages may indeed be involved with it. Each case is different, which points strongly to the need of field measurements and accurate modeling.
- Normally a length of pipe should be running parallel to an HVAC system to induce high current loads, but not always. In some crossings of shallow angles, these currents can still be achieved.
- There is an “end effect” situation as well, where current tries to preferentially leave the pipeline near the point of its deviations from being parallel

Bare Pipe or Coated Implications



How do we identify AC Corrosion?

- Field inspections of a suspected AC corrosion area should be exposed, but undisturbed prior to inspection. Cleaning or blasting them will erase critical clues to the cause of the corrosion.
- There are similarities between AC corrosion and MIC and may be misread by inspection, especially if the location has been cleaned.
- Both AC corrosion and MIC have a layered contour with each layer going deeper into the metal.
- Major differences may be that with MIC there likely is a smooth bottom to the pit, while with AC corrosion, the bottom may be somewhat level with small circular dimples scattered in the bottom.
- Measure the pH of liquid in the pit. A high pH is usually indicative of AC corrosion, while a low pH indicates possibly MIC is the corrosive agent.
- MIC can have some channel corrosion underneath the coating running away from the source of the corrosive acids produced along weak adhesion areas of the coating. Normally it is found that with AC corrosion, the corrosion is fairly locally confined and the coating may be disbonded only on the outer edges of the main pit.

A “Classic” AC Corrosion Pit



Point of AC Exit Example



Difficulty of Inspections When Cleaned

- It is important not to sand blast the anomaly prior to inspections! Important clues can be erased.
- Characteristic shapes and edges are too subtle to establish fully if the corrosion was MIC (probable), or AC corrosion (possible).
- It is very important that the inspection crew sees the anomaly excavated prior to any cleaning or disturbance of the anomaly.

An Unusually Large AC Corrosion Anomaly

- Anomaly indications of CIS, DCVG, ACVG, and soil resistivity indicated the location as an excavation location.
- Upon excavation, a large anomalous ball of material was adhered to the pipe coating – much of the coating underneath was intact

Upon Excavation



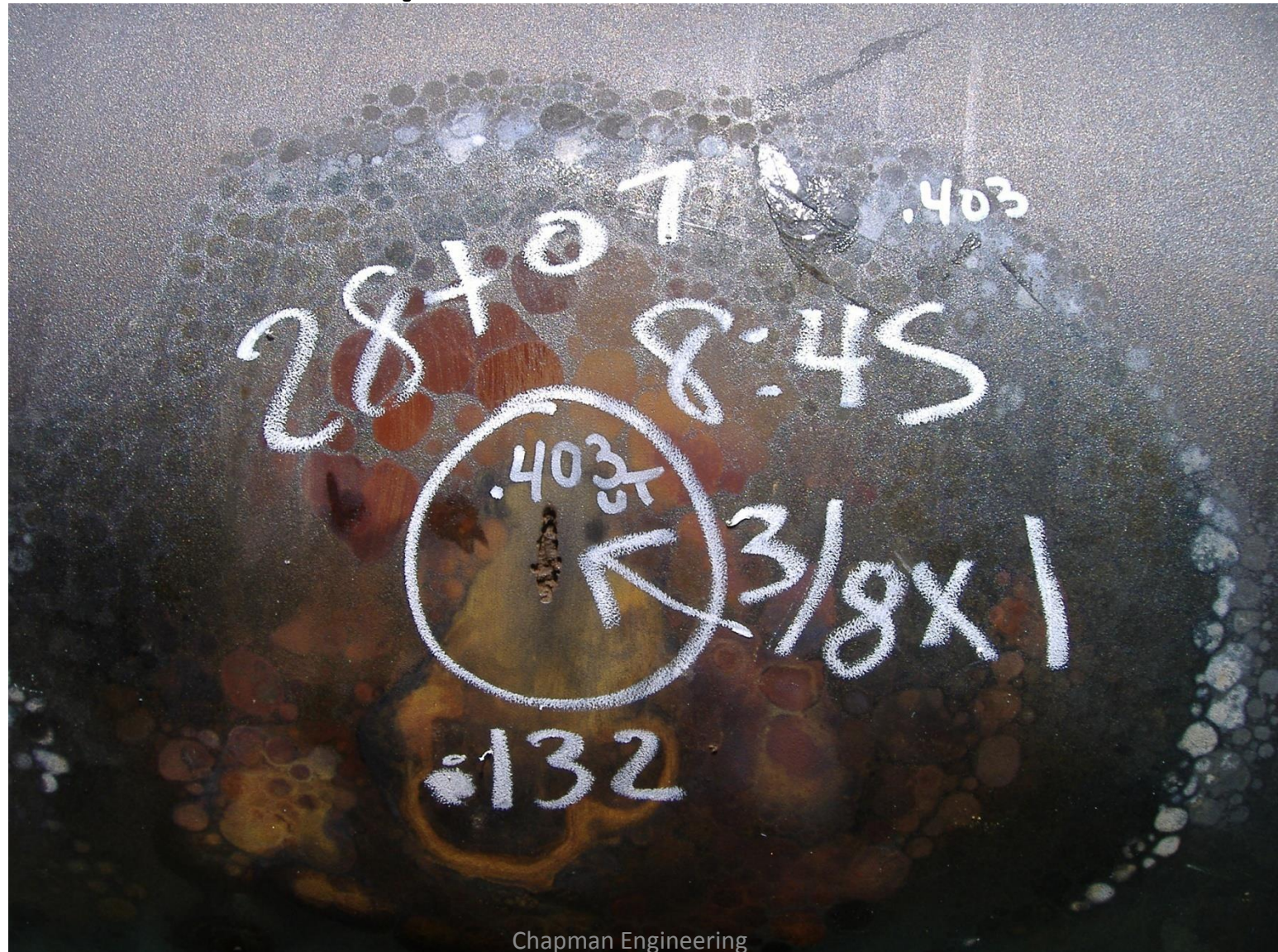
Removed Corrosion Product Ball



Area Under Corrosion Product



Close Up of Corrosion Area



Discussion

- The characteristic shapes of the AC corrosion are noted in the bottom of the pit.
- Layers of corrosion are evident in the pit outer walls, as well as indicated by rings in the corrosion product ball.
- Layers and rings of corrosion product are due to periods of higher current loads, and lower soil resistivity due to rains or soil moisture.
- The corrosion of .132" on a .403" wall indicates a corrosion loss of 32.8%. The time period is unknown.

Final Examples – Look For the Characteristic Shapes



How do YOU Discover AC Corrosion?

- As PIM procedures mature, more emphasis on surveys will be required to detect AC issues especially in HCA's.
- Reviewing AC readings on ECDA reports and as found by ILI pig runs with wall loss, a big sign.
- Evaluate likelihood of AC corrosion by estimating current drain from 1cm^2 area, soil resistivity measured in field, and AC potential.
- Request AC corrosion modeling (CDEGS Software or others).

Construction, Pig Run, ECDA Insp.

| | | | | | | | | | | | |
|----------------|-------------------------|-------------------|-------------|----------------|--|--|-------------|-----------------|-----------------|-------------------------|---|
| Line | 12" Diam | 43.60 Miles | | | | | | | | | |
| HCA | | 41.80 Miles | | | | | | | | | |
| | | | | | | | | | | | |
| Station | Depth | Length In. | Dug | ACVolts | Comments | Meas 090709 | | | | Confidence Ratio | |
| 465+53 | 21% | 1.89 | | | | | | | | | |
| 465+53 | 47% | 3.25 | 2008 | 10.23 | Installed 10 mag anodes and decoupler. | 0.5VAC @0.5A | | | | 0.4468 | |
| 674+91 | 19% | 1.85 | | | | | | | | | |
| 674+91 | 31% | 1.28 | 2009 | | | | | | | 0.6129 | |
| 675+01 | 10% | 1.18 | | | | | | | | | |
| 675+01 | 17% | 1.00 | 2009 | 15.22 | | | | | | 1.7000 | |
| 2311+71 | 27% | 1.30 | | | | | | | | | |
| 2311+71 | 51% | 0.88 | 2008 | 1.3 | High concern area | | | | | 1.8889 | |
| | | | | | | | | | | | |
| | | | | | | | | | | | Scatter indicates good calibration ILI. |
| | Wall thicknesses | | | | | Loss Rate Per Year Depth Inches | | | | | MPY Per |
| | 2001 | 2008 | 2009 | | Evaluating the wall loss rates | 2008 | 2009 | 2008 MPY | 2009 MPY | VAC | AC Volt |
| 465+53 | 0.312 | 0.246 | 0.165 | | Loss rate 100% between 2008 and 2009 | 0.0094 | 0.0183 | 9.36 | 18.33 | 10.23 | 1.792 |
| 674+91 | 0.312 | 0.253 | 0.215 | | Loss rate 43% between 2008 and 2009 | 0.0085 | 0.0121 | 8.47 | 12.09 | | |
| 675+01 | 0.312 | 0.281 | 0.259 | | Loss rate 49% between 2008 and 2009 | 0.0045 | 0.0066 | 4.46 | 6.63 | 15.22 | 0.436 |
| 2311+71 | 0.312 | 0.228 | 0.153 | | Loss rate 65% between 2008 and 2009 | 0.0120 | 0.0199 | 12.03 | 19.89 | 1.3 | 15.300 |
| | | | | | | | | | | | |
| | | | | | | | AVG | 8.58 | 14.24 | 8.92 | 5.84 |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |

Calculate Amps/M²

- Formula from 1995 NACE International paper
- $i_{ac} = (8 * V_{ac}) / (\rho * \pi * d)$
- i_{ac} is Current AC per m²
- V_{ac} is measured value
- ρ is soil resistivity in ohm meters
- D is diameter in meters (0.0113M)

Current Density

| | |
|---|-----------------------------------|
| AC INTERFERENCE EQUATION: $I=8(VAC)/(\rho)(\pi)(d)$ | |
| I = current density in A/m² | |
| ρ = soil resistance in Ω-cm | 350 Ω-cm |
| d = diameter of holiday in cm | 1 CM |
| π = Pi | 3.1415927 |
| v = recorded AC voltage | 2.5 VAC |
| | Total: 182 A/m² |

A penny has a diameter of 2.0 cm
 A nickel has a diameter of 2.2 cm
 A quarter has a diameter of 2.5 cm

AC Corrosion Theory - Current Density

| | |
|---|-------------------------------------|
| AC INTERFERENCE EQUATION: $I=8(VAC)/(\rho)(\pi)(d)$ | |
| I = current density in A/m² | |
| ρ = soil resistance in Ω-cm | 10000 Ω-cm |
| d = diameter of holiday in cm | 1 CM |
| π = Pi | 3.1415927 |
| v = recorded AC voltage | 30 VAC |
| | Total: 76 A/m² |

A penny has a diameter of 2.0 cm

A nickel has a diameter of 2.2 cm

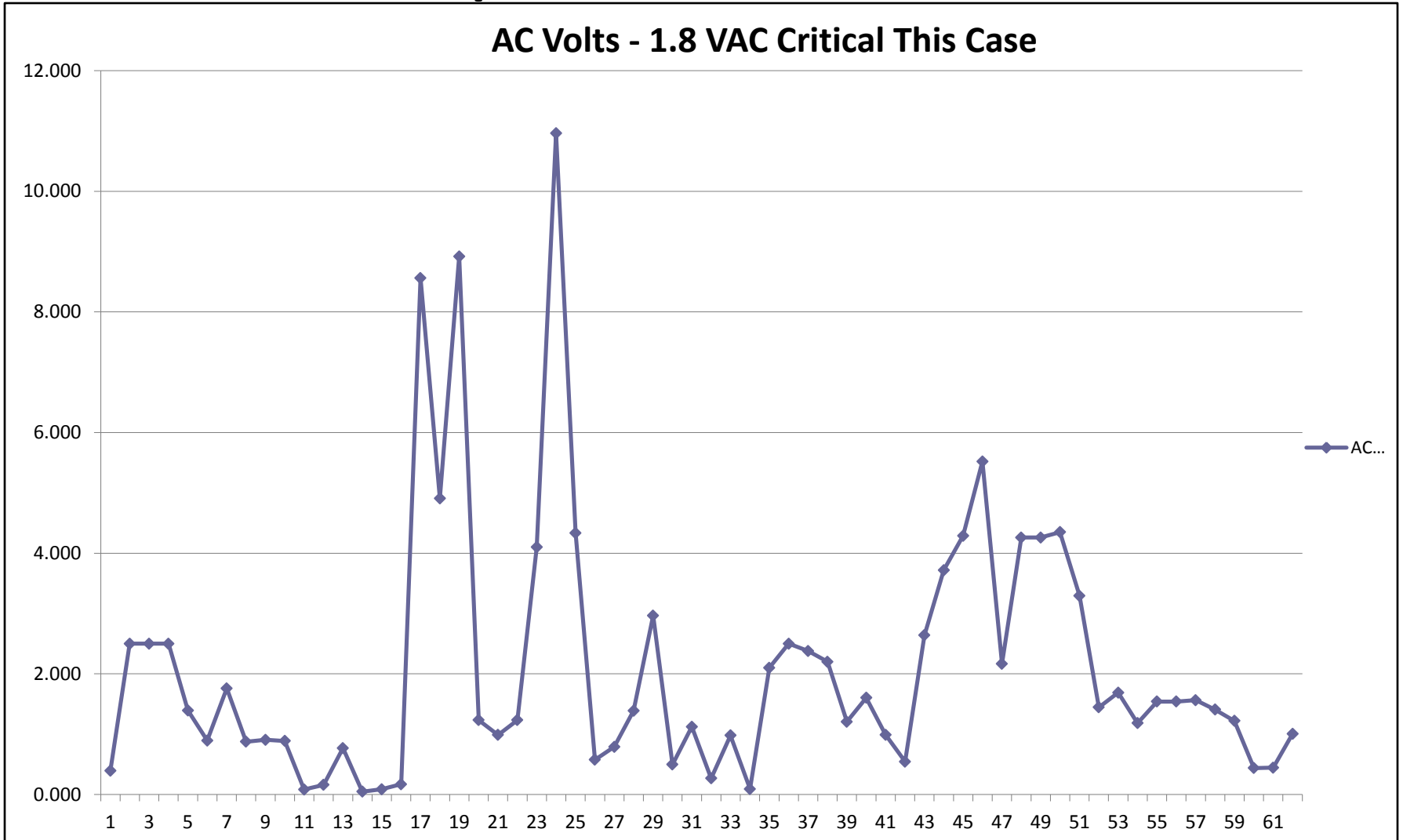
A quarter has a diameter of 2.5 cm

T/L Annual Survey with AC Potentials

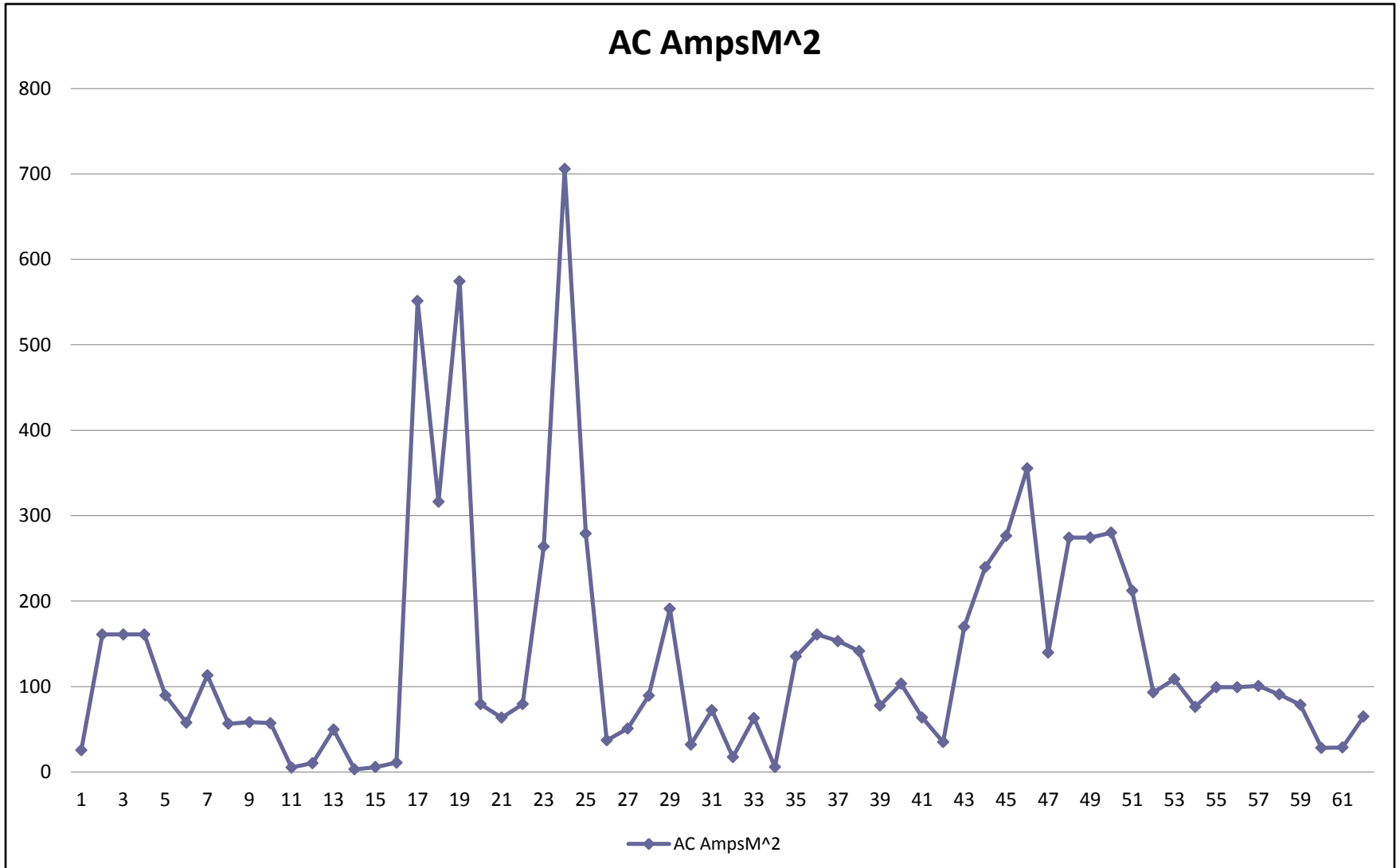
| Survey Summary | | | | | | | | | |
|----------------|-----------|---------|--------|--------|--------|----------------------|-------------------------------|---------------|--|
| Pipeline 12" | DCD Sta + | | >1 VAC | >4 VAC | >6 VAC | AC Density W/1cm Def | Suggested Mitigation For 2009 | Deg | Comments |
| Location | Date | AC P/S | | | | >100 Likely | | | |
| MS: 0 00 | 9/22/2009 | 0.394 | | | | 25 | | | 799 AC AMP ON BOND |
| MS: 35 38 | 9/22/2009 | 2.5 x | | | | 161 | | | |
| MS: 35 59 | 9/22/2009 | 2.5 x | | | | 161 | | | |
| MS: 35 60 | 9/22/2009 | 2.5 x | | | | 161 | | | |
| MS: 47 42 | 9/22/2009 | 1.394 x | | | | 90 | | | |
| MS: 78 57 | 9/22/2009 | 0.894 | | | | 58 | | | |
| MS: 107 45 | 9/22/2009 | 1.76 x | | | | 113 | | | |
| MS: 176 21 | 9/22/2009 | 0.876 | | | | 56 | | | |
| | 9/22/2009 | 0.906 | | | | 58 | | NEW T/L | |
| MS: 228 75 | 9/22/2009 | 0.888 | | | | 57 | | | |
| MS: 263 64 | 9/22/2009 | 0.083 | | | | 5 | | NEW T/L | |
| MS: 311 56 | 9/22/2009 | 0.161 | | | | 10 | | | |
| MS: 316 12 | 9/22/2009 | 0.77 | | | | 50 | | | |
| MS: 364 50 | 9/22/2009 | 0.048 | | | | 3 | | | |
| MS: 382 23 | 9/22/2009 | 0.088 | | | | 6 | | NEW T/L | |
| MS: 404 30 | 9/22/2009 | 0.171 | | | | 11 | | NEW T/L | |
| MS: 447 66 | 9/22/2009 | 8.561 x | x | x | | 551 | Point Drains | | Could be horizontal - wide area |
| MS: 462 60 | 9/22/2009 | 4.91 x | x | | | 316 | Mags at 0.17 ohms | NEW T/L | Loc of 10 Mag anodes - need drain here in near future. |
| MS: 491 74 | 9/22/2009 | 8.92 x | x | x | | 574 | Point Drains if Possible | | Loc from 480+16 to 484+52 |
| MS: 518 55 | 9/22/2009 | 1.234 x | | | | 79 | | NEW T/L | |
| MS: 565 88 | 9/22/2009 | 0.988 | | | | 64 | | | |
| MS: 583 27 | 9/22/2009 | 1.234 x | | | | 79 | | NEW T/L | |
| MS: 617 34 | 9/22/2009 | 4.099 x | x | | | 264 | | | |
| MS: 665 67 | 9/22/2009 | 10.96 x | x | x | | 706 | Horizontal | Hor 1 NEW T/L | Connect at MLV |
| MS: 668 67 | 9/22/2009 | 4.332 x | x | | | 279 | | | |
| MS: 774 65 | 9/22/2009 | 0.576 | | | | 37 | | | |
| MS: 818 88 | 9/22/2009 | 0.79 | | | | 51 | | NEW T/L | |
| MS: 832 89 | 9/22/2009 | 1.389 x | | | | 89 | | | |
| MS: 876 45 | 9/22/2009 | 2.966 x | | | | 191 | | NEW T/L | |
| MS: 910 21 | 9/22/2009 | 0.498 | | | | 32 | | NEW T/L | |
| MS: 913 78 | 9/22/2009 | 1.124 x | | | | 72 | | | |
| MS: 915 07 | 9/22/2009 | 0.269 | | | | 17 | | | |
| MS: 929 70 | 9/22/2009 | 0.98 | | | | 63 | | NEW T/L | |
| MS: 959 26 | 9/22/2009 | 0.092 | | | | 6 | | NEW T/L | |
| MS: 971 12 | 9/22/2009 | 2.1 x | | | | 135 | | | |
| MS: 990 25 | 9/22/2009 | 2.5 x | | | | 161 | | NEW T/L | |
| MS: 1012 23 | 9/22/2009 | 2.38 x | | | | 153 | | | |
| MS: 1050 10 | 9/22/2009 | 2.2 x | | | | 142 | | NEW T/L | |
| MS: 1086 24 | 9/22/2009 | 1.207 x | | | | 78 | | | |
| MS: 1100 96 | 9/22/2009 | 1.604 x | | | | 103 | | NEW T/L | |
| MS: 1133 37 | 9/22/2009 | 0.989 | | | | 64 | | | |
| MS: 1181 58 | 9/22/2009 | 0.544 | | | | 35 | | | |
| MS: 1231 80 | 9/22/2009 | 2.64 x | | | | 170 | | | |
| MS: 1254 48 | 9/22/2009 | 3.72 x | | | | 240 | | | |
| MS: 1270 87 | 9/22/2009 | 4.29 x | x | | | 276 | | | |
| MS: 1276 64 | 9/22/2009 | 5.52 x | x | x | | 355 | Horizontal | Hor 2 | Open area, no surface pipe |
| MS: 1288 47 | 9/22/2009 | 2.168 x | | | | 140 | | NEW T/L | |
| MS: 1304 25 | 9/22/2009 | 4.26 x | x | | | 274 | | | |
| MS: 1315 41 | 9/22/2009 | 4.26 x | x | | | 274 | | | |
| MS: 1326 00 | 9/22/2009 | 4.35 x | x | | | 280 | | | |
| MS: 1360 90 | 9/22/2009 | 3.294 x | | | | 212 | | | |
| MS: 1388 80 | 9/22/2009 | 1.446 x | | | | 93 | | | |
| MS: 1395 30 | 9/22/2009 | 1.688 x | | | | 109 | | | |
| MS: 1415 65 | 9/22/2009 | 1.184 x | | | | 76 | | | |
| MS: 1447 89 | 9/22/2009 | 1.542 x | | | | 99 | | | |
| MS: 1447 90 | 9/22/2009 | 1.542 x | | | | 99 | | | |
| MS: 1451 47 | 9/22/2009 | 1.565 x | | | | 101 | | NEW T/L | |
| MS: 1459 65 | 9/22/2009 | 1.408 x | | | | 91 | | | |
| MS: 1466 85 | 9/22/2009 | 1.221 x | | | | 79 | | | |
| MS: 1484 20 | 9/22/2009 | 0.439 | | | | 28 | | | |
| MS: 1499 49 | 9/22/2009 | 0.445 | | | | 29 | | | |
| MS: 1523 41 | 9/22/2009 | 1.007 x | | | | 65 | | | |
| | | VAC-1 | | 39 | | | | | |
| | | VAC-4 | | 11 | | | | | |
| | 7 | | | | | | | | |

Graph AC Potentials

AC Volts - 1.8 VAC Critical This Case



Graph AC Current Density



How is AC **Safety** Mitigated?

- Locations of pipe to soil test leads, and any surface pipeline appurtenance can be measured to determine locations of possibly high enough voltage to require mitigation for safety. Accurate modeling will also disclose areas of expected safety issues.
- These locations can be mitigated with short runs of material that can permanently shunt the current to the power line ground system economically.
- Step potentials must be considered in these areas, and normally, step potential mats are indicated in all locations of surface pipe appurtenances such as block valves and risers to protect personnel
- All Test Lead contacts in high potential power line ROW parallel systems should be dead face front style to prevent contact with personnel. Covers are also indicated as further assurance of protection from public interaction in areas of high population densities.

Other Safety Hazards

- Test leads attach directly to the pipeline can have dangerous AC Voltages, and should be of the “dead face front” style, so no electrical contact is possible to the person taking readings.
- Pipeline bonds also may have high AC Voltages in these areas and should also be constructed so no physical contact is made by the technician.
- Can you think of another significant possible shock hazard item in these areas?

Rectifier

Negative Leads!

The negative lead connects to the pipeline and can have the same high AC Voltages present – they should be capped or taped to prevent contact.

Does it matter if the rectifier is off? No, as these voltages come from the pipeline, not the rectifier power source.

Does an equipotential mat protect the person? Possibly not, as the mat is not connected to the pipeline, and cannot be trusted to protect the worker from pipeline AC!



AC Corrosion Theory - Summary

- Induced AC voltage may be a cause of corrosion at coating defects where AC current escapes the pipe wall into the soil.
- Small rather than large coating defects are susceptible to AC corrosion effects.
- The surface area of the pipe at a coating holiday is important since the corrosion rate increases with increasing current density.
- Large holidays would have a lower current density than small holidays if both were exposed to the same soil conditions.

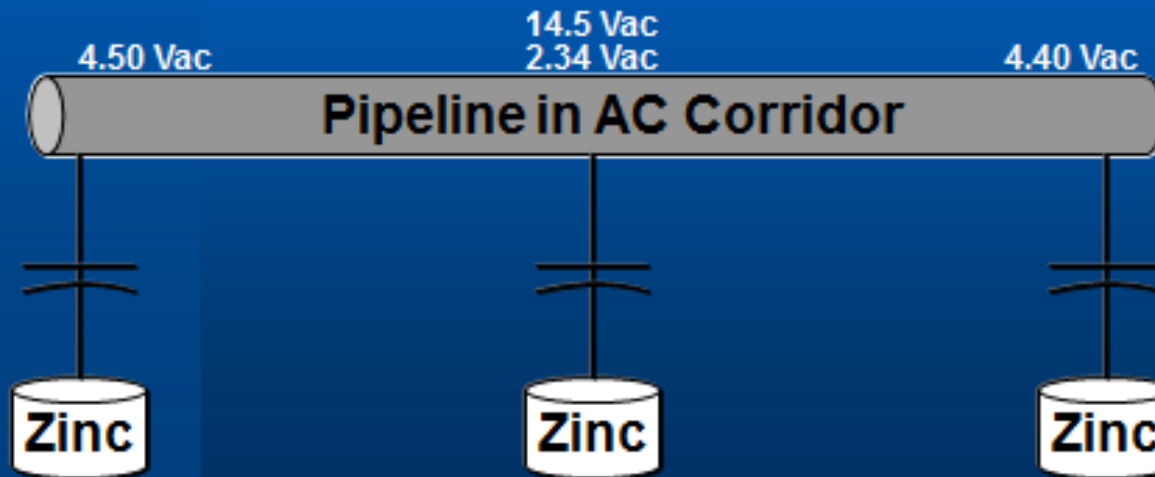
How are AC Corrosion Issues Mitigated?

- A cookie cutter approach may be used, but cannot be assured of success as there may be areas that have not been modeled and found that can have significant issues of AC corrosion that may not be covered by short isolated segments of parallel or deep well drains.
- Areas for spot installations or longer runs of material may be disclosed by a good interpretation of the topography, and looking for areas of divergence and convergence between the pipeline and the power lines involved.
- Areas of known high current density may be generally indicated at major divergence points, and near power line substations, but many others may be on the line, and not discovered without field surveys and appropriate modeling of the systems. It is strongly suggested any line with discovered AC corrosion wall losses should be modeled and an appropriate complete system installation designed and proposed for consideration.

Are Simple Fixes Enough?

AC Mitigation – Sacrificial Anodes

➤ Mitigation Field Example – Sacrificial Anodes



AC Mitigation – Modeling Defines What is Required and Where

- Mitigation wire provides a benefit in the mitigation of AC corrosion. For a coating holiday located in the vicinity of the mitigation wire, the effective resistance of the holiday is increased due to the mutual resistance between the holiday and the mitigation wire, thereby reducing the AC current density at the holiday.



Power Co. Data Needed

What is needed for proper AC Mitigation Modeling?

Proper AC mitigation modeling is based on information of the capabilities of the AC power system(s) and the orientation of the pipeline with the power lines, as well as the topography and other information.

Field survey work required is to determine separation distances, orientation angles and especially importantly, soil resistivity profiles.

Check with your AC Mitigation Modeling company for a document to be used for this data request.

Needed information:

Information can help reduce the overall cost of the grounding system. Accurate information will reduce the number of overly conservative assumption that will have to be made. Some information listed may not apply for this job.

Pipeline:

- Plan & profile
- Length of pipeline
- What is at each end of the pipeline?
- Does it connect to any other pipelines along the route?
- Distance from electrical transmission and distribution lines that parallel the pipeline
- What electrical lines cross the pipeline?
- Location of above ground equipment such as valves or above ground piping
- Buried depth of the pipe
- Pipe diameter and wall thickness
- Pipe coating and resistance value
- Corrosion protection (CP) grounding system design
- Grounding of pumping station
- Any other grounding that connects to the pipeline

Transmission Lines that parallel the gas line

- Plan & profile
- Transmission structure drawings
- Voltage of each circuit
- Phase arrangement of each circuit
- Maximum design current for each circuit
- Fault current (magnitude and phase angle) at beginning and end of parallel to gas pipeline for each circuit.
- Number of shield wires and size of wire
- Size and spacing of conductors.
- Number conductors in bundle for each circuit
- Grounding of structures (number and depth of ground rods)
- Ground reading of structures
- Pictures of structures
- Aerial video of transmission line (geo referenced would be great)

Electric Generation site (when gas line connects to electric generation site)

- Grounding system (switch yard and around generators).
- Fault current (single phase fault) magnitude and phase angle
- Current contribution from sources (step up transformers and from all lines)
- Need structure information for all transmission lines that have shield wire that connects to substation grid.

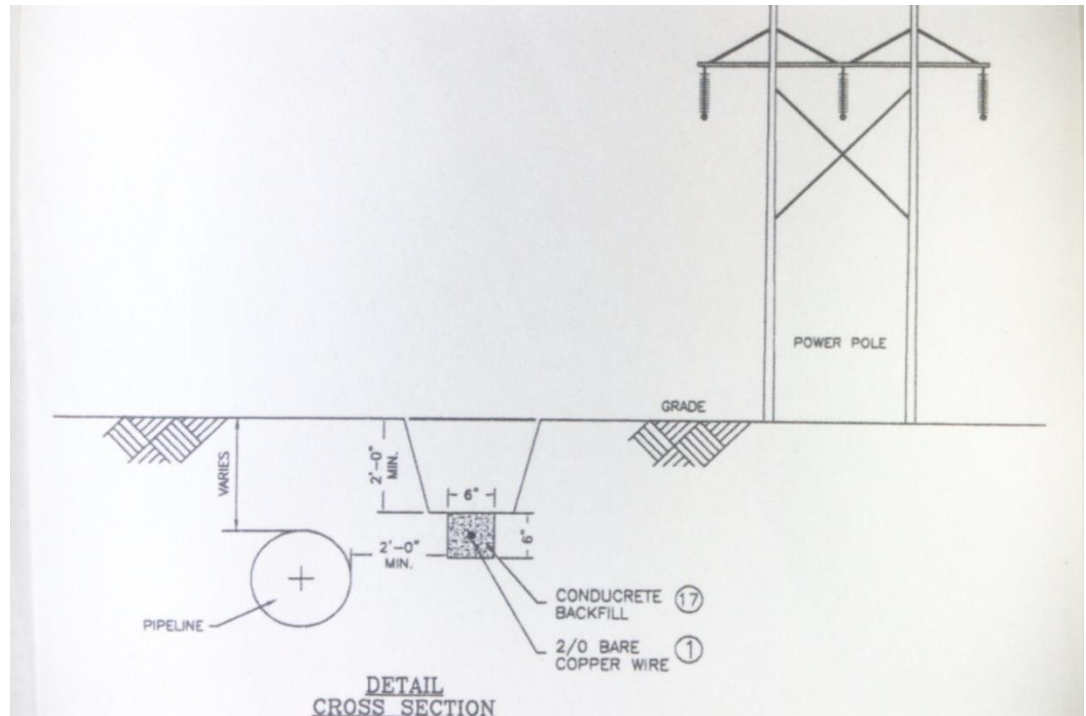
Typical Solid Media AC Mitigation – Single Linear

To the side of the pipe nearest the power line, a long trench is made for the installation of mitigation media. In this case a bare copper wire is used with a layer of conductive concrete.

The conductive concrete lowers the resistance of the system, protects the copper wire from corrosion, and lowers the impedance value of the wire to allow faster dissipation of fault currents.

Zinc wire or ribbon can also be used, but should have a surrounding prepared backfill .

Modeling will determine the length, location, wire size, and placement of these systems.



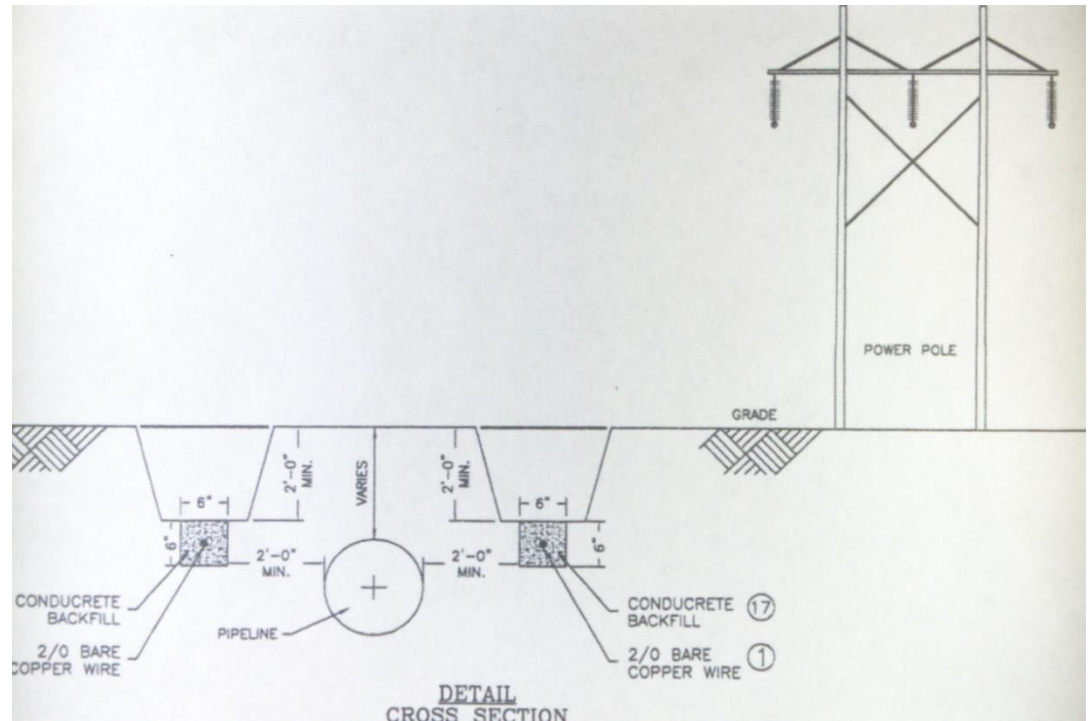
Solid Media AC Mitigation – dual run system

When the modeling demands even higher current dissipation, dual runs of media may be installed.

In locations where the pipeline may be centered between two High Voltage AC systems, the use of two runs may also be required.

The length and size of these systems is again determined by modeling to specifically fit the situation.

Keep in mind any future growth of the HVAC power system as they can increase their current and voltage rating to serve new clients in the future – ask if they have expansion plans.



Types of AC Mitigation for Corrosion Control

- Linear grounding systems – allow the dissipation of AC current through the soil back to the power line grounding.
 - Various materials are used including zinc, copper, and steel
- Point Drain grounding – these systems are similar to deep wells in that they use vertical elements into the soil to achieve low resistance grounding to carry localized area AC currents back to the power line system.
 - Normally for low angle crossings or deviation points

Grounding Materials Used

- Zinc Ribbon or Wire
- Zinc over steel wire
- Copper Wire
- Combination Steel over Copper Wire
- Steel Wire

- Common Backfills
 - Native Soil
 - Bentonite
 - Conductive Concretes



Issues with Grounding Materials

- Zinc systems have been problematic in some ways, including passivation and issues of corrosion of the zinc media and jointing areas.
 - In areas of high sulfur content in the soil (agricultural fertilizers, etc) zinc can form a surface coating of Zinc Sulfate which has a resistivity value of 6,000,000 ohm cm and can diminish the zinc from being able to pass current.
 - Directly connecting zinc can increase the burden on CP systems.

Issues with Grounding Materials

- Bare copper wire has been used with good results, but issues of corrosion and theft are deterrents to its use.
 - Bare copper is highly corrosive in the presence of chlorine (salt water) and sulfur compounds and must be protected in a way that does not inhibit its ability to pass current to the soil.
 - Theft issues of bare copper are world wide and expected to continue.

Steel Grounding Systems

- Once considered too high in resistance value to use for grounding, the issue of theft of copper are now causing some to experiment with steel for these systems.
 - The current carrying ability of steel is less than copper so larger diameter wires of steel may be required.
 - Steel has more issues with corrosion than copper or zinc and must also be protected in a way that does not inhibit its ability to handle the current required.

Field Installations of Linear AC Drains

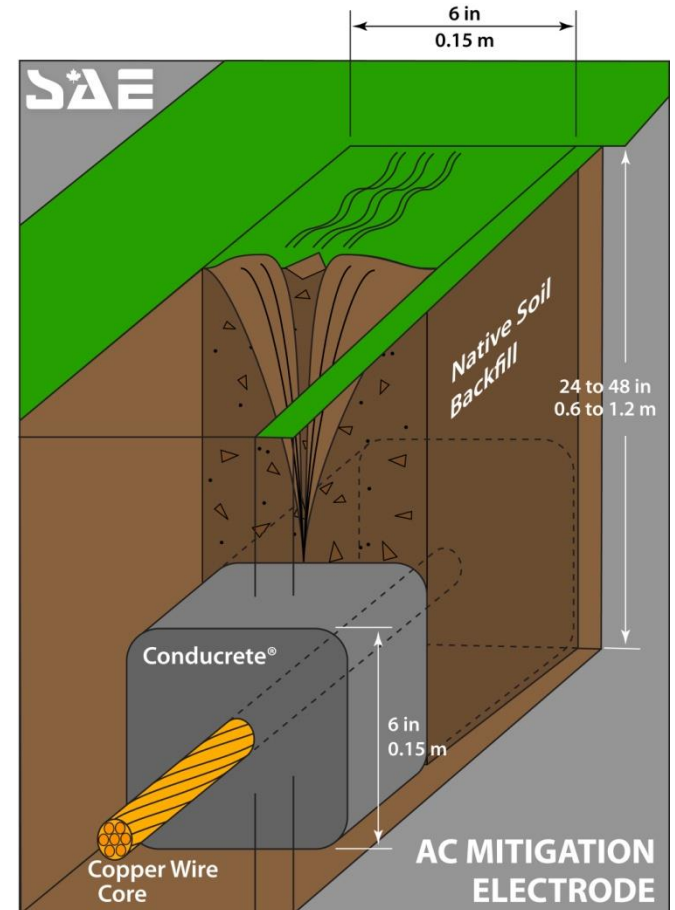


Ripper Installation

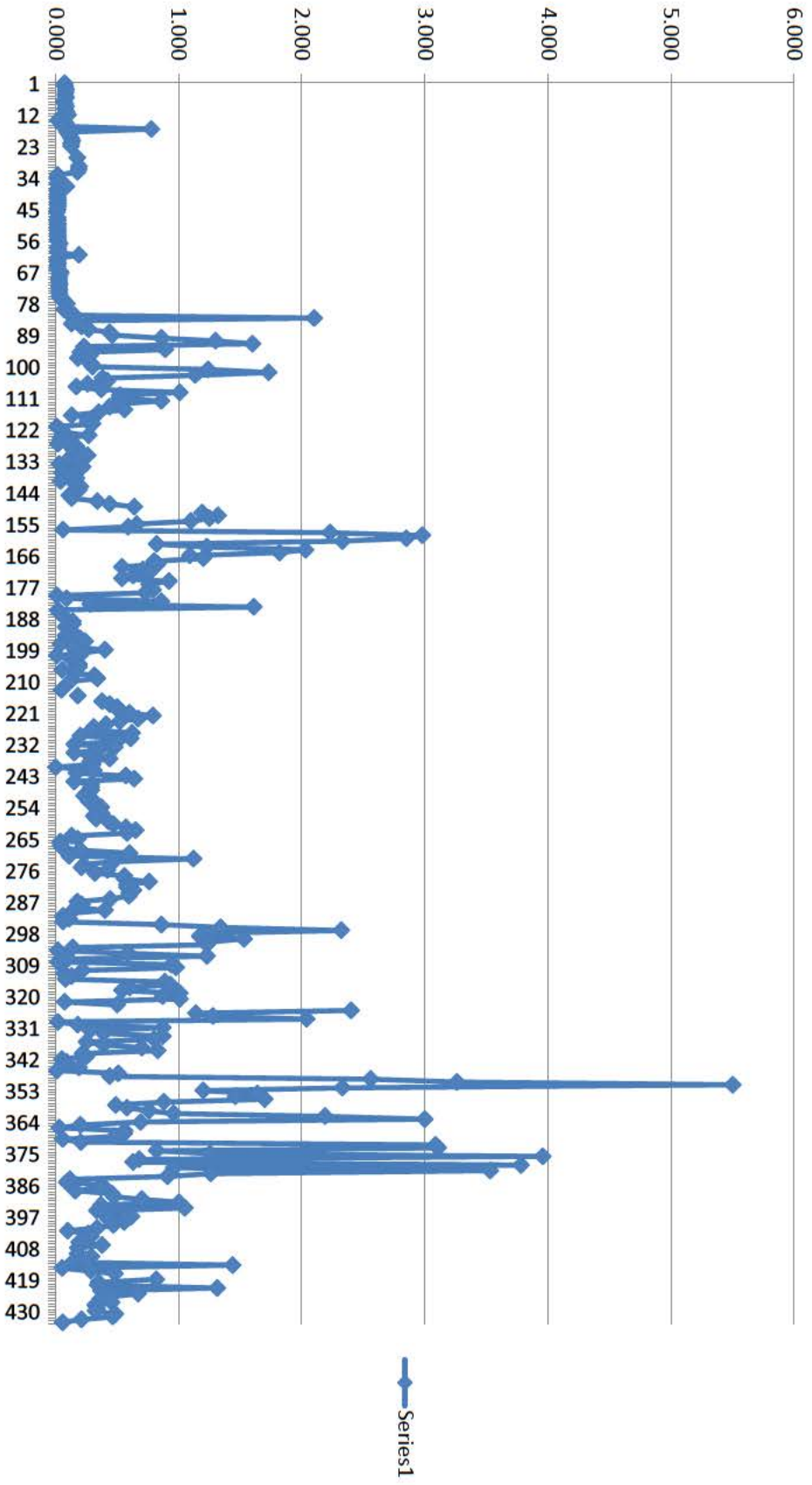


Solid Media Backfill – Ground Enhancement

- Diagram of a typical conductive concrete over copper AC Mitigation electrode as installed:
 - A large copper core is encapsulated in a conductive concrete backfill
 - The entire electrode sets up to provide a mean strength of 3000 psi
 - When set up, the AC Mitigation electrode becomes a single, solid conductor with a large surface area able to safely dissipate large amounts of current
 - The electrode system protects the copper core from corrosion and deterioration, thus extending the operational lifetime by 10 times normal



Results Copper/Conductive Concrete



Copper in Conductive Concrete and Bare



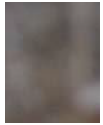
Point Drains



Solid Media Backfill – Conductive Concrete

- Conductive concrete can have a resistivity of 3 ohm/cm
- It has the same porosity as bentonite
- It is hygroscopic and will retain moisture
- It has been used to enhance grounding systems for over 100 years (Marconites).
- It reduces impedance and resistance of AC mitigation systems and enhances their ability to pass current to the earth.
- It reduces the electrolytic corrosion process of copper by over 85% to 90%, extending copper life to 50 years or more in AC Mitigation service.

Lightning Damage



Would your AC Mitigation System Survive?



Questions or Comments

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