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PERFORMANCE OF DEEP GROUNDBEDS IN WESTERN CANADA

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ABSTRACT

A review of the performance of twenty deep groundbeds installed in Western Canada between 1964 and 1975 is made. These groundbeds were installed at depths between 75 meters (250 feet) and 100 meters (330 feet) in a variety of formations from the prairies to the mountains.

The historical performance is measured by the ability of the groundbed to provide the required current. The primary limiting factor is the resistance to earth of the anodes. Poor performance of groundbeds is attributed to a variety of causes including incomplete coke breeze backfill, cable failures, anode connection failures, gas blocking and electro-osmosis effects. These in turn were due to poor material quality control, inexperienced installation crews and a learning experience.

Practices recommended and those to be avoided are also discussed.

INTRODUCTION

A general description of deep anode groundbeds and their installation is given in NACE RP-072-85 [1]. A deep groundbed is defined in this document to be one or more anodes installed vertically at a depth of 15 meters (50 feet) or more below the earth's surface. They can be "open hole" (anodes in aqueous electrolyte only) or "closed hole" (surrounded by backfill).

The anodes reviewed have been installed in "closed holes" that are 75 meters (250 feet) to 100 meters (330 feet) in depth and generally 23 cm (9") in diameter. The performance of twenty deep groundbeds installed between 1964 and 1975 in Western Canada has been reviewed.

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Although many different anode materials can be used in deep anode groundbeds[2,3], the majority in Western Canada employs a high silicon cast iron (HSCI) anode backfilled in coke breeze and is the anode reviewed. Metallurgical coal coke breeze was used in most installations prior to 1985 and calcined petroleum coke breeze has been used since that time in Western Canada.

The performance of a groundbed is dependent on several factors. These range from the design, quality of material, installation practices, location of anodes relative to strata and the configuration of the piping to be protected.

The performance of the deep anode groundbed related to these factors is covered in this paper.

HISTORY

The progression of groundbeds for congested piping went from large remote shallow anodes to distributed shallow anodes and finally to deep groundbeds. Early attempts to protect plant piping using a remote shallow groundbed located 300 meters (1000 feet) away from the plant, circa 1955, was unsuccessful. Only the perimeter piping was protected but not the core of the plant. The next design distributed shallow anodes throughout the plant or refinery such that the anodes in effect paralleled most of the piping. Although this was successful in providing protection, it proved to be a high maintenance system especially with continued plant construction destroying the cables and anodes.

The need for a better design became obvious and the benefit of a deep groundbed was then considered. The response of plant piping to current from a deep groundbed was simulated by a short-term test with a water well casing. This proved to be a pessimistic test as some of the current discharged at the ground surface like a shallow groundbed.

The improved response to the deep anode groundbeds was therefore a pleasant surprise. With a high resistivity soil strata existing between the anodes and the plant piping, a uniform current was achieved and there was no evidence of an anode potential gradient at the surface.

The first deep anode groundbed in Western Canada was installed in 1964 for the protection of congested piping in a gas plant[4]. Earlier installations had been made dating back to the mid 1950s[2] in the USA. The installation at the time was somewhat experimental and certainly drilling crews were inexperienced in handling cathodic protection materials. Unfortunately this added to the cost and this type of groundbed experienced a slower acceptance until their benefits became fully realized.

Their benefits were soon realized and now they are used in the protection of every type of oil and gas facility often in conjunction with other types of groundbeds.

They are especially suited to the following situations.

- Lower resistivity strata below a high resistivity surface soil.
- Limited land availability
- Congestion of piping, structures or utilities

EARLY CONSTRUCTION LESSONS

There were several difficulties with the installation of a deep anode groundbed due to inexperience in the industry in general and with the drillers not being familiar with cathodic protection materials.

The early deep anode systems used a 50 mm x 1.5-meter (2”x60”) high silicon iron anode connected in strings of three with a cable from the top and bottom of each string brought to the surface. This was thought to be a cost savings from individual anodes, yet it would take two cable breaks to isolate any one anode. It was later concluded that the cost savings in materials did not offset the additional handling and installation costs and individual cables offered less opportunity to damage.

The anode strings were attached to a support pipe with spacers to center them in the hole. They were heavy and awkward but still fragile and the crew had to be trained to install them carefully. Unfortunately the rig crews were accustomed to heavy steel pipe and occasionally treated the anodes the same way, breaking them in the process.

They also were not concerned about the cable insulation or twisting the connections at the anodes. The effect of the latter was to apply pressure on the anode connection and to reduce the cable diameter at the anode cap that increased the possibility of water ingress to the anode-cable connection. The connection in turn then corrodes resulting in a premature failure of the anode.

The anodes were backfilled in a metallurgical coke breeze by mixing it in a slurry and hand shoveling into the hole. As coke breeze is close to the density of water, the fine coke breeze particles tried to float to the surface while the heavier particles were settling causing a bridge to occur. The addition of detergent helped to “wet” the coke breeze but did not solve the problem. These bridges had to be broken by a slow water circulation but subsequent results indicated that this was not always achieved.

Figure 1 demonstrates the poor success of hand backfilling an early groundbed in 1964. The resistance of the groundbed increased within a year to a value that was not tolerable and was replaced in 1968 by drilling a new hole nearby. The only difference in design was that coal coke breeze slurry was pumped through a perforated support pipe rather than hand backfilled. A lower, tolerable resistance was maintained by the replacement groundbed. Granted the evidence is sparse however the change in pumping procedure was the only variance between the two installations.

A method was eventually developed to pump the coke breeze slurry through a pipe or the support pipe to displace the mud from the bottom of the hole upwards. This prevented excessive washing of the coke breeze from the hole and reduced the coke breeze installation time from up to two days to as little as 20 minutes.

Initially, when calculating coke breeze amount, it was assumed that the drilled anode hole would be a uniform cylinder when in fact the diameter can increase with continuous working of the hole or the sides can wash out as shown in Figure 2 or the formation can be fractured. An allowance for this extra coke breeze must be made when ordering the material.

Eventually individual anodes were used with a cable brought to the surface from each anode. This reduced the cost of installation, as the prior method required three crewmembers to carry the anodes and a fourth to attach them to the support pipe. More importantly it avoided the problem with the damaging cables when handling the triple anode string.

It is also important to avoid the use of nonmetallic strapping material as this could set up the "end effect" discussed below.

ANODE FAILURES

Although any anode could be considered for deep groundbeds, the high silicon cast iron (HSCI) anodes are the most popular in Western Canada. It is the anode used in all of the groundbeds reviewed.

Anode failures can be from any one of the following:

- Anode consumption
- Cable to anode connection failure
- Cable break
- Excessive soil drying (electro-osmosis).
- Gas blocking
- High ash content coke causing nonconductive scale formation.

Early anode failures were not attributed to fast consumption of the anode. As the anodes are consumed, there is typically a reduction in the overall diameter and length. In addition, there is an end effect due a higher current density discharge at the anode ends that tapers the end of the anode (Figure 3). When this occurs at the cable connection end of the anode, a premature failure can occur with the loss of the connection. An expanded anode end or center-tap tubular anode is used to overcome this problem (Figure 4). Similarly an end effect can occur if a nonmetallic material covers the anode surface. Figure 5 shows a metal strap being used to attach the anode to the support pipe.

The cable to anode connection can be lost if moisture is able to ingress down the cable to the connection itself. This in turn would be due to a poor anode cap seal, by twisting the anode cable to reduce its diameter or by damaged cable insulation. The connection will then corrode and the anode will be lost. This appears to have been a cause of several failures based on the sudden failure of anode strings. When lead connections were used, they had to be caulked; otherwise the shrinkage of the lead would make a poor connection. This caused the rejection of many anodes.

Once anode cable insulation is broken, rapid corrosion of the copper takes place. Breaks in the insulation were believed to occur in three cases. Construction damage, a sharp rock in the hole that punctures the insulation or the anode string settling and crimp the cable on the anode cap (Figure 6) will cause failure. The selection of the type of insulating material has to be considered as polyethylene is subject to attack by chlorine or other halogens[5,6].

The electro-osmosis effect[7] noted at the shallow anode is also applicable to the various strata that the deep groundbeds were installed. Once the high silicon iron anode is dry, the oxide film formed becomes nonconductive. The natural replenishment of moisture driven from the anode varies between soil types and geographic areas. The current density of the anode has to be adjusted accordingly. If the rectifier is turned off for a period of time, the resistance will reduce but quickly increase when re-energized if it is suffering from this effect. A reduction in the anode current density is needed until a balance with moisture replacement is achieved.

A gas is formed at the anode due to the electrochemical reactions taking place. If this gas is not allowed to escape, it has the effect of increasing the resistance of the anode. Vent pipes are normally included in the design for this purpose in “closed holes”. Again, if the rectifier is turned off to stop gas formation and to allow the gas to escape, a reduction in resistance can be seen. If the gas is permanently trapped then no change will be noted.

COKE BREEZE QUALITY

Metallurgical coal coke breeze was used exclusively in the early deep groundbed installations and their replacements. This provided good service until lack of quality control allowed coke breeze with low carbon content and high ash content.

When the carbon content of the coke breeze reduces and is replaced by ash, a nonconductive scale can be formed at the anode surface. This renders the anode completely inoperative within a relatively short time. Carbon content greater than 90% is required.

Eventually a calcined petroleum coke breeze was used. This generally proved to yield a lower resistance groundbed that is illustrated by comparing the initial and replacement resistance of four different groundbeds using metallurgical coke to three others replaced with calcined petroleum coke breeze in Figure 7. All groundbeds are otherwise in the same strata and the installation procedure was the same.

ANODE LOCATION RELATIVE TO SOIL RESISTIVITY

The formation within the normal depth of a deep groundbed in Western Canada is stratified with layers such as clays, sand, gravel, glacial tills, sandstone, shale, and limestone all with different soil resistivity. Although all soil types are not present, the soil resistivity log in Figure 6 illustrates the variation in resistivity that can be expected. These strata are not parallel with the surface and are not consistent in depth even over short distances and the values change significantly from the prairies to the mountainous areas. As an example, shale tends to be softer in the prairies and of lower resistivity than the shale closer to the mountains.

There are different schools of thought regarding the placement of anodes in a deep groundbed hole. The first assumes that the anode current will find its way through the coke breeze to the lower soil resistivity while the second believes in locating the anodes in uniformly low resistivity as shown in Figure 8. There is some truth to the first philosophy if there was only one anode in the column of coke breeze or if they are spaced a large distance apart. When several anodes are installed in the same column close together, a “crowding factor” must be considered as shown in Figure 9.

The anode in the high resistivity zone is unable to impress the same amount of current as those in low soil resistivity due to the opposing current from the other anodes in the coke breeze column. This “crowding factor” limits the current in the column and thus each anode is forced to impress the majority of the current directly to the soil. The amount of current will then be in proportion to the resistivity of the soil opposite to the anode.

This is illustrated in Figure 10 by the actual current output of the anodes in two deep groundbeds located within 5 kilometers (3 miles) and in the same general type of soil conditions. Groundbed A was installed without consideration to the change in soil resistivity while the anodes in Groundbed B were installed in the lower resistivity soil established by a log of the hole prior to installation.

The resistance of the individual anodes in Groundbed A varied significantly and as a result the current output varied in inverse proportion. In addition, one anode is impressing 42% of the total output and will only last one-third (1/3) the life of the average anodes in

Groundbed B. When this anode fails, the overall resistance of the Groundbed A will increase significantly and the desired current will not be available. A resistor could control the current output of this anode but in this case, the required current could then not be supplied. Resistors are a high maintenance item as they are subject to surge failures and should be avoided where possible.

With the exception of Anode #2 in Groundbed B, the distribution of current is relatively uniform, resulting in a lower groundbed resistance and uniform anode life without the need for control resistors. Locating the anodes in uniformly low resistivity based on a log of the hole is beneficial.

LOGGING OF DEEP ANODE GROUNDBEDS

There are three basic methods to log a deep anode groundbed (see Figure 11).

- Single-electrode in the hole
- Two-electrode tool
- Four-electrode tool

The resistance of a single electrode is compared to one on the surface as it is lowered down the hole. The two-electrode tool measures the resistance between an upper and lower electrode on the same tool. The four-electrode tool measures the soil resistivity rather than resistance as the tool is lowered down the hole.

Method 1 (single electrode tool) is the poorest in defining the strata of the three methods as it determines the average resistance to the surface. It does give general indications of broad ranges of resistivity but if low resistivity soil is at a premium, it may miss some opportunities to locate anodes in the best soil. Method 2 (two-electrode tool) is better in defining the strata than Method 1 but poorer than Method 3. The measurement of soil resistivity in Method 3 (4-electrode tool) has provided the best definition of strata over the resistance methods.

Figure 6 was obtained using Method 3. The sections of high resistivity strata would have either been missed or the peak and valley values diminished with the other methods.

It should be noted that all methods include the lower resistivity mud in the measurement as shown in Figure 12. The actual resistivity will be higher than that measured but the relative resistivity can be used to locate the anodes, as the mud resistivity is uniform.

Although Method 3 is preferred, any of the above methods is superior to installing anodes without consideration to spacing them in the lowest resistivity soil.

DEEP GROUNDBED PERFORMANCE

The performance of the deep anode groundbed is measured in its ability to provide the necessary current for the desired life of the installation. Performance has varied as with any other type of groundbed.

Quality control and inspection of the groundbed materials is important to ensure top performance. The areas of prime interest are the anode, cable to anode connection, the cable insulation and the coke breeze. The metallurgical analysis of the anode should be reviewed and the casting inspected for inclusions. The cable and anode connections must be watertight and the resistance of the cable to anode measured. The coke breeze must have a high carbon content (>90%). The calcined petroleum coke breeze had a higher carbon content than metallurgical, which accounts for the lower resistance of the replacement groundbeds in Figure 5.

The installation practices will then have the next greatest impact on the performance of the groundbed. The first groundbed installed in 1964 was not considered a success as shown Figure 1 that was believed to be due to the poor backfill around all anodes from the hand backfilling operation. In addition the third groundbed installed elsewhere in 1964 but by pumping coke breeze provided over 30 amperes for 16 years as shown in Figure 13. Backfilling by pumping a coke breeze slurry has proven to be much more effective.

A review of another 14 deep anodes is made in Figure 14 and Figure 15. Seven of the groundbeds in Figure 14 had a low effective life between 7 and 11 years. The life of the remaining four in Figure 14 was between 15 and 18 years. The six groundbeds in Figure 15 did however perform beyond initial expectations in spite of an anode string failing in two of them.

The groundbeds reviewed all had relatively early failures. The maximum life of other deep anode groundbeds has been 30 years. In these cases, the failure appeared to be due to the consumption of the anode alloy rather than faulty material or installation practices.

Current to the individual anode strings is monitored on all groundbeds to predict the replacement time as shown by the poorest performing groundbed in Figure 16. This data shows a sudden anode failure in two strings in the seventh year. With the cable from the top and bottom, individual anodes can fail within the string and a current output from the others is still possible. In this case it appears that the first cable failure did not isolate any anodes but that the second cable failure isolated the entire string.

Considering the deep groundbeds reviewed were the pioneers, their performance overall was very good. The successes by far outnumbered the failures. The performance of the last generation of deep groundbeds appears to have improved with the longer life experienced. Expectations of 25+ years are realistic.

CONCLUSIONS

- Deep groundbeds have proven to be a beneficial type especially under the following conditions.
  - Lower resistivity strata below a high resistivity surface soil.
  - Limited land availability
  - Congestion of piping, structures or utilities
- Premature failures in deep groundbeds have occurred for the following reasons.
  - Careless installation practices especially in handling of anodes and cables or in anode lowering techniques.
  - Inexperienced crews mishandling materials.
  - Cable insulation breaks.
  - Cable to anode connections allowing moisture ingress.
  - Too high of a current density for the electro-osmosis characteristic of the soil.
  - Low carbon content coke breeze.
  - Anode end effect. Especially at the cable end

- Gas blocking.

- Anode alloy consumption would be the cause of failure of the longer life deep groundbeds.
- Locating anodes in the lower soil resistivity strata as determined by a log of each hole accomplishes a more consistent distribution of current between anodes and a lower groundbed resistance than uniform spacing.
- Individual HSCI anodes proved advantageous over anode strings due to ease of installation and more flexibility in spacing.
- Pumping of coke breeze from the bottom of the hole to displace the drilling mud achieves a superior backfill.
- Adequate coke breeze must be pumped to allow for any washouts of the hole, fractures in the formation or expanded diameter.
- Quality assurance is necessary to ensure a long life groundbed.

REFERENCES

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4. W.B. Holtsbaum, W.B. P.Eng , Cathodic Protection of In-Plant Piping. NACE Canadian Region Western Conference Feb 1964.
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6. Lawicki, P.E., Premature Failure of Anodes in Deep Ground Beds, Paper 243 Corrosion 80
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FIGURES

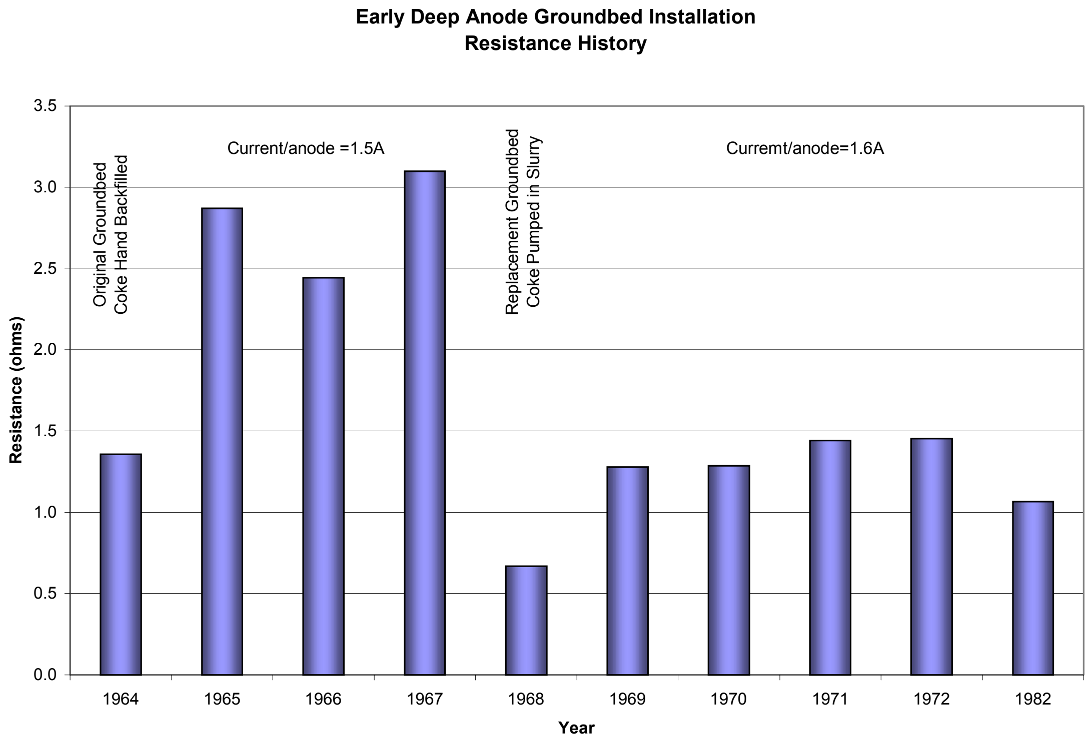
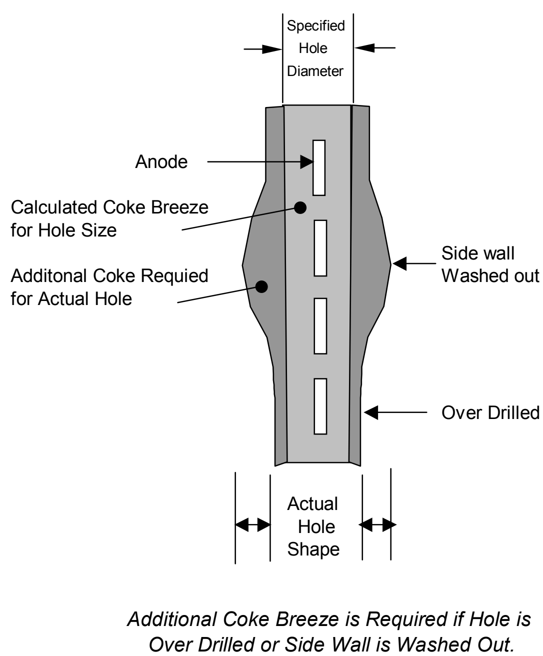


Figure 1 - Deep Anode Installed in 1964 (Original was hand backfilled while replacement pumped coke in slurry.)



Additional Coke Breeze is Required if Hole is Over Drilled or Side Wall is Washed Out. Allow for Extra Material.

Figure 2 - Possible Anode Hole Shapes Requiring More Coke Breeze

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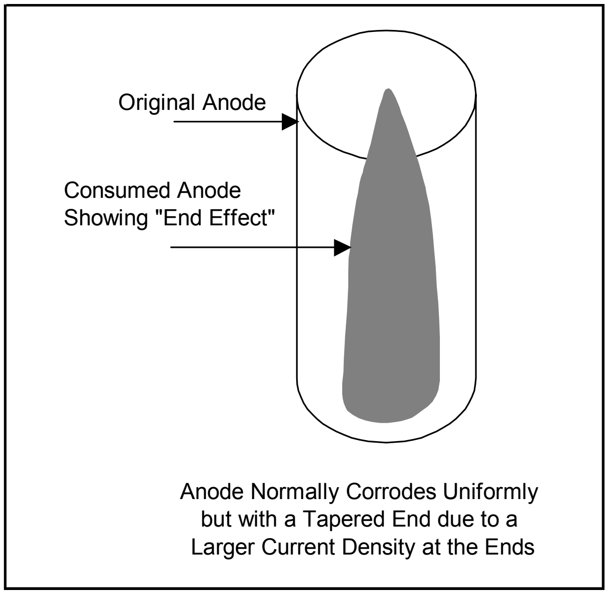

Figure 3 - Normal Anode Consumption

Figure 4 - Center Tap Tubular HSCI Anodes. Cable to anode connection at arrow.

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Figure 5 - Anode attached to support pipe and vent pipe covered with fabric screen

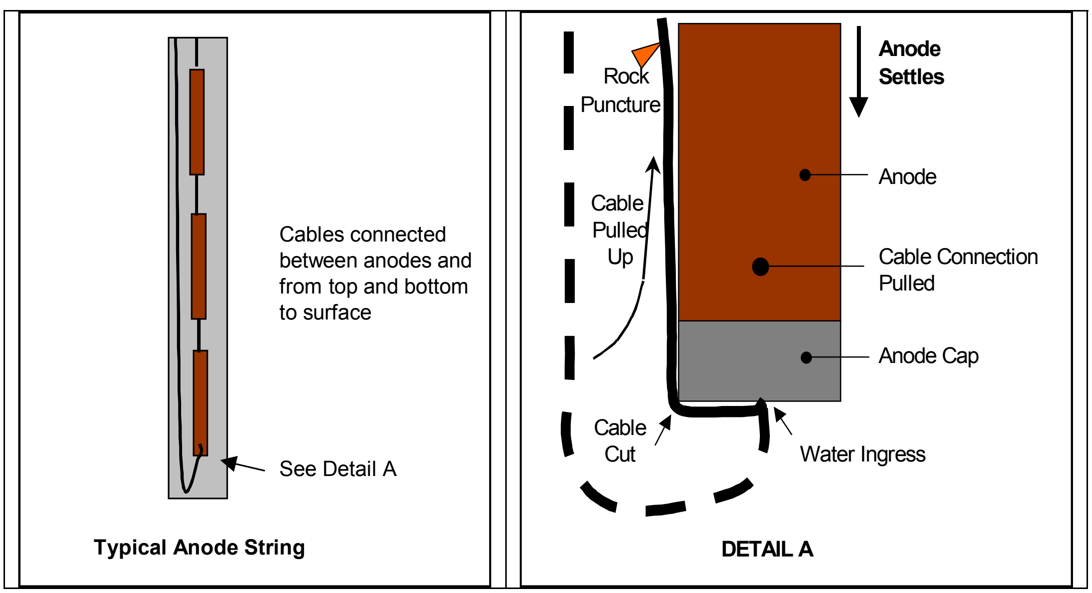

Figure 6 - Typical Anode String in Early Installations Showing Possible Cable Failures

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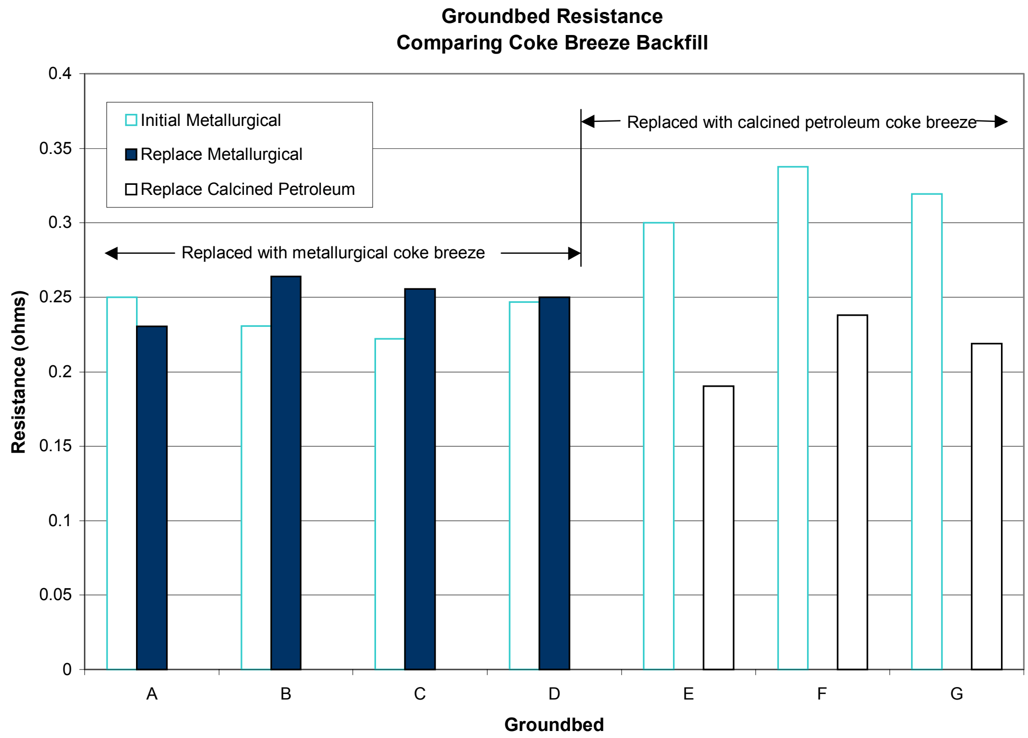

Figure 7 - Comparison of Deep Anodes Replaced with Different Coke Breeze

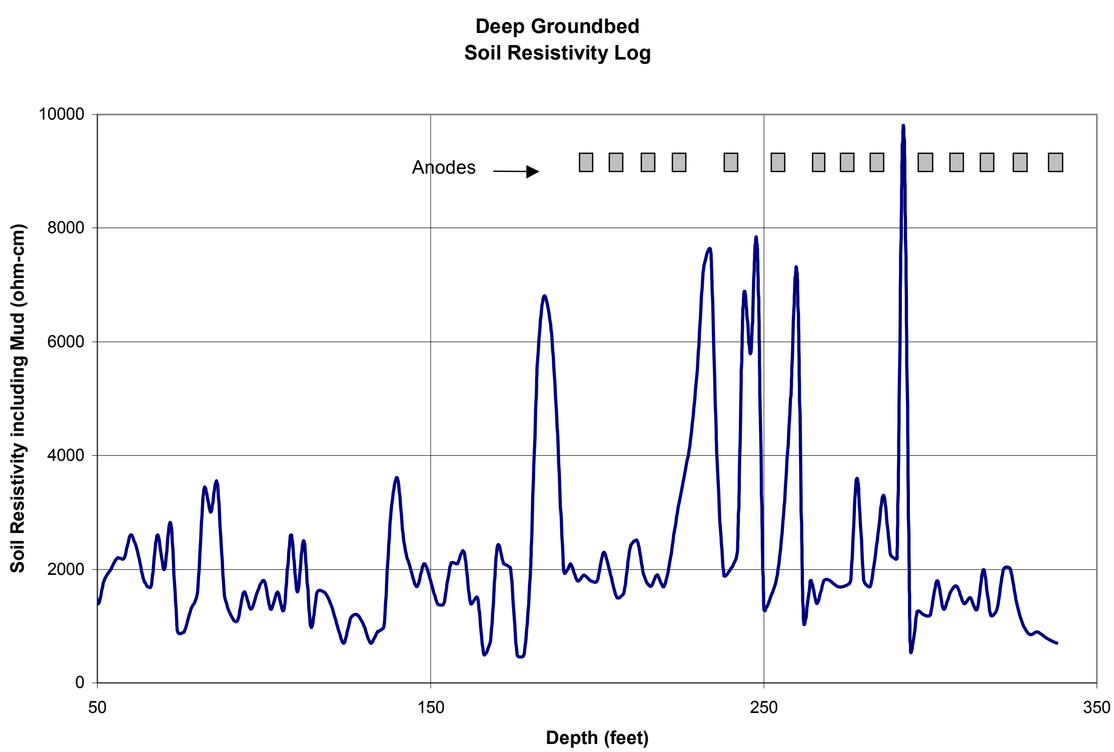

Figure 8 - Sample Soil Resistivity Log

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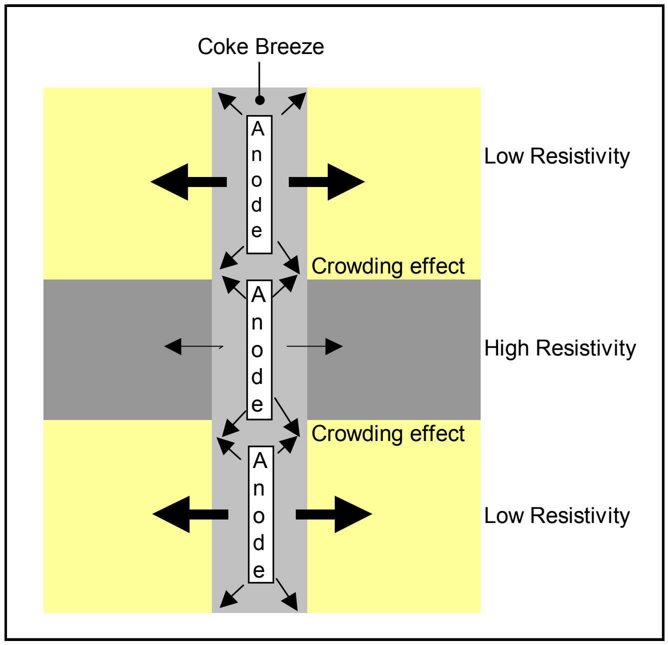

Figure 9 - Illustration of Current Crowding Effect Between Anodes

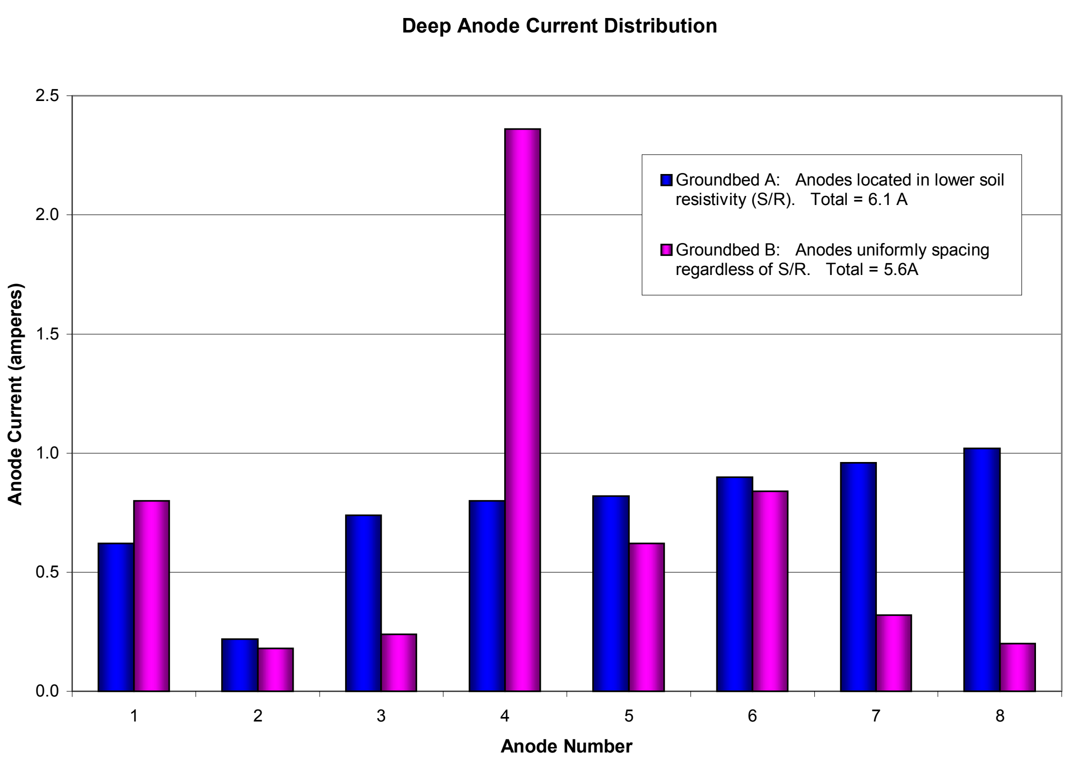

Figure 10 - Anodes Uniformly Spaced Compared to Others Located with Log

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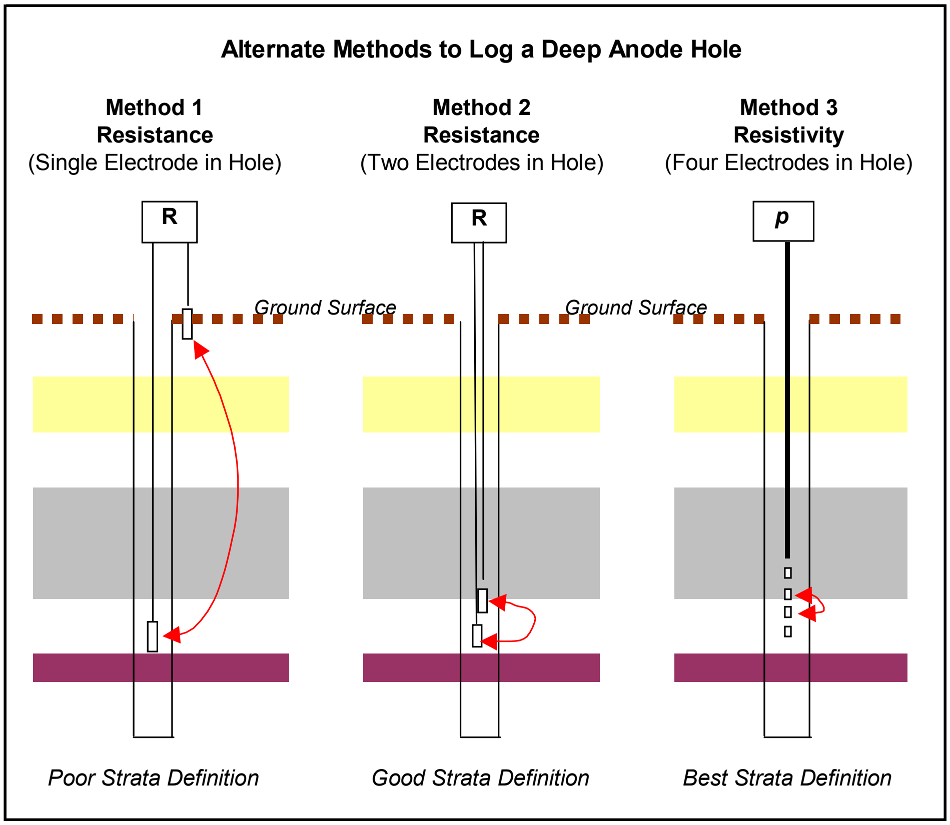

Figure 11 - Soil Resistivity Logging Methods

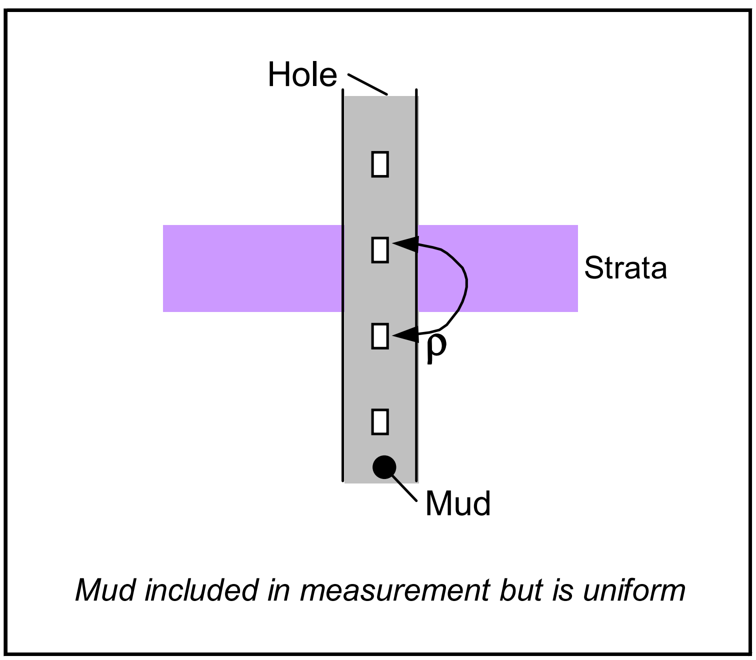

Figure 12 - Soil Resistivity Log includes Drilling Mud in Reading

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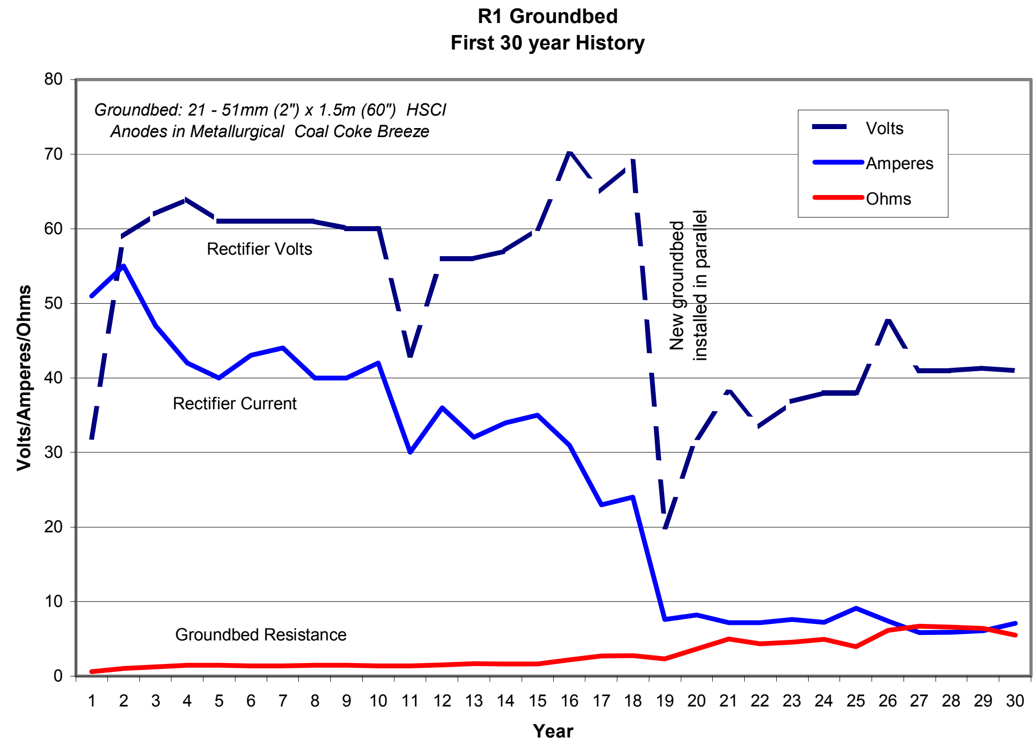

Figure 13 - History of a Deep Anode Installed in 1964

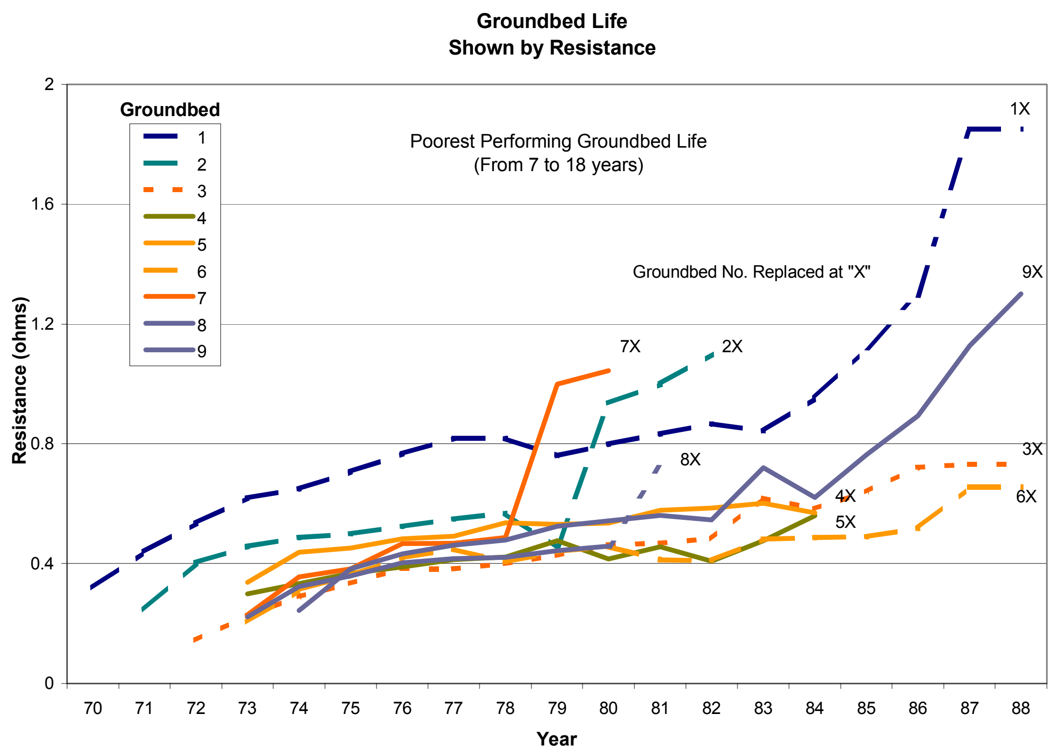

Figure 14 - Life of Nine Groundbeds Illustrated by Resistance

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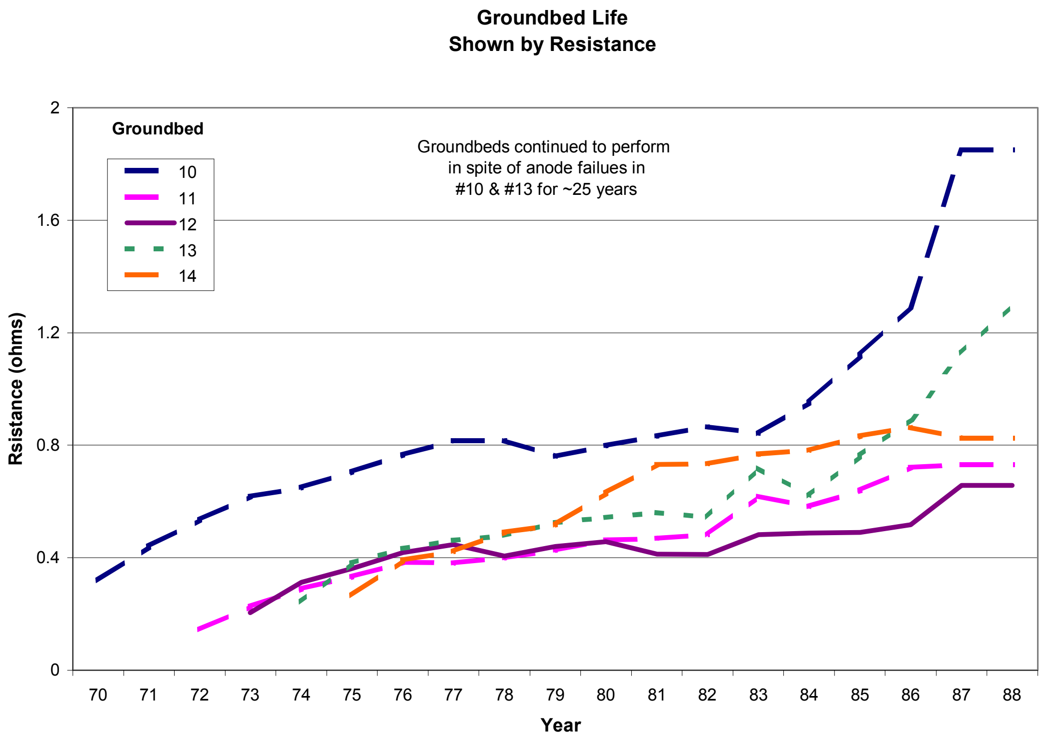

Figure 15 - Life of Five Groundbeds Illustrated by Resistance

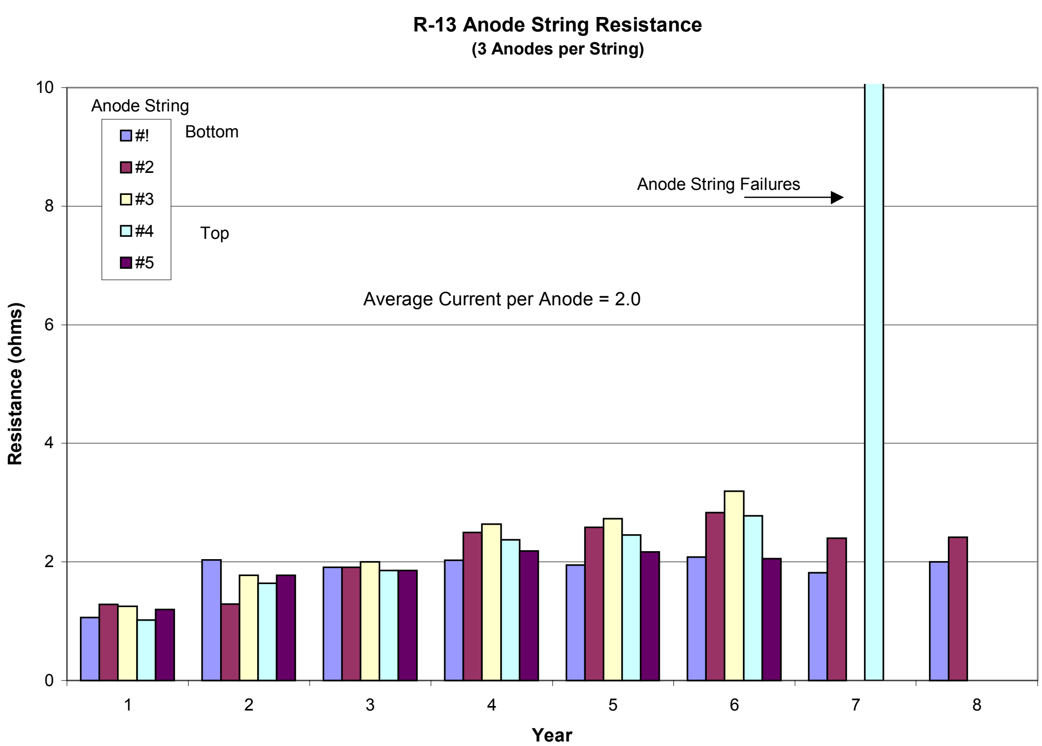

Figure 16 - Anode String Failures with Time

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