

Understanding and Preventing Guyed Tower Failure Due to Anchor Shaft Corrosion

Craig M. Snyder, President

Sioux Falls Tower Specialists, Inc./

AnchorGuard - Corrosion Control For Tower Anchors

Sioux Falls, South Dakota

ABSTRACT

Towers have been popularly used to support various antenna systems since the 1940's with very little attention given to corrosion of buried tower components. Many tower Facilities are coming of age and the problem of anchor shaft corrosion is now becoming an industry issue. This paper analyzes the causes of anchor shaft corrosion and gives the means of protecting existing and future towers against the catastrophic effects of corrosion.

HISTORY

On September 26, 1990, a 350' microwave tower fell to the ground. Tragically, two service personnel were on the tower at the time of the collapse. Both men were seriously injured and required multiple surgeries and much time to recover from their injuries. The cause of the failure was discovered to be due to excessive corrosion on one of the three steel anchor shafts that supported the structure. Although other tower failures have occurred due to anchor shaft corrosion, the seriousness of this failure involving personal injury has prompted wide-spread industry attention.

The Electronic Industries Association committee responsible for writing the standard entitled Structural Standards for Steel Antenna Towers and Antenna Supporting Structures (EIA/TIA-222-E), has been engaged in studying this issue and changes to the standard in this regard appear imminent. The Canadian Standard Association's standard entitled Antenna, Towers, and Antenna-Supporting Structures (CAN/CSA-S37-M86) currently contains an appendix that outlines the problem and lists possible solutions. It is clear that as more and more data becomes available, action to curtail or mitigate corrosion on anchors will be an important part of maintaining the integrity and long life of guyed tower Facilities.

WHAT IS CORROSION?

Corrosion Fundamentals

Corrosion is an electrochemical process. It is essentially the tendency of a refined metal to return to its native state. There are certain conditions which must exist before a corrosion cell can function. Figure I illustrates the four essential elements of a corrosion cell. Necessary elements

include the anode, the cathode, an electrical path between each, and an electrical conductive electrolyte.

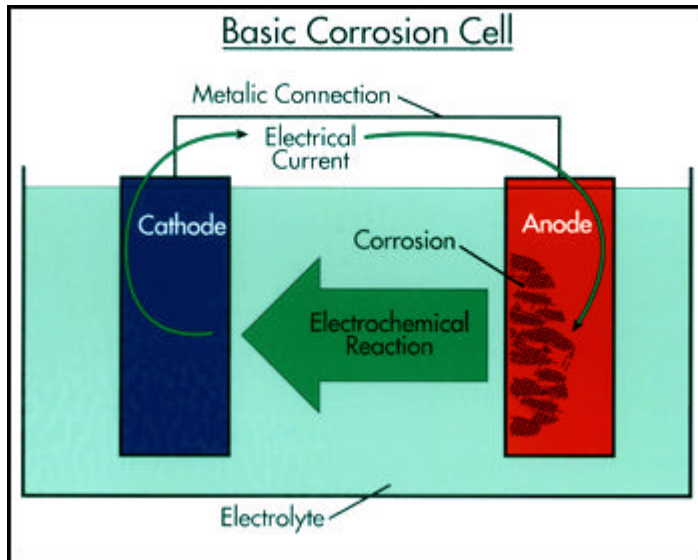


Figure 1- Basic Corrosion Cell

The driving force behind the corrosion cell is a potential or voltage difference between the anode and cathode. Once each of the four conditions have been met, an active corrosion cell is set in place. When functioning properly, there will be a measurable DC voltage which can be read in the metallic path between the anode and the cathode. When the two are electrically bonded, the anode is positively charged and the cathode is negatively charged. Conventional current flows from positive to negative and thus current discharges from the anode and is picked up at the cathode through the electrolyte. The current then returns from the cathode to the anode through the electrical path. This flow has a detrimental effect on the anode known as corrosion.

The above stated example is a corrosion cell in its simplest form. It is important to know that each of the four elements of the corrosion cell will effect how severe or mild the effects of corrosion are. We will begin by discussing the four elements of a corrosion cell and how they interact with one another.

Dissimilar Metals and the Galvanic Series

In a corrosion cell, the anode and the cathode will typically be composed of dissimilar metals. Each different metal finds its place in the GALVANIC SERIES. In figure 2, we see where several more commonly used metals are located in this series. The metals placement in the series is a function of the electrical relationship or POTENTIAL the metals have to one another.

If we were to choose two metals from the scale, electrically bond them and immerse them in an electrolyte, we would find that the voltage produced would equal the differences in the two metals' potentials. For example, if we use the mild steel and copper as our anode and cathode, the voltage measured between the two will be approximately -.6 volts.

COPPER --.2 --.6

Figure 2 - The Galvanic Series

In corrosion terms, the metal higher on the scale is the anode and the metal lower on the scale is the cathode. In this example, the mild steel is anodic to the copper and therefore will corrode - provided that the other two conditions of the corrosion cell are met.

There is also a direct relationship between the sizes of the anode and the cathode as to the severity of the corrosion cell. If the area of the cathode is very large in relationship to that of the anode, the corrosion cell will be more severe, and thus the faster the anode will deteriorate. On the other hand, if the anode is very large in relationship to the cathode the effects of corrosion are much less and the anode deterioration is more gradual. Figure 3 illustrates this relationship as it might be seen on a typical tower anchor support.

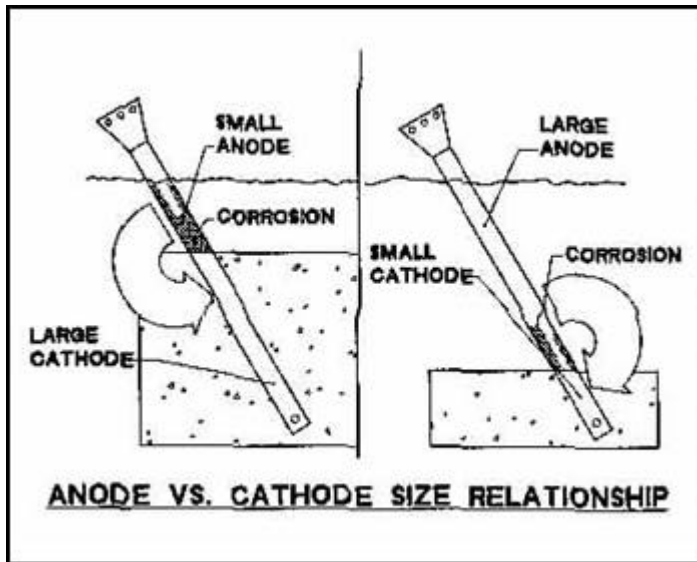


Figure 3 - Anode vs Cathode Size Relationship

Effects of Electrolytes on the Corrosion Cell

Many different environments could be considered electrolytic. Tower anchor supports are most commonly located in soil and concrete. This paper will confine its study of electrolytes to only these two.

Each type of soil has a measurable resistivity. Soil resistivity can be measured by using a soil resistivity meter. This measurement is defined in ohm-centimeters (ohm-cm). The method of measuring soil resistivity used most often is the four-pin method. Figure 4 illustrates the soil resistivity meter as it would be set up using the four-pin method. A lower resistivity measurement typifies a more conducive environment to the flow of current. The absence of oxygen in the soil also contributes to the enhancement of the corrosion cell. For example, clay type soil in a wet climate may measure 1,000 ohm-cm and therefore be a very good electrolyte. Sandy or rocky soil in a dry climate may measure 20,000 ohm-cm and therefore be a very poor electrolyte. The resistivity of the soil is a very important factor in evaluating the variables of the corrosion cell. When all variables of a corrosion cell remain constant, the electrolyte resistivity becomes the determining factor in the design and application of corrosion control measures.

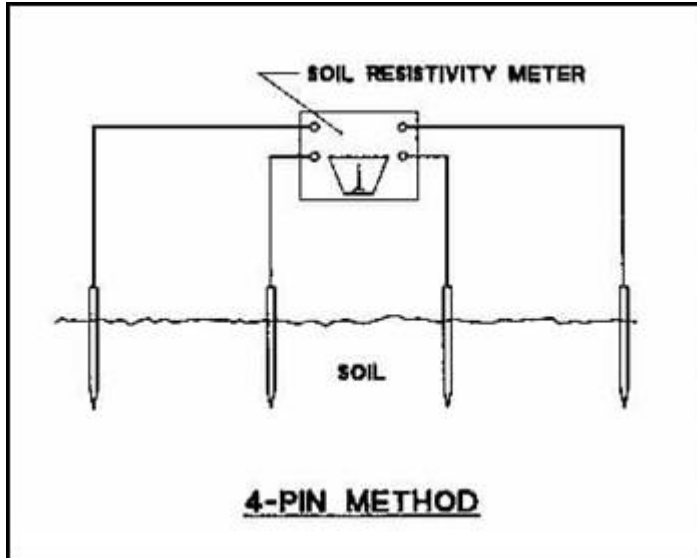


Figure 4 - Soil Resistivity by the Four Pin Method

It is also important to know that soils vary drastically from place to place across the globe. Soil type can even vary within inches! The variability of soil can cause multiple corrosion cells on the same structure. Figure 5 illustrates how various soil types can create a corrosion cell on a tower anchor shaft. In this illustration, we find the upper soil layer a looser, somewhat gravelly soil and below that a more dense clay type soil. The portion of the shaft in contact with the clay type soil acts as an anode to the portion of the shaft in contact with the looser gravelly soil, which is consequently the cathode. Again, we have a corrosion cell where the shaft deteriorates in the anodic areas.

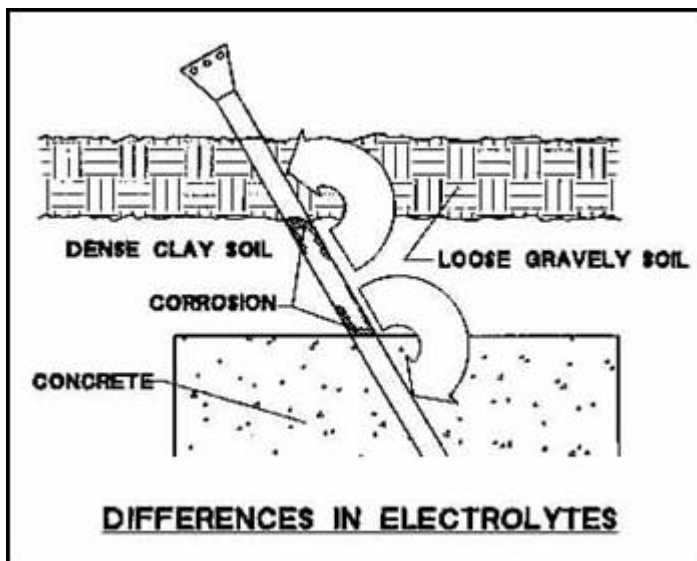


Figure 5 - Differences in Electrolytes

When considering the placement of a new tower site, the geotechnical soil investigation should include a determination of soil type including soil resistivity and chloride and sulfate ion presence. These items are critical to the design of corrosion control measures. If a geotechnical study is not required, soil samples can be taken and analyzed separately by a competent corrosion control firm.

HOW DOES THE CORROSION CELL AFFECT ANCHOR SUPPORTS?

For many years, the tower industry has used a basic anchor design similar to the one shown in Figure 6. This design presents a large number of benefits, especially in its use of the soil as a means to contain the anchorage. However, it is now becoming increasingly evident that the problem of corrosion on the anchor has not been sufficiently addressed in this design. In this section, we will discuss anchor support designs as they relate to the corrosion cell.

Galvanic Corrosion

Example 1. Figure 6 shows the basic design of a typical anchor support. The anchor support has all the necessary elements of a corrosion cell. The shaft itself acts as both anode and cathode as well as the electrical path between the two. The concrete and soil act as dissimilar electrolytes. The soil has less oxygen just above the concrete anchorage and consequently, less resistivity. The electrical path is the shortest between the anode and the cathode at the same point as the oxygen deficient soil, thus the deteriorating action of corrosion is most strongly in effect in this area. Experience has shown that this is the area most likely to deteriorate and cause the tower to fail.

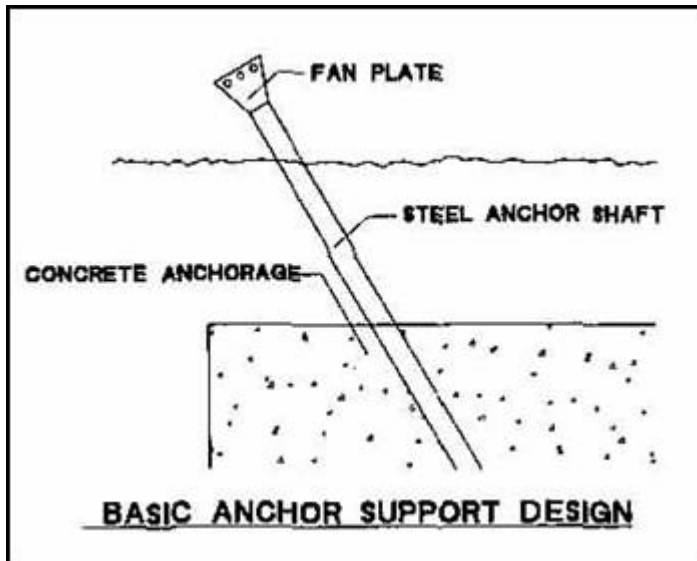


Figure 6 - Basic Anchor Support Design

Example 2. The second example shown in Figure 7 has the same basic anchor support design, however, now a copper grounding rod is incorporated as a means of lightning protection. The electromotive force series notes that copper is lower on the scale than steel and when coupled with steel will produce the measurable current previously spoken of. The two dissimilar metals activate a corrosion cell in which the steel anchor shaft is the anode and the copper ground rod is the cathode. Depending on the resistivity of the soil, this combination can contribute to rapid deterioration of the anchor shaft.

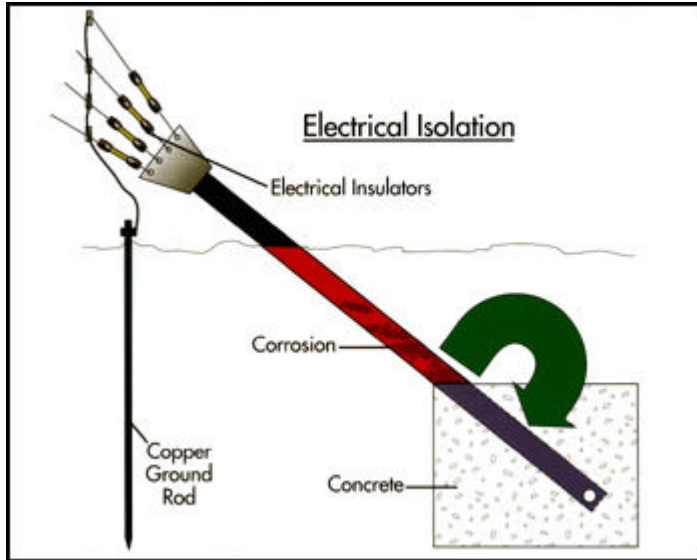


Figure 7 - Anchor Support With Copper Grounding

Experience has shown that by using galvanized grounding rods for lightning protection, this particular corrosion cell can be avoided. However, changing ground rod type alone does not preclude the possibility of the existence of other corrosion cells, such as those mentioned in example 1.

Stray Current Corrosion

The third common example of anchor support corrosion is known as "stray current" corrosion. Figure 8 illustrates how stray current can adversely effect the buried components of a tower facility.

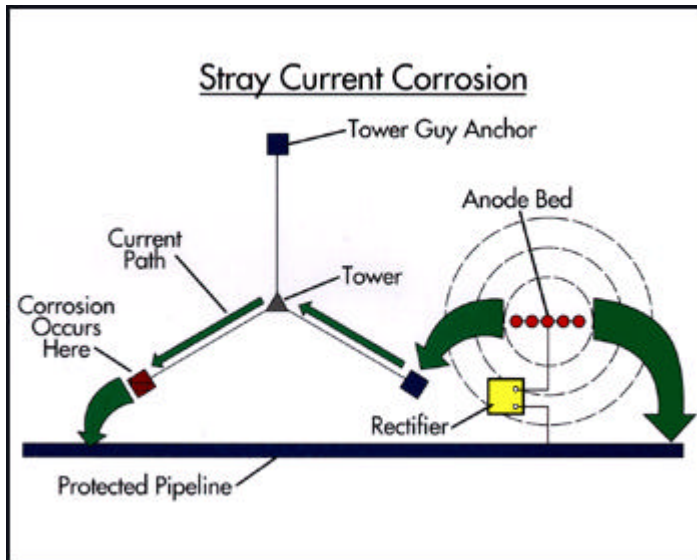


Figure 8 - Stray Current Corrosion

Many buried structures such as petroleum pipelines are protected against corrosion by means of impressed current cathodic protection systems. (See the following section for a more detailed explanation of Cathodic Protection.) Electrified railways and welding or plating operations will also put direct current into the ground. If a tower is near any one of these, it could be exposed to stray current corrosion. In Figure 8, the tower is used as a path of least resistance for current flow through the electrolyte. Stray current is picked up on one anchor support and travels by means of the guy cables to the alternate anchor where it subsequently discharges. The structure rapidly deteriorates at the place where the current discharges. This problem can be alleviated by electrically bonding the tower to the structure generating the stray current, essentially making it part of the protected structure.

HOW CAN CORROSION BE MITIGATED ON ANCHORS?

There are several options available to curtail, if not wholly eliminate, the problems associated with corrosion on anchor supports. In the following section, we will discuss these options. When designing a tower corrosion control system, all of the following examples should be considered. More than one of the options will be required in most instances.

Galvanization and Epoxy Coatings

The first example of corrosion control and the one currently used most often is that of coating the buried steel shaft. Usually anchor shafts are hot dipped galvanized with a zinc coating. This is advantageous as the zinc acts as an anode to the steel shaft. However, if galvanizing is used by itself as corrosion control the zinc can rapidly deteriorate leaving the exposed steel shaft open to damage. Hot dipped galvanizing in many cases gives a false sense of security because of the satisfactory appearance of the galvanizing above grade.

Epoxy coatings are also often used to protect shafts. This is accomplished by coating the entire shaft with an epoxy that acts as an insulator to protect the steel shaft from direct exposure to the electrolyte. This method is beneficial in protecting against corrosion, however, it has been proven that even the best epoxy coatings cannot guarantee 100% isolation from current. In addition, the coating can be damaged during shipping or installation, leaving small anomalies or "holidays." If the shaft is then buried with these "holidays," the "big cathode, small anode" scenario spoken of earlier comes into play. The shaft is open to accelerated corrosion in small areas that rapidly become larger. This type of concentrated deterioration is worse than if the shaft were left to corrode on its entire surface more evenly.

Concrete Encasement

Another option to prevent anchor shaft corrosion can be seen in Figure 9. In this option, the entire anchor shaft is encased in concrete. This method of anchor design is sometimes used for its structural capacity but it also has its corrosion control advantages. The greatest advantage is that it all but eliminates one essential element of the corrosion cell. The concrete has such a high resistivity that even with copper grounding electrically connected, current flow is substantially impeded. In addition, if the entire shaft is encased there is no anode/cathode relationship on the shaft itself.

The disadvantage to this alternative is the possibility that the concrete could become cracked or broken. If this should happen and water or soil fills the cracks, a corrosion cell would be created. The anode would be the area inside the cracks exposed to the water or soil, and the cathode would be the portion of the shaft inside the uncracked concrete.

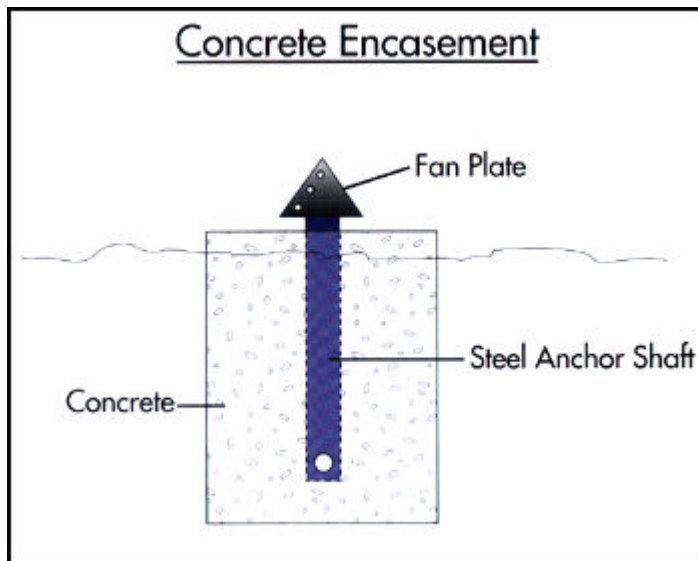


Figure 9 - Concrete Encasement

Cathodic Protection

Cathodic protection is a process of using the known variables of a corrosion cell to effectively mitigate the detrimental effects of corrosion. There are two types of cathodic protection commonly used. The first is known as galvanic anode and the second is impressed current. We will discuss each.

Galvanic Anode. Figure 10 illustrates the application of galvanic anode cathodic protection to a typical anchor support. The anchor support without cathodic protection installed is anodic to the copper grounding system and the portion of the shaft inside the concrete. By electrically bonding sacrificial anodes to the anchor support, the current flows away from the sacrificial anode and toward the anchor shaft and copper ground rod. It then returns through the electrical path. In this way, the elements of the corrosion cell have been used to make the anchor shaft the cathode, thereby eliminating corrosion where corrosion is not wanted.

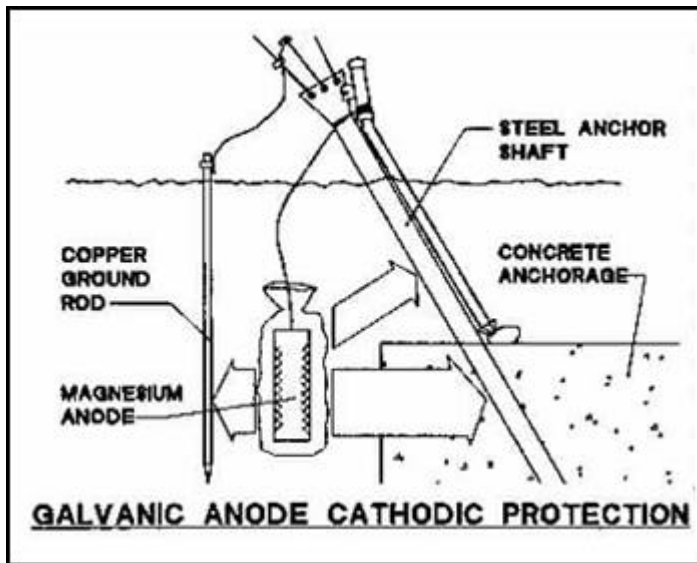


Figure 10 - Galvanic Anode Cathodic Protection

Sacrificial anodes vary widely in their sizes, shapes and make-up. Anodes are typically made of magnesium or zinc. The anode is usually placed in a cotton bag surrounded by a gypsum, bentonite and sodium sulfate mixture. This mixture is used for the purpose of assisting in the activation of the current flow and to ensure that moisture remains around the area of the anode. A wire is attached to the inner core of the anode and is designed to be bonded electrically to the member to be protected.

Following installation of the galvanic anode cathodic protection system, it is essential that it be monitored regularly to ensure its proper operation. A DC volt meter and copper/copper sulfate reference electrode (half-cell) is the most common method of checking the system after its installation. The tip of the half cell is placed in the soil with one lead of the volt meter connected to it and the other to the structure being tested. The measurement should show a voltage shift from the same test conducted on the structure before the system installation.

Impressed Current. Impressed current cathodic protection also uses buried anodes, but in a somewhat different fashion than the galvanic anode system. Rather than relying on the electromotive force of magnesium, DC voltage is impressed on the anodes by means of a voltage rectifier. The rectifier supplies ample current to the anodes to allow current to flow through the electrolyte and toward the protected structure. An electrical connection is made from the rectifier to the structure in which the return current flows. Figure 11 illustrates a typical application of this system at a tower site.

An advantage of impressed current cathodic protection is that the entire system can be centrally located near the base of the tower. The tower and its guy cables are the electrical connections to the anchor supports - provided the guy cables do not have cable insulators. The anodes are placed strategically in the same central location. The rectifier is then mounted on the transmitter building or anywhere AC power is readily accessed.

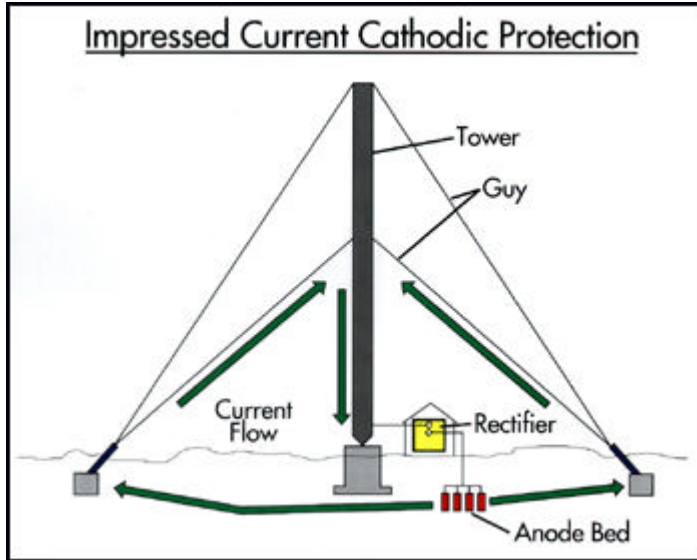


Figure 11 - Impressed Current Cathodic Protection

As with the galvanic anode system, the impressed current system also requires maintenance. It is recommended that the rectifier be inspected regularly and potential measurements be taken in the same fashion as explained in the Galvanic Anode example. This system allows for adjustment in current through changing the rectifier output.

Electrical Isolation

The final example of corrosion control is electrical isolation. Figure 12 shows an anchor support that has been electrically isolated from stray current or galvanic corrosion associated with dissimilar metals. This type of system is commonly used on AM radio towers to isolate the transmitting structure from the ground.

Electrical isolation employs guy wire strain insulators to eliminate the electrical path between the tower and the anchor support. It is an effective way of eliminating the galvanic cell problem associated with copper grounding systems, while at the same time taking advantage of the properties of copper as a means of superior lightning protection. In addition it protects against stray current corrosion. If applied correctly, the lead from the ground rod is attached to the guy cable on the "tower side" of the insulator so as to isolate the ground rod from the anchor shaft. This will ensure lightning protection and at the same time eliminate the copper-steel galvanic relationship. It also breaks the electrical connection required for stray current corrosion to take effect.

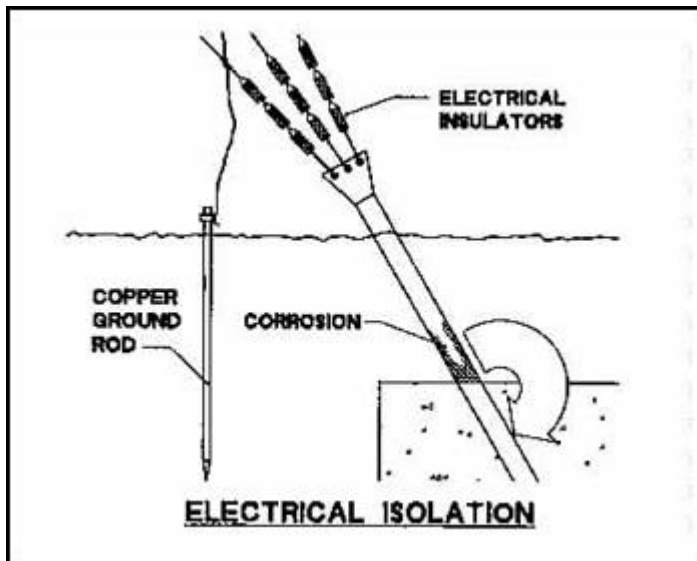


Figure 12 - Electrical Isolation

CORROSION ON EXISTING STRUCTURES

To this point we have discussed what corrosion is, how it works in the example of tower anchors, and we have given several methods for its control. The question now becomes what about existing facilities that may or may not have already sustained structural damage due to corrosion. This section will outline methods for investigating this potentially serious problem and give methods of remedial action that can be taken.

Anchor Inspection

It is becoming increasingly clear that many guyed towers have already sustained anchor corrosion. This has placed the structural capacity of the tower in question. Typical inspection procedures in the past have been to dig around the anchor to an approximate depth of twelve inches below grade. In many cases, corrosion is found during such an inspection, but is often determined to be acceptable. Based upon the principals of corrosion previously discussed, this method of detection is likely insufficient. The most extensive corrosion will usually occur closest the concrete anchorage which is often several feet below the surface of the soil. If any amount of corrosion exists at the upper levels of the anchor shaft, further investigation is usually warranted.

The most proven method of anchor investigation is to fully expose the steel shaft portion of the tower anchorage. This involves carefully removing the soil around the shaft to the depth of the concrete footing. Care should be taken so that the concrete footing is not overly exposed, which could result in the failure -of the anchorage and the tower. If structural capacity of the anchor is in question, temporary anchorages may be advisable. Once the soil has been removed from around the anchor shaft, the shaft should then be cleaned so as to allow measurement of the steel member. Typically, sand blasting or some other acceptable method of cleaning the shaft to a bare metal condition will be required. It is important that the shaft be free of soil and corrosion scale so that accurate measurements can be taken. It would not be uncommon for the shaft to appear to be satisfactory based on appearance prior to cleaning. This is true in part because of the thick corrosion scale build-up that clings to the face of the steel, giving the false impression that the shaft size or dimensions have not been altered substantially by corrosion. After cleaning the shaft, it can then be measured by means of micrometer or ultra-sonic thickness tester and reference given to the portion of the shaft above grade that has likely not sustained corrosion damage. Repair or replacement may be required, if corrosion has left question as to structural capacity of the shaft.

Applying Protective Measures

Epoxy Coating. If the shaft is determined to be structurally sound, then the bare metal anchor shaft provides an excellent surface for application of epoxy coating. Bituminous epoxy is the most commonly used and best alternative for coating of buried steel. Care should be taken to ensure complete saturation of the entire surface of the shaft. If anomalies or "holidays" are left in the coating, a corrosion cell could be even more severe than if the shaft were left alone.

Cathodic Protection. Once the shaft has been coated properly, additional measures such as cathodic protection should be applied. A properly coated member will allow a substantial reduction in the amount of cathodic protection needed. Cathodic protection has been shown to be the most economical method of anchor shaft corrosion control. Its monitoring capabilities also add to the benefits of this form of corrosion control. Research in the field of cathodic protection for tower anchors has produced a viable product for the protection of anchors that is now available. For more information about this product, contact the author.

SUMMARY

Corrosion of guyed tower anchors is fast becoming an issue of critical importance. Towers designed and built without consideration to corrosion control are in jeopardy. A tower's age is a key factor when considering the potential for structural damage due to corrosion, but age alone cannot predict the extent of corrosion damage. Towers scheduled to be built should include corrosion control measures. Existing towers should be investigated for damage and then protected against corrosion. Several methods exist to mitigate corrosion of buried tower components. Cathodic Protection has been proven to be the best when considering all the variables of the corrosion cell.

Just as construction of each tower requires careful consideration of structural design, each tower site must be assessed to determine appropriate corrosion control measures to be taken. The long-term benefits of proper corrosion control will far exceed short-term cost savings of choosing none. As technology and awareness increase, appropriate corrosion control is becoming an important industry standard.

REFERENCES

- [1] Control of Pipeline Corrosion, A-W. Peabody, National Association of Corrosion Engineers, Houston, Texas.
- [2] Basics Electricity of Cathodic Protection, Robert E. Gill, Technical Paper, National Association of Corrosion Engineers, Houston, Texas.
- [3] Corrosion Control For Underground Metallic Structures, John H. Fitzgerald, III, P.E., The Hinchman Company, Detroit, Michigan.
- [4] Structural Standards For Steel Antenna Towers and Antenna Supporting Structures, EIA/TIA-222-E, Electronics Industries Association, Washington, DC.
- [5] Antennas, Towers, and Antenna-Supporting Structures, Canadian Standard Association, CAN/CSA S37-M86, Rexdale, (Toronto) Ontario, Canada.