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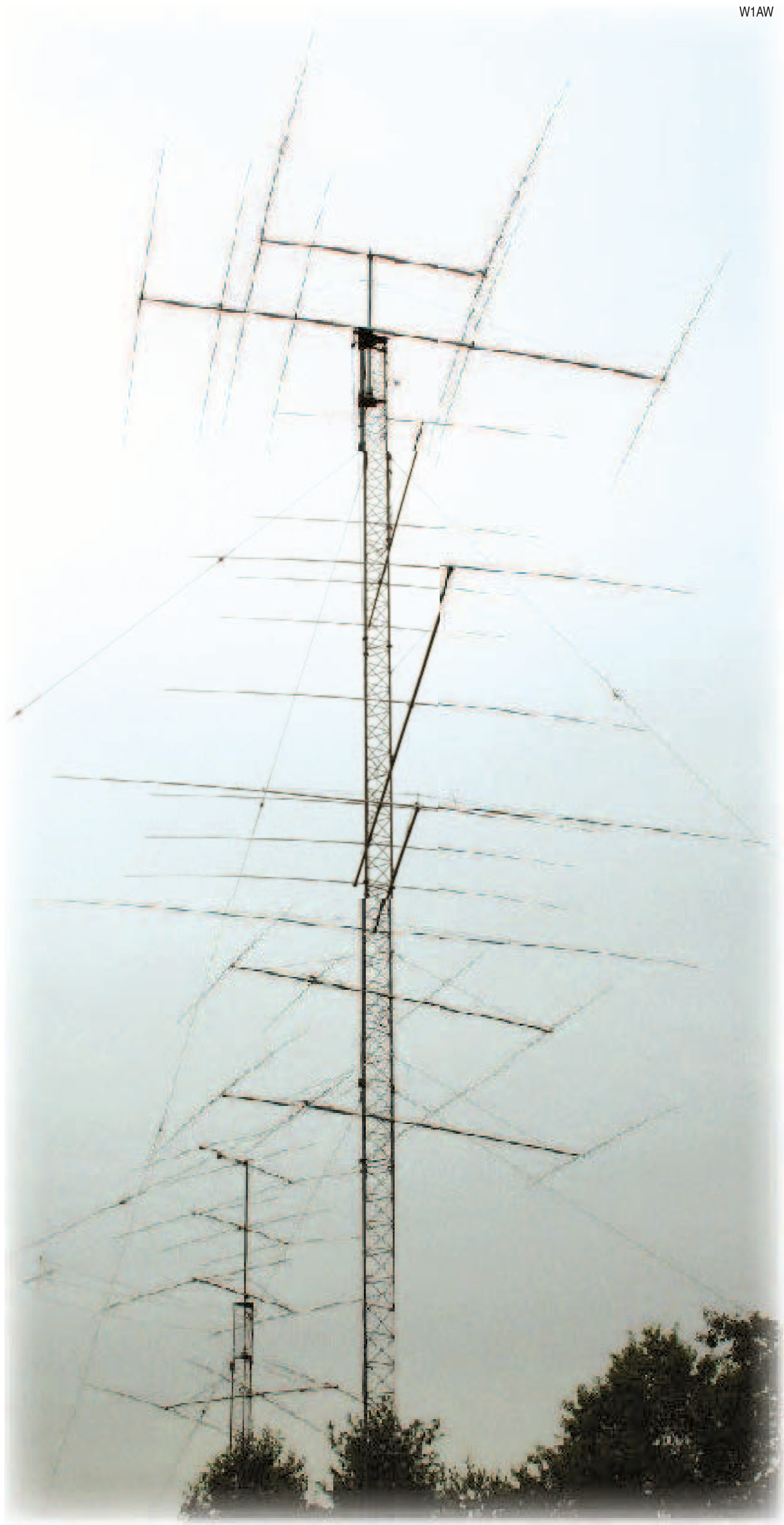
Is Your Tower Still Safe?

Galvanic corrosion — what it can do to underground structural tower components, and ways the problem can be avoided.

Tony Brock-Fisher, K1KP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Guyed towers are one of the most common and practical ways to support antennas for HF and VHF use. Many hams go through the exciting process of planning, gaining approval, purchasing and installing guyed towers for their ham antenna installations. The process of selection, approval and installation of such towers is usually the subject of intense focus and discussion with hams fortunate enough to be able to afford them.

Once the tower is installed its condition and that of its support structures is often ignored as the ham's attention naturally turns to installing antennas. Over the years, antennas may come down for repair or replacement, but seldom does the tower itself receive the attention it needs to keep it in safe and working condition. Any type of extensive antenna support structure, be it a simple roof-mounted tripod or a large guyed or self-supporting tower, should be inspected regularly for safety.

What You Can't See Can Hurt You

This inspection should be conducted annually at least, and it is prudent to conduct some sort of inspection anytime before climbing a tower. Often this inspection will include checking the visible parts of the tower for rust, corrosion, tightness of hardware and other key structural points. But what about the parts of the tower that are not easily visible? Even though they are more difficult to inspect, they should be checked as well. This article discusses one critically important aspect of tower inspection and maintenance for guyed towers: the inspection of the underground parts that provide vital support for the guyed tower.

A guyed tower is a unique engineering structure. The vertical load of the weight of antennas (and climbers) is supported by a very strong and rigid structure — the metal braced tower itself. The tower is, however, held in a vertical orientation by a system of guy wires that serve to keep the tower upright. If more than one set of guys are used, they also serve to keep the tower *in column* or straight, which prevents bending forces from acting on the tower. The guys are a critical part of the tower — as anyone who has had a tree fall on a guy wire can attest.

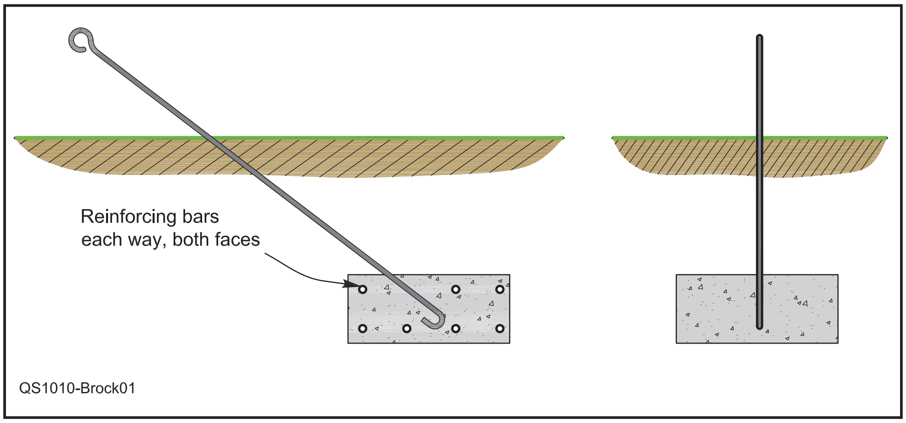

Figure 1 — Detailed views of typical concrete encased buried guy anchor and rod. See www.rohnnet.com for detailed information about anchoring their towers.

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Figure 2 — Guy anchor rod inspection. This rod has lost all of its galvanized coating, exposing the steel to corrosion.

The guys typically are made of extra high strength stranded (EHS) steel wire. They run from the tower to ground-mounted anchors at three locations equally spaced (120°) around the base of the tower. In most amateur installations, even though multiple guy wires may be used at each of the three directions, they often terminate in a single anchor point at ground level. The single guy anchor point, if not properly maintained, can be a single point failure with catastrophic results.[1] [Note that multiple anchor points will add a measure of redundancy. — *Ed.*]

A typical guy anchor consists of an equalizing plate that combines the loads of multiple guy wires into a single point. The single point is then attached to a guy anchor rod. The guy anchor rod extends from the equalizer plate to a concrete anchor, which is usually partially or completely buried in the ground to a depth extending below the frost line. See Figure 1.

If installed according to the manufacturer's instructions, the guy anchor rods have the majority of their length buried underground in the soil. The end of the guy anchor rod has some sort of structural element, such as a simple bend or a welded plate, that is embedded in the concrete base to provide positive support for the load the guy anchor rod must support. As with most tower components, the guy anchor rod is galvanized to prevent corrosion.

The portion of the anchor rod that is below ground level can be subject to corrosion that goes unnoticed in a normal tower inspection. For this reason, it is important that the guy anchor rods be excavated for inspection down to the concrete level, so their condition can be evaluated over their entire length.

It is not uncommon for guy anchor rods to be installed in ways other than per the manufacturer's directions. In most cases, the manufacturer has already discovered the best way to install and use the product, so in general it is good practice to follow the manufacturer's directions. This is K7LXC's Prime Directive: "Do what the manufacturer says!"[2] While some manufacturers recommend that the concrete base be installed below ground level and backfilled with earth, it is not uncommon practice to simply dig a hole down to below the frost line, perhaps install some forms, add the guy anchor rod in the desired position, and fill the hole/forms with concrete back up to grade level.

This has the advantage of not leaving any portion of the guy rod buried in direct soil contact. Since the entire rod is not encased in concrete, it can be inspected without excavation. The high resistivity of the concrete offers protection against corrosion of the portion of the rod that is encased in the concrete, as little or no current flow occurs through the concrete. This would seem to be a case where deviating from the manufacturer's directions may be a good idea — even Steve, K7LXC, condones the pouring of concrete for guy anchors above grade level.

Real Life Examples

I've had a 78 foot guyed tower installed at my present location for 16 years. The guy anchors were installed exactly per the manufacturer's recommendations, with the exception that after the concrete was poured and set, the rods were given a coating of bituminous tar. Recently I had become aware of the potential dangers of anchor-rod corrosion, and finally this spring the nagging fears led me to pick up a shovel and actually inspect the guy anchor rods.

Following the recommendations of experts, I excavated the rods from ground level down to the top of the concrete. After exposing the rods, I scraped them carefully with a garden trowel to be sure to remove any adhering soil (and, potentially, rust accumulation). I paid particular attention to the point at which the rod entered the concrete, as this can be the area that suffers the most serious corrosion. For two of my anchor rods, I discovered that the tar coating had not provided sufficient protection, as the tar and the galvanizing underneath it were essentially gone. The rods had visible rust on them, but fortunately they were not rusted sufficiently to reduce the strength (see Figure 2). I tapped the rods along their length, especially near the concrete, to make sure there were no large amounts of rust that would look normal but actually be a serious weakening of the rods. One of the rods looked essentially like the day it was installed; the tar coating was intact, along with the galvanizing underneath it. Interestingly enough, that rod was in the wettest location.

What Happened?

What had occurred was a classic case of corrosion. The chemical composition of the soil, along with oxygen and moisture, had led to the conversion of metal, first zinc and then steel, to oxides. The components used in tower construction are typically made of steel for strength. Steel rusts very quickly when left exposed to the elements. To prevent this rapid corrosion and prolong the useful life of tower components, the manufacturer usually galvanizes the components by hot-dipping them in zinc. While the galvanization does protect the steel as long as it is intact, the two metals involved, zinc and steel, can actually accelerate corrosion, once there is a break in the zinc coating, as described below.

Even though the coating of zinc may appear complete, wear, stress at load bearing points and corrosion of the zinc always result in the exposure of some of the steel. Therefore, there are two dissimilar metals in electrical contact, and also in contact with an electrolyte (water). We have the familiar components of a battery, as shown in Figure 3.

If two dissimilar metals are electrically connected and immersed in an ionic solution, a process known as *galvanic corrosion* occurs.

[1]Notes appear on page 47.

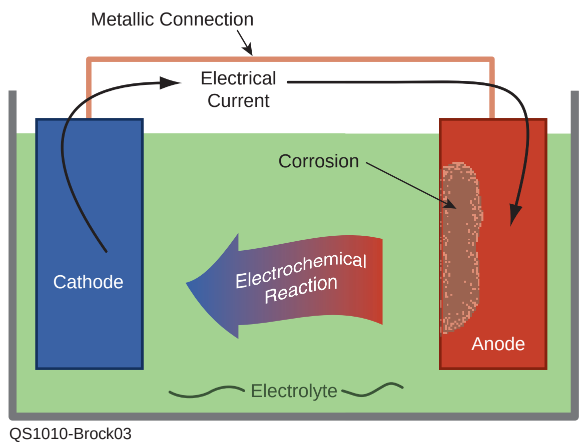

Figure 3 — Elements of a basic corrosion cell. The battery action accelerates corrosion effects.

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Figure 4 — All the materials required to build six sacrificial anodes.

In this case, an electric current flows from one of the conductors, through the electrical connection to the other conductor, and back to the first conductor through the ionic solution (electrolyte). Essentially, a battery is formed by the two conductors and the electrolyte. The direction of current flow is determined by the types of metals involved and their relative positions in the galvanic series. The galvanic series is a list of conductive materials in order of their electrical activity, from most negative to most positive.[3] In the case of zinc and steel, zinc is more negative (–1.0 V) compared to steel (–0.6 V). This means that if a battery is formed with zinc and steel, current flows in a loop from the steel, through the electrical connection to the zinc, and then through the electrolyte (moist earth) back to the steel. Electric current flow in an electrolyte occurs through the migration of ions.

The negatively charged hydroxide ions migrate to the positively charged zinc (anode). The positively charged zinc ions combine with the hydroxide ions to form zinc oxide and hydrogen gas. The zinc corrodes because the different electric potential means the zinc gives up its electrons to form ions more easily than the iron. Note that in this case, the zinc corrodes but the electric potential protects the iron from corroding. This is an example of a sacrificial anode (zinc) in a cathodic protection system. If instead of zinc, a more noble material (more positive in the galvanic series) such as copper were used, the reaction would go in the opposite direction: The iron would be corroded while the copper would be protected.

Such is the undesirable but typical case in which a guy anchor rod is protected against lightning by the connection of a nearby copper ground rod. It is often recommended that the guy anchors be grounded for lightning protection using a ground rod that is electrically connected to the guy anchor. Usually, such ground rods are copper or copper clad steel.

In the event of a lightning strike, this allows the current to bypass the anchor rod and concrete anchor. If the lightning were allowed to pass through the rod and anchor, the concrete could be shattered by the sudden heat and steam generated by the strike. The copper of the ground rod is, however, much more positive than steel or zinc in the galvanic series, so the connection of the copper ground rod would actually increase the rate at which the zinc galvanizing is consumed. So while it is good practice from the lightning point of view to add the copper ground rods, it is detrimental from a corrosion point of view. It would be better to use a galvanized steel ground rod, or provide additional corrosion protection for the anchor rod.

Difference in Electrolytes

In addition to different metals, galvanic corrosion can also be caused by a difference in electrolytes. Consider the fact that the guy anchor rod is located in at least two and possibly more different electrolytic environments. There may be layers of different types of soil, with differing chemical compositions and pH levels. A portion of the guy rod is encased in concrete, which has higher resistance and is often more cathodic than the soil above. This explains why the most severe corrosion often occurs right at the point at which the rod enters the concrete base. In fact, this condition was evident on my guy anchor rods. This is why it is critical to excavate all the way to the base while performing inspections of the guy anchor rods. It is not sufficient to dig down a foot or so and check the condition of the rod — you must always inspect the rod over its entire length, paying close attention to the point at which it enters the concrete.

In the case of two of my tower anchor rods, the zinc had been completely expended doing its job protecting the steel structural member of the rod. It's important to note that covering the rod with tar had probably been a bad idea. This is because the tar coating could never be perfect, and any small imperfections would expose a small area of zinc. Because of the small area, the electric current would be concentrated at that point, and cause the zinc to be corroded rapidly there. The zinc corrosion was probably actually accelerated by the tar coating. This is an excellent example of the corollary of the K7LXC Prime Directive: "*Don't* do what the manufacturer doesn't tell you." Likewise, it would be a bad idea to attempt to coat the rod with a thin layer of concrete, or to retrofit an existing below-grade anchor by adding new concrete up to ground level. Either approach can leave cracks or gaps into which water can enter and cause corrosion. In these cases, there is no way to inspect the potential corrosion visually.

What's Next?

With the zinc nearly totally gone from the anchor rods, there is nothing to prevent the steel from turning to rust, leading to an eventual failure of the tower. At the present time there is adequate strength in the steel rods to support my tower — so it would be desirable to somehow protect the rods in their existing state. What is needed is a means of stopping the corrosion process.

I was aware that sacrificial zinc anodes are used in marine environments, and that the zinc electrodes are user replaceable. In this case, because the electrolyte is so good, either fresh or saltwater, there is no need to completely cover the surface to be protected with zinc galvanizing — a small chunk of zinc, immersed in the water and connected to the metal to be protected is all that is needed to create cathodic protection for the structural metal. The zinc anodes are rapidly corroded, but easily replaced. Could such a system work for anchor rods?

I conducted an Internet search and found that there are companies that market systems specifically for this purpose. The system consists of a technique to restore the cathodic protection that is lost when all the zinc has been used up. Because they are designed for commercial applications, the cost was prohibitively high for amateur use.[4] Nevertheless, I had verified that the idea of cathodic protection using a sacrificial anode could be made to work for guy anchor rods. After more research, I learned how the system should be constructed, and where the materials could be located inexpensively.

The Solution

The system for cathodic protection of guy anchor rods is fairly simple. It consists of the addition of a sacrificial anode that is electrically connected to the structure to be protected and chemically connected to the electrolyte involved. Each of these elements present special requirements for the case of underground corrosion protection.

Sacrificial Anode Material

First, the sacrificial anode material should be magnesium, not zinc. The reason for this choice is that magnesium is much farther away electrically in the galvanic series from steel than zinc, being the most negative metal in the series. This provides several advantages. First, it provides a much larger driving voltage potential for the electrical cell. Given that the electrolyte in this case can be much higher impedance than the case of immersion in water typical of boats, this provides an additional measure of protection. Second, the potential difference of the magnesium would serve to protect not only the steel of the structural element, but the zinc coating as well. In a system with more than two types of metal, the metal with the most negative potential will be the site of corrosion, and its generated electrical potential will serve to protect all the other metals in the system with more positive potentials.

Connection of Anode to Electrolyte

In the case of underground cathodic protection, the sacrificial anode needs to make good electrical contact with the electrolyte. This cannot be reliably achieved by simply burying the anode in the ground. Typically this connection to the electrolyte is facilitated by surrounding the anode with a special material that is engineered for this purpose. Although many different materials might be appropriate, the most commonly used material for local underground corrosion protection is a mixture of gypsum, Bentonite and sodium sulfate. This material effectively reduces the electrical resistance of the connection by increasing the surface area.

Additionally, the ionic behavior of sodium sulfate provides excellent electrical connection in an environment without using a chemical that is completely soluble, such as common salt, which would dissolve quickly and simply leach away into the soil. The Bentonite serves to maintain water content and soil contact in the area of the electrode even under dry conditions. This mixture is called #6 by the supplier.[5]

Commercially Available Materials

It may seem that magnesium anodes and the special backfill material might be hard to procure. However, the Internet once again comes to the rescue. I found a company that sells exactly the materials needed, in reasonable quantities and at reasonable prices.[6] The backfill material is available in 50 pound bags. The electrodes are 1.312 × 12 inch magnesium rods, which come with a 3 foot long lead of #12 THHN wire with a hose clamp connector at the end. I placed an order via e-mail, and received the electrodes and backfill via UPS the following week. The cost for materials to protect an average size amateur tower was under $150.

I found a source of cotton bags on an auction site as well. I was able to buy 8 × 16 inch cotton bags with a drawstring top very cheaply.[7] I used two electrodes per guy anchor for a total of six anodes (see Figure 4). The anodes are prepared by filling the bag with the backfill mixture, then inserting the electrode into the center of the bag full of backfill and closing the drawstring at the top (see Figure 5). One 50 pound bag of backfill was the perfect amount to fill six bags of the specified size.

Anode Location and Installation

The recommended installation of the sacrificial anodes is one on either side of the guy anchor rod, about midway between the concrete anchor and the point where the rod exits the ground. The location is not critical, so if you have to dodge large rocks it is okay to relocate the hole a bit. The installation should be as deep as possible, up to 6 feet, in order to make the best electrical contact with the underground electrolyte environment. Simply use a power auger or post hole digger to make a small round hole on each side of the anchor rod. The bags are placed at the bottom of the hole with the lead wire coming to the surface. It's a good idea to backfill around the bag with soil to the top of the bag, then tamp the soil around the bag with a tool handle before filling the remainder of the hole to grade level.

Electrical Connection

The sacrificial anodes need to be electrically connected to the guy anchor rod by #12 AWG THHN wire. The wire supplied on the electrodes was not long enough to reach a connection point above ground, so I made a twisted/soldered splice to another piece of #12 AWG wire. I made no attempt to weatherproof the splice, as it will be protected by the system. The leads are buried a few inches below the soil to keep them out of the way of the lawnmower. The electrical connection to the anchor should be in an accessible location for testing later on, so bring the wires from the anodes up the ground rod, secured by nylon ties, to a point above grade where they can be connected. I simply attached the wires to the existing ½ inch turnbuckle bolts with an additional ½ inch nut (see Figure 6).

Is it Working?

In order for the system to provide cathodic protection to the ground anchors, there has

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Figure 5 — Bag filled with backfill material and magnesium electrode before closing.

Table 1

My Voltage Measurements Used to Verify and Monitor Cathodic Protection

Day	*NE Guy Anchor*			*S Guy Anchor*			*NW Guy Anchor*		
	N BLK (V)	*E WHT (V)*	*Current (mA)*	*E BLK (V)*	*W WHT (V)*	*Current (mA)*	*W BLK (V)*	*N WHT (V)*	*Current (mA)*
0	0.313	1.287	1.135	0.908	0.810	3.50	1.461	1.420	1.35
1	0.971	0.935	1.220	0.587	0.558	3.13	1.233	1.238	3.37
2	0.894	0.860	1.331	0.577	0.548	3.15	1.203	1.199	3.32
4	0.810	0.792	1.112	0.563	0.533	3.02	1.172	1.160	2.55
10	0.732	0.703	1.171	0.507	0.490	1.872	1.069	1.069	3.17
29	0.619	0.570	1.212	0.508	0.511	1.77	0.848	0.859	3.95

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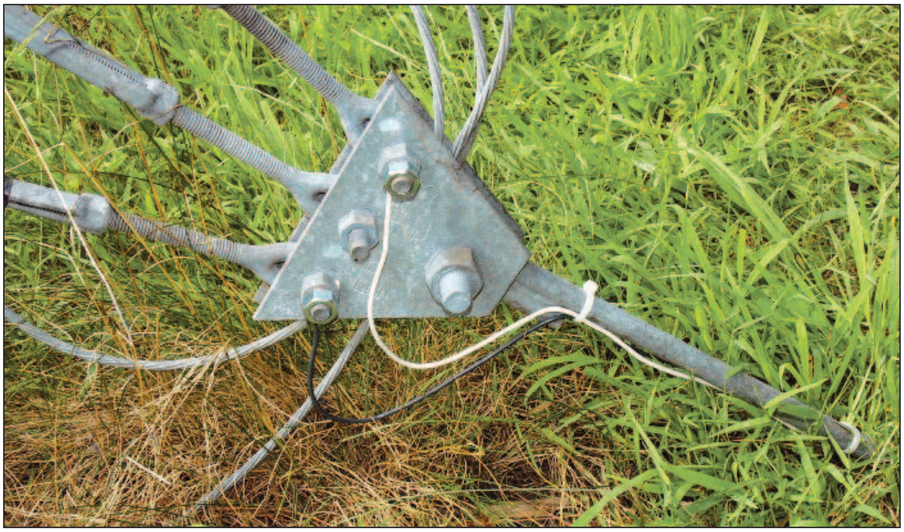

Figure 6 — View of electrical connection to guy anchor.

to be an electric potential generated by the system. To check for this, temporarily disconnect the anode leads from the guy rod. Connect a digital voltmeter (DVM) between each of the anodes and the guy anchor rod, with the ground lead of the DVM to the guy anchor rod. You should see a negative voltage. The exact voltage you read will depend on many factors, including the soil conductivity, the moisture content of the soil and electrode bag, and the condition of the guy anchor rod.

Next, set the DVM to measure current between the guy anchor rod and the leads from the anodes (connect them together for this measurement). You should see a current flowing from the cathode (guy anchor) to the anodes. These voltages and currents can be measured and recorded over time to check the efficiency of the system. Typically the efficiency will increase gradually after installation, as the electrical conductivity of the disturbed soil is reestablished and the bags' moisture content increases. Table 1 shows the measurements I made immediately following installation.

The measurements I made on day zero showed a wide disparity, even between electrodes at the same guy anchor. After one day (with frequent rain), the measurements become much more similar between electrodes at the same guy anchor, with the difference between electrodes becoming less than 30 mV. When measuring the voltage potential with the electrodes disconnected, you are measuring the electrical potential of the corrosion cell formed by the magnesium anode and the guy anchor cathode. This will depend on the metals involved — so if the guy anchor rod is in good shape, and still has the zinc galvanized coating, the potential will be lower than if the guy anchor rod has lost the zinc coating. In that case the potential will be determined by magnesium and steel.

In my case, I had two guy anchor rods that had lost much or all of the zinc galvanization (NE and NW), with the third anchor rod (S) still retaining the zinc. The voltage measured on the good anchor was much lower than the others, indicative of the fact that I was seeing the potential difference between magnesium and zinc, not magnesium and steel. If the current is seen to decrease a long time after installation, this may be an indication that the anodes are completely used up and need to be replaced.

You should make a test sheet on which you can record the electrode voltages and currents over time. You should see the voltages increase after installation, then stabilize. Measuring the electrode voltages should definitely be part of your regular tower inspection process.

The installation of a cathodic protection system does not in any way obviate the need for regular inspections of the guy anchor rods. You should still excavate and inspect the rods periodically to be sure that they are not corroding and becoming unsafe.

Conclusions

The important points of this article are as follows: First, buried components of tower structures are susceptible to corrosion, and therefore should be excavated and visually inspected on a periodic basis. The appropriate time period will depend on the exact installation and soil conditions; it is this author's opinion that the first inspection should occur no more than five years after initial installation, and the interval between inspections can be adjusted based on the amount of corrosion found. Second, a sacrificial anode can be installed to create a cathodic protection system to prevent corrosion of buried tower components. This sacrificial anode can be a commercially available unit, or the components can be purchased individually and installed by the ham at a much lower cost.

Notes

[1]C. Snyder, "Understanding and Preventing Guyed Tower Failure Due to Anchor Shaft Corrosion," Sioux Falls Tower Specialists.

[2]S. Morris, K7LXC, "UP THE TOWER — The Complete Guide to Tower Construction," 2009, Champion Radio.

[3]**www.corrosionsource.com/handbook/galv_series.htm**, or **www.ocean.udel.edu/seagrant/publications/images/corrosion.pdf**.

[4]**www.anchorguard.com**

[5]**www.brancekrachy.com**

[6]See Note 5.

[7]**www.organzabagg.com**

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