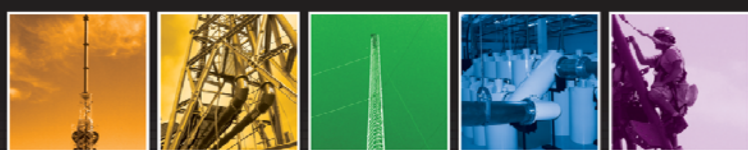
Around the World, Across the Spectrum, Your Single Source For Broadcast Solutions.

Tower Site Grounding, Guy Anchor Rods, and Galvanic Corrosion



New York Ennes Workshop

Saturday, November 5 2011

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Guy Anchor Rod Corrosion

Foundation Steel Corrosion

- Explanation of the Corrosion Process
- How to Self Evaluate Corrosion Risk Probability
- Anchor Rod Inspection Methods
- Corrosion Prevention Methods

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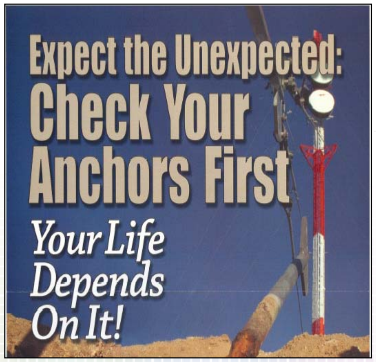
NATE Advertising Campaign

The National Association of Tower Erectors recommends the inspection of ***all*** anchor rods before ***any*** tower work is performed even though this increases inspection cost



Anchor Rod Corrosion Resulting in TOWER FAILURE

Two towers in the Evansville area have fallen down as a result of **Galvanic Corrosion in the last ten years.**

Why Did This Tower Located in Evansville, Indiana Collapse?

Underground (UNDETECTED) guy anchor shaft corrosion

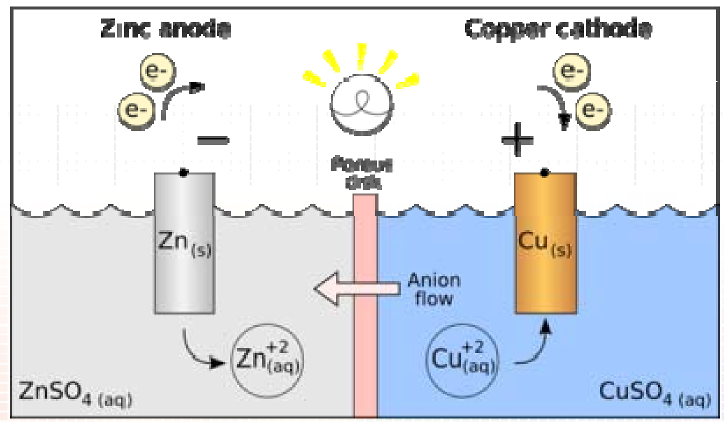
Galvanic Corrosion Defined

- Galvanic corrosion occurs when two different metals and/or alloys have electrical contact with each other and are immersed in an electrolyte
- This effect is a galvanic couple where the more active metal corrodes at an accelerated rate and the more noble metal corrodes at a retarded rate
- When immersed, neither metal would normally corrode as quickly without the electrically conductive connection

Galvanic Corrosion

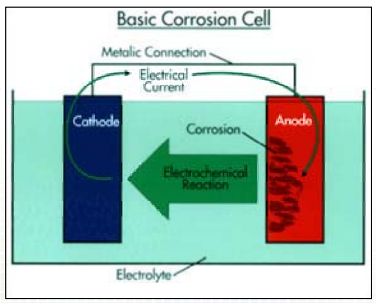
- An electrochemical process causing deterioration via a reaction between or within the metals
  - Between (External) Metals with different electromotive potentials such as copper and zinc
  - Within (Internal) Difference in the environment of two sections of the same metal such as soil and concrete or layers of sand and layers of clay along a galvanized guy anchor

Example of a Galvanic Cell



Four elements of a cell all of which are required for the cell to be active and produce an electrical potential

1. Anode
2. Cathode
3. Electrical Path (conductor)
4. Electrolyte



Three Basic Requirements for the Electrical Potential

- Dissimilar metals
- Electrolytic agent
- Electrical path

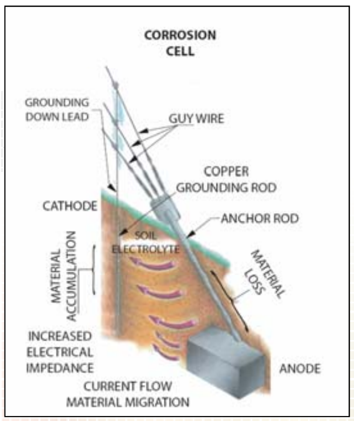
Dissimilar Metals

• More Reactive	
• Magnesium	• -1.55 Volts
• Zinc	• -1.10 Volts
• Aluminum	• -0.86 Volts
• Carbon Steel	• -0.68 Volts
• Stainless Steel	• -0.61 Volts
• Copper	• -0.43 Volts
• Less Reactive	

Example of Cell

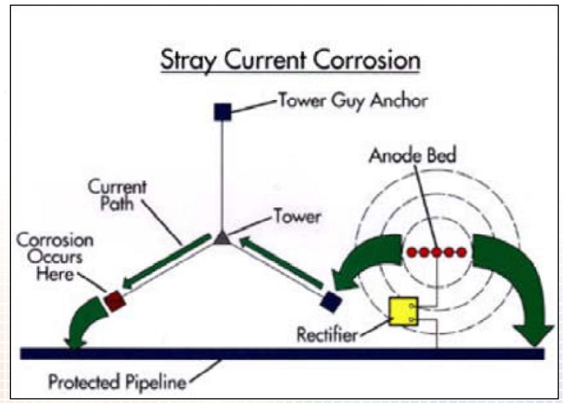
- Voltage difference between Zinc (galvanize) and copper ground rod is:
- V = 1.55 – 0.43 = 1.12 Volts
- 1 milliamp current flow = 0.02 pounds Zinc in one year.
- Typical ground rod resistance = 25 ohms
- Current = 1.12 volts / 25 ohms = 45 milliamps = 0.9 pounds of Zinc per year

External Galvanic Corrosion



- “Dissimilar Metals” in Guy Tower Anchor

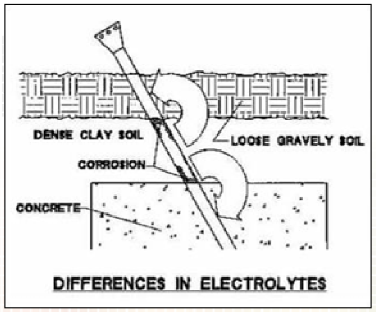
Stray Currents in a Guyed Tower



Internal Galvanic Corrosion

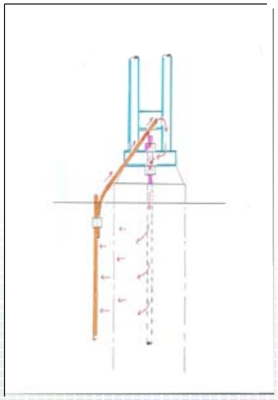
- **Within** (*Internal*) Difference in the environment of two sections of the same metal such as *soil* and *concrete* or layers of *sand* and layers of *clay along a galvanized guy anchor*

Galvanic Corrosion resulting from layers of different material



Internal Corrosion

Example of Galvanic Cell



Q: Why Won't Hot Dip Galvanizing Prevent Steel from Corroding?

A: The main component of galvanizing is zinc. Zinc is very high in the galvanic series and acts as an anode, while coated steel acts as the cathode. When exposed to the atmosphere (CO2), zinc quickly forms its own passivation film. . .

Q: Why Won't Hot Dip Galvanizing Prevent Steel from Corroding?

- You could use a galvanized ground rod instead of a copper ground rod here. Since the voltage difference = zero, you won't have a current flowing

. . .However, this passivation film (zinc coating) becomes unstable in the absence of oxygen and quickly erodes, or sacrifices

Methods of Evaluating Corrosion Risk Probability

- Review Geo Tech Report
- Conduct Visual, On-Site Inspection
- Perform On-Site Electrical Testing

Soil Parameters

- Soil classification elements with the greatest impact on corrosion rates are:
  - – Particle size and Aeration
  - – Moisture content
  - – Bactria and Microbiologic activity
  - – pH
  - – Other natural chemical elements

Methods of Reporting Soil Particle Size

(#1) Soil Type	(#2) Particle Size	Corrosion Rate
Sand	.07 to 2 mm	Low
Silt	.005 to .07 mm	Moderate
Clay	less than .005 mm	High

- ✓ Low Corrosion Rate – Coarse grain soil, less than 50% passing through a # 200 sieve (#3)
- ✓ Higher Corrosion Rate – Fine grain soil, more than 50% passing through a #200 sieve.

Soil Particle Size and Corrosion

- Generally, large particles such as rock and sand are well-aerated and less likely to contribute to corrosion.
- Small particles, considered more aggressive soil, are more susceptible and would include:
  - Clay, Silt and Compact Peat
  - Sandy-Silt in salt water or tidal marshes

Aggressive Soil Types

Soil Symbol	Soil Type	Corrosion Rate
PT	Peat and other highly organic soils	HIGH
OH	Organic clay	
CH	Inorganic clay	
MH	Inorganic silts and very fine sands	
OL	Organic silts	
CL	Inorganic clays, silty clays, lean clays	
ML	Inorganic silts with fine sands	
SC	Clayey sands, sand-clay mixtures	
SM	Silty sands, sandy silts	MODERATE

Moisture Content

- Usually represented in % moisture by soil weight, or
- Difference between in situ soil weight and dry soil weight
- **Generally, the greater the moisture content the greater the corrosion probability: > 15% moisture by weight would be considered aggressive soil**

Bacteria and Microbiologic Content

- High levels of bacteria in the soil consume oxygen, resulting in poorly aerated soil leading to accelerated corrosion
- Bacteria levels can be requested during a geo-tech investigation and should be expected in organic soils like peat or near animal waste sites

Hydrogen Ion Activity (pH)

- Extreme corrosion rates are to be expected in soils having Low or High pH. The pH range is from 0 to 13, with 7 considered neutral.
- **A reading < 6 or > 8 should be considered aggressive soil and may include:**
  - *Cinder, Ash, or Slag Fills Organic Fills, Mine and Industrial waste*

Chloride Concentration

- Chloride ions facilitate the corrosion process
- High levels are typically found in areas of historic salt water
- May also result from de-icing operations
- **Chloride concentrations in soil > 50 ppm is considered aggressively corrosive for steel**

Soils with Sulfur

- Sulfur or sulfur-forming soils can produce extremely acidic soil conditions when exposed to air
- This often occurs in tidal flats or near mining activity where the soil is exposed and well drained

Reclaimed Soils

- Towers located on land that has been mined for coal
  - Coal chunks left in the fill will drop a tower faster than anything else
  - In these locations, you must encase the guy rod in concrete to avoid catastrophic failure

Evaluating Corrosion Risk Probability Using Visual Inspection

Visual and Agriculture Data
Water Level and Rain Fall

- The longer steel remains wet, the higher the corrosion rate.
- Large amounts of rain can create more acidic, thus *corrosive* soil.

Evaluating Site Soil Through Visual Inspection

Road Side Excavation
Sandy Soil has low cohesion
Slanted Face
Non-aggressive soil

Road Side Excavation
Clay has high cohesion
Steep Face
Aggressive soil

Evaluating Site Soil Through Visual Inspection

Surface Observation
Clay Soil has high cohesion
Aggressive soil

Shallow Digging
Clay Soil has high cohesion
Aggressive soil

COLOR: *A simple method to determine soil classification and particle size*

Tan, Red or Light Brown colors indicate large particle, well-aerated soil with low moisture content, as it doesn't hold water for long periods

Lower Probability of Corrosion

COLOR and Particle Size

Gray and green/gray soil indicates smaller particle size with poor aeration.

Aggressive soil

Anchor shaft installed less than one year ago

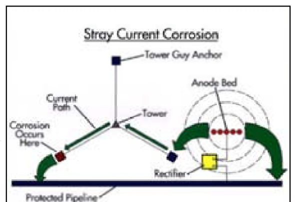
Visual (and Nasal) Inspection
Bacteria sources, pH and Agriculture Data

- Use visual inspection *or your nose*
- pH and Bacteria levels can also be obtained from an agricultural equipment supplier at no or little cost

Visual Inspection of Anchor Shaft

Visual Inspection

Look for evidence of Pipe Lines and other stray current sources



National Pipeline Mapping System (NPMS)

www.npms.phmsa.dot.gov

National Pipeline Mapping System (NPMS)
www.npms.phmsa.dot.gov

Pipeline operator contact for the geographic area you specified. (Do another search)

Pipeline Operator Name	Person to Contact	Entity to Contact	Contact Address	Phone/Fax/Email
BP PIPELINE (NORTH AMERICA) INC.	Bobby Roye (Compliance Team Leader)		4502 E. 41st St., Suite 300, Tulsa, OK 74135	Phone: 8005486482 Email: royebw@bp.com
TEXAS GAS TRANSMISSION LLC		Gas Control - Texas Gas Transmission, LLC	P.O. Box 20008 3800 Frederica Street, Owensboro, KY 42301	Phone: 2706886800 Email: Mike.K.Nance@txgt.com

Visual Inspection
Look for Other Sources of Stray Currents

Sources of Direct Electrical Current Generation or Use.

- Plating works
- DC supply systems in industrial plants
- Large direct drive motors
- Welding equipment

Ground Resistance Test Set

- High soil resistivity generally equates to a low corrosion rate, while Low soil resistivity can lead to a high corrosion rate
- Soils with a resistance of less than 10,000 Ohm-Cm would be considered corrosive

Resistance of a Single Ground Rod

$$R = (\rho/2\pi L)(Ln(4L/a)-1)$$

- R = Resistance
- L = Length of Rod
- ρ = Resistivity of Soil (ohm-cm)
- a = Radius of Rod

Example of Resistance Calculation

- Soil Type: Clay
- ρ = 1500 Ohm Cm
- 5/8” X 10’ Driven Rod
- R = (1500/1915.11)(Ln(1219.2/0.794) – 1)
- R = 4.963 Ohms

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Example of Resistance Calculation

- Soil Type: Sand
- ρ = 50000 Ohm Cm
- 5/8” X 10’ Driven Rod
- R = (50000/1915.11)(Ln(1219.2/0.794) – 1)
- R = 165.4 Ohms

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Soil Resistivity Comparison

- Surface soils 100 – 5,000 ohm-cm
- Clay 200 – 10,000 ohm-cm
- Sand and gravel 5,000 -100,000 ohm-cm
- Surface limestone 10,000 – 1,000,000 ohm-cm
- Limestone 500 – 400,000 ohm-cm
- Shales 500 – 10,000
- Sandstone 2,000 – 200,000 ohm-cm
- Granites, Basalts, etc. 100,000 ohm-cm
- Slates 1,000 – 10,000 ohm-cm

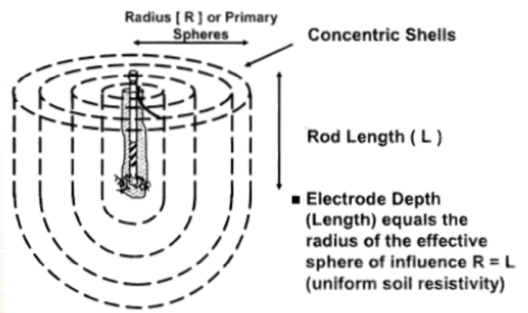
Multiple Ground Rods

- If multiple ground rods are used, they must be spaced properly (beyond sphere of influence).
- Ground rods do not exactly add up in shunt.

Spheres of influence

- Resistance due to sum of a series of “shells” surrounding the electrode
- Closest “shell” has smallest circumference, therefore resistance is highest
- Outer “shells” have larger circumference, therefore lower resistance
- Lower the resistance of closest “shell”, lower the overall resistance

Sphere of Influence



For Two Ground Rods

- Space rods > Sphere of influence
  - Sphere of influence = driven rod depth
- $R1 = (\rho/4\pi L)(Ln(4L/a) - 1)$
- $R2 \approx (\rho/4s)(1 - L^2/3s^2 + 2L^2/5s^2)$
- $R \approx R1 + R2$
- R = multiple ground rod system resistance
- L = ground rod length
- ρ = resistivity
- a = radius of ground rod
- s = spacing of ground rods

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Resistance of Each Ground Rod

- Soil Type: Clay
- ρ = 1500 Ohm Cm
- 5/8" X 10' Driven Rod
- $R = (1500/1915.11)(Ln(1219.2/0.794) - 1)$
- R = 4.963 Ohms

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Example calculation of two rods
(Spacing Greater than Length)

- ρ = Resistivity (1500 ohm-cm)
- L = Length of rod (304.8 cm or 10 feet)
- a = Radius of rod (0.794 cm or 5/8 inch)
- S = Spacing between rods (609.6 cm or 20 feet)
- R = 2.4814 + 0.1844
- R = 2.5212 ohms
- Single rod resistance = 4.963 Ohms

Roof Top Towers

Roof Top Towers

Roof top tower anchor located in cooling tower with high humidity

On Site Testing System Resistance and Current Flow

- Measure the resistance and current in the grounding rod
- Testing the anchor rod circuit can also be instructive

Predicting Active Corrosion Cell using Resistance and Current Measurements

- Single 10’ ground rod resistance of less than 16 Ohms indicates more aggressive soil.

- Direct Current flow in excess of 15 mA indicates an aggressive soil.

Predicting Active Corrosion Cell using Current Measurements

- Discharged current is capable of corroding the galvanize coating on the steel at the rate of 0.02 pounds a year per milliamp of discharge current. In the case of a 25 ohm single copper ground rod against a galvanized tower, you would have a 0.25 volt potential giving you 10 MA (0.2 pounds of metal per year).

Predicting Active Corrosion Cell using Current Measurements

- Discharged current is capable of corroding the galvanize coating on the steel at the rate of 0.02 pounds a year per milliamp of discharge current. In the case of a 5 ohm single copper ground rod against a galvanized tower, you would have a 0.25 volt potential giving you 50 ma (0.4 pounds of metal per year).

Predicting Active Corrosion Cell using Current Measurements

- So, the lower the ground resistivity, the higher the ground current if galvanic corrosion occurs.

Predicting Active Corrosion Cell Using D*irect Current Measurements*

- 1 amp-yr = 20 # steel
- 27 mA = .027 amps
- 0.027 amp x 20 # steel = 0.54 pounds of steel of steel loss in 1 year

Anchor Rod Inspection Methods

- Limited Excavation
- Total Excavation
- Cylindrical Guided Wave-Ultra Sound
  – I would only recommend this method if the top of the anchor rod was available for direct coupled excitation as with the ERI anchor rod

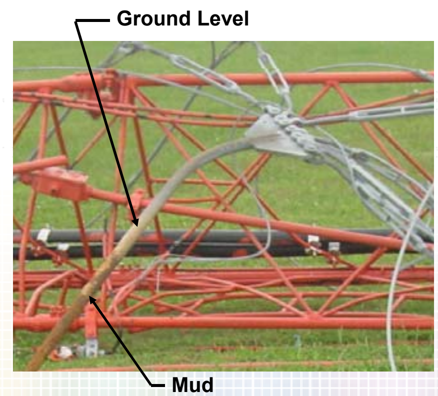
Limited Excavation

- Requires digging by hand around anchor shaft to depths of 12" to 30"
- Assumes "If corrosion is found, the anchor will need to be dug up"
- Also, "No corrosion detected. Investigation completed"

Limited Excavation

Not indicative of Rod condition

Limited Excavation



Limited Excavation – Hydro Excavation

Limited Excavation – Hydro Excavation

Advantages

1. Non-destructive
2. Evacuates hole soil
3. Cleans anchor rod

Disadvantages

1. Only visual inspection
2. Difficult to measure amount of material loss

Total Excavation

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Total Excavation

- Expensive
- Potentially Destructive
- Dangerous
- Difficult to repeat

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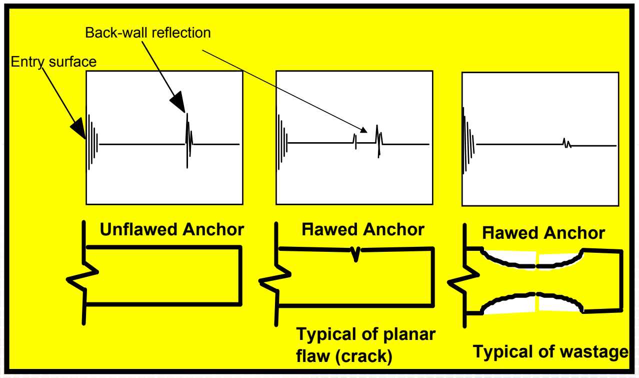
Digging Is Not Always an Option

Ultrasound: Longitudinal Wave

Ultrasound: Longitudinal Wave



Ultrasound: Limited Surface Area; Small Transducer limits testing ability I do not recommend this excitation method

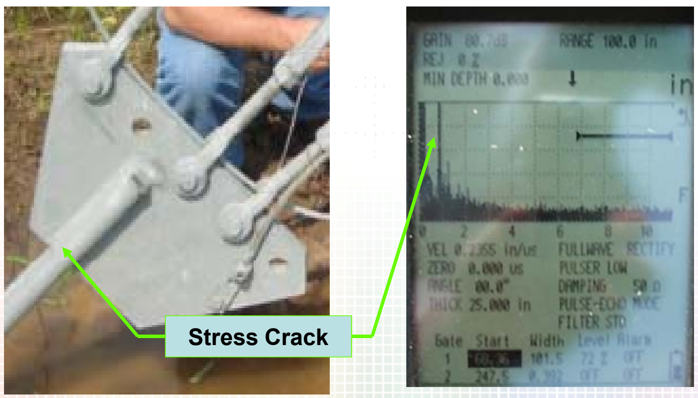
Ultrasound: Shear Wave or "Guided Wave"
I don't recommend using this excitation method

Ultrasound: Limited Surface Area; Small Transducer limits testing ability

- I do not recommend using small transducer or side launching transducer for measuring the condition of guy anchors.
- The results are questionable

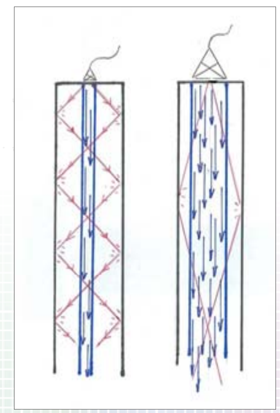
Field Application of Longitudinal Wave Displaying *Stress Cracks* in Anchor Shaft

May be better found with magnetic particle test



Beam Spread

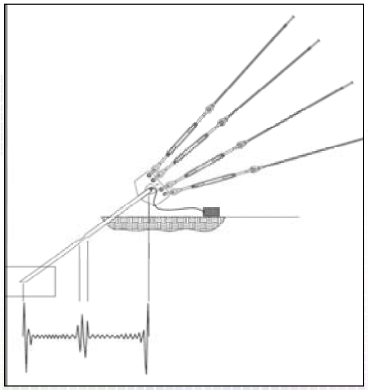
Transducer Diameter	Beam Spread
3/8 inch	48 degrees
1/2 inch	34 degrees
¾ inch	22 degrees
1 inch	16 degrees



Limitations of Ultra Sound Technology

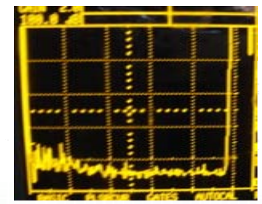
- Diameter of anchor rod: Small diameter creates increased resistance
- Length of anchor rod: Longer rod creates increased resistance
- Condition of the end of the rod
- Altering Anchor Rod requires Structural Analysis

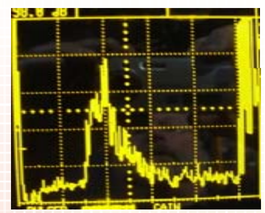
ULTRA™ Guy Anchor Rod from ERI was designed for use with ultra sound

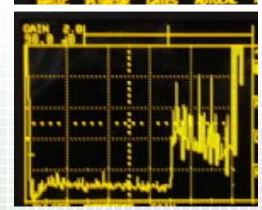


20’ x 2-1/2” dia Rod,
25% x-section area removed.
Test area, 12” in length, 6.5’ from one end.

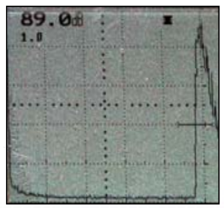
ULTRA™ Test Results

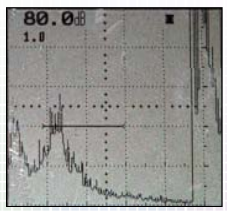




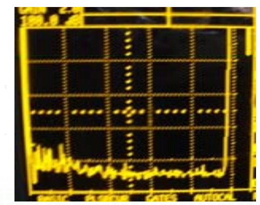


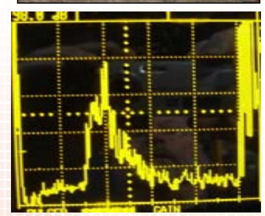
Ultra Sound Field Results

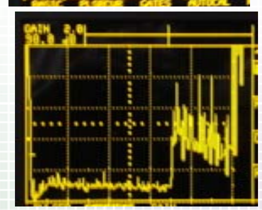




ERI ULTRA Anchor, Ultra Sound may be the most promising Method of Inspection and Detection of Anchor Deterioration







ERI ULTRA Anchor, Ultra Sound may be the most promising Method of Inspection and Detection of Anchor Deterioration

- If you use this unique rod, you will need to make an initial measurement of the rod with Ultra Sound to make sure that you establish a bench mark for future measurements.

Preventing Corrosion

- By disrupting the electrical circuit we are able to reduce the corrosion rate.
  - Concrete Encasement
  - Coatings
  - Impressed Counter Current
    - I've never seen this in the US Tower Market
  - Sacrificial anode
  - Galvanized anchor

Concrete Encasement: Best anchor available

Considerations:

- Expense
- Corrosion may still occur under the concrete but this is unlikely
- Cracks can occur if not properly grounded

Coatings

Anchor Shaft with Plastic Tape

Anchor shaft with tar adhesive

Coatings

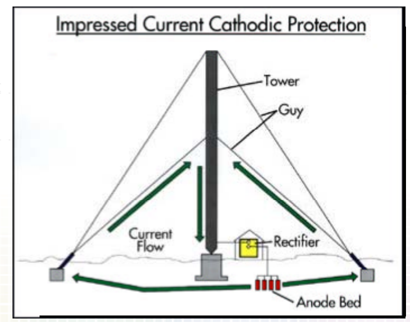
CHALLENGES:

- Difficult to apply in the field but can be applied at the factory
- If damaged, accelerated corrosion can occur

Impressed Counter Currents

Associated Problems

- Expensive
- Difficult to Maintain
- Over protections can lead to corrosion
- May lead to increased corrosion rate in non protected structures



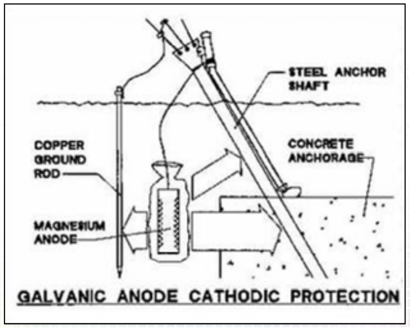
Impressed Counter Currents

- In my 42 years at ERI, I have never seen a tower in the United States of America with an electrical circuit providing impressed counter currents

Sacrificial Anodes

Challenges:

- Maintenance
- May Increase Grounding System Resistance
  - Multiple anchor rods can be used to reduce grounding system resistance



Galvanized Ground Rod

- Since the galvanized anchor will be at the same potential on the galvanic chart, no current will flow between the anchor and the ground rod.

Increased Electrical Resistance Resulting From Galvanic Corrosion Action

SUMMARY

- Understand the Corrosion Mechanism
- Recognize Possible Sources of the detrimental Electrical Current
- Galvanized Zinc alone may not be sufficient protection

SUMMARY CONTINUED

- *Evaluate Corrosion Risk*: Note soil characteristics, make visual inspection, if necessary, measure current flow
- Interrupting the galvanic cell will reduce likelihood of corrosion
- Reversing the polarity of the galvanic cell will prevent corrosion

Questions?

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