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CATHODIC PROTECTION OF POWER LINE STRUCTURE FOUNDATIONS

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ABSTRACT

This paper presents actual case histories of sacrificial anode cathodic protection installations on a variety of power system pole and tower foundation types. The case histories show strong points and weaknesses of various grounding system and cathodic protection system designs and present some operating system histories. Grounding system design, foundation design and cathodic protection system design recommendations are made for future power line construction projects.

INTRODUCTION

Early power lines were constructed with solid copper conductors supported by glass insulators from single wooden poles. Indeed, some very early low voltage powerlines were actually suspended from live trees. When AC systems began to show their technical and commercial superiority over low voltage DC systems in the early 1890's, [1] transmission line voltages began to increase. Over the years, utility companies have constructed larger and larger central generating stations because economy of scale reduced capital and operating costs per megawatt of system capacity. Larger central stations located further from the ultimate load led to the requirement for higher and higher transmission line voltages as it became necessary to reduce transmission line power losses to an acceptable level.

Increased line voltages require longer insulators to provide an acceptable breakdown impulse level (BIL) for transient voltages. As insulators became longer, the physical limitations of glass and ceramic insulator materials required that they be suspended from the structure crossarm rather than to support the conductor above the arm on post type insulators. The increasing line voltages also required greater conductor to conductor separation and greater conductor to ground separation. Increasing conductor size increases the physical load placed on the structure through the insulator string. All of these requirements led to the need for more massive support structures for the power line circuits.

Taller and more massive structure requirements led the industry to consider metallic support structures or towers as they have been come to be known. If one wishes to embed an iron or steel structure in the earth and have it last for the system's design life, usually in excess of fifty years, corrosion control measures must be considered. Quite frequently, the only corrosion control that has been provided for directly embedded structures is a galvanized coating on the steel. Galvanizing is a coating formed on the surface of the steel by dipping the structure members in a molten bath of zinc, producing a protective coating several mils thick. Since the zinc film, and inter-metallic compounds at the zinc-steel interface are anodic to the underlying steel substrate, they will sacrifice themselves in an electrochemical cell in order to provide a measure of protection to the steel. However, there is a very limited amount of zinc available, per unit area, as a sacrificial anode. Galvanized coatings of adequate thickness perform quite well against atmospheric corrosion for extended periods of time. For underground applications, galvanizing usually does not perform as well. In all but the most benign soil environments, corrosion rates for either zinc or iron will, usually, be greater below ground than above ground. Copper grounding electrodes and conductors, usually employed by the electric power industry, will significantly increase the corrosion rate on the underground portion of the steel structure.[2, 3] This is so because copper is cathodic to all other engineering materials and because it draws approximately twenty times as much current per unit area than steel does to become polarized. Thus it can be seen that copper is a very poor neighbor in the soil environment and will cause accelerated corrosion on other underground metals that are electrically in common with it.

If one wishes to achieve a reliable structure life of fifty years or more, additional corrosion control measures must be considered. Properly designed concrete encasement of all steel below grade is one useful technique. It does have some limitations. Cathodic protection is another viable alternative and will be discussed in detail in this paper.

CATHODIC PROTECTION

Cathodic protection is an electrochemical technique for mitigating or arresting corrosion in a continuous electrolyte such as soils or natural waters. Sacrificial anodes, usually of high purity zinc or magnesium alloy, in a specially prepared backfill are buried in the earth close to the structure and the lead wire supplied with the anode is connected to the structure with a mechanical or a welded connection. The number and size of anodes to be installed per structure are determined by the corrosion engineer based upon the surface area and condition, metals involved, grounding, soil resistivity and desired service life for the anodes. Where large amounts of cathodic protection current are required, impressed current systems employing rectifiers and inert material groundbeds may be employed. This is frequently the case in power plants where a massive copper grounding grid may exist.

With adequate monitoring and maintenance, cathodic protection can be maintained almost indefinitely and a useful structure life of 100 years is not unreasonable. Since one is not dealing with a pressure vessel such as a cross country, high pressure pipeline, minor pitting corrosion may be tolerated on powerline tower foundations. Therefore, annual cathodic protection surveys may not be necessary. It is essential that an installed cathodic protection system be periodically retested so that depleted anodes may be replaced before any significant corrosion takes place on the structure foundation. An initial acceptance survey, which includes every leg of every structure, should be performed within one to six months of completion of the circuit. Complete retesting at three to five year intervals is generally satisfactory, provided that the owner has set up a firm written policy and procedure to assure testing at those intervals. If the test interval is allowed to slip for too long a period, what is perceived as a protected structure may actually be freely corroding.

Iron and steel grounding electrodes have been used successfully without supplemental cathodic protection for more than 65 years in Germany and Russia.4 If one were to eliminate copper grounding from metallic tower foundations, the corrosion rate on steel foundation members in direct contact with the soil would be reduced and cathodic protection could be achieved at much lower current output from the cathodic protection anodes.[2] This equates into less money for a smaller anode or into increased service life from the same size anode. Iron, steel or galvanized iron grounding electrodes and conductors are compatible with the cathodic protection system since they draw so little current, compared to copper. The grounding system will be protected from corrosion along with the structure foundation.

Actual case histories on several operating power systems are presented to illustrate the successes and failures of sacrificial anode cathodic protection systems on powerline structure foundations.

CASE HISTORIES

Dallas Power & Light 138KV and 69 KV Circuits

Dallas Power & Light Company (DP&L) has an extensive network of 138KV and 69KV transmission lines throughout their service area. All circuits utilize galvanized steel shield wires which bond all structures in common. Most older circuits are galvanized steel latticework towers with either grillage foundations or poured pier foundations. See Figure Number 1. More recent construction has been a single steel galvanized pole with a poured pier foundation. Until recent times, the top elevation of the poured pier was not specified or monitored closely during construction. Local grade changes due to urban construction has placed soil above the top of the concrete pier at other locations. Many of the piers are now below grade with the bottom of the galvanized steel structure directly embedded in the earth. This causes a rather severe corrosion concentration cell with the exposed steel anodic to the steel in the concrete foundation and to the copper ground plate in the soil. Most of the service area is in low to very low resistivity soil types that are quite corrosive in nature. Some single pole structures were coal tar epoxy coated and directly embedded. They were provided with cathodic protection via a prepackaged magnesium anode, but were also grounded with copper ground rods and bare copper conductors.

DP&L retained an outside corrosion engineer to perform a cursory inspection and survey of the various structure types and to perform on-the-job training for DP&L engineering personnel.[5] An eight hour corrosion control training seminar was also held for engineering, inspection, construction and supervisory personnel.

System corrosion control recommendations included:

1. Concrete encapsulate poured pier foundations for a minimum of nine inches (23 cm) above grade with a sloped crown on new construction.

2. On existing poured piers completed below grade, roughen the top surface, apply a bonding agent, form up and pour concrete a minimum of nine inches (23 cm) above grade. This fix becomes essentially zero maintenance in future years.

3. Where this is not practical, install a zinc anode. See Figure 1.

4. Eliminate copper grounding wherever galvanized steel is installed below grade.

5. Provide a "johnny ball" insulator in guy wires close to the pole attach point for galvanized steel guy anchors or install a 2 inch (5 cm) x 2 inch (5 cm) x 60 inch (1.5 m) zinc anode at the anchor.

6. Using DP&L inspectors, survey and tabulate the status of all steel structure foundations and begin corrective measures as time is available.

7. Install zinc anodes on direct embedded steel foundations per Figure Numbers 2 through 4.

Texas 345KV Circuits

A Texas company (TEX) completed approximately 187 miles of a single 345KV circuit in 1982 - 83. Supporting structures are dual CorrTen poles with direct embedded, coal tar epoxy coated butts. Heavy angle structures are triple poles, some with poured pier foundations. Each outside pole is grounded with a 3/4 inch (1.9 cm) x 10 foot (3.1 m) copper clad groundrod connected with 10 feet (3.1 m) of 7 stranded No. 8 Copperweld conductor to a split bolt post on a grounding pad above grade. A 17 pound (7.7 kg) high-potential magnesium anode was installed at each groundrod, regardless of the soil conditions or resistivity. Both shield wires are grounded to each structure at the tower attach points. See Figure Number 5.

Surveys conducted by TEX within two to three years of completion showed that most structures were not adequately protected. An independent corrosion engineer was contacted in early 1986 to recommend changes to the cathodic protection system design for a proposed additional 35 mile circuit to be constructed in 1986. Based upon a review of existing and proposed construction records, the following recommendations were made.[6]

1. Insulate shield wire with fiberglass strain insulator from power plants and substations.

2. Substitute 3/4 inch (1.9 cm) x 10 foot (3.1 m) galvanized steel ground rods and 3/8 inch (0.95 cm) galvanized steel cable for the copper clad materials. Provide two groundrods per structure per the previous construction standards.

3. Do not provide supplemental grounding for structures with poured pier foundations. Instead, use anchor rods in the piers for grounding electrodes.

4. Install only one 1.4 inch (3.6 cm) x 1.4 inch (3.6 cm) x 60 inch (1.5 m) hi-pure prepackaged zinc anode for each structure.

5. Anodes are to be furnished with a No. 6 AWG (13.3 sq. mm) stranded copper conductor connected to the anode core with a compression connector followed by silver soldering. This is necessary to handle fault currents. See Figure Number 6.

The corrosion engineer and TEX personnel conducted a cursory survey of the various circuits in mid 1987 with the following results.[7]

<u>For the older copper grounded circuits:</u>

1. Structures in high resistivity soils are protected with an average anode current output of 7.0 milliamperes.

2. Structures in moderate resistivity soils are protected with an average anode current output of 47.7 milliamperes.

3. Many of the anodes in low to moderate resistivity soils are nearing the end of their useful life. Estimated initial anode current outputs probably were in the range of 200. to 300. milliamperes.

4. Anodes in the lower resistivity soils are depleted and the structures are no longer protected. Estimated initial anode current outputs probably were in the range of 300. to 500. milliamperes.

5. The excessively high current outputs from the high potential magnesium anodes have plated out calcareous coatings on the copper grounding system. This will tend to increase the grounding system resistance to remote earth but will definitely reduce the current requirement demand of the copper from future anodes.

<u>For the new galvanized steel grounded Circuits:</u>

1. The entire circuit is constructed in an area of low resistivity soils.

2. All structures are polarized to essentially the open circuit potential of the anodes.

3. Average anode current output is 7.0 milliamperes.

Recommendations were made concerning replacement anodes of zinc, standard H-1 alloy magnesium or high-potential magnesium depending upon in-situ soil resistivity. Recommendations were also made to replace copper grounding with zinc grounding in certain moderate resistivity soils so that longer lived zinc anodes could be employed. The practical service life limit for magnesium anodes in 15 to 20 years, whereas zinc anodes may be designed for 30 to 40 year lives or even longer. This cuts down on replacement labor and equipment costs. See Figure Number 7. Finally, resurveys at five year intervals were recommended.

Arkansas Power & Light Company 345KV Circuit

Arkansas Power and Light Company's (AP&L) El Dorado to Louisiana State Line 345KV Transmission Line was constructed in 1968-69. It is a single circuit supported by guyed aluminum lattice towers (see Figure Number 8) and self supporting steel towers. Guyed towers have center points of screwed, galvanized steel anchors or poured concrete foundations with rebar cages isolated from the center point pin. Both shield wires are grounded at the tower attach points. Cathodic protection was provided when the structures were installed. Thirty pound (13.6 kg) zinc anodes were installed in the lower resistivity soils and 20 pound (9.1 kg) high potential anodes were installed elsewhere.

AP&L retained an independent corrosion engineer to conduct a survey of the circuit in early 1986.[8] Eighty five percent of the structures surveyed were still adequately protected. Most of the depleted anodes appeared to be magnesium. Recommendations were made for an anode replacement program. A 100 percent survey of the circuit and all structure legs or guys is to be performed to determine anode replacement needs. Choice of zinc or magnesium anodes is to be field determined by a soil resistivity test to be performed in each anode borehole. The anode replacement program is to be followed up by retesting at five year intervals.

AP&L 500KV Circuits, McNeal Area

The El Dorado to McNeil 500KV Transmission Line was constructed in 1984-85 and was completed in the spring of 1985. The Hot Springs to McNeil 500KV Transmission line was constructed in 1984-85 with completion in August 1985. See Figure Number 9. The galvanized steel guyed towers have center points of galvanized steel helix anchors or poured pier concrete columns with isolated rebar cages. Grounding is via 3/4 inch (1.9 cm) x eight foot (2.4 m) or 10 foot (3.1 m) copper clad groundrods and Number 4 AWG (21.15 sq. mm.) copper wire. Additional wire, as a counterpoise, and/or additional rods were installed to achieve a maximum resistance to remote earth of ten ohms, without considering the contribution of the structure itself. At least one ground rod was installed at each center point or at one self supporting tower leg. Several self supporting angle towers have extensive driven pipe piling foundations.

An independant corrosion engineer, working with AP&L inspectors performed a survey the circuits with the following results.[9, 10] Soil resistivities along the rcuits ranged from low to very high. Structure-to-soil potential and structure-ground current flow measurements showed that a considerable amount of zinc was being stripped from the galvanized surfaces by the couple to copper grounding. Many structures no longer exhibited potentials in the range that one would expect of newly embedded galvanized steel surfaces.

The following recommendations were made:

1. Install cathodic protection as soon as practicable in order to preserve as much galvanizing as possible.

2. Remove all copper grounding wherever the structure to remote earth resistance is less than ten ohms without the supplemental grounding.

3. Test each anode installation location with a single probe soil resistivity tester to determine whether to install zinc or magnesium anodes.

4. Install a minimum of two anodes per the layout shown in Figure Number 10 and test for the necessity of installing additional anodes.

5. Anodes are to be installed in accordance with Figure Number 11.

6. Install anodes on pipe piling with the type, size and number to be determined by soil resistivity and the total pipe exterior surface area.

7. Perform a 100 percent resurvey at five year intervals.

AP&L Dell to Mississippi River 500KV Circuit

Original plans for the Dell to Mississippi River 500KV Transmission Line were to construct the circuit to the same standards as the previously cited case history, except for the use of all self supporting structures. Right-of-way clearing was just beginning when AP&L called in the consulting corrosion engineer to evaluate the right-of-way and to make recommendations for electrical grounding and cathodic protection.11

Soil resistivities along the circuit ranged from low to very low. The following recommendations were made:

1. Poured pier foundations with the rebar cage separated from the soil by at least 4 inches (10.2 cm) of concrete requires no further protection.

2. Bond the rebar in common with grounding conductor, contained within the concrete to serve as the grounding electrode.

3. Install cathodic protection for all helical screw anchors or driven piling.

4. Install pipe piling instead of "H" piling

5. Provide supplemental galvanized steel grounding only when the structure foundation cannot meet 10 ohms or less by itself. Supplemental grounding should not be required in low resistivity soils.

6. Install prepackaged zinc anodes on helical screw anchors and pipe piling with the size and number determined by the total exposed galvanized steel surface area.

7. Anodes are to be installed in accordance with established construction drawings.

8. Perform a 100 percent resurvey at five year intervals.

Recommendations were also made for coating the driven pipe pilings in order to cut down on the number of anodes required to acheive the selected design life for the anodes.

CONCLUSIONS

Steel powerline support structures (towers), if left to their own devices may be expected to freely corrode where in direct contact with the soil and to eventually fail. The presence of copper grounding systems will tend to accelerate this process.

Cathodic protection is an electrochemical technique for mitigating or arresting corrosion in a continuous electrolyte such as soil or water. With adequate maintenance, cathodic protection can be maintained almost indefinitely. Elimination of copper grounding systems reduces corrosion on unprotected structures and increases the useful life of the cathodic protection anodes.

Several actual case histories are presented to show the effectiveness of cathodic protection systems for power line towers and the extent of maintenance required to assure system effectiveness.

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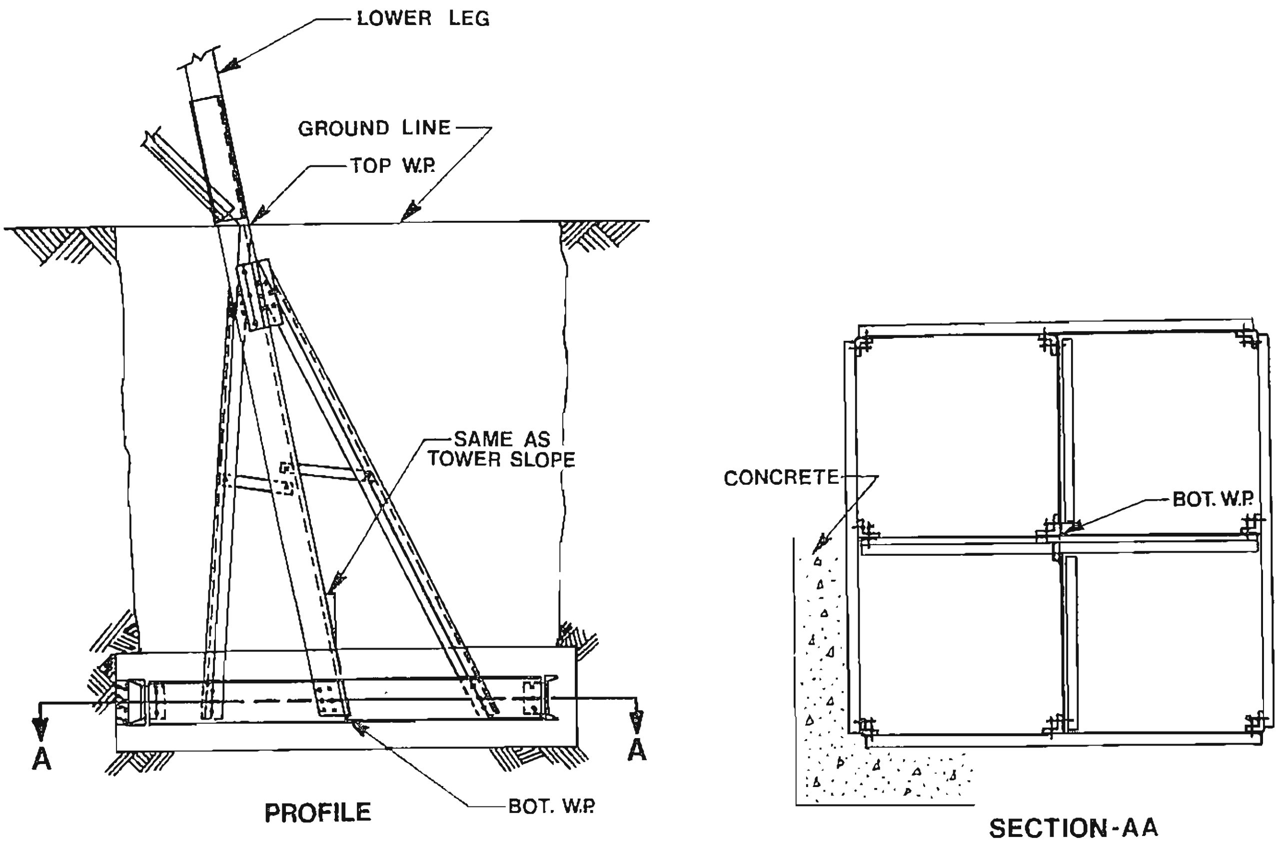


FIGURE 1

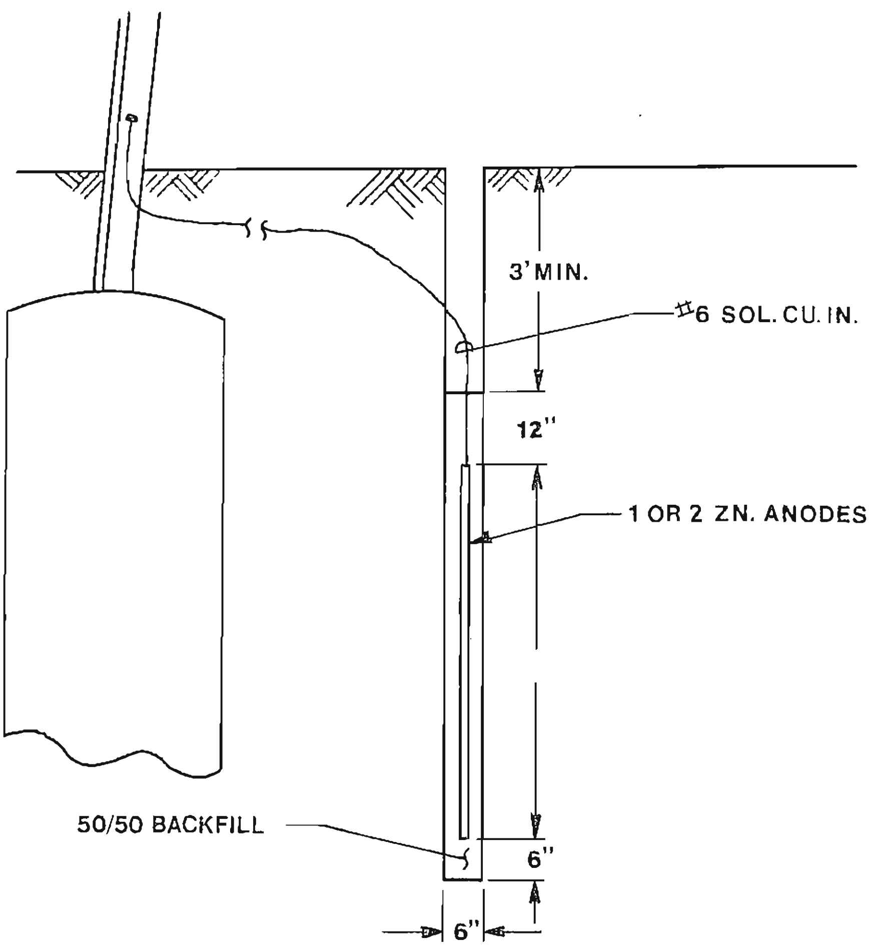
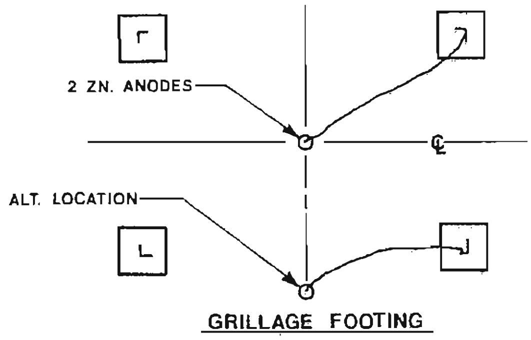


FIGURE 2 - Zinc Anode Installation



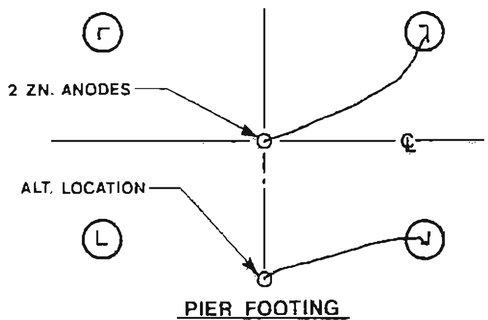


FIGURE 3 - Anode Installation Layout

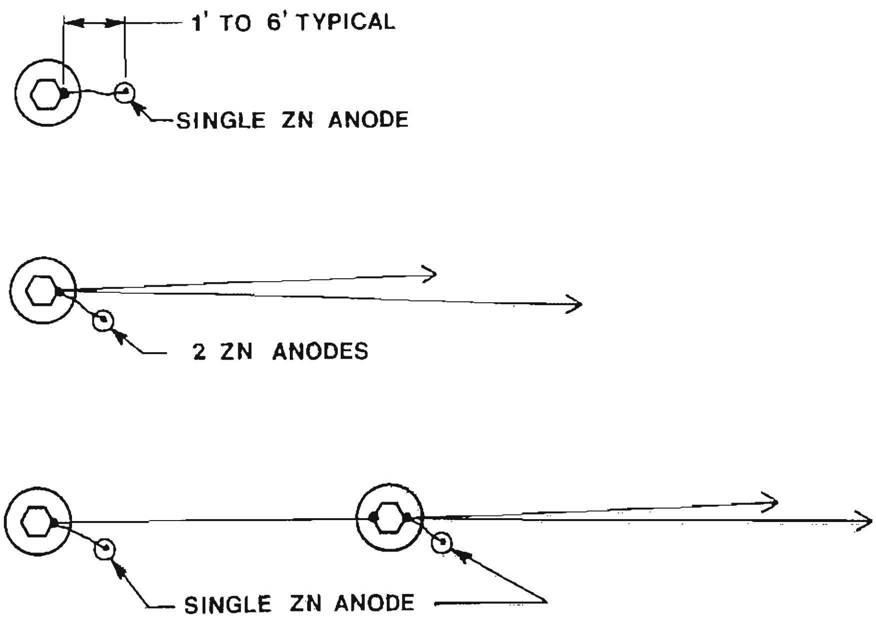


FIGURE 4 - Steel Poles & Anchors

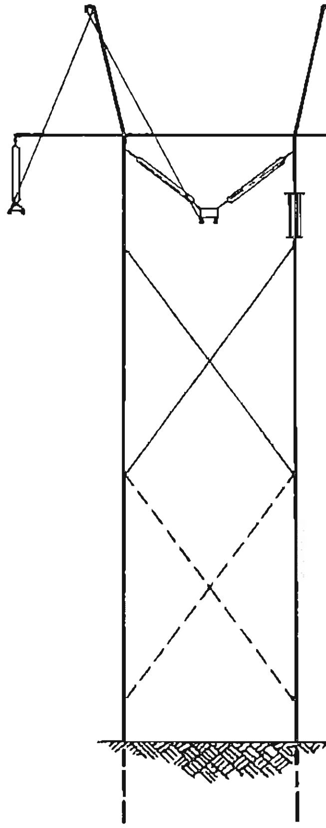
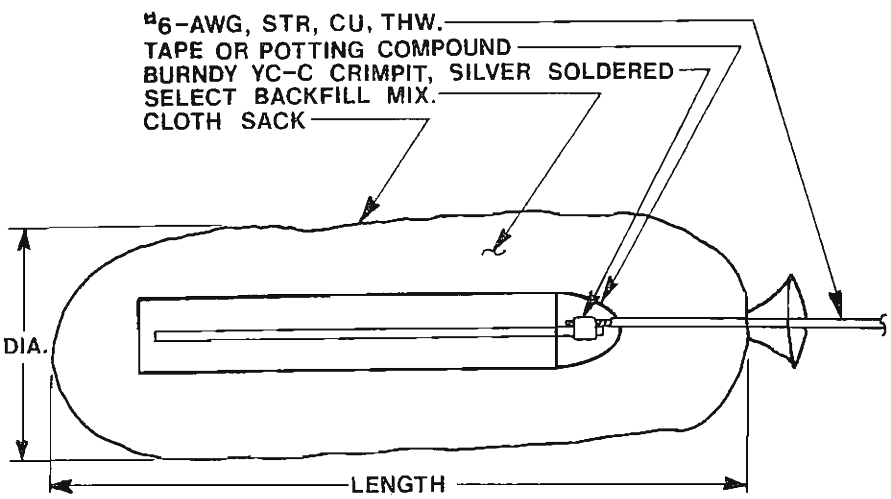


FIGURE 5 - 345 KV Structure



NOMINAL ANODE SIZE (POUNDS)	COMPLETE PACKAGE WEIGHT (POUNDS)	PACKAGE DIAMETER (INCHES)	PACKAGE LENGTH (INCHES)	LEAD WIRE LENGTH (FEET)
17D3 GALVOMAG	42	6	28	20
1.4"x 1.4"x 60" ZINC	90	6	66	18
2"x 2"x 2" ZINC	120	6	66	15

FIGURE 6 - Sacrificial Anode Detail

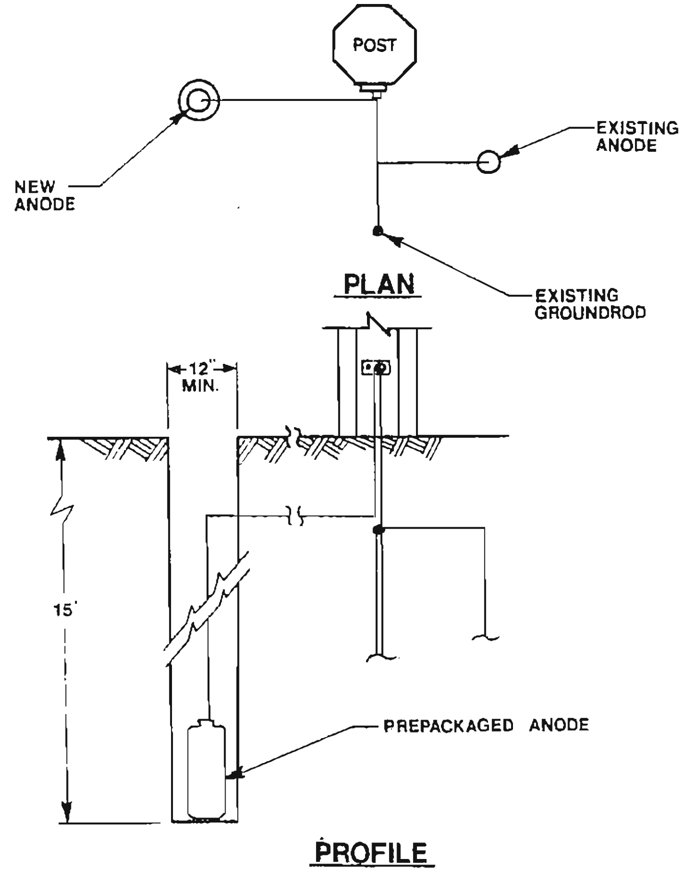


FIGURE 7 - Replacement Anode Installation

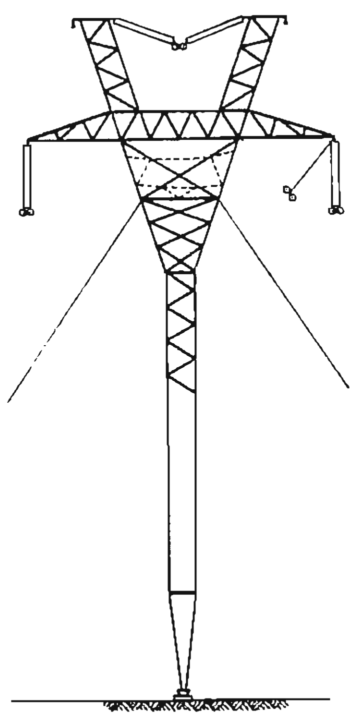


FIGURE 8 - 345 KV Guyed Tower

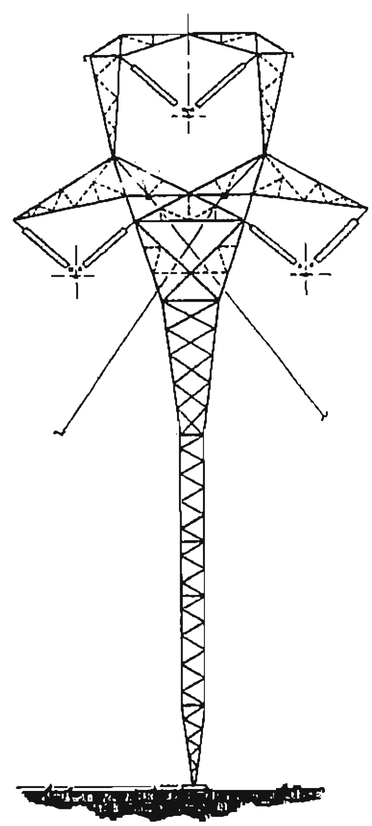


FIGURE 9 - 500 KV Guyed Tower