INTRODUCTION

Poles for overhead contact systems (OCS) are composed of various types of materials including steel, wood, fiberglass or concrete, and are available in different shapes including round, square, multi-sided or rectangular tubes, wide flange sections, solid circular or lattice style. There are two basic types of foundations; embedded or anchor base. For an embedded pole foundation, the pole is either inserted into a foundation hole with concrete poured around the pole, or inserted directly into the earth if of wood, concrete or fiberglass material. Anchor base foundations utilize anchor bolts to transfer loads from the pole to the supporting foundation. The anchor bolts protrude from the top of the foundation and mate with a base plate that is welded to the bottom of a steel pole.

This paper discusses the merits and drawbacks of each type and style of pole, the various foundations available for supporting them, and the cost differences between them as they relate to the transit industry. It also presents maintenance and safety concerns with the different styles of poles and foundations, formulas used to calculate strength and deflection of the pole, foundation diameter and depths, and it further presents an historical account of the origins of the poles and foundations discussed herein.

Also discussed are creative solutions to overcoming obstacles both underground and overhead with the placement of poles and methods used to strengthen and/or repair poles that are in place.

Background

The first poles used to support electrical overhead wires were wood and were used for a telegraph line running between Washington D.C. and Baltimore, Maryland that was constructed in 1844. This was the first successful telegraph operation as the electrical conductors were suspended above the ground and attached to the pole by glass insulators. The line was constructed by Samuel Morse with a grant of $30,000 from the United States Congress. The contract called for furnishing 700 straight and sound chestnut posts with the bark in place and having the dimensions of eight inches in diameter at the butt and tapering to five or six inches at the top. Out of the 700 poles, 680 were 24 feet and 20 were 30 feet long.

Wood poles are essentially the stem of trees with bark and branches removed and the stem shaped. Various species of trees are used for wood poles such as Chestnut, Southern Yellow Pine, Douglas Fir, Jack Pine, Lodgepole Pine, Western Red Cedar and Pacific Silver Fir with various treatment methods to prevent decay. Typical treatment methods are creosote, pentachlorophenol, copper naphthenate, and borates. Wood poles continue to be used for supporting overhead contact lines on railways and transit systems.

Granite poles were used in Switzerland for supporting telegraph wires quite successfully and the stone construction was used due to a shortfall of timber (Fig.1). They were impervious to the problems associated with wood and steel.
Iron poles were used since the infancy of street railways and one such installation was by the Thomson-Houston Electric Company of Lynn, Massachusetts (which later became the General Electric Company). They supplied iron poles to the West End Street Railway of Boston, Massachusetts, for their first trolley line electrification in 1888. A standard for iron pole types was proposed by “American experts” in the street railway industry as stated in the Engineering Journal, Volume 59, of March 29, 1895 where five classes of iron or steel poles were proposed for use in connection with well-constructed trolley lines. Each class of pole was to be 31 feet long and set in the ground to a depth of 6 feet. Loadings were as shown in Table 1.

Further, the specification stated that the poles must be able to withstand a drop test butt foremost from a distance of 6 feet onto a solid substance three times and show no signs of telescoping or loosening of the joints. The joints were made by swaging and Figure 3 shows a detail of the telescopic joint.

<table>
<thead>
<tr>
<th>Standard for Iron/Steel Poles</th>
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<tbody>
<tr>
<td>Pole Type</td>
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<tr>
<td>-----------</td>
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<tr>
<td>No. 1</td>
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<td>No. 2</td>
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<td>No. 4</td>
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<td>No. 5</td>
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</table>

Table 1

Another type of early pole was the “Tripartite Steel Pole” which was composed of three steel U bars rolled in one piece and arranged at angles of 120° around the axis of the pole. The three members were bound together by malleable iron clamps designated as collars and spreaders and tapered to a 1:100 slope approximately (Fig. 2).

A further version utilized angles bent to 60° rather than a U shaped plate. Tripartite poles were used not only for street railway lines but also for electric railroads and transmission and distribution lines throughout the United States. The most interesting feature of these poles is that the ultimate steel strength was from 90-100,000 psi and the yield strength was 50-60,000 psi.

A notable early steel pole was the “Diamond Steel Pole” which consisted of two bent plates held together in a square shape by angles. The bent plates are tapered to any desired taper so the pole is essentially a square tapered steel pole (Fig. 4).
The use of iron poles is referenced in the Street Railway Journal, Volume 13, No. 10, 1897, where the Niagara Falls & Suspension Bridge Railway used lattice poles and then channel poles consisting of a center web tapering to the top and two outside flanges on each side riveted to the web. A similar pole was used on the Manhattan Bridge in New York City in 1917 which consisted of steel plates riveted together to form a tapered pole.

A pole known as the Bates Expanded Pole was developed and utilized for railway suspension. It was made by taking specially rolled I beams that were passed under a rotary shear 30 ft in diameter which cut the web of the beam and provided for expansion of it. The beams were then charged into a furnace and taken to an expanding machine which gripped the two flanges and pulled them apart forming a truss from the sheared parts of the web. The beam became a pole and final manufacturing processes such as cooling, straightening and painting were undertaken.

Concrete poles were considered an alternative to wood to increase life span and reduce maintenance. One of the first installations was done on the Panama Railway in Central America in 1856 as an alternative to wood. In the jungle environment, wood soon decayed from moisture and insect infestation so it was thought that concrete would be a viable alternative. The concrete poles were 12 feet long with 6 or 8 inch tops and 15 inches square at the base. Wires were carried on iron brackets fastened to the poles with iron bands. The poles failed due to their inability to withstand lateral stresses and were replaced by concrete poles with square wooden centers which also failed due to the wood swelling and cracking the concrete [1]. Some of these poles, however, lasted in service for almost 30 years.

Various experiments for constructing reinforced concrete poles were made in Europe, and the first known experiment was made in 1896 by a French engineer, M. Henebique. The reinforcing consisted of round rods and twisted wires and the poles were installed on the Le Mans Tramway Company in France. Another test of the same system was made in 1900 at Bologne, Italy by M. Porcheddu [2].

Concrete telegraph poles were installed for a line that was several miles long in the vicinity of Maples, Indiana, USA and were made by a Mr. H.W. Tapp. They were from 25 to 35 feet long and 9 inches square at the base for a distance of 17 feet, and then tapered to 6 inches at the top. The poles had climbing niches for the spurs of linemen’s boots and holes near the top to receive iron rods which held the crossarms.

Mr. C.A. Alderman of the Cincinnati Northern Traction Company stated that they were using a concrete trolley pole (Fig. 5) and that he expected to see it in wide use [2].

An unusual pole developed in 1924 by James Cyril Stobie of Australia found a means to overcome problems of limited timber supplies and termite infestation of wood poles. The pole was made of two steel beams filled with concrete. This design eliminated the need to import timber, and prevented termite attack. The first pole was erected on South Terrace in Adelaide, Australia. The poles have been in wide use ever since first inception for both electric utility work and transit OCS support (Fig. 6).
A most notable concrete pole was used along Van Ness Avenue in San Francisco, California where the poles supported street lights and overhead trolley span wires since installation in 1914. This was constructed of cast reinforced concrete, a cast iron ornamental cap, cast iron removable base and made with a decidedly ornamental flair that is classic. The poles were part of the H streetcar line constructed to link neighborhoods with the Panama-Pacific International Exposition at Harbor View (now Marina District) [3]. These poles will soon be retired from use with the rebuilding of Van Ness Avenue starting in 2016 (Fig. 7).

It was reported in Railway Engineering and Maintenance of Way, June 1911 that a high-tension transmission line between Livet and Grenoble, in France installed poles of thoroughly dried round wood and covered with a stiff concrete paste so that the wood pole was the core. 3/16” diameter round rods were wound in a spiral with longitudinally round rods tied to them. The diameter of the longitudinal rods varied from 1/16” to 1/8” depending upon the length and strength desired.

In 1927, Henry Ford electrified part of the Detroit Toledo & Ironton railroad from River Rouge to Carleton, Michigan and constructed reinforced concrete catenary supporting structures. These were extremely sturdy structures as they were spaced 300 feet apart. Many are still standing today and were so rugged that it took demolition crews two days to demolish each structure. Each structure contained 95 cubic yards of concrete and 257 feet of rebar (Fig. 8).

POLE TYPES FOR TRANSIT WORK

The most common types of poles are presented herein for discussion. Tubular tapered steel poles are the most widely used today for transit work. Wide flange poles are the next most widely used with straight tube, sectional, and wood following. Prior to the light rail renaissance, embedded poles were the norm but the majority in use presently is the anchor base type. Some transit systems continue the use of direct embedment as a less expensive and more maintainable type of pole installation.

Wood Poles

Wood pole standards of construction and strength are shown in ANSI Standard O5.1-2008 where the permitted stress level of various species must be determined by multiplying the designated fiber strength by the factors shown on Table 261-1 of the NESC. Wood poles are classified by their length, top circumference and bottom circumference measured 6 feet from the butt end. Lengths vary in 5 foot increments such as 25, 30, 35, 40, etc., to 110 feet and circumferences in 2 inch increments such as 15, 17, 19, etc. Each class of pole has a minimum tip circumference. A Class 1 pole, for example, has a 27
inch minimum top circumference, but greater top circumferences are available.

Pole classification numbers have a requirement for the load the pole must be able to withstand 2 feet from the top and this is shown in Table 2. A pole’s height and class are typically abbreviated as “30-6” which is a 30 ft long-Class 6 pole. A convenient formula to determine the resisting moment is:

\[ \text{Resisting moment} = 0.000264 f c^3 \text{ lb} \cdot \text{ft} \]

Where \( f = \) ultimate fiber stress in bending (lbs/sq inch)
\( c = \) pole circumference 6 feet from the butt (inches)

<table>
<thead>
<tr>
<th>Pole Class ANSI O5.1</th>
<th>Horizontal Load in lbs</th>
<th>Pole Class ANSI O5.1</th>
<th>Horizontal Load in lbs</th>
</tr>
</thead>
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</tr>
<tr>
<td>H4</td>
<td>8,700</td>
<td>5</td>
<td>1,900</td>
</tr>
<tr>
<td>H3</td>
<td>7,500</td>
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<tr>
<td>H1</td>
<td>4,400</td>
<td>8</td>
<td>Not Used</td>
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<td>1</td>
<td>4,500</td>
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<tr>
<td>2</td>
<td>3,700</td>
<td>10</td>
<td>370</td>
</tr>
</tbody>
</table>

Table 2

As an example, a Class 1 southern yellow pine pole 30 feet long with a minimum top and bottom circumference of 27 inches and 37.5 inches respectively has a resisting moment of 104,650 lb-ft. [8]. Deflection of wood poles can be countered by raking them away from the line of pull. If the pole can be back guyed or head guyed, a pole of lesser strength can be used and the raking of it can be foregone but the compressive strength of the pole must withstand the forces imparted into it from the guy.

Wood poles are the least expensive type of pole to purchase and an installation using a Southern Yellow Pine Class 2 pole, 30 feet long costs approximately ~$370.00. A mechanized pole setting crew can install a pole in one hour. Table 6 provides a comparison of material pole costs. A 30-2 pole, set 6 feet in the ground with a span wire attachment height of 22 feet can safely withstand a side pull of 3,700 lbs. Rake of cantilevered wood poles for transit use should be 12 inches in 24 feet for span wires, and 6 inches in 24 feet for bracket arms according to the American Transit Association standard D14 Direct Suspension Overhead Construction.

Additional cost savings are possible with the use of wood poles if joint-use is permitted. In this scenario, utilities can own the pole and allow other utilities or transit authorities to attach to it or have rental or attachment rights agreements. Joint-use poles require close coordination between the pole owner and the tenants when maintenance is required. Typical wood poles with treatment can last up to 35 years.

Steel Poles

For the purpose of this paper, steel pole types shall include tubular straight, tubular sectional, tubular tapered, and wide flange beams. The strength of these poles is dependent upon their yield strength and cross sectional area. IEEE Standard for Supporting Structures for Overhead Contact Systems for Transit Systems outlines the construction and performance criteria for sectional and tapered tubular steel poles. ASTM standards define the type of steel and strength.

Tubular

Typically for transit work, tubular straight and sectional poles are made with pipe conforming to ASTM A500 Gr. C, where the yield strength of steel is a minimum of 50,000 psi. A recent ASTM standard for tube construction, A1085, has been issued and specifically states higher yield strengths. Some transit projects have used tubular poles made of Corten® steel to increase longevity from corrosion but the most common method for corrosion protection is hot dip galvanizing per ASTM A213 and A153.

Tapered tubular poles are manufactured with a process that forms the pole over a hardened steel mandrel which increases the yield strength to a minimum of 55,000 psi. Other formed tapered poles with multi sides also have similar yield strengths. Higher strength steel yields are possible with some tapered poles being made to a strength of 60,000 to 70,000 psi at yield.

They can also be formed using a brake press where the flat sheet of steel is bent to form a multi-sided tube. Steel strengths are similar and the quantity of sides determines their roundness.

A distinct advantage of round poles made of tubular steel, concrete, or wood is that the strength is the same in any direction due to the symmetry of the
shape. Bending stresses are distributed consistently regardless of the direction of the applied load. They also offer greatly increased resistance to torsion than other structural shapes due to the greater rigidity characteristic of the tubular design.

Existing tubular poles that are direct embedded into the earth can be reinforced for additional strength or resistance to deflection by inserting re-bar and concrete into its interior. Strengthening is more difficult with anchor base poles. The base plate typically has a hole in the center for condensation drainage that needs to be blocked while the concrete cures.

**Wide Flange**

Wide flange poles have been made to ASTM A36 standards but are now being specified to ASTM A572 or ASTM A992 standards where the yield strength is 50,000 psi. These typically have a higher strength to weight ratio than tubular poles and are therefore generally less expensive. Wide flange poles have two varying strength axes: the X-X direction and the Y-Y direction, each with a different section modulus and thus a different allowable bending moment and deflection. The X-X axis provides the greatest resistance to bending due to the increased moment of inertia of the flanges about the neutral axis. Having only one strong direction for pull can be restrictive.

Wide flange poles can be reinforced for strength with plates or angles welded or bolted to the flanges. This is done quite frequently in Europe and also with Amtrak as a way to minimize weight and cost while obtaining additional strength. If the loads increase on an existing pole, the pole can be retrofitted with plates or angles to strengthen it and avoid a potentially costly pole replacement.

**Concrete Poles**

Concrete poles have become common place in the electrical industry and used world-wide in transmission, distribution, and electric railways and transit. A standard was developed under the guidance of the ATA as standard D108 for cast reinforced concrete poles but was discontinued in 1941 due to the decreasing use of this pole type at that period in time. Current pole construction typically can use hollow reinforced spun cast poles or static cast, both of varying diameters and lengths. Spun cast poles have higher compressive strength than static cast because the concrete is consolidated during the process. Classification of spun concrete poles is shown in Table 3. Bulletin 1724E-206 of the United States Department of Agriculture, Rural Development Utilities Programs provides guidance for technical aspects of design, materials, manufacturing, inspection, testing, and delivery of concrete poles.

<table>
<thead>
<tr>
<th>Classification of Spun Concrete Poles</th>
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<tbody>
<tr>
<td>Pole Type</td>
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<tr>
<td>-----------</td>
</tr>
<tr>
<td>C-02.4</td>
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<tr>
<td>C-02.9</td>
</tr>
<tr>
<td>C-03.5</td>
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<tr>
<td>C-05.7</td>
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<td>C-06.5</td>
</tr>
</tbody>
</table>

Table 3

Some pole types use pre-stressed reinforcement with one type of pre-stressed concrete pole using galvanized steel strands to pre-stress the poles. They are cast with condensed silica foam (CSF), an additive which yields a dense concrete for reduced moisture absorption.

**Polymer Poles**

Fiber reinforced polymer poles are very light and can be transported by hand. These poles are not in common use for transit systems due to their extreme flexibility and bending under load. For utility use the Rural Utilities Service requires its electric cooperatives to submit requests for approval to use fiberglass poles.

**Laminated Wood Poles**

Laminated wood poles are occasionally used as cantilever poles when wood poles are not strong enough to withstand the loads. The utility would typically provide the loading to the pole manufacturer to design the pole. When installed, they are usually set deeper in the pole hole and backfilled with gravel rather than earth.

**POLE FOUNDATIONS**

Pole foundations are classified as direct embedment or anchor base. The setting of poles can be accomplished by either direct embedment or onto a new or previously installed foundation with anchor bolts where the pole has an anchor base plate attached. When set directly into the ground, wood poles are typically backfilled with the excavated earth while steel poles have the hole filled with concrete. Anchor base poles are mostly steel but can be concrete or wood set into a socket with a base plate.
The base plate is mounted onto anchor bolts but a foundation can be made with the socket cast-in-place and the pole set into it.

Prefabricated foundations can be used and they have a socket in a donut hole fashion for inserting the pole into it after the foundation has been installed. It can also be done with anchor bolts protruding for attachment of anchor base poles.

**Direct Embedment**

Wood and concrete poles are typically set directly into an excavated hole in the ground with the removed fill put back in and tamped to compact the fill. For extreme loadings or poor soil conditions, the pole should be keyed and heeled or concrete may be used as fill. A rule of thumb for the depth setting of wood poles is 10% of the pole length plus 2 feet. Tables 5 through 8 of ANSI O5.1 list the approximate groundline distance from the butt for different lengths of poles and is very close to the “10 and 2” rule. An alternative to the rule of thumb is the use of a nomograph design aid by AASHTO DTS that is based on the equivalent horizontal load, allowable soil bearing pressure, and width of the pole at embedment.

Steel poles should be set in concrete for maximum foundation strength. They have historically been set directly into the pole hole with concrete poured in without reinforcing rods. The direct contact with earth provides an excellent electrical earth ground. Both round and wide flange poles have been set in this manner. A concrete pad that the pole rests on has also been used. However, a separate grounding arrangement is required for this type of installation.

When the open area between the pole and the excavated hole wall becomes large, the addition of foundation reinforcing should be considered. Reinforcing rods inserted between the pole and the hole wall will ensure concrete stability and rigidity, and also prevent concrete cracking. The standard method is to use a circular cage of horizontal and longitudinal bars which sits between the pole and the excavated hole wall. Where a steel caisson of sufficient strength is employed, reinforcing rods may not be needed.

Another method of embedded pole foundation uses an interior pipe set into the hole to which concrete is poured between it and the hole wall in a donut fashion. The pole is set into the inner pipe and then concrete poured in and the pipe acts as reinforcement.

When poles are set in city streets with granite curb stone for the foundation to bear against, the foundation is more resistant to rotation as it has a substantial bearing surface to rest against, thereby requiring less depth or width for the foundation. When set with no curb or top bearing member, a key of substantial material such as granite curbing or a reinforced concrete slab can be installed to provide additional bearing surface if required.

**Anchor Base**

Anchor base foundations consist of anchor bolts embedded in a concrete foundation typically with reinforcing. The anchor bolts vary in diameter and depth according to the load that will be applied to them. For transit work, 4 anchor bolts are typically used although more can be used if warranted. The base plate for the pole is usually above grade and the anchor bolts exposed. Some agencies require a layer of grout between the top of foundation and the bottom of the base plate. Another method of pole mounting on the foundation is to have the top of the foundation below grade so that the pole anchor plate and part of the pole is set into the foundation and concrete is poured over it giving the appearance that the pole is embedded. Leveling nuts are often used to set a pole to the proper vertical alignment and rake.

Another type of anchor base foundation uses a structural steel member such as a wide flange shape or steel tube with a base plate welded to it inserted in the foundation hole. The plate has bolts attached to it and the pole with its base plate is mounted onto this. The foundation insert plate can be either below or above grade. This precludes the use of a reinforcing cage and inserted anchor bolts, and makes for a quicker and simpler installation of the foundation (Fig. 9).

Anchor bolts for transit work typically conform to ASTM A449 or F1554 for various grades and strengths. Anchor bolts can be either threaded at one end and bent 90° at the inserted end or threaded at both ends. It is better to have both ends threaded so a lower and upper template can be used to hold them consistently parallel for the pole base plate to be set onto them. The use of hooked anchor rods is permitted per AASHTO Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals. However, it cautions that threaded cast-in-place anchor bolts perform significantly better than hooked anchor bolts regarding possible pullout prior to development of full tensile strength. The American Institute of Steel Construction (AISC) Manual prohibits the use of
hooked anchor rods in tension, and cites limited pullout strength of hooked rods.

Pole foundations with anchor bolts are subject to construction accidents where equipment can strike them causing bending. Re-bending them straight can cause stress fractures as the type and grade of anchor bolt may not be known. Any repairs to straighten the bolts should be made according to AISC guidelines.

In the event rock is encountered while drilling, a rock socket foundation can be installed. The driller will switch drill bits to a smaller diameter coring bit. The first few feet of rock are considered incompetent, and the minimum rock socket depth is typically 5 feet into competent rock. However, additional drilling depth is often required to provide enough overlap between the rebar cages of varying diameters. This development length ensures that the stresses in the rebar are transferred to the concrete using the bond between the steel and concrete. Rock socket foundations are significantly more expensive than traditional foundation installations and drilling is a much slower process.

MAINTENANCE AND SAFETY CONCERNS

Wood Pole Repair

About 1900 the practice of using concrete bases around the decayed butts of wooden poles became quite common. This practice continues today where fiberglass sheets impregnated with resins are used to compensate for rot and decay and provides a very efficient method for wood pole butt repair. Another technique used is to replace a portion of the lower wood pole with a concrete or wood pole. In this method, the bottom of the wood pole is cut free from the top portion and removed while pole derrick trucks hold the top in place. The concrete bottom portion called a modular pole is inserted in the same hole and the top portion attached to the concrete portion through a steel sleeve. Total time takes around 90 minutes to install an 18 foot module [5].

Still another method for wood pole repair is to use a reinforcing clamp that clamps around the pole and is partially buried in the pole hole.

Steel Pole Repair

Steel sleeves for round poles and flat plates for wide flange poles are typically used for repairs. Historically, one method of reinforcing tubular steel poles because of corrosion was to insert a commercially available reinforcing cage made of high strength carbon steel twisted bars into the interior of the pole and fill the void with concrete. The cage had a concrete iron base attached to it at the factory where they were assembled but at the top a hooked cap temporarily confined the upper ends of the rods to allow the cage to pass through the narrow upper section of the pole. Upon withdrawal of the cap the bars flared out but did not touch the pole walls as shims were attached to them. At this point, concrete was pumped into the pole to cover the rods. This method was devised and employed by the New York Pole Company. This procedure significantly increased the strength of the pole which compensated for the loss of cross sectional area due to corrosion [4].

During the construction of trackless trolley lines in the United States in the 1930’s to 1950’s, existing steel trolley poles supporting streetcar overhead were similarly reinforced to increase their strength. Reinforcing rods and concrete were put into the poles which substantially increased the strength of the pole. Of note is a method used in San Francisco where they inserted used cable car slot zee angles as reinforcing with the concrete.

A novel method by the Ohio Brass Company for exterior repair of tubular poles at the ground line was the use of a split sleeve that was placed around the pole butt at the ground line in a hinge fashion. The sleeve was larger than the pole base diameter so that after installation, concrete grout could be poured into the void sealing the sleeve to the pole thus arresting further corrosion.
Tubular poles are usually fabricated with a corrosion collar around the butt section at the ground line that acts as a sacrificial member. A collar can also be used to make a repair to an existing steel pole by welding a sleeve around the pole above and below grade when the pole is severely corroded. The collar can be attached to an existing pole by using a split sleeve and welding circumferentially at its base, top and seams.

Corrosion of the interior of tubular poles has been a concern especially for older poles protected with only paint. Interior corrosion can cause significant loss of cross sectional area over time and the inside of the poles should be periodically checked. Corrosion of the joints where water collects is a problem on very old sectional poles. New construction uses either beveled joints or welds for water shedding. If the joint area is corroded, it can be cleaned to bright metal by grinding and then welded in place with a bevel weld. The repaired area should then be coated or painted to prevent further corrosion.

Corten® steel has been used for transit poles and this material provides weathering characteristics that protect the material below the surface. Once weathered, the surface has a dark rust color that can stain surrounding surfaces such as concrete foundations and sidewalks. A particular problem with Corten® steel is that it can continue to corrode and essentially rust away. Use of this type of steel with transit poles may require special welding materials and techniques to ensure that the weld material weathers at the same rate as the steel being welded. The material in itself is not rustproof and if water is trapped behind a fitting or clamp, accelerated corrosion and loss of metal will occur so provision for either drainage of water or prevention of moisture accumulation must be considered. This type of steel is sensitive to humid sub-tropical conditions and areas where there is a high sea salt content in the air. The Omni Coliseum in Atlanta, Georgia, constructed of Corten® steel, never stopped corroding due to the high humidity of the area and had large holes developed in the structure. It was demolished 25 years after construction.

Repairs to the material can be made by welding patches or fillers if the corrosion is localized and small. Full scale corrosion of the pole would warrant complete replacement.

Anchor Base Pole Repair

Anchor base poles are particularly vulnerable to corrosion at the anchor bolts and where snow, ice and deicing salts are encountered, accelerated corrosion can occur. Where anchor bolts are exposed under the base plate, inspections can be conducted and remedial action taken if corrosion is taking place. The anchor bolts should be thoroughly cleaned to remove all rust and then painted with an appropriate type of paint to impede further corrosion.

Placing grout between the bottom of the base plate to the foundation top and around the anchor bolts does not fully protect the bolts. The grouting method has a tendency to crack, allow moisture in and then trap it further causing accelerated corrosion. Figure 10 shows the effects of grouting the base plate.

![Figure 10](image)

A common malady of anchor base poles is the anchor bolts in the foundation being bent prior to the pole being set on it. A bent anchor bolt can be straightened depending on the severity of the bend and the type of anchor bolt used. Typically anchor base pole foundations use one of two types of anchor bolts designated by ASTM standards; F1554 or A449. Type F1554 Grade 36 anchor bolts less than 1” dia. can be cold bent to their straight position if not bent more than 45 degrees. For diameters greater than 1 inch, the rod has to be heated to 1,200° F to make bending easier. Bending should be done using a rod bending device called a hickey. After bending, the rods should be visually inspected for cracks. If there is concern about the tensile strength of the anchor rod, the rod can be load tested. Type A449 should not be bent as it is more brittle and stress cracks will most likely result from the bending and compromise the structural integrity of the anchor bolt.

In the event an anchor bolt must be replaced due to deformation or corrosion, the damaged bolt should
be cut flush with the top of the foundation. A new hole can then be drilled adjacent to the existing anchor bolt, and an anchor rod can be epoxied in the hole. The column base plate will likely require field drilling to accept the new anchor rod. An alternative solution is to core around the existing bolt to an appropriate depth, clean and thread the rod, and install an extension to the anchor rod using a coupling. A final and more expensive option is to install a new foundation next to the existing foundation. The existing pole can either be transferred to the new foundation, or a new pole can be installed. If necessary the old pole can then be removed in addition to part of the old foundation to an appropriate level below grade. [7].

An alternative to drilling the pole base plate which may not have sufficient space for the repositioned hole is to have a sub-base plate with a hole pattern matching the new hole pattern of the foundation and added bolts for attaching the pole base plate.

OVERCOMING INSTALLATION OBSTACLES

Various obstacles can be encountered during the planning and installation phases of an OCS line during line construction such as below grade utilities or overhead structures. Poles are usually designed for the particular situation or obstruction. One such method where there is an obstruction directly over the pole and the pole cannot be relocated is to bend the pole around the obstruction. An excellent example of this is on the George Washington Bridge between New Jersey and Manhattan. The suspension cables that support the bridge deck sag to a low point that obstructs the street lights which are directly under them. To place the streetlights consistently from the road curb, they have been curved with an offset as shown in Figure 11.

Such an arrangement can be done for the foundation of the pole where it is set in a narrow sidewalk and a duct line or other obstruction or utility is directly under it. This works particularly well for embedded poles where the below grade section is either curved with an offset or cut and welded to form the offset. Just such an arrangement was done at the MBTA in Boston with center reservation poles along Brighton Avenue and sidewalk poles along Huntington Avenue.

Another approach for use with anchor base poles is to have a plate or beam attached horizontally to the foundation anchor bolts and the pole with anchor plate attached to the offset beam. The pole can then be mounted directly over the obstacle and the bending moment of the pole transferred to the foundation through the horizontal beam. This can be either above or below grade depending on the installation situation. This approach may require a larger foundation as the axial loads will now generate a moment about the top of the foundation.

COST COMPARISON OF POLE TYPES

Pole installation costs consider materials and labor. Other factors affecting cost are the location where the pole is installed, underground obstructions, overhead obstructions, soil conditions, loads the pole must withstand, local codes and ordinances, architectural nuances and unforeseen conditions or requirements. The most cost effective approach to pole design is to select the pole type and foundation that provides the required performance for the lowest installation and maintenance cost.

The foundation of the pole can add significantly to the overall cost. The simplest type of foundation is the direct embedded type. An anchor base pole requires a reinforcing cage and anchor bolts in the foundation. These must be inserted into the hole with care as the bolt pattern must be exact and at an exact elevation above the top of foundation. The majority of transit systems use one of these two types of foundations. Precast foundations offer a fast and simple method compared to standard foundations but the void between the foundation wall and pole hole
must be sufficiently filled and tamped to prevent foundation movement.

Not all pole and foundation types are feasible for each application. Sometimes there are special requirements restricting use of certain pole and foundation types. City streets in shopping districts require different attention than private rights of way in rural settings. A city installation may require ornate tubular steel poles of different colors while rights of way could allow the use of wide flange poles or even wood poles. In order to achieve an equal cost comparison for the various types of poles and foundations, ideal conditions are assumed and each pole must be sized for the same loading and soil conditions. The deflection for steel poles has been limited to 2% of length. Table 6 shows a comparison of poles and the relative cost of the installed unit.

**Pole Cost Comparison**

<table>
<thead>
<tr>
<th>Pole type</th>
<th>Allowable Moment (psi)</th>
<th>Weight (lb) at 28 feet</th>
<th>Deflection (in) at 2,000 lb load</th>
<th>Cost in $</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 WF 8 x 28</td>
<td>67,500</td>
<td>784</td>
<td>4.31</td>
<td>680.00</td>
</tr>
<tr>
<td>2 Tapered</td>
<td>65,395</td>
<td>442</td>
<td>5.8</td>
<td>2,507.00</td>
</tr>
<tr>
<td>3 3 section</td>
<td>52,000</td>
<td>905</td>
<td>5.32</td>
<td>3,010.00</td>
</tr>
<tr>
<td>4 Straight Pole</td>
<td>44,722</td>
<td>799.5</td>
<td>5.83</td>
<td>2,730.00</td>
</tr>
<tr>
<td>5 Wood Class 4</td>
<td>81,400*</td>
<td>590.4</td>
<td>10.69</td>
<td>270.00</td>
</tr>
</tbody>
</table>

*Note: 2, 3, and 4 include ground sleeve in cost*

<table>
<thead>
<tr>
<th>Pole type</th>
<th>Weight (lb) at 28 feet</th>
<th>Deflection (in) at 2,000 lb load</th>
<th>Cost in $</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 Wood Class 4</td>
<td>81,400*</td>
<td>590.4</td>
<td>270.00</td>
</tr>
</tbody>
</table>

Material costs for each pole type can fluctuate based on availability and demand at the time of purchase, and the quantity of poles required can affect the unit price. Changes in construction crew and equipment costs for pole and foundation installation can also affect project costs. Finally, prices can vary based on competitive bidding and any negotiation methods employed during procurement.

**FORMULAS FOR POLE AND FOUNDATION DESIGN**

Determination of strength and deflection for poles and foundation strength is calculated from various formulas developed from structural, civil and geotechnical analysis. National and local safety codes apply to the allowable loads and deflections based on climatic conditions and local ordinances. Some agencies may require more stringent safety factors than others so having one standard for all is not in effect. For electrical conductor support, the basic standard is the National Electrical Safety Code (NESC) and all overhead systems must meet that at a minimum. Some transit agencies use American Association of State Highway and Transportation Officials (AASHTO) as a guideline for overhead standards for poles. The state of California has its own criteria and is General Order 95 (GO-95) of the Public Utilities Commission.

The American Transit Engineering Association, later the American Transit Association (A.T.A.) adopted simplified formulas for determining pole loadings, deflections and foundation depths and diameters that could be used for everyday engineering of overhead contact systems. Other national organizations such as the American Society of Agricultural Engineers and the Rural Electrification Administration have also put forth formulas for foundations. Another source of methods and formulas that are used under European standards is a manual titled, “Contact Lines for Electric Railways” by Siemens and EU Standard 50119.

The formulas listed herein, although not all inclusive, provide typical formulas used for transit OCS design and were adopted by many agencies. The derivations for determining these equations have been omitted as only the derived equation is used but the reader of this paper can find the derivations in engineering text books if they so desire. Many of the equations and formulas are simplifications that provide reasonable accuracy and ease of use.

**Pole Loading**

Loads on poles are typically lateral and/or vertical with the latter attributed to the weight of the pole and all attachments to it or to the vertical forces imparted into it from the use of back guys. Lateral load is the transverse force applied to the pole at right angles at varying heights above the ground line. Typically, these are moment loads and are calculated by the force multiplied by the attachment height of the force to obtain the bending moment. If multiple span wires are at different heights but share the same loading direction, the moments are added to obtain total moment. When the loads are in different directions, a resultant moment is obtained after each separate moment is determined. This can be done mathematically, but the simplest way to calculate the resultant moment is to generate a force diagram, and this holds true for any type of pole. Allowable moments for poles are typically supplied by the pole manufacturer. For steel poles, this is usually 2/3 of the yield strength of the material. Further discussion
Pole deflection can vary during the service life of the pole and wind loading, span wire loading, and bracket arm loading can vary due to seasonal and temperature changes. The pole should be designed so that maximum deflections will not be exceeded.

**Pole Foundations**

Poles foundations can be of two types, direct embedment or anchor base when set in the earth. Attachment to walls or other concrete or steel structures is a separate type of foundation. These connections use anchor bolts, and the strength of the wall determines the capacity of the resisting moment. When such an installation exists, the wall or structure designer should design the structure while also considering the proposed OCS loads.

The calculation of the foundation strength is the same for both types when placed in soil. With direct embedded poles, typically, no reinforcing rods are used and the pole is inserted into an excavated pole hole directly and the hole filled with concrete for steel poles and, in some cases, wood poles. Large diameter foundations will require reinforcing of some type and an analysis must be undertaken to determine the size, type and quantity of reinforcing rods required for the foundation. With wood poles, concrete poles, or composite steel concrete foundations, the hole is backfilled usually with excavated soil and sufficiently tamped.

Poles subject soil to shearing stresses that offer resistance compromising cohesion, dilatancy and friction. The maximum resistance of a soil to shearing stress is its shear strength whereas bearing capacity is the maximum intensity of load that the soil will safely carry without the risk of shear failure. Therefore, shear strength is the resistance to the stresses occurring in the soil and bearing capacity is the intensity of loading just before the soil collapses.

The bearing pressure consists of the bearing pressure applied at the bottom of the foundation including the weight of the foundation, weight of the pole and all of its assemblies, and any soil immediately overlying the foundation minus the pressure calculated for a height of soil extending from the bottom of the foundation to the lowest ground surface level immediately adjacent to the foundation.
The type of soil that the pole is set in is generally classified to bearing capacity, shear strength, friction angle and cohesion. Soil friction angle is a shear strength parameter of soils. Its definition is derived from the Mohr-Coulomb failure criterion and is used to describe the friction shear resistance of soils together with the normal effective stress. In the stress plane of shear stress-effective normal stress, the soil friction angle is the angle of inclination with respect to the horizontal axis of the Mohr-Coulomb shear resistance line. The lower the friction angle, the less bearing capacity the soil exhibits. The higher the friction angle, the more dense the soil and, consequently, the greater the bearing capacity.

Different standards organizations classify soil for structure installation such as American Association of State Highway and Transportation Officials (AASHTO), the Unified Soil Classification System (USCS), Code of Federal Regulations, CFR, ASTM, and state and local building codes in the United States. For transit and electric railway work, Table 5 shows safe bearing values for various types of soil as indicated in A.T.A. Engineering Manual Section D104-55 and provides a simplified but effective measure of soil conditions including appropriate safety factors for the design of poles supporting OCS. This method has been an accepted industry practice for determining pole foundation sizes for many years.

### A.T.A. Soil Criteria

<table>
<thead>
<tr>
<th>Soil Group</th>
<th>Safe Bearing Value (Lbs./Sq. Ft.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse Gravel, Hard Pan, Cemented Sand and Gravel, Soft Shale</td>
<td>10,000</td>
</tr>
<tr>
<td>Firm and Dry Clay, Fine Gravel</td>
<td>6,000</td>
</tr>
<tr>
<td>Moderately Dry Clay, Firm Sand, Old Fill</td>
<td>4,000</td>
</tr>
<tr>
<td>Clay and Silt, Moist and Soft Clay, New Fill</td>
<td>2,500</td>
</tr>
</tbody>
</table>

*Table 5*

### Pole Footings

Catenary structure or pole support footings fall into two categories: side bearing and gravity footing. The selection of the type of footing is based on cost and interference from surrounding structures such as utilities, underground structures or buildings. Typically, a side bearing footing is chosen for OCS support due to its simplicity and economy. They can be square or circular but circular is easier to excavate.

One type of gravity footing is the slab footing where it is typically shallow and used either with portal structures or poles with back guys to stabilize the pole. This method has been used on electrified railroads such as the Former Lackawanna Railroad and Amtrak. The foundation slab has considerable area but little depth. Due to a short moment arm of the portal structure this style footing is more economical for portal structures.

Another type of footing is the side bearing type which is the most widely used for transit and electric railway work. With this type of footing, a hole is excavated to a depth with a particular diameter and the pole or pole anchor rods inserted and concrete poured into the hole. It provides a very effective foundation for poles with a variety of soil conditions. The depth and diameter of these foundations can be calculated from simple formulas when the soil bearing capacity is known. A foundation with a moment of 40 kip-ft (40,000 ft-lbs) in soil with a safe bearing capacity of 6,000 lbs/sq. ft and a depth of 6 feet will require a 29.11 inch diameter foundation using formula (f10) whether it is embedded or anchor base.

A side bearing foundation that has particular added resistance to soil shear is the restrained or keyed foundation. Poles set in city sidewalks against granite curbstones are considered restrained as the foundation bears against a curbstone secured by the street pavement and is shown in formula (f11).

### Soil Capacity

Soil bearing capacity can be determined from test borings along the route or at each pole location and this is usually done for large projects or where soil conditions are required to be known. The soil strength can be determined from a Standard Penetration Test (SPT) through blow counts. The borehole is made to a pre-determined depth and the split spoon sampler is lowered into the hole. The sampler is driven into the soil by hammer blows and the number of blows required to advance the sampler 6” is recorded. This occurs for three 6” intervals and the last two intervals are added together to determine the Standard Penetration Number, N.

Where poles are set without previous knowledge of soil conditions, experienced line crews digging the hole can determine the type of soil and equate it to soil charts. An engineer can verify or alter the
diameter and depth to suit the individual pole location. Soil conditions are not always homogeneous with depth. In such cases, it is often necessary to increase the foundation depth to reach a soil layer of adequate strength.

The SPT blowcount results can correlate with certain soil properties relevant to geotechnical engineering design for the pole foundation. It is recommended that the services of a geotechnical engineer be used for determining soil conditions and foundation requirements for challenging situations and for areas prone to earthquakes or other abnormal and unusual geotechnical conditions.

Formulas

Pole Deflection

Formulas for pole deflection reference Figures 15 and 16. Formulas for the deflection of poles are given in the following equations:

(f1) One section pole:

\[ D = \frac{L^3 P}{3 E I} \]

(f2) Two section pole:

\[ Y_{100} = k \left( \frac{x_1^3-x_2^3}{I_1} + \frac{x_2^3}{I_2} \right) \]

(f3) Three section pole:

\[ Y_{100} = k \left( \frac{x_1^3-x_2^3}{I_1} + \frac{x_2^3-x_3^3}{I_2} + \frac{x_3^3}{I_3} \right) \]

(f4) Four section pole:

\[ Y_{100} = K \left( \frac{x_1^3-x_2^3}{I_1} + \frac{x_2^3-x_3^3}{I_2} + \frac{x_3^3-x_4^3}{I_3} + \frac{x_4^3}{I_4} \right) \]

Refer to Figure 23; \( K = W_{100}/3 \ E; W_{100} = 100 \ lbs \)

(f5) Tapered pole:

\[ D = \frac{288 \times L^3 \times H}{E} \left( \frac{1}{I_b} + \frac{1}{I_m} \right) \]

(f6) Wide flange pole:

\[ D = \frac{P \times H^3}{3 \ E \ I} \]

(f7) Wood pole:

\[ D = \frac{6.78 \ L^3 \ P}{E \ (d_a^2 \times d_1)} \]

Note: \( E = 1.6 \times 10^6 \) for Southern yellow Pine

\( E = 2.9 \times 10^6 \) for Steel

Where:

\( D = \) Deflection in inches

\( L = \) length of pole at applied load in inches

\( P = \) Load applied in pounds

\( E = \) modulus of elasticity

\( I = \) Moment of inertia

\( I_b = \) Moment of Inertia at ground line

\( I_m = \) Moment of Inertia at middle of pole

\( H = \) Height of pole above Ground Line at load

\( Y = \) Deflection in inches/100 lbs

\( d_a = \) Diameter at the ground line

\( d_1 = \) Diameter where the force is applied

Pole Guys

Formulas for pole guys reference Figures 12 and 13, and are as follows:

(f8) Back Guy:

\[ P_2 = \frac{P_1}{\cos \theta_1} \]

(f9) Side Walk Guy:

\[ P_3 = P_2 \cos \theta_2 \]

\[ P_4 = P_2 \sin \theta_2 \]

\[ \text{Figure 12} \]
Where:

\( P1 = \text{Tension in conductor} \)
\( P2 = \text{tension in guy wire} \)
\( P3 = \text{tension in guy wire with strut} \)
\( P4 = \text{Compression force in strut; compression force in pole} \)

**Pole Foundation**

Formulas for pole foundations are given in the following equations:

(f10) Free Standing, Fig. 14 and 16:

\[
W = \frac{10 \, P \, [H + (0.7 \, d)]}{K \, d^2}
\]

(f11) Restrained, Fig. 15:

\[
d = \left[ \frac{4 \, P \, H}{S \, D} \right]^{1/3}
\]
Where:

\[ P = \text{Load in lbs} \]
\[ H = \text{Height of load in feet} \]
\[ d = \text{Depth of foundation in feet} \]
\[ D = \text{diameter of foundation in feet} \]
\[ K = \text{Soil bearing capacity in lbs/sq ft} \]
\[ L = \text{Arm length to point of force} \]
\[ a = \text{Attachment point of guy in feet} \]
\[ e = \text{Guy attachment point above arm in feet} \]
\[ S = \text{Lateral Pressure, psf/ft, See Table 7} \]
\[ W = \text{Width of foundation parallel to track in feet} \]

Formula (f10) may be applied to either a simple cantilever beam acting as a single track overhead support or it may be applied to the legs of a portal structure. In that latter case, if the columns are fixed at the footing, the theoretical moment arm of each column is half the distance from the fixed base to the knee brace. In other words, the point of contraflexure in the neutral axis of the column falls at the halfway point, A, shown in Figure 17. For pin end columns, the moment is zero as shown in Figure 18.

Gravity footings are primarily designed to be self-supporting because of their weight including the weight of the structure but there will be some side bearing effect that must be taken into consideration. Formulas (f12) and (f13) may be used for the calculation of the maximum toe pressure of a rectangular concrete footing and for the maximum overturning moment.

### Formula (f12):

\[
Pt = \left[ \frac{1}{bc} \right] \left[ V + \frac{6PH}{bc} \right]
\]

### Formula (f13):

\[
P_h = \left[ \frac{c_b^2}{6} \right] \left[ Pt - \frac{V}{bc} \right]
\]

Where:

\[ Pt = \text{Maximum toe pressure, lbs/sq ft} \]
\[ c = \text{Width of footing parallel to track in feet} \]
\[ b = \text{Width of footing perpendicular to track in feet} \]
\[ V = \text{Weight of footing plus structure in lbs} \]
\[ P = \text{Cantilever load in lbs} \]
\[ h = \text{Distance between applied load and bottom of footing in feet} \]

### Table 7

<table>
<thead>
<tr>
<th>Class of materials</th>
<th>Density or consistency(^1)</th>
<th>Lateral pressure per unit depth(^2), kPa</th>
<th>Lateral sliding coefficient(^3), (k_{cx})</th>
<th>Vertical Pressure(^4), Sy</th>
<th>Friction angle(^5), (\phi)</th>
<th>Density(^6), (\rho)</th>
<th>Estimated Constant of Lateral Soil Reaction(^7), (n_c), (S_c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Massive crystalline bedrock</td>
<td>180</td>
<td>200</td>
<td>200</td>
<td>1200</td>
<td>100</td>
<td>2000</td>
<td>1000</td>
</tr>
<tr>
<td>2. Sedimentary and foliated rock</td>
<td>60</td>
<td>100</td>
<td>100</td>
<td>400</td>
<td>30</td>
<td>15000</td>
<td>1000</td>
</tr>
<tr>
<td>3. Sandy gravel and/or gravel (GW and GP)</td>
<td>firm</td>
<td>45</td>
<td>38</td>
<td>2000</td>
<td>120</td>
<td>6250</td>
<td>40000</td>
</tr>
<tr>
<td>4. Sandy, silty sand, clayey sand, clayey gravel (IS, WP, SM, SC, CM, and GC)</td>
<td>firm</td>
<td>30</td>
<td>30</td>
<td>1500</td>
<td>90</td>
<td>1570</td>
<td>10000</td>
</tr>
<tr>
<td>5. Clay, sandy clay, silty clay, and clayey silt (CL, ML, MH, and CH)</td>
<td>medium</td>
<td>20</td>
<td>15</td>
<td>20000</td>
<td>785</td>
<td>5000</td>
<td>5000</td>
</tr>
</tbody>
</table>

\(^1\) Density or consistency
\(^2\) Lateral pressure per unit depth
\(^3\) Lateral sliding coefficient
\(^4\) Vertical Pressure
\(^5\) Friction angle
\(^6\) Density
\(^7\) Estimated Constant of Lateral Soil Reaction

The effectiveness of the gravity footing is greatly dependent upon its shape and upon the angle at which the pullover load is applied. Figure 19 illustrates a square gravity footing with the load applied in line with a central axis. Figure 20 illustrates the same square gravity footing with the load applied...
diagonally while Figure 21 illustrates a circular footing with the load applied at any point.

The stated formulas apply to Figure 19. Where the load is applied diagonally, Figure 20, the same set of formulas may be used, however in calculating the footing size it must be remembered that the value of P for use in the formulas is equal to P’ cos Θ. For the round footing, Figure 21, the formulas may be used for obtaining maximum toe pressure and maximum overturning moment providing both formulas are multiplied by 0.66.

Bracket Arm Loading

Formulas for determining the loading on the pole and bracket arm are referenced in Figure 22 and are given in the following equations:

A. Loading of the Arm:

   Compressive Force (lbs)
   
   \[
   P_c = \frac{P \cdot L}{e}
   \]  
   (f14):

   Max. Bending Moment in Arm (ft-lbs)

   (f15):  
   \[
   M = P \left[L - a\right]
   \]

B. Loading of the Arm Guy:

   Tension Force (lbs)

   (f16):  
   \[
   P_g = \frac{P \cdot L}{e \cdot a} \sqrt{e^2 + a^2}
   \]

C. Moment at Base of Pole (ft-lbs):

   (f17):  
   \[
   M = P \times L
   \]

Where:

\[
\begin{align*}
P & = \text{Load in lbs} \\
L & = \text{Arm length to point of force in feet} \\
a & = \text{Attachment point of guy in feet} \\
e & = \text{Guy attachment point above arm in feet} \\
h & = \text{Height of arm on pole above ground line in feet} \\
M & = \text{Bending Moment of pole in ft-lbs}
\end{align*}
\]

Comparison of Poles

It is difficult to state what pole or foundation is the best or better than others as many factors come into play including economy and personal preference. A foundation with a key and footer provides the most bearing surface and this is often difficult to install in restricted installations. The use of a solid and strong curb stone or other bearing device that bears against the foundation and the street offers a very strong foundation. This can help to limit the depth of the foundation hole. The following provides a list of advantages and disadvantages for some of the most common pole types.

Straight Steel Pole

Pros:

- Quality control ensured at manufacturing facility
- Provides constant diameter, easy to adjust pole bands up or down the pole and requires less inventory
- Less deflection than sectional or tapered poles
- Can be less expensive than equivalent sectional or tapered pole as there is no manufacturing required
- No restriction on angle of pull
- Can be internally reinforced if direct embedded
- Can be externally repaired due to corrosion
Cons:
- Weight per foot not as efficient as sectional or tapered poles
- Less visually appealing due to straightness
- Interior of pole is subject to unseen corrosion

Sectional Steel Pole

Pros:
- Provides constant diameter in each section
- Easy to adjust pole bands up or down the pole
- Less weight than constant diameter straight pole
- Weight per foot more efficient than straight pipe
- No restriction on angle of pull
- Can be internally reinforced if direct embedded
- Can be externally repaired due to corrosion

Cons:
- More expensive than straight pipe or wide flange section for given section modulus
- Interior of pole subject to unseen corrosion
- Sections of pipe must be properly secured to prevent telescoping. Finished joint construction not visible for inspection and quality control
- Section joints can be a source of corrosion

Tapered Steel Pole

Pros:
- Less weight than constant diameter straight pole
- No restriction on angle of pull
- Efficient weight per foot
- Less risk of corrosion when compared to sectional steel poles
- Quality control ensured with automated shop manufacturing process
- Can be externally repaired due to corrosion

Cons:
- Pole diameter varies along the entire pole length making adjustment of attachment hardware more difficult
- Will deflect more than straight pole of similar base diameter and gauge.

Wide Flange Steel Pole

Pros:
- Provides high strength per weight per foot in strong axis direction
- Less expensive than straight pipe or tapered poles for strength
- More stiffness thus less deflection
- No interior corrosion

Cons:
- Strong axis and weak axis limiting direction of pull
- Straight without taper, thus not visually pleasing unless special adaptations made

Wood Pole

Pros:
- Least expensive pole type
- No restriction on angle of pull
- No grounding requirements as wood is nonconductive
- Ease of installation direct embedded and backfilled with earth.
- Can be externally repaired due to corrosion

Cons:
- Risk of decay at ground line from fungi and insects. Even treated poles lose resistance to decay over time
- Wood poles can warp over time
- Limited available strength for high strain loads compared to steel and concrete poles

Concrete Pole

Pros:
- Not susceptible to the same surface corrosion and decay as steel and wood poles
- High compressive strength
- High resistance to fire
- Ease of installation if direct embedded and backfilled with earth

Cons:
- Spun concrete poles can sink further into earth under high compressive loads due to open cross-section
- Risks of concrete cracking and spalling
- Weak in tension, and rebar can corrode if exposed to moisture
- Heavy and can require heavy machinery to install

CONCLUSION

Poles of varying materials and types have been used for aerial wire support since the advent of the telegraph in 1844. Wood was the primary material initially but variations with concrete were used for repair, strength or longevity. Early concrete poles
were unsuccessful and subsequent experimentation led to improved materials and construction. Tubular iron and steel poles were introduced in the late 1880’s and other forms of steel poles developed soon thereafter using sections, cross bracing and other structural shapes. Notable poles were the Tripartite, Diamond Tapered, Bates Extruded and the Stobie Pole.

Suitable concrete poles were developed for transit and railroad use and the Van Ness Avenue poles of San Francisco are an excellent example of architectural grace, strength and longevity. The portal structures from Henry Ford’s electric railroad of 1927 are still standing and are a good example of sound engineering and quality construction.

Different types of poles are used in transit and railway installations with wood being the least expensive and, at one time, the most widely used. Wide flange and tubular steel sectional, tapered, or straight poles are the most common in use today. Some concrete poles are used for transit work but are predominantly used in the utility industry.

Various standards organizations have developed classifications for different types of poles such as ANSI 05.1 2008, USDA Bulletin 1742E-206 for concrete poles, IEEE Standard for tubular poles (P1630), and the AISC Steel Construction Manual for a variety of steel shapes.

Foundation design incorporates not only selection and sizing of foundation materials, but also soil mechanics. The type and strength of soil plays an integral role in determining foundation types and parameters. Numerous organizations classify soil such as AASHTO, USCS, ASTM, and A.T.A. Geotechnical engineering assistance should be used for unusual conditions such as earthquake zones and abnormal geotechnical situations.

Pole footings provide foundation stability and the type of footing is determined by soil conditions, location, economy and are side bearing or gravity type with the slab footing used for shallow installations with portal structures or back guys. Side bearing footings can be square or circular in shape and can be strengthened with the use of pole footers and pole keys for additional bearing capacity. The use of city sidewalks provides an excellent means of restraint for foundations.

Soil bearing capacity can be determined from test borings with a standard penetration test using blow counts to determine soil strength. Soil type can also be determined during foundation excavation by visual observation.

Simplified formulas allow easy and accurate calculation of pole and foundation loadings and pole deflections. Comparison of pole advantages and disadvantages indicate how pole types compare with each other for various installations.

ACKNOWLEDGEMENTS

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END NOTES

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4-Electric Railway Journal, Volume 32, page 929, October 10, 1908.
5-7th Paper titled “A method for Fast Replacement of Wooden Utility Poles by Replacing the Bottom half with a Concrete Module and Eliminating the Conventional Pole Top Transfer Costs”, Transmission and Distribution Committee, IEEE/PES Transmission and Distribution Conference and Exposition, April 1-6, 1979
6-American Transit Association, Engineering manual Section D104-55, Catenary Overhead Construction for Electrically Propelled Railway Vehicles
7-2nd Edition of the AISC Design Guide 1, under Base Plate and Anchor Rod Design
8-Table 3, ANSI 05.1 Wood Poles, Specifications and Dimensions

List of Figures

Fig. 1 Illustration of granite poles supporting telegraph wires
Fig. 2 Illustration of Tripartite steel poles
Fig. 3 Telescopic Joint
Fig. 4 Square Tapered Steel Pole
Fig. 5 Concrete Trolley Pole
Fig. 6 Stobie Pole
Fig. 7  Van Ness Avenue Concrete Poles
Fig. 8  Concrete Catenary Supporting Structure
Fig. 9  Steel Shape Anchor Base Foundation
Fig. 10 Anchor Base Plate Grouting Effects
Fig. 11 George Washington Bridge Streetlights
Fig. 12 Back Guy
Fig. 13 Sidewalk Guy
Fig. 14 Cantilever Pole Foundation
Fig. 15 Restrained Pole Foundation
Fig. 16 Gravity Footing Cantilever Pole
Fig. 17 Fixed Portal Structure
Fig. 18 Pinned Portal Structure
Fig. 19 Rectangular Foundation with Straight Pull
Fig. 20 Rectangular Foundation with Angled Pull
Fig. 21 Circular Foundation
Fig. 22 Bracket Arm
Fig. 23 Deflection for Sectional Pole

List of Tables
Table 1  Standard for Iron/Steel Poles
Table 2  Classification of Wood Poles
Table 3  Classification of Concrete Poles
Table 4  Cost Comparison Between Poles
Table 5  A.T.A. Soil Criteria
Table 6  Pole Cost Comparison
Table 7  Soil Properties for Post Foundation Design