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Design, Erection, and Maintenance of Antenna Structures

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This is not intended to be a treatise on tower design. The object of this discussion is to give the average broadcaster, owner, manager, or engineer a practical understanding of tower structures. General problems concerning tall structures are discussed in order to aid the broadcast people who are responsible for buying and maintaining towers. Electrical problems will not be discussed.

TOWER COST

The approximate cost of a tower installation is of prime importance for planning purposes. The accompanying curves show approximate costs of typical installations. These curves are intended to show the scale or range of dollars involved. The cheapest tower structure is the simplest one, such as an AM tower. This tower merely holds itself up, with a set of lights. Obviously, anything you add to the tower such as coaxial lines, signs, and so on, will increase the wind load, which in turn increases the weight and cost. It is impossible to show all the different conditions which arise. For example, only a few of the items which will increase cost are:

Winter erection
Inaccessible sites
Foundations in swamps, rock, sand, tide water, or any water
Heavier wind-design load
Top hats
Special insulators
Electric signs
Large high-gain antennas
Large amount of coaxial
Elevators
Multiple antennas

Towers over 1,000 ft. usually involve special engineering for the particular conditions required. Hence, the cost of towers over 1,000 ft. is very approximate. People often inquire about the tallest tower which can be built. At the present time, there is no particular engineering reason why towers can not be built up to 3,000 or 4,000 ft. with present-day materials and equipment.

Self-supporting Towers versus Guyed Towers

The obvious advantage of a self-supporting tower is that it requires less ground area at the base of the tower. This often is necessitated because of crowded conditions, such as putting up a tower in the center of a city block, on a roof top, or on a small mountain top. The area required for a typical self-supporting tower will be roughly a square or a triangle somewhere between 7-1/2 and 20 percent of the overall height of the structure, depending on the designer. AM towers tend to be a little more slender than the TV towers. The disadvantage of a self-supporting tower is that, as a general rule, it is more expensive. An additional disadvantage of a self-supporting tower is that the designer does not usually investigate whip or inertia forces. These whip forces tend to be larger in a tall, slender self-supporting tower with a heavy weight on top (such as an antenna) than in a guyed tower.

The obvious advantage of a guyed tower is its cheaper (installed) cost. Most guyed towers today are built with a uniform cross section and, in many instances, a constant weight in cross section. This makes for cheaper fabricating and easier and cheaper stacking during erection. A guyed tower is lighter than a self-supporting tower. The guys, in effect, form a very large base. A guyed tower having less steel is usually cheaper to paint and to maintain, since it has fewer members and the members are easier to reach on the way up and down the tower.

The area required for a guyed tower varies with the designer. Current practice is to place the guy anchors out from the base pier a distance equal to

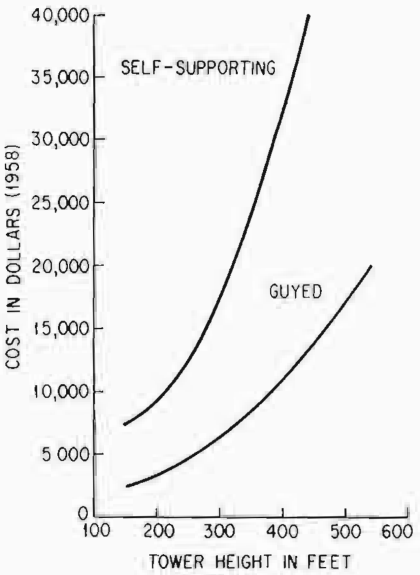


Fig. 1. Approximate installed cost of 30-lb. insulated AM towers. Cost includes tower, foundations, FAA lights, and erection.

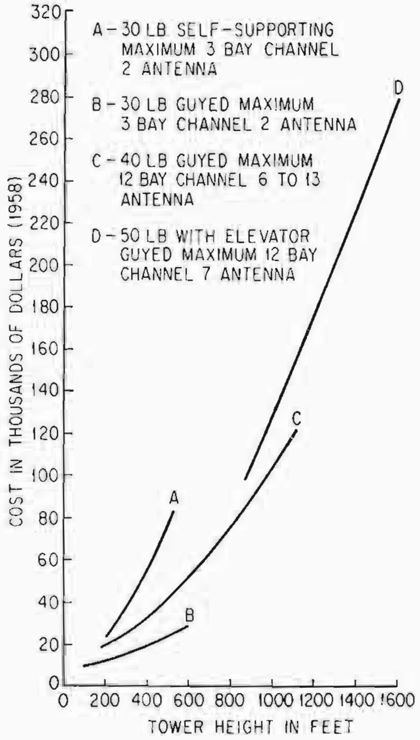


Fig. 2. Approximate installed cost of TV towers. Cost includes tower, foundation, erection, FAA lights, erection of coaxial and antenna.

50 to 100 percent of tower height. The tower designer knows that as he pulls in his guy anchor distance, he increases the down load on the tower and so runs up the size of guys and the size of vertical members. This tends to run up the cost of the tower.

It is not always necessary to buy all the land enclosed by the outline connecting the anchors. Many towers have guys crossing a public road. There are many tower installations where it was necessary to buy or long-lease a small plot at each guy anchor and at the base of the tower.

Tower Material

Most towers today are built from steel for the simple reason that steel is more economical than any other material available at the present time. It is possible to build towers from wood, any number of aluminum alloys, and a number of other materials. Wood is usually uneconomical over 80 or 90 ft. and the broadcast range begins at 150 ft. Aluminum alloys tend to give a lighter but a more expensive tower. The broadcaster usually is more interested in the cost than the weight of the tower. There may be a day when the basic cost of some of these aluminum alloys will come down and steel will go up, so that it may be economical to use these aluminum alloys.

Probably the most commonly used steel is structural carbon steel which comes under ASTM A-36 specifications. The yield of this material is 36,000 psi. It has good elongation and very good working and welding properties. Its base price is relatively cheap.

Pipe is used by some manufacturers. Pipe generally comes under ASTM A-53. This pipe has a yield of about 35,000 psi, depending upon the grade. Pipe is fairly easy to work as a rule and is suitable for welding. Its popularity is due to the fact that it has a low base price. The disadvantage is it comes only in certain specific sizes.

Mechanical steel tubing, both welded and seamless is used in various grades and alloys to

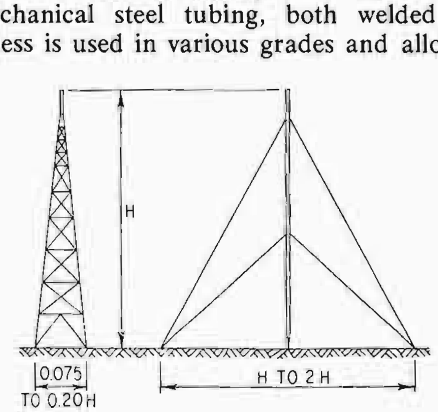


Fig. 3. Relative space requirements for self-supporting and guyed towers.

meet specific requirements. Exacting properties such as tensile strength, ductility, and weldability can be produced. A big advantage of tubing is that both the outside dimensions and the wall thickness can be varied at will by the buyer. The disadvantage of tubing is its relatively high base price.

Taller towers, or towers with exceptionally heavy wind loading generally have solid round leg members, since the heavier loads involved put it out of the range of tubing strength. A wide variety of steels are now available in the industry, ranging from the standard A-36 (36,000 psi yield) to 100,000 psi yields and higher. These higher strengths are obtained by altering the chemical properties (alloy steels) and their cost generally speaking increases with strength. Many other desirable properties for a given application, such as corrosion resistance, weldability and toughness can be obtained through judicious selection of steel types available.

There have been some towers using high carbon strip rolled into Vs. Towers using this material very seldom have welding connections because of the previously mentioned difficulty encountered in welding.

High yields up to 110,000 psi are obtainable from stainless steel in the 17-7 or 18-8 varieties which have good working and welding properties. Although an excellent material, its high cost prohibits its use in commercial tower construction at the present time. It has been used by the U.S. Navy for masts on seagoing ships.

Commercial machine parts usually get high strength by heat-treating higher carbon steel. The higher carbon steel is more difficult to weld. Also, heat treating large, bulky tower columns is uneconomical. For this reason, high-carbon heat-treated steel is very rarely used in tower work.

SHAPE OF MATERIAL

There is no particular magic in any one structural shape. All shapes have their advantages and their disadvantages. The different tower designers have different shape preferences. Different tower manufacturers have different shape-fabricating facilities. It might be interesting to review some of the more commonly used steel shapes.

Steel Angle

The most easily available shape and the one used in great amounts is the structural steel angle. The advantages of a steel angle are its universal availability, low initial cost, ease in fabricating, ease in shipping, ease of galvanizing, and ease of assembly. Because these structural angles make 90° angles, most towers which use angles are four sided. Three-sided towers using angles are possible. The largest single disadvantage of a structural angle shape is that the angle runs up the wind load and, consequently, the weight of the tower, particularly as the height of the tower increases. Almost all towers were made of angles, at one time, when the heights were low. Today most tall towers make use of cylindrical shapes.

A much-used shape is a steel strip which is rolled into a V or some shape approximating a V. The main advantage of a rolled strip is that it is possible to form an approximate 60° angle. This makes it relatively simple to fabricate a triangular cross-sectional tower. The advantages and disadvantages of formed strips are about the same as those of structural angles.

Cylindrical

A solid round steel bar has become popular, particularly in the taller towers. The advantage of a solid bar is that it has low wind resistance for a given cross-sectional area. Its base price is also relatively inexpensive. The solid bar tower tends to run the tower weight up if the designer is not careful.

The advantage of a tube to a tower designer is that it has a circular shape which keeps the wind load down and it gives the tower designer the most efficient material distribution to carry a column load. Tubular towers are usually more efficient and lighter, have fewer parts, and are cleaner looking than those of other shapes. The greatest disadvantage of a tube is its relatively high initial base price for the material.

To sum up shapes, it must be borne in mind there is no particular magic in any of the shapes used. It always amazes people to see different companies using different designs, different types of facilities, and different shapes and coming out with approximately the same tower cost.

TOWER ASSEMBLY

The three principal methods of putting a tower together in the field are bolting, riveting, and welding. The latter two methods are seldom used. Since bolts are used almost universally in tower erection, a discussion of the various types of bolts and bolting practices is in order.

We may also note at this time the advantage of the prefrabricated tower section where most of the assembly work is done in the shop. The expensive erection bolting is then kept to a minimum with a resultant saving in time and cost.

Bolts

High strength ASTM A-325 bolts are generally used in the tower industry. Even higher strength

ASTM A-490 bolts can also be used where higher loads are encountered, in order to hold down the size of the connection.

The properly tightened high-strength bolt exerts a high clamping force, thereby creating a stiffer connection. It is desirable that the high-strength bolts be tightened to at least the minimum tension specified by the manufacturer. The following are the most commonly used methods for torquing high-strength bolts.

1. Torque wrench. An indicator which registers torque is a component part of this wrench.
2. Pneumatic impact wrench. Air pressure is controlled so that the wrench stalls at desired torque.
3. Pneumatic impact wrench with internal automatic cutoff which shuts off air supply when proper torque is reached.
4. The nut is turned to an initial tightness. Then the nut is given prescribed amount of visual turn with the wrench.

Ribbed or Dardelet bolts are sometimes used. These bolts have ribs along the body of the bolt. These ribs dig into the bolted material, provided the holes are undersize. If properly used, they make a rigid connection. They are not popular with erectors because of the extra work involved in driving the bolts into undersized holes. Their effectiveness is lost of holes are not undersized. These bolts require locking devices.

It is mandatory that all bolts and nuts be drawn tight. All nuts (except on high-strength bolts) should be locked in some manner to prevent them from working loose. This can be accomplished in many ways. A simple way is to stake the nuts by upsetting the thread on the bolt after bolt is on. A great variety of patented lock nuts, washers, and devices are available. They all seem to be fairly effective provided they are put on and put on tightly.

Number of Faces on a Tower

The number of faces a tower has is usually dictated by the economy of fabrication and erection. The simplest tower is one which has a circular cross section, which, in effect, has no face at all. Wooden poles would make such a tower, and tall radio towers have been designed out of large-diameter steel or aluminum tubes. An extreme case of the number of faces on a tower would be a tower made up of eight, ten, or even twelve faces. There is no reason why good towers with that number of faces could not be built, and they sometimes are. It should be pointed out that a poorly designed tower is a poorly designed tower and a well-designed tower is a well-designed tower irrespective of the number of faces the tower has. At the present time, most towers are built using either a triangular or a rectangular cross section.

Preassembly by Welding

Some towers are preassembled by welding in the shop. These prefabricated sections may be anywhere from 5 to 30 ft. in length. The length of the section preassembled in the shop is dictated usually by handling, shipping, and erection facilities. The advantage of prefabrication is that it takes some work from the erector in the field and puts it into a better equipped and organized shop. These preassembled sections may be made from material of any shape. The welding gives a stiffer, lighter, and cleaner, subassembly as a general rule.

Erectors like prefabricated sections because they save money by merely stacking sections, having fewer bolts to contend with, and fewer joints to check. The biggest disadvantage of the prefabricated tower is its bulk and resultant increased freight cost. For this reason, prefabricated sections are used in shorter towers. For example, shipping a 1,000-ft. tower in sections 1,000 miles would incur a total freight bill far in excess of the savings in erection. It is not correct to state that a prefabricated or preassembled tower is better than a knocked-down one, or vice versa. Total cost is the measure.

TOWER CONFIGURATION

The Uniform-Cross-Section Radiator

Most people are under the erroneous impression that the uniform cross section in radio towers was dictated by the radiation properties of an AM tower. It is true that the radiator of uniform cross section from top to bottom has radiating properties which an electrical engineer says are easier to predict. But note that self-supporting towers are tapered, although it is possible to build them with a uniform cross section. The electrical engineer simply has to contend with the radiating properties of a tapered structure.

Tapered guyed towers and nontapered self-supporting towers are built but not as a general rule. Most guyed towers are built with constant cross section and most self-supporting towers are tapered because of one simple reason—it is cheaper to build them that way.

Straight Base versus Pivot on a Guyed Tower

A guyed tower may be designed to come straight down at the base pier or to a pivot. Either method is satisfactory providing the conditions encountered are properly engineered. The advantage of a pivot base is that the pivot relieves a large bending moment at the pivot. In Fig. 4 this is graphically illustrated by comparing the mo-

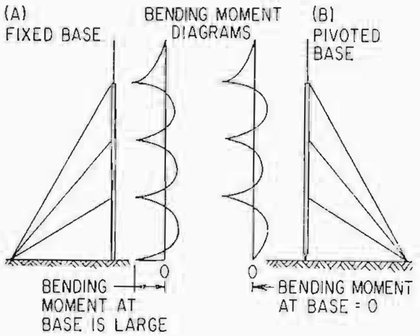


Fig. 4. Effect of a fixed base on a guyed tower.

ment curves of the two types of towers. The pivot saves steel and takes bending off the base insulator, if there is an insulator. The load on a pier is pure down load and the pier is a bit easier to design. The advantage of a straight fixed base is ease in fabrication. The erector can start erecting without using temporary guys. However, the bending moment tends to increase weight, the size of insulators (if any), and the size of the base pier. Also, the pier top must be perfectly level to distribute the load evenly from each tower leg.

Tower Weight

The weight of a tower is quite important. The weight comes into the calculations of the strength of the tower in a very simple manner. The heavier the tower, the greater is the total down load; consequently, more steel is needed and the sizes of the base insulator and base pier go up. In the 200-ft. AM guyed tower range, the weight is relatively a small percentage of the total design load, usually somewhere between 10 and 20 percent. This percentage increases with the height of the tower. In the 1,000-ft. tower range, the weight becomes an appreciable item. Skillful designers of steel towers recognize this fact and make some effort to keep down the dead weight. It is possible to have two towers equally strong and yet with entirely different weights. For example, as a general rule a four-sided tower made up of structural angles will weigh more than a triangular tower using round members and yet the design strength will be about the same in either case. The statement that tower A is stronger than tower B because it is heavier or vice versa is simply not true if both towers are designed to the same specifications.

A heavier tower will generally tend to have larger inertia or whip forces than a lighter tower. Usually these forces are not serious, but they may well be. For example, in a tall, self-supporting tower with a slender ratio and with a heavy antenna on top, whip forces are appreciable.

There is one practical minimum limit to the weight of a tower. The size of the members should not be so small that they are susceptible to damage in transit, during erection, or during maintenance climbing operations later on. Tower members should be rugged enough so that they can be handled as structures and not as fragile china. The average erector with heavy boots should be able to climb the tower without rolling over edges, bending thin members, or kinking

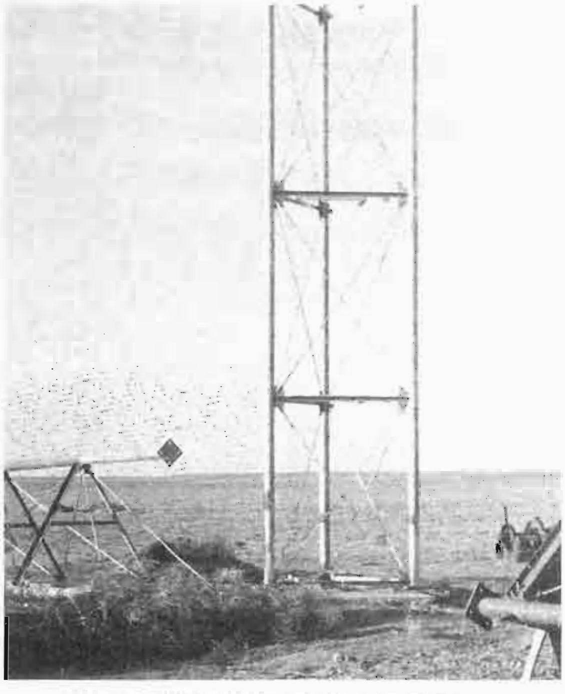
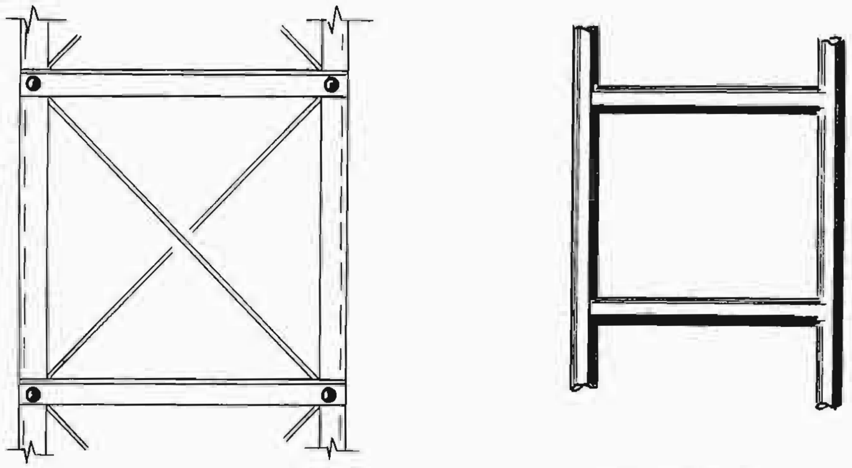


Fig. 5. Photograph showing fixed-base tower.

Fig. 6. Photograph showing tapered-base type tower.


CONVENTIONAL "X" TYPE BRACING

RIGID TYPE FRAME

Fig. 7. Conventional X-type and rigid-frame bracing.

small rods. Most towers used in the broadcast range today have members which are sturdy enough for ordinary usage.

Rigid-frame Trusses

Towers are designed as trusses, either the conventional type X or diagonal bracing or the rigid-frame type. The joints of a rigid-frame type of truss are moment-resisting and are usually welded. Conventional-type trusses are usually bolted at joints, and the joints are considered to be hinged. In rigid-frame trusses, the members have bending stresses as well as axial stresses. Standard methods of analysis can be used for determining the stresses. Rigid-frame trusses tend

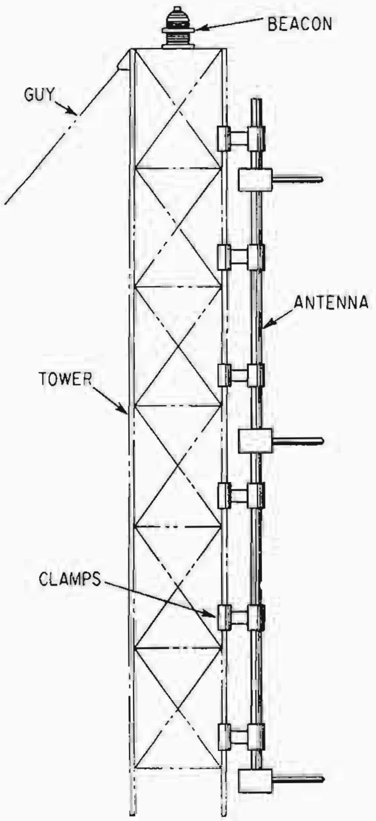


Fig. 8. Side antenna attachment.

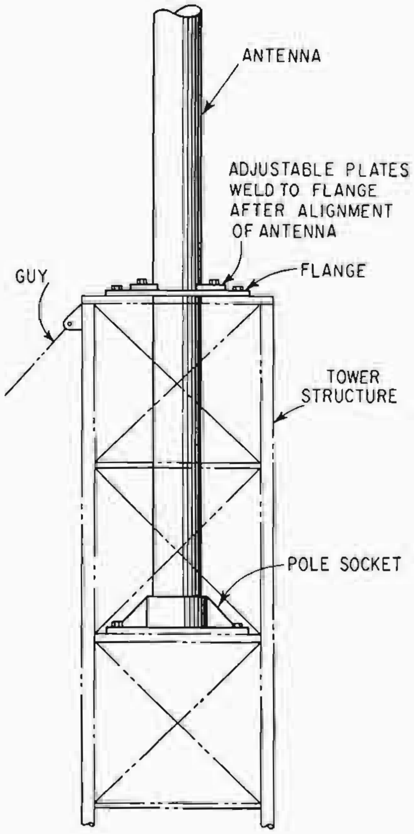


Fig. 9. Telescopic antenna mast attachment.

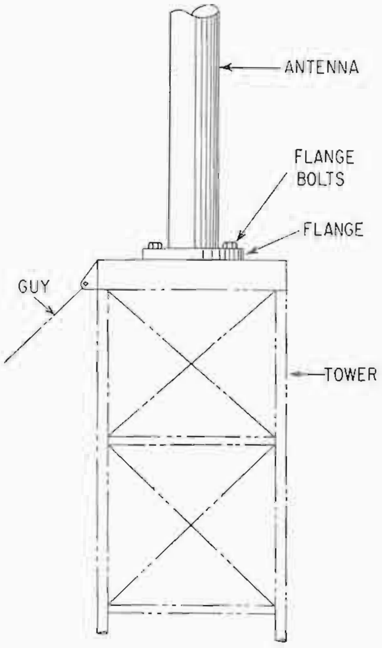


Fig. 10. Flange antenna attachment.

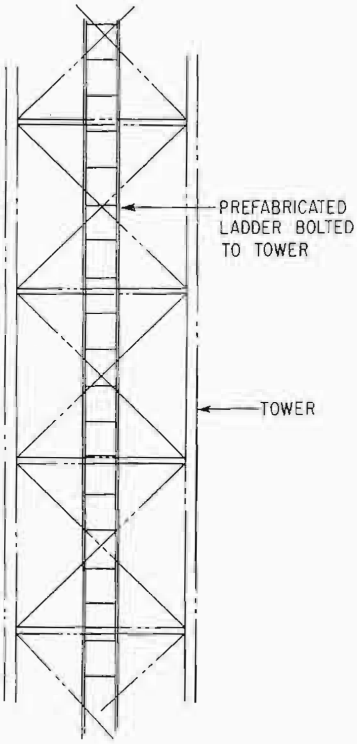


Fig. 11. Ladder mounted on tower face.

to be very clean aerodynamically and offer a minimum resistance to wind. They have also proved themselves quite economical for towers, particularly in the short heights.

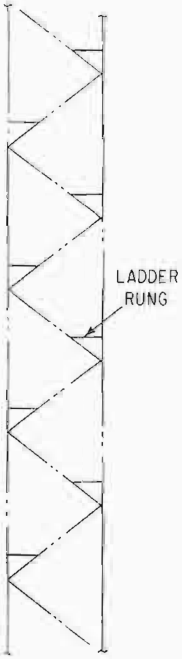


Fig. 12. Ladder steps welded to tower structure.

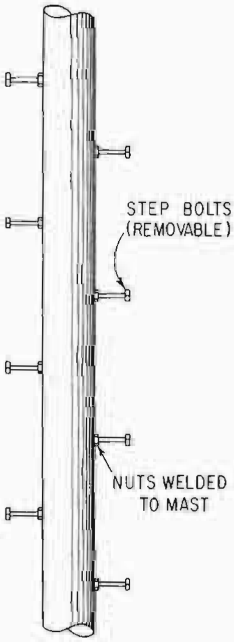


Fig. 13. Step bolts on cylindrical mount.

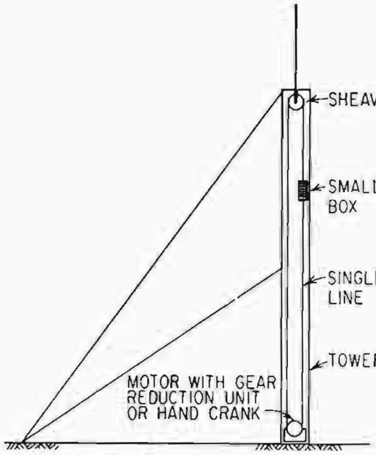


Fig. 14. Dumb-waiter type of lift.

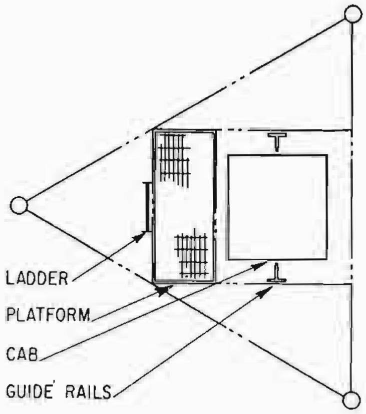


Fig. 15. Typical section through elevator.

TOWER ATTACHMENTS

Antenna

The prime purpose of a TV tower is to support the TV antenna and its feed system. The attachment of the antenna to the tower is a problem, especially when the antenna is large.

Antennas have been mounted on towers in three different methods. One method is to side-mount the antenna onto the tower. In general, when this method is used, the radiating elements are clamped onto the vertical tower members. This method of mounting the antenna has the advantage that the loads caused by the antenna are kept to a minimum and also the antenna loads can be distributed over the tower easily.

A second method of mounting an antenna on a tower is with the telescoping-pole type of mount. The pole telescopes down the center of the tower, the distance depending upon the size of the antenna. At the top of the tower, the pole has some sort of adjustable guide so that it can be plumbed. The bottom of the pole fits into the pole socket. Usually the pole socket is a fixed position and is not adjustable.

The third common type of antenna mount is the flange mount. A flange-type antenna mount suddenly dumps a large overturning moment into the tower. If the moment is large relative to the capacity of the tower as with some TV antennas, the problem can become quite nasty structurally.

Usually it is necessary to install the antenna in a vertical position. The top of the tower or the leveling plates as furnished by some manufacturers should be checked to make sure they are level before actual installation of the antenna.

Climbing Facilities

A tower must have some climbing facilities in order to maintain it and its equipment. Sometimes short towers have the tower members themselves arranged in such a manner that they act as step bars. Various climbing facilities are illustrated in Figs. 11, 12, and 13. When towers are short, step bolts similar to the ones seen on telephone poles are occasionally used. As the tower height increases, these step bolts do not give a feeling of security to the person climbing. As a general rule, ladders are provided on tall towers. Erectors themselves usually prefer a ladder on the face of the tower, since the erector likes to climb on the outside of the tower where he has fewer encumbrances. Most engineers and station people, however, who climb the tower occasionally to check antennas or lights feel safer if the ladder is within the confines of the tower cross section so that the outside of the tower forms, in effect, a natural safety cage. A safety cage is sometimes provided so that it is practically impossible to fall out. Usually, safety cages are not called for, since they add wind load to the tower and, consequently, increase the cost.

On taller towers, some form of hoist or elevator is occasionally used. The simplest arrangement, shown in Fig. 14 is, in effect, a form of dumb waiter.

Tower Elevators

It may take a man 3/4 hr. to climb the full length of a 1,000-ft. tower. If there is any equipment to be lugged up, this adds quite a burden to the climber. For this reason, it is often desirable to install an elevator in towers over 1,000 ft.

The elevator adds to the wind and dead loads, and so, the tower has to be designed originally to carry the elevator. A well-designed elevator embodies the elements noted in Fig. 16. There are many variations of the details required.

An elevator suitable for use in a tower consists of a driving mechanism, car, guide rails, hoisting

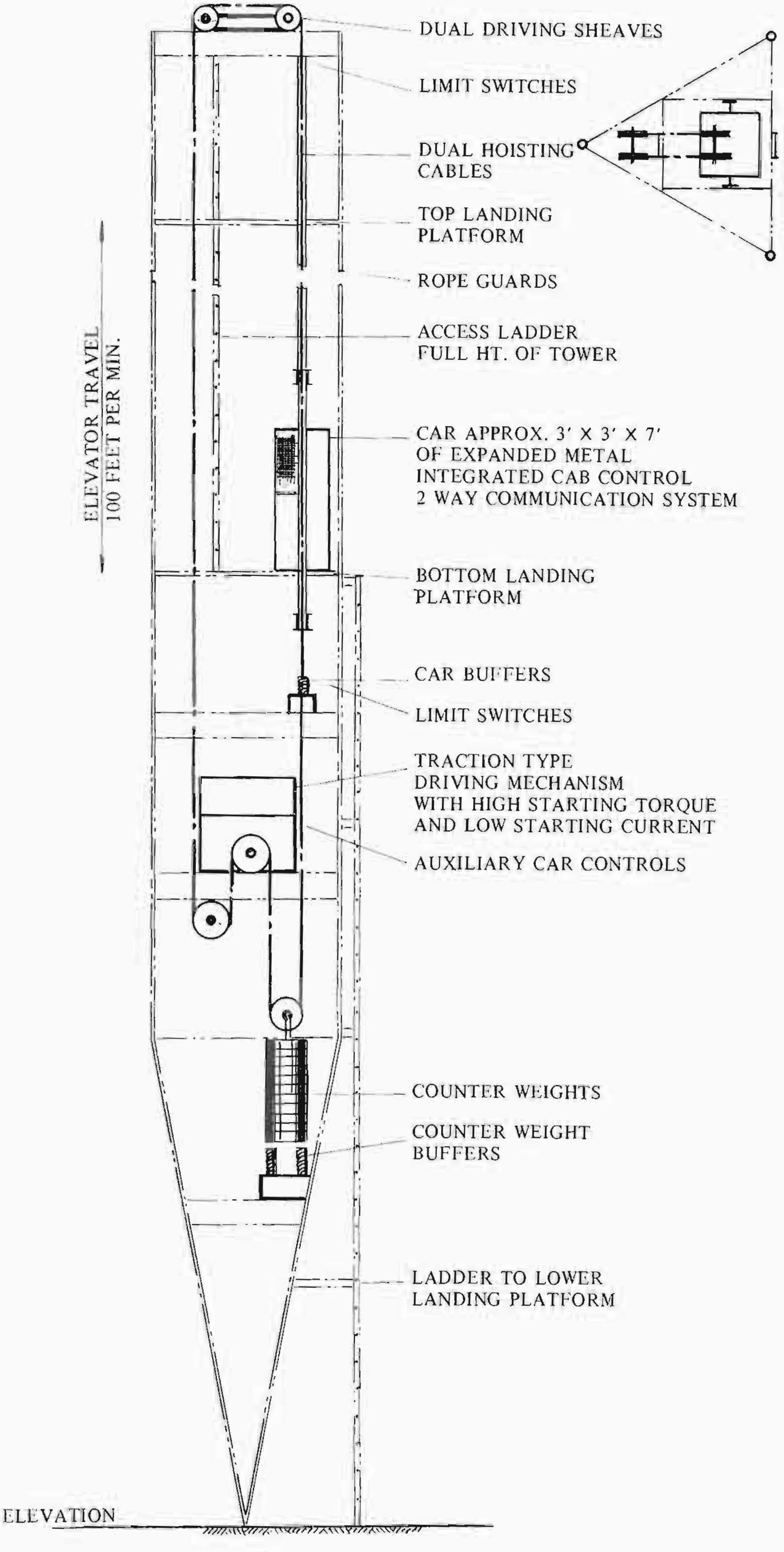


Fig. 16. Typical elevator installation.

cables, counterweights, integral and auxiliary cab controls, and two-way communication system. The guide rails should be machined to provide a smooth, steady ride. The T shape is commonly used, but rounds are used to cut wind loads. The driving mechanism should be a traction type with a high starting torque and low starting current. Rope guards are necessary to prevent entanglement of the hoisting rope in the tower structure during severe wind storms.

Different people prefer cages of different sizes. The tower designer leans toward a small cage; the owner would rather have a large cage. Elevators have a relatively slow rate of climb, simply because it keeps the power requirements and the cost down. The commonly used rate of ascent for elevators today is 100 fpm. Elevators are available with electronic controls and two-way communication systems in cab and tower base so that the operator is able to stop the cage at any height.

Considerable attention is given to safety devices in the design of a tower elevator. For example, in case of hoisting-cable failure, spring-loaded cams automatically are brought into play to freeze the car against the guide rails. Limit switches stop the car motion past either the upper or lower landing platforms should the operator fail to do so. The brakes on the driving mechanism are spring applied, electrically released, and designed to be automatically applied in the event of interruption of power from any cause. A tension device is supplied, limited by moistureproof switches which will cut off power in the event of cable stretch or excessive cable motion. Finally an access ladder is supplied for the full height of the tower to be used as an emergency descent.

TOWER PROTECTION

Galvanizing

Galvanizing is the process of coating metals, usually steel and iron, with zinc. One of the peculiarities of the zinc trade is that this coat is expressed in ounces of zinc for a square foot of surface. Most galvanizing is done via the "hot-dip" method. That is, steel is dunked into a zinc bath and then pulled out. The excess zinc drips off, and a certain thickness of zinc stays on the steel. If a thick coat is desired, the steel is dunked a second or even a third time. This is termed a double or triple hot dip. How does this zinc help? Zinc is higher than steel in the electrochemical series. It means that the zinc tends to be eaten away over an area before the steel does, even if the zinc surface is scratched to expose bare steel. Corrosion of steel is delayed until the adjacent blob of zinc is depleted.

Obviously, the life of the coat depends on the thickness or weight of the zinc coating and the atmosphere. For years, the American Society of Testing Materials has been testing miscellaneous weights of zinc on steel structures in different parts of the country. There are available estimated life curves of zinc coats in various atmospheres, expressed in years versus the coat thickness, in such locations as Pittsburgh, Pa.; Sandy Hook, N.J.; and Ames, Iowa.

Almost all guy strand and wire rope are zinc-coated for the simple reason that the individual wires making up the guy are small and usually run in diameter from 1/16 to 3/16 in., so that corrosion is a critical factor.

Since the zinc coat will impose an additional cost, should one galvanize? This will depend upon conditions. First of all, it is impossible for steel to corrode if the paint is properly kept up. However, there may be installations in certain highly corrosive atmospheres where maintaining the paint will present quite a problem. Those installations are not too frequent. If the broadcaster properly maintains his paint, then this should be adequate. On small, unattended towers where inspection may not be too regular, there is some merit in galvanizing. It is also possible in large, unusual towers where a special dispensation has been obtained to paint only a portion of the tower that it may be worth galvanizing only those portions of the tower which are never painted.

Tubular members, if galvanized, should be galvanized both inside and outside or else the drain holes should be plugged up. Care should be taken to seal the ends of tubes on tubular structures if they are not galvanized. Moisture or oxygen cannot get inside a properly sealed tubular member, and therefore there is no possibility of corrosion on the inside surface.

Painting

FCC Requirements

The Federal Communications Commission has prescribed a set of standards to provide an effective means of indicating the presence of obstructions to air commerce. Radio and TV towers, because of their height, are considered as possible obstructions to air navigation by the Federal Communications Commission and, therefore, must be marked and lighted accordingly.[1]

To comply with these regulations, the towers are painted in contrasting colors of white and international orange in alternate bands for maximum visibility during daylight hours. The exact spacing of these bands is spelled out on the face of the construction permit. The FCC also requires that towers be painted as often as necessary to maintain good visibility. Obviously the painting becomes quite a maintenance problem, and if it were not for this paint regulation, probably the cheapest finish would be a coat of zinc.

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[1] Federal Communications Commissions Rules and Regulations, Part 17.

Surface Treatment

Paint will not stick to brand-new galvanized surfaces. The erector should treat the surfaces of the galvanized parts. Some fabricators give galvanized parts a special treatment prior to shipment so that the surface is prepared for painting. Any number of solutions have been made to etch this smooth zinc coat. The simplest and most commonly used treatment is plain vinegar or a weak acetic acid solution which is applied to the surfaces in the field prior to painting. A better solution is as follows:

2 oz. copper chloride
2 oz. copper nitrate
2 oz. sal ammoniac
2 oz. muriatic acid
1 gal. water

Apply with rag or brush to the tower, and allow to dry for 10 hours before applying paint. Galvanizing will first turn black and then a dull gray. Such a treated galvanized surface requires no primer. Another way to treat galvanized sections is to let them weather a period of three months to a year depending on whether the tower is located in a dry or a salty and moist atmosphere.

Application

Paint usually consists of two coats. The outside coat is a hard enamel, either orange or white and sometimes black. The enamel has wearing qualities and is relatively tough. However, enamel does not stick very well to plain steel. For this reason, towers usually have a primer coat. The purpose of the primer coat is to effect a bond between the steel and enamel.

Primer will not stick to a surface which has scaled rust, mud, dirt, oil, or grease. For that reason, the surface has to be fairly clean. If the rust is scaly, it should be wire-brushed off. If the surface is dirty or oily, it should be wiped with a thinner, alcohol, gasoline, or any number of cleaners or detergents. There are many good primers—red lead, iron oxide, zinc cromate, and combinations thereof. The primer should be on the thin side, since a thick primer has a tendency to peel. The primer has no staying qualities; that is, it will not weather very long.

Tests show that international orange and white enamels from most reliable companies are good. The life of the orange and white paint depends upon the location. In the dry desert parts of the United States towers do not require repainting for 10-year stretches. Towers along the seacoast, which are constantly subjected to salt spray and sunshine, require a new coat of paint approximately once a year. There is no fixed rule in the length of the life of the outside coat.

Broadcasters should be cautioned about getting unusually cheap prices for painting or repainting a tower from unknown erectors who happen to be passing through town. These "fast prices" sometimes leave one with a tower where only the bottom 100 ft. are painted beautifully and the rest of the tower is painted on the bottom surfaces only.

On paint maintenance contracts, broadcasters should make sure that the painter has public liability and property damage insurance coverage, since it is very difficult to keep the paint from flying, even in a very small wind. This is a very definite hazard, since neighboring buildings and cars are constantly being covered by flying paint.

TOWER GUYS

Steel Guy Material

Rope and Strand

Tower guys are usually made out of steel rope or steel strand. Both rope and strand are made up of high-strength steel wires. A number of wires spun as a single group is called a strand. A number of strands spun to form a group is called a rope.

The advantage of steel rope is that it is flexible. That is, it is capable of being run over sheaves or pulleys continuously. The disadvantage of rope is that it has a low modulus of elasticity (it is more stretchable than strand) and, as a general rule, it is more expensive than strand. Strand as a rule is preferred in towers because it has a high modulus of elasticity, does not stretch so much as wire rope, and is cheaper per foot for a given strength.

Catalogue value for strand modulus of elasticity is 24 million. This 24 million is a minimum figure. The 24-million figure is fairly consistent and constant. Coiling and uncoiling strand decrease this figure less than 1 percent, but it comes back to the 24 million.

It is the considered opinion of most engineers that there is no such thing as a yield point for strand. The curve falls off gently to a breaking strength. The catalogue values of the ultimate strength or breaking strength of strands are always minimum. The range of breaking strength is usually 2 to 10 percent above catalogue values.

Strand is made from high-carbon cold-worked wire. It is very rugged and very insensitive to notch defect. It will take quite a beating. A good approximation of estimating the percentage of reduction in strength of strand is to note how much wire is cut. For example, if you have 19 wires in a strand and one wire is nicked halfway through, then that strand is subject to a reduction in breaking strength of approximately 1/38 of the catalogue value.

As a rough rule of thumb, it takes 2 percent of the breaking strength of a 19-wire strand to stretch that strand or cable out to its true length. A 1 by 7 strand will require approximately 5 percent of breaking strength.

Prestressing

When a prestressed cable is wound up on a reel and then unwound in the field, there is a negligible amount of length lost. This has been proved many times by checking on long cables for 1,000-ft. towers and on suspension-bridge cables.

Prestressing the guys at a strand manufacturer's plant takes out some of the structural stretch. Most wire manufacturers will pull the guy to 50 percent of ultimate and hold for approximately 1/2 hr. Prestressing will stretch the strand somewhere from 1/10 to 1/4 of 1 percent of the length.

Bird Caging

Bird caging can occur in both manufacturing and in handling in the field. Bird caging prior to shipping is rare. Bird caging in the field is caused by a kink in the strand, unreeling improperly, allowing a large reel to get away, getting a loop in the strand, dropping a guy, or anything that puts wires in compression. Since most strands (19 wires and over) have lays going both ways, there is no method of really fixing a true bird cage. There is no tendency for wires to unravel and bird-cage by themselves. That is, all strands are basically very stable.

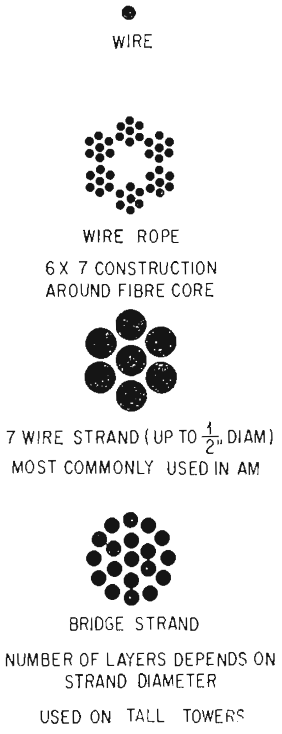


Fig. 17. Composition of typical guy material.

Fatigue

We have never heard of a fatigue failure of wire where it enters a socket on a guyed tower. However, such failures have occurred in sockets which come out on highly loaded shovels where there is continuous large vibration on strands which are constantly highly loaded in tension.

This question arises every now and then when the tower guy has been stretched in a wind storm and you take up the slack: Is the guy breaking strength reduced? The answer is No. For example, strand in preloaded concrete slabs have initial tensions up to 70 percent of the breaking strength, and the working tension of the strand is 50 percent of the breaking strength. Notice that you can take strand and load it to 70, 80, or 90 percent of the breaking strength; unload the strand; and still get 100 percent breaking strength.

Zinc Coat

The usefulness of a zinc coat on a guy comes from the fact that the zinc coat wastes away instead of the load-carrying steel. The zinc does not protect the strand wire indefinitely. The fact that zinc wastes away rather than steel is good. It should be pointed out that the smaller the wire diameter, the thinner is the zinc coat. Using a galvanized socket instead of a black one on the end of a guy will not appreciably increase the life of the guy. It is also for this reason that when you have a corroded clip, the best thing to do is to leave it alone. Corrosion usually starts at the threads where the zinc is stripped, and there is usually enough "meat" in the rest of the clip and in the guys to take care of itself.

AM Guys

Guys on AM towers have to be made nonradiating. The currently accepted method is to break the guys up with insulators into lengths approximately one-seventh of the wavelength on the radiator. Obviously, this breaking up of the guys is a necessary nuisance. People constantly are looking for guy materials which would be nonradiating. To date, such materials as nylon and dacron have too much stretch to be of any practical value. However, in the foreseeable future, it is possible that some such material may be usable. A new polyester film material Mylar bears watching. At the moment it is expensive, but it does not have the great stretch which nylon has.

Guying Arrangement

A three-way guying arrangement where the guys are laid out 120° apart in plan form shown on accompanying Sketch A of Fig. 18 gives the

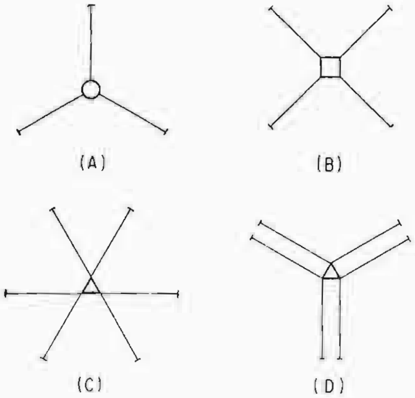


Fig. 18. Commonly used guying arrangements.

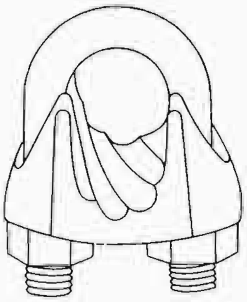


Fig. 19. Wire-rope clip.

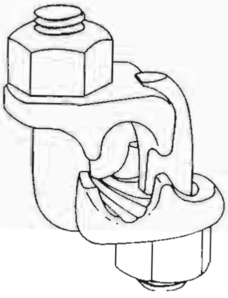


Fig. 20. Laughlin safety clip.

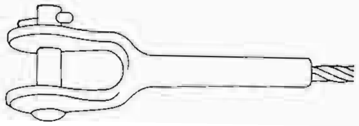
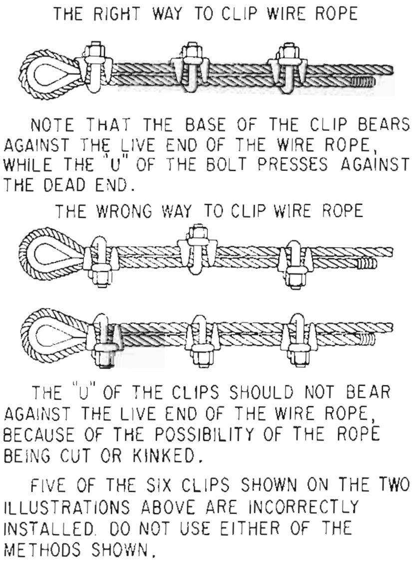


Fig. 21. Swage fittings.



THE RIGHT WAY TO CLIP WIRE ROPE

NOTE THAT THE BASE OF THE CLIP BEARS AGAINST THE LIVE END OF THE WIRE ROPE, WHILE THE "U" OF THE BOLT PRESSES AGAINST THE DEAD END.

THE WRONG WAY TO CLIP WIRE ROPE

THE "U" OF THE CLIPS SHOULD NOT BEAR AGAINST THE LIVE END OF THE WIRE ROPE, BECAUSE OF THE POSSIBILITY OF THE ROPE BEING CUT OR KINKED.

FIVE OF THE SIX CLIPS SHOWN ON THE TWO ILLUSTRATIONS ABOVE ARE INCORRECTLY INSTALLED. DO NOT USE EITHER OF THE METHODS SHOWN.

Fig. 22. Proper method of applying rope clips.

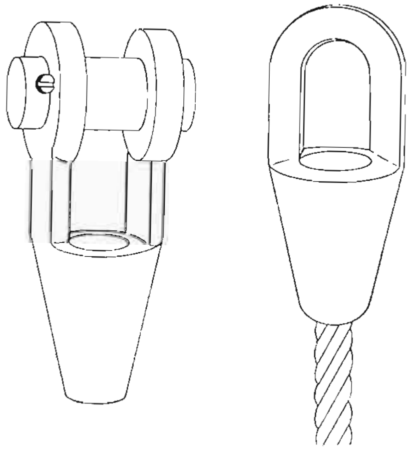


Fig. 23. Wire-rope sockets.

simplest possible guying arrangement which will support a tower in a wind from any direction. This gives the smallest number of guys and usually tends to give you cheaper foundations and a smaller number of insulators.

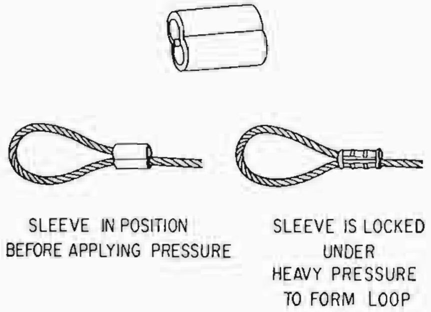


Fig. 24. Nicopress sleeve-type fitting.

A much-used guying arrangement is shown on Sketch B of Fig. 18. A foursided tower has four sets of guys spaced 90° apart in platform.

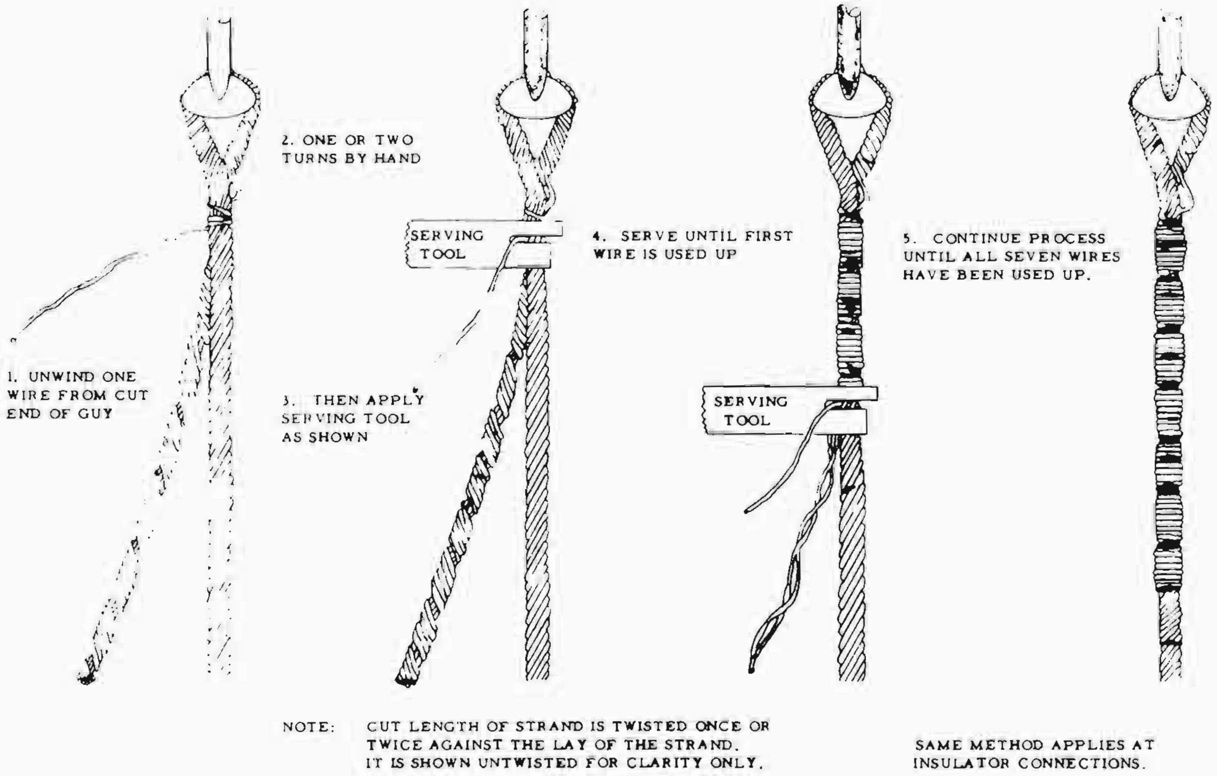
A guying arrangement such as shown in plan form C (Fig. 18) has been used in tall towers. The disadvantage is the need for more anchors. The advantage is that it tends to save in the column load on the tower and some weight.

A guying arrangement as shown on plan form D (Fig. 18) shows double guys coming off each face. The advantage of this system is that it gives the tower some torsional resistance until the tower has twisted. The disadvantage of plan form D is extra handling by the erector. Most erectors prefer single rather than double guys.

Guy Connections

Clips

The most commonly used guy connections at the insulators are steel clips. These clips are relatively cheap, and they are easily available. They are used by the millions. The efficiency of the clip depends upon drawing the clip up tight. In Fig. 22 showing a properly drawn up clip, you will notice that the yoke must make a definite dent on the surface of the strand. It is also a known fact that after you put load on a guy, you can pull the clip up a little more. Since this is very difficult to do in a guy with many insulators in it (which are made in the field), clip efficiency should not be rated over 80 percent. It is possible to get clip efficiencies in a laboratory over 95 percent. The greatest danger in a clip is that the erector may forget to draw up all clips securely. The best visual inspection that we know of is to check whether the yoke of U part of the clip puts a definite dent in the guy. These clips come in many shapes and forms such as shown. All clips rust sooner or later. When a clip is drawn up, some of the zinc strips off the threads and you have a focal



NOTE: CUT LENGTH OF STRAND IS TWISTED ONCE OR TWICE AGAINST THE LAY OF THE STRAND. IT IS SHOWN UNTWISTED FOR CLARITY ONLY.

SAME METHOD APPLIES AT INSULATOR CONNECTIONS.

Fig. 25. Serving guy connections.

point of corrosion. Most clips are sturdy and have enough "meat" in them to last for many years. This corrosion depends on the atmosphere in which the tower is sitting. Some erectors have lately been spraying their clips with clear plastic lacquers which come in pressurized cans.

Serving

A neat and clean-looking connection which is very simple to apply has been developed by the power companies in their work. It is the so-called "serving." The several wires are unraveled, then each individual wire is rolled back on the strand. The efficiency of this method is usually in the high 90 percents. It makes a clean connection. It is a safer connection than a clip connection, since you do not run the risk of forgetting to run up the clips tightly. It also does away with the problem of corrosion of the clips.

Sleeves and Sockets

There are several makes of sleeves which are press fittings. This again was developed by power companies. They are good-looking and neat on smaller sized guys.

Large guys usually make use of zinc sockets. On most towers today, the sockets are supplied on the strand by the guy fabricator, since their application takes a certain amount of skill and technique. These sockets are usually made of cast or forged steel.

Preformed Guy Grips

Another relatively new guy end fitting is the preformed guy grip. This grip is essentially a wire loop with a "pig tail" which wraps around the guy end. This pig tail is made of a series of side by side wires which wrap neatly around the guy, and which have an abrasive material which increased the friction and keeps it from pulling loose.

This type grip is generally used with guy diameters 1 in. or under, and combines the desirable characteristics of clipped guys (field installation) and socketed guys (it develops the full strength of the strand, thus requiring a smaller factor of safety than is required for clips). It is generally cheaper than socketing in the sizes mentioned above, although field installation costs will be slightly higher than for socketed guys.

Guy Tension

The proper initial tension in guys is an integral part of tower design and should be determined by the tower manufacturer. Proper guy tension is necessary in order to control the deflection of the tower so that certain specified limits are not exceeded and in order that deflection of the tower does not weaken it.

Common values of initial tension in guys vary between 5 and 25 percent of the breaking strength of the guy, depending on the design and requirements. In general, a low initial tension tends to give a more flexible and lighter tower. A high initial tension tends to give a stiffer and heavier tower. Initial guy tension in a properly designed tower seems to have little effect on the ultimate strength of the tower.

During erection and in maintenance, there is danger of putting too much tension in guys. This overloads the tower as a column and literally pulls the tower down to failure.

Initial tension is seldom specified on small AM and communication towers up to heights of 200 or 300 ft. In these cases where the exact initial tension in guys is not critical from the deflection point of view but is critical in that overload can cause tower failure, tower manufacturers should specify an initial tension and the erector or the maintenance men should check the guy tension by some convenient method such as with a dynamometer.

It is common practice on taller towers with a pivot base that guy tensions are adjusted either so that the tower deflects as a straight line from its base to its top when loaded with the design load or so that the differential deflection at guy points is taken into account in calculating the stresses in the tower members. On these large towers, the erection drawings always specify guy tension and some method of checking it. A number of methods commonly used to measure initial tension in the field are described.

Methods for Determining Guy Tension

Calibrated-rule method. In the calibrated-rule method, two buttons are attached approximately 8 ft. apart to the lower end of the guys. During fabrication of the guys, the required initial tension is applied to the guy. While this load is on the guy, a rule is marked exactly the same as the buttons. In erection, the guy is tightened up until the marks on the buttons line up with the marks on the rule.

Although various stable metals are used to fabricate the rule, this system is subject to errors from several sources. The most likely source of error is the fact that the gauge length (approximately 8 ft.) is relatively small and therefore the change in length of the guy in the 8-ft. length will be very small. The eye cannot see much closer than 0.01 in., and an error of this magnitude would result in a 10 to 20 percent error in the initial guy tension. It is doubtful that the erector in the field would take the trouble to read these calibrations with any great precision.

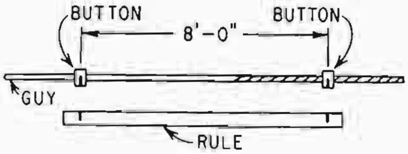


Fig. 26. Calibrated-rule method.

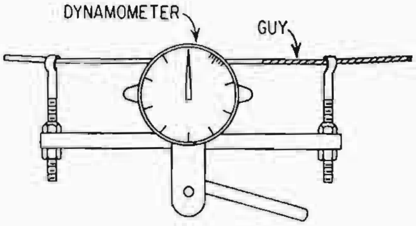


Fig. 27. Shunt-type dynamometer.

Temperature is another factor that must be compensated for, particularly when the linear coefficient of expansion of the guy differs from the rule.

Shunt-type dynamometer. This type of dynamometer or tensiometer is used in determining and maintaining the proper sag or tension in guys. It can be used without breaking-in on the guy to be tested and can be left on the guy until the dial shows the desired reading.

The principle of the shunt dynamometer is based on the relation of the tension in the strand to the force necessary to displace it in a direction perpendicular to the axis of tension.

The dial is graduated from 0 to 100 units and does not read directly in pounds. Tension is determined from graphs specially prepared for each size and type of wire or cable on which the dial reading is plotted against tension in pounds. The manufacturer guarantees the accuracy to within plus or minus 2 percent of the dial reading.

On relatively short towers with small guys, use of a mechanical tensiometer is probably the most practical method to measure guy tensions. On tall towers with large guys, the sag of the guys becomes appreciable and can be used as a measure of guy tension. The guy-sag method is a relatively simple and very practical way to check the guy tension.

Guy sag can be checked with a transit or with a sight bar. We shall briefly describe the sight-bar method. A straight bar made of steel or wood with two hooks is used to make the line of sight parallel to the guy. If the unaided eye cannot see clearly to set the intercept, a telescope can be used as shown in Fig. 28. It is important in making up this sight bar that the line of sight of the bar be parallel to the guy at its point of attachment. This method is quite accurate in setting initial tension when the guys and intercepts are large. For example, a 100-ft. intercept read with 2 ft. has an approximate error of 2 percent. Tension is given by the following formula:

$$T = \frac{WL^2}{2l}$$

The values of the weight of the guy per foot, the span of the guy, and the recommended tension of the guy should be readily available from the tower manufacturer.

Example: 1,000-ft. tower with 1-in. guy strand

L = 1,220 ft.
W = 2.14 lb./ft.
I = 160 ft.
$$T = \frac{(2.14)(1{,}220)^2}{(2)(160)} = 9{,}950 \text{ lb.}$$

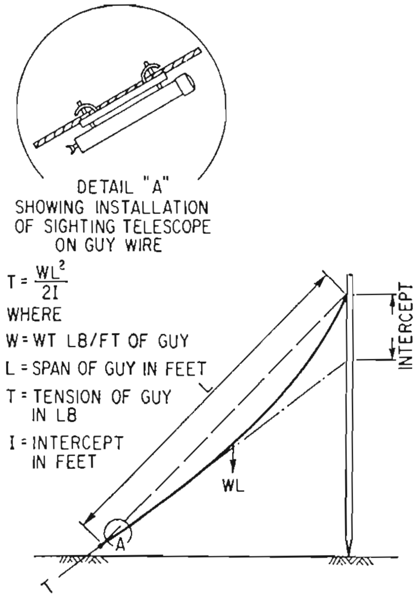


Fig. 28. Use of "sight bar" for determining guy tensions.

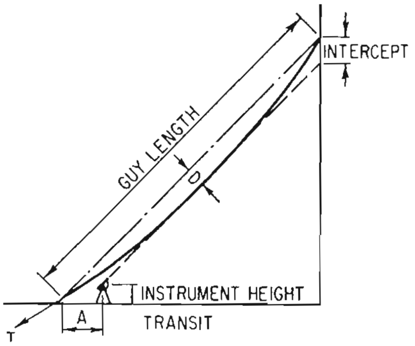


Fig. 29. Transit-intercept method for tensioning guys.

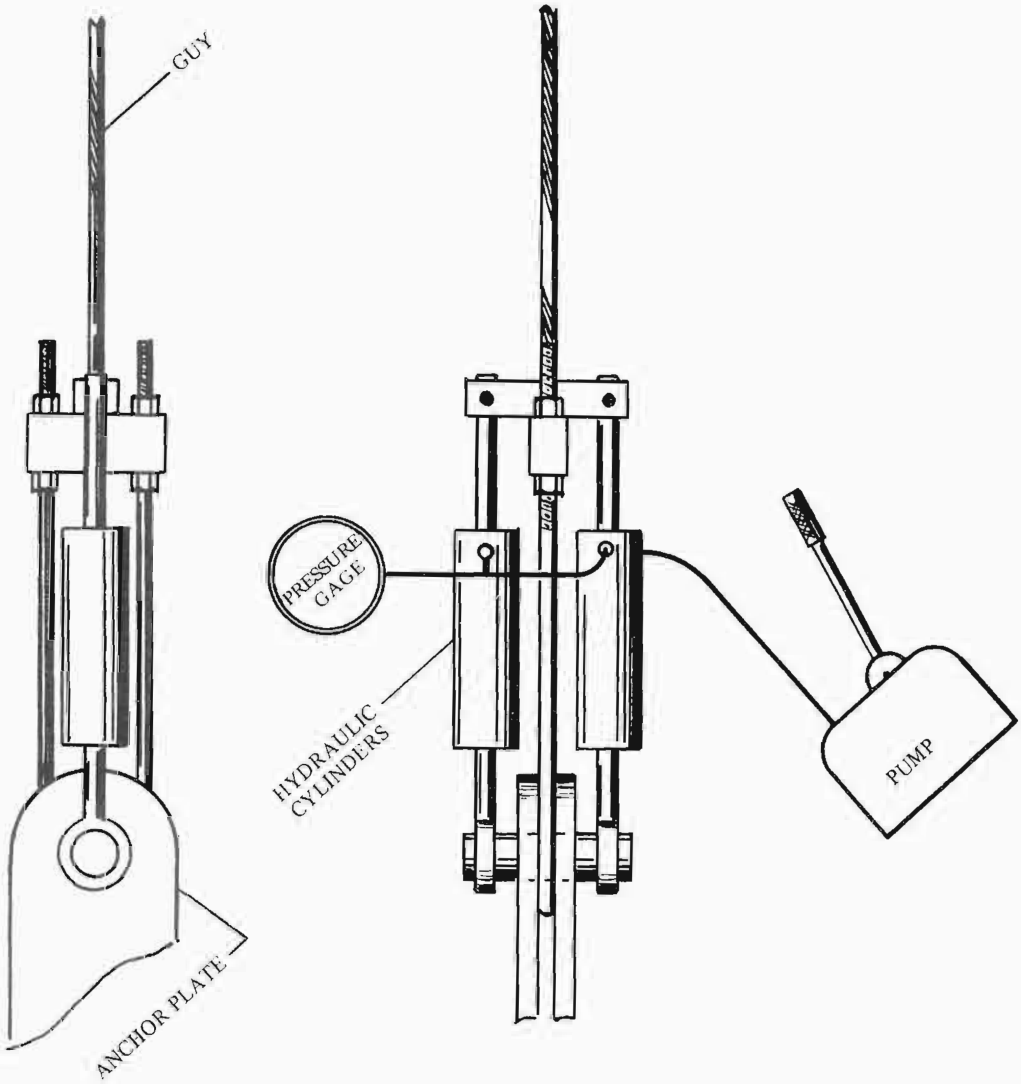


Fig. 30. Hydraulic-cylinder method for measuring guy tensions.

Transit-intercept method for tensioning guys. With guy length and desired tension *T* known, the sag *D* is calculated from standard formulas. Again with known instrument height a sight line is established tangent to the guy and ground distance *A* and tower intercept determined. At erection a transit is set up using these intercepts to establish the line of sight. The guy is then tightened until it becomes tangent to the line of sight.

Hydraulic-cylinder method for measuring guy tensions. The guy is put under the required tension with two push-pull hydraulic cylinders which are usually pumped up by hand. The required tension is read on the pressure gauge. The nuts are pulled up on the U bolt or turnbuckles to hold this tension in the guys. Hydraulic units are then removed. It is recommended that the hydraulic cylinders and gauge be checked accurately prior to use, since there is a tendency for errors to creep into the gauge.

Spring method of tensioning guys. A spring with known deflection characteristics is selected and installed in the guy anchor connection. The guy is tightened until the spring has deflected the desired amount, thereby obtaining the required tension in the guy. A combination tubular spring cover and spacer of predetermined length is normally used to obtain the correct deflection. Caution: Do not continue to tighten the guy after the spacer has bottomed; otherwise, excessive tension will be applied to the guy.

Vibration method of measuring guy tensions. The guy is set properly vibrating by pulling the guy back and forth sideways with the hands. Vibrations are timed with a stop watch. This reading is then substituted in the following formula and the initial tension is calculated.

$$\text{Cycles/min.} = \frac{170T}{L \times (\text{wt./ft. of guy})}$$

where L = length of guy, ft.
T = guy tension, lb.

The vibration method applies to guys of uniform weight and is not applicable to guys with insulators or other concentrated weights. It must be pointed out that this system is only as accurate as the measurement of the frequency of the guys.

Dynamometer method. As shown in Fig. 33, a tension-type dynamometer is mounted between a cable grip and usually a chain hoist. A load is applied to the dynamometer, and when the desired reading is reached, the guy turnbuckle is tightened accordingly. The dynamometer equipment is then removed.

$$S = \sqrt{1{,}000^2 + 700^2} = 1{,}220.6555 \text{ ft.}$$

Given: W = 2.073 lb./ft.–1-in.-diam. guy
T = 10,000 lb.–initial tension

Sag in guy wire with 10,000-lb. tension

$$D = \frac{WS^2 \cos\theta}{8T}$$
$$= \frac{2.073 \times (1{,}220.6555)^2 \times 0.57346}{80{,}000}$$
$$= 22.1411 \text{ ft.}$$

Assume that the guy takes the shape of a parabola

$$L = S + \frac{8D^2}{3S}$$
$$= 1{,}220.6555 + \frac{8(490.2283)}{3{,}661.9665} = 1{,}221.7265 \text{ ft.}$$

Length of guy at 10,000-lb. tension.

Guy Vibration

Although guy vibration is not, as a rule, a serious problem, it may be well to note its effect. Tower guys have been known to vibrate in a few isolated instances. The natural frequency of any tower guy is a function of:

1. The length of the guy
2. The tension in the guy
3. The weight distribution of the guy

A change in any of these constants will change the frequency of the guy. The natural frequency of a guy without ice is different from that with ice simply because the weight of the ice changes the weight distribution of the guy and automatically increases the tension in the guy. Obviously, if a guy begins to vibrate, changing any of these constants, namely, knocking ice off the guy, adding weights to it, shortening its effective length by a bridle, increasing or decreasing its

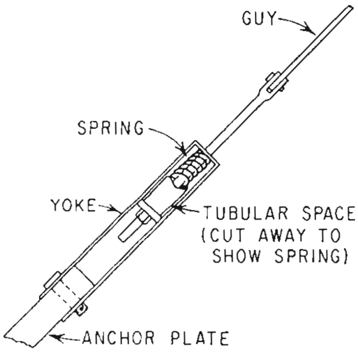


Fig. 31. Spring method of tensioning guys.

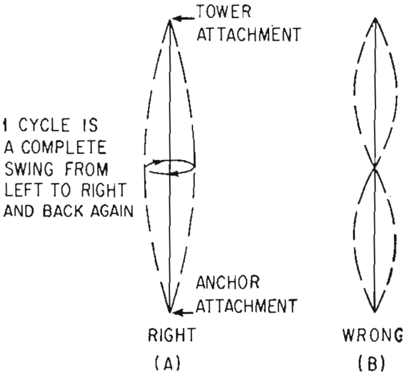


Fig. 32. Vibration method of measuring guy tensions.

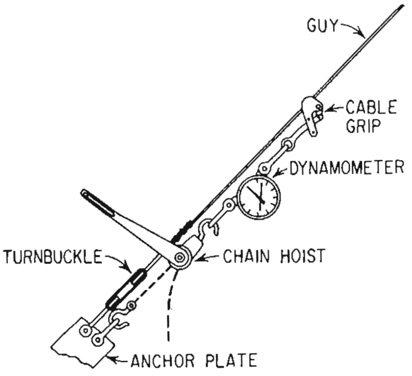


Fig. 33. Dynamometer method.

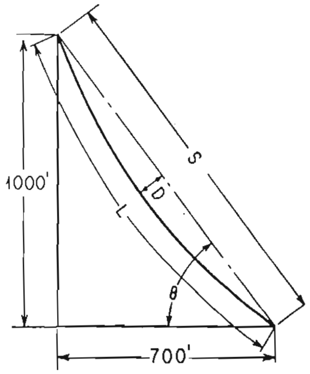


Fig. 34. Method of calculating guy lengths.

tension, should kick the guy out of the vibrating frequency. If long guys are provided with weights which are attached to the guys at irregular intervals, the probability of vibration is theoretically reduced. Insulated towers have these weights already on them in the form of guy insulators. Some towers come with some form of cast-iron weights which are clamped around guys to form the guy dampener. Most tower designers feel that a guy dampener is easy enough to install should you get vibration where no dampeners were specified.

WINDS, WEATHER, AND HAZARDS

Wind Velocity

The Weather Bureau aims to get true wind velocities at a height of approximately 10 m (33 ft.) in open exposure and ten times as far from any obstruction as it is high. The Bureau tries to approach this ideal, but it should be obvious that sometimes it is virtually impossible to find such an exposure for all wind directions in a well-built-up city and even in some airports. The Weather Bureau's figure for true wind is measured over a 1-min. time interval. Some countries use up to 10 min. The Weather Bureau also gives the fastest mile as maximum gust velocity or the peak indication of a pressure tube anemometer. A cup anemometer tends to overregister in a gusty wind. However, this overregistration is very small and never more than a few percent.

Indicated versus True

There is misunderstanding about indicated and true wind velocity. Any figure obtained from a Weather Bureau today or in the last quarter century is a true wind velocity. This true wind velocity is also the indicated velocity. This is because anemometers have been calibrated and the indicated and the true are practically the same. However, in about 1898, the Weather Bureau discovered that the anemometers were registering approximately 25 percent too high. In order to avoid throwing away at least a quarter century of Weather Bureau records already obtained, the Bureau decided to keep on with the figures which were 25 percent high. This continued until about 1924. This means that records prior to 1924 may show an indicated and a true wind velocity differing by approximately 25 percent. Any wind velocities given by a Weather Bureau since that time are true wind velocities.

Since air is a viscous fluid, the ground has a certain amount of "slowing-up" effect on the wind velocity. Another way of putting it, wind velocity tends to increase as height above the ground is increased. Obviously this velocity gradient is not a constant, nor is it easy to express. The Weather Bureau gives the formula shown in Fig. 35 for velocity ratios as expressed in terms of height. The constant N is somewhere between 2 and 7. Although we do not know how much faster it is actually blowing at 1,000 ft. as compared with ground, we are sure that it is blowing faster. For that reason, taller towers should be designed to a slightly higher wind load.

In addition to this wind gradient, there is what the Weather Bureau calls a velocity gradient. This means that in addition to the average maximum wind velocity, there may be superimposed gust velocities for short durations. Much work has been done studying these gusts, and there are some empirical estimates. There is no sure prediction of gusts. It is reasonable to assume that gusts are possible which exceed the maximum wind velocity by a factor between 10 and 30 percent.

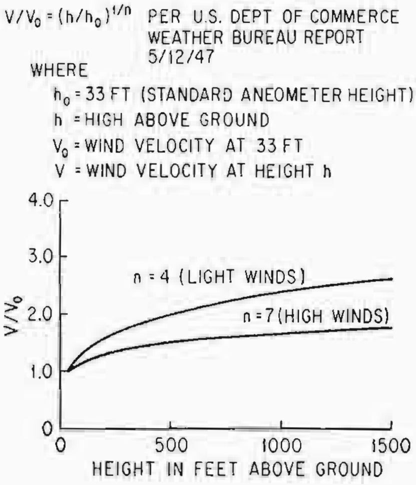


Fig. 35. Variation of wind velocity with height.

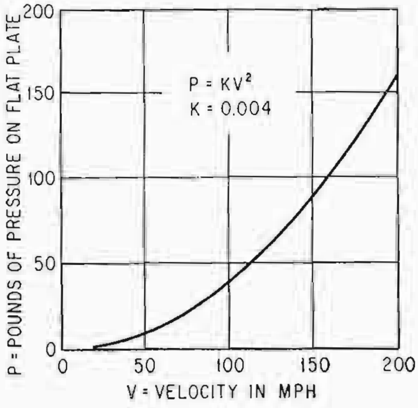


Fig. 36. Wind pressure versus velocity curve.

Hurricanes

Hurricanes are large-diameter tropical storms. These hurricanes usually start out in the Gulf of Mexico or the Caribbean Sea or in the Atlantic Ocean east of the Caribbean. The plotted tracks of past hurricanes cover practically every part of the Gulf of Mexico and the Caribbean Sea and much of the North Atlantic Ocean. They are apt to strike most of the Gulf ports and most of Florida. A good many veer off the southeastern coast of the United States and swing out to sea. However, many of them cruise up through Georgia, the Carolinas, and New England. Hurricanes have a counterclockwise wind system. The strongest winds are somewhere between 75 and 100 mph. Occasionally, they may get up to 150 mph. The eye, or the dead portion of the storm, usually runs about 10 miles in diameter. The outside dimensions of a hurricane which covers the width of the destructive winds could be anywhere from 25 to 400 miles. In the United States, hurricanes reach a peak frequency in August, September, and October. It is possible to design hurricaneproof towers at slight additional cost. The EIA Tower Standard RS-222 shows recommended tower strengths for different heights and locations.

Some hurricanes are accompanied by a strong tide which in some cases can be 10 or 12 ft. high when it reaches the seacoast. In certain bays where there is a narrow channel, this rise may be as high as 50 ft. These waves are certainly unusual, and although towers have been known to be washed away, no attempt has been made to design towers to withstand such tides.

Tornadoes

Tornadoes, or twisters, occur in most parts of the United States. The highest probability of their occurrence seems to be the Mississippi Valley, but one can expect them in the Southwest, Middle West, or Southeast parts of the country. The highest frequency occurs during the months of April, May, and June. A typical tornado starts in the late afternoon, usually moves from the southwest to the northeast, and cuts a path of destruction somewhere between several hundred yards and a mile wide. The winds inside this twister are very high and are believed to exceed 500 mph at times. No attempt is made to design towers to withstand these high wind velocities, but because of the narrow path involved, the probability of a tornado hitting a tower is not too high.

Wind Pressure

The commonly accepted formula for wind pressure is $P = KV^2$. P is wind pressure in pounds per square foot of projected area; K is the wind conversion factor depending on the shape; V is the actual wind velocity in miles per hour. The nominal value for K pressure on flat surfaces is 0.004. Notice that the pressure is proportional to the square of the velocity. If we plot this, we get the curve in Fig. 36. The commonly accepted practice is to use 0.004 for flats and angles and shapes and two-thirds of this value for cylindrical shapes.

Specifications

The EIA specifications for towers were drawn up by representatives of various tower manufacturers. These specifications cover very broadly, but very adequately, all important points in designing steel towers. It is best if broadcasters keep this in mind. There are other specifications probably as good, but they tend only to confuse things. For example, the American Institute of Steel Construction has a set of specifications which were drawn up primarily for large buildings and bridges. It is possible to misuse specifications. For example, AISC reads, "members subject to stresses produced by wind forces may be proportioned for unit stresses 33-1/3 percent greater than those specified for dead and live stresses." The intent of that paragraph was secondary wind bracing for structures with heavy live loads. A tower is not such a structure. This paragraph should not be used in radio-tower design, for if it is carried out to its literal conclusion, it is possible for broadcasters to specify a 30-lb. wind-load AISC tower and obtain approximately a 20-lb. EIA tower.

EIA specifications take a practical look at the method of analysis. EIA recommends that wind loads be expressed in terms of pounds per square foot projected area. Consequently you hear the expression "the tower is a 30-, a 40-, or a 50-lb. tower."

Wind versus Tower Failure

The question often arises, at what wind velocity will a tower fall down? It is very difficult to give an honest answer to that question. Let us take an example: Assume a 40-lb. tower. This means that the tower was designed for a 40-lb. wind pressure on flats, safety factor 1.8, so that the yield of the structure would be approximately at a wind pressure of 40 times 1.8, or 72 lb. Looking at the pressure-wind-velocity curve, 72 lb. equals about 134-mph wind velocity. Theoretically, a wind of 134 mph distributed uniformly over the structure produces yield in a structure, and this usually means failure. But how do we know how fast the wind was blowing on the tower? How do we know that the wind was distributed uniformly over the structure? Probably the best record available is the Department of Commerce Weather Bureau, miles away at a different elevation. For example, assume the anemometer 750 ft. below your tower. Wind velocity at your tower could be 134 mph, but the wind velocity versus height curve in Fig. 35 shows that there is approximately a 1.5 times increase in velocity, or at the anemometer, 750 ft. below, the wind is blowing about 90 mph. If you throw in a 10 percent gust factor, it is possible that the anemometer 750 ft. below your tower registered 80 mph when it was 134 mph at the top of your tower. For this reason, it is very difficult to correlate wind velocities as given by the Weather Bureau miles away from the tower site with the actual wind velocity blowing through the top of the tower. We do know that from past experience, in certain locations, towers designed to certain wind pressures seem to stay up and are adequate. The best indication for any given location is past experience.

Wind Loading

It is interesting to note the effects of installing different items on a tower. By far the greatest single contributor to the load on a tower is the area exposed to the wind. This means that the less area there is exposed to the wind, the less tower is needed to support itself. The simplest tower is a small AM radiator whose function is to support itself, with possibly one small lighting line. The other extreme is where signs, elevators, spare coaxial lines, antennas, and other equipment are installed on the tower. The accompanying graph (Fig. 37) is made in an attempt to show vividly the effect of various items "hanging" on a tower. The tower is a typical clean tower in the 500- to 600-ft. height range with various items being added on, one at a time. Obviously, it is not very difficult to double or even triple the side load on a tower by adding these items. The addition of any single item or article to the tower increases the wind load on it. This, in turn, means that the

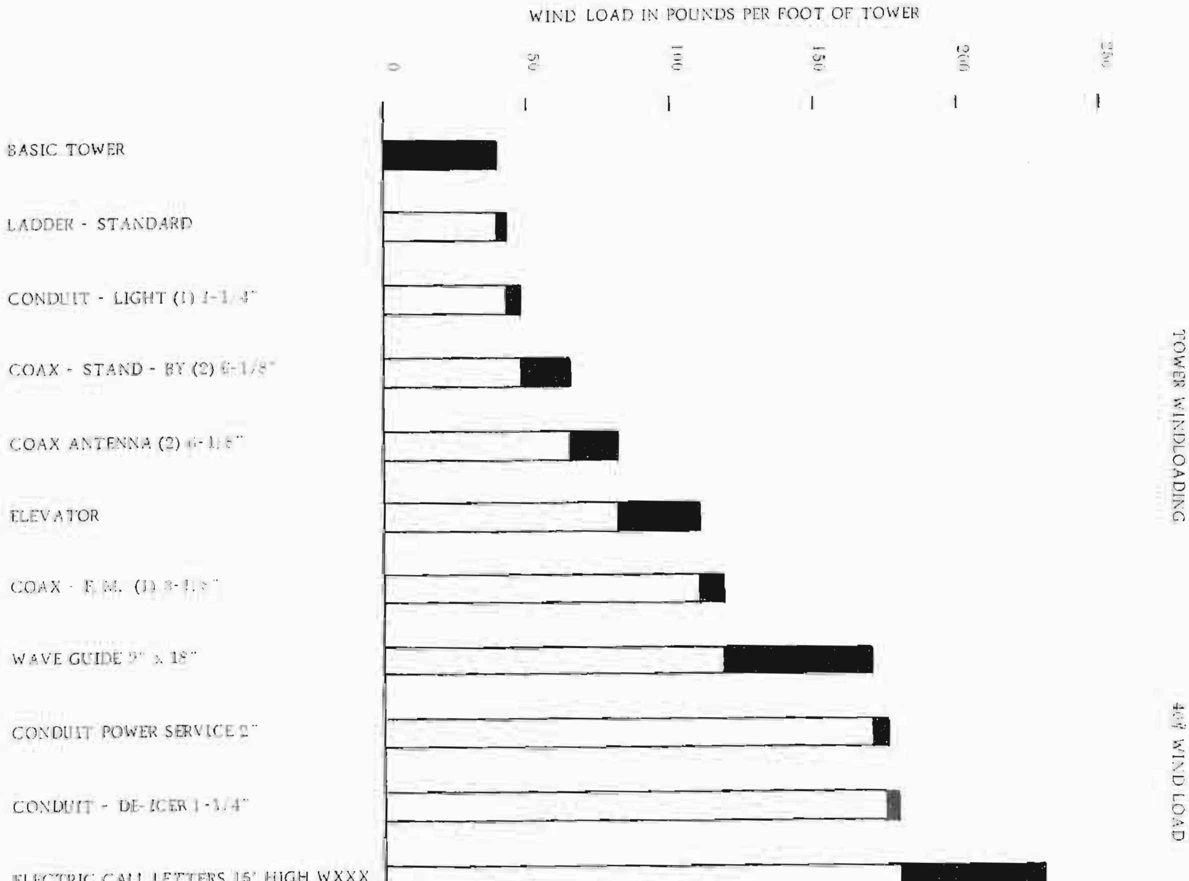


Fig. 37. Wind load in pounds per foot of tower.

tower has to be stronger, heavier, and possibly a little bigger in cross section. This additional cross section increases the wind load, which increases the weight and the cost of the tower. Obviously, you cannot hang all these components on the tower without increasing the weight and cost.

Icing

Ice tends to form on all structures exposed to the elements under certain conditions of humidity and temperature. The temperature is usually a little below freezing, and the air is superladen with moisture. Icing is spotty both in location and in frequency. You usually do not get much ice in dry climates, in very cold weather, or in very warm weather. There has been ice as far south as Atlanta, Ga. To find out how icing conditions are in your locality, ask the engineers at your local power company. Utilities constantly have trouble with ice. Tall towers, around 1,000 ft., tend to get layers of ice farther up the tower. You usually find more ice on mountain tops.

Recently updated EIA Specifications, although not specifying a specific radial ice accumulation for a given area, do call for a minimum 1/2 in. radial ice where applied, and provides for the simultaneous application of wind and ice loads on the tower (including on guys) and accessories. Ice load design has two basic effects on tower design; namely, weight increase and increase in projected wind area. Thus cost will generally increase very appreciably when ice is specified in a design.

Prevention of Icing

A number of ideas on preventing ice formation on towers and guys have been advanced. Heating elements have never been tried to deice the tower as far as we know. Heating elements are used on the antennas, not to prevent damage to the antenna, but rather to prevent damage to the radiating properties. The most practical solution seems to be to make the tower strong enough to carry the ice.

Falling Ice

Ice falling off the structure presents a hazard. A chunk of ice 4 or 5 in. thick falling several hundred feet carries quite a "wollup." Automobiles parked at the base of the tower or even some distance from the base of the tower can be damaged. Ice has been known to break beacons, lights, and microwave gear on the way down. It is certainly a hazard to horizontal runs of coaxial lines. A simple corrugated-iron or wooden shield to deflect the flying ice is adequate. Icing over 1 in. in thickness, except in isolated cases, is rare. Pictures of ice 1 and 2 ft. thick taken on Mount Washington should not be used as a guide in designing a tower.

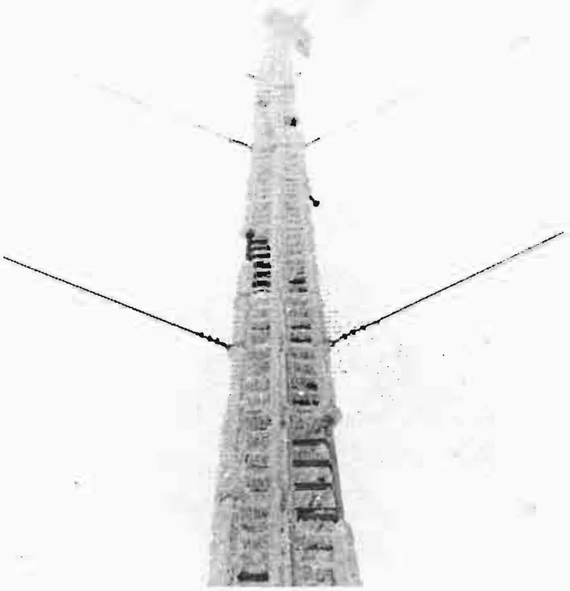


Fig. 38. Ice formation on a tower.

Earthquake Loading

Towers on the West Coast are usually required to meet the Pacific Coast Uniform Building Code for earthquake loadings. This code says as follows:

In determining the horizontal force to be resisted, the following formula shall be used:

$$F = CW$$

where F = horizontal force. lb.
W = total load tributary to the point under consideration
C = 0.05 for towers which are connected to a building
= 0.025 for radio towers which are not supported by a building

This horizontal force F is added directly to the wind load. In a short, light tower, say 200 ft., this does not add an appreciable amount of load to the tower. In a tall, heavy tower, this factor may be considerable.

Atomic Blasts

One of the atomic blasts out in the Nevada flats was made to test a number of civilian defense items. The bomb was set off on a 500-ft. steel tower. Two small cities were built, the first approximately a mile from the blast, the second approximately 2 miles from the blast. Depending on the size of the bomb, all steel within a certain radius is immediately atomized and, for all practical purposes, simply vanishes. So it is impossible to build an atomic bombproof tower. One practical observation was that in the test city, alongside brick and wooden homes which were badly mangled, a guyed 150-ft. AM tower designed as a 30-lb. EIA tower at 250 ft. survived undamaged, although there was evidence of the tower having moved a great deal during the blast. A 100-ft. self-supporting tower, noninsulated, loaded with two-way radio antennas, designed to approximately 20-lb. EIA load, failed at the same site. A very rough conclusion may be that a short guyed 40-ft. EIA tower is approximately a little better than average small buildings. Since the blast gave the tower a violent "jerking about," as it were, the whip or inertia forces must have been high. Consequently, the above conclusion may not be the same for towers which have larger inertia or whip forces. Inertia forces are greater in the case of self-supporting towers and guyed towers with heavy top loads from antenna.

INSULATORS

Base Insulators

Current practice for AM radiators is to have the base of the tower insulated, although there still are some shunt-fed installations.

Most insulators today are made of porcelain. There is no reason why other materials could not be used, such as wood, glass, or fiberglass and other new plastics.

Since current practice is to use porcelain, this discussion will concern porcelain insulators. A designer of porcelain insulators always keeps in mind that porcelain is strong in compression but weak in tension. Therefore, the insulators are always designed so that the load pushes on either a mass of solid porcelain or a cone of porcelain. The designer tries to make sure that there is no bending or tension induced into the porcelain portion of the insulator. Most guyed towers come down to a single-point pivot, and the insulator will have a rounded surface so that the tower can pivot. This is to prevent any bending being induced back into the porcelain, and most of the load is pure compression. Fig. 39 shows a typical installation. Sometimes a rain shield is put over the top of the insulator in an attempt to keep the insulator dry, since the flashover value of dry porcelain is better than that of wet porcelain. However, most rain shields are very ineffective in a driving rain unless they form a complete shroud down and around the porcelain. Since porcelain is fragile and subject to cracking, some care should be exercised in handling it. There have been instances where water has got into the cone, the drain hole has plugged up with dirt, and the water froze and shattered the insulator. This is quite unusual. The cost of base insulators with leakage paths greater than 10 ft. increases rapidly.

The self-supporting tower presents a unique problem in that the base insulator has to transmit either compression or tension from the leg member. The accompanying cross section of a typical push-pull insulator in Fig. 40 shows how this is accomplished. This insulator works in such a way that the upper cone works when the load is down (compression on the pier) and the bottom cone works in compression when the load is an upload on the leg member. These insulators are usually very bulky and expensive, and except for the smaller sizes, delivery and availability are not too good.

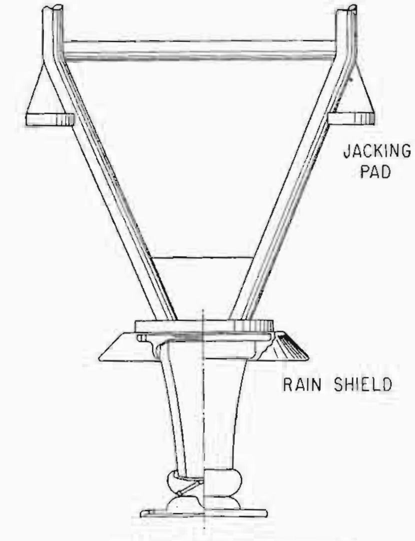


Fig. 39. Typical base insulator for guyed towers.

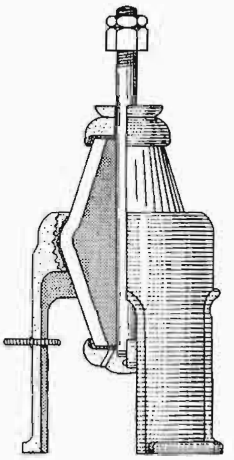


Fig. 40. Push-pull type of insulator for self-supporting towers.

It is perfectly possible to have a three-legged or four-legged guyed tower which is shaped so that it sits on all three or four legs on the pier, in which case, three or four insulators will be required at the base of the tower. Some designers prefer this form, and there is nothing wrong with it provided the insulators are capable of transmitting a certain amount of tension and the foundation pier is absolutely level.

Large special insulators are sometimes used, but they are not typical.

Once in a great while, the porcelain on a base insulator will crack. The crack may be due to an old flaw, an external blow, a lightning hit, or water getting inside the porcelain and freezing. In order to change the base insulator, the tower must be raised slightly. This is not a particularly difficult operation, but it is very critical. Sometimes, on tall towers, jack pads are incorporated into corner legs to facilitate raising the tower.

Raising Base Insulator above Ground

The base insulator of an AM tower is located so that unusual weather will not ground the insulator. Sometimes, 1 or 2 ft. above the ground is adequate. The insulator is usually placed in a concrete pier 3 to 5 ft. tall. Occasionally, insulating may be as much as 25 ft. above the ground as is shown in the accompanying photograph, Fig. 41. Sometimes, in an array of four towers on a sloping piece of ground, it may be desirable to locate all insulators in the same horizontal line. Each tower sits on a pier of a different height. Concrete is generally used up to about 5 to 10 ft. Over that height, some sort of steel pier is probably the most economical.

Fig. 41. Example of raising base insulator for flood-water conditions.

Guy Insulators

Typical guy insulators and guy-insulator assemblies are shown.

The most commonly used guy insulator for AM work is the so-called strain insulator. Since most AM towers are under 300 ft., most towers use these insulators. The insulators were developed by the power companies and are made in large quantities so that they are easily available and the cost per unit is very low. They come with multifins to increase leakage path and are used with strand up to 1/2 in. Another advantage of a strain insulator is that if an insulator cracks, the tower fails safe; that is, the interlocking loops of strand keep the guy intact.

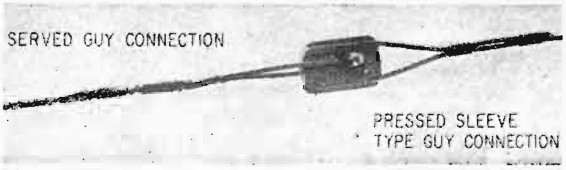


Fig. 42. Typical strain insulator.

Where it is desired to have the insulators capable of being inserted after erection, the open-type insulator is sometimes used. A strand over 1/2 in. is very stiff, and it is very difficult to pull around the insulator. Great care must be taken to make sure that the strand hugs the loop all around its periphery. In other words, the strand must be forced around the grooves on the insulator. If this is not a snug fit at both sides of this insulator, the insulator will tend to cock, the insulators will be loaded at a point rather than over a surface, and the desired mechanical strength will not be obtained.

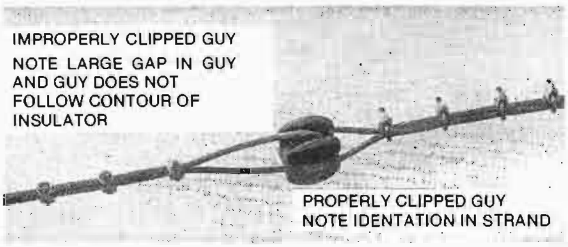


Fig. 43. Improperly and properly clipped guy.

On large guys and when the leakage path is greater than that obtained by strain insulators, the so-called cone insulators are used. This cone insulator is nothing more than a base insulator with a basket around it. You will notice that the load is transmitted through a cone of porcelain in

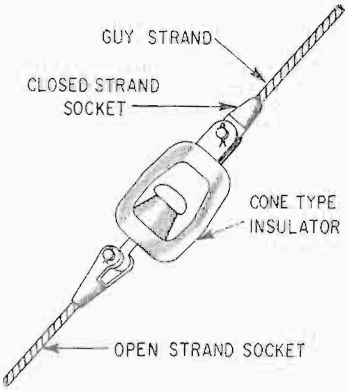


Fig. 44. Cone-type guy insulator.

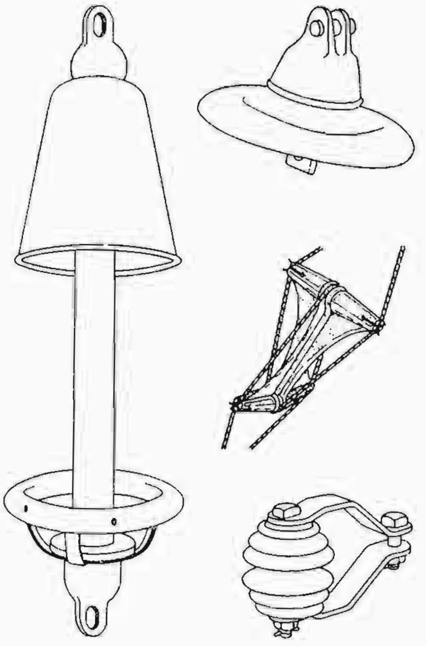


Fig. 45. Miscellaneous guy insulators.

compression. It is interesting to trace the load transmitted through one of these insulators. The load comes down the guy, through the top socket, then around the insulator, through a steel yoke and to the bottom of the cone. All this load so far is tension. The load is transmitted through the porcelain to the top of the cone in compression. The top of the cone has a pivot with a gonglike piece hanging down to pick up the bottom socket. These insulators are large, clumsy, expensive, and not easily available. Also, they do not fail safe.

Several other types of guy insulators which have been used are shown. Porcelain insulators have a very good life. Replacement of cracked strain insulators is not common. For replacement, the guy is dropped or an erector slides down the guy to the point in question.

Sectional Tower Insulators

There are some installations where by sectionalizing a tower it can be used for more than one function. A sectionalized tower can be used to control the AM radiating characteristics of a tall tower. This allows a tall TV tower to be used as an AM tower. This is possible by insulating portions of the tower from one another. As shown in the illustration (Fig. 46), either the pivot type or the push-pull type of insulator can be used to sectionalize a tower. It is desirable to taper the tower for the pivot-type insulator. The push-pull type of insulator is used at each leg member as is used in a self-supporting design. In either case it is necessary to check the shear transfer across the insulator.

With a sectionalized tower, periodic inspections of the insulators are mandatory. A failure in a sectionalizing insulator very likely will cause the tower to fail.

BONDING

An AM tower is a radiator. Hence, it is important that the steel tower acts as one continuous electrical unit. Faying surfaces on a galvanized tower are not painted and as a rule are considered sufficiently bonded through the zinc contact. Two methods of bonding steel towers are shown below.

The weld type of bond is positive, but extreme care must be taken when welding near guys. It is possible to damage guy strand with the molten weld slag. The copper-jumper type of bonding is a bit more troublesome. The holes must be absolutely clean and free from rust and paint. The wedges should be driven in tightly to make good contact and exclude any moisture to preclude any electrolytic action.

LIGHTNING

Since the steel tower is usually the tallest object in its vicinity, it is always the first to be hit by lightning. As a matter of fact, the tower itself forms an electrical umbrella, as it were, for adjacent structures. Since steel is a very good conductor, lightning does not damage the tower or its guys. Although there have been many rumors about lightning shattering concrete foundations, we have never been able to find a

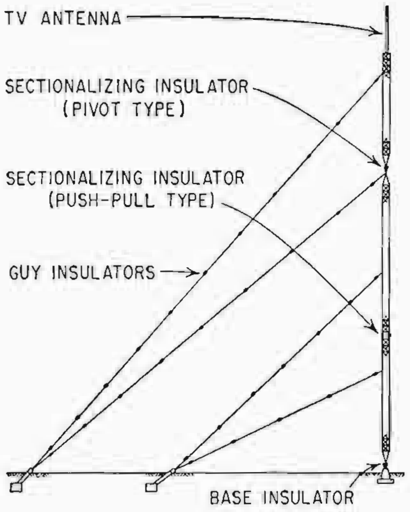


Fig. 46. Example of a sectionalized tower shown with two types of sectionalizing insulators.

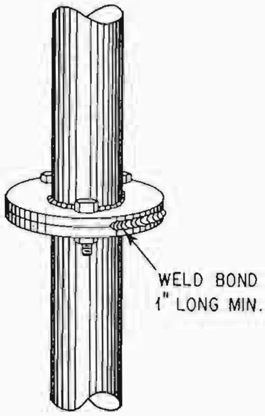


Fig. 47. Weld-type bonding.

record of such an incident. An AM tower, with its screen and radials, automatically makes a very good ground for dissipation of lightning. TV and other towers should be adequately grounded simply as a precaution to keep the lightning path away from the transmitter house. A typical guy cable grounding system is shown in Fig. 49. Lightning, however, can and has done damage to any and all kinds of electrical equipment on the tower. It seems almost impossible to build a tower where the manufacturer can guarantee that lightning will not knock out pieces of electrical wiring, lamps, junction boxes, etc.

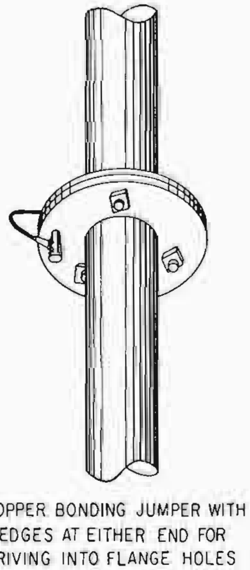


Fig. 48. Jumper-type bonding.

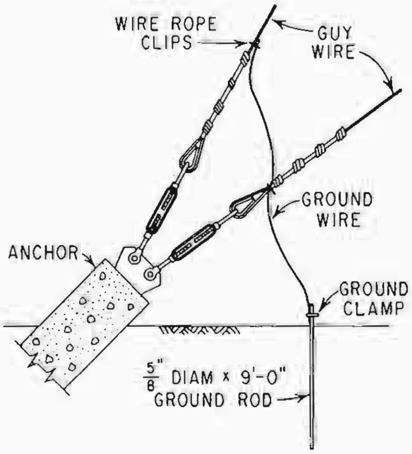


Fig. 49. Grounding at guy anchor.

SOILS, ANCHORS, AND FOUNDATIONS

Soil Exploration

On small towers such as a 200-ft. guyed AM tower, the magnitude of loads is not large enough as a rule to warrant soil exploration, unless, of course, the soil is very sandy or swampy. If the condition of the ground is in doubt and on tall TV installations where the magnitude of load is appreciable, a thorough soil exploration is certainly advisable. In most parts of the country, there are soil engineers who are familiar with the type of soil in a particular location. Test bores are usually made at the tower base and at the anchor foundation locations. At the base of the tower, test bores should be approximately 25 or 35 ft. deep, whereas at the guy anchors, test bores should be a little deeper than the anchor depth.

The purpose of the test bore is to help determine the allowable unit bearing pressure for design. Sometimes, local building codes set their own values for local conditions. There are any number of methods used to study the subsurface conditions. A simple test which permits classification of the soil may or may not be adequate to tell the bearing capacity. For that reason, a test boring log should be turned over to competent soil engineers, who will then convert the data to allowable bearing capacities of the soil. Soil engineers are usually more familiar with local conditions, codes, and geology than others far removed. For purposes of approximation, the allowable bearing values of foundation soils are given in Table 1.

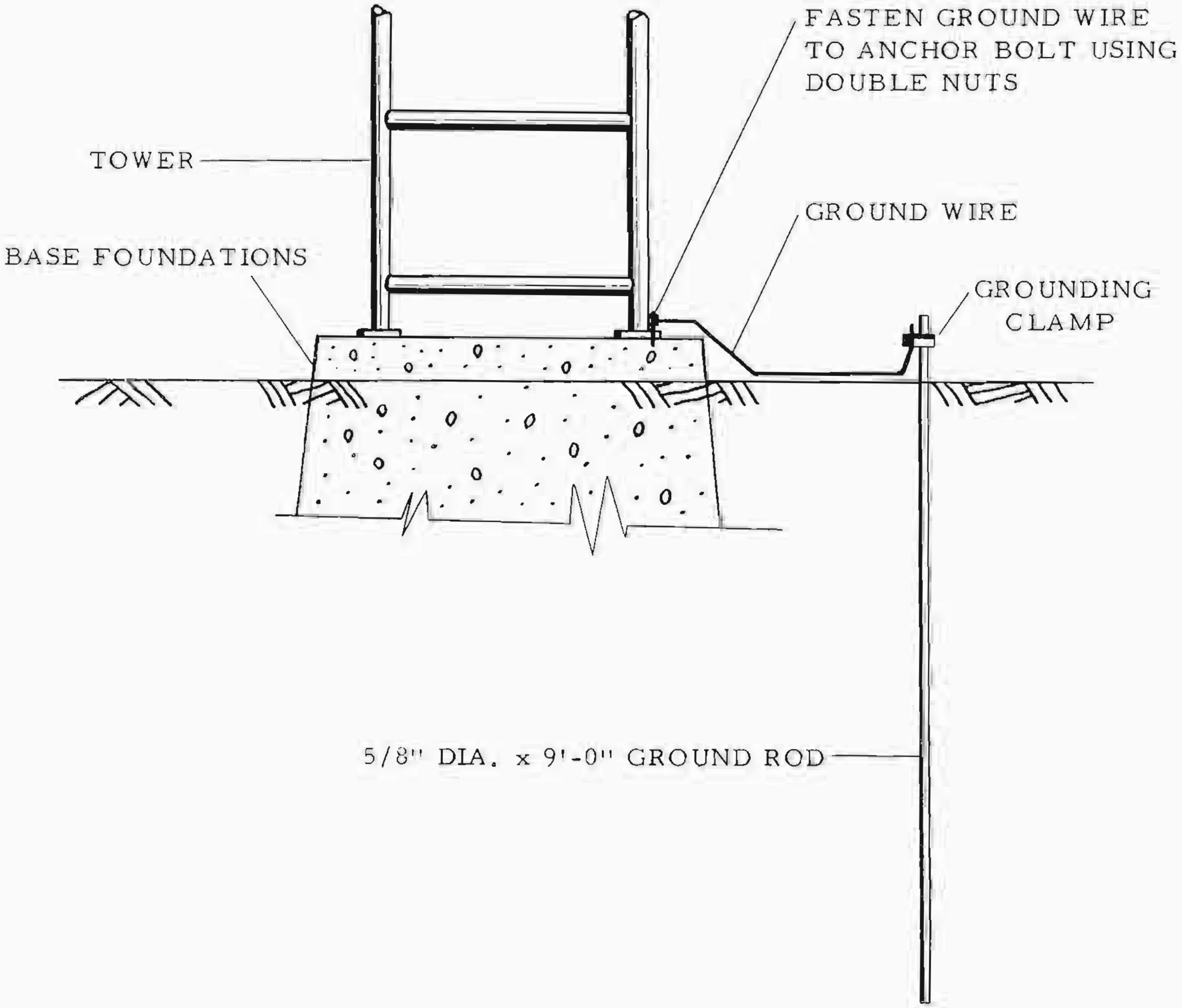


Fig. 50. Grounding at tower.

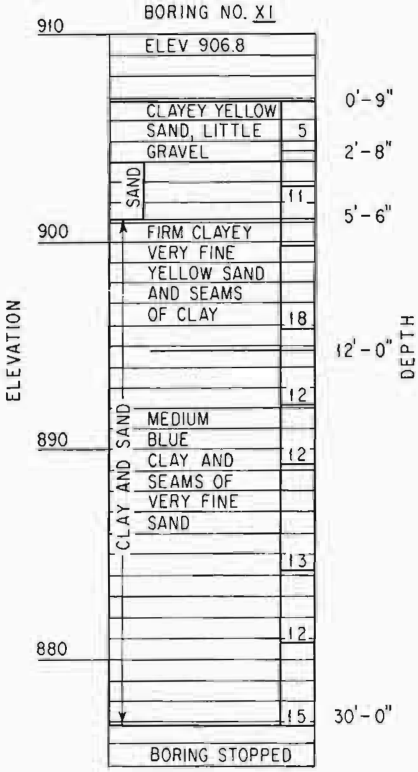
TABLE 1

Approximate Allowable Bearing Value of Foundation Soils

Soils	Bearing Capacity, Tons per sq. ft. Approximate Depth 3 ft.	 Approximate Depth 6 to 10 ft.
Soft silt and mud	0.1–0.2	0.2–0.5
Silt (wet but confined)	1–2	1.5–2
Soft clay	1–1.5	1–1.5
Dense firm clay	2–2.5	2.5–3
Clay and sand mixed firm	2–3	2.5–3.5
Fine sand (wet but confined)	2	2–3
Coarse sand	3	3–4
Gravel and coarse sand	4–5	5–6
Cemented gravel and coarse sand	5–6	6–8
Poor rock	7–10	7–10
Sound bedrock	20–40	20–40

A typical log of a boring is shown in Fig. 51. This log is in turn analyzed by a competent soil engineer who will recommend allowable unit bearing pressure for design.

BORINGS ARE PLOTTED TO SCALE OF 1"=6', USING USG AND GS AS FIXED DATUM.



USED 8'-6" OF 2-1/2" CASING

RIGHT HAND COLUMN INDICATES NUMBER OF BLOWS REQUIRED TO DRIVE 2" O D SAMPLING PIPE ONE FOOT, USING A 140 LB WEIGHT FALLING 30 INCHES

Fig. 51. Typical boring log.

Anchors and Piers

Tower base foundations are usually made of reinforced concrete and are designed to carry the total column load of a tower. The area of the footing should be of sufficient size to prevent detrimental settling of the tower structure.

Anchor foundations, on the other hand, exert little down loads. The vertical component from a guy is resisted by the weight of the concrete and earth overburden. The horizontal component is resisted by friction on the anchor base and by the lateral resistance of soil on the face of the anchor.

At some installations the allowable bearing pressure of the soil is very low or an underlying stratum is exceptionally poor. Serious settling of the foundation may occur under these conditions, and it is advisable to drive piles under the footing.

Figs. 52 to 62 show the many types of base pier and anchor designs for radio and TV towers. Many metal-type anchors for small tower installations are available for different soil conditions, and the illustrations are self-explanatory. The screw-type swamp anchor has a pipe for its shank. The length of the shank is increased by coupling additional pieces of pipe until the screw has been driven into hard soil. Various types of guy anchors are shown.

The photograph in Fig. 63 shows an anchor installation at KOA-TV, Denver. Usually, the small flats on top of hills make a self-supporting tower a must. However, it is possible to install tall guyed towers in rough, mountainous terrain. Naturally, this usually brings about installation problems. Probably the costliest item is making the tower base and each anchor point physically accessible to trucks and erection equipment. Tower designers like to choose sites so that each anchor falls off approximately the same. However, this is not always possible or absolutely necessary.

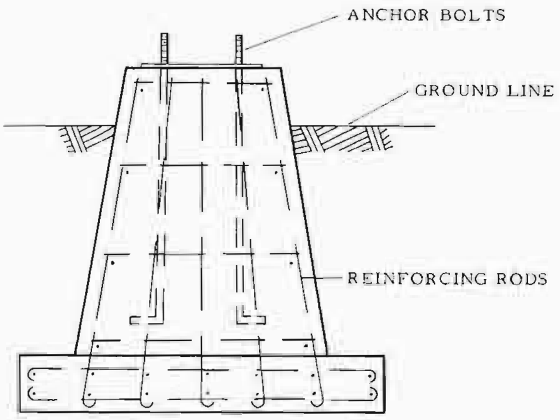


Fig. 52. Typical reinforced-concrete base pier.

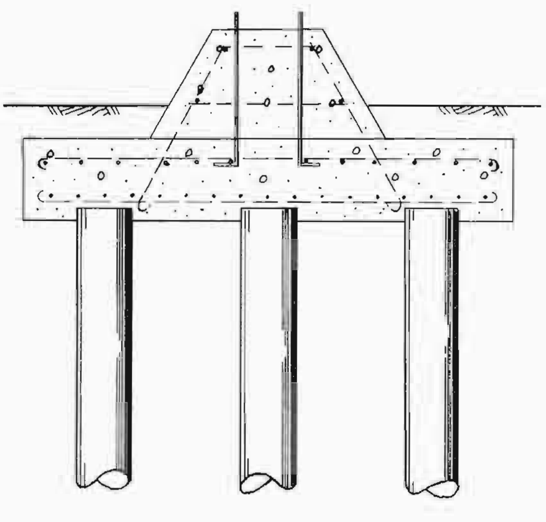


Fig. 53. Base pier of reinforced concrete on piles for use in poor soils.

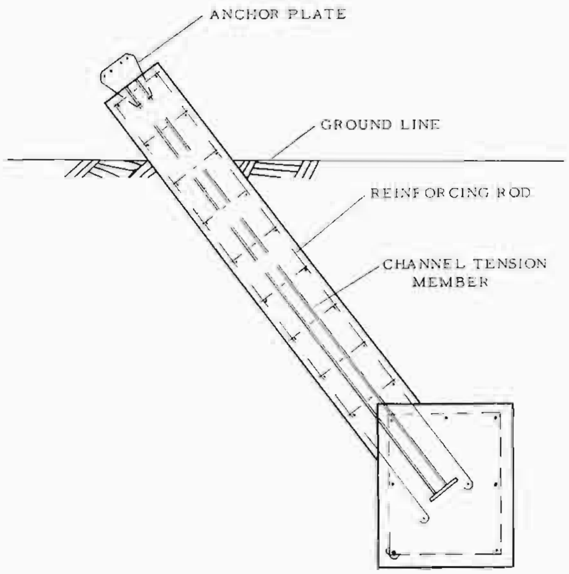


Fig. 55. Typical reinforced-concrete guy anchor.

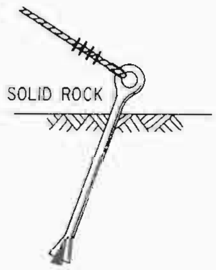


Fig. 56. Wedge-type rock anchor.

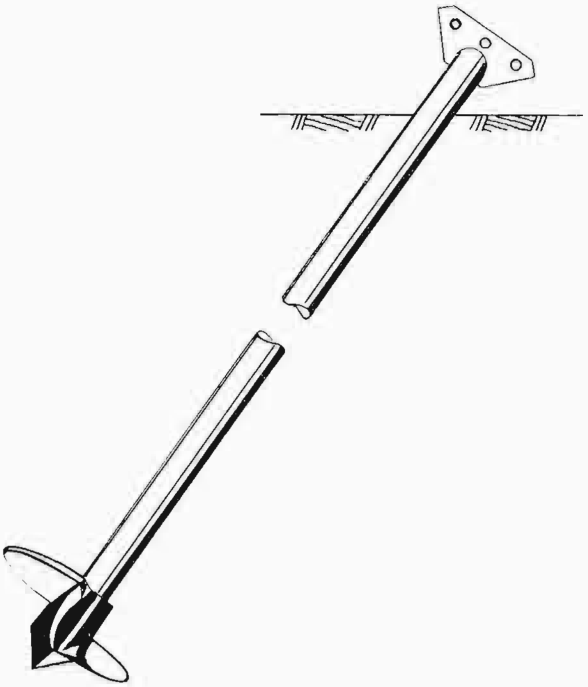


Fig. 54. Screw-type swamp anchor.

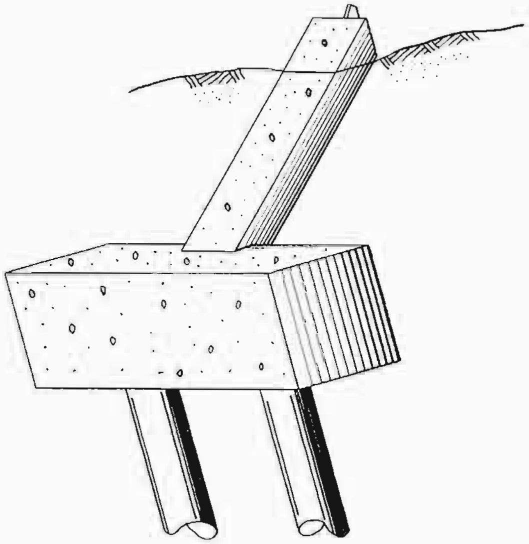


Fig. 57. Reinforced-concrete guy anchor on piles for use in poor soils.

Concrete Foundations

Reinforcing

Most foundations are made of reinforced concrete (see Fig. 52). Since the concrete is in a wet plastic state when it is poured, it must be confined until it hardens. Usually, these forms are made of wood. Sometimes in small towers, forms are dispensed with at the anchors simply by digging a hole of rectangular shape and allowing the sides of the earth to give the concrete its shape. On a large tower, the wooden forms run into a considerable amount of money.

Except for tiny foundations, concrete piers and anchors are always reinforced with reinforcing bars of the deformed type of steel. The purpose of these bars is to help carry any tensile stresses in the concrete block, since concrete is essentially a compressive load-carrying material. Deformed steel is used, since the deformed surfaces give a better mechanical bond to the concrete. Since reinforcing bars are universally obtainable, the steel is usually procured locally. The reinforcing bars should be carefully wired and placed to-

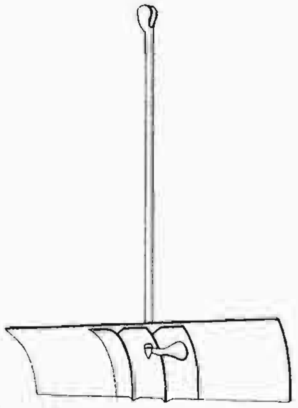


Fig. 58. Two-pieced metal anchor for clay or loam.

Fig. 59. Screw-type earth anchor.

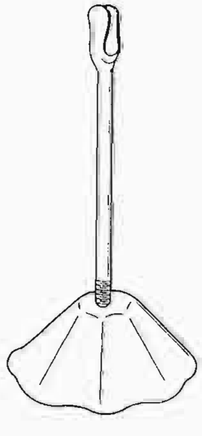


Fig. 60. Cone-type anchor for rocky soils.

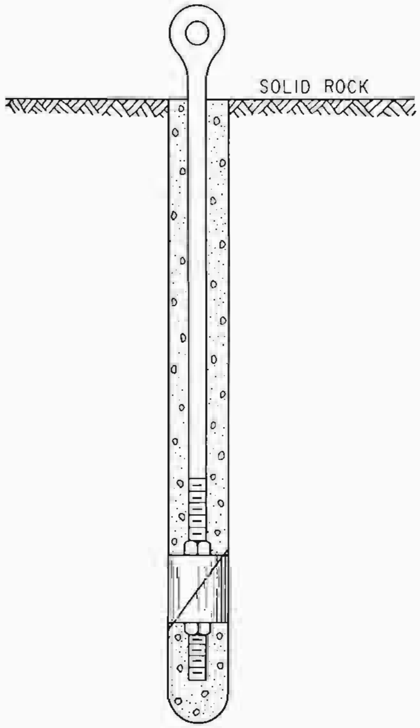


Fig. 61. Expanding rock anchor.

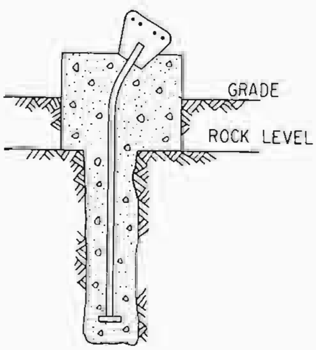


Fig. 62. Concrete-type rock anchor.

gether as called for on the foundation drawing prior to pouring the concrete. Sometimes these bars are welded together into a subassembly.

Mix

The concrete is usually obtainable from a local ready-mix plant. The foundation designer always specifies the proportions of the mix and the water-cement ratio or strength of concrete. These items should be relayed to the supplier of the concrete. A typical mix is 1-2-4, where the numbers 1-2-4 represent the proportions of cement, sand, and gravel. The water-cement ratio is often expressed by specifying approximate compression strength of the concrete after 28 days. A typical strength is 3,000 psi.

Pouring

As the concrete is being poured, precautions should be taken to see that the forms are filled completely. The usual method is simply to poke or churn the concrete with a pole or shovel, especially along the edges of the forms. Care should be taken to see that the steel arms which protrude from the forms are not moved or disturbed by the pouring of the concrete.

On towers where the guys are supplied with fixed lengths, it is most important to know the exact dimensions from the working points at each guy anchor. These are surveyed and determined prior to pouring the concrete. Since the concrete may disturb the steel anchor arms, it is advisable to survey the installed anchors and get a new set of readings locating these work points.

When concrete is poured under water, proper forms and a comparatively dry mix will aid procedure. Where the simple method of depositing the concrete under water directly is not possible, a cofferdam can be built. A cofferdam is a temporary wall structure out of which water is pumped so that work can be carried on in a comparatively dry area.

Freezing

Frozen concrete may not suffer any visible deterioration, but its strength is greatly decreased. Some precautions must be taken during freezing weather. Fresh concrete, when frozen, is easily recognized by its white color, whereas ordinary concrete will remain a slate color. One precaution is to heat the ingredients and water prior to mixing and then cover the poured concrete with layers of hay or straw. Sometimes heat is introduced from a portable heater. Another precaution is adding calcium chloride to the mixture. This generates heat during the setting period.

Fig. 63. Guy anchor installation at KOA-TV, Denver, Colo.

Strength

There are occasions where high strength in concrete foundations at an early age is desired so that the erection of steel can begin at the earliest possible moment or to make possible early reuse of forms. In cold-weather construction, high early strength reduces the time of protection required. High strength at early ages can be achieved by using a type III portland cement usually designated as high-early-strength portland cement or by using richer mixtures of other types of portland cement. The type III cement costs more than the normal portland cement.

Since the important factors which govern the strength of portland cement concrete are the relative proportions of cement and mixing water and conditions during curing, great latitude in obtaining desired strengths at a given period can be obtained by adjusting these factors. Sometimes, calcium chloride is used as an accelerating admixture to increase the rate at which concrete develops its early strength. The calcium chloride is particularly effective in increasing strengths at 1 to 3 days. On the other hand, for a given water content, high-early-strength cements give higher strengths than normal portland cement either with or without the accelerator at the later ages up to about one year.

TOWER ACCEPTANCE

Inspection

Most towers are very simple structures physically. Assuming that the tower was designed by a competent engineer to EIA standards and that the number and size of members called for by the manufacturer are adequate, the job of checking

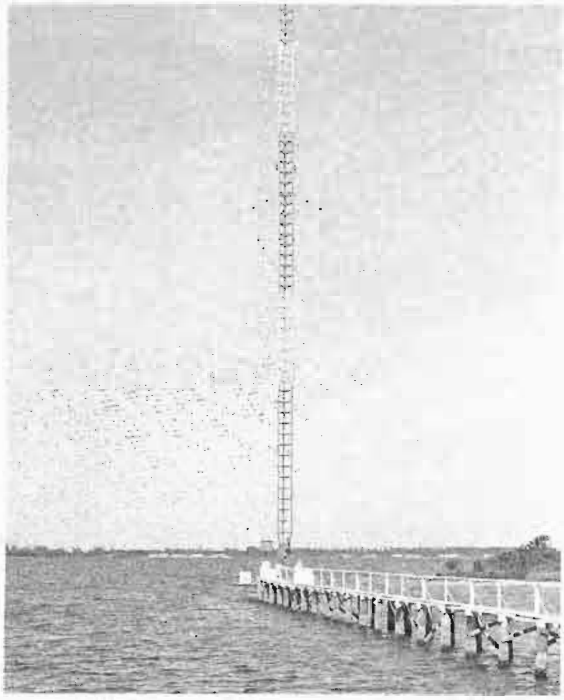


Fig. 64. Photograph of a water installation. The erection costs rise very rapidly. Cofferdams are built prior to pouring the foundations, and the erector must invent ingenious devices to get his material to the base of the tower in the water. The photograph is station WMMB, Melbourne, Fla.

should not be too complicated. The following is a suggested checkoff list:

Tower Inspection Checkoff List

1. Has the site been cleaned of all debris, paint, cans, reels, and miscellaneous erection junk?
2. Is the tower plumb?
3. Is the tower painted properly—international orange and white—per construction permit?
4. Are the bolts pulled up tight?
5. Are all the nuts secured and locked as called for by the manufacturer?
6. Are the turnbuckles safety-wired to prevent back turning?
7. Is the service entrance cable or conduit attached securely?
8. Check anchor distances against tower drawing.
9. Were holes for the foundations dug deep enough as per drawing?
10. Are the anchor holes backfilled? If not, the first rain will make a sizable depression over the anchor.
11. Is the coaxial system tight?
12. Does the lighting system work?
13. Are all the junction boxes secured with watertight gaskets in them?
14. Look at the face of the tower. Is there any appreciable twist in one face?
15. On large towers, check the guy tensions by the method given to you by the manufacturer.
16. Look at all the members from the ground. Are any of them visibly damaged or bent during the course of construction?
17. Did the erector leave any unpaid bills around town that you know of?

Three chronic complaints about erectors are:

1. Shorting in the lighting system
2. Sloppy paint job
3. Leaks and dents in the coaxial system.

General Erection Notes

There is a tendency for the broadcaster to take a long time to decide what tower to buy and then expect an erector on the site before the material has arrived. These boys do not get paid for days they do not work. If they are held up because of lack of material, they resent it! Very often, the broadcaster, with no ill intent, tells the erector that most of the material is on the site and the balance is in transit. This may be true, but unless the last bolt and every piece of coaxial, anchor, and tower is on the site, one can never be sure when it will get there! Less-than-carload shipments are very slow. The erector will cry for extras, and bad feeling begins. You can't blame the erector. Bear in mind that the average erector many times works under adverse conditions and is away from home.

Tower-erection business is very competitive. Most bids are based on the erector's being able to get to the site. He does not necessarily need a four-lane highway, but he should be able to drive the truck to the base of the tower and drive to each anchor. The fact that you can walk on the site does not necessarily mean that it will hold up a truck. He also needs a cleared piece of land to assemble his material.

It is not the erector's responsibility to get a building permit. It is customary for the tower buyer to get all permits simply because they are usually obtained under local conditions which change from town to town all over the country. Sometimes it is a matter of a two-dollar license. In other cases, political intervention or an expensive engineering analysis and approval are required.

Erectors bid on the understanding that they will work regular hours. Overtime is expensive, and one should expect some resentment from the erector when he is asked to work overtime at no extra cost.

It would be wise to allow a somewhat longer time for erection than promised by the erector. He usually thinks in terms of elapsed working days and does not count Sundays, Saturdays, holidays, opening days for fishing, opening days for hunting season, or days or rain, sleet, and high winds.

Often winds are 10 mph on the ground but 30 mph aloft at 700 ft. (see Fig. 35).

Erection work is usually risky work simply because it is off the ground. The more you push the workmen, the more prone to accidents they become. The erector is not going to get paid until he finishes the job, so he, too, is anxious to complete it.

The erector expects electrical power at the base of the tower prior to starting the job. Otherwise, he has trouble getting temporary lights and he will complain.

Erection work is usually thankless and dangerous. Working conditions, because of cold, rain, mud, swamps, rocks, snow, wind, and weather, in general, are never so good as those in an air-conditioned factory. The men have to be of a tougher breed. Understanding their problems helps everyone.

Insurance

If a station decides to hire its own erector to install the tower, it is recommended that the following evidence of insurance from the erector (in the form of certificates) be obtained. The following different insurance certificates are customary today:

1. Workmen's compensation and occupation diseases, including employer's liability insurance. *Limits:* This insurance should be checked with the statutory requirements as applicable in the state in which the work is being performed. Employer's liability should be at least $25,000.
2. Contractor's public liability insurance which covers damage and injury to objects and people not under the care and custody of the contractor. *Limits:* Bodily injury, $15,000/100,000; property damage, $15,000/100,000.
3. Contractor's protective liability insurance protects the contractor with his subcontractors. For example, the contractor may sublet the foundations or sublet the electrical work or paint because of union problems. *Limits:* Bodily injury, $15,000/100,000; property damage, $15,000/100,000.
4. Automobile liability insurance. This covers all motor vehicles owned or leased, including nonownership liability covering contractors' employees' personal cars and trucks. *Limits:* Bodily injury, $100,000; property damage, $100,000.
5. Direct damage insurance. This insurance provides for protection against all risk of the tower, antenna, lines, and the equipment which the erector is working on or material which is in his (erector's) custody until completion of the job. *Limits:* Should be set to cover the value of the tower, lights, coaxial lines, antenna, and any other equipment he is installing, plus erection labor involved.

The owner should have an insurance policy covering any loss to the tower once the tower erection is completed and the customer has accepted the tower. Values are set for replacement values, namely, the price which he has paid for the tower and equipment on the tower plus the cost of erection.

TOWER LIGHTING[1]

Since a tower is a hazard to air navigation, the government prescribes certain warning lights to be installed on the broadcast towers. In general the lighting requirements are spelled out in a pamphlet put out by the FAA called "Standards for Marking and Lighting Obstructions to Air Navigations." However, the exact lighting requirements are given very specifically in detail in the construction permit from the FCC for every station. These specific instructions may differ from the general specifications. Since the maintenance of the tower lights is a never-ending problem, it behooves the station management to see what can be done to keep the lighting requirements down. For example, any tower in the shadow of a taller obstruction, such as a taller building, a taller tower, or a taller hill, can usually be installed without any lighting.

The electrical system is essentially very simple. It consists of a number of lamps which are fed by one or more circuits either 110 or 220 60 cycles alternating current. On AM towers, the RF must be isolated from the 60-cycle current. Circuits are made and broken intermittently by a flasher. A photocell is used to turn the lights on and off automatically at certain light levels.

Maintenance of lighting systems as a rule is fairly simple. Lamps burn out and must be replaced. It is possible to double the lamp-replacement period by installing two lamps at every light requirement and connecting these two lamps with a small relay which turns on lamp 2 upon failure of lamp 1.

The most chronic tower-lighting complaint is water getting into the system and causing shorts. Here again, it is a matter of making sure that all connectors and covers are installed neatly and made watertight. It seems that about as many leaks occur in the conduit system as in the system which uses flexible cable.

Some stations with tall towers have experienced broken glass on beacons due to falling ice and have installed small ice shields over the beacons. Most flashers today use a mercury switch to make and break the circuit. These mercury switches are relatively trouble-free. Flashers which use con-

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[1] FCC Docket No. 19331 proposes to change the tower lighting requirements.

tactors for making and breaking a circuit tend to give trouble because contact points burn and pit.

Tall towers requiring several beacons and side lamps are usually fed with several circuits of color-coded TW wire in rigid conduit. Most short AM towers make use of service entrance cable or any number of flexible cables, since this system is cheaper.

Since the beacon is the uppermost point on a tower, it is usually protected with a lightning rod, which reaches a couple of feet above the beacon. Most TV antennas have a lightning rod built into the antenna. As a conservative precaution, it is wise to ground physically in the junction boxes the neutral or ground wire in the lighting system at several levels on the tower.

SIMPLIFIED TOWER DESIGN

Calculating Wind Load

The method of calculating wind load on a tower is given in Sec. 2 of EIA Standard RS-222A. On triangular tower structures, wind pressure is applied to 1.5 of the projected area of all members in one face. Pressure is applied to the projected area of lighting lines. Calculations below are for 30 psf on flat members and 20 psf on round members.

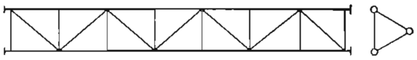

Fig. 65. Typical triangular tower section.

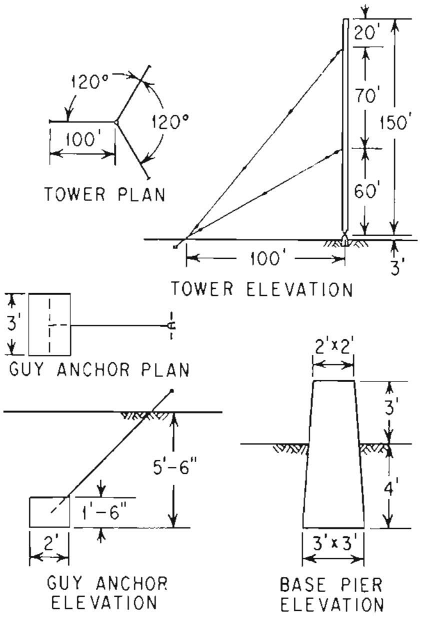

Fig. 66. Tower sample analysis.

1. Tower

Member	External Diameter, in.	Length, in.	Number of pieces	Projected area, ft.^{2}
Cross member 3/4 in. I.P.S.	1.05	16.34	8	0.95
Diagonals 3/4 in. I.P.S.	1.05	39	7	1.99
Verticals 1-1/4 in. I.P.S.	1.66	240	2	5.53
Total projected area				8.47

Wind load:

$$\frac{\text{Projected area} \times 1.5 \times \text{wind pressure}}{20 \text{ ft.}} =$$

$$\frac{8.47 \times 1.5 \times 20}{20} = 12.71 \text{ psf}$$

2. Lights:

$$\text{Total projected area} = \frac{1 \times 20}{12} = 1.67 \text{ sq. ft.}$$

$$\text{Wind load} = \frac{\text{projected area} \times \text{wind pressure}}{20 \text{ ft.}}$$

$$= \frac{1.67 \times 20}{20} = 1.67 \text{ psf}$$

3. Total wind load = 12.71 lb./ft. + 1.67 lb./ft.
= 14.38 lb./ft.

Shear, Moment, and Loading

Obtain shears and moments, considering the tower as a continuous beam. Assume that the points of support deflect as a straight line. Use the moment-distribution or similar method. Allow for eccentric application of the load by the guy. The eccentric moment is the vertical component of the load in the guy multiplied by its distance from the center of the tower.

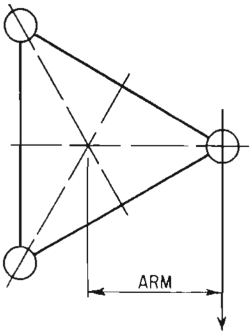

Fig. 67. Shear and moment analysis.

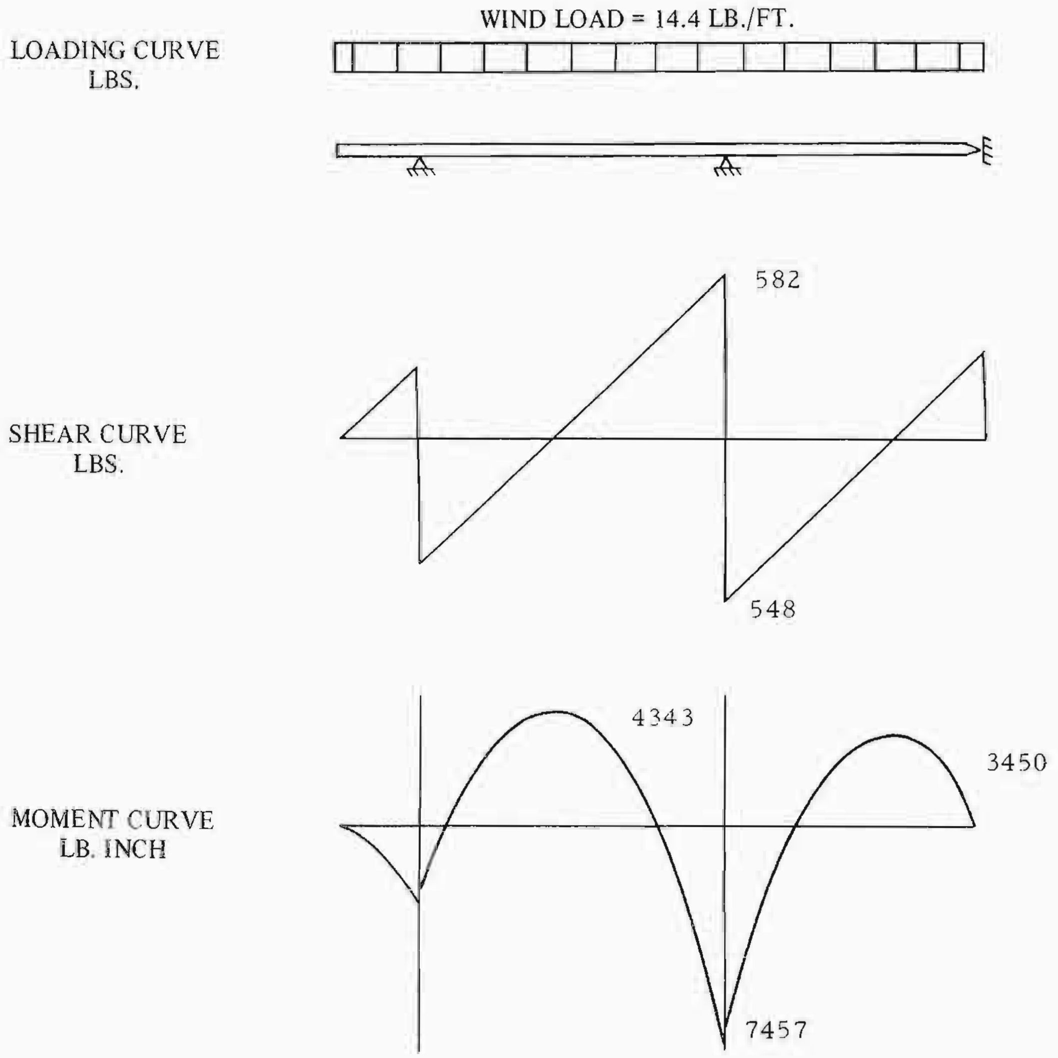

Fig. 68. Loading, shear, and moment curves.

Diagonal Struts

Diagonal struts resist tower shear. Assume that two-thirds of the shear is carried by one face of the tower.

Maximum shear = 582 lb.

$$\text{Load} = 2/3 \times 582 \times \frac{34.1}{18} = 735 \text{ lb.}$$

Check the strength of the member for compression and for tension using allowable stresses (see RS-222A Par. 3.1.1).

Horizontal Struts

The load in horizontal members is equal to the horizontal component of the load in diagonal members.

$$\text{Load} = 735 \times \frac{18}{34.1} = 388 \text{ lb.}$$

Check the strength as for diagonal strut.

Column Load on Tower

The wind direction shown is critical for the column load on the tower. Two guys are on the windward side of the tower and apply a vertical load. Assume that the tension in the leeward guy is negligible, then the load in each guy is

$$\text{Tension} = \text{reaction} \times \frac{\text{length}}{\text{guy radius}}$$

The column load is the sum of the weight plus the vertical components of the guys.

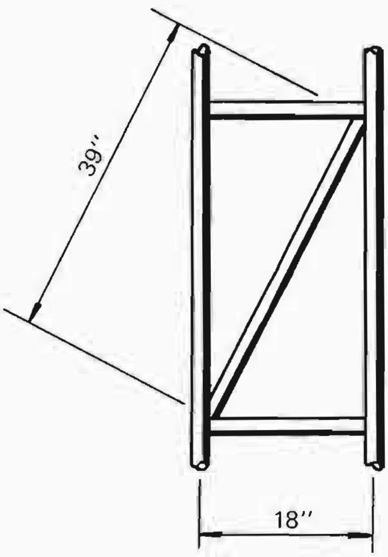

Fig. 69. Diagonal and horizontal struts.

Load in Vertical Member

The vertical members of the tower must be designed for combined compression and bending. The load in a vertical member is equal to the column load divided by 3 plus the chord load due to bending M/d where d is depth. The tower must be checked for tension in the vertical members and for compression. At the point of maximum moment in the first bay, the member is checked as follows:

$$\text{Column Load} = 4{,}423 \text{ lb.}$$

$$\text{Moment} = 3{,}450 \text{ ft.-lb.}$$

$$\begin{aligned}\text{Load} &= \frac{4{,}423}{3} \pm \frac{3{,}450}{1.30}\\ &= 1{,}474 \pm 2{,}650\\ &= 4{,}124 \text{ lb. compression}\\ &= 1{,}176 \text{ lb. tension}\end{aligned}$$

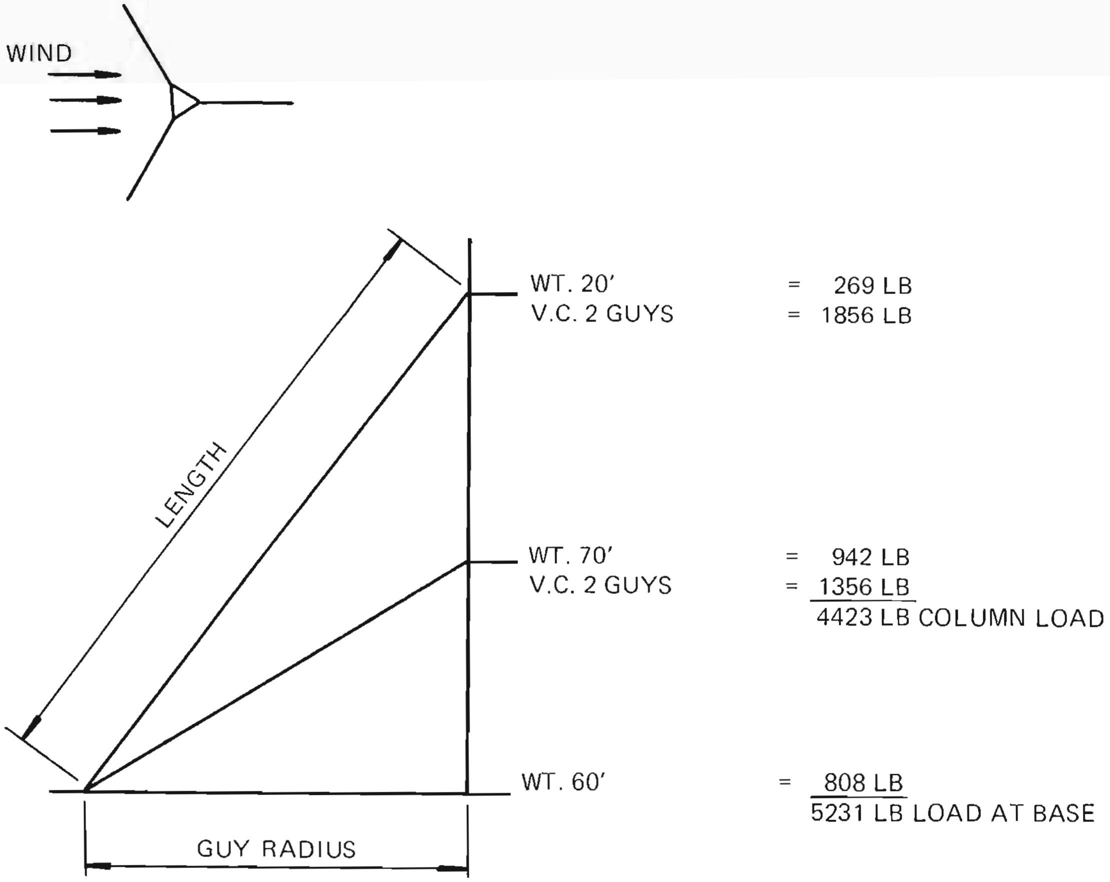

Fig. 70. Column-load analysis.

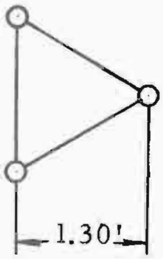

Fig. 71. Vertical-member load.

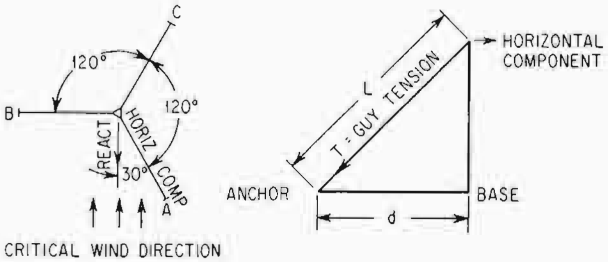

Fig. 72. Critical loads for three-way guying.

Check the strength of the member for compression and for tension, using allowable stresses in RS-222A (Par. 3.1.1).

The tower acting as a column between guys may be critical if the slenderness ratio becomes large. In general, if the ratio of the span between guys divided by the face width of the tower is 40 or less for triangular towers and 50 or less for square towers, column action of the tower is not critical.

Guy Load

The load in guys depends on the guying arrangement and on the direction of the wind. For any number of equally spaced guys, there is a critical wind direction, and this direction must be used to obtain the maximum guy load. Critical loads for three-way guying are shown in Fig. 72.

By statics

$$\text{Horizontal component (guy } A) = \frac{\text{tower reaction}}{\cos 30°}$$

$$\text{Horizontal component} = \frac{R}{0.866} = 1.154R$$

and

$$\text{guy tension} = T = 1.154R \times \frac{L}{d}$$

In practice, especially on tall towers, an allowance is made for wind loads on guys and for erection tension or initial tension in guys. EIA Standard RS-222A (Par 8.2) requires a factor of safety of 2.5, based on the ultimate strength of the guy strand.

For a sample tower, guy loads are as follows:

Guy No.	R, lb.	L, ft.	d, ft.	Crit. guy load, lb.	Guy size, in.	Ultimate strength, lb.	Factory of safety
1	1,130	117	100	1,526	1 X 7 X 1/4 E.H.S.[a]	6,650	4.36
2	714	164	100	1,350	1 X 7 X 1/4 E.H.S.[a]	6,650	4.93

[a] Extruded Hardened Steel.

Foundation Loading

1. Base foundations must be proportioned so that the area of the base is greater than the total column load plus the weight of the concrete pier divided by the allowable soil bearing pressure.
2. By EIA, RS-222A, bearing pressure for normal soil is 4,000 psf.
3. Applied column load = 5,230 lb.
   Weight of concrete pier 44.3 cu. ft. at 140 lb./cu. ft. = 6,200 lb.
   Total load on base = 11,430 lb.
   $\text{Bearing pressure} = \frac{11{,}430}{3 \times 3} = 1{,}270 \text{ psf}$
4. Bearing pressure is considerably less than 4,000 psf, and the pier has a large factor of safety.

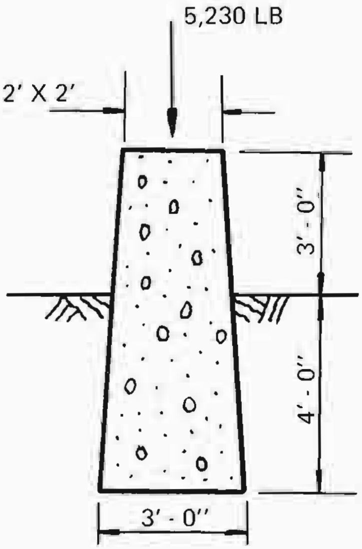

Fig. 73. Base-foundation analysis.

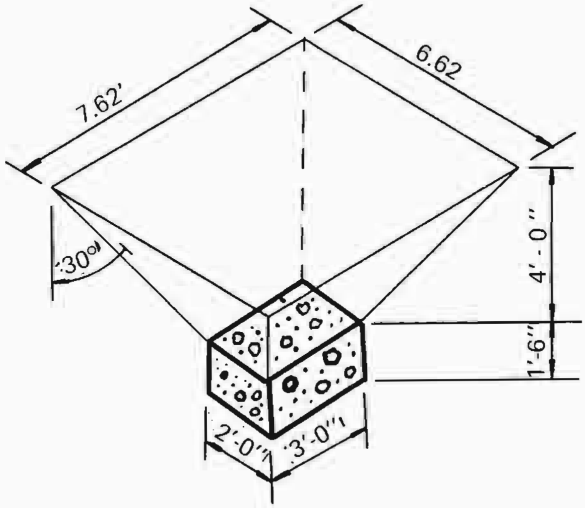

Fig. 74. Guy-anchor analysis.

Guy Anchors

1. Guy anchors are designed for the resultant load of guys when the wind is blowing in the critical direction.

2. Vertical load is resisted by weight of concrete and earth overburden. EIA specifies in uplift that the foundations shall be designed to resist two times more than the applied load assuming that the pier engages a 30° frustrum as an earth overburden. Resistance to horizontal load is provided by friction on the base of the anchor and by lateral resistance of soil on the face of the anchor. Friction on the base is usually small and is neglected. Lateral resistance can be obtained by Rankine's formula for passive resistance:

$$P = wh \frac{1 - \sin \phi}{1 + \sin \phi}$$

where P = resistance, psf
W = unit weight of earth – 100 lb./cu. ft.
h = depth to point considered – 4.75 ft.
ϕ = angle of internal friction of soil assumed to be 30°

$$P = 100h \frac{1 + 0.5}{1 - 0.5} = 300h = 300(4.75)$$
$$= 1{,}425 \text{ psf}$$

3. Allowable uplift on anchors:

For weight of earth:
$4/3(6 + 50.4 + \sqrt{302.4}) = 98.5$ cu. ft.
98.5 cu. ft. × 100 lb./cu. ft. = 9,850 lb. of earth
For weight of concrete:
2 ft. × 3 ft. × 1.5 ft. = 9 cu. ft.
9 cu. ft. × 140 lb./cu. ft. = 1,260 lb. of concrete

$\dfrac{9{,}850 \text{ lb.}}{11{,}110 \text{ lb.}}$ of earth × 1/2 = 5,555 lb. allowable uplift

4. Allowable horizontal load on anchor

= resistance psf × frontal area
= 1,425 psf × 3 ft. × 1.5 ft.
= 6,420 lb.