ITRAINONLINE
COMMUNICATION TOWER HANDOUT

Developed by: Alberto Escudero Pascual, IT +46

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1. About this document

These materials are part of the ItrainOnline Multimedia Training Kit (MMTK). The MMTK provides an integrated set of multimedia training materials and resources to support community media, community multimedia centres, telecentres, and other initiatives using information and communications technologies (ICTs) to empower communities and support development work.

1.1 Copyright information

1.2 Degree of Difficulty

The degree of difficulty of this unit is Basic.

1.3 Acknowledgements

Constructing towers and masts requires years of experience. Therefore, I have collected the best online resources from experienced tower builders. Three people deserves special acknowledgement:

Mr. Mark D. Lowell (N1LO), the author of the *N1LO Guide Tower Topic Summary*. The guide is a digest of his own experience and the TowerTalk forum, an email forum with thousands of experienced tower builders.
Source: http://www.qsl.net/n1lo

Mr. Steve Morris (K7LXC), a professional tower installer, the founder and moderator of the *TowerTalk forum*.
Source: http://www.championradio.com/installs.html

Last but not least, Mr Rick Kunze, an experienced tower builder and founder of ColusaNET Inc, he has put together an excellent site of his *150 ft self supporting tower* construction project.
Source: http://www.do-it-yourself-tower.com/

2. Introduction

Radio masts and communication towers are typically tall constructions specially designed to carry antennas for radio communication. Such radio communication includes television, radio, GSM and Internet traffic.

Towers and masts are used in numerous applications in wireless networks from broadband point-to-point systems to LMR[1] networks. Towers and masts are often required to raise antennas above tree lines and roof tops for line-of-sight connections.

This unit is a general guide, practical oriented, for establishing a communication tower or mast. The guide is applicable both for self supporting towers and guyed masts.

3. The standard

The *Structural Standards for Steel Antenna Towers and Antenna Supporting Structures* (ANSI/TIA 222-F-1996 was published in March 1996 by the TIA (Telecommunications Industry Association). The objective of the TIA 222-F document was to provide a set of minimum criteria for specifying and designing steel antenna towers and antenna supporting structures.

The document includes topics as wind loading, paint, guys, foundations, bolt tightening, climbing and maintenance. The document is not free of charge (costs about 100 USD), but it is highly recommended to have a copy of it when you are planning to erect a communication tower/mast.

4. Definitions: Towers and Masts

In engineering terms, a **tower** is a **self-supporting** structure while a **mast** in **supported by stays or guys**.

The terms "tower" and "mast" are often used for the same type of structure, which of course can cause confusion. Tower and mast have different definitions in American and British English. In *American English*, both types of structures are often called *towers*, while in *British English*, people always use *mast* instead.

To avoid this confusion, in this unit we are using the engineering terms:

- tower = self-supporting
- mast = supported by stays or guys.

1 Land Mobile Radio - wireless for specialized applications as taxi, police or emergency services

5. Types of towers and masts

This section presents the three most common types of towers/masts that are used today in wireless communication; **self-supporting** tower, **monopole** and **guyed** mast[1].

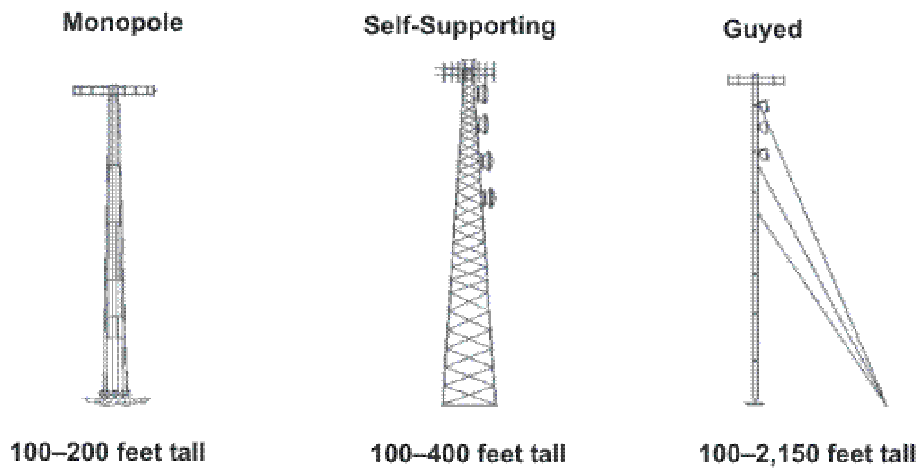

Image 1: The three most common types of communication towers/masts.

Source: Centers for Disease Control and Prevention (http://www.cdc.gov)

5.1 Monopole tower

Monopoles are hollow tapered poles made of galvanized steel They are constructed of slip jointed welded-tubes and can be up to 200 feet (60m). Due to its construction, they are expensive to manufacture but simple to erect.

Monopoles are primarily used in urban environments where there is limited space available for the footprint[2] of the tower base. The maximum footprint of a 200 feet monopole is approx. 6x6 feet (2x2 m)

Image 2: A monopole tower
Source: http://commons.wikimedia.org

1 Notice that the “guyed” **mast** pictures only a set of guys (this is for graphical reasons only)

2 The physical space needed for the deployment.

5.2 Self supporting tower

A self supporting tower (free-standing tower) is constructed without guy wires. Self supporting towers have a larger footprint than monopoles, but still requires a much smaller area than guyed masts.

Due to its relatively small footprint, this kind of tower is commonly seen in cities or other places where it is short of free space.

Self supporting towers can be built with three or four sided structures. They are assembled in sections with a lattice work of cross braces bolted to three-four sloping vertical tower legs.

The wider the base of the tower is, the larger antenna load is acceptable.

Image 3: A self supporting tower with no need of guys.

5.3 Guyed mast

A guyed mast is secured with guy wires that are anchored in a set of concrete bases on the ground.

A guyed mast consists of identical three-sides section (approx. 10 ft (3m) each) that are stacked upon each other. Unlike monopoles for example, the guyed masts do not taper as they rise, since each section has the same width.

As a result of the guys, this kind of mast has a large footprint. On the contrary, guyed masts can be higher than non-guyed towers and allow larger antenna load.

A guyed mast is ideal for most communication needs, including wireless Internet, cellular and antenna radio towers.

Image 4: A guyed mast with two level of guys attached in three points each.
Source: http://commons.wikimedia.org/

6. How to choose a tower type

There are in general four major consideration when selecting the type of tower for your deployment:

1. Antenna load
2. Tower footprint
3. Height of tower
4. Budget

6.1 Antenna load

The antenna loading capability of a tower depends on the structure of the tower. The more surface area of antennas, coaxial cables, brackets and other equipment mounted on the tower and exposed to the wind, the more robust tower is required.

To make sure that your equipment adds a load less than that maximum allowed value for your tower, you must estimate the effective wind load for your equipment.

The wind load is proportional to the area of the exposed structure and to the distance from the attachment to the ground. Curved and perforated shapes (grids and trusses) offer less wind resistance and are therefore preferred to achieve a low wind load. Solid dishes are quite vulnerable to wind load and should be avoided in windy environments.

The average wind speed of the site must also be taken into consideration. The average wind speed depends on where on the earth the site is located, the altitude and type surroundings (rural or city). Online statistical data is available from meteorological institutes.

There are many ways to calculate the wind load, some are better than others. The “latest” and probably most accurate method is specified in the latest IEA-222 standard specification.

6.2 Tower footprint

The footprint of a tower is the amount of free space on the ground that is required for the installation. Depending on the structure of the tower, it requires more or less space for installation.

For tall guyed masts (>100feet, 30m), each guy anchor is typically 10-15m from the base of the mast. For a mast with 3 guy wires per level, that results in a footprint of approx. 90-200m^2.

6.3 Height of tower

If you need a structure that is less than 40 feet, you can in fact eliminate the expense and additional work that is required for guying it. Instead you can bracket mount the tower to a house or garage roof even.

As mentioned earlier, adding guys cables to a structure will allow higher height.

6.4 Budget

A general rule of thumb is:

“The smaller the tower base, the more costly to purchase and install the tower”

Monopoles have the smallest footprint of all towers, and is hence the most expensive type of tower to install. It is followed by self supported towers and then guyed masts which require the largest footprints.

Additionally, depending on the tower type you choose, certain tools, machinery and cranes are needed to assemble the tower which must be taken into consideration in the final budget.

7. Tower location

When selecting the physical location of the tower/mast, there are a set of things that you should bear in mind. Naturally, you must make sure that you have the necessary free space on the ground where the tower will be placed. Check the specifications of the tower/mast that you aim to purchase for the size of the footprint.

The ideal site for a tower/mast is a flat, level field. However, any reasonably level space, in which there is sufficient space for the base foundations, can be utilized. The site should be free from obstructions like trees and buildings. Not only the spot for the tower needs to be clear, also the surrounding area as you will need some free space when assembling the tower.

Do not forget that trees have roots. Digging a hole through a massive root system is not a dream.

Medium sized and tall towers/masts normally require massive digging since concrete foundations must be put in place. Always call for *underground utilities check* to make sure that there is no infrastructure dough down at the place you have planned for your tower/mast.

Also, if the tower is high, always check with the regulators in the country if you need to apply for a license and/or register the tower to any authority. If the site is close to an airport, there are special regulations that need to be followed.

8. The base

All towers need a steady base to stand upon. The purpose of establishing a base under a tower is to keep the tower from sinking under its own weight and the pressure of the guy wires (if such are being used).

Most towers/masts are established on top of a **concrete base** that has a pier pin or bolt embedded in it. A less common solution is to have a tower section embedded in the concrete base. The first option with a pier pin/bolt embedded has the following advantages:

1. The bottom section of the tower does not need to be plumbed
2. No need to worry about water in the tower legs (it will naturally pour down the legs and out though the weep holes in the base plate)
3. It gives the tower the flexibility to turn a bit from side to side to absorb torque in high winds (resulting in less stress on the bottom section of the tower)
4. No need to worry about how the “base section” will interfere with the steel re-bar in the tower base

Self supported towers (no guyed wired) need one central concrete foundation with as many attachment points as the sides of the tower structure. In that way, a three-sided self supported tower needs three attachment points (anchors) in the concrete foundation.

A guyed tower needs one concrete base for each guy wire and one central base for the tower itself.

The following sections (Section 9-11), present a step-by-step process for establishing a concrete foundation for a self-supporting tower. The procedure for making concrete bases for a guyed mast is very much the same, except for the number and size of the bases and the attachment points.

Section 14 focuses on guy wires for masts (not needed in self-supporting towers).

9. Digging the hole

The digging of the base hole can be done by hand if the tower is small enough. As the tower grows, the amount of soil to be dough increases rapidly. It is highly recommended to hire a backhoe (with an experienced operator) for digging a hole for a tower in large scale.

There are some issues that you should keep in mind before you start to dig:

Undisturbed soil
It is important that the base is surrounded by “undisturbed” soil to avoid it from shifting. Therefore, make sure that you do not remove more soil from the sides than what is necessary.
If necessary, have the backhoe operator to dig a hole with rough dimensions and then build up the walls by hand.

Larger volume than expected
Always expect that the final volume of the hole will be larger than you first expected. Digging with a backhoe is not a precision work and you will normally end up with a hole with larger dimensions that what you planned for. That means that more concrete is going to be needed.

Typically, soil will fall off from the sides into the hole. The hole will be *bell shaped* after you have removed the loose soil. The result will be that you may need up to least 25% more filling to your hole.

Forming the hole

Avoid using wooded forms to shape the hole. Over time, the wood will rot and a gap will be formed around the concrete which will reduce its stability.

If the surrounding soil is so poor (dry and sandy) that you need to use forms, remove them after the concrete has stabilized. Also, make sure to fill up the gap between the soil and the concrete and pack the soil. This will restore some stability to the base.

Finally, the hole must be shaped very accurately and loose material must be removed before the hole is filled up with concrete.

Image 5: a) Digging the hole for the base with a backhoe b) The hole is finished with straight and even edges.

Source: http://www.do-it-yourself-tower.com/

10. Building a re-bar cage

A cage of reinforcement bars, “re-bar cage“, is required to give the concrete the tensile strength it needs to support the load of your tower.

Two layers of re-bars must be placed in the hole, one bottom grid and one upper grid. They will be joined together with the support of **standees.**

The first level of re-bar should be placed at least 3” from the soil as it needs to be covered with at least 3” of concrete. The re-bars has to be covered by concrete to keep them from corroding (see Section 17). If re-bars start to corrode inside of the concrete it will expand and cause cracks in the concrete.
The re-bars must not only be embedded in concrete in the bottom of the cage, the same rule applies for all situations were the re-bars will be exposed to earth, i.e. bottom, sides and top.

To space the re-bar away from the surface of the hole, you place small blocks of concrete called **Dobies** in the soil.

After placing the dobies on the soil, build a grid of re-bar and tie them together with wire or plastic tie-wraps.
Do not weld as that weakens the re-bars.

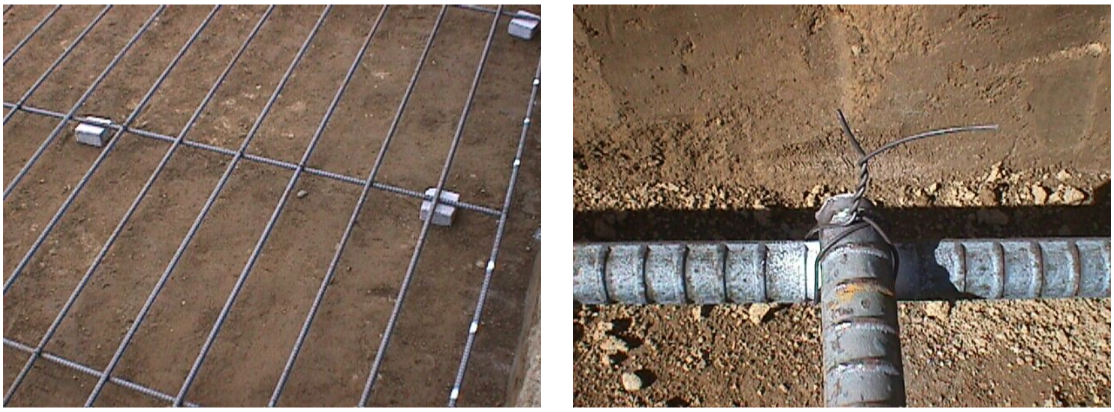

Image 6 a) Using Dobies to create space between re-bars and the soil. b) Using wires to tie the re-bars to a grid.
Source: http://www.do-it-yourself-tower.com/

Re-bars are sized in reference to1/8" steps in diameter. In that way a #4 re-bar is 1/2" diameter (4* 1/8) and a #6 re-bar is 3/4" (6* 1/8) diameter.   As a rule of the thumb, do not use re-bars less than #5 (5/8" diameter).

When the bottom grid of re-bars is in place, it is time to mount the standees. The standees will be tighten to the lower grid to support the upper grid. The standees must be customized according to your specification and normally come from the re-bar supplier.

With the help of extra dobies, place the *J-Bolts* inside of the re-bar cage. The tower will be attached to the J-bolts. The lower part of the J-bolts get embedded in the concrete with one end sticking up above the foundation.

When the standees are securely tied in place, the upper grid will be assembled on top of them in the same manner as the lower grid.

Image 7: a) Two layer of re-bars inter-connected with standees. b) J-Bolts that will connect the base of the tower to the concrete foundation.

Source: http://www.do-it-yourself-tower.com/

On top of the upper grid of re-bars, the triangular shaped structure of re-bars is formed to host the base of the tower.

When the re-bar cage is in place, it is time to fill it up with concrete.

RE-BAR NO-NO's

1. Never let the re-bar get in contact with the soil
2. Never weld the re-bars, use wires to knit instead

11. The Concrete foundation

Concrete is a mixture of **paste** and **aggregates**. The paste, composed of cement and water, coats the surface of the fine and coarse aggregates. **Portland cement** is the most common type of cement and consists of a mixture of oxides of calcium, silicon and aluminium.

Through a chemical reaction called **hydration**, the paste hardens and gains strength to form the rock-like mass known as concrete. Hydration is the key issue behind the success of concrete; its plastic and mouldable state when newly mixed but hard and strong as rock when hardened.

11.1 Concrete composition

Typically, a concrete mix should be about 10-15 % cement, 60 - 75 % aggregate and 15 - 20 % water. All ingredients must be carefully selected to create a good final product.

Most natural water that is drinkable and has no taste or odor, can be used for making concrete. Even some waters that are not drinkable are still suitable for concrete. Excessive impurities in the mixing water will affect the setting time, the concrete strength, may cause efflorescence and staining. Additionally, it may cause corrosion of the re-bar structure which will cause volume instability and reduced durability.
Concrete specifications normally states limits for the level of **chlorides, sulphates, alkalis, and solids** in mixing water.

The aggregates must also be carefully chosen. The type and size of aggregates affects the thickness of the concrete. Aggregates are inert granular materials such as **sand, gravel**, or **crushed stone.**

11.2 Mixing concrete

Just like digging a hole, mixing concrete can be done manually or by machine. When casting a small concrete foundation, the concrete can easily be mixed up by hand while larger bases definitely needs machinery.

As an example, a 80 pound (36 kg) bag of Quickrete will make 2/3 cubit feet (0,02 m^3) of concrete. It takes about 10 minutes to mix one bag of this in a wheelbarrow and dump it into the base. A tower base 3'x3'x3' is one cubic yard which requires no less than 40 bags. That would take 6 hours of mixing by hand.

For medium size bases, it is easier to order a truck of concrete and use wheelbarrows to shuttle the concrete to the pour site. Alternatively, a concrete mixer can be hired and used on site.

If you are having trouble with the truck not reaching the base excavation, you can collect all your friends and set up a brigade of multiple wheelbarrows to move the concrete to the hole. Alternatively, you can rent a motorized wheelbarrow.

For large bases, contract for a concrete pumper truck which can deliver loads up to 400 m away from the truck.

11.3 Pouring the concrete

If you choose to mix the concrete by hand, a large wheelbarrow and a hoe will be required. Additionally, a **tamping/vibrating tool** is a must for making the concrete flow out into your form and around your re-bar cage.

For large bases, you must rent a flexible concrete vibrating tube to make the concrete flow.

Image 8a shows how one person (left) holds the motor while another person (right) works with the "stinger" which vibrates very hard. By doing so potential flaws, such as honeycombs and air pockets, are eliminated.

The centre area inside of the J-Bolts (where the tower will be placed) should be **flat** with a **brushed finish**. The area outside the J-Bolts should slightly **slope** with a **floated finish**.

Image 8: a) Using a vibrator in the wet concrete to eliminate flaws such as honeycombs and air pockets. b) The central area should be flat with a brushed finish while the surrounding area is sloping (outwards) with a floating finish (completed only in the right corner).

Source: http://www.do-it-yourself-tower.com/

11.4 Hydration

Concrete does not *dry,* as many people often refer to, it *hydrates*. Hydration is a chemical process between the paste and the aggregates which requires **time** and **water**.

Concrete continues to gain strength though hydration as long as it stays moist. As soon as it runs out of water (gets dry), the hydration process stops and the material does not gain any more strength.

The strength grows with *decreasing momentum*, i.e. most of the strength is gained early on in the hydration process. In a properly mixed concrete, the majority of the strength will take place the first 10 days. Therefore, you should never put stress on the concrete within 10 days.

11.5 Curing

Curing is a process that aids the hydration of the concrete. When the concrete is poured into the hole it should be kept moist with a temperature of 50-75°F (10-24°C). A correct curing process in essential for the quality of the concrete. Good curing implies that evaporation of water should be prevented or reduced.

CONCRETE NO-NO's

1. **Sun** on freshly poured concrete.
   - Keep it covered with wet straw (or old wet rug) plus plastic or tar paper.

2. Excessive **heat**.
   - Do not pour concrete when the temperature is too high.

3. Pouring concrete into a **hole** that is **dry**.
   - Wet the bottom and sides of the hole before you pour the concrete otherwise the dry soil will suck all the water out of the concrete. That will result in a weak mix when it cures.

4. **Stressing** the **fresh concrete**
   - Do not put any stress on the tower base while the concrete is hydrating. Do not assemble the tower too quickly.

5. **Dry concrete** surface while **curing**
   - Give it a spray with water as often as possible to keep it wet.

11.6 Concrete strength

Concrete is a very strong material when it is placed in compression, i.e. it can handle heavy load. However, it is extremely weak during tension. That is why we need to use reinforcement in concrete structures when tension is applied to the material.

Material	***Tension (psi)***	***Compression (psi)***
Bricks, common light red	40	1000
Portland Cement, 1 month	400	2000
Portland Cement, 1 year	500	3000
Portland Concrete, 1 month	200	1000
Portland Concrete, 1 year	400	2000
Granite	700	19000

Table 1: The tension and compression values of different sorts of concrete.

12. Anchors

The anchor is the metallic structure that connects the guy cables to the concrete foundation. Anchors are critical infrastructure and they are truly the only thing that keeps a tower in place when the wind is blowing. If you lose an anchor, you will loose a guy cable and consequently the whole tower (can) goes down.

The anchor can be of type “earth anchor” or “concrete anchor”. An earth anchor is not as strong as a concrete anchor, but it is easier and cheaper to install. An earth anchor should only be used for small masts in combination with stable soil. The strength of an earth anchor depends on the type of soil they are installed in. By determine the type of soil you have, you can estimate the *pull-out rating* of the anchor.
Soils with clay will provide a higher pull-out strength while softer soils containing more sand and loam will give you a lower pull-out strength. Also, softer soil will become saturated with water during rainfall season which will result in a much lower pull-out strength. If applicable, earth anchors can also be drilled into large rocks.

13. Assembling the tower

Communication towers and masts are typically manufactured in sections which are put together on the site of the deployment. Some models though, normally shorter structures, are self-erecting towers that come in “one piece”.

This section focuses on towers/masts that constitute of a set of sections that need to be assembled. Such structures can both be self supporting tower and guyed masts.

13.1 Inspection of tower sections

Before you start to actually assemble the tower sections, make a thoroughly inspection of the metal pieces to avoid working with defective material. The inspection should be done shortly after the delivery of the material and before accepting them to the supplier. Look for the following characteristics:

1. Bent or twisted sections
2. Deformed or bent ends
3. Mis-aligned joint sleeves
4. Welds with cracks or multiple pinholes
5. Gaps, flakes or separations in the galvanizing
6. Missing assembly bolts
7. Bent braces
8. Improperly drilled bolt holes
9. Legs that you cannot see light through which are clogged with debris
10. Rust that is more than light surface rust. Use a flash light to peer inside of each leg and looks for interior rust.
11. Legs that have been repaired or welded to other than the original factory brace and joint-sleeve. These welds are often easily identified by surface rust.

13.2 Pre-assembly on the ground

A basic strategy when assembling towers is to **break down** every big task into many small **subtasks** and have a **detailed practical plan**, from start to end, before you start to assemble it. Do not start with a task if you do not know how to finish it.

GENERAL HINTS FOR TOWER ASSEMBLING

When installing a guyed section, pull the guys up separately and do not attach them to the section. If experienced, pre-installation of the guy attachments to the tower section is a good idea though, since that is a quite complex task that should be avoided to do in the air.
Install all bolts with the nuts on the inside of the tower. In that way you will reduce the protrusion on the outside legs and avoid getting stuck with your climbing gear and damage both your clothes and your skin.

For guyed masts, a set of useful tricks follows:

1. Start by pre-assemble the tower sections on the ground, starting with the base sections. Install the **guy attachment points** but do not fully tighten all the bolts until after installation of the guys.

2. Calculate how long each guy cable must be and then add 10 feet (3 m) to the result. **Pre-cut** all the **guys** and mark each one of them with a tag to identify which guy it is intended for (1^{st}, 2^{nd}, 3^{rd} etc.).

3. Pre-install the **guy grips** on one end of each guy cable, but only halfway. Leave one side “un-wrapped” so that when you raise the guy up to the guy bracket, you can easily slip the free end of the guy grip through the thimble and finish the wrap quickly while you are up on the tower.

13.3 Gin pole

A gin pole is a useful tool for lifting tower sections on top of each other. A gin pole is typically a long piece of metal tubing with a pulley in the top with a set of ropes attached to it. In the bottom of the gin pole, a bracket is attached that clamps to the leg of the tower.

When the first tower section is put in place over the concrete base, a gin pole is mounted at the top of that tower section. By pulling the ropes (by man power) from the ground, the gin pole allows to lift up a tower section above the top section of the tower and set it down onto the previous section. Meanwhile a tower section is lifted up with the gin pole, one or two persons are needed in the tower to undo the bolts and to place the section correctly when it is lowered.
Gin poles are also used for the reverse process, when disassembling a tower.

An important issue about gin poles is the type of ropes used. It is recommended to use a braided rope even though it is more expensive that a twisted rope. A braided rope avoids the unwind/wind cycles that occur under load and is also far easier to coil than a twisted rope.
Nylon is a cheaper option but it is elastic and stretches quite a bit under tension which will reduce the control of the lifting object.

The length of the rope should be approx. twice the height of the tower plus some extra length (at least 50 feet, 15m) so that the ground crew can keep a safe distance away from the bottom of the tower.
For example, for a 100 feet (30m) tower, your rope should be at least 250 feet (75m) long.

In 2004 the Telecommunications Industry Association (TIA) and Electronics Industry Association (EIA) accepted and implemented a gin pole standard entitled " *Structural Standards for Installation of Antenna and Antenna Supporting Structures"* (TIA/EIA-PN-4860 - Gin Poles). The aim of the standard was to improve the safety for tower workers.

13.4 Assembling of high towers

If the tower is very high, assembling of the tower sections can not be done manually with a gin pole. Then, a crane is needed to lift up the tower sections to the right place. Still, you need experienced people in the tower to mount the pieces together.

Image 9: Using a crane to place the top segment on a high self-supporting tower.

14. Guy cables

A guy cable (or *guy wire*, *guy rope*) is a metallic wire that gives stability to tall structures like masts. One end of the guy is attached to the tower in an attachment point while the other end is attached to the concrete foundation in a guy anchor.

The guy cables act like extension springs in two different ways (modes):

Mode 1
They change length relatively easily ***without*** significant ***elastic stretching*** as the *droop in them is pulled tight,* resulting in a very ***low spring rate***[1] until all the slack is pulled out.

Mode 2
Once they are tight (the droop is pulled out), they can still change length by ***stretching elastically,*** although only with much larger changes in tension (***larger spring rate***).

1 Spring rate it the amount of force needed to compress a spring.

14.1 Types of guy wires

The most commonly used guy wires are EHS Steel guy wires, Phillystran and Pultruded fiberglass.

EHS (Extra high strength) Steel Guywire

Specified in the ANCS (American National Standards Institute) standard ASTM B227-04 with the title *"Standard Specification for Hard-Drawn Copper-Clad Steel Wire"*.

An EHS steel wire is made of a set of galvanized twisted steel strands and is the most commonly used guy cable.

Image 10: EHS galvanized guy cable

Phillystran

A non-conducting guy wire material made out of Kevlar (aramid fiber) fiber core with a PCV jacket. Phillystan is both strong and light weighted.

The purposes of the PVC jacket jacket are:

1. To protect the cable from abrasion during installation
2. To prevent moisture from wicking into the core
3. Most importantly, to protect the core from UV damage

Pultruded fiberglass

Pultroded fiberglass is much more elastic than steel. In order to have the same spring rate as steel guys and hence, the same ability to stabilize a tower, the cross-sectional area of the fiberglass must be must larger (4.83 times) that the steel.

In the case of a EHS guy, the equivalent solid fiberglass rod diameter would be twice the EHS size you want to replace.

14.2 Pre-load in guy cables

It is recommended that the guy wires should have a initial tension (pre-load) of approx. 10-15% of its ultimate breaking strength[1] to stretch out the slack in them. The exact amount of pre-load depends on the type of guys used and how high up in the tower/mast they are attached.

When you add pre-load to a guy wire, you will straighten it out as it is it is not perfectly straight as it is. However, due to gravity, the wire will never be entirely straight and there will always be a concave curve even though it is pulled beyond the specified pre-load. At some point, the stretching will make the wire to expand elastically which means that it goes from mode 1 to mode 2.

If you add too large pre-load to your wire, you are reducing its ability to absorb additional load (from the tower moving) before it reaches its breaking strength.

The larger the diameter of the guy, the higher spring rate which implies that it can better resist a change in length (i.e. movement of the tower) for the same loading force. However, a larger diameter will make the guy wire heavier and hence, it requires more pre-load tension to pull out the slack (still 10-15% of the tensile strength).

In summary, using a thicker guy wire will allow more flexing of your tower since it has a higher spring rate, and hence, much larger forces are required to make it change length.

1 Breaking Strength - The measured load required to break a wire rope in tension.

As a rule of thumb, if the guy is attached in the top of the tower (100%), the tension should be 8% of the tensile strength. For 80% of the tower's height, 10% tension should be applied. If the anchor point is at 65% of tower height, 15% tension can be applied as you loose a lot of wind load in this last type of installation. The breaking strength will improve the control of the flexibility and still not cut down on the cable strength.

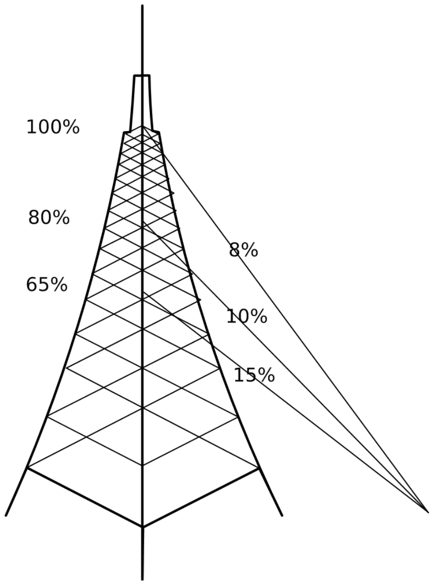

Image 11: Suggested pre-load in guy wires for different height of the tower.

Source: IT +46

Depending on the height of the tower, you must choose the right diameter of the guy cable that can handle the load of the tower.

For example, a *Rohn 25* tower requires a 3/16" EHS guy. That wire has a breaking strength of 4,000 lb (1800kg) which allows a tension of 400 lb (180kg).

Type	***Diameter (inch)***	***Diameter (mm)***	***Breaking strength (lb)***	***Breaking strength (kg)***
EHS (7 strands)	3/8"	9.5	15,400	6985
EHS (7 strands)	5/16"	7.9	11,200	5080
EHS (7 strands)	1/4"	6.5	6,600	2994
EHS (7 strands)	3/16"	4.8	3990	1810

Table 2: Breaking strength for EHS guy wires with different diameters.

14.3 Termination of guys

The guy wires need to be terminated in a way so that they can be securely attached to the guy anchors.

For EHS, preforms or aka. "dead ends" are the most reliable and easiest way to terminate a guy.

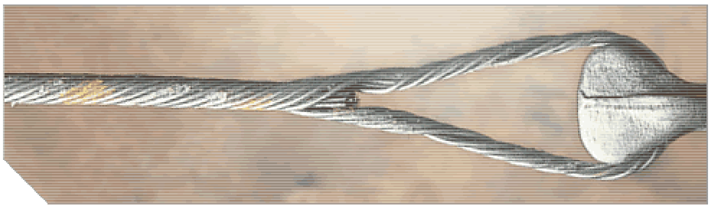

Image 12: A terminated guy cable with a “dead end”.

Use thimbles over the preforms for ALL terminations. Many thimbles are teardrop-shaped which you need to open up when installing them. There are also thimbles that are U-shaped with enough clearance in the mouth that you should have a minimum of fuss installing them.

Image 13: a) Tear drop shaped thimbles. b) A “dead-end” terminated guy cable with a thimble.

14.4 Tightening the guy cables

As you assemble the mast, section by section, you need to tighten the guys accordingly. Normally, a tower has 2-3 levels of guys (depending on the height of the tower/mast) and three guys on each level.

Image 14: A guyed mast with a total of six guy wires (two levels with 3 guys each).

Naturally, you will start with the guys closest to the base. Start by tighten all three guys moderately and then check the tower for plumb with a tall level.
It is recommendable to use turnbuckles as it will allow you to fine tune your adjustments later on.

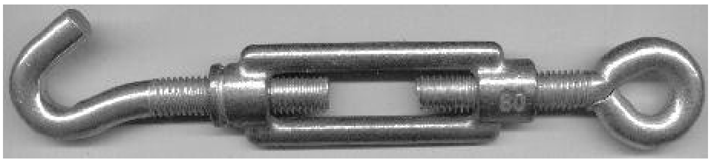

Image 15: A turnbuckle used to tighten guy wires.

Source: Wikimedia.org

14.5 Measuring the tension

You should strive to achieve equal tension in all guys at the same level, assuming that the guy anchors are at the same distance from the base.

An inexpensive, easy to use and accurate way to measure guy wire tension is with a **LOOS guy wire tension gauge**. The gauge is manufactured of rugged anodized aluminium and is corrosive resistant and hence, has a long life time. The guy cable can be adjusted (tightened/loosen) while the gauge remains on the cable.

GENERAL TIPS FOR GUY TENSIONING

Put a separate wire, or one of the long loose ends, through all the turnbuckles to prevent them from loosening

Loop a cable through all of the thimbles (in a circle) in case one of the turnbuckles breaks.

The guy tension changes with temperature due to expansion and contraction. That means, if the initial tension was done in the winter, it will loosen up in the summer due to expansion caused by higher temperature.

14.6 Measuring tower plumb

As you are tightening the guy wires and measuring the tension, you need to measure how plumb your tower is, so that you do not end up with a tower in Piza[1] style.

A simple method to measure the plumb is to use a plumb bob. A plumb bob is a weight that is attached to a line. The line is suspended to the center of the tower at the first guy point. The plumb bob will form an exact vertical line (due to gravity) and the guys should be adjusted so that the tower is parallel with the bob line.

If the wind catches the line (depending the weight of the bob and the wind conditions) you can place a bucket of water at the base of the tower to reduce the swinging of the bob.

When the first tower section is plumb, you continue to the next section.

Image 16: A plumb bob used to adjust the guys in order to ensure a vertical tower.

1 The top of the leaning tower in Piza is about 5 m (16 ft) from the vertical. An excellent example of a tower that is not plumb.

14.7 Temporary guys

When you are assembling you tower, some of the tower sections (most of them) will not be equipped with guy wires since normally only two layers of guys are used. That means that you will be working in tower sections that might be 2-3 tower sections above the last guy point. Most people seem to feel comfortable climbing two sections (approx. 6m) above the last guy point. More experienced climbers might allow 3-4 tower sections above the last guy point until the sway becomes too great. The solution to this problem is to add temporary guys to tower sections placed between guy points. The temporary wires are removed when the permanent guy wires are in place.

A good rule of thumb is to use temporary guys any time if you are 2 sections (20 feet = 6m) or more above the last permanent guy set.

Temporary guys do not need to withstand the same load that permanent ones must. If you plan to finish all permanent guys the same day (and the weather is fair), you can allow fairly light temporary guys. However, if you can not compete the permanent guying in one day, you should go for more stable temporary guys.

The material of the temporary guys should have a very low stretch (i.e. being stiff) like lightweight steel cable or twisted polyester.

15. Climbing

It should not come as a surprise to you, that climbing a 150 feet tower is dangerous. Climbing tall structures requires adequate **training** and **equipment**.

As a rule of the thumb, a person with no climbing experience, should not climb a tower higher than he/she can survive after a possible fall to the ground.

The safest, most comfortable, and most versatile type of climbing belt is a **seat harness**. If you are a professional tower climber, you will need to follow OSHA requirements for harness and use a "fall arrest" type of harness. This harness typically has a full body arrangement.

Image 17: a) Seat harness b) A harness with fall arrest.

Source: Klätter och Högfjäll, http://www.klatterochhogfjall.com (Image 17a)

You should be equipped with a belt around your waist with accessory loops for tool buckets and carabiners.

GENERAL TIPS FOR CLIMBING EQUIPMENT

Stay away from leather belts which are no longer approved by OSHA. The leather can dry out and become seriously weakened.

Make sure that the climbing gear that you are using is comfortable to wear for long periods as you will probable be up in the tower for many hours.

Do not be cheap when it comes to climbing equipment. A mistake can be fatal and you have only one life in this game. Also, you will perform the work better if you feel safe and enjoy the time up in the tower.

Try to keep all equipment as light as possible

Other climbing equipment that is relevant:

- Climbing lanyards
- Carabiners
- Ropes

Finally, you will need appropriate clothes for the mission including helmet, shoes and gloves (do not forget to drink!).

16. Lightening protection

Lightning protection is a must for any structure elevated above the surroundings. Lightening is a common enemy to wireless installations in high structures and must be prevented as far as it can.
There are generally speaking two different ways that lightening can damage your equipment, direct and indirect hits.

16.1 Direct hits

Towers should be equipped with Franklin rods properly grounded at each foundation point. Legal requirements in most areas only require grounding of the tower, but guy-cable grounding is advised as well.

The mast top should be connected to the ground by a low resistance cable, usually of copper or similar conductive material. Suitable ground clamps to attach the cable to the mast and the ground system are needed. The cable must have a good electrical connection, so make sure that all paint and rust (corrosion) are removed from the area where the clamp attaches to. Also, use dielectric grease on the clamp connection to prevent any electrolysis activity due to dissimilar metals.

However, if the lightening hits the tower itself (or the equipment) there is very little that can save it.

16.2 Indirect hits

Induction currents (indirect hits) through nearby lightning strike can cause damage to outdoor radio equipment. It can be prevented by using surge protectors to vulnerable equipment and choosing radios that have a higher voltage rating. However, surge protectors does not protect the antenna, only the radio.

17. Corrosion

Corrosion is an attack on material though a chemical reaction with the environment. Materials affected by corrosion are not only metals but also for example plastics. The environment that can cause corrosion can be air (oxygen), water and chemical substances.

Corrosion implies deterioration of useful properties in the material and is something you want to avoid to all prices. A well-known case of corrosion is weakening of steel due to oxidation of the iron atoms.

In fact, corrosion is the tendency of a **refined metal to return to its native state**.

There are certain conditions which must exist before a so called **corrosion cell** can function. The following elements are needed:

1. Anode (positive charged)
2. Cathode (negative charged)
3. Electrical path (between anode and cathode)
4. Electrical conductive electrolyte

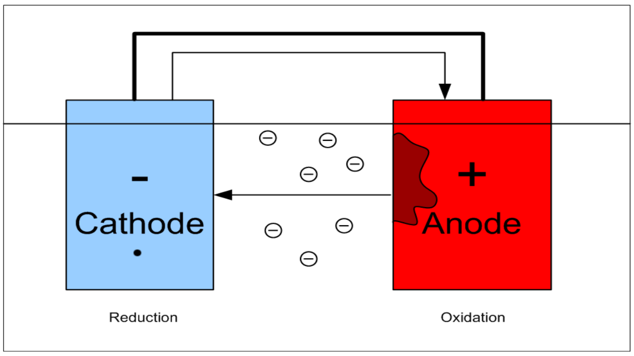

Image 18: An active corrosion cell

Source: IT +46

The cause behind a corrosion cell is a **potential** (voltage) **difference** between the anode and cathode. When all four conditions (see element 1-4 above) are met, an active corrosion cell is in place.

When the anode and cathode are electrically connected, the anode is positively charged and the cathode is negatively charged. When corrosion takes place, electrons moves from the anode (positive) to the cathode (negative). In the anode, **oxidation** occurs while in the cathode, a process called **reduction** takes place.

Oxidation implies that electrons are emitted which has an detrimental affect on the anode which weakens the material. Reduction implies that the electrons are bound to the material.

Often, moist from rain or humid air will play the role as the electrolyte and cause corrosion. Also, oxygen can contribute to corrosion.

The impact of corrosion in guy anchors or re-bars can be extensive, not only financially costly but also cause fatal accidents with people involved. The problem with corrosion can be prevented, or at least greatly reduced, by having these risks in mind when establishing a tower and using a suitable method for preventing corrosion.
Also, careful maintenance of the tower within regular intervals is important.

17.1 Corrosion prevention

In simple words, corrosion in terms of tower constructions includes the existence of the following two elements:

- Oxygen (or dis-similar metals)
- Electrolyte (a liquid with free ions like water with minerals)

The corrosion prevention mechanisms that exists, targets these two elements.

17.1.1 Antioxidant joint compound

Corrosion can be prevented by using an **antioxidant joint compound** which can protect the metals from moisture An efficient antioxidant has two components:

- Finely divided metal particles (zinc or copper)
- A durable grease (based on silicone or petroleum)

The grease will hold the metal particles and stick them to the metal surface and exclude both oxygen and moisture.

17.1.2 Cathodic protection

Corrosion can also be prevented by the use of "Cathodic protection". Cathodic protection makes use of the known process in a corrosion cell to effectively avoid the negative effects of corrosion.

Galvanic anode protection is a simple method of cathodic protection which is based on the idea of a **sacrificial anode**. In the case of a preventing corrosion to a tower anchor, a sacrificial anode is electrically bonded to the anchor support.
The material of the anode must be higher on the galvanic series[1] than the metal is should protect. In that way, the anode will corrode instead of the anchor or tower components (there of the name, sacrificial). A sacrificial anode is normally made of magnesium or zinc.

It is not only the material of the anode and cathode that matters for corrosion, it is also a relationship between the sizes of the anode and the cathode that has an impact on the severity of the corrosion cell.

- When the area of the **cathode** is very **large** in relationship to that of the anode, the **corrosion cell** will be more **severe**, and thus the faster the anode will deteriorate.

- If the **anode** is very **large** in relationship to the cathode, the effects of corrosion are much less and the anode deterioration is more gradual.

Since the purpose of the sacrificial anode is to be corroded, it must be replaced after some time.

See document "Understanding and Preventing Guyed Tower Failure Due to Anchor Shaft Corrosion" for further information about corrosion related to towers.

1In the galvanic series, each metal has his own placement (a number) according to the potential it has to other metals.

18. Maintenance

The tower should be inspected at least twice per year. The inspection should (at minimum) include the following:

- Ensure that all hardware is tight
- Ensure proper tension in the guy cables
- Inspect for corrosion. If corrosion is found, remove loose pieces and add paint.

19. Conclusions

To establish a communication tower requires a great deal of planning, access to experienced personnel and good tools. Without any of these components, the tower will not stand up for a long time.

A "base" of good quality is essential for the life time of a tower/mast. If the base in not done with care, fatal accidents can occur which might not just turn out to be expensive but also include personal tragedies.

The TIA (Telecommunications Industry Association) has established a set of standards that relates to tower establishments:

- The "*Structural Standards for Steel Antenna Towers and Antenna Supporting Structures* (ANSI/TIA 222-F-1996)", it provides a set of minimum criteria for specifying and designing steel antenna towers and antenna supporting structures.
- *"Structural Standards for Installation of Antenna and Antenna Supporting Structures"* (TIA/EIA-PN-4860 - Gin Poles), it is another standard that aims to improve the safety for tower workers.

It is highly recommended to have a copy of these standards when planning for a tower/mast structure.

The five main issues to remember for this unit can be summarized as follows:

1. Select the type of tower depending on antenna load, footprint, height needed and financial budget.
2. A base foundation of good quality is essential for a safe tower with long lift time
3. Working at high height does always imply danger. Do not be cheap when it comes to security. Use good equipment and play safe.
4. Make sure that you have the time that you need. Stress will allow you to make mistakes which can be very costly.
5. Always keep in mind the risks of corrosion and prevent it as far as you can. Also plan for continuous inspections for corrosion and other defects.