match your antenna to your tower

Here's how to calculate wind area, wind load, and bending moment

Have you heard the story *about the ham across town who bought a new $500 long-boom tribander to replace his older, smaller beam? He rented a "cherry-picker" at $50 an hour to have it installed on top of the tower he'd originally bought for his 5/8-wave CB antenna in the days before he'd become a ham. The rotator, a small CDE unit he'd bought for $10 at a flea market, had worked fine with the TH3JR that he'd also purchased soon after getting his ham ticket.*

A few months later, a snowstorm driven by 50 MPH winds demolished his entire antenna system, and worse yet, sent the tribander crashing through the roof of his neighbor's house. He wound up in a hassle with his insurance company over the damages, and the neighbor soon began circulating a petition to ban antennas and towers from that city.

You don't think this could happen? Look at the towns of Burbank, Illinois, and Cerritos, California, and see what Amateurs in those communities are fighting. A ruined antenna and tower may not only rob your wallet, but may also rob you and your friends of your operating privileges because of the negative publicity that inevitably follows such an incident.

the match game

When someone says that an antenna is perfectly "matched," most people assume that he or she means that the VSWR is a perfect 1:1. But there's another kind of "match" that's at least as important as VSWR and essential in preventing the kind of mayhem described above. This is the match that occurs when an antenna is *physically* mated to its mast, rotator, tower, and any other antenna on the tower.

How can you determine whether your antenna is properly "matched"? Well, for starters, check the specifications of the equipment you're now using. Don't wait until something happens; you may have added a small VHF antenna or a 30/40 meter add-on kit without realizing that you've exceeded the wind-loading of your tower or rotator.

Start by referring to your antenna instruction or assembly manual. All legitimate antenna manufacturers include both electrical and mechanical specifications with their products. If you can't find your manual, or if the specifications are not listed, write or call the manufacturer's customer service department for this information.

wind area

Look for the entry titled "Wind Area" or "Effective Surface Area" under "Mechanical Specifications." This number, expressed in square feet or square meters, is a measure of the physical size of the antenna. It represents the maximum surface area against which the wind could theoretically push. The total wind area figure should represent the "worst-case" surface area of the antenna — a combination of both the total boom and total element surface areas.

If two or more antennas are mounted within approximately 2 feet of each other, their wind areas can simply be added together to provide a total Antenna System Wind Area. This wind area should be equivalent to or less than the rated wind area maximums of the rotator and tower.

As an example, consider a tribander with a wind area of 5.7 square feet (0.53 square meter) and a 2-meter vertical with an area of 1.5 square feet (0.14 square meter) mounted 2 feet (0.61 meter) above the tribander. The total Antenna System Wind Area of this system would be 7.2 square feet (0.67 square meter),

By Roger A. Cox, WBØDGF, Telex Communications, Inc./Hy-Gain Division, 8601 Northeast Highway 6, Lincoln, Nebraska 68505

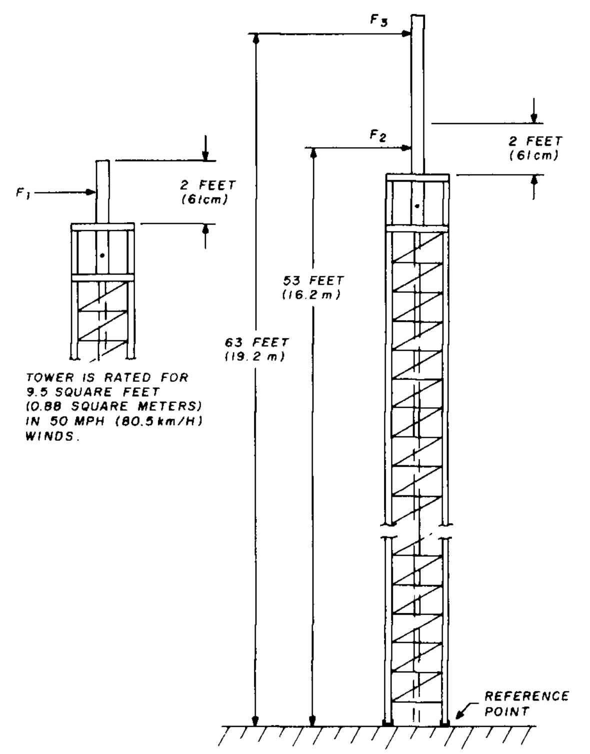

fig. 1. Locations of forces on tower masts.

and would easily match a tower rated at 9 square feet (0.84 square meter) or a rotator rated at 8.5 square feet (0.79 square meter).

Determining wind area becomes more complex when you want to stack two or more HF beams or numerous arrays of VHF Yagis, because under these circumstances the separation required for good electrical performance is almost always greater than 2 feet (0.61 meter).

To analyze complex antenna systems made up of antennas spaced *more* than 2 feet (0.61 meter) apart, you need to know how each antenna contributes to the loading of the entire system.[1] Check your manual under "Mechanical Specifications" once more; you should be able to find the "Wind Load" of the antenna at a specific wind velocity. [Usually a wind velocity of either 80 (129 km/hour) or 100 MPH (161 km/hour) is used.]

wind load

The wind load of an antenna is related to the wind area of the antenna through the equation:

$$F = PA \qquad (1)$$

where F is the wind load force in pounds, P is the wind pressure in lb./ft.^{2}, and A is the antenna wind area in ft.^{2}. P is dependent upon the wind velocity, V, and is usually* found from the equation:

$$P = 0.004\ V^2 \qquad (2)$$

where V is the wind velocity in MPH. At 80 MPH, $P = 25.6$; at 100 MPH, $P = 40\ lb./ft.^2$.

In **fig. 1** a tower with a wind load limit of 9.5 square feet in 50 MPH winds is shown. From **eq. 2** we can find the pressure, P, which the wind exerts on the antenna in a 50 MPH wind.

$$P = 0.004\ (50)^2$$
$$= 10\ lb./ft.^2$$

In order to find the maximum force which may be exerted on the tower, we use **eq. 1**.

$$F = PA = 10(9.5) = 95\ lbs.$$

Therefore the maximum allowable force within the 2-foot limit is 95 pounds.

the bending moment

In order to evaluate the effects of placing more than one antenna on a mast above the tower, we must look at the bending moment, M, with respect to the weakest point in our tower/mast system. The moment, M, is found by

$$M = FD \qquad (3)$$

where F is the force and D is the distance to the weakest point. The moments may be added together for the various antennas as long as the same point is used as a reference. In **example 1**, if we suspected that the tower base was our weakest point, and that our force F_1, was applied to the mast 53 feet above the point, the moment, M_1 could be expressed as:

$$M_1 = F_1D = 95(53) = 5035\ ft.\ lbs.$$

If we were to replace F_1 with an antenna that exhibited 50 pounds of force, and added another antenna 10 feet above it that exhibited 40 pounds of force, would we exceed the allowable moment of 5035 ft. lbs.? Your first guess may be no, because the forces add up to only 90 pounds and this is less than the 95 pounds we had before. And if you were to compare wind areas, you would find that the 50 pound antenna at 5 square feet and 40 pound antenna at 4 square feet also add up to less than 9.5 square feet, or rated wind area for this tower.

But if you were to add up the moments,

$$M = \Sigma\ FD \quad (\Sigma = sum\ of \ldots)$$

$$M_2 = 50\ (53) = 2650$$

$$M_3 = 40\ (63) = 2520$$

$$M_2 + M_3 = 5170\ ft.\ lbs.$$

*The equation $P = 0.004\ V^2$ takes wind gusts and turbulence into consideration. For a steady (laminar) flow, the equation $P = 0.00256\ V^2$ should be used. Consult the Uniform Building Code (UBC) for a more thorough explanation.

you would find that they easily exceed the moment limit of 5035 ft. lbs.

The base of the tower may not always be the weakest point of your tower/mast system. Other susceptible points are the point of attachment of the top set of guy wires, a house bracket, a junction in a telescoping tower or mast, or even the point of attachment of the mast to the tower. If you've used short inserts to reinforce the mast, the end of any insert within the mast may be a point of vulnerability as well. Your best bet is to follow the tower and mast manufacturer's recommendations whenever you stack large antennas.

rotator wind area

As in determining the wind area of your antenna, you should begin analysis of your rotator's wind area by reading your instruction manual. If the specifications are not listed, or if you cannot find your manual, write or call the manufacturer's Customer Service Department for this information.

Look in the specifications section for the entry titled "Maximum Wind Area." There will be two different entries — one for mast mounting and one for inside tower installations. For mast mounting, there will also be a maximum distance of the antenna above the rotator provided; this is usually 2 feet (0.61 meter).

Just as in the previous example, if all of your antennas are mounted within this range (2 feet/0.61 meter) you may add the antenna wind areas together and compare that total to the rotator's rating.

loading

If you're using a small tower or mast, with the rotator installed on top, be extra careful to observe the rotator's mechanical limitations on side thrust. Use the procedures shown in the wind load section of this article with the rotator's rated wind area and wind speed to determine the maximum force that can be applied within 2 feet (0.61 meter) of the top of the rotator. If no wind speed is given, use a conservative figure such as 50 MPH.

As an example, consider the Hy-Gain CD4511. When mast-mounted, its rated wind area is 5.0 square feet (0.46 square meter). I will use 50 MPH as the wind speed. Using **eqs. 1** and **2**:

$$F = 0.004\ V^2\ A = 0.004\ (50)^2(5) = 50\ lbs.$$

In this case, using a distance of 2 feet (0.61 meter) above the rotator, the moment is 100 ft. lbs. You can use the same procedures shown in the bending moment section to evaluate the effects of placing more than one antenna on a mast above a rotator.

Although stacking antennas above a rotator installed on top of a mast or tower is not recommended, it can be done if the maximum moment limitations are adhered to. The weakest point in this case is assumed to be the center of the rotator.

Although slightly exceeding the maximum ratings of a rotator may not break or permanently damage it, doing so will more than likely impair its operation in some way, especially during windy conditions. Continued use in this manner is sure to shorten the useful life of your rotator.

If you install a rotator inside a tower, a different set of mechanical limitations applies. The side thrust is now less important, but the stall and braking torque of the rotator is more important. This is why a different wind area rating is listed for rotators installed within a tower.

The rotator's wind area rating within a tower is usually related more to the braking power rather than to the stall torque of the rotator. The braking power is the maximum allowable torque that the antenna load may present to the rotator without causing it to rotate. This torque is usually not a steady torque, but rather a pulsing, almost sinusoidal torque produced by the antenna rocking back and forth in a violent wind storm.

moment of inertia

The amount of torque produced by this rocking action is directly related to the moment of inertia of the antenna. The moment of inertia is similar to the bending moment as discussed earlier, because it is related to force and its distance from a reference axis. However, complex structures such as antennas must be analyzed as the summation of all the moments produced by the various portions of the antenna. Also, since each moment is directly related to the mass of each antenna portion and the square of its distance to the axis, an antenna with a very long boom with heavy elements will have *more* total moment of inertia than an antenna with a short boom with very light elements, even though they may have the same total wind area! This has produced some difficulty in assigning wind area ratings for rotators. Luckily most commercially available Amateur antennas have short enough booms so that their wind areas and moments of inertia are closely related. However, on long-boom homebrew, commerical, or military-type antennas, one has to be extremely cautious when selecting a rotator when given only a wind area rating.

Although the wind area rating of a rotator is not wholly determined by the rotator stall torque, a higher stall torque is required for turning larger antennas. On a calm day, the act of rotating the antenna produces wind against each element and boom. This wind is a force that opposes the direction of rotation. If, at full speed, this force produces the amount of torque required to stall the rotator, the rotator will slow down until the wind force is less than that which produces a stall. Therefore, a rotator with a small stall torque will sometimes turn more slowly than one with a higher

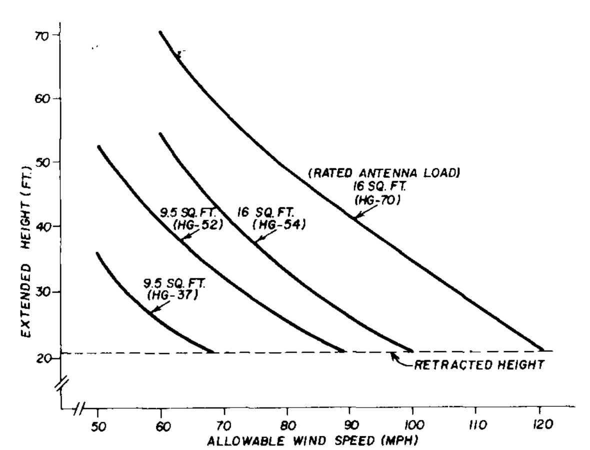

fig. 2. Extended height of self-supported crank-up tower is a function of wind speed and antenna location.

stall torque. On a windy day, the rotator with less stall torque may not be able to overcome the forces produced by the wind.

towers

Every tower ever commercially manufactured has some kind of instruction manual or specification guide, no matter whether it is a crank-up, guyed, or self-supporting tower built of steel or aluminum tubular or right-angle stock.

The manuals accompanying crank-up towers, with which I am most familiar, list a "wind load limit." This is the maximum wind area in square feet (or square meters) that the tower will *safely* hold at its maximum height at a particular wind velocity. The industry standard is to rate these towers at either 50 MPH (80.5 km/hour) or 60 MPH (96.6 km/hour).

Because of the specific nature of crank-up towers, the owner can crank the tower up and down for antenna installation and servicing and also crank the tower down whenever high winds are expected. With the tower completely retracted, the bending moment at the base of the tower caused by the antenna load is significantly reduced.

If you're willing to crank the tower down every time strong winds are expected, it's possible to expect your antenna system to survive near-hurricane conditions even with the maximum allowable antenna wind area. **Fig. 2** shows the wind velocities under which you can expect a Hy-Gain crank-up tower to survive given the maximum rated antenna loads at the extended heights shown in the graph.

For example, if you have a 9.5 square foot (0.8 square meter) antenna load on your Hy-Gain HG-52SS tower, which is cranked down to 21 feet (6.4 meters), you can expect your system to survive a wind velocity of 90 MPH (145 km/hour). (This assumes, of course, that the tower was properly installed, and that all the manufacturer's recommendations were followed.)

You can also expect your fully extended tower to survive higher wind velocities than specified if the antenna wind area is less than the maximum rating for the particular size tower. **Fig. 3** shows how the maximum antenna wind area for a given tower varies with the allowable wind velocity. For example, the HG-70HD, which is rated at 16 square feet (1.5 square meters) in 60 MPH (96.6 km/hour) winds, can safely handle only 10 square feet (0.9 square meter) in 70 MPH (113 km/hour) winds.

As you can also see from **fig. 3**, larger antenna loads may be possible if lower wind velocity figures are used. Unless your tower is sheltered from the wind, it would be dangerous to assume that the wind would always stay under 30 MPH (48 km/hour). These figures should be used only as a demonstration of what may be possible in your installation. Other factors such as the type of soil, ice loading, and wind-driven sand (sandstorms) may affect your particular installation. Again, your best bet is to follow the manufacturer's recommendations on anything questionable.

The manufacturers of guyed towers (such as the Rohn Model 25G and Model 45G) usually recommend specific guying configurations depending on the height of the tower and the specific area of the country in which installation is planned.[3] The maximum wind area is specified as "allowable load" for each type of tower.

The Electronic Industries Association has divided the continental U.S. into 3 wind load zones (see **fig. 4**).[4]

Zone A encompasses most of the United States. Short towers constructed within this zone should be capable of withstanding loading of 30 pounds per square foot (147 kilograms per square meter). This corresponds to approximately 87 MPH (140 km/hour) winds.

Zone B encompasses northwest Washington, north-central California, part of the northern Great Plains and northern Rockies, the area surrounding Madison, Wisconsin, and most of the Gulf Coast and eastern seaboard. Short towers within this zone should be capable of withstanding loading of 40 pounds per square foot (196 kilograms per square meter). This corresponds to approximately 100 MPH (161 km/hour) winds.

Zone C encompasses two areas, the southeast tip of Florida and most of the eastern coast of North Carolina. Short towers within this zone should be capable of withstanding loading of 50 pounds per square foot (245 kilograms per square meter). This corresponds to approximately 112 MPH (180 km/hour) winds.

Fig. 5 shows typical guying configurations for the Rohn Model 25G guyed tower installed in Zone A at various heights. This configuration is for an "allowable load" of 6 square feet (0.56 square meter).

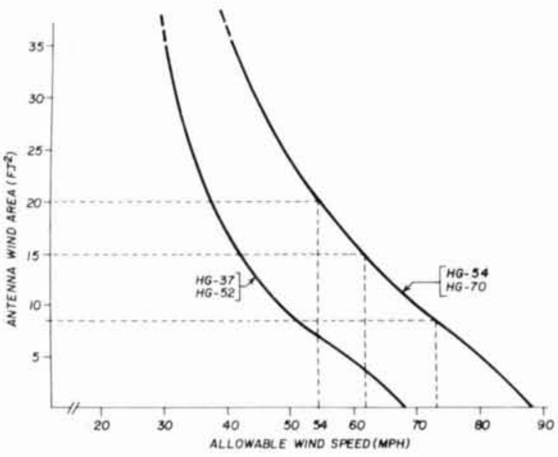

fig. 3. Example of antenna wind area versus wind speed for four commercially-available towers.

Self-supporting towers are similar to crank-up towers in their specifications. They usually specify a maximum wind area or wind load limit at a particular wind velocity. If a particular manufacturer does not list a wind velocity with the load rating, you should ask for this figure from its customer service department. If the wind velocity rating given is less than 50 MPH (80.5 kmph), you may wish to add guys to your tower if you are at or near the rated load. If the wind velocity given is greater than 80 MPH (129 kmph), the rated loading should be safe unless you live in Zones B or C, as previously mentioned. If you do live in one of these zones, be sure to choose a tower with a rated wind velocity figure greater than 100 MPH (161 kmph), or be prepared to add guys.

masts

While the mast doesn't receive as much attention as the tower or rotator in the ratings game, it can be of vital importance in maintaining the integrity of your antenna system.

Only a few manufacturers supply masts for antenna systems. Normally it's easier and cheaper for an individual to purchase a length of steel tubing at the local lumber yard or electrical supply store than it is to purchase it by mail order. For the average antenna installation, this is quite adequate. A length of 2-inch (51 mm) O.D. schedule 40 or schedule 80 pipe is suitable for a tribander and a small VHF antenna. However, if you plan to stack HF antennas in Christmas-tree fashion to assemble an array of VHF antennas for EME, you may wish to analyze your system and consider other possibilities.

Following the previous examples given, find the wind area for each antenna, boom, and mast in your system. Use these wind areas and an appropriate wind velocity to determine the loading from each. Multiply these loads by the distance to the nearest supporting boom, mast, or tower to find the bending moments of these points. To analyze the flexural strength at these points, you'll need to have information about the structural member at each point.

You will also need the initial moment of inertia, I, of the cross section about the neutral axis. This can be obtained from:

$$I = \frac{\pi(d_1^4 - d_2^4)}{64} \; in.^4 \qquad (4)$$

(for a circular cross section)
where d_1 is the members O.D. in inches, and d_2 is the members I.D. in inches.

U.S. WIND LOADING ZONES

Recommended wind loading zones values of wind loading in pounds per square foot for tower designs as recommended by Electronic Industries Association (RS222C).

WIND LOADS FOR VARIOUS AREAS IN U. S.

Tower Height	ZONE A	ZONE B	ZONE C
Under 300 Ft.	30 Lbs/Sq. Ft.	40 Lbs/Sq. Ft.	50 Lbs/Sq. Ft.
301 Ft. to 650 Ft.	35 Lbs/Sq. Ft.	48 Lbs/Sq. Ft.	60 Lbs/Sq. Ft.
Over 650 Ft.	50 Lbs/Sq. Ft.	65 Lbs/Sq. Ft.	85 Lbs/Sq. Ft.
MAP CODE			

fig. 4. Chart details recommended wind loading on towers of various heights, per E.I.A. RS222C.

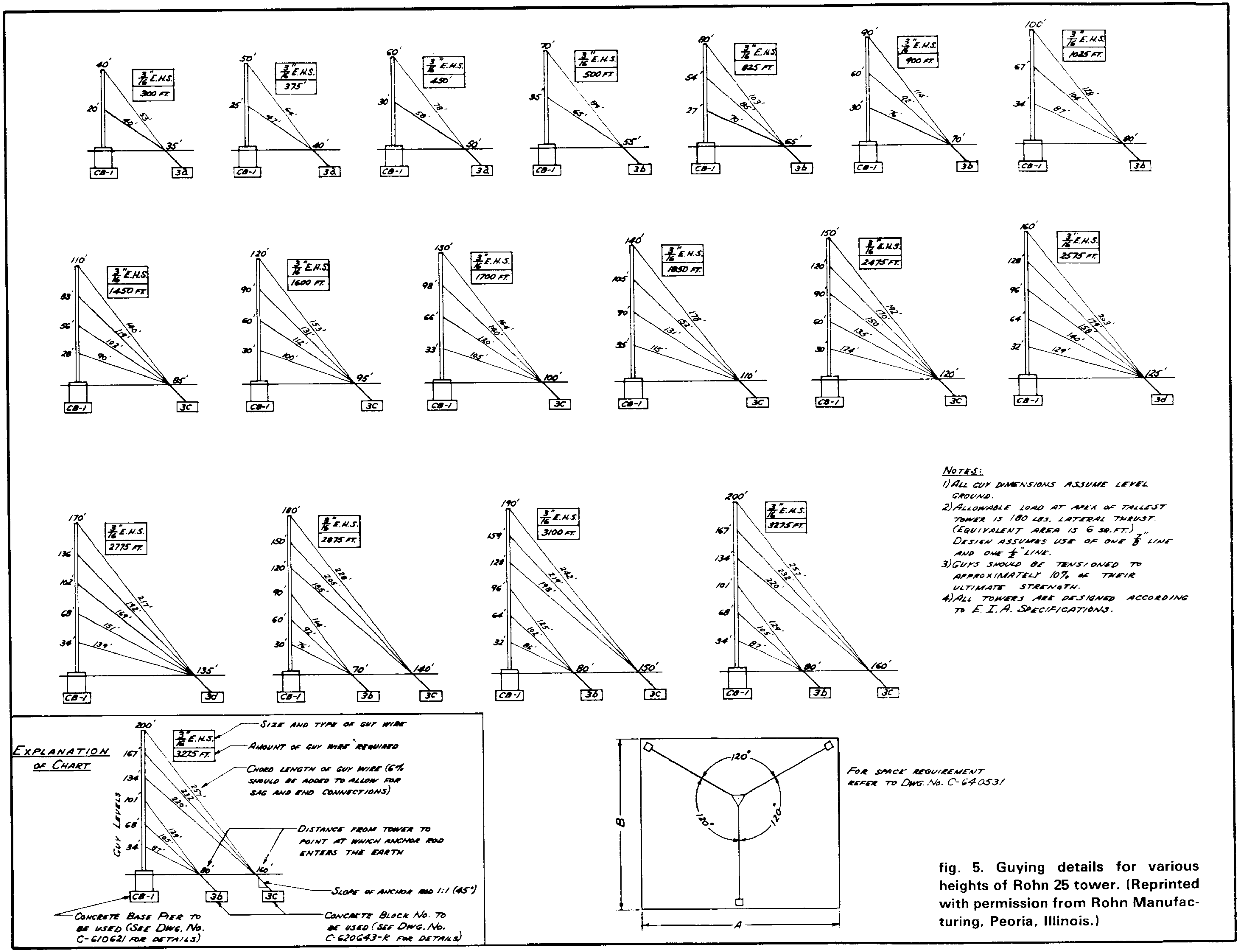

fig. 5. Guying details for various heights of Rohn 25 tower. (Reprinted with permission from Rohn Manufacturing, Peoria, Illinois.)

You will also need the initial distance from the neutral axis to the extreme fiber where failure occurs, c.

$$c = \frac{d_1}{2} \text{ inches} \qquad (5)$$

The flexual strength can then be obtained by

$$f = \frac{12\,M\,c}{I} \text{ lbs./in.}^2 \text{ (psi)} \qquad (6)$$

The constant 12 is necessary for the feet-to-inch conversion if the moment is expressed in foot pounds.

When the flexural strength exceeds the yield strength given for the particular member, the member will deform or break. The yield strength for tubular steel is typically 50,000 - 100,000 pounds per square inch. You will need to check with your local supplier to obtain this information.

Your masts and supporting booms should be strong enough to support your antenna system and be able to withstand the environmental conditions in your area. For example, if you live near salt water or in a highly industralized area, you should be especially vigilant about preventing and correcting corrosion.

Normally antenna and tower manufacturers are aware of these concerns and take steps to protect their product. Antennas are made from a corrosion-resistant alloy of aluminum, usually 6063-T6 or 6061-T6. Towers are normally hot-dip galvanized steel.

Masts purchased locally may not have any protection at all. If the mast has a very thick wall, this may not be a problem, but thin-walled steel or aluminum may be susceptible to corrosion if not protected.

summary

It may be unwise to follow the old saying, "If it doesn't come down, it isn't big enough." It's to your advantage to ensure the integrity of your antenna/tower system by matching the components so that your antenna system stays where it's supposed to stay. Know the limitations of your system's components and how each component interacts with the other and with the environment. It's up to the manufacturer to supply you with sufficient information to enable you to analyze your system, so that you can enjoy your hobby and not have to worry about your installation or your neighbor's roof.

references

1. Eugene Fuller, W2FZJ, "The Application of Stress Analysis to Antenna Systems," *ham radio*, October, 1971, page 23.
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ham radio