DESIGN DATA
FOR PIPE MASTS

Design your own antenna mast using steel pipe

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One of the best materials available for building self-supporting antenna masts is steel pipe. It is widely available, uniform in quality, and reasonable in price. A well-designed mast is adequately strong, neat and attractive, and relatively light weight. And, using steel pipe, it's not too difficult to design a fold-over mast which allows all antenna work to be done at ground level. Even maintenance on the mast itself does not require work at any great height.

However, attaining all of these advantages does require some design work. This is particularly important for safety. The purpose of this article is to present a set of design curves which will give a safe and satisfactory design, while using the minimum of material.

Construction

The general construction of a typical fold-over pipe mast is shown in **Figure 1**. At the top are the antenna and rotator, carried by the smallest size pipe. This is inserted into the upper end of the next size pipe for a short distance, and fastened by through-bolts or welding. The second section is inserted into the next larger, and so on. The bottom section is hinged to a fixed upright pipe, which gives the fold-over feature. It, in turn, nests into a larger section of pipe set into the ground. A yoke is provided to fasten the mast to the upright after erection. **Figure 1** shows a block and tackle for pulling the mast to the vertical position, but a winch fastened to the upright may be used instead.

Most mast designs use the widely available standard weight pipe, each size of which nests neatly into the next larger size, over the range from 1-1/2 to 4 inches. Larger sizes still nest, but there is a gap between the walls. Very high masts, or those with unusually heavy top loads, can be built with extra-strong or double extra-strong pipe, but such designs are not considered here as the data are calculated for standard weight pipe.*

Design criteria

Because of the change in diameter, beam formulas cannot be applied to a stepped diameter mast as a whole. Instead, each individual pipe section must be analyzed by itself, as a free body, starting at the top. The section load must then be transferred to the next lower section. This is done by converting the lateral load to a couple, acting across the diameter of the section, then multiplying the couple magnitude by the ratio of pipe diameters to get the top load of the next section. Intermediate antennas can be assumed to be concentrated at the junction of sections. The next section is then considered.

The critical or design load on a section may be caused by wind load when the mast is vertical, or by erection load as the mast is being raised. Both loads should be calculated and the design chosen for the worst of the two.

For wind load, two design winds are commonly used. For most of the country, it is assumed that the worst wind to be encountered is 85 mph, a value to be expected once in 50 years or so. For Florida, the Gulf Coast, and locations

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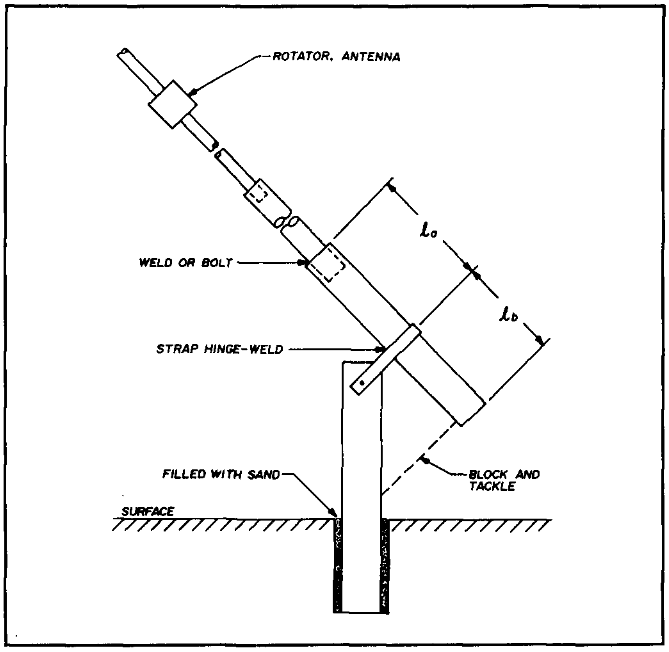
**Standard and extra strong* (ASTM nomenclature) are the two pipe weights commonly encountered. The American Petroleum Institute has a separate designation for well casing, but this is called tubing rather than pipe — although some sizes are identical to pipe sizes. The critical dimensions for standard weight pipe are:

Size	Outer diameter	Wall thickness
4 inch	4.5 inch	0.237 inch
3-1/2 inch	4.0 inch	0.226 inch
3 inch	3.5 inch	0.216 inch
2-1/2 inch	2.875 inch	0.203 inch
2 inch	2.375 inch	0.154 inch

The ASTM recommended fiber stress values for *standard* weight pipe is 20,000 psi (bending). The design procedure presented here uses a 10-percent reduction from this stress figure, based on good used pipe.

Note that the extra-strength and double extra-strength sections do not nest because of thicker walls. Such heavier pipe can be used for the topmost section and for the standing or ginpole section. However, the curves apply only to standard weight pipe or tubing of the sizes given in the table. **Editor**

FIGURE 1



General layout of the fold-over pipe mast (not to scale).

like Cape Hatteras, a maximum wind of 125 mph is also used. Your county engineer can provide the recommended value for your location (see **reference 1**).

During erection there is some deflection, or bending, of the mast. The greatest load occurs when each section is horizontal; this is the loading which must be designed for.

The wind and erection impose two different types of load on the section. One is the concentrated load at the topmost end of a section due to the forces on the section above. The second is the distributed load acting along the length of the section. As the concentrated load becomes larger there is less strength left for the distributed load, so the section length must become smaller. Accordingly, the problem of design is to determine the allowable section length.

The concentrated load during erection is the weight of the antenna, rotator, and sections above the one being considered. The concentrated wind load includes the sum of all wind loads above the section being considered. The usual load is calculated on the basis of projected area. This is the area covered by the shadow of the object. If the object is not symmetrical, like a Yagi beam, the largest projected area is used. The loading depends on whether the object is flat or round, as follows:

Wind loading in pounds per square foot

	85 mph wind	125 mph wind
Flat objects	30.3	65.9
Round objects	18.1	39.0

The projected area is often given in the instructions for commercially made antennas and rotators. It is easily calculated from the dimensions of the element.[1]

Given this concentrated load on the topmost section, design of the mast itself involves solving section load equations for allowable section length. To simplify this process, the equations have been reduced to a series of graphs — **Figures 2** and **3** for load during erection, and **Figures 4 A** and **B** and **5 A** and **B** for wind loads. Use of these curves will be explained through an example.

Example

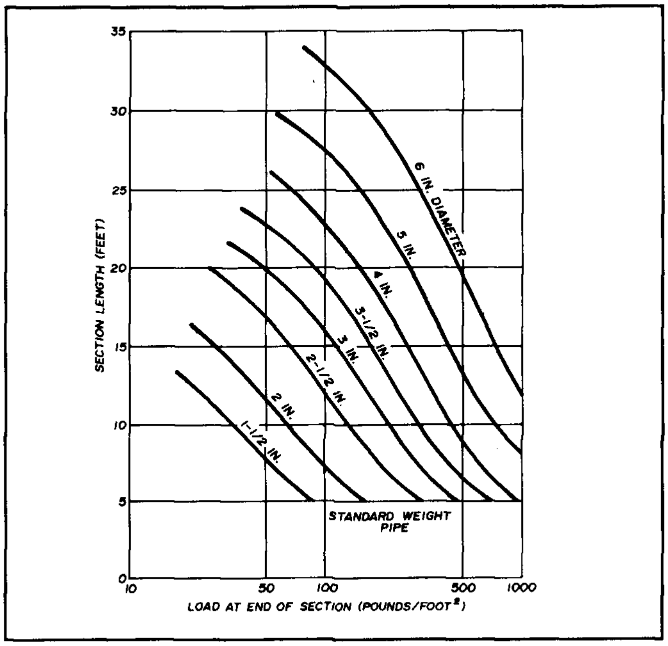
Assume that the design is for an all-tubing 6-meter antenna, having 2 square feet projected area and weighing 15 pounds. A small TV rotator is available, having 1/2 square foot of mostly flat plate area, and weighing 8 pounds. This area is not subjected to unusual winds. Mast height is 40 feet.

The concentrated load on the top section is 15 + 8, or 23 pounds. Entering **Figure 2** at the bottom with this weight and moving upwards, it is seen that the top section could consist of 12 feet of 1-1/2 inch pipe, 16 feet of 2-inch pipe, or 20 feet of 2-1/2 inch pipe. In keeping with the scale of the antenna, suppose the 1-1/2 inch diameter pipe is used.

The concentrated wind loading is due to 2 square feet of antenna and 1/2 square foot of rotator. From the table above, the loading is (2 × 18.1) + (0.5 × 30.3), or 51 pounds per square foot. Reading upward from this load on **Figure 4**, it is seen that the maximum allowable length for 1-1/2 inch pipe is 8 feet. Since this is the critical value, it becomes the length of the topmost section.

Assume that the sections are to be fastened by welding, with 6-inch insertion into the next section. From **Figure 3**, the weight of the 8-1/2 foot total of the top section is 23 pounds. The wind loading on the exposed 8 feet from **Figure 5** is 25 pounds per square foot. Thus, the weight load at the top of the second section is 23 + 23, or 46 pounds and the wind loading is 51 + 25, or 76 pounds per square foot.

FIGURE 2



Allowable section length at erection for standard weight pipe, fiber stress = 18 kips. (The units of force are pounds, tons, kilograms, etc. In engineering practice the word *kip* is frequently used; it merely means 1000 pounds. Thus 18 kips can also be written 18,000 pounds. Ed.)

Using **Figure 2** again, the maximum allowable length of the next section with the nesting 2-inch pipe is 11-1/2 feet for erection loads. From **Figure 4**, the allowable length for wind loads is 9 feet, which becomes the section length. Proceeding as before, the loads on the next section are 46 + 35, or 81 pounds during erection, and 76 + 35, or 111 pounds per square foot for wind.

Again, using **Figures 2** and **4**, the allowable length of 2-1/2 inch pipe is 13 feet for erection load, and 12-1/2 feet for wind load. The 12-1/2 feet is the length ℓ_a in **Figure 1**. The load on the section ℓ_b in **Figure 1** is the same in magnitude, so this part could also be 12-1/2 feet long. However, a stock length for pipe is 21 feet. Assume that this is all that's available. Then the third section will need to end 1 foot above ground to reach the desired 40-foot total height. This is not unreasonable.

If a counterweight is added to the lower part of the third section to just balance the top weight, the erection loads on the fixed upright pipe are essentially zero. Even if no counterweight is used, the balancing effect of the part ℓ_b of **Figure 1** reduces the load on the upright to less than the load on section ℓ_a of **Figure 1**. Thus, if the upright is no smaller than the lowest mast section, it will have adequate strength for erection.

The wind load on the upright is that of the upper sections plus that on the top 10-1/2 feet of the lower section, plus some amount on the upright. Assume that the upright is fully exposed (a safe assumption). The wind load to the top of the upright is 111 + 55, or 166 pounds per square foot maximum, the exact value depending on the final choice of upright length. From **Figure 4**, the upright can be only 6 feet long if it is 2-1/2 inches in diameter, or 13 feet long if it is 3 inches in diameter. Since 12-1/2 feet is needed as a minimum, this is just about right (half of the 21-foot length of the 2-1/2 inch section, plus 1-foot ground clearance).

Even with the curves, the process is somewhat tedious and it's easy to make mistakes. Most of the tedium and mistakes can be avoided by transferring the relations to a computer program.*

While this design is intended to be used without guys, they can be added for greater safety or increasing the allowable wind load. Usually the wall thickness is sufficient to withstand the compressive forces caused by guy tension, but this should be checked if a guyed design is attempted.

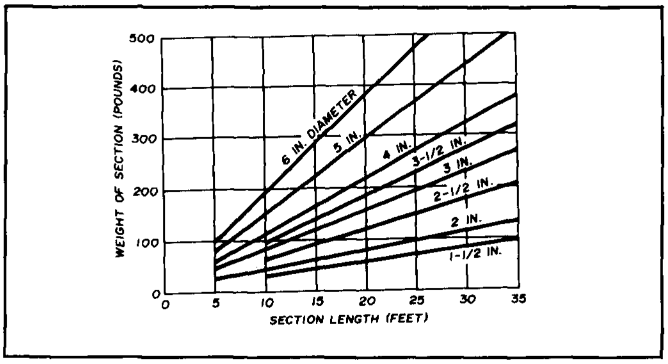
Factors affecting the length of pipe buried in the ground are discussed below. For this example, assume that this is 10 percent of mast height, or 4 feet. Total upright length is thus 13-1/2 + 4, or 17-1/2 feet. The jacket section buried in the ground needs to have 1-inch clearance, so it must be a 4-foot length of 5-inch diameter pipe.

The results of this design example are:

Top section: 1-1/2 inch diameter top section, total length 8-1/2 feet, exposed 8 feet.

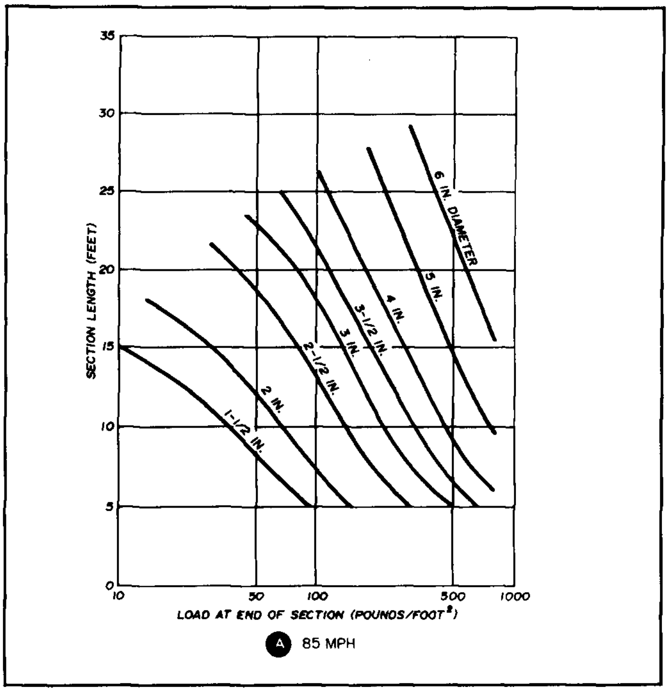
Second section: 2-inch diameter second section, total length 9-1/2 feet, exposed 9 feet.

FIGURE 3



Weight of standard pipe.

FIGURE 4A



Maximum allowable section length for standard weight pipe with winds of 85 mph (fiber stress = 18 kips).

Lower section: 2-1/2 inch diameter lower section, total length 21 feet, hinge at 12-1/2 feet, 1-foot ground clearance at bottom.

Upright: 3-inch diameter upright, total length 17-1/2 feet, exposed 13-1/2 feet, buried 4 feet.

Jacket: 5-inch diameter, total length 4 feet, all buried.

If necessary, this design could be carried higher, using larger pipe sizes.

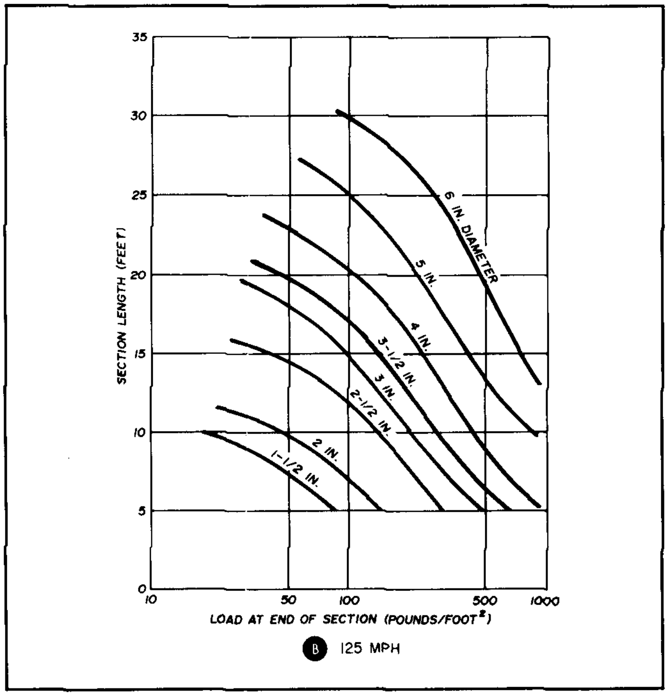
It is often necessary to try several initial assumptions as to length and diameter of the top section. With a little practice, this can be done in a few minutes.

Construction details

The 6-inch overlap assumed in the example is sufficient for either welding or bolt fastening. Bolts are suggested as they are simpler and allow disassembly.

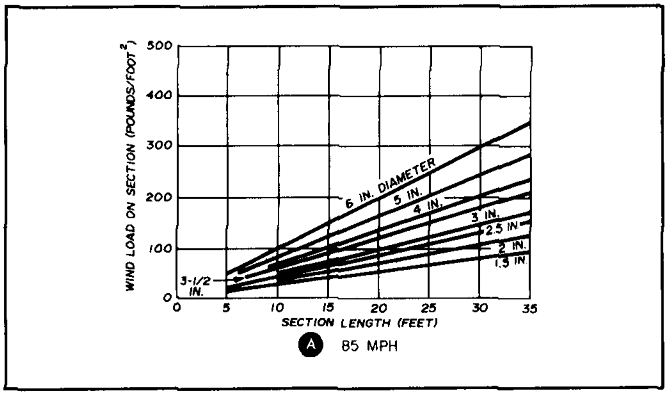
**Such a program is included in the author's "Practical Antenna Design and Analysis" available from MiniLab Books, Daytona Beach, Florida, 32021-1086, or from the HAM RADIO Bookstore.* Editor

FIGURE 4B



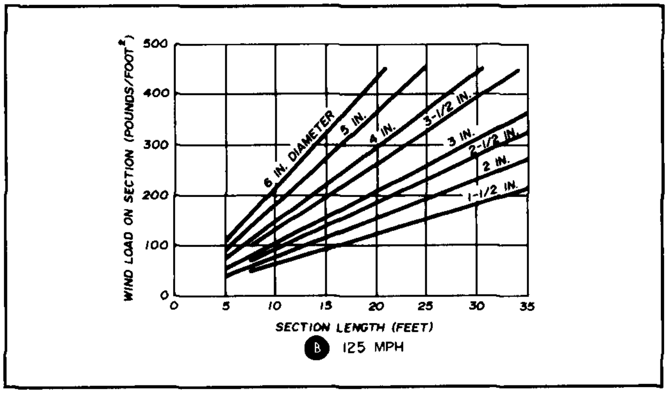
Maximum allowable section length for standard weight pipe with winds of 125 mph (fiber stress = 18 kips).

FIGURE 5A



Wind loading for standard weight pipe, 85 mph winds.

FIGURE 5B



Wind loading for standard weight pipe, 125 mph winds.

Two bolts at right angles passing completely through both pipe sections are recommended. The thread root diameter should be no less than the thickness of the larger section. As a refinement, drill and tap the outer pipe for alignment screws to be placed just above the top bolts and just below the bottom ones. These are a necessity if the pipe sections differ much in size (for example, if a 4-inch pipe is to be nested into a 5-inch one). The space between pipes can be filled with silicon rubber in the final assembly.

The "U" strap hinge shown in **Figure 1** should have a thickness at least as great as the wall thickness of the pipe it supports. For strength in bending, its width can be about 12 times the thickness. The pin hinge diameter should be at least twice the wall thickness for bending strength. (These bending forces are likely to occur in handling and erection, and are difficult to estimate).

A second "U" and pin can be placed at the very bottom of the movable mast part to anchor it to the ginpole section. The pin can be drilled for insertion of a padlock, to prevent sabotage or tampering. A bicycle chain does nearly as well. Another refinement is to wrap both the ginpole and lower pipe section with several turns of barbed wire, about 8 feet above ground level. This helps prevent anyone from climbing the mast.

The suggested assembly routine is to mark each section with the bolt locations and the nesting length. Then lay the pipe on the ground, with blocks or pegs to hold it in place. Use a cord to get the correct alignment. Drill one of the bolt holes, insert the bolt, and then drill for the other one. Without shop facilities, it's nearly impossible to pre-drill these holes and have them line up.

Weight and area aloft can be reduced by turning the entire mast. This complicates the attachment to the ginpole section. However, the bearings needed can be simple sleeve bearings — essentially "U" straps with filler blocks, plus bearing rings attached to the pipe. The vertical load on these bearings can be removed by mounting a heavy-duty rotator under the very bottom of the mast and using a scissors jack to raise the rotator and mast just enough to take the load off the straps. Look at one of the commercial designs for ideas.

Since guys are not needed, the rotating mast type is excellent for stacked beams.

Foundations

Because of the great variability of soils, it isn't possible to provide a set of all-purpose design curves for foundations. The best way of proceeding is to work with your county engineer, and use the practices developed for your particular area. The local power or telephone company should also be able to supply the necessary data.

For reasonably good soils, like firm loams or clays, a good starting point is to assume that the foundation depth is equal to 10 percent of the height, with the jacket set in concrete of sufficient size to keep the soil load to a safe value. A maximum load of 4000 pounds per square foot is often used, with the design adjusted to give a 100-percent safety factor above the design load. If you haven't done this work

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before, the county engineer can show you the steps.

The ginpole pipe section going into the ground must be protected from rust and corrosion on the inside and outside. This is especially important to prevent rusting at the waterline, if free water is present.

Usually, adequate protection can be assured by painting the pipe with a grout of cement and water. Even better protection can be obtained by wrapping the outside with several layers of builder's felt, painted with cold application roofing tar as the felt is wound on.

Pipe sections can be sealed with wooden plugs and a layer of silicon putty. The entire mast and all hardware should be painted as a last step before installation of the antennas. Aluminum Rustoleum™ is suggested, as it is compounded to remain flexible, and is nearly as good for rust prevention as a zinc coating.

Safety

More and more communities are requiring permits for structures of this type. There may be height restrictions. Know your local laws!

In many areas, one requirement for obtaining a permit is certification by a professional engineer. You can usually save time and cost by doing the preliminary design and analysis yourself; use standard formulas or the curves here. Do the work neatly, in an easy-to-follow form. The engineer will want to at least check the method and critical loads. If he wants to do a complete analysis, you'll be able to use it to argue about the cost of insurance coverage (a generous policy is recommended).

Any antenna mast can become a hazard if good safety practices are not followed. Remember that a quarter- or half-ton of steel 30 to 70 feet in the air is no toy. If you lack experience or don't have the proper facilities, get qualified help. Always remember, *safety is no accident.* **hr**

REFERENCE

1. John J. Nagel, K4KJ, "How to Calculate Wind Loading on Towers and Antenna Structures," *Ham Radio*, August 1974, page 16.

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