The Guying Problem
A Calculator Approach To Real Life

There were no amateurs around when everyone thought the world was flat and Pythagoras held the answer to most problems. These days the Earth is round, amateurs want towers and masts, and Pythagoras can't handle most situations. N4PC presents a tutorial on how to compute guy-wire lengths in real-life conditions, without having a few hundred feet left over stored in your basement.

BY PAUL CARR*, N4PC

If the world were flat, many of our guying problems would be greatly simplified. The old, familiar Pythagorean theorem could be used to calculate the lengths needed for our guying requirements. All too often, however, we find ourselves in a situation where this theorem will no longer suffice. These guy lengths can be determined by using some simple laws of trigonometry. Don't panic! With the use of a simple, inexpensive scientific calculator, the exercise becomes easy. Perhaps you will even find it fun. Here is how it is done.

Case I—The Earth is Flat

Ahh . . . here is the easy case. The assumptions are that the mast will be perpendicular to the earth, and both the attachment height on the tower and the distance from the tower to the anchor are known. (If they are not known, they can be measured very easily.) We have all the components necessary to use the Pythagorean theorem.

Just as a matter of review, the Pythagorean theorem may be stated as follows: In a right triangle, the square of the hypotenuse is equal to the sum of the squares of the two remaining sides. The hypotenuse is the longest side of the triangle, and the two remaining sides are sometimes called the legs. As an equation, this becomes:

$$c^2 = a^2 + b^2$$

As a matter of convention in this article, I will use lower-case letters to denote the sides of a triangle, and upper-case letters to denote the angles opposite the respective sides.

Example for Case I. For this example, assume that we have a mast with a guy attachment height of 40 feet. Also assume that we have a ground attachment of 20 feet on one side and 25 feet on the other side (see fig. 1). This will give us a chance to solve the example twice.

Let's review what is known, and determine what is to be calculated. We have two triangles, and we know the leg lengths in both cases. So here we go.

Remember the equation is:

$$c^2 = a^2 + b^2$$

By substituting the known information into the equation, we have:

$$c^2 = (40)^2 + (20)^2$$

The information is most easily entered into the calculator on a right-to-left format. Enter 20 (square) (plus) 40 (square) (equals) 2000. **(I have shown the function keys in parentheses for clarity.)** Now the only thing remaining is to extract the square root of the number. The number 2000 should be displayed on the calculator so (square root) reveals the answer—44.72136. The square root function is often on the same key as the square function, and it is accessed by hitting the "second function" key. This means that we will need about 45 feet for the guy plus any surplus for attachments on both ends.

I will give the next problem in the form of an equation and let you practice the key strokes to establish your confidence. This is for the example where you have the ground attachment distance of 25 feet.

$$c^2 = a^2 + b^2$$
$$c^2 = (40)^2 + (25)^2$$
$$c^2 = 2225$$
$$c = 47.169906$$

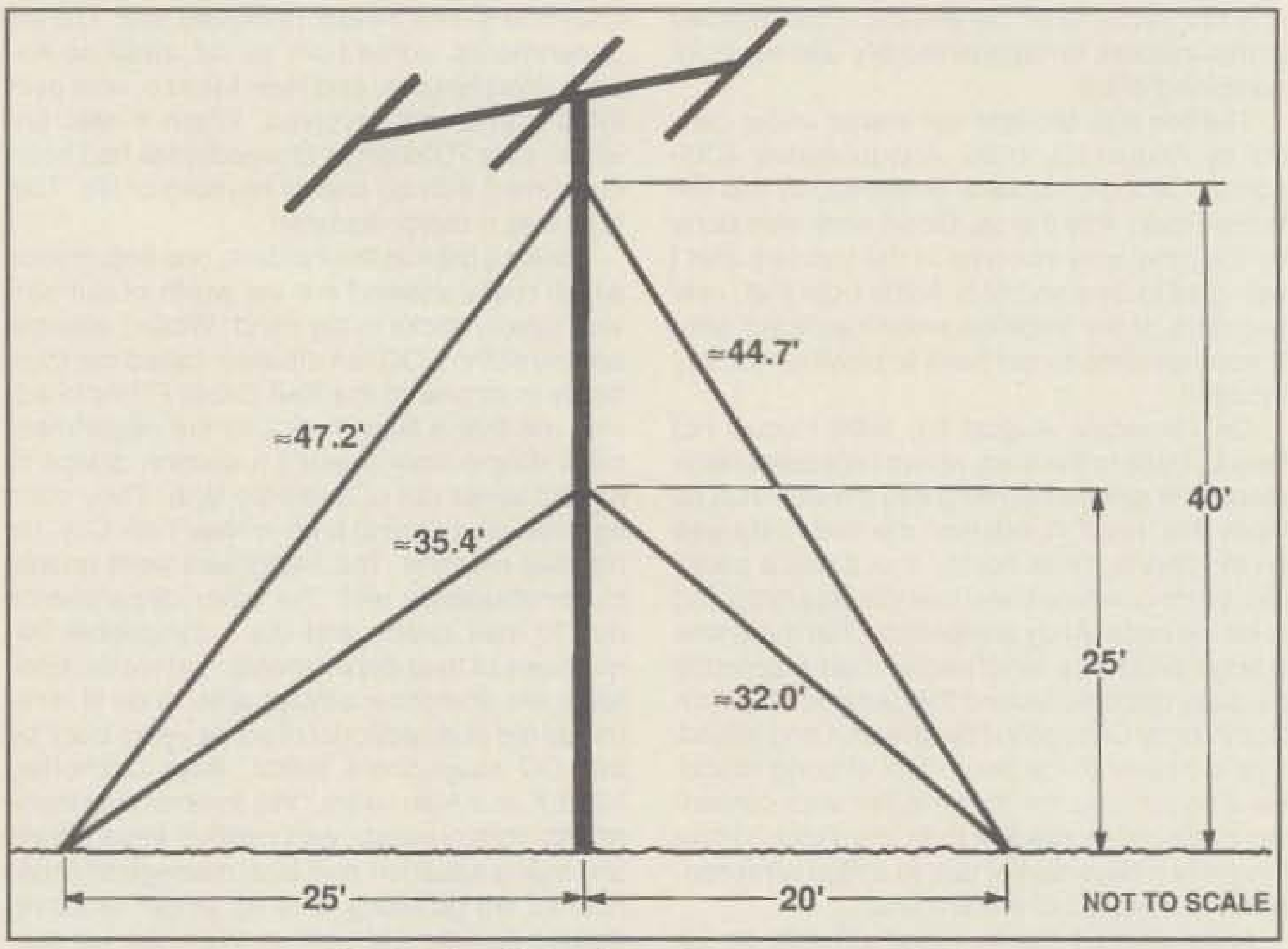

Fig. 1– The tried and true Pythagorean method.

*97 West Point Road, Jacksonville, AL 36265

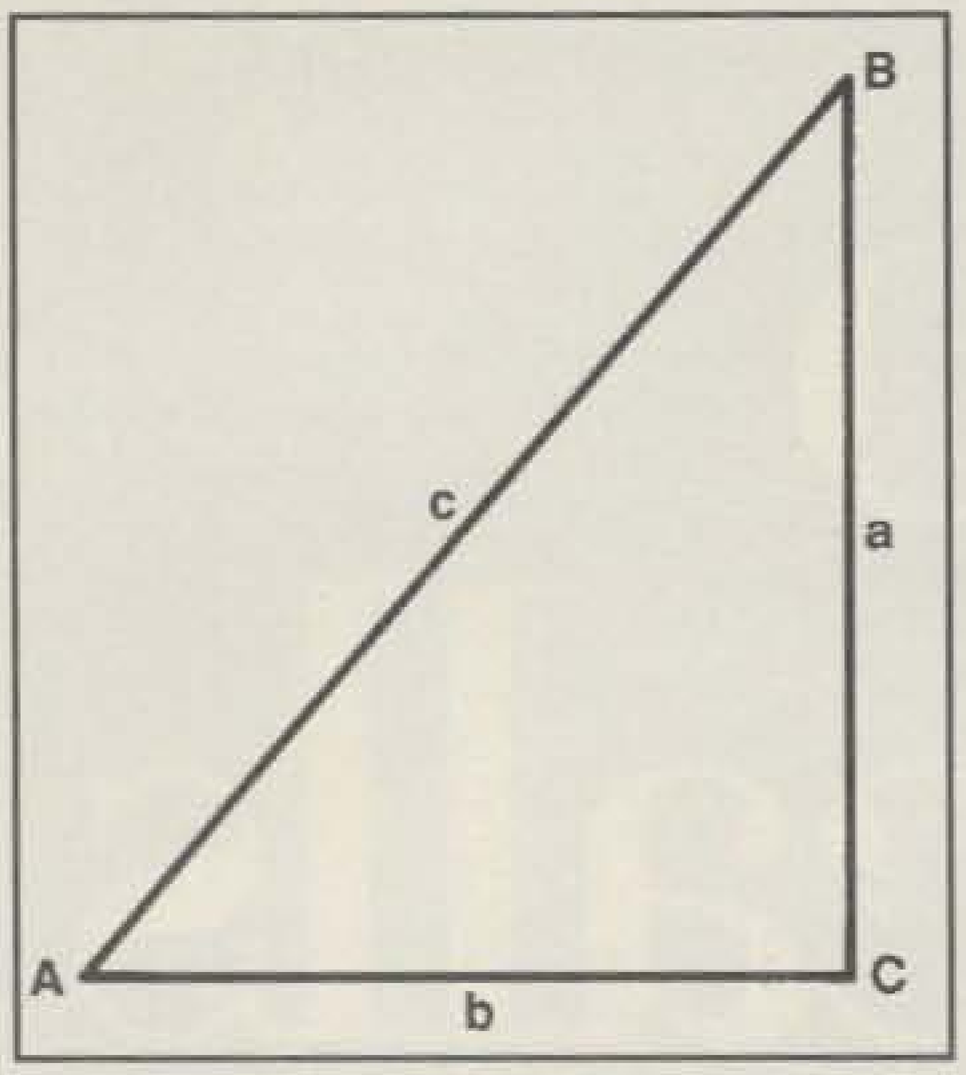

Fig. 2– Basic right-angle trigonometry.

The net length for this guy is about 47 feet, plus the length for the attachments on both ends of the guy.

You would probably want to guy a tower of this height in two places. Now practice calculating guy lengths for an attachment height of 20 feet. The answers are shown in fig. 1.

For this example, it is easier to calculate the guy lengths than it is to write about it. Remember, practice makes perfect.

Beyond The Pythagorean Theorem

The Pythagorean theorem will work very well if we restrict our study to situations that involve only flat ground and right triangles, but this is the exception rather than the rule. As a result, we need to develop mathematics that will handle the general case of triangles.

Basic Trigonometry. The measure of all parts of a triangle can be determined if we know three parts, one of which must be a length. In order to accomplish this task, we need to establish the relationship between the sides of a triangle and the angles opposite. This can be done using a right triangle (see fig. 2). The three functions that we will develop are Sine A, Cosine A, and Tangent A. There are three additional functions which are the reciprocals of these functions, but these are all we will need. These functions may be defined as follows:

$$\text{SinA} = \frac{\text{opposite}}{\text{hypotenuse}}$$

$$\text{CosA} = \frac{\text{adjacent}}{\text{hypotenuse}}$$

$$\text{TanA} = \frac{\text{opposite}}{\text{adjacent}}$$

Now that we have established these three functions, we can develop two laws that will allow the solution of general triangles.

The Law of Sines. The law of Sines may be stated as follows: In any triangle, the side lengths are proportional to the Sines of the opposite angles. As an equation, this becomes:

$$\frac{a}{\text{SinA}} = \frac{b}{\text{SinB}} = \frac{c}{\text{SinC}}$$

This formula is useful when two sides and the angle opposite one of the sides is known, or when two angles and one side are known. (If two angles are known, the remaining angle can be determined by finding the sum of the two known angles and subtracting the result from 180 degrees.) Remember that the sum of the interior angles of a triangle equals 180 degrees. This is a very handy formula, but we will find another law more useful for the guying problem. I have not shown an example using this law, but I have included it for completeness.

The Law of Cosines. The last law that we will need for our problem is the law of Cosines. At first glance it appears to be an expanded version of the Pythagorean theorem. The law may be stated as follows: In any triangle, the square of any side is equal to the sum of the squares of the two remaining sides minus twice the product of those sides and the Cosine of their included angle. As an equation, this becomes:

$$a^2 = b^2 + c^2 - 2bc\text{CosA}$$
$$b^2 = a^2 + c^2 - 2ac\text{CosB}$$

and

$$c^2 = a^2 + b^2 - 2ab\text{CosC}$$

This law is for the case when two sides and the included angle are known, or when three sides of the triangle are known. For our purposes, the first case will apply.

If this law is applied to a right triangle, the last term of the formula disappears because the Cosine of 90 degrees is zero. We now have the tools necessary to attack the more difficult guying situations.

Case II—The Earth is Not Flat

This statement should come as no great surprise. Most of our guying situations will involve situations where the Pythagorean theorem will not apply. Consider the case where the antenna mast must be placed on an incline (see fig. 3). In this case, we will use a tower attachment of 40 feet, and anchor points of 20 and 25 feet, respectively. In both cases, we can measure the distance to the anchor points, but we must calculate the angle formed between the tower and the ground. Here is one way to accomplish the task.

Again look at fig. 3. The 19 foot distance from the anchor point on the high side perpendicular to the tower can be found rather easily, but you still will need some additional equipment. You will need some string, a plumb line, a string level, a helper, and perhaps a step ladder. The plumb line and the string level can be purchased at a hardware store for a nominal price.

Have a helper hold a string at the anchor point. Stretch the string horizontally until you are over the location of the base of the tower. Place the string level on the line and raise the line until it is level. Use the plumb line to determine when the proper horizontal length has been reached. Measure the horizontal line length. You now know two sides of a right triangle. The angle at the base of the tower can be calculated using trigonometric functions.

We know the hypotenuse of the small right triangle and the measured length of the side opposite the angle in question, so we can use the Sine function. Remember that the formula for the Sine function is:

$$\text{SinA} = \frac{\text{opposite}}{\text{hypotenuse}}$$

By substituting we have:

$$\text{SinA} = \frac{19}{20} \quad \text{or}$$

$$\text{SinA} = 0.95$$

We are trying to determine the angle the Sine

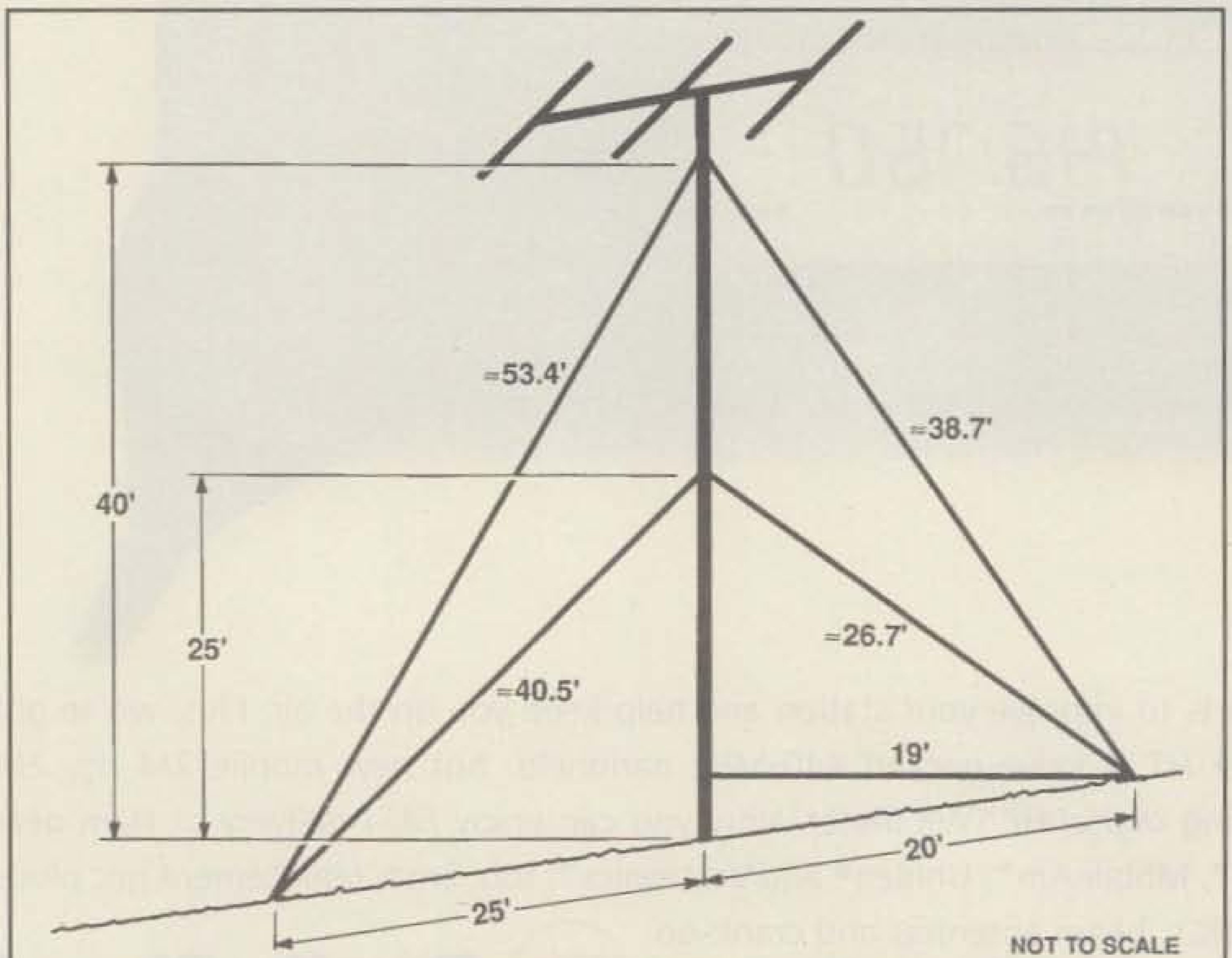

Fig. 3– If you live on an incline, there is an alternative to renting a bulldozer to flatten it out.

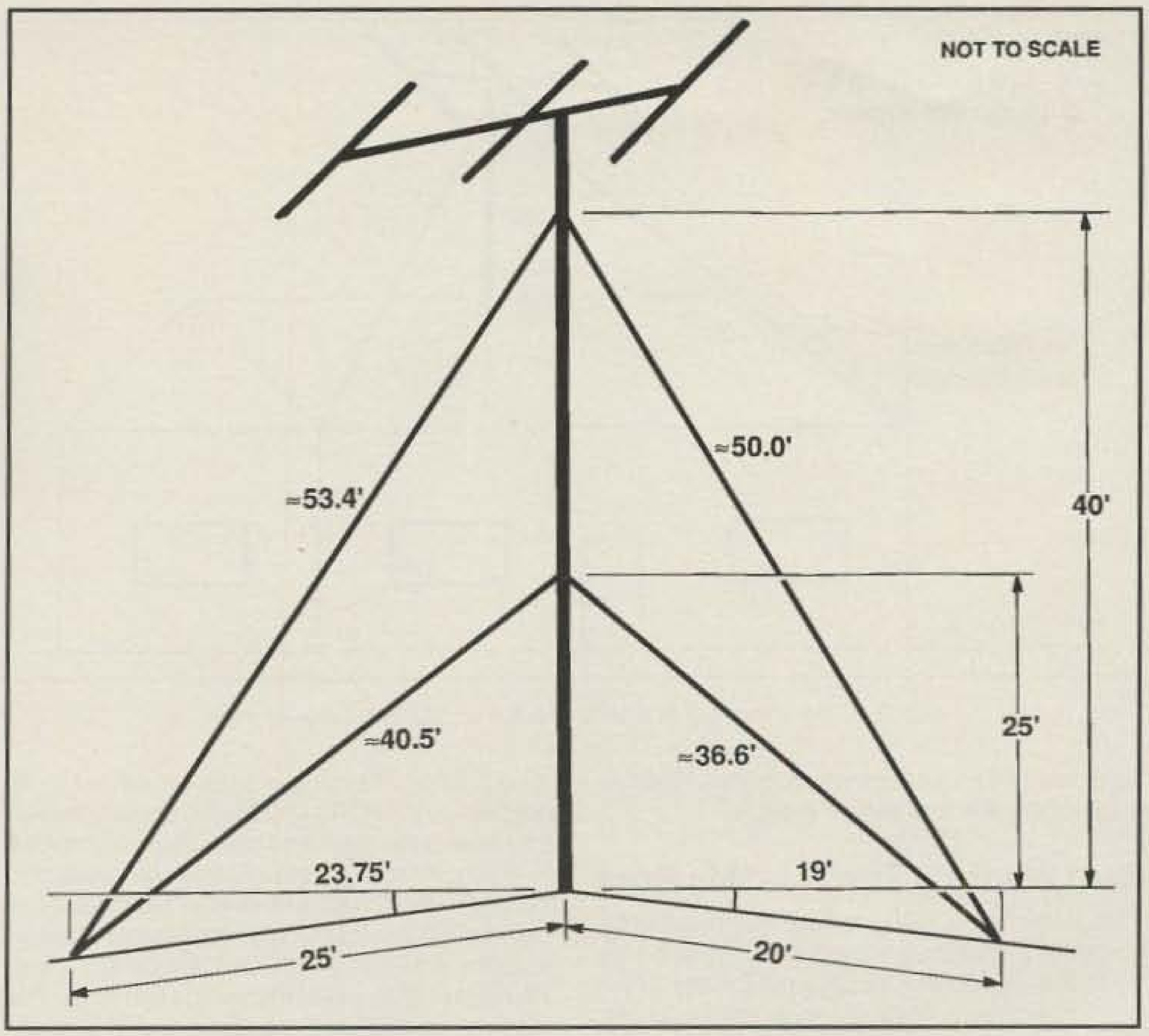

Fig. 4– Taking advantage of a bump in the terrain for additional height doesn't have to pose a great guying problem.

of which is 0.95, so enter 0.95 and press (second function) Sin (equals) 71.805128. The angle at the base of the tower is approximately 71.8 degrees. We can also calculate the remaining angle at the base of the tower. Since these two angles are supplementary—i.e., their sum is 180 degrees—the remaining angle is 180 – 71.805128, or 108.19487 degrees. This angle will be used when calculating the remaining guy length.

We still have the guy length calculation to complete. If we examine the known data, we find that we have an oblique triangle, and we know two sides and the included angle between those sides. The remaining side length can be determined by using the Law of Cosines. The formula that we need is:

$$c^2 = a^2 + b^2 - 2abCosC$$

by substituting, we have:

$$c^2 = (40)^2 + (20)^2 - 2(40)(20)Cos(71.805128)$$

Key the information into the calculator as follows: 2 (times) 40 (times) 20 (times) 71.805128 (Cos) (equals). The number "499.59984" should appear on the screen of the calculator. Store this number in the calculator memory. Continue to key the information into the calculator as follows: 40 (squared) (plus) 20 (squared) (minus) (memory recall) (equals) 1500.4002. The only thing remaining is to extract the square root of that number, and this produces the desired answer of 38.734999. So we need about 38.7 feet of guy material plus any length needed for end connections.

For the remaining guy length, I am going to put the necessary information in the formula and let you do the calculations. The formula is:

$$c^2 = a^2 + b^2 - 2abCosC$$
$$c^2 = (40)^2 + (25)^2 - 2(40)(25)Cos(108.19487)$$
$$c^2 = 2849.4998$$
$$c = 53.380706$$

The thing that you may have noticed when you obtained the Cosine of the angle was the fact that the result was negative. This is because the Cosine of an angle between 90 and 180 degrees is negative. This is one of the properties of the Cosine function. The guy lengths for the 25 foot attachment point are shown in fig. 3.

Let's look at another possibility: Perhaps the antenna will sit on a slightly elevated spot of terrain. We amateurs want to take advantage of every bit of elevation that we can find (see fig. 4). Again, I am assuming anchor points at 20 feet and 25 feet. This time have your helper hold the end of the string at the point where the base of the mast will be placed. Using the same technique with the string level and plumb line, measure the horizontal distance from the base of the mast to the anchor point. (Again, I have shown 19 feet for this example.) If we find the ratio of the horizontal distance to the length along the ground, we again have 0.95. This will be the Cosine of the small angle at the base. Key the information into the calculator as follows: 0.95 (second function) (Cos) (equals) 18.194872. This angle must be added to 90 degrees to find the measure of the angle at the base of the antenna, which is 108.194872. The calculation technique will be the same as the second guy shown above. The actual calcula-

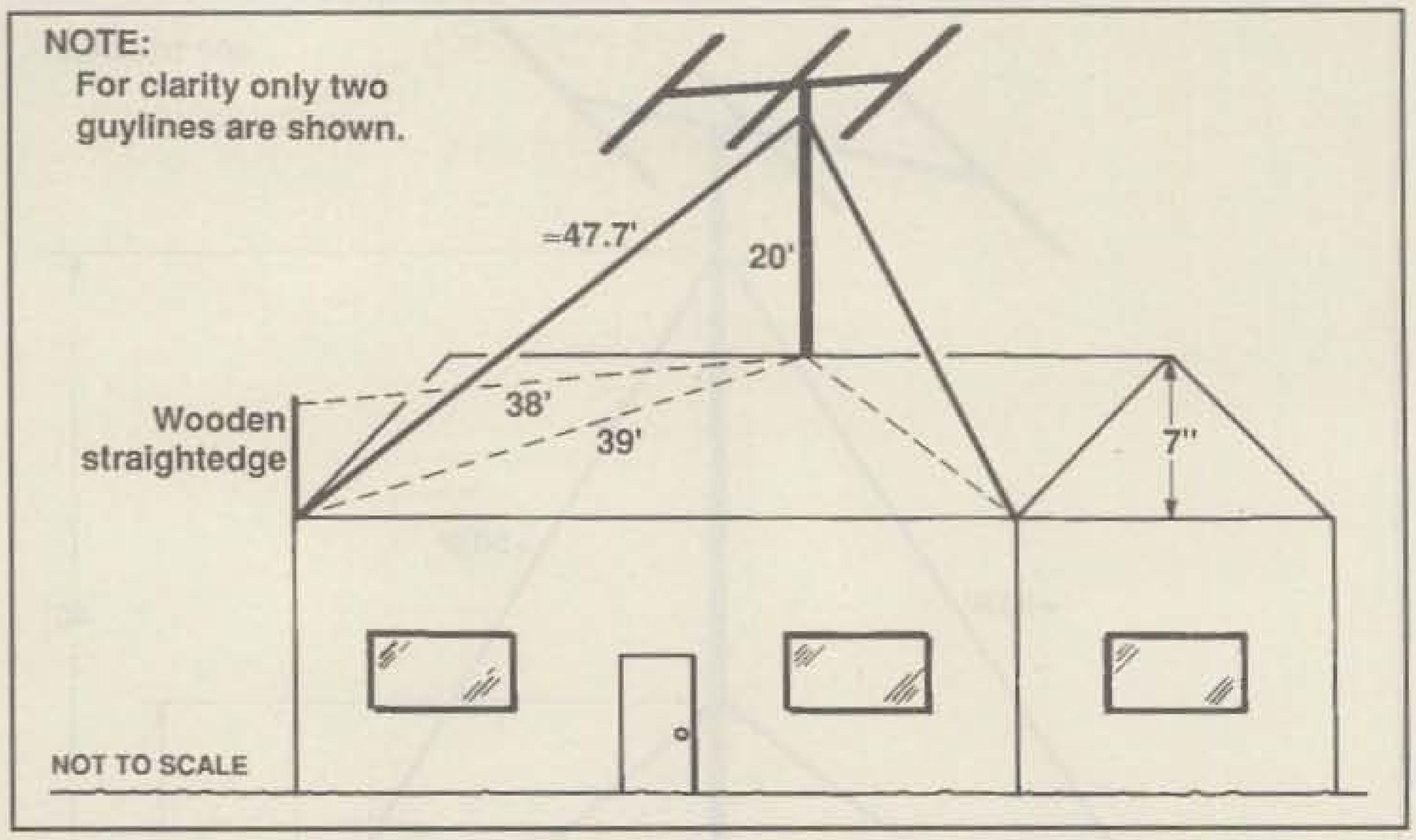

Fig. 5– The universal scenario—a tower or mast on your roof.

tions are left as an exercise for you. The calculated lengths are shown in fig. 4.

But I Want My Tower on My Roof

This is the case that provides the most challenge for guy calculations. However, since we have developed the techniques for the previous examples, no new theory is necessary for this case.

For this example, assume that you are going to place a mast with a 20 foot attachment height in the center of a roof structure as shown in fig. 5. Remember, the measurements that we make in this example must be made at roof height. **Be extremely cautious—safety first.**

The distance along the roof can be made using a tape measure. Have your helper hold one end of the measuring tape at the point where the base of the mast will be placed. You probably will need a ladder to reach the roof position where the guy will be attached. Let's assume the roof measures 39 feet for this example.

Next we need to determine the horizontal distance from the anchor point to the base of the mast. For this measurement we will need a straight piece of wood that is longer than the vertical height difference between the base of the mast and the anchor point. We will also need a carpenter's level. The measurement can be made as follows.

Attach the string to the wood and place the string level on the string. Have your helper hold the end of the string at the place where the base of the mast will be placed. Use the carpenter's level to be sure the sting is perfectly aligned over the anchor point. Check the string level to make sure that the string is perfectly horizontal. When both these conditions are reached simultaneously, the length of the string will be the same as the long leg of the right triangle shown in fig. 5. For this example I am going to assume that distance is 38 feet. We now have the information needed to calculate the guy length.

We will use the two measurements just obtained to calculate the Cosine of the small angle between the base of the mast and the surface of the roof. The Cosine of this angle will be the ratio of 38 feet to 39 feet, or 0.9743589. Key the information in this manner: 0.9743589 (second function) COS (equals 13.002826). This angle must be added to 90 degrees to yield 103.00283, the angle between the base of the mast and the surface of the roof.

We now have all the information needed to calculate the length of the guy. Key this information into the formula for the Law of Cosines as follows: 103.00283 (COS) (times) 20 (times) 39 (times) 2 (equals) (store in memory). The number –350.99861 should be stored in memory. Continue the calculation: 20 (square) (plus) 39 (square) (minus) (memory recall) (equals) 2271.9986. Now take the square root by entering (second function) (square root), and 47.665487 should appear on the calculator display. The net guy length is approximately 47.7 feet. Now that was not so bad was it?

Remember, the accuracy of the calculation is dependent on the accuracy of your measurements. I never think it sufficient to make only one measurement when solving these problems.

For this last example, I have not repeated the formulas. Refer to the previous examples for statement of these formulas. Perhaps you could have the formulas memorized by now!

Afterthoughts

Perhaps your calculator operates a bit differently than what I have described. If you encounter difficulties, refer to your calculator instruction book.

I have made no attempt to cover all possible guying problems that you may encounter, but I have tried to equip you with a working knowledge of some of the more helpful laws of trigonometry. When working on your guying problems remember these basic rules:

1. Think.
2. Make a sketch of your guying situation and label all known information.
3. Make careful measurements.
4. Verify your measurements.
5. Make careful calculations.
6. Verify your calculations.
7. Ask yourself if your calculations are reasonable.
8. Safety first.

Perhaps this presentation will help to remove any fear that you may have about mathematical calculations. It is not as bad as you may think. Good luck! ■