Anchor smarter

Jan 1, 2003

Often when things don't seem to make sense there is a reason, like the time I dove on my anchors to clean the scum from the rode. After anchoring for two weeks in 25-knot trades, I found my 35-pound CQR still lying on its side. If the load on this anchor had been anywhere near the 1,200 pounds designated by the American Boat and Yacht Council (ABYC) anchor load table, why wasn't it buried in the coral sand?

Recently, when I talked to the skipper of the 127-foot passenger boat (seen in photo at right) he told me that the 32-pound aluminum anchor he carries on the bow held the boat off the beach in a 35-knot blow, using a 1/2-inch nylon line with 35 feet of chain on a 5:1 scope. According to traditional wisdom this is impossible for a boat with this much windage, yet it happened.

Assessing the adequacy of an anchoring system can be extremely frustrating because of the lack of agreement in published information. I am not sure I can relieve the frustration, but I can shed some light on the lack of agreement, show you that nothing is wrong with the passenger vessel mentioned above, and offer some practical ways to measure how effectively you've set your anchor.

Design usually compares two parameters: system load and system strength. By definition a successful design is one in which the load is less than the strength. Now, in any design a certain level of uncertainty exists. Normally this uncertainty is handled by applying a safety factor, to either or both the load and strength. The greater the uncertainty the greater the safety factor. Safety factors normally range from 1.2 to four. When safety factors get above six the value of the analysis isn't much better than guessing. Let us study the confusion in anchor design by looking at the uncertainty and safety factors first in load and then in strength.

Anchor load

It turns out that all anchor design is based on the classic drag equation.

Equation 1:

Where the load (F) is dependent on the density of the fluid (r), in this case either air or water; the area of the boat (A) against which the fluid flows; the drag coefficient (C), which depends on the aerodynamic or hydrodynamic shape of the object; and the velocity of the fluid (V).

Fluid density varies with temperature and pressure. Fortunately, the errors generated by assuming a density relative to standard temperature and pressure are minimal and can be ignored without serious consequence. That is the last of the good news.

Fluid (air or water) velocity flowing by a boat is not always straightforward. Current velocity is generally better behaved than wind velocity because it is often less than two knots. The lower velocity and the greater density of water removes most of the turbulence from the fluid and makes the calculations easier and more accurate than those concerned with air.

Wind, on the other hand, does not flow by the boat; it boils by it. The wind striking a boat can vary greater than 20 percent in both velocity and direction within a few seconds. Thus the load from a 30-knot wind is essentially a mythical beast. The wind velocity is never steady, gusting constantly from 24 to 36 knots, and buffeting the boat from side to side.

Complicating this process further, the constant rising or falling of load on the boat is generally out of phase with the load on the anchor rode due to the inherent damping involved in the system. Thus, at any one time the load may be going up while the wind velocity is going down. Even at best we have introduced into the classic equation an error between 20% and 50%.

With very little reflection, anyone can see that the exact area of a boat exposed to the wind is time consuming to calculate. Consider summing up all the little areas of hull, cabin, dodger, winches, wires, masts, dinghies, and in-laws fishing from the bow. This could take days, and then the dinghy moves. To make matters worse, any given boat swings at anchor and exposes a different amount of side area to the wind from time to time, adding or subtracting area continually. The error in load introduced by the inaccuracy of the area could be as much as 75% to 150%.

While the area of a boat is difficult to calculate accurately, the drag coefficient is impossible to calculate accurately for a shape as complex as a boat. True, you can break the boat into simple shapes like spheres, cylinders, and plates, where these coefficients are better known, but composite shapes require approximation. Approximation leads to error.

These coefficients are generally found by testing and are only accurate for the boat that was tested. Shape coefficients have been measured for racing yachts and large ships. There is quite a spread on these numbers, ranging from 0.4 to 1.2. Experts generally use their judgment (guess), to select a number somewhere in between these two extremes and hope they are safe. The difference between the high and low is 300%, so this could easily introduce 150% error.

Obviously this equation is not so simple to use, and most experts end up providing various tables to help the boater select the proper anchor load. Let's see if we can determine the safety factor used in these tables, starting with the most famousthe ABYC table derived by Robert Org, which is used by nearly all marine supply houses (this table can be found in my book, Modern Seamanship).

ABYC table

Right off, there is some confusion about the safety factor involved in these tables. One large catalog supplier states that,"these loads are the minimum numbers," indicating they believe that they contain no safety factor. Another seems to agree, because it states, "the ABYC numbers are actual pounds of load and have no safety factor built in. Therefore anchor systems must be based on a value greater than given in the table."

On the other hand, according to ABYC's Tom Hale, who should know, "the ABYC numbers are overstated and contain a considerable safety factor."

So who is right?

In 1996 Robert Smith published data on anchor testing he performed in various areas on the west coast. Some of the information he published was startling and reinforced a belief of my ownthat anchor loads are greatly overestimated. Smith's work stimulated my own tests of actual anchor loads on small recreational boats. Adding a load cell into the anchor rode, I measured wind loads and setting loads on several different boats. My tests agreed with the results found by Smith. Table 1 shows a comparison between the loads recommended by ABYC for a 15-knot wind, compared to real loads measured on recreational boats by Smith and myself.

This shows that the ABYC table overestimates anchor loads on average by a factor of 4.7. Thus Tom Hale of ABYC is right: these numbers do contain a considerable safety factor. And rightly so, for these numbers do not deal directly with dynamic loads, in the hopes that they are covered by the safety factor. Dynamic loads are commonly dealt with that way, for they are exceedingly complex.

Round up the usual solutions

There are a number of other authors who have discussed getting static anchor load by using the classic drag equation. But the problems of getting the exact area are generally left to the reader or estimated using tables and curves. In the instances for which enough data were provided to check the calculations relative to actual test data, I found that the calculations were larger by a factor of about four, a little better than ABYC. We can conclude from this that anchor loads are considerably overestimated. But, wait if anchor loads are so largely overestimated, why do anchors still fail?

Because static anchor load is not the whole story. Anchor load is also affected by the user's technique, and dynamic load. Unfortunately neither of these two factors lends itself to detailed analysis. For example, consider the boater who anchors his 30-foot boat by dropping a 60-lb anchor and 300 feet of 5/8-inch chain in a pile on the bottom. The chain snags the anchor, the wind rises, and the boat drags onto the rocks. This mariner's erroneous conclusion might be: "I need a larger anchor."

Dynamic loads on anchors are a more complex issue than static loads. Happily, dynamic loads are relatively unimportant in protected anchorages until the wind velocity rises above 25 knots or waves approach three feet in height. Traditionally, dynamic conditions are handled by doubling the static loads. Whereas this is the traditional solution, it is not always a safe solution, especially for those using chain rode. A better solution is to have a basic understanding on how dynamic loads affect your system, and how to best reduce these loads.

Finally, even if we do get a good number for load we still have to deal with the strength half of the design process. We have good numbers for the strength of steel and nylon, but in the anchor failure arena rodes rarely part. The most common anchor system failure is dragging. Anchor dragging is not an anchor failure. The anchor does not come away bent or broken. Commonly, all that happens is the strength of the bottom material was insufficient to hold the anchor in place. Thus anchor failure is routinely a bottom material failure. But what do we know about bottom materials strength?

Bottom strength

There are very few discussions of bottom strength in the boating literature. Our greatest single source of information on bottom material comes from notations on navigational charts. Types of bottom include sand, shells, gravel, and mud. Once in awhile these notations are modified by words like soft or firm. But how strong is mud? Well it turns out that the strength of mud can vary from a fraction

of a pound to 10,000 lbs per square foot. This is an enormous difference that totally overshadows the problems with calculating the load. This is a difference of four orders of magnitude, or 1,000,000% error, which renders the 400% error in the load insignificant.

This begs the question: why go through all the hoops to get an accurate load number, unless we can reduce the inaccuracies involved in estimating bottom strength? Even when we have such terms as good, bad, soft, and hard, we still are forced to lump the entire gamut of strength into four categories. That reduces the error down to only 250,000%.

Thus, in order to accurately design an anchor system and reduce the probability of anchor system failure, we need to concentrate on bottom strength. Obviously the best way to get bottom strength information is through testing. There have been numerous anchor tests reported in the literature. Most of these tests consist of simply lowering an anchor over the side, pulling on the anchor rode and measuring the failure load on various types and sizes of anchors. These test are not designed to determine bottom material strength. In fact, most ignore gathering any definitive data on bottom material.

Of course, for any one given bottom material, load certainly depends on the type and size of the anchor; but as we have just seen, the variability of bottom material strength overpowers everything else. These tests are really only useful to compare relative holding power, not give absolute holding power, and many times they yield different results when performed in different material types.

As far as providing the boater with bottom strength values, they are only valid if you are going to anchor within 15 feet of where the anchor test was performed using the same anchoring system. Anywhere else they only have limited value. What the boater needs is the strength associated with the anchor on the end of the rode right where it is presently lodged in the mud. Getting that strength is not as difficult as one might think.

Recall that most anchor tests are variations on tossing an anchor overboard, pulling on it as hard as possible, and recording some data. Notice the similarity here between anchor testing and setting your anchor. It turns out that, if you can measure the anchor load while setting your anchor properly, you have performed a very accurate test of the bottom strength relative to the anchor currently on the end of your rode in the precise spot where you want the data. Nothing could be more accurate. The only catch is that we need a way to measure the load.

Accurate bottom strength

One way is to buy a load cell, but that is a little expensive. Another way is to calibrate your engine. Since the power created by the engine is essentially the same at any given rpm, we can use rpm to indicate power and then convert that power to load in pounds. Thus your tachometer becomes the load cell.

Calibrating your engine rpm to the load in pounds can be done in a couple of ways. All solutions require the engine horsepower/RPM curve for your engine. This power curve can be obtained from the engine manufacturer. The most accurate solution requires you to run a test on your boat speed in reverse as follows:

1. Pick a flat calm day, in a large body of water, with very little traffic. Controlling a boat at high speed in reverse is difficult, and other boats do not expect a boat to be moving in reverse at high speeds. Once you are at the test location,

2. Turn the speed sensor 180° (if necessary). Not all speed sensors read accurate reverse speed in their normal position. Don't forget to return it to its original position after the test.

3. Make several different runs in reverse, holding the boat on a steady course and speed at several different rpm values.

4. Record both the rpm and speed in reverse.

5. Average the values of speed for each of the runs at each rpm.

Using this data and your engine power/rpm curve, the engine thrust can be calculated in pounds, if the speed was recorded in knots and the power in horsepower, by using:

Equation 2:

thrust = 325 x hp x efficency/ velocity in reverse

The efficiency term takes into account such things as losses in the drive train and efficiency of the propeller. The efficiency factor is the product of the energy losses through the drive train, which for most boats is between 0.6 and 0.8, plus the propeller losses. Since the growth on the boat's bottom has an effect on velocity, it is best to do the test with a clean bottom. The efficiency factor is the product of the energy losses through the drive train, which for most boats is between 0.6 and 0.8 plus the propeller losses, which are listed in table 2.

Therefore, if you have an average boat with a three-bladed prop the efficiency factor would be 0.7 x 0.29 or about 0.20. At this point you have all the information to construct a table relating engine rpm to load in pounds (see table 3 on next page).

When you finish you will have a load for each step in rpm. Now what is even more convenient is to convert these loads in pounds to loads in knots of wind. Remember that all static loads are calculated using equation 1 above. By grouping all the known values together and letting that be equal to a single constant K: K=CAr/2

we get this: F = KV2

Now by going to the ABYC table and selecting a load for your boat at a giving wind speed you can calculate an approximate K value for your boat.

Equation 3:

K = Load (lbs)/(Wind Velocity (kts))

Now if you want a little more accuracy you can calculate K using the following equation:

Equation 4: K = 0.004A

for which A is the area of the boat and rigging exposed to the wind. Using the K value from equation 3 or 4, you can now calculate an approximate wind velocity relative to each of the rpm loads in your engine table. At this point you can now plot a curve of your boat's engine rpm relative to wind velocity, which is all you need to turn your setting procedure into an anchor test.

Let's go briefly through whole testing procedure:

1. Lower the anchor to the bottom in a manner such that very little chain piles up on the anchor, and

2. slowly idle back away from the anchor, with a light resistance on the rode to straighten the rode and drag it off the anchor.

3. At about 3 to 1 scope, briefly snub up the line to help the anchor get its initial set.

4. Pay out rode until maximum rode length is reached, and

5. increase the engine rpm in small (200 rpm) steps until full throttle is reached in reverse or the anchor drags.

6. Record the maximum rpm attained without dragging in your log.

This process pulls the anchor into the bottom and at the same time tests the bottom for strength. If the anchor does not fail under this procedure you have put a lower limit on the bottom strength surrounding your anchor. This is a minimum bottom strengthbecause you haven't failed the material, bottom strength could actually be greater. True, you don't know how much greater, but you do know that the bottom is at least as strong as the load you measured.

How useful is this information? Well on my boat Bird of Time, my measurements with a load cell show that I can stress the bottom to a little less than 600 lbs, which on my boat is equivalent to a little less than 50 knots of wind. In 40 years of boating I have anchored in winds greater than 50 knots less than five times. That doesn't mean I won't have to anchor in 50 knots tomorrow, but an overwhelming majority of the time my anchor will hold if this condition is met.

Now, if you reach full throttle and didn't fail the bottom, go to step 13. If the anchor drags before you reach full throttle you have actually failed the bottom material during this test. Then:

7. Reduce throttle until dragging stops.

Since you have now actually failed the bottom material, you have a very accurate test of the exact bottom strength relative to the anchor currently on the end of your rode not more than a few feet from where the anchor currently rests. This is maximum bottom material strength. Any load above this value will most assuredly cause another failure. At this point,

8. get an accurate wind velocity forecast from a weather report.

9. Pick off bottom strength from your rpm wind velocity curve.

10. Compare the two wind velocities.

11. If sufficient difference exists go to step 13.

12. If not, return to step 1 in a different location or with a different anchor.

13. Engine to idle, adjust scope.

14. Kill engine, mix margaritas.

Using this procedure you now have all the information necessary to make the decision as to whether to reset your anchor or not. Like you, I used to feel quite uncomfortable when my own anchor dragged at full throttle, and I would often reset until it held. But since I have been testing real anchor loads using a load cell, I understand that this is not always necessary.

For example, on one three-week summer period during which I measured my anchor load, it never rose above 100 pounds. I can load my rode to 127 lbs with my engine at idle. In fact, during the last two years since I have been measuring anchor loads, I found that I could have anchored my 44-foot boat successfully on a 12-pound anchor more than 80% of the time.

Now, to those guys who step on buttons to get their anchors up that's no problem, but for the few who still use muscle, jerking up 12 pounds compared with 45 makes a big difference. So, setting the anchor and reaching full throttle without pulling the anchor really means I am using too strong an anchor 99.9% of the time.

The more accurately your load is known, the less courage it takes to avoid resetting. And we have seen that, if you have to calculate load, there is an inherent inaccuracy (400% to 500%) in that process. However, it is possible to increase the accuracy of your calculated number with a little vigilance on your part when you have measured a maximum bottom strength during setting.

As the wind rises, take notes on the velocity while you stand your anchor watch. Average the wind velocity values a few minutes either side of the peak value. Now, using equation 3, your rpm failure load value, and this average velocity, you can calculate a new K value. If this value is less than your last value, the new value is more accurate. Correct your wind rpm curve to reflect the new and more accurate K value. If the anchor drags and you get the wind velocity when it failed, you will have a very accurate K value. One such failure will reduce the probability of future failures, and you can reduce your anchor size, anchor smarter and sleep more soundly.

Don Dodds is the author of Modern Seamanship and Modern Cruising Under Sail, published by Lyons Press.