Will my anchor hold?

Following the numerous debates on anchors and anchoring in PBO, **Prof. John Knox** decided to conduct a series of experiments...

ABOUT THE AUTHOR
John Knox recently retired from a Personal Chair of Physical Chemistry at the University of Edinburgh. He's had a lifelong interest in boats and in the 1960s became interested in kayaking while on sabatical leave in Utah. He took to dinghy sailing in the 1970s, first in a Graduate and later an Albacore dinghy. In 1983 he bought *Myfanwy*, a Hustler 35, and has sailed extensively on the west coast of Scotland.

MOST of us worry about our anchors. I know I've crossed my fingers and hoped for the best on numerous occasions because anchoring is more an art than a science. I've heard all the old rules such as "never use a scope of less than three times the depth" and "if in doubt, let more out", but I decided to carry out a few experiments to see if they really held true.

There are two aspects to this anchoring business. The first concerns the forces that act on an anchor, which I wrote about in PBO 386. I don't want to say more about that here. Instead, I'm going to look at how anchors behave when used to moor a yacht to the bottom.

My experiences with *Anchorwatch*, a device that measures anchor cable tension, have led me to follow a simple routine. I tighten the cable until the reading matches the maximum figure it's likely to reach, given the local weather conditions. Then I set the *Anchorwatch* alarm to a slightly lower setting. By doing that, I'm assuming the anchor will hold to this tension regardless of how often stresses occur, whether the direction of pull changes, or because of any other factors.

This is a big assumption. So, the main purpose of my experiments was to look at how anchors behaved when dragged through the seabed, and how badly they suffered from roll-out. (Roll-out occurs when an anchor is dragged and corkscrews through the seabed, losing its grip).

I'm also interested in the behaviour of anchors when they're veered – and how holding depends on scope.

Since a fair amount of folklore is attached to the subject of scope, I also decided to take a closer look at the effects of cable length.

I've been unable to find much useful information on these topics. But, despite this, the results of my experiments are both unexpected and, dare I say it, even disturbing...

Anchor speak...

ANGEL – a weight used to make the pull on the chain more horizontal and reduce snatching.

CABLE – chain or warp, also known as a 'rode'.

CATENARY – the curve of the anchor chain.

FLAKING – a way of arranging the anchor chain so that it's laid down on the deck in big loops, ready to be let into the water.

ROLL-OUT – when an anchor is dragged and corkscrews through the seabed, losing its grip.

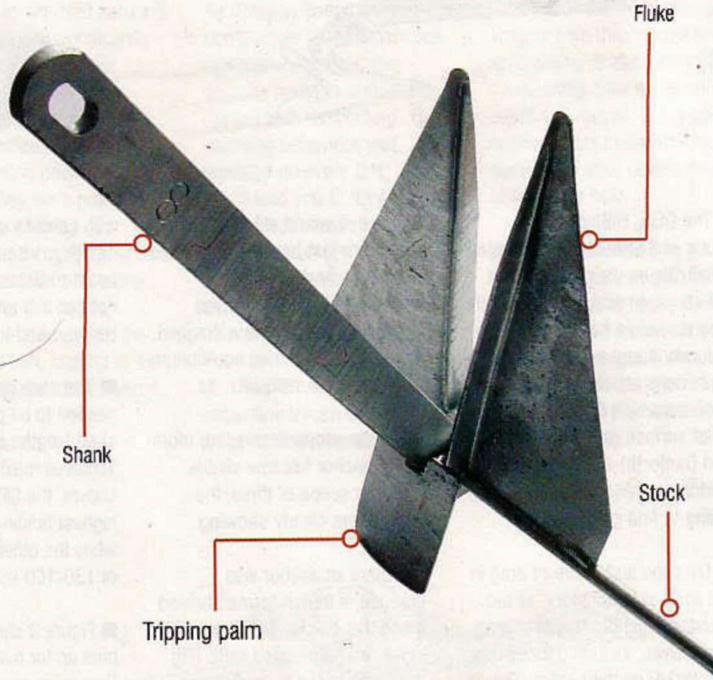
SCOPE – *the length of anchor* cable.

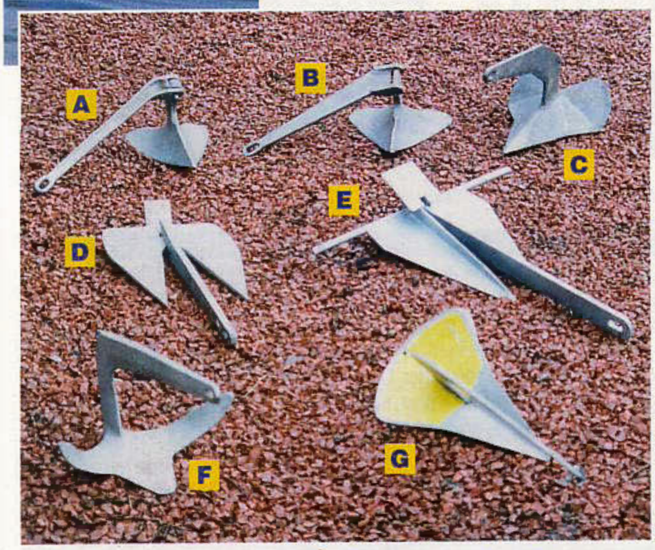
TRIPPING LINE – a line made fast to the top of the anchor and supported in the water by a buoy. It can be used to pull the anchor out of the water head first.

VEER – to let out more cable.

WARP – also known as a 'cable'. A rope used to moor a boat to a fixed point.

WEIGH – to raise the anchor from the seabed.





A CQR 10 lb – 4.8 kg, 480 sq cm; **B** HiBlade 10 lb – 4.7 kg, 510 sq cm; **C** Delta 6 kg – 6.7 kg, 620 sq cm; **D** Brittany 6 kg – 6.2 kg, 560 sq cm; **E** Danforth 6 kg – 6.2 kg, 610 sq cm; **F** Bruce 5 kg – 4.9 kg, 300 sq cm; **G** *SPADE 6.5* – 5.1 kg, 460 sq cm

The anchors I tested

■ I assembled a collection of anchors ranging from a 1 kg Bruce to a 16 kg Fisherman. Most of the tests were carried out on anchors in the 5-7 kg range, plus the 2 kg Danforth – I've called these the standard anchors. Manufacturers' details show that as the size increases, its weight goes up by the cube of any linear dimension and its area increases as the square.

Apart from the Bruce, which has a small surface area for its weight, the areas of the 5-7 kg range from 460-620 sq cm.

My test rig

I used a shallow tidal pool, with a firm, sandy bottom, at Londniddry Bents, east of Edinburgh. The pool, with its uniform seabed and ease of access, was as near to laboratory conditions as I was likely to find. The shallow water meant that observing the behaviour of anchors under test was easy. The idea was simple; to lay the anchors on the seabed, then drag them a distance of 6-8 metres at a constant speed. This would establish whether an anchor remained vertical when pulled, or whether it was prone to roll-out. I tried to keep the speed of drag constant at three centimetres per second, which equates to 120 metres per hour. This is a fast, though not unrealistic, speed for an anchor to drag.

To achieve the pull, I built a rig which incorporated a five-part block and tackle, and an *Anchorwatch* load cell to measure the pull. The pulley was exactly one metre above ground level to make calculating the scope easy;

the cable was accurately marked at one metre intervals.

With this arrangement I could develop a pull of 300 kg and, by adding a further two-part tackle, I could manage 600 kg. This was enough to put the 15 kg anchors through their paces. The disadvantage of my rig is that, as the anchor is pulled closer to it, the scope decreases. To avoid this, I pulled each anchor for one metre, then moved the rig back by the same length.

Finally, the scope for each one-metre pull was measured at the point taken.

Turn the page for some unexpected results

How did they perform?

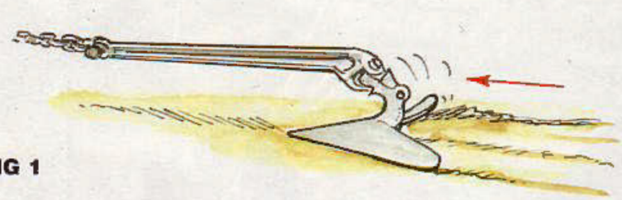


FIG 1

FIG 2

■ The CQR, HiBlade, Delta, Bruce and SPADE anchors, which initially lie on their sides, must roll into a vertical position before they develop a hold. The others naturally adopt a vertical position. A previous article noted that anchors which lie comfortably on a flat surface (principally the CQR and Danforth) are prone to skidding across the seabed and failing to find grip (Fig 1).

■ Over the first metre of drag in the sand at Londniddry, all the standard anchors began to bury themselves, including those that initially lay on their sides. The force needed to drag the anchors rose slowly to a steady, or plateau, value. At this point, the pulling eye would either be on the surface or just below it. At infinite scope, the anchors didn't continue to bury themselves indefinitely as they were dragged. Instead, they reached equillibrium just below the surface.

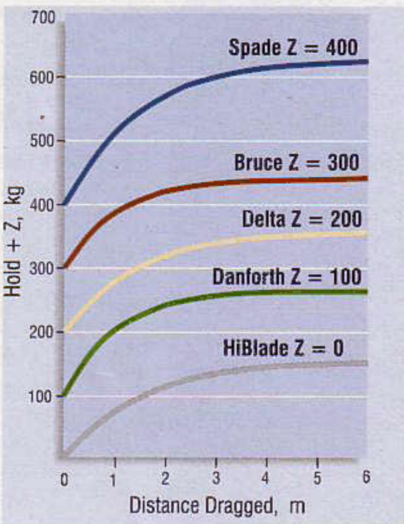
■ As the scope decreased, more of the anchor became visible, until at a scope of three, the flukes were clearly showing.

■ Where an anchor was dragged, a trench formed behind it and this quickly backfilled with loose, un-compacted sand (Fig 2). These areas were clearly visible after several tides, and may explain why some popular anchorages are criss-crossed with patches of poor holding. We mostly cruise around the west coast of Scotland and have noticed this effect at Canna Harbour and Puilladobhrain.

■ The standard anchors all needed to be pulled about five shaft lengths before they achieved maximum hold. As Fig 4 shows, the SPADE gave the highest holding figure at 240 kg, while the others were in the range of 130-160 kg.

■ Figure 3 shows how the force built up for five of the anchors as they were dragged at a scope of six. The 2 kg Danforth merits special mention because of its remarkable figure of 160 kg, but

FIG 3: HOLD V DISTANCE DRAGGED*



Hold when veered

One of the most important characteristics of an anchor is its behaviour when veered. It's vital the hold remains firm when the wind or tide changes direction and the boat pulls from another angle. To find out what happens to my anchors under such conditions, I pulled the anchors to their plateau hold at a scope of 5.I, then moved the frame and pulled at an angle of 90°. The results can be seen in Table 1.

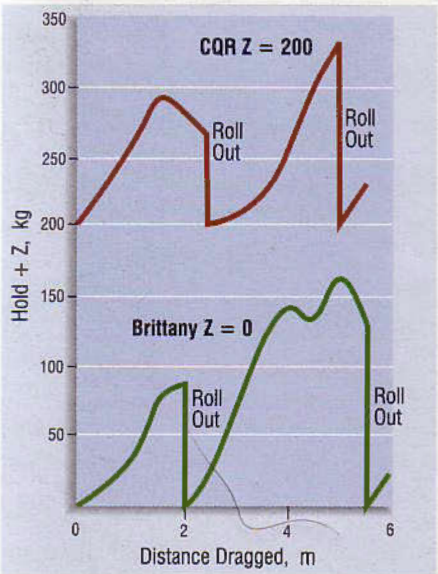
■ The roll-out behaviour was an exaggerated version of what happened in the straight pull. The roll-stable anchors (HiBlade, Delta, Bruce and SPADE) stayed buried when veered. As tbey turned in through the sand, their holding power decreased by 70%, but then returned to normal.

■ By contrast, the Brittany and CQR rolled out quickly when veered, and only regained their hold after re-engagement with the seabed. The Brittany turned over onto its back before it re-engaged, but would quickly roll out again. The 10 lb CQR behaved similarly. The 35 lb CQR was different; on one occasion after roll out when veered, it re-engaged lying on its side and continued to plough, giving virtually no hold. The only way to

TABLE 1: HOLDING OF ANCHORS WHEN VEERED THROUGH 90° DRAG RATE 3 CM/SEC; SCOPE 5

Anchor	Nominal Weight	Comment
Anchors stable when veered		
HiBlade	10 lb	Rolled onto its side but remained partially buried. Hold down to 40% during veer, then quickly rolled back to vertical and re-established its previous hold.
Delta	6 kg	Shank remained vertical during veer, hold down to 30% during veer, then re-established after 1 m drag; 15 kg as for 6 kg version.
Bruce	5 kg	Rolled to 30° off vertical, hold down to 30% during veer but re-established after 1 m drag.
	15 kg	As for 5 kg version.
SPADE	5 kg	Remained fully buried throughout veer. Hold reduced to 30% during veer but immediately re-established plateau value.
Anchor of intermediate roll stability		
Danforth	2 kg	When veered to port, rolled out. When veered to starboard, remained buried. Often failed to re-engage after roll out.
	6 kg	When veered to starboard, rolled to horizontal, with the stock vertical, then rolled back to normal position, tracking 30° to line of pull. When veered to port, remained stable.
	15 kg	Hold of 650 kg was the maximum which could be exerted by the equipment. On veering to port or starboard, it stayed buried and regained its hold, but the drag distance was very short. Result was therefore inconclusive.
Anchors Unstable when Veered		
CQR	10 lb	First veer: rolled out and re-engaged after 2-3 m drag. Second veer: same.
	35 lb	First veer: rolled out and re-engaged after 2 m drag. Second veer: rolled out, failed to re-engage after 7 m drag.
Brittany	6 kg	Rolled out when veered after 1 m drag. Re-engaged, but rolled out again within 2 m drag.

FIG 4: HOLD V DISTANCE DRAGGED



*** NB: to show the curves in Fig 3 clearly, a factor of 'Z' has been added. For example, the Bruce anchor is measured from zero, but starts at 400 kg instead of 0 kg, because its 'Z' factor is 300 kg.**

this was dependent on my digging in both flukes by hand. If allowed to set itself naturally, the results were significantly worse at around 100 kg.

■ Sometimes the Danforth anchors reared up, with their flukes pointing down into the sand, as they were pulled. This made the anchor tip over sideways and engage only one fluke. The anchor then either rolled out, or if it dug in, tracked at around 30° to the direction of pull, leading to the poor holding mentioned above.

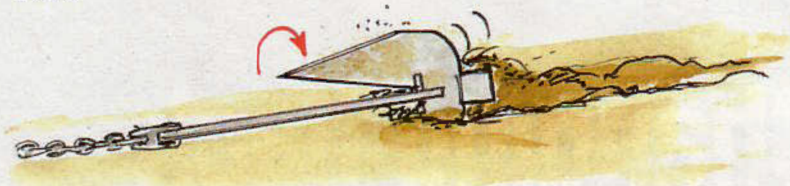
■ Fig 4 also shows the performance of two standard anchors, the 10 lb CQR and 6 kg Brittany. Both gave figures comparable to the others but, as the pull went on, they became unstable and would roll out with no warning. This worrying behaviour was repeated on every test, and might lead you to think your anchor was secure, when, in fact, it was on the point of roll out (Fig 5). Both anchors would reset quickly, but then repeated the roll-out process.

■ The CQR made a serpentine trench when dragged, and seemed prone to rolling out every half cycle. The 35 lb one was more stable, but still made the same wriggly path through the sand.

■ The 6 kg Brittany rolled out consistently after dragging for about 1-3 metres. It did this suddenly and unexpectedly, sometimes after developing quite a high hold.

■ The traditional, 16 kg Fisherman anchor could only achieve about ⅒ of the figure expected of a modern anchor of the same weight. It may be much better on a rocky seabed, where the flukes could catch in crevices.

FIG 5



reset the CQR from this position would be to lift the anchor from the seabed and drop it again.

■ The 2 kg Danforth again behaved erratically, performing well when veered to starboard, but rolling out quickly to port. The 6 kg version displayed a similar willingness to roll out, but to starboard. The heaviest Danforth, at 15 kg, was roll stable in both directions, but its hold was too great for my rig to pull it any distance.

Why the differences?

I can only speculate why some of the standard anchors are much more roll stable than others. The Delta, HiBlade, Bruce and SPADE all perform well; the CQR and Brittany badly, while the Danforth was somewhere in-between.

Although the CQR and HiBlade appear similar in construction, their performance differs greatly. Perhaps weight distribution accounts for it? The HiBlade seems to be weighted towards the nose, which may help it dig in. The Brittany and Danforth are also similar in design, yet the former's performance figures are much worse. Could this be due to its completely flat flukes? Those of the Danforth are swept at the edges to give greater strength and this may also improve its holding ability.

Both the Bruce and SPADE are concave. This might make them more roll stable.

Which one worked best?

1 The SPADE was the best performer for a given weight. It was roll stable and held extremely well. It was also the most deeply buried anchor.

2 The Delta, HiBlade and Bruce were all roll stable and gave about 60% of the SPADE's hold.

3 The Danforth was less roll stable and didn't always set quickly. Once set however, it gave a very good hold, typically 30% greater than a SPADE.

4 The Brittany and CQR were unstable. The former consistently rolled out when pulled straight and veered. The CQR mirrored the Brittany when veered and was little better on a straight pull.

5 Heavier anchors typically performed better than lighter versions of the same model. A 15 kg anchor will give two or three times the hold of a 5-7 kg model and also seemed to be significantly less likely to roll out.

6 Roll-stable anchors didn't pull out of the seabed when dragged slowly. Indeed, in practice, it would be very difficult to pull an anchor so hard that it came out, unless it met weed or some other physical obstruction.

NOTE: It's important to emphasise that all the results from my experiments are strictly relevant to one type of seabed, namely uniform, medium-hard sand. Results may vary with other materials.

Best performer
THE SPADE

*Details of *Anchorwatch* from Anchorwatch UK, 67 Morningside Park, Edinburgh, EH10 5EZ www.anchorwatch.co.uk E: anchorwatchuk@aol.com Thanks to Alain Poiraud of SPADE contact: SPADE BP 103-40, rue Ibn Béchir Safouane, 2036 La Soukra Tunisia T:+216 71 869099 F:+216 71 865250 E-mail: info@spade-anchor.com, Bill Faerestrand of Lewmar and Joe Lamb for providing anchors for my experiments and to Bobs Boat Shop in Poole. T: (01202) 736704 F: (01202) 388704

COMING SOON

■ Next month, Prof Knox looks at how the weight, scope of cable and speed of drag affects an anchor's holding ability.

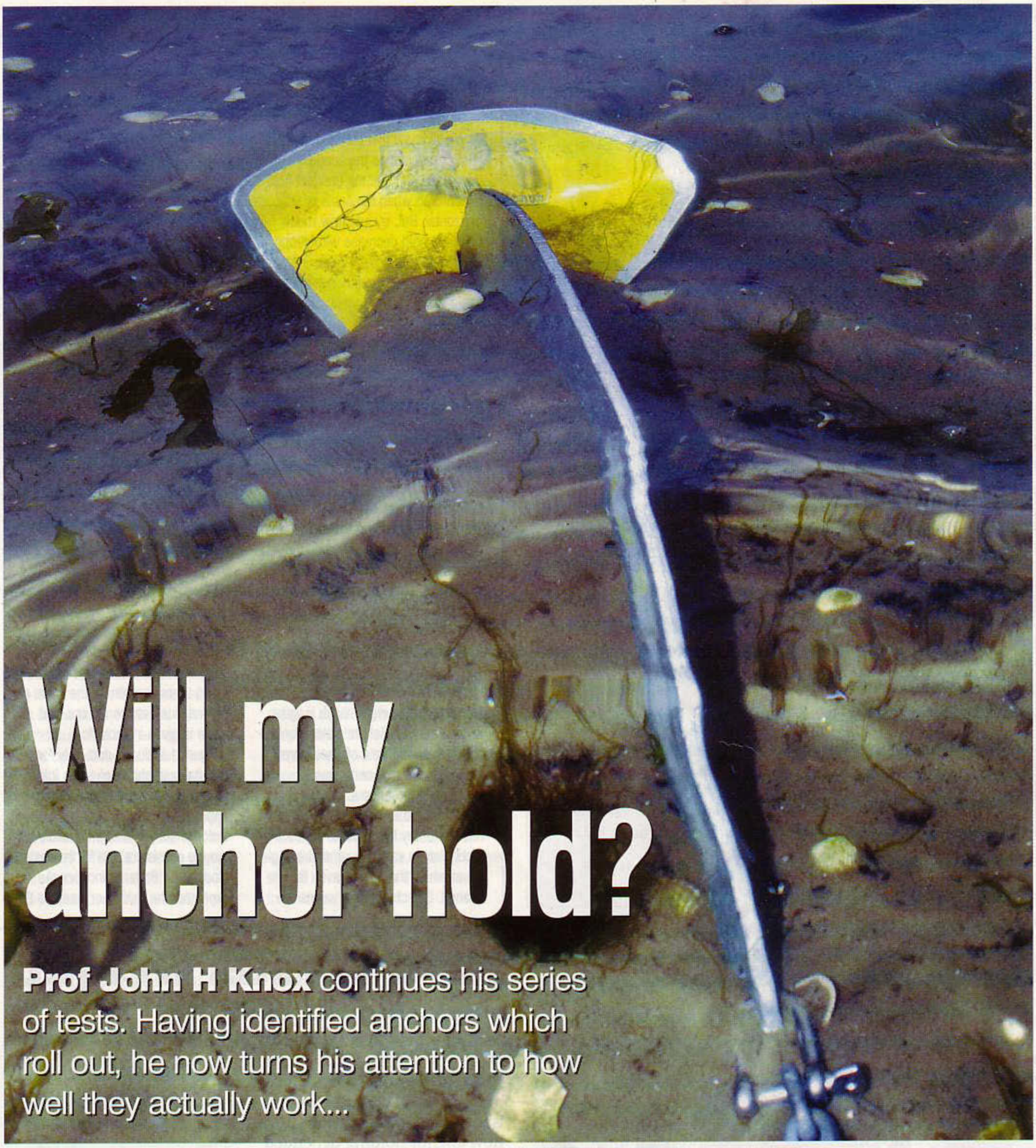


Photo: Laura Kerr

Will my anchor hold?

Prof John H Knox continues his series of tests. Having identified anchors which roll out, he now turns his attention to how well they actually work...

THERE are many reasons why some anchors tend to roll but this month I show how the holding of a roll-stable anchor depends upon scope, anchor weight and the rate it's dragged through the seabed.

For those who missed last month's article, I'd simply say that my experiments were conducted in a shallow tidal pool at Longniddry beach on the shores of the Firth of Forth, where the bottom was medium-hard sand. Anchors were dragged through the sand by a 5 or 10-part pulley system that enabled forces of up to 700 kg to be applied at the anchor. The cable was either nylon multiplait or, for the heavier anchors, wire plus ¼-inch chain. It passed over a pulley held one metre above the sand by means of a pyramidal frame. The scope, S/D (S=cable length from pulley to anchor, D=the height of the pulley above the sand), was therefore equal to the length of the pulling cable from the anchor to the pulley, measured in metres.

How we measured them

The tension on the anchor cable was measured using ANCHORWATCH, a device invented by Kevin Scott and myself which uses a load cell to measure forces up to a ton. The CQR type, HiBlade, Delta, Brittany, Danforth, Danforth copy, Bruce, claw and SPADE anchors tested ranged in weight from 1 kg to 15 kg.

ABOUT THE AUTHOR

■ John Knox has had a lifelong interest in boats and in the 1960s became interested in kayaking while on sabatical leave in Utah. He took to dinghy sailing in the 1970s, first in a Graduate and later an Albacore dinghy. In 1983 he bought *Myfanwy*, a Hustler 35, and has sailed extensively on the west coast of Scotland.

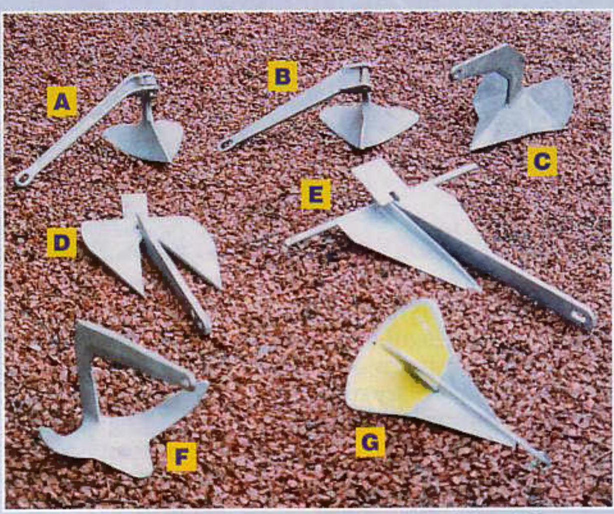
IN CASE YOU MISSED PART 1

The story so far...

The SPADE gave the best results in last month's test

IN my previous article, I looked at the roll stability of some commonly used yacht anchors. The results were surprising and disturbing. The Brittany (6 kg) rolled out when dragged some five shank lengths and when veered. The plough (10 lb) also behaved in the same way, while the plough (35 lb) rolled out consistently when veered but not when dragged straight. I concluded that, under stress, these anchors could drag – with serious consequences for a yacht and her crew. The HiBlade, Delta, claw and SPADE anchors, on the other hand, were stable to rolling, both when dragged straight and when veered, with the SPADE giving the best hold. The Danforth and copy anchors were somewhere in-between. It was difficult to set symmetrically, but when it did, it gave a remarkable hold. However, when veered, it tended to roll out – though that wasn't inevitable. It was hard to lift, however. This month, I consider how the holding of roll-stable anchors depends upon the scope of the cable, the anchor weight and the rate at which they are dragged through the seabed.

The anchors...



Anchors are listed by name, claimed weight, actual weight and the surface area of the fluke

A Plough 10lb – 4.8kg, 480 sq cm; **B** HiBlade 10lb – 4.7kg, 510 sq cm; **C** Delta 6kg – 6.7kg, 620 sq cm; **D** Brittany 6kg – 6.2kg, 560 sq cm; **E** Danforth copy 6kg – 6.2kg, 610 sq cm; **F** Claw 5kg – 4.9kg, 300 sq cm; **G** SPADE 6kg – 5.1kg, 460 sq cm

THE FIRST TEST

Hold versus scope

■ We all know that the hold of an anchor reduces as the scope decreases and that the greatest hold is achieved when the cable is horizontal. But, by just how much does the hold decrease with scope, and do all anchors perform similarly? Although one of the functions of chain is to keep the cable close to horizontal, as soon as there's real tension, it runs more or less straight from the anchor to the stemhead. Consequently, it leaves the anchor at a finite angle to the seabed. This is the normal situation when you're worrying whether your anchor will hold. In all my experiments, the cable was straight between the anchor and pulley, whether it was nylon or wire. So, the scope (S/D) was simply related to the angle (q) that the cable makes with the seabed, by the equation: $S/D = 1/Sin\ q$. I also made sure the anchors were launched and initially pulled at the scope required for any particular test. So, when working at a scope of three, I'd launch the anchor at this scope, and pull it at the same scope for six to eight shank lengths in order to establish its plateau hold. A standard drag rate of about three centimetres per second was maintained throughout. This is about 1/20 knot, so is extremely slow relative to any boat speed. Figure 1 plots plateau values against the angle (q) at which the cable leaves the seabed. Selected scope values are also shown by the vertical lines in the figure. For clarity, the data points for each anchor are displaced vertically by an amount given by the value of Z. The relation between scope and angle is given in Table 1.

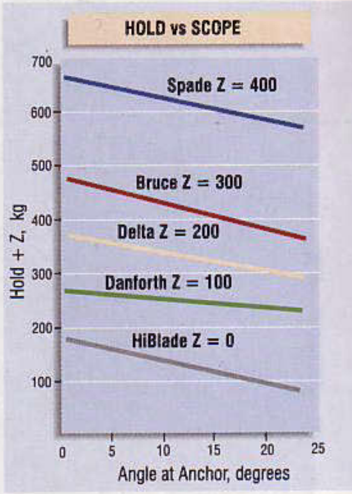


FIGURE 1 Dependence of hold upon Scope for 5-7 kg Anchors and 2 kg Danforth, ploughing at 3 cm/sec

Figure 1 includes data only for the roll-stable anchors, plus the 2 kg Danforth which was stable when engaged symmetrically. Unfortunately, it was impossible to provide consistent data for the unstable plough and Brittany anchors. As expected, the hold decreased as the

Hold versus weight

■ The weight of an anchor required for a given yacht obviously depends upon its size. But the question of just how the two should be related is unclear. I was able to test how anchor holding depended upon the weight using the roll-stable claw and Delta which I had available in a range of weights from 1 to 16 kg. The results are shown in Figure 2. The anchors were pulled at a scope of five. The weights used for plotting the data are their true ones rather than those quoted by the manufacturers. Within the limits of error, the holding power at a scope of five is proportional to the weight for these types of anchor.

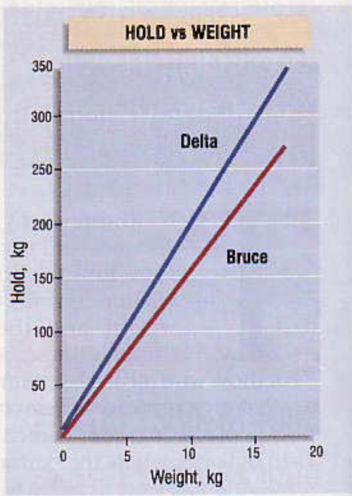
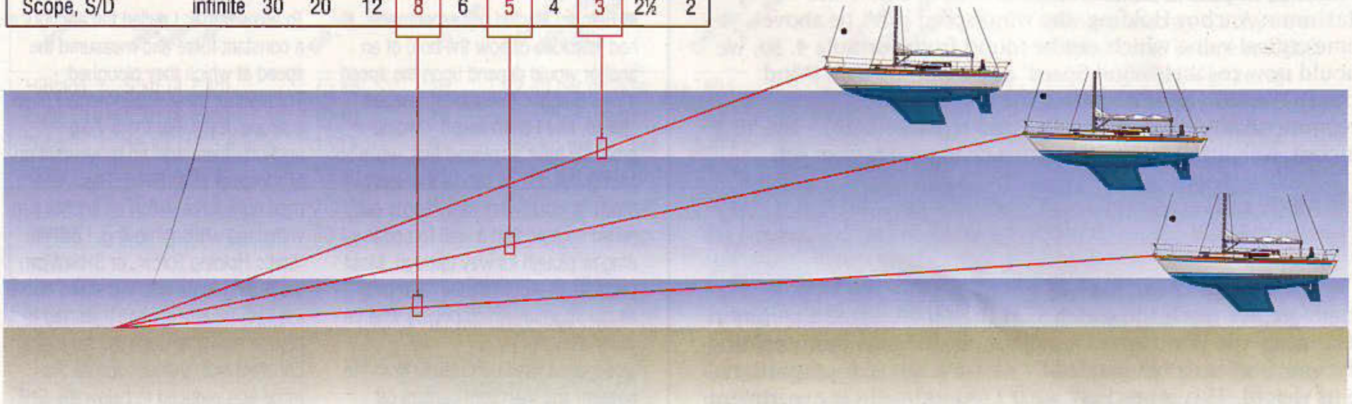


FIGURE 2 Holding power was proportional to weight at a scope of five for these anchors

TABLE 1 SCOPE S/D AND ANGLE AT ANCHOR, Ø (S/D = 1/ SINØ)

Angle, Ø, at Anchor	0°	2°	3°	5°	7°	9°	11°	14°	20°	24°	30°
Scope, S/D	infinite	30	20	12	8	6	5	4	3	2½	2

Basically, what this all comes down to is scope and angle. As the scope gets less and the angle becomes bigger, the less likely your anchor is to hold well. In Prof Knox's experiment, the SPADE gave the flattest dependence on scope, while the claw and HiBlade gave the steepest.



angle at the anchor increased, and the scope lowered. The decrease in hold was more or less linear with the angle but wasn't the same for all anchors. Those which showed the least decrease as the angle steepened were the SPADE and Danforth. The Delta came next. The steepest decline of hold with angle was found on the claw and HiBlade; Table 2 summarises the data on the basis of scope.

I was surprised at the large differences between anchors, with the Danforth coming out best in terms of how its hold decreased with scope. Of course, this anchor has disadvantages referred to in my first article; it was particularly difficult to get it to engage symmetrically – its stability is also suspect because it can roll out when veered. The SPADE is, therefore, the best anchor overall in terms of stability, and holding when dragged, which declines only slightly with the amount of scope.

The hold of the Delta seemed to go through a flat range between ten and four, then quickly declined as the scope went down to 2½.

The claw and HiBlade showed the sharpest decline in hold with decreasing scope, so, with these anchors, it's particularly important to work with a large scope when conditions are bad. Nevertheless, a scope of five for the anchors tested ensures that not more than 30% of the hold is lost.

As I've argued before, a scope of five should be regarded as the minimum for safe anchoring.

TABLE 2 HOLDING AND SCOPE WHEN PLOUGHING AT STANDARD RATE

Anchor	Hold at infinite scope in kg	% of Maximum Hold at Scope 5	Hold at Scope 5, in kg	% of Maximum Hold at Scope 3	Hold at Scope 3, in kg
SPADE 6 kg	250	85%	210	70%	180
Danforth 2 kg*	170	90%	150	80%	135
Delta 6 kg	180	80%	145	60%	110
HiBlade 10 lb	190	75%	140	53%	100
Claw 5 kg	170	70%	120	45%	75

*Note. These values apply to the Danforth only when it is engaged symmetrically.

The mean dependence of hold upon weight at scope 5 for the claw and Delta anchors, when ploughing at three centimetres per second, can be expressed as:

FORMULA 1
Anchor Holding Force in kg = 20 x (Anchor Weight in kg)

The question now is: what anchor weight should be used for a particular yacht?

Manufacturers recommend anchor weights for yachts of different lengths, but they don't explain how they arrive at their recommendations, nor whether they base them on theory or simply experience. Having surveyed the recommendations for steel anchors by several manufacturers and vendors, I find they can be represented quite well by a very simple formula. There are exceptions, particularly the recommendations in the Plastimo catalogue for Brittany anchors (where somewhat heavier anchors are recommended for shorter yachts), but overall, recommendations follow Formula 2 within about ±20% for anchors between five and 50 kg.

FORMULA 2
Anchor Weight in kg = (1/9) x (LOA in metres)^2

Thus, for a yacht of 11 metres (33 ft) LOA, the recommended weight would be in the range of 11 to 16 kg, and for an 18 metre yacht (60 ft), it would be 30 to 45 kg. The upper figures would apply to cruising yachts and the lower ones to racing vessels. Boat owners will recognise that these figures are much in line with normal practice.

The question now is: can anything more be deduced from Formulae 1 and 2? Indeed, yes, but a third relationship is needed which connects peak cable tension with LOA and wind speed. As I and others have argued elsewhere, the wind resistance of a yacht is proportional to its frontal area which is roughly proportional to its LOA squared. It's also proportional to the wind speed squared. Of course, the actual cable tension experienced by a yacht at anchor varies widely as the yacht tacks and surges, trying to shake itself loose from its anchor. However, if the anchor isn't snubbing at its chain, the peak load experienced, in practice, is given to a reasonable approximation (see PBO 386) by Formula 3:

FORMULA 3
Peak Cable Tension = (1/500) x (LOA)^2 x (Wind Speed)^2

In this and subsequent formulae, any force, such as cable tension or anchor holding, is measured in kg, anchor weight in kg, LOA in metres, and wind speed in knots.

Let's suppose that conditions are such that a yacht's recommended anchor is just holding, or rather, to be more precise, that under the peak loading it'll drag or plough at three centimetres per second, which could be regarded as a maximum for safety. For this situation, we can then replace 'Peak Cable Tension' from Formula 3 with 'Maximum Anchor Holding':

FORMULA 4
Maximum Anchor Holding = $(1/500) \times (LOA)^2 \times (\text{Wind Speed})^2$

What this implies is that if we want to keep below the Maximum Anchor Holding, the wind speed can't be above some critical value which can be found from Formula 4. So, we should now re-label 'Wind Speed' as 'Maximum Safe Wind Speed'. We can also incorporate the manufacturers' recommendation from Formula 2 and replace '$(LOA)^2$' by '(9 x Anchor weight)'. Making these two changes, we now get:

FORMULA 5
Maximum Anchor Holding = $(1/500) \times (9 \times \text{Anchor Weight}) \times (\text{Maximum Safe Wind Speed})^2$

Therefore, we reach the conclusion that, if we agree a common Maximum Safe Wind Speed for all yachts, the maximum holding of an anchor, as recommended by manufacturers, is proportional to its weight. This is precisely what I found by direct experiment and have expressed in Formula 1. So, we can finally compare the manufacturers' recomendations, as expressed in Formula 5, with the experimental data, expressed in Formula 1, by replacing 'Maximum Anchor Holding' in Formula 5 with '20 x Anchor Weight' from Formula 1. This gives:

FORMULA 6
$20 \times (\text{Anchor Weight}) = (1/500) \times (9 \times \text{Anchor Weight}) \times (\text{Maximum Safe Wind Speed})^2$

Anchor Weight is present on both sides of Formula 6 and cancels as it must. After re-grouping, the numbers we finally get are:

FORMULA 7
Maximum Safe Wind Speed = (20 x 500/9)1/2 = 33 knots

This is interesting because it implies that the recommended anchors for yachts of different LOA will be adequate up to Force 7 or 8 when they're buried in medium-hard sand, such as that used for my experiments. This seems an entirely reasonable conclusion, although I've not seen it expressed in just this way before. I'll call this the 'Force 8 Rule'.

Of course, this Force 8 Rule applies to a specific seabed material, and has been deduced from data for two average anchors, the Delta and the claw, at a Scope of five. If you expect a Force 8 or more, the rule suggests that you should seek a seabed with superior holding, an anchor with superior holding, or that you should deploy two or more anchors. The SPADE, for example, can hold 40 or 50% more than the HiBlade, Delta, or claw. Since the safe wind speed goes up as the square root of the safe holding (Formula 5), the SPADE would be adequate to roughly 20% higher wind speed. Likewise, if you deployed two anchors and if both developed their full hold, the wind speed you could expect to resist would be ahout 40% more than with a single anchor.

Correction

■ In the first feature of this series, published in PBO 427, while a genuine 15kg Bruce anchor was one of those tested, the picture on page 79 shows a 5kg Claw anchor, rather than the genuine Bruce. With the exception of the 15kg Bruce anchor tested, any reference to a Bruce anchor in the first article should read Claw anchor. Similarly, the anchor referred to as a CQR in the first article was, in fact, a copy of the CQR pattern and should be referred to as a plough.

THE FINAL TEST

Holding power and speed of drag

■ Before I started my experiments, I had little idea of how the hold of an anchor would depend upon the speed it was dragged through the seabed. Indeed, had I been asked, I would probably have answered that, while an anchor will hold in sand if it doesn't move, it would very likely come out if pulled so hard that it was forced to drag or plough its way through. Most yachtsmen would define 'dragging' as the situation which occurs when a yacht's anchor disengages itself completely from the bottom, and the yacht canters off downwind with possibly catastrophic consequences. The first thing my experiments showed was that there are in fact two quite distinct types of 'dragging'.

PLOUGHING

The first is what I've just described. The second kind of dragging occurs when an anchor is forced to drag or plough through the material of the seabed while still remaining buried. This is the kind of 'dragging' that I studied in my experiments. Ploughing is probably a better word to use. As I've shown, an anchor which drags or ploughs through the seabed while still buried will hold just as well as, indeed better than, an anchor which remains static. Ploughing is dangerous only when the anchor rolls out, or is forced out by some obstruction, such as weed or rock, as it slowly moves through the seabed material. Typical safe ploughing rates can be up to a few centimetres per second, or say a tenth of a knot (5 cm/sec). My experiments give no information on what happens when this rate is exceeded.

The question I became interested in as a result of my initial experiments was: how does the holding force of an anchor depend upon the rate at which it ploughs through the seabed? To answer that, I pulled the anchors at a constant force and measured the speed at which they ploughed. Throughout these experiments I used a scope of ten. For the 5-7 kg anchors, there was no movement up to a force of 50 to 80 kg. This maximum force which an anchor can withstand without moving, I call its 'Static Holding Force', or SHF. When the pulling force was increased above the SHF for any anchor, it started to plough slowly through the sand at a constant rate. But as soon as the force was reduced to below the SHF, the anchor would stop moving. The force required to make an anchor plough through the seabed, I call its 'Dynamic Holding Force', or DHF. This force is a function of the ploughing rate, and is equal to the SHF when the anchor is just on the point of moving. Figure 3 shows the results for the 5-7 kg anchors. It can be seen that the DHF increased more or less linearly with the rate of ploughing. The HiBlade, Delta and claw behaved very similarly, while the SPADE gave somewhat higher values of both the static and dynamic holds. Figure 4 shows the data for the 15 kg Bruce and Delta anchors. The linearity is less good as the range of ploughing speed was rather small. Table 3 summarises the numerical results.

WIND SPEED

The broad conclusion is that, in the sand of Longniddry beach, the SHF of a modern anchor at scope ten averages around 11 times its weight, while the DHF at three centimetres per second ploughing rate averages around 27 times the anchor weight. However, there's quite a variation from one anchor to another. The SPADE gives the best performance, while the HiBlade, Delta and claw aren't far behind, in agreement with the conclusions reached in my first article.

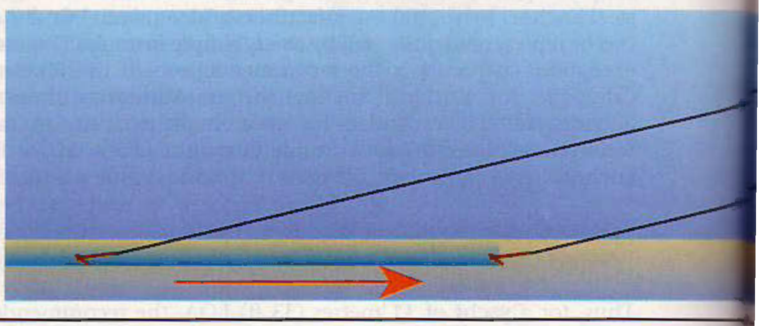


TABLE 3 HOLDING FORCE AS A FUNCTION OF PLOUGHING SPEED AT SCOPE 10

Anchor	Weight (True Weight in Brackets), kg	SHF, kg	SHF/True Weight	Dependence of DHF upon ploughing rate, kg per (cm/sec)	DHF, kg, ploughing at 3 cm/sec	DHF/True Weight ploughing at 3 cm/sec
HiBlade	5 kg (4.7 kg)	75 kg	16	22 kg per cm/sec	140	30
Delta	6 kg (6.8 kg)	70 kg	10	21 kg per cm/sec	135	20
Delta	15 kg (16.3 kg)	150 kg	9	155 kg per cm/sec	600 kg	28
Claw	5 kg (4.9 kg)	55 kg	11	26 kg per cm/sec	135 kg	27
Bruce	15 kg (16.2 kg)	105 kg	6.5	90 kg per cm/sec	375 kg	18
SPADE	6.5 kg (5.1 kg)	80 kg	16	38 kg per cm/sec	190 kg	37
MEAN			**11**			**27**

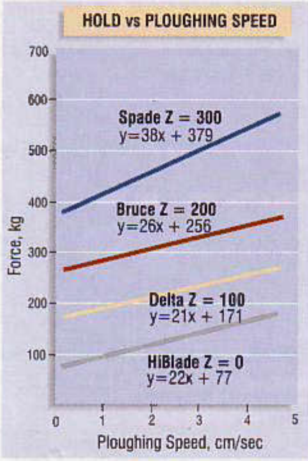


FIGURE 3 Dependence of hold upon ploughing speed for 5-7 kg anchors at Scope 10.

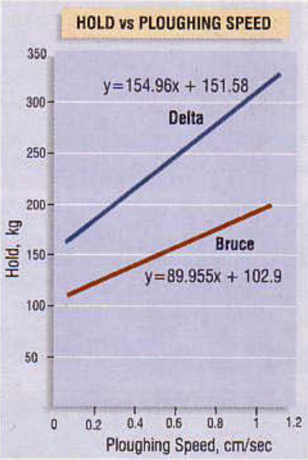


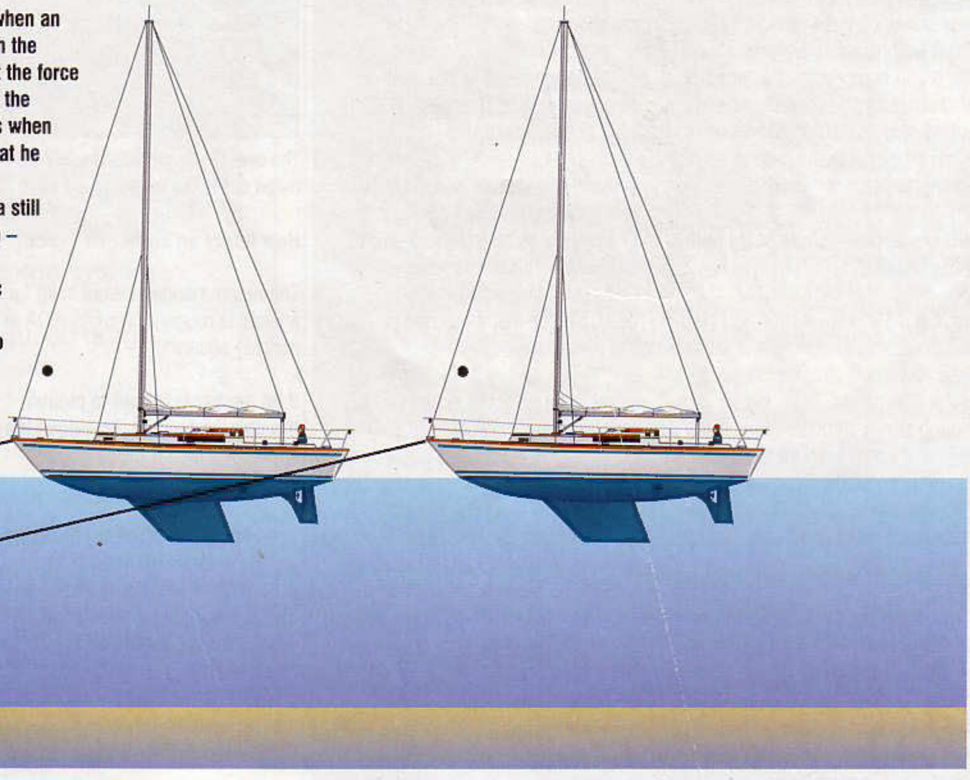
FIGURE 4 Dependence of hold upon ploughing speed for 15 kg anchors at Scope 10.

We can now calculate the wind speed at which anchors, at scope ten, will just begin to move when buried in medium-hard sand – when the SHF will be exceeded. This is simply done by by replacing the number 20 in Formula 7 by the number 11. This gives 24 knots, or about Force 6, as the the wind speed at which a recommended anchor will, on average, just start to plough in medium-hard sand. Applying the same argument to the DHF gives 40 knots, or Force 8 to 9, as the wind speed at which recommended anchors will plough at three centimetres per second. It now seems clear that we should accept that, even at large scope, our anchors will plough slowly through a seabed of medium-hard sand whenever the wind is above about Force 6, and, more significantly, when the wind is up at Force 8. Of course, the ploughing won't generally be continuous, as the force on an anchor cable fluctuates wildly and randomly. It's only the peak forces which will be large enough to cause ploughing. So, an average ploughing rate, in say a Force 8, may still be quite modest, perhaps one centimetre per second. But even this means nearly 30 metres per hour which is hardly insignificant, especially if you've chosen a small patch of sand in a weedy patch for dropping anchor.

My observations may well explain why dragging incidents often seem to occur when an anchor has apparently been holding well under stress for a long time, and then jumped out suddenly and unexpectedly. We've certainly experienced this worrying phenomenon once or twice. What seems likely to have happened is that the anchor has initially buried itself perfectly well, but has then slowly walked downwind in small steps each time its SHF has been exceeded. If the anchor was a plough or Brittany, it may have simply rolled out after ploughing a certain distance or veereing, then failed to re-engage. Even with a roll-stable anchor, it could've ploughed into weed or deep water where the scope is too small for strong holding.

TO SUM UP...

Here, Prof Knox talks about what happens when an anchor is pulled or made to 'plough' through the seabed. There are two relevant factors, first the force a buried anchor can exert without moving – the *static* hold – and, second, the force it exerts when it's made to plough – the *dynamic* hold. What he found was that although anchors give a substantial hold when stationary, they give a still greater hold when they are forced to plough – the faster they plough, the greater the hold. The SPADE was best on both counts – static and dynamic – although the HiBlade, Delta and claw came close behind. Prof Knox also concludes that anchors will start to plough slowly around Force 7 when buried in medium-hard sand..



Conclusions Which one worked best?

MY experiments show a number of interesting and, in some cases, quite unpalatable results.

My overall winner is the SPADE because it never rolled out and also gave the best hold, with very little change when the scope was decreased.

On the other hand, the Brittany rolled out whatever the situation, even when veered. The plough wasn't much better. As for the Danforth and its copy, even they were a little dubious in terms of roll out and shouldn't be relied upon completely.

The HiBlade, Delta and claw all did well but their holding power was less than the SPADE's.

OVERALL ASSESSMENT **ANCHOR PERFORMANCE IN MEDIUM HARD SAND**

Anchor	Setting	Holding overall	Performance in Straight Pull	Performance when Veered 90°	Hold v Scope from 2_ to infinite	SHF*, per unit anchor weight	DHF**, per unit anchor weight ploughing at 3cm/sec	Overall
Plough	★★★	★★★	Can roll out	Rolls out	n.v			**Rolls out**
HiBlade	★★★★★	★★★★	★★★	★★★	★	16	30	★★★★
Delta	★★★★★	★★★	★★★	★★★★	★★★	10	24	★★★
Brittany	★★★★★	★★★	Rolls out	Rolls out	n.v.			**Rolls out**
Danforth/copy	★	★★★★★	Can roll out	Can Roll out	★★★★★			★★
Claw	★★★★★	★★★	★★★★★	★★★★★	★	8	22	★★★
SPADE	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★	16	37	★★★★★

NOTES: ★★★★★ - Excellent, ★★★ Good, ★ Moderate. *SHF = Static Holding Force: force which anchor will hold without moving. **DHF = Dynamic holding Force: force which anchor will hold when ploughing at a finite speed.

FOOTNOTE: I must emphasise that my conclusions apply to the performance of anchors in a seabed of uniform medium-hard sand. Other seabeds may give different results, particularly different quantitative results. Much experimentation still needs to be done in other seabed materials. However, I'm confident that the main qualitative conclusions will remain.

Anchoring your questions answered

How much cable should I deploy, and should it be chain or warp?

The answer has been given in my earlier articles dealing with wind forces. Briefly, there are two very simple rules. First, if you anchor with all chain, the length (in metres) required for safe anchoring is equal to the wind strength (in knots) multiplied by a factor which depends upon the water depth and chain weight, but is typically about 1½. If you can't deploy this amount of chain, snatching will occur and you should add 10 or 20 metres of nylon multiplait to the rode to act as an energy absorbing spring.

Will my anchor come out if I pull it too hard?

No, not if it's properly set. You can pull your main anchor much harder than you would ever want to and it will not come out. It will simply plough slowly through the seabed. However, some anchors are unstable when dragged and may roll out. They should be avoided in my judgement – see my answer to the next question!

Do all anchors perform similarly or are some better than others?

Some anchors roll out when forced to plough through the seabed. This was certainly true with the plough and Brittany, but there may be others. Anchors which are stable to rolling and will plough indefinitely through the seabed are the SPADE, HiBlade, Delta and claw, and again there may be others which I've not tested. The Danforth is somewhere between and shows some indications of instability. Some anchors, like the Danforth and plough, don't set well initially, especially if the seabed is hard.

What happens when the wind direction or tide changes? Will my anchor still hold?

Yes and No! The roll-stable anchors can be veered without pulling out. The plough and Brittany roll out; the Danforth sometimes comes out. Roll-out is dangerous since there's no guarantee that these anchors will reset.

What's the effect of scope on the holding of an anchor?

As the scope decreases, the holding power decreases. Some anchors are better than others. The SPADE shows the least effect of decreasing scope, the HiBlade and claw show the most, but even these lose only about 30% of their holding going from infinite scope to scope five, although they lose up to 50% of their holding power going from infinite scope to scope three.

Photo: Laura Kerr

The overall winner was the SPADE anchor – it gave good hold and never rolled out in the tests carried out by Prof Knox in medium-hard sand

How heavy an anchor do I need?

The recommended weight in kg for a yacht is roughly (¼) of its (LOA in metres) squared.

If an anchor is forced to plough through the seabed, how does the speed at which it drags depend upon the force applied?

The force up to which a well buried anchor will hold in medium hard sand without moving, called its SHF, is around 11 times the anchor weight. An anchor of the recommended weight buried in medium-hard sand will hold without moving up to about Force 6. When a larger force is applied, an anchor will slowly plough through the seabed. In a Force 8, such an anchor, buried in medium-hard sand, will plough under peak loads at about three centimetres per second.

Which anchor should I choose?

You should always choose a roll-stable anchor. Of these, the SPADE performed the best for its weight. It gave the highest hold, the least reduction of hold with scope, the highest static hold (SHF), and the lowest rate of ploughing when the SHF was exceeded. It was closely followed by the HiBlade, Delta and claw in that order.

■ I'm most indebted to Alain Poiraud of SPADE, and to Bill Faerestrand of Lewmar (Scotland) for the loan of several of the smaller anchors I tested.