How Anchors Work

John Knox reports on his recent experiments with anchors

We bought our first cruising yacht, *Myfanwy*, a Hustler 35 in 1983. A few years later, in July 1988, we experienced our first real storm when we were anchored in the small but sheltered anchorage on the west side of Gometra, itself on the west of Mull. We had been warned of a gale on the VHF and had set two anchors, our 15 kg CQR and 15 kg Bruce. Overnight the wind rose and blew a steady F8-9. We spent a very anxious night. In the morning we were relieved to find that we had not moved. The centre of the depression passed about breakfast time. Then the wind then came back from the opposite direction with even more force. One of the party remarked, *"The waves look like hotels floating past."* We were glad not to be out in it!

We were comparative novices at the time and this incident convinced me that I did not understand much about anchoring. We had been very lucky. As a scientist I decided that I needed an instrument which would measure the anchor cable tension so that I could check what was going on. This resulted in the development of **Anchorwatch**. It measures the anchor cable tension, the peak tension over a period of time, and sounds an alarm when the load exceeds a pre-set value. Over the years **Anchorwatch** has become an essential piece of safety equipment, in use whenever we anchor.

In a sheltered anchorage the peak wind force is given roughly by:-

Wind force in kgf = (1/500) x (LOA in metres)^2 x (wind speed in kt)^2

So for *Myfanwy*, LOA 10.5 metres, in F9 (45 kt), we would expect the peak wind force in otherwise sheltered conditions to be around (1/500) x 10.5^2 x 45^2 = 300 kgf *(1 kgf or 1 kilogram force = 1 kg weight = 9.8 Newtons)*. However, if there are waves, and particularly if you experience snubbing with that unnerving banging of the chain on the bow roller, the force can be much larger. Snubbing arises as follows: if a yacht is unrestrained or only slightly restrained in windless conditions, it will move back and forth as each wave passes - rather like an eider duck on a calm day. It will also pitch. If it is restrained by an anchor cable, the cable will alternately be asked to stretch and contract as a wave passes. If you try to restrain this natural motion very high forces can develop, especially if the background wind has already pulled the cable taut. What you need is a spring. The simplest spring is something like 10 metres of nylon multiplait. By including this in the anchor cable, you can accommodate far more extension than the catenary. A nylon spring is particularly effective at high loads where the catenary fails. You can easily test this the next time you experience snubbing. Lead an appropriate length of nylon multiplait from a stem cleat and clip it on to the chain beyond the bow roller. Then let out at least another 3 metres of loose chain to take up the extension of the nylon under load. The effect is amazing!

Anchor Testing - Once we got our anchoring technique sorted out, I became interested in how different anchors behave when put under real stress such as we experienced in the July 1988 storm. It is almost impossible to conduct proper tests on board a yacht as the pulling force cannot be controlled. You need land-based equipment. Fortunately, near Edinburgh, we have some easily accessible tidal pools at Longniddry beach, Gosford Bay on the south side of the Firth of Forth. The seabed is medium-hard sand. Tidal pools are ideal as the test anchor can be on the seabed under water and easily seen, while the pulling equipment is on the beach. And there is no tide to bother about. Figs.1 & 2 show the set up.

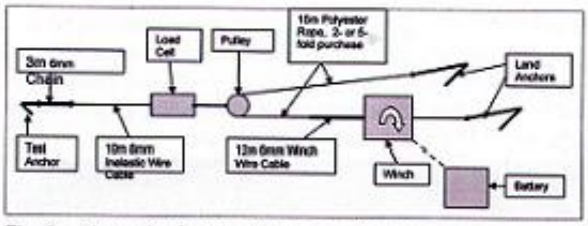

Fig. 1 - schematic of anchor testing equipment

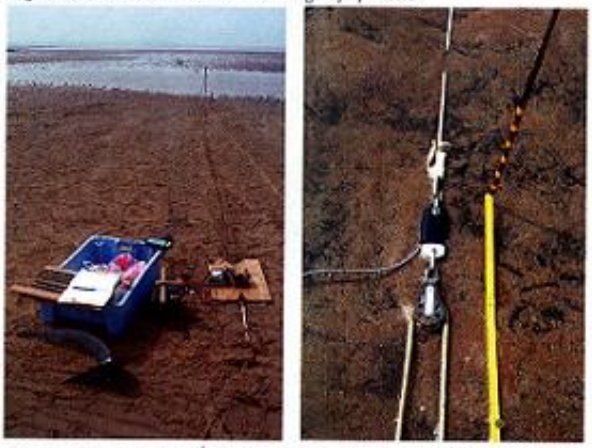

Fig. 2 - the anchor testing equipment; left, general view, the test anchor in the distance; right, the load cell and twin pulley

The basic experiment is straightforward. I lay out and tension the equipment, placing the anchor carefully on its side on the sand. The winch is started and every 5 to 10 sec the load, displayed by Anchorwatch, is noted. The winch pulls the anchor at between 1 and 3 cm/sec depending upon the purchase used. Mostly I use a 5-fold pulley system and get a pulling rate of 1-1.5 cm/sec. The test proceeds in stages. In each stage, the anchor is pulled 0.5 to 1 metre, and the winch is then locked. As the elasticity of the pulling system relaxes, the tension on the anchor cable falls rapidly, but after a minute or so it settles down to a steady value. This can be maintained more or less indefinitely if the anchor and the sand around it are not disturbed. This is the Static Holding Force (SHF) of the anchor. It is the maximum force which the anchor can withstand **without moving in the seabed at that stage of the test**. The resisting force when it is moving is called the Dynamic Holding Force (DHF). At Longniddry, when pulling at 1.5 cm/sec, the DHF is about twice the SHF. At 5 cm/sec (0.1 knot), it is 3 to 5 times the SHF.

The experiment continues in stages until the anchor has ploughed 5 to 8 metres through the sand. For most anchors the SHF increases gradually as the anchor ploughs and ultimately it reaches a steady value after some metres ploughing. This steady value is called the Ultimate Holding Capacity (UHC), a term taken from the oil-rig industry. The UHC is the highest force which an anchor will resist **without moving in the seabed when it is fully buried**. If a force greater than the UHC is applied, a good anchor will plough indefinitely if it does not encounter an obstruction. Some of the heavier anchors I tested did not reach their UHCs within the distance I could conveniently pull them. Their SHFs were still rising when I terminated the test. I would like to emphasise that the UHC is the key property of an anchor for the cruising yachtsman. Ideally one should never stress one's anchor above its UHC. However, the fact that a good anchor will develop a higher resisting force than its UHC when forced to plough, is a valuable safety factor in occasional surges or gusts. Under these circumstances the key thing is that the anchor should not roll out.

It is important to note that all my results have been obtained in a particular type of seabed, namely **medium hard sand**. Different results would undoubtedly be obtained in different sea-beds although the general order of anchor performance would probably be unchanged. Much work still needs to be done.

Fig. 3 - the anchors tested, from the left, back row, 22 kg CQR, 16 kg Delta, 5 kg Atlantic (Bruce copy); front row, 4 kg Rocna, 5 kg Spade, 8 kg Knox, 10 kg Manson Supreme.

The Actual Tests - A typical example of how the SHF and DHF behave when an anchor is pulled, is shown in Fig. 4 for the 5 kg Spade. The black diamonds represent the DHF-values taken every 5 or 10 seconds, while the red squares represent the SHF-values when the winch has been locked and the tension allowed to fall to its steady value. Both SHF and DHF rise towards steady plateau values. The final plateau value of the SHF is the UHC of the anchor, 105kgf in this instance.

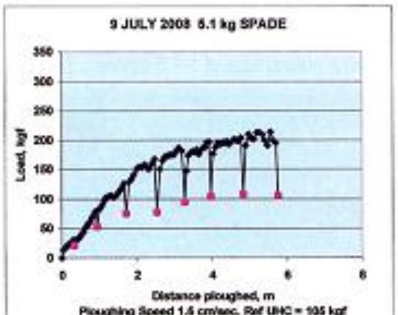

Fig. 4 - plot of DHF & SHF against distance ploughed for 5.1kg Spade anchor

Unfortunately, the SHF of any given anchor varies over time, so it is necessary to standardize the measurements. On each test occasion, I therefore calibrate the hold of the test anchor against that of the 5.1kg Spade measured on the same occasion. Over the years the UHC of the 5.1kg Spade has varied randomly from about 90 to 150kgf. While the points on the charts are the experimentally measured values, a precise comparison of the holds of different anchors, requires that the SHF and UHC-values be scaled, or "normalized", to a standard value for the UHC of the 5.1kg Spade. I have taken this as 120kgf. Accordingly, on each chart, I have given the value of the UHC of the 5.1kg Spade measured on the same test occasion as "Ref. UHC". The normalized UHC of any anchor is then defined as:

Normalized UHC = (measured UHC) x (120/Ref UHC)

Since the UHC of any particular anchor type increases roughly with its weight, it is convenient to represent an anchor's "Efficiency" by the ratio (UHC/Weight). The Efficiency of the 5.1 kg Spade as shown in Figure 4 is therefore (105/5.1) = 20. When this is normalized to the standard UHC of 120kgf for the SPADE, the "Normalized Efficiency" becomes (105/5.1) x (120/105) = 25.

Anchor-use Survey - Looking around Scottish marinas I find that around 50% of the anchors displayed are CQRs, 20% Deltas, and 20% Bruces. Other anchors such as the Danforth, Fortress, Spade, Manson Supreme and Rocna, account for no more than 10%, although there is now a noticeable increase in the number of "New Generation" anchors on view. Over the last few years, along with other family members, I have been developing a new Knox anchor. Its efficiency exceeds that of the other new generation anchors I have tested. We are hoping to launch it in 2012. All being well, it will be the first new Scottish anchor, indeed UK anchor, since the Delta.

First, I deal with the three classic anchors: the Bruce, Delta and CQR, then the New Generation anchors: the Spade, Manson Supreme, Rocna and Knox.

Bruce, Bruce-type and Delta Anchors - the **Bruce** anchor was invented by Peter Bruce in the 1980s. When we bought *Myfanwy* with its 15 kg CQR, we thought it wise to back it up with the new Bruce anchor. It had an excellent reputation. In the storm of July 1988 we set both our CQR and Bruce. We were surprised and dismayed, when we eventually lifted the anchors, to find that it was the CQR which was holding while the Bruce had dragged, fouled and was giving no hold. What on earth was going on?

My tests on the Bruce may provide the answer. As seen from Fig. 5, our 16kg Bruce gave a remarkably low hold for its weight, only about 80 kgf, less than that of the 5 kg Spade! The Normalized Efficiency of this anchor was only about 6. Good modern anchors are now giving Efficiencies in the range 20 to 40. Lighter Bruces and their numerous copies behave similarly, giving very poor efficiencies.

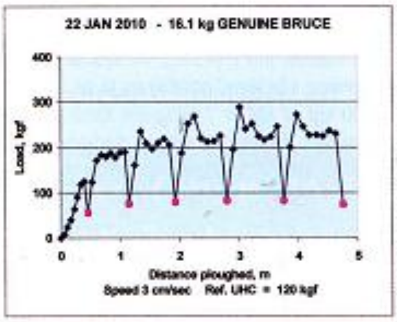

Fig. 5 - plot of DHF & SHF against distance ploughed for 16.1kg Bruce anchor

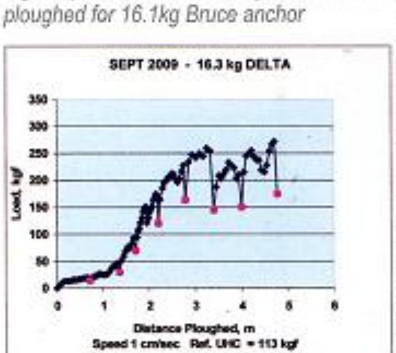

Fig. 6 - plot of DHF & SHF against distance ploughed for 16.3kg Delta anchor

The **Delta** Anchor was designed by Gordon Lyall of Simpson Lawrence around the 1990s. It was based on the CQR but without the hinge. It had been known for some time that the CQR tended to roll out, as the Delta Patent reveals, a fact not widely advertised! The Delta is reliable and roll-stable. The results of a typical test are shown in Fig. 6. Initially there is a bit of a delay as the anchor engages the seabed. This is typical of plough-type anchors whose flukes bear on the seabed rather like a palette knife smoothing paint or plaster. Initial engagement depends primarily upon the weight under the tip of the anchor. Concave or scoop-type anchors engage more rapidly. As Figure 6 shows, the UHC of the 16kg Delta was around 160kgf. It had evidently been reached when it had ploughed about 3 metres. The Normalized Efficiency was around 11. Lighter Deltas have similar efficiencies. The Delta does not actually bury itself but ploughs a trench with sand banks on either side. It is easy to raise.

The **CQR**, invented by Sir G. I. Taylor in 1933, is still by far the most widely used anchor in the UK. When forced to plough, it behaves in an unusual and indeed unnerving way as shown in Figs. 7 & 7A

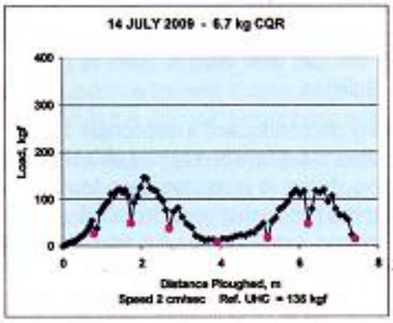

Fig. 7 - plot of DHF & SHF against distance ploughed for 6.7kg CQR anchor

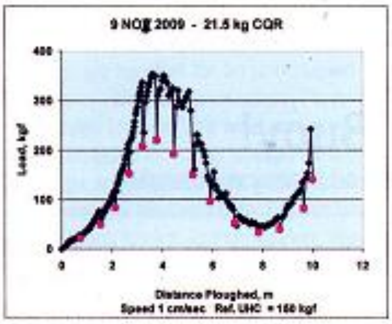

Fig. 7a - plot of DHF & SHF against distance ploughed for 21.5kg CQR anchor

Both the 6.7 kg (13 lb) and 21.5kg (45 lb) CQR initially embed themselves effectively. Their SHFs increase to 50 and 220kgf respectively. But after this something odd happens. The hold starts declining to a minimum and then the cycle repeats itself. The half wavelength of the behaviour is about 4 metres for the 6.7kg anchor and about 8 metres for the 21.5kg anchor. The maximum (SHF/weight) values are poor, at around 7 or 8 when normalized. In the shallow water at Longniddry, both anchors describe serpentine tracks through the sand. At the extremes of the serpentine, where the hold is lowest, they have rolled onto their sides with one half of each fluke proud of the surface and the bars at the back of the anchors vertical instead of horizontal. On further pulling, the anchors roll back and regain their previous hold. This behaviour speaks for itself. I leave it to you to come to your own conclusions. My tests confirm what Simpson Lawrence already knew more than 20 years ago!

New Generation Anchors - The **Spade**, which I have used as my standard test anchor, has proved an excellent anchor with a very high UHC/weight ratio of around 25, as already shown in Fig. 3. We have used a 13 kg Spade now as our main anchor for many years. When I tested our 13 kg Spade at Longniddry, it did not reach its UHC after ploughing 4 metres, when its SHF was 270kgf. Its UHC was probably around 350kgf kgf, corresponding to a Normalized Efficiency of about 30.

The **Manson Supreme** from New Zealand gave a good performance as shown in Fig. 8. Its Normalized Efficiency was around 20.

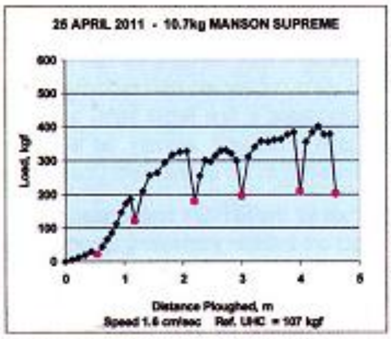

Fig. 8 - plot of DHF & SHF against distance ploughed for 10.7kg Manson anchor

The Manson is a very robust anchor and a considerable advance on the Delta.

The **Rocna** anchor, also from New Zealand, behaved excellently as shown in Fig. 9. The UHC of this anchor was not reached after ploughing 5 metres when its SHF was already 380kgf. Its UHC is probably around 450kgf, so its Normalized Efficiency is probably around 35, a value only approached by the Spade.

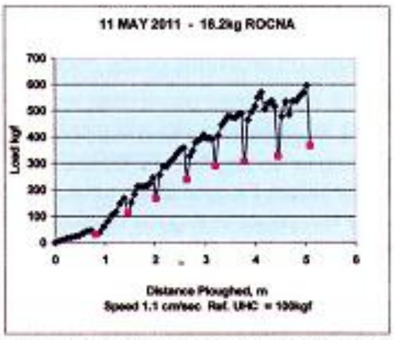

Fig. 9 - plot of DHF & SHF against distance ploughed for 16.2kg Rocna anchor

All these new generation anchors engage immediately, even in hard sand, and dig deep into the seabed. In Scotland this gives less opportunity to foul the anchor with kelp! However they can be difficult to raise. In general, anchors need a vertical force around 60% of the maximum setting force to dislodge them. Shank bending can then be an issue if care is not used.

The Knox Anchor - As our experience of anchoring developed, I began to wonder why anchors were so complicated and so different in their appearance and design. Could one not design something just as good but without all the weights, curved flukes and additional components - an anchor which would be just as good but maybe lighter and easier to manufacture? It has proved a long quest and an education. There is no general theory of how to design an anchor so it is very much a seat-of-the-pants operation. Many prototypes are required and one cannot ever be sure that the latest bright idea will prove to be any improvement on the last. However, one thing did come out of my early experiments, namely that the Danforth-type of anchor with its divided fluke seemed to provide considerably greater hold for a given weight than the traditional rigid single-fluke anchors. This proved to be something of an illusion, but not entirely. I soon noted that these anchors were generally too light for their performance. Early on, I bent the flukes of my own 2 kg Danforth. Bending shanks by lateral loads is also a problem, as recent pictures on the internet have shown for the Rocna and Spade in spite of their use of high tensile steels. But no anchor will resist infinite loads so a compromise must always be accepted. Raising a deeply set anchor should always be done slowly.

Our standard test applied to the latest 8 kg Knox Anchor (see Fig. 3) gave results shown in Fig. 10. This Load v Distance chart is very similar to that of the 16 kg Rocna. The UHC has not been reached in this test and is likely to be around 450kgf giving a Normalized Efficiency of around 50, far more than that of any other anchor I have tested. Have we made a breakthrough?

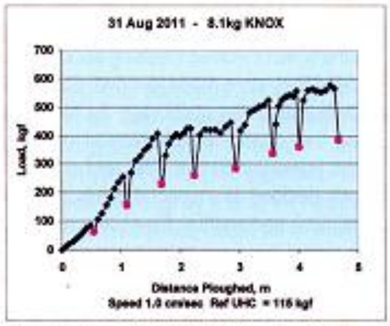

Fig. 10 - plot of DHF & SHF against distance ploughed for 8.1kg Knox anchor

Our next step is to manufacture a number of these anchors and have them tested in the real world by experienced yachtsmen. I would be delighted to hear from any RHYC Members who might be interested in helping with this project.

Please contact me for more details.