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Anchor

1. Anchor Function

In the Anchoring Tackle chapter, we have specified what an anchor is expected to perform:

- *Function*: The anchor is the "fixed point" of the anchoring.
- *Req. 3*: A perfect anchor should "hold" (= remain in the same place) whatever the direction and magnitude of the forces that act on the boat.

Anchors include 2 essential parts:

- One or more flukes, which must be dug into the bottom in order they can act as the fixed point.
- A shank, which links the fluke(s) to the rode.

Most modern anchors come into 2 categories:

- Flat anchors, which have 2 flat flukes and an articulated shank (fig. 4.1a).
- Plough anchors, which have a single plough-shaped fluke. The shank is either rigidily linked (fig. 4.1b) or articulated to the fluke (fig. 4.1c). The fluke can be convex, flat or concave.

Figure 4.1a - Flat anchor

Figure 4.1b - Rigid plough anchor

Figure 4.1c - Articulated plough anchor

2. Holding Conditions

Whatever the anchor type, optimum holding depends on several conditions:

- Condition 1: the fluke(s) must be completely and symmetrically buried in the bottom (fig. 4.2 and 4.3)
- Condition 1 bis: if present, the articulation must be in the "open" position (fig. 4.1a and 4.1c).
- Condition 2: conditions 1 and 1 bis should remain if the magnitude of the pulling force changes.
- Condition 3: conditions 1 and 1 bis should remain if the heading of the pulling force changes.
- Condition 4: the tension on the pulling eye of the shank must be parallel to the seabed.

Conditions 1 and 1 bis mean the anchor has been correctly set. Ideally, this should be done during the anchoring process, although the best anchors "automatically" complete an incomplete initial setting when the wind freshens.

Good settings

.3 - Bad settings

Beyond a certain force, which depends on the characteristics of the anchor and of the bottom, any anchor would drag (or break...).

Condition 2 simply means that a well-set anchor should neither swing out of the bottom nor turnover on its side when the pulling force increases, even when it drags.

Condition 3 means that a well-set anchor must re-align itself to a new heading.

Note: Meeting conditions 2 and 3 requires a very good anchor design.

Condition 4 depends neither on the anchor nor on the way it has been set: it depends on the rode behavior, as we'll see in the Static and Dynamic Behavior chapters. If the rode cannot maintain the tension on the pulling eye parallel to the bottom, the holding power is reduced, depending on both the angulation and the anchor design (see below).

3. Choosing an Anchor

Warning: This page is intended to allow understanding and estimating the behavior of an anchor rode in real situations. It is neither an anchor test bench, nor an anchoring manual! So, you won't find here any performance comparison between commercial anchors, nor advices on the "right way" to anchor.

Thanks to the above criteria, however, you should be able to make the most of the test results that are regularly published in boating magazines. Those results often need some interpretation, though. Actually, the comparisons are not always equitable, if only because the selection criteria may vary. Generally, those tests compare anchors of the same weight, but sometimes it is the size, or (seldom) the price that rules the choice! Moreover, for commercial or advertising reasons, "political cant" often prevails, which requires reading between the lines: for example, if the paper claims "this anchor is very good, but it needs to be oversized", you may well understand "this anchor has poor holding"!

Let's just add that the old salt's advice "bring aboard anchors of different types" is obsolete: now universal anchors exist that hold better than all the others in sand, mud, clay, gravel or weed seabeds - we exclude rocky bottoms, which should be avoided whatever the anchor!

4. Estimating the Holding Power of an Anchor

First, a definition: the holding power F_h is the value of the maximum pulling force an anchor accepts without dragging in given conditions.

Second, let's get things straight: nobody is able to estimate what will be the actual holding power of your hook when you throw it overboard in an unknown anchorage! The situation is not hopeless, however:

- experimental data abound about anchor holding in most "standard" bottoms (i.e. soft or hard sand or mud);

- for a given anchor design, estimating the influence of the size is not an impossible task!

4.1. Holding Power Models

The traditional theory, as applied to big ships for decades, assumes the holding power is proportional to the mass of the soil that is moved by the anchor when dragging. For anchors the same shape and same material, this means the holding power is proportional to the anchor mass (eq. 4.1):

$$F_h = K\,M \qquad (4.1)$$

If you look at the holding power claimed by yacht anchor manufacturers in their data sheets, e.g. Fortress®, you would find they approximately use this simple relation.

On the other hand, the oil industry have spent huge sums of money in theoretical research and anchor development, so that the results they publish should be reliable, at least for anchors from 1 to 100 tonnes (metric tons).

The Vryhof Anchor Manual admits that "It is not easy (...) to calculate the Ultimate Holding Capacity (UHC) of an anchor from the commonly known soil mechanics formulas. The main problem is the prediction of the volume of soil mobilised by the anchor. To a large degree, it is this volume which determines the UHC".

Vryhof as well as other anchor manufacturers (e.g. The Bruce Anchor Group) use the same relation to predict the UHC of their products:

$$F_h = K\,M^{0.92} \tag{4.1a}$$

So the power holding of very big anchors is almost proportional to their weight. The coefficient K depends on the anchor type and on the holding quality of the ground: typical values for the most recent models span from 40 (very soft clay) to 80 (in mud).

What if we apply this formula to steel anchors between 5 and 50 kg?

- For the typical 15 kg range focused on by most holding tests published in boating magazines, we get an UHC around 500 daN in very soft clay and 1000 daN in mud. Actually, modern 15 kg anchors exhibit performances 2.5 times better, even in non optimal conditions (more on that below).
- From 10 down to 5 kg, however, the formula gets closer and closer to the measured holdings.

How can this be interpreted? Intuition suggests anchors that penetrate deeply into the seabed may meet denser layers down below than near the surface, hence an improvement as the anchor size increases.

But another influential factor, completely overlooked (AFAIK), is the "suction effect". And yet, this effect is the "holding secret" of concrete slab sinkers (fig.4.4) used in deadweights many boating harbors rely on!

Figure 4.4 - Concrete Slab Sinker

A properly proportioned sinker will create suction to such a degree that when slightly buried its holding power does not depend on its weight: the contact area between the seabed and the sinker bottom is the point here. Typically, on a muddy seafloor, the holding power of a concrete tab can exceed 20 x its weight!

OK, back to our standard anchor ;-).

A common experience (fig.4.4a):

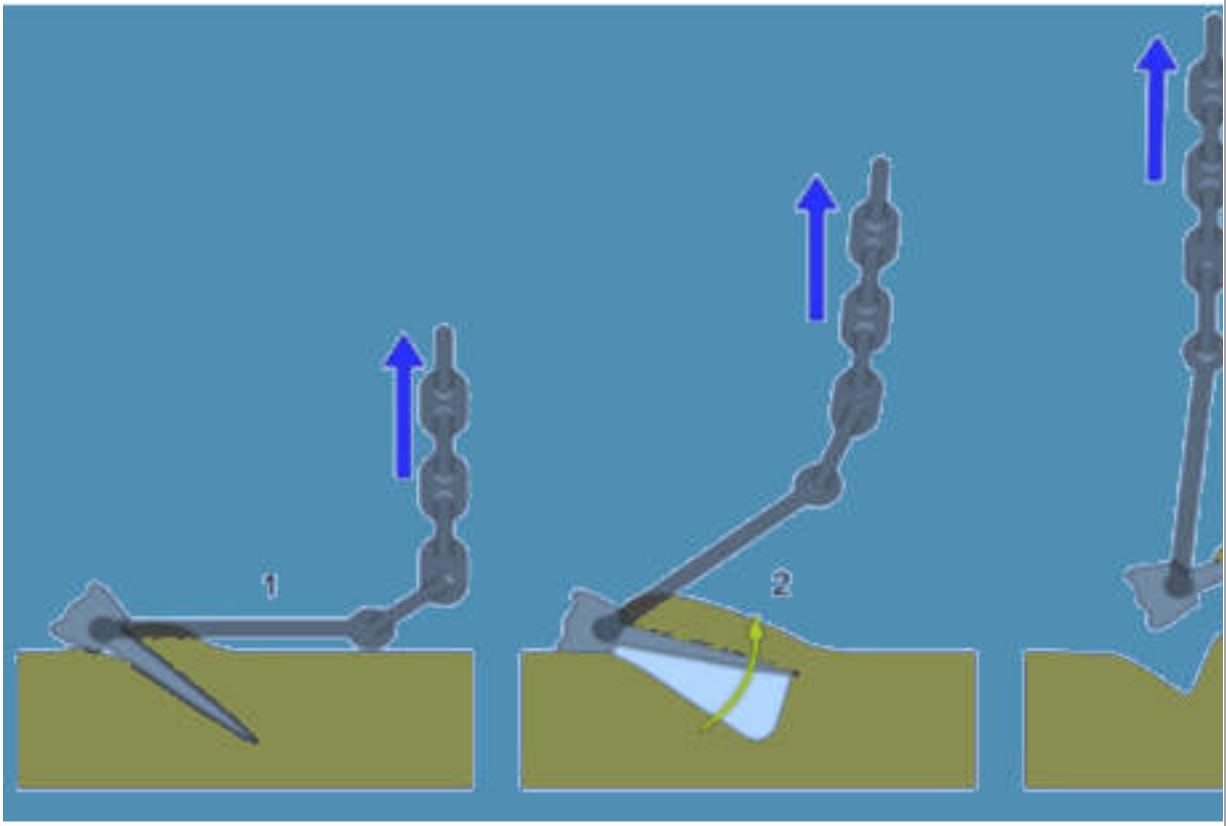

Figure 4.4a - Weighing Anchor

1. When you decide to weigh anchor, you first come away (in order to get the rode approximately vertical and taut).
2. Then you (or preferably your windlass ;-)) lift the anchor shank, up to a point where a strong resistance crops up. It is caused by the partial vacuum that is created under the fluke point(s) when they begin to move up. If the fluke edge were watertight, neither water nor seabed components could enter to fill this vacuum space. In this case (close to what happens with well designed mooring slab sinkers), the resistance could be easily derived from the hydrostatic pressure at the seabed level.
3. In practice, water and/or seabed elements eventually enter and fill the space under the fluke(s), which restores the pressure balance and finally allows complete lifting of the anchor.

A similar behaviour occurs when pulling a settled anchor too strongly (whatever its angulation - see 4.3 below): as soon as the anchor begins to drag (compressing the ground ahead), a partial vacuum is created behind it, which increases the resistance to dragging. This *could* explain the above-mentioned contradiction between measured holdings and theoretical results as given by eq.4.1a.

Anyway, an analysis of a few tests than have been carried out on an homogeneous range of anchors of 10, 12, 16 and 20 kg shows their holding powers is best fitted by eq. 4.2:

$$F_h = K\,M^{1.4} \qquad (4.2)$$

Honestly, there is no proof this formula is applicable to all anchor types, but it seems appropriate to the best anchors used on cruising yachts nowadays, say within a 8 to 25 kg (17 to 55 lb) weight range. If this is true, the holding power of different types of anchors on a given seabed should only differ by the value of their holding coefficient K.

To go in greater depth, we have analyzed a dozen anchor tests published in various magazines. This was not an easy task, because the results depend on the bottom texture, the waterdepth, the type and length of the rode etc., which all vary according to the experimentation procedures.

Note: At the tensions that are necessary to drag modern anchors, the rode is generally very taut, which may result in significant angulations, even with long scopes. In other words, most tests measure the holding power with a non-horizontal pulling force! This should not be criticized unduly, however, since the same would occur in real anchoring situations, as we'll see in the Dynamic Behavior chapter.

4.2. Influence of Bottom Holding

With that in mind, we found the results of such different tests on a dozen anchor types were rather consistent. For a typical steel anchor of mass M (in kg), whether flat or plough, with no angulation, the holding power F_h (in daN) can be roughly estimated through eq. 4.2 with the following values of K:

m holding quality	Poor	Medium	Good	Excellent
ing coefficient K	5	12	22	35

Note: The official metric unit for forces is the Newton (N). DecaNewton (daN) is more generally used, as 1 daN approximately equals 1 kgf (about 2 lb). To get F_h in lb with M in lb, use eq. 4.2 then multiply the result by 0.73.

To characterize the bottom holding quality, specialists of soil mechanics would use odd notions e.g. Attenberg's classification, cohesion, thixotropy or isotropy - not very useful for us! That's why I chose a loose 4 degrees scale, which obviously need some further explanation:

- Poor refers to seabeds that are difficult for anchors to set in, e.g. rocky shelves covered with a thin sand layer, dead coral + weeds, gravel + shells, thick weeds.

- Medium refers to soft sand or mud, which does not exert a strong resistance even if the anchor is completely burried, and to heterogeneous bottoms e.g. sand + weeds.
- Good refers to most sand or mud anchorages where you can see yachts at anchor, or which are recommended on your cruising guides ;-)
- Excellent refers to dense sand or mud bottoms - but soft enough to allow the anchor to set correctly.

Eq. 4.2 is represented graphically in fig. 4.4b:

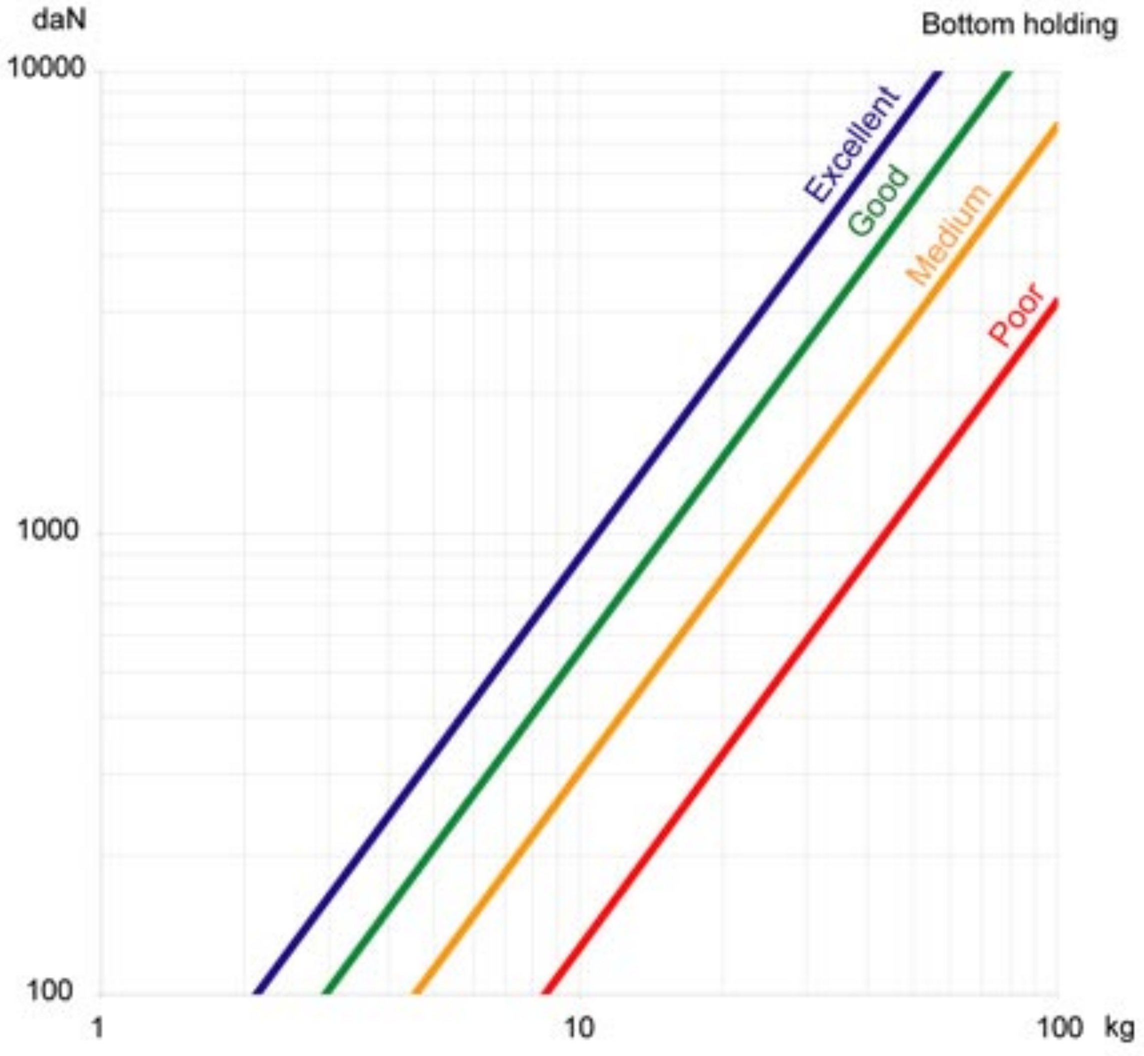

Figure 4.4b - Holding Power vs. Anchor Mass

Alternatively, you can directly compute F_h given M and K with the following form:

Units Metric Imperial

Anchor mass M kg Bottom holding K

Holding power F_h daN

4.3. Influence of Angulation

Condition 4 states the tension on the pulling eye of the shank must be parallel to the seabed. However, most anchors are somewhat tolerant to moderate positive angulations (up to 10 degrees typically), because the resistance of the soil on the fluke(s) creates a torque that tends to pin the shank to the bottom (fig. 4.5).

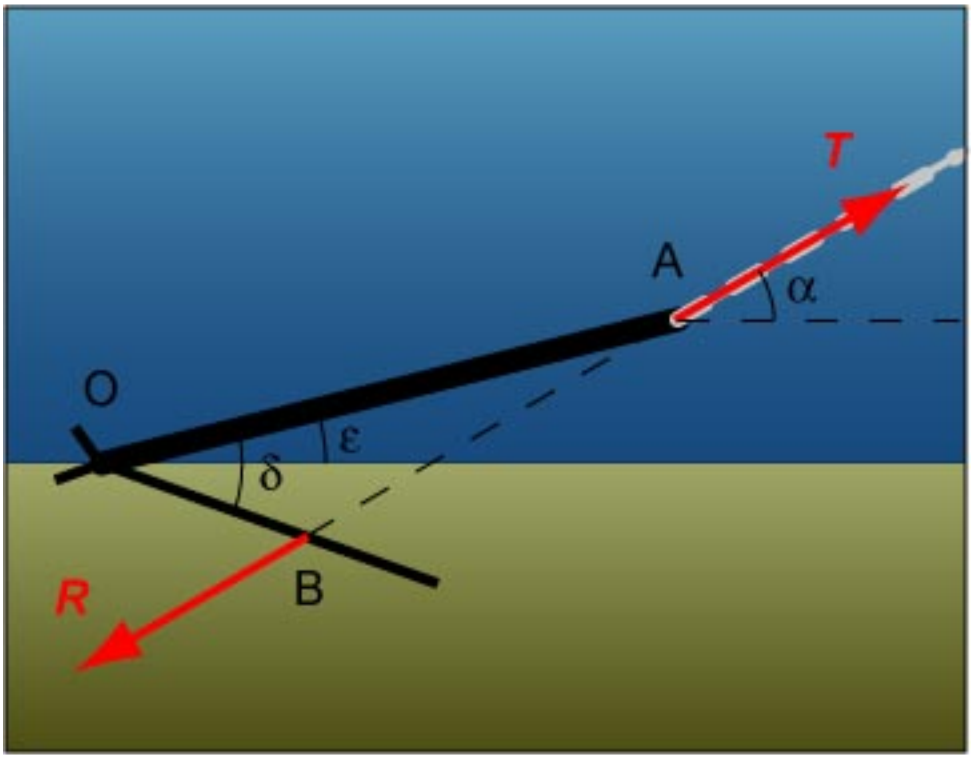

Figure 4.5 - Angulation

Hence, as long as the anchor holds, the angle ε between its shank and the bottom is significantly lower than the rode angulation α.

Given the ratio p = OA/OB and the fluke-shank angle δ, simple geometry yields:

$$\varepsilon = \alpha - \operatorname{atan}\left[\frac{\sin\delta}{p - \cos\delta}\right] \quad (4.3)$$

For example, if δ = 32° and p = 4, the shank remains pinned to the bottom until the rode angulation α reaches about 10°.

Of course, this does not mean the holding power is the same as for α = 0, because the vertical component of the tension F tends to pull the whole anchor out of the bottom.

The influence of angulation is never published in the manufacturers' data sheets, nor in independent test results. By default, we assume a "parabolic" reduction factor:

$$F_h(\alpha) = F_h(0)\left[1 - (\alpha / \alpha_0)^2\right] \quad (4.4)$$

where α_0 is the angle at which the holding power vanishes. It allows adjusting the reduction rate for different anchor designs (fig. 4.6).

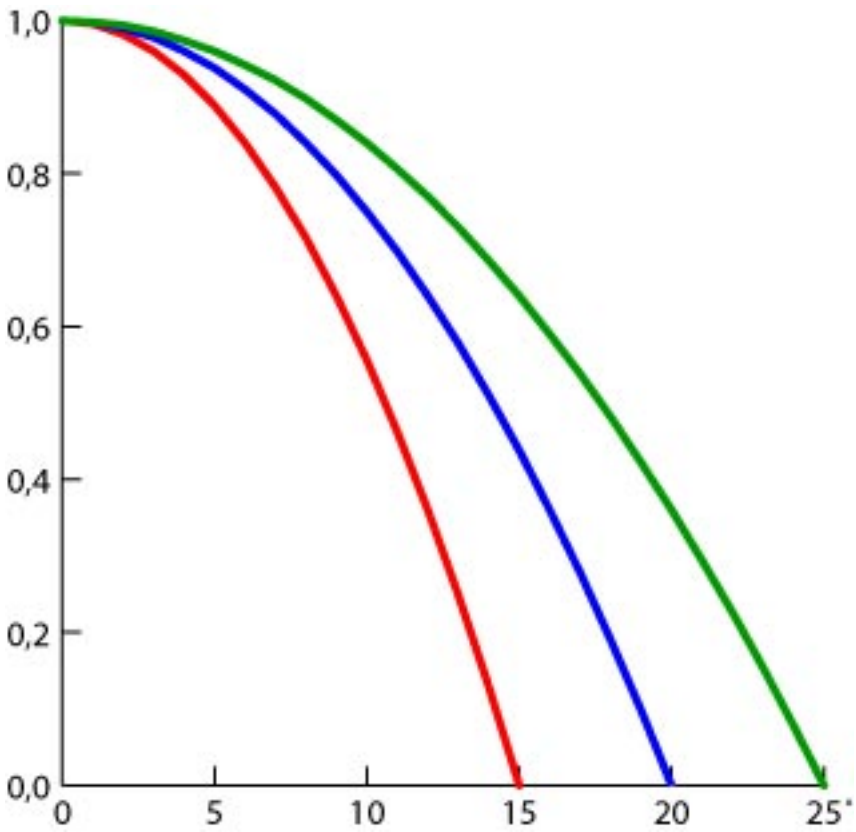

Figure 4.6 - Holding Power reduction vs. Angulation

For example, an anchor with α_0=15° will retain 60 % of its maximum holding power for a 10° rode angulation.

4.4. Influence of Anchor Design

All things being equal, the holding coefficient K may considerably vary from an anchor design to another. If we only consider the most common anchor models that are used aboard modern cruising yachts, the various field tests show their holding coefficients span a wide range, from one half to more than twice the typical value given in our table above. An example: equ. 4.2 tells that, on a "good" bottom, the holding power of a typical 12 kg (26 lb) steel anchor would exceed 700 daN (1500 lb). Actually, most tests show the worst 12 kg anchors barely reach 350 daN (770 lb) on good bottoms, while the best ones perform well over 1400 daN (3000 lb).

For light-weight aluminum-alloy anchors, which have less than half the weight of a steel one the same size and the same holding power, K should be multiplied by 3. However, it is common knowledge that some lightweight anchors are difficult or impossible to set in hard bottoms and/or weeds.

4. Conclusions

The above formulae and graphs should be used very cautiously, for at least 3 reasons:

- They are meaningless if the anchor is not correctly set.
- They do not take the anchor design into account.
- Estimating the holding quality of the seabed is a bit of challenge!