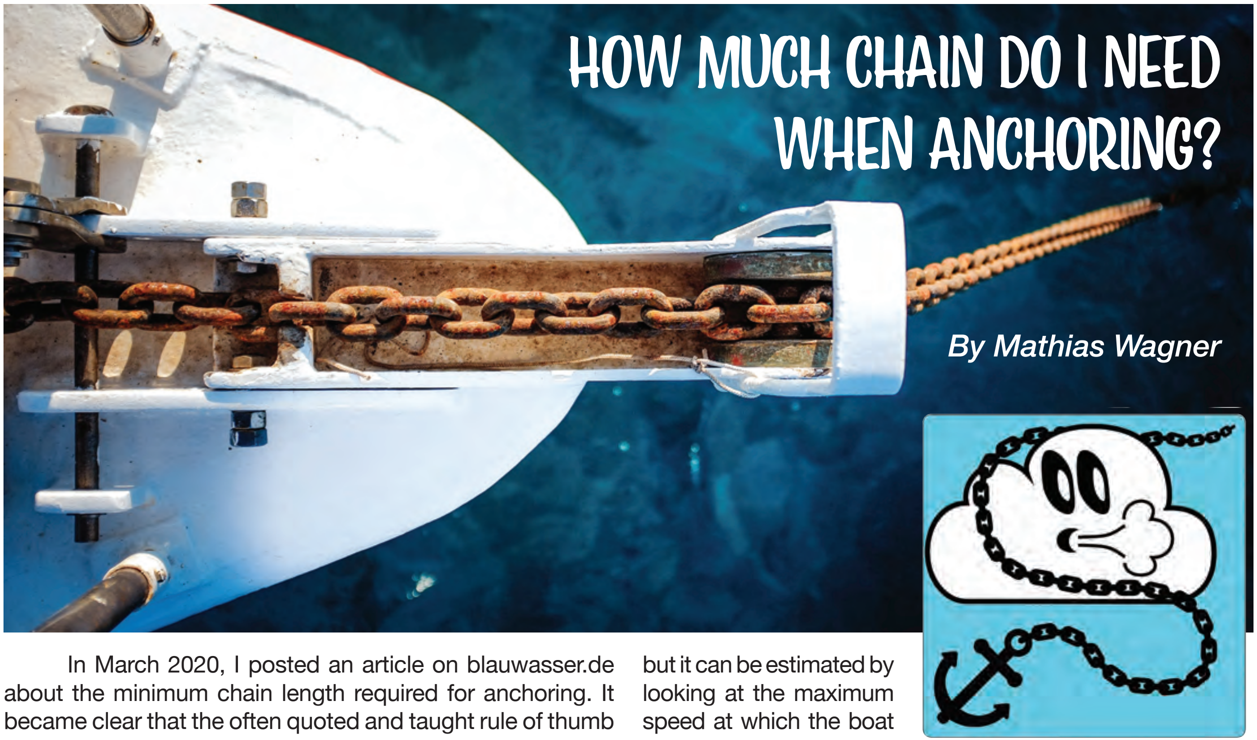
HOW MUCH CHAIN DO I NEED WHEN ANCHORING?

By Mathias Wagner



In March 2020, I posted an article on blauwasser.de about the minimum chain length required for anchoring. It became clear that the often quoted and taught rule of thumb “chain length = three times water depth” (or simply “more in a lot of wind”) doesn’t take into account the different boat types and sizes and the very different anchoring scenarios.

The results at that time referred to the so-called static anchoring, where everything has settled down: The wind pushes the boat away from the anchor, but it is at rest. In particular, there are no gusts and no swell, and the boat does not sail at anchor. In this case, one finds a simple relationship: $L = Y(Y + 2a)$, where L is the chain length, Y is the anchor depth and a is a parameter defined as the wind force acting on the boat divided by the chain weight per running metre. Of course, these assumptions are not entirely realistic, and so I would like to present here the extension to dynamic anchoring and, in this context, also my easy-to-use app for Apple and Android, which calculates, among other things, the minimum required anchor chain length and the load exerted on the anchor. In this extended scenario, gusts and swell are taken into account. It also makes a lot of sense to include an elastic snubber/bridle in the considerations.

As before, the approach is the following: When wind, gusts, and swell hit the boat, it is pushed further away from the anchor. To do this, it must first accelerate, then it slows down again and eventually comes to a standstill for a short moment. This is the moment when the boat has stretched the chain most and thus pulls most strongly at the anchor: Peak load! The entire kinetic energy of the boat has now been converted into potential energy of the chain (and, if applicable, into the stretching of a snubber/bridle). So if one can calculate the energy of a swell, one also knows by how much the potential energy of the chain will have to change as a result, since the sum of all energies remains constant as long as one does not take friction or similar into account.

It is difficult to calculate the energy of a swell exactly, but it can be estimated by looking at the maximum speed at which the boat moves away from the anchor when it is hit by a swell. Using this speed and the mass of the boat, one can then calculate the energy of the swell transferred to the boat. This immediately raises the question as to how well a chain (without a snubber/bridle) can absorb energy.

To answer this, let us first consider two extreme cases: First, the case where the chain is almost horizontal, i.e. when the anchor and the bow roller have only a few metres difference in height to each other. In this case, the chain has a hard time absorbing additional energy since the chain forms a more or less straight almost horizontal line between the anchor and the bow roller and it can thus hardly tighten any further, i.e. gain more height above the ground in order to absorb yet more energy. This is the shallow water scenario with a potentially bar-taut chain. On the other hand, if the chain is hanging down almost vertically with very little wind, it also absorbs very little energy as the chain then essentially only moves sideways. Between these two extremes, the chain works much better. So my aim in this article is to find out more about this with the help of my app.

Let us now look at these two cases more quantitatively as shown in Figure 1: A) no wind, no swell, the chain simply hangs vertically down at the bow. B) After an extremely strong gust or swell, the chain is completely taut and pulls at the anchor with a certain angle. Obviously, in case B the chain has a larger potential energy because the chain is on average hanging higher and more chain is needed. The difference in potential energies between B and A is $m\,g / 2\,Y\,(L - Y)$, where $G = m\,g$ is the weight of the chain per running metre, Y is the anchor depth, and L is the length of the chain. So if the swell tries to transfer an even greater amount of energy to the chain, the anchor will definitely break free.

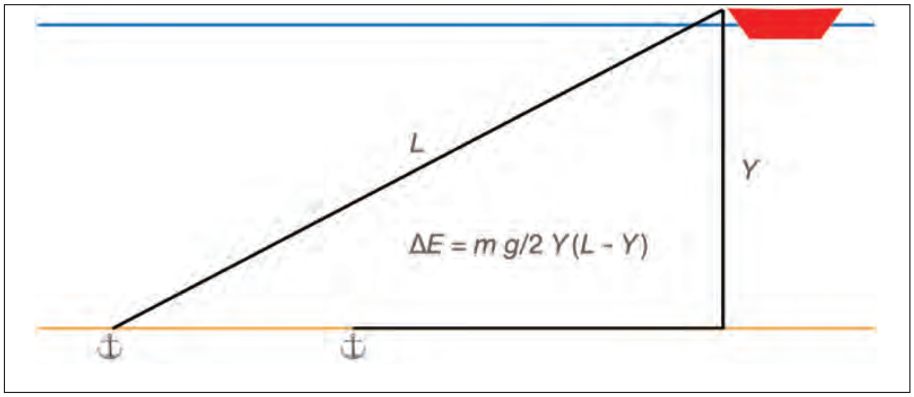


Figure 1: (left) The difference in potential energy of two extreme cases: No wind at all / swell with vertical chain versus so much wind and swell that the chain becomes completely taut. The difference between these two energies is the maximum energy that this chain can absorb.

Figure 2: (right) Elasticity of an anchor chain as a universal function of the ratio of chain length to anchor depth (= scope). The maximum at scope L/Y ≈ 1.4 is

However, it may do so even if this maximum energy has not quite been reached because the more the chain is stretched, the more load it exerts on the anchor. Enormous loads can be generated in this way.

There are at least two interesting results here: First, the maximum energy that can be absorbed by the chain gets smaller when the anchor depth Y gets smaller: If I halve the anchor depth, then I roughly halve the maximum energy that the chain can absorb, which is bad. So the chain does not work well in shallow water — in fact, the shallower the worse. Chain likes depth! But there are limits here, too. Using the formula above, one finds that — at a fixed length L — the chain can absorb the most energy when it has a ratio of chain length to water depth of 2:1 when fully stretched: scope L/Y = 2. This does not mean, however, that one should now go off and only pay out twice the water depth as chain when anchoring. Yes, the chain likes this, but the anchor does not at all. For one thing, it is then pulled at a rather steep angle, which has a negative effect on the holding power, and secondly — and more seriously — the load peaks then passed through from the bow to the anchor are enormous. (Otherwise the chain would not be so extremely taut.) One thus needs much more chain to prevent this scenario with a very taut chain.

Let us, therefore, assume that the chain always pulls horizontally at the anchor in order to put only the minimum load on it. And, furthermore, the chain is already somewhat stretched due to a steady base wind without swell and gusts. How well can the chain then cope with having to absorb more energy, if the steady base wind and with that the required chain length L are slowly increased at a fixed anchor depth Y?

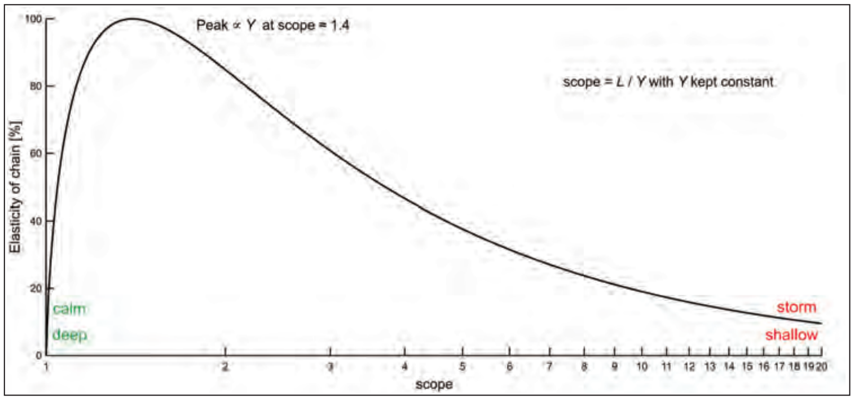
This question can be nicely answered by looking at the elasticity of the anchor chain. By this I do not mean the elasticity of the metal of the individual chain links, but the springiness of the chain as a whole when it is firmly fixed at one end, the anchor, and pulled tighter at the other end. Its own weight will always make it spring back to its original position when this pull is eased again.

To put it more precisely: If gusts or swells (in the presence of a fixed steady base wind) pull a little more on the chain at the bow, e.g. with an additional 1 daN, how much more energy can the chain absorb? Obviously, one wants this value to be high. The chain should be able to take a lot!

Now, how does this look like concretely? Let's take a chain that is long enough so that there is always some chain lying on the seabed in front of the anchor and therefore it is always pulling horizontally at it. Within the framework of my model, I can then exactly calculate the elasticity of the chain (see Figure 2). On the left is calm, on the right is storm. The horizontal axis is scope, i.e. the ratio of chain length L to anchor depth Y, whereby only the part of the chain that counts is lifted off the seabed. The vertical axis is the elasticity divided by the elasticity at the maximum of the curve (which is at a scope of ≈ 1.4 and is proportional to the anchor depth Y). At the maximum of the curve, 100% is then automatically reached.

Perhaps this simple thought experiment can help to better understand the graph in Figure 2: I am anchoring at 5 metres depth, measured from the bow roller. There are 100 metres of chain paid out, but they are not being used yet because there is almost no wind. I am now on the far left of the diagram. The elasticity of the chain is poor, but that doesn't matter because there is hardly any wind. Now the steady base wind starts blowing stronger and stronger and I slowly move to the right in the diagram. When 1.4 * 5 = 7 metres of chain have been lifted off the seabed, I am already at the maximum of the chain's elasticity. Of course, that's still not a lot of wind — just 7 metres of chain are needed so that it pulls at the anchor horizontally in a depth of 5 metres. So, now it's blowing more and more and I'm moving further and further to the right, away from the maximum. When the 100 metres of chain are completely off the seabed, I have a chain length to anchor depth ratio of 100:5 and have thus reached the right edge of the graph. So although I use more and more chain, the chain becomes less and less elastic. In other words, the higher the steady base wind, the less the chain is able to absorb strong gusts or swells. Sure, it can absorb large static loads, but not gusts and swells. So here one needs a very good snubber or bridle to absorb these peak loads and keep them away from the anchor. Qualitatively, this is the same result as in Figure 1, but now with somewhat more realistic boundary conditions for the chain.

The graph in Figure 2 has not only scope as its horizontal axis, but also wind strength: Little wind on the left, a lot of wind on the right. And not only that, this axis could also be labelled with the water depth: Shallow on the



given here as 100%, and is proportional to the anchor depth Y when measured in absolute values. In other words: If the anchor depth doubles, the elasticity also doubles. For this reason alone, anchoring in deeper water is better. What is important here is that the scope is not simply the ratio of some arbitrarily chosen chain length to the water depth, but must also fulfil the condition that the chain pulls horizontally at the anchor. The easiest way to ensure this is to use more than enough chain and, when determining the scope, only take into account the part of the chain L that has lifted off the seabed.

right, deep on the left. To appreciate this, one only has to bear in mind that a chain that pulls horizontally at the anchor also turns only very little towards the water surface initially, as can be seen in the example catenary graph on the right. It has the steepest ascent at the bow, where more chain can be paid out if necessary. All other things being equal, the required scope L/Y — i.e. the ratio of chain length off the seabed to anchor depth — thus becomes smaller when anchoring in deeper water. To illustrate this, for an exemplary wind load the corresponding L/Y values are drawn in the diagram on the right. It is for this reason that the right side of the diagram of Figure 2 with a large scope is more likely to be found in shallow water than in deep water. With this the results from above are confirmed again: A chain in shallow water does not work well in a storm, its elasticity goes down the drain. And it cannot be repeated often enough: Snubbers or bridles are indispensable here, as we will also further see in a moment with a concrete example.

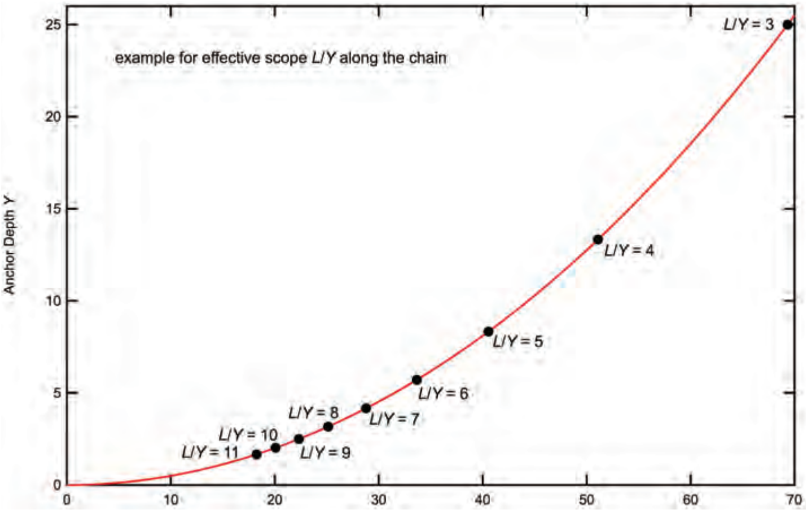
But that's not all — these poor properties of a chain in shallow water mean that every gust, every swell pulls jerkily at the anchor - with enormous loads that can be many times the static load on the anchor. Neither the anchor nor the cleats at the bow like it when the chain gets taut! Experienced sailors know this problem only too well and avoid it.

On the other hand, the chain works best with a required scope of only 1.4, whilst still maintaining a horizontal pull at the anchor, and so it is not surprising when sailors report having anchored off Greenland with 100 metres of chain at 40 metres anchor depth without any problems in a storm. At such large anchor depths the required scope (i.e. the ratio of chain length to anchor depth whilst still pulling horizontally at the anchor) has already become quite small. Accordingly, the "operating point" of the chain is close to the optimal maximum in Figure 2. And, this maximum is also larger because it is proportional to the anchor depth. Chain likes depth!

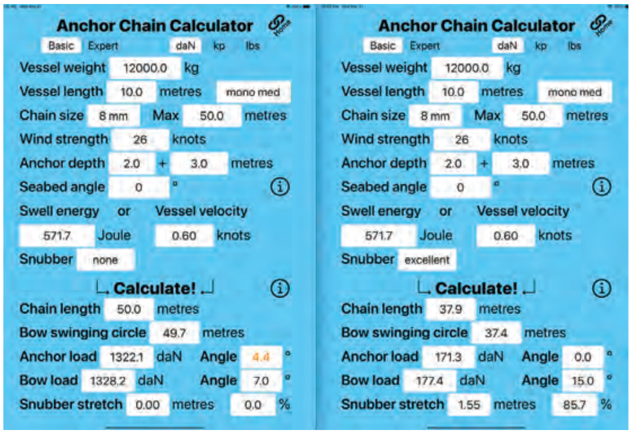
In order to find out more precisely and quantitatively about the issues indicated above when anchoring in shallow water, I now use my AnchorChainCalculator app. It is available for both Apple and Android devices.

There are two modes in which the app can be used: "Basic Mode" and "Expert Mode." I'll start in Basic Mode. After entering a few parameters such as anchor depth (calculated from the bow roller), wind strength, chain thickness, boat length and type (i.e. mono, cat, tri, and whether of bulky, medium or slim built), weight of the boat, swell energy in the form of velocity over ground at the anchor, quality of the snubber/bridle, and possibly the slope of the seabed at the anchor, the app calculates, among other things, the minimum required chain length and the load acting on the anchor. To be clear, the app does not guarantee that the anchor will hold, this depends on the anchor and the nature of the seabed, among other things. But the app calculates how long the chain must be so that it still pulls the anchor horizontally (or according to the gradient of the seabed). This is one of the essential prerequisites for keeping the load on the anchor as low as possible and thus giving it the best possible chance of holding.

In the first case considered, I limit the maximum chain length to 50 m and do not use a snubber/bridle at all. I anchor



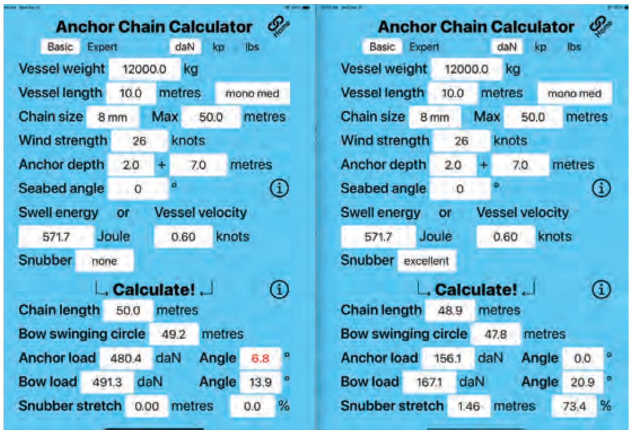
Anchor Depth (x) versus Length of Chain (L)



Vessel weight 12000.0 kg
Vessel length 10.0 metres mono med
Chain size 8 mm Max 50.0 metres
Wind strength 26 knots
Anchor depth 2.0 + 3.0 metres
Seabed angle 0 °
Swell energy or Vessel velocity
571.7 Joule 0.60 knots
Snubber none
Chain length 50.0 metres
Bow swinging circle 49.7 metres
Anchor load 1322.1 daN Angle 4.4 °
Bow load 1328.2 daN Angle 7.0 °
Snubber stretch 0.00 metres 0.0 %

Vessel weight 12000.0 kg
Vessel length 10.0 metres mono med
Chain size 8 mm Max 50.0 metres
Wind strength 26 knots
Anchor depth 2.0 + 3.0 metres
Seabed angle 0 °
Swell energy or Vessel velocity
571.7 Joule 0.60 knots
Snubber excellent
Chain length 37.9 metres
Bow swinging circle 37.4 metres
Anchor load 171.3 daN Angle 0.0 °
Bow load 177.4 daN Angle 15.0 °
Snubber stretch 1.55 metres 85.7 %

Figure 3, AnchorChainCalculator App: Anchor load in shallow water (5 metres) with a lot of swell. Left: No snubber / bridle; Right: Excellent snubber / bridle. The anchor load in the first case is gigantic.



Vessel weight 12000.0 kg
Vessel length 10.0 metres mono med
Chain size 8 mm Max 50.0 metres
Wind strength 26 knots
Anchor depth 2.0 + 7.0 metres
Seabed angle 0 °
Swell energy or Vessel velocity
571.7 Joule 0.60 knots
Snubber none
Chain length 50.0 metres
Bow swinging circle 49.2 metres
Anchor load 480.4 daN Angle 6.8 °
Bow load 491.3 daN Angle 13.9 °
Snubber stretch 0.00 metres 0.0 %

Vessel weight 12000.0 kg
Vessel length 10.0 metres mono med
Chain size 8 mm Max 50.0 metres
Wind strength 26 knots
Anchor depth 2.0 + 7.0 metres
Seabed angle 0 °
Swell energy or Vessel velocity
571.7 Joule 0.60 knots
Snubber excellent
Chain length 48.9 metres
Bow swinging circle 47.8 metres
Anchor load 156.1 daN Angle 0.0 °
Bow load 167.1 daN Angle 20.9 °
Snubber stretch 1.46 metres 73.4 %

Figure 4, AnchorChainCalculator App: Anchor load in slightly deeper water (9 metres) with a lot of swell. Left: No snubber/bridle; Right: Excellent snubber/bridle. Anchor load in the first case is still large, but significantly less than with a 5 metres anchor depth.

at 5 m anchor depth in 26 knots of wind, and there is quite a heavy swell. On the chart plotter I see from time to time that the velocity component of VOG (Velocity Over Ground) pointing away from the anchor is large: 0.6 knots. The app then calculates a huge peak anchor load of 1322 daN (Figure 3, left), which is well over a metric tonne! Moreover, the chain pulls at the anchor with an angle of more than 4°. It is very likely that the anchor will break out under these conditions.

So this is quite heavy stuff - and this although I have a ratio of chain length to anchor depth of 10:1 - far more than the rule of thumb mentioned at the beginning requires - but it is related to the fact that I anchor in quite shallow water with a lot of swell. In the second case, I assume the same situation, but I now add an excellent snubber/bridle. Everything else remains the same. Now the anchor load goes down dramatically to only 171 daN (Figure 3, right), and the chain pulls horizontally at the anchor as it should. Even better, I don't even need the whole chain any more: Only just under 38m of chain need to be deployed. The anchor load has gotten smaller by more than a factor of 7!

If I don't have a snubber/bridle, it still helps to relocate to deeper water. At 9m anchor depth and again only 50m chain, this results in an anchor load of 480 daN at the peak (Figure 4, left), which is already much less than the enormous anchor load at 5m anchor depth (Figure 3, left). This may go against intuition, but in this case, all other things being equal, deep water is better than shallow water! Put another way: The same swell is much more dangerous in shallow water than in deep water. Again, a snubber/bridle makes a significant difference; the anchor load is then reduced to 156 daN (Figure 4, right), the chain is again sufficiently long so that it pulls horizontally at the anchor, and the stretch of the snubber/bridle is also marginally less than in shallow water. What a difference: 156 daN compared to 1322 daN in the first case. And all this because I went from 5 to 9 metres anchor depth and used an excellent snubber/bridle. Now, the anchor is very unlikely to break free.

Table 1 summarises these 4 cases and a few others. One can see that a chain in shallow water has a hard time absorbing a strong swell and keeping the peak load away from the anchor, but even a bad snubber/bridle immediately brings a lot of relief. However, a poor snubber can also be overloaded very quickly, as the loads are still much larger than if one uses a very elastic snubber.

Furthermore, one can see that it does not really help to simply deploy more chain in shallow water. At an anchor depth of 3 metres and with an "ok-ish snubber," 41.7 metres of chain are sufficient to pull the anchor horizontally. If I use even more chain, it lies uselessly on the seabed despite the strong swell, helping only marginally through its friction on the seabed. It turns out the anchor load is not significantly reduced by this (see below). So if the seabed is poor and the 350 daN overload the anchor, then one either has to improve the snubber/bridle and/or move to deeper water and pay out a little more chain. The old motto "a lot of chain helps a lot" is thus somewhat misleading. It would be more correct to say "A lot of chain helps a lot if one gives it the necessary anchor depth."

To emphasise again: In all the cases we looked at, the swell was very large, but of the same strength. It then makes sense to anchor at a greater depth and thereby reduce some of the impact of the swell. Of course, this does not mean that one should also follow this advice if the swell is much bigger at the new anchorage in deeper water! Even more relief is obtained when using very good snubber/bridle.

This is just one example of how to use the AnchorChainCalculator app: Examine scenarios, what if... It is deliberately chosen to be a bit extreme: A SOG at anchor of 0.6 kn is quite a lot - especially with a comparatively moderate wind of only 26 kn. Normally, one might only see 0.1 - 0.3 kn. The chain thickness could also be chosen one size larger for this size of boat.

In Expert Mode, one can set some parameters even more precisely, e.g. the effective windage area and the snubber/bridle. By switching back and forth between the two modes, one can see how the corresponding parameters depend on each other. I have to admit, though, that I usually stay in Basic Mode and I have saved my bridle as “custom” there, after having measured it once with the tips described in Expert Mode.

Offline descriptions and tips in English, German and French are provided for both the input and the output values, which are hidden behind the two smallilike info buttons at the right edge of the screen. In the top right corner is the home button, which takes one to the web page with the detailed description: https://trimaran-san.de/anchor-chain-calculator/ (Or correspondingly the German / French description, if that is the system language in the phone / tablet). And if one prefers to calculate in kp instead of daN, one can also set this. Or feet and pounds, that also works. And of course all entries are saved, so that next time one only has to enter changed values.

In summary, with my AnchorChainCalculator app one can calculate the minimum required chain length, with which the chain still pulls horizontally at the anchor and thus puts as little load on it as possible. It also determines the load that acts on the anchor. A few simple boat parameters and, of course, information about the weather and the sea, which are described in more detail in the offline help, serve as input values. What is missing at the moment is a mix of anchor chain and rode, but that may come in an update at some point. Currents are also not taken into account. But otherwise all essential factors are included in the calculations. The consideration of swell in particular sometimes leads to astonishing results that one might not have expected intuitively, at least not to this extent. In any case, the results show that the old rules of X times anchor depth can sometimes be extremely wrong and their blind application is not compatible with the spirit of good seamanship. Furthermore, it was shown that snubber/bridle are not only there to stop annoying noises of the chain at the bow, but are rather an essential means for absorbing shock loads at the bow and thus preventing them from getting passed through to the anchor - especially in shallow water when the chain fails.

Once you have “got the hang of” your boat, you quickly get a feel for what chain length the app will advise to use. But it’s always reassuring when you’re at anchor at 40+ knots to check again that the chain is long enough and that the snubber/bridle is not overloaded!

HELPFUL LINKS:

Description of the app in English
https://trimaran-san.de/anchor-chain-calculator/

Video Tutorial:
https://www.youtube.com/watch?v=4PsbMtYCUqE

AnchorChainCalculator App in Apple Store:
https://apps.apple.com/us/app/id1533741243

AnchorChainCalculator App in Google Store:
https://play.google.com/store/apps/details?id=de.trimaran_san.anchorchaincalculator

Accurate description of the underlying mathematics and models:
https://trimaran-san.de/die-kettenkurve-oder-wie-ein-mathematiker-ankert/