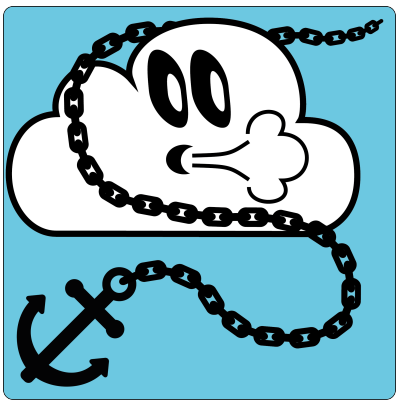
How much chain do I need when anchoring?



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 RYA rule of thumb "chain length = four times water depth" (or simply "more in a lot of wind") is far too unspecific to take into account the different boat types and sizes and the very different anchoring scenarios.

The results at the time referred to the so-called **static anchoring**, where everything has settled down: The wind pushes the vessel away from the anchor, but it is at rest. In particular, there are no gusts and no swell, and the vessel does not sail at anchor either. In this case, one finds a simple relationship, $L = \sqrt{Y(Y+2a)}$, where L is the minimally required chain length such that the chain still pulls horizontally on the anchor shank, Y is the anchor depth, as measured from the bow roller, and a is a parameter defined as the ratio of wind force acting on the vessel and chain weight (in water) per running metre or foot. Of course, these assumptions are not entirely realistic, and so I would like to put forward the extension to **dynamic anchoring** and, in this context, also present my easy-to-use app for Apple, Android and web-online (LITE), which calculates, among other things, the **minimally required anchor chain length** and the **load exerted on the anchor**. We allow for chain with snubber or bridle setups, as well as a mix of chain and rope, or just rope only. Gusts and swell are also taken into account. This will cover the vast majority of anchoring scenarios. It turns out that dynamic anchoring will affect those vessels most that move a lot about at anchorage, so smaller vessels and multihulls with a comparatively large windage area but relatively small weight. Very heavy vessels that “just sit there no matter what” are least affected by it.

As before, the approach is the following: When a gust or swell/waves hit the vessel, 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 vessel has stretched the chain (and rope) most and thus pulls most strongly at the anchor: Peak load! The entire initial kinetic energy of the vessel has now been converted into potential energy of the chain (and, if applicable, into the stretching of a snubber / bridle / rope). Kinetic energy is the energy acquired by a body when moving with a certain velocity. Potential energy is the energy a body attains when it is lifted off the ground, or is elastically stretched. For instance, pumped water storage power plants work according to this principle. So if one can calculate the energy transferred to the vessel when hit by a swell or a gust, 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. Friction helps to dissipate energy and thereby reduce the anchor load. Therefore, we are erring on the safe side when ignoring it.

It is difficult to calculate the energy of a swell or a gust exactly, but it can be estimated by looking at the maximum speed at which the vessel moves away from the anchor after it was hit by a swell or a gust. Using this speed and the mass of the vessel, one can then approximately calculate the energy of the swell/gust transferred to the vessel — it is the kinetic energy of the vessel at maximum speed at anchor. This immediately raises the question as to how well a chain (without a snubber / bridle) can absorb energy, anyway? A

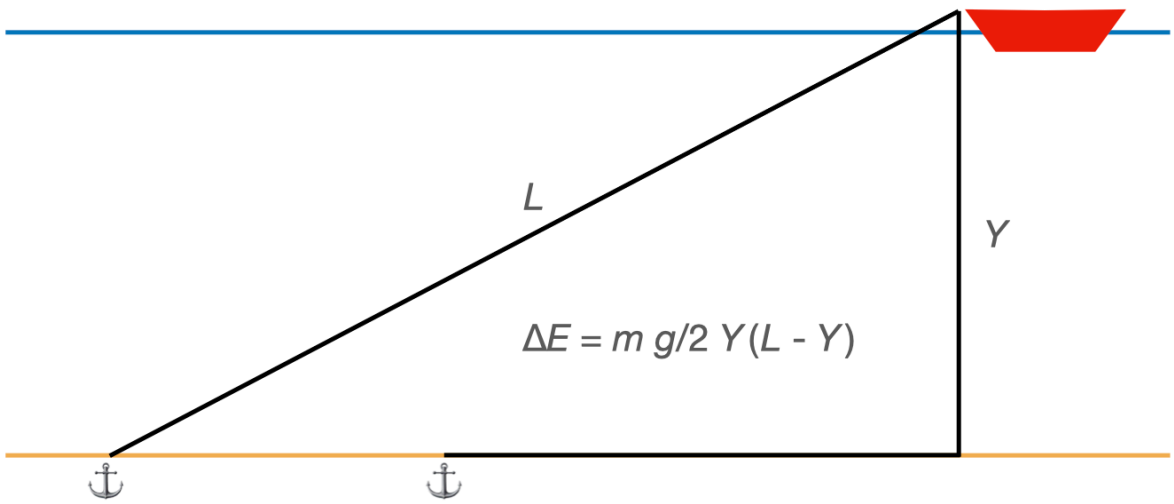


Figure 1: The difference in potential energy of two extreme cases at anchor: No wind at all and no swell resulting in a slack chain hanging down vertically versus so much wind and swell that the chain becomes completely taut and is a straight line from anchor to bow roller. The difference ΔE between these two potential energies is the maximum energy that this chain can absorb.

chain can store additional energy as it gets raised further off the seabed (potential energy), but how much energy is that?

To answer this, let us first consider qualitatively two extreme cases: Firstly, 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. From a purely geometrical point of view, the chain forms a more or less straight and almost horizontal line between the anchor and the bow roller, and it can thus hardly tighten any further — and thereby gain more height above the ground — in order to absorb yet more energy. This is the shallow water scenario with a possibly 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 and there is no gain in height. 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 and ultimately derive recommendations for safer anchoring.

Let us in the next step look at these two extreme cases more quantitatively as shown in Figure 1: A) no wind, no swell, the slack chain simply hangs down vertically at the bow. B) after an extremely strong and long-lasting 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 above ground and, on top, more chain is needed as well. 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 (in water) per running metre or foot, Y is the anchor depth, measured from the bow roller, and L is the length of the chain. So if a gust or a swell tries to transfer an even greater amount of energy to the chain, the anchor will most likely break free, or be dragged through the seabed or something else bad will happen. 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: Firstly, the maximum energy that can be absorbed by a chain of **fixed** length L 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 absorb energy well in shallow water — in fact, the shallower it is the worse it gets. 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, i.e. a scope of $L/Y = 2$. 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 very negative effect on the maximal holding power and, secondly — even more serious — the load peaks passed through from the bow to the anchor are enormous. Otherwise, the chain would not be so extremely taut to begin with. One thus needs much more chain to prevent this scenario of a very taut chain.[1]

Let us, therefore, assume that the chain always pulls horizontally at the anchor in order to have 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 chain length L required to keep the angle at the anchor shank zero 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 intrinsic elasticity of the metal of the individual chain links, but rather 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, the bow. 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 force of 1 N, 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-hand side of the graph it is calm, on the right it is storm. The horizontal axis is scope, i.e. the ratio of chain length L to anchor depth Y — where only the part of the chain counts that 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, as measured from the bow roller. There are 100

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[1] The example of a taut chain also shows what this is all about: As the chain cannot get much more stretched, the vessel will only move a very little further backwards. Since energy (or work) equals force times distance, the force, i.e. the anchor load, must increase accordingly (for the same energy) in order to compensate for a shorter distance. In fact, in the extreme case, this can well mean that some chain might be lying on the seabed, unused, whilst the anchor load is still going through the roof! More chain simply does not help here!

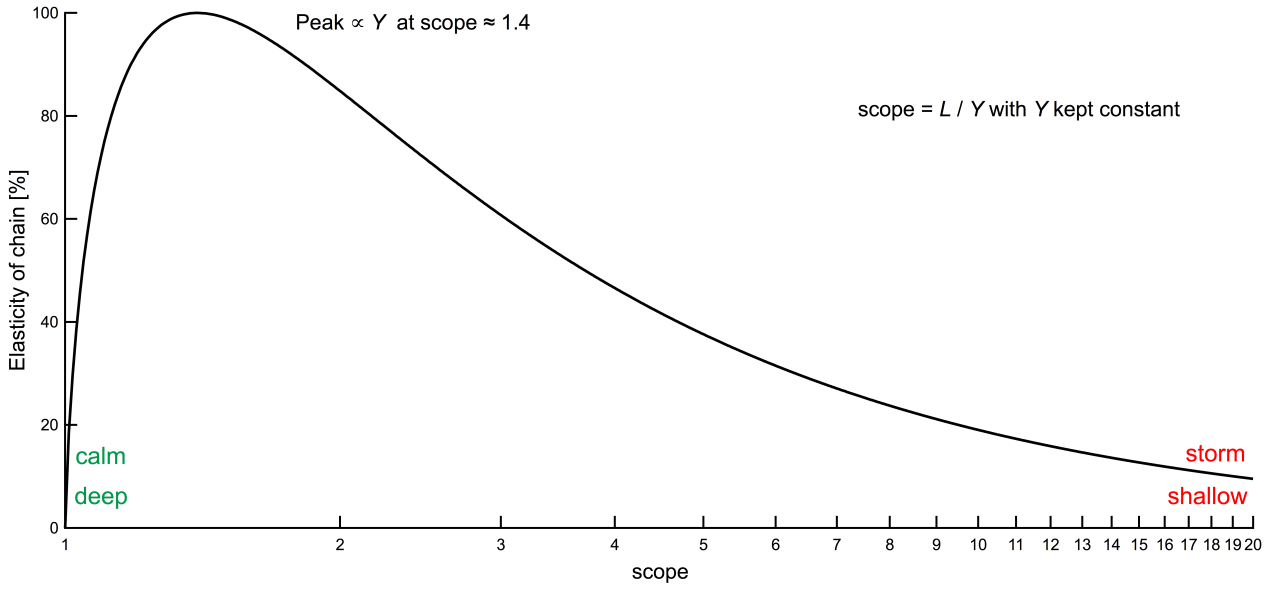
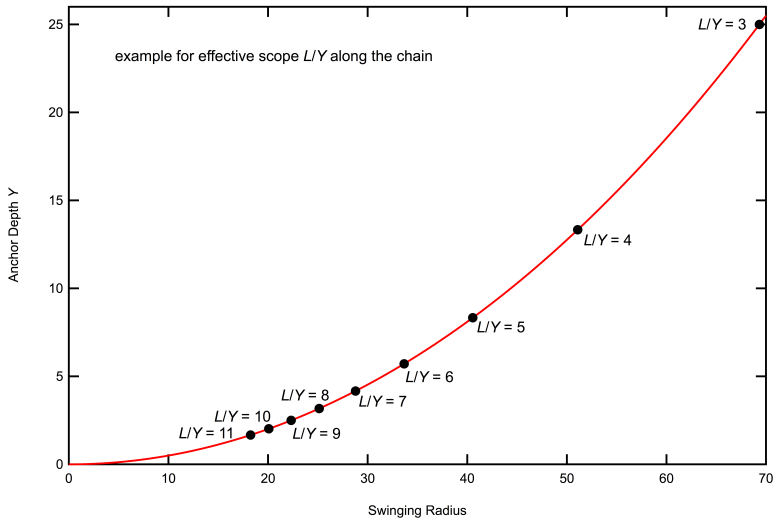


Figure 2: Elasticity of an anchor chain as a universal function of the ratio of chain length to anchor depth (= scope). The maximum at scope $L/Y \approx 1.4$ is given here as 100%, and is proportional to the anchor depth Y when measured in absolute values. In other words: If the anchor depth doubles, the maximum 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 fulfill 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.

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. Now it is blowing more and more and I am 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 I have thus reached the right edge of the graph. So what happens is that 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 on top. Sure, it can absorb large static loads, but gusts and swell, no way. Consequently, 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 much more realistic boundary conditions for the chain.

For the graph in Figure 2 we have used scope for its horizontal axis, but other parameters are possible as well, e.g., wind strength: Little wind on the left, lots of wind on the right. And not only that, this axis could also be labelled with the water depth: Shallow on the right, deep on the left. To appreciate this, one only has to bear in mind that a chain that pulls horizontally at the anchor initially turns only very little towards the water surface, 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 further, the corresponding *L/Y* values are drawn in the diagram on the right for an exemplary wind load. 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 to keep the anchor loads reasonable, as we will also further see in a moment with a concrete example.

But that is 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, a chain of fixed length 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 in a storm off Greenland with 100 metres of chain at 40 metres anchor depth without any problems. 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 — second advantage — 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 as well as online with a reduced functionality as a LITE version, which is completely sufficient to follow this example.

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, vessel length and type (i.e. mono, cat, tri, and whether of bulky, medium or slim built), weight of the vessel, swell or gust energy in the form of velocity over ground at 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 size and type of 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 horizontally on the anchor shank (or according to the slope 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. Of course, it is also possible to limit the length of the chain, in which case the chain will pull at the anchor shank with an angle and the anchor load will increase.

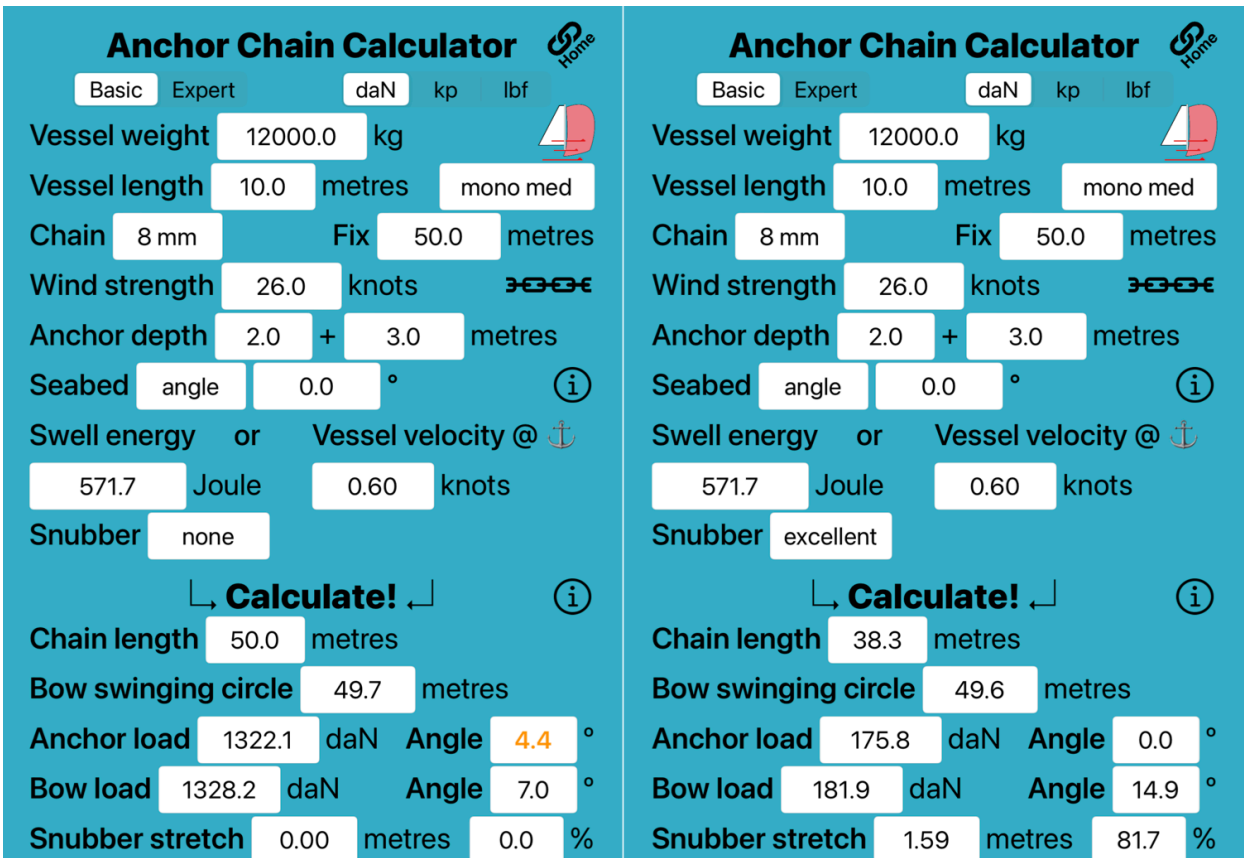


Figure 3: AnchorChainCalculator App: Anchor load in shallow water (5 metres) with a lot of swell. Left: No snubber / bridle. Right: Excellent snubber / bridle. The anchor load in the first case is gigantic — well in excess of a metric tonne!

In the first case considered, I limit the chain length to 50 m and do not use a snubber / bridle at all. I anchor at 5 m anchor depth in 26 knots of wind, and there is quite a heavy swell or strong gusts. On the chart plotter I see from time to time that the velocity component of SOG (Speed 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 this is related to the fact that I anchor in quite shallow water with a lot of swell or strong gusts, resulting in a lot of movement of the vessel. Now, in the second case, I assume the same situation, but this time I add an excellent snubber or bridle. Everything else remains the same. Now the anchor load goes down dramatically to only 176 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 over 38 m of chain need to be deployed, and almost 12 m remain unused, either in the locker or on the seabed. The anchor load has gotten smaller by more than a factor of 7!

All this for the sole reason that I have used an excellent snubber / bridle, which absorbs almost 82% of the swell energy. And what does "excellent" mean? One can get an idea of this by looking at the elastic stretch that this snubber / bridle experiences in this scenario:

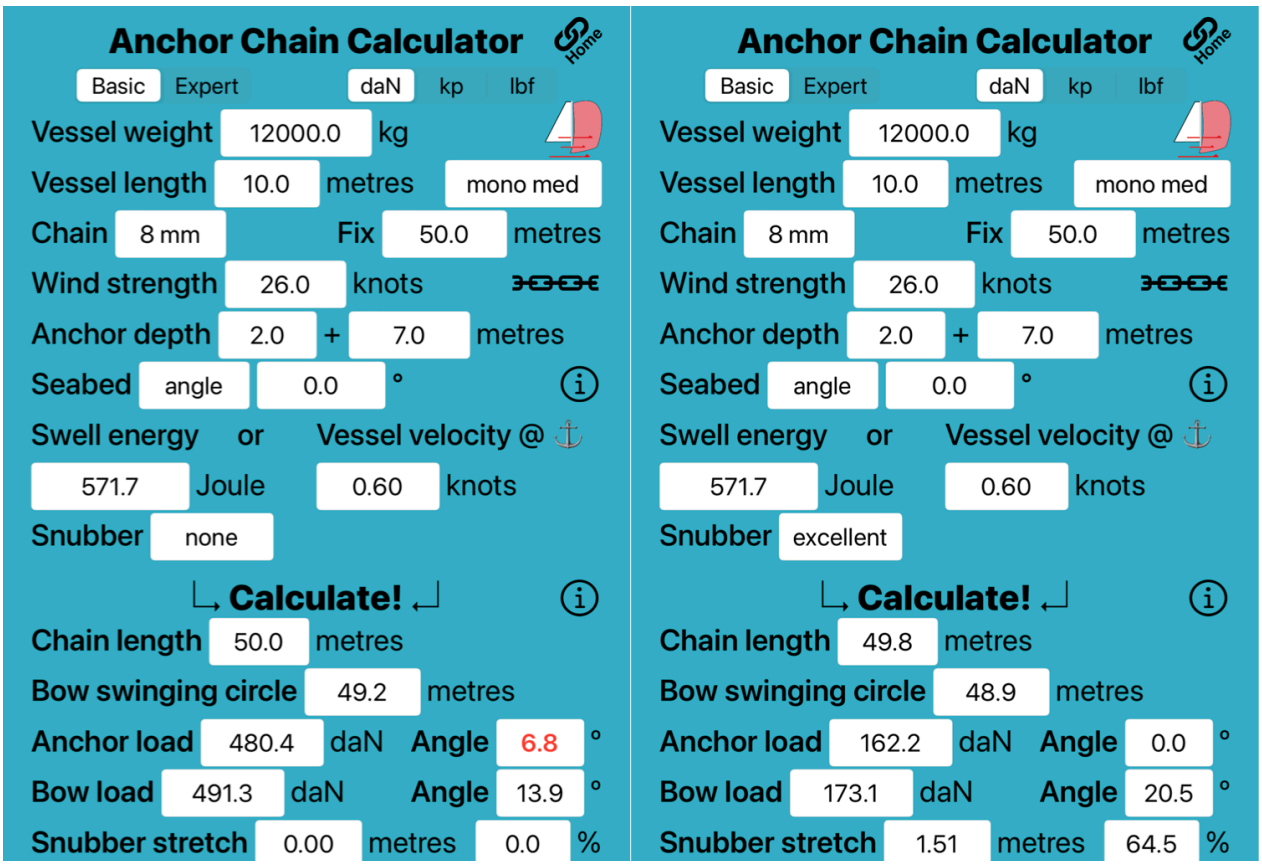


Figure 4: AnchorChainCalculator App: Anchor load in slightly deeper water (9 metres) with a lot of swell. Left: No snubber / bridle. Right: Excellent snubber / bridle. The anchor load in the first case is still large, but significantly less than in the case of 5 metres anchor depth.

An astonishing 1.59 metres. That's a lot and it is not doable with the short stub of snubber as unfortunately seen only too often at anchorages. Since snubbers / bridles must not be overstretched, such a massive stretch can only be handled by a very long snubber / bridle (or a longer rode). It will certainly have to be 12 metres or longer. As far as the app is concerned, an excellent snubber is defined as stretching by 1.6 metres at 8 Beaufort wind (and 0 metres anchor depth and no swell / no gusts).

If I don't have a snubber / bridle, it still helps to relocate to deeper water. At 9 m anchor depth and again only 50 m 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 5 m anchor depth (Figure 3, left). This may go against intuition, but in this case, all other things being equal, and in particular using the same chain length, deep water is better than shallow water! Put another way: **The same swell / gust is much more dangerous in shallow water than in deep water.** (I am not talking about the dangers of strong surf here! Those come on top.) Again, a snubber / bridle makes a significant difference — the anchor load is then reduced to 162 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: 162 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 / gust and keeping the peak load away

12000 kg weight, 8 mm chain, 10 m mono hull, 26 kn wind, 0.6 kn vessel velocity at ⚓	**3 m ⚓ depth**	**5 m ⚓ depth**	**9 m ⚓ depth**
No snubber	50 m chain ⚓: Error, Error Error	50 m chain ⚓: 1322.1 daN, 4.4° 0 m stretch	50 m chain ⚓: 480.4 daN, 6.8° 0 m stretch
Lousy snubber Stretch @ 8 Beaufort: 0.05 m	50 m chain ⚓: 558.5 daN, 0.3° 0.15 m stretch	50 m chain ⚓: 450.0 daN, 1.9° 0.12 m stretch	50 m chain ⚓: 338.9 daN, 5.3° 0.10 m stretch
Ok-ish snubber Stretch @ 8 Beaufort: 0.2 m	41.8 m chain ⚓: 352.8 daN, 0° 0.39 m stretch	50 m chain ⚓: 310.8 daN, 0.2° 0.35 m stretch	50 m chain ⚓: 257.7 daN, 3.8° 0.29 m stretch
Excellent snubber Stretch @ 8 Beaufort: 1.6 m	30.2 m chain ⚓: 182.7 daN, 0° 1.63 m stretch	38.3 m chain ⚓: 175.8 daN, 0° 1.59 m stretch	49.8 m chain ⚓: 162.2 daN, 0° 1.51 m stretch

Table 1: Overview of all scenarios considered here. The anchor load, especially in shallow water with strong swell or gust, is reduced significantly by a snubber or bridle. The more elastic these are, the more the anchor is relieved. At an anchor depth of 3 metres and a very strong swell / gust, without any snubber / bridle, there is no solution within the scope of my model, because the chain on its own simply cannot absorb enough energy (cf. Figure 1). It first gets taut and then the anchor breaks free, or it is pulled along the seabed, thereby dissipating the surplus energy.

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. Firstly, as the load is still much larger than if one uses a very elastic snubber and, secondly, because the stretch of a poor snubber is very likely substantially more than the maximal stretch as recommended by the manufacturer.

Furthermore, one can see that it does not really help simply to deploy more chain in shallow water. At an anchor depth of 3 metres and with an "ok-ish snubber", 41.8 metres of chain are sufficient in my example for the chain to pull the anchor horizontally. If I use even more chain, it lies almost uselessly on the seabed despite the strong swell / gust and only helps marginally through its friction on the seabed. It turns out the anchor load is not significantly reduced by this. So if the seabed is poor and the 352 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 given the necessary anchor depth to do its work"**.

How much does a chain lying on the seabed actually help?

Every so often the argument is made that it is the chain lying on the seabed which is holding the vessel and not the anchor. To bust this myth, let me briefly compare all this with the static friction force of a chain lying on the seabed: According to Taylor and Valent, the static friction coefficient μ of a chain is 0.9 to 0.98, depending on the seabed conditions. The holding power of a chain with weight *G* lying on the ground is thus μG, and the anchor is relieved by this load. As an example from Table 1, let me consider the case of "Excellent snubber" and 3 m anchor depth with 30.2 m chain. If I now increase this chain to 49.8 m to compare it with the case of 9 m anchor depth, then almost 20 m of chain (8 mm) lie on the seabed. This results in a holding power due to the chain's friction of μG = 0.9 * 20 m * 1.22 daN/m = 22 daN. This is not a lot, but in this case, by chance, it just compensates for the difference in anchor load between 3 m and 9 m anchor depth for an excellent snubber. In general, however, it must be said that the static friction of a chain lying on the seabed is far from being a substitute for a good snubber / bridle — particularly so when it blows really hard and most of the chain is off the seabed, anyway. In the above example — for a chain lying on the seabed to generate enough holding power — by way of friction only — to replace the excellent snubber and reduce the anchor load from 1322 daN to 176 daN, an additional chain length of (1322 - 176)/ (0.9 * 1.22) = 1044 metres is required! So, the chain's friction force is simply not enough to make a substantial impact, really, and once the chain starts moving, the friction gets reduced even further. For this reason, it is nonsense when some folks claim that it is not the anchor but the chain that holds the vessel. The chain connects the vessel with the anchor, which will hold the vessel, and this as elastic as possible.

To emphasise once again: In all the cases we looked at, the swell or gust was very large, but of the same strength.[2] It then makes sense to anchor at a greater depth and thereby reduce some of the impact of the swell or gust. Of course, this does not mean that one should also follow this advice if the swell or gust is much bigger at the new anchorage in deeper water! Even more relief —in any scenario — is obtained when using very good snubbers or bridles.

[2] In fact, I kept all variables constant except for the anchor depth and the quality of the snubber, which were varied individually and both together. This is a typical scientific approach to understand how a system depends on a particular parameter. However, this does not mean at all that I suggest that the swell /gust is always the same in shallow and deep water. It is merely a means to compare results and understand the effect a parameter has.

Digging in the anchor by reversing with engine

Now, how does this compare to the anchor load generated when putting the engine into reverse to dig in the anchor whilst setting it? The answer to this is quite useful: It gives an idea up until which wind strength / swell the anchor setting has actually been tested when setting it, thus giving us some confidence that — in the absence of changes of wind direction or current — we will be ok at the anchorage up to that point and, likewise, when we may not be ok anymore. Some folks dig in their anchor with the help of the engine and then forget about it. But most of the time this procedure is not equivalent to gale force wind, far from it. To get an idea of the anchor load caused by reversing the engine let us recall that $p = f\,v$, where p is power, f is force, and v is velocity. So, all we have to do is — whilst not at anchor and without any sails up — to put our engine into full reverse and measure the speed v we can achieve that way. Ideally, there will be no current or waves, and the apparent wind will be zero. The force with which the vessel is then pushed through water is then simply given by $f = \eta\, p/v$, where we have introduced an efficiency correction η, which accounts for all losses from the raw engine horse power to the actual effective power the propeller is having. This efficiency factor is normally anything between 30% and 60%, and generally on the lower side for out-boarders. Assuming, for our example case discussed in Table 1, an engine of 40 HP, a maximum velocity in reverse of 6 kn, and an efficiency of 50%, we arrive at f = 50% * 40 HP / 6 kn = 483 daN. This is very comparable to the anchor loads seen in Table 1 when using a snubber, but far less compared to when anchoring at only 5 metres or less, and not using a snubber.

Since heavy displacement vessels with comparatively little windage area will not move as much at anchor as light-weight multihulls do, it is also clear that the effect of dynamic loads as discussed here is much more dramatic for multihulls than for heavy monohulls.[3]

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 vessel, which would improve its elasticity.

The app (for Apple and Android) also allows to analyse a combination of chain and rope — see Table 2. In this case, if the chain is not too long, the chain will absorb almost no energy compared to the rope and hence the chain will effectively always work in the

[3] Let me give a simple example to understand this better: Consider a heavy ball of mass M at rest getting hit by a much lighter ball of mass m. After impact, the heavy ball will be set in motion. Using the physics' conservation laws of energy and momentum, it is easy to calculate the energy thus transferred to the heavy ball and one finds that this energy transfer gets smaller and smaller as the weight (mass) of the heavy ball increases compared to the light ball. In fact, the energy transferred is proportional to $M\,m^2/(m + M)^2$. Same principle apples to gusts and swell. The heavier a vessel is, the less energy can be transferred by a swell / gust of given strength. Roughly, all other things being equal, a vessel twice the weight will have only half the energy transferred. As a result, the effects of dynamic anchoring become less severe then. For this reason big ships are not affected by this at all. Likewise, older, more traditionally built vessels which have not been tuned for maximum sailing performance are less affected as well, which may explain why many old salties find it difficult to reconcile the effects of dynamic anchoring with their experience.

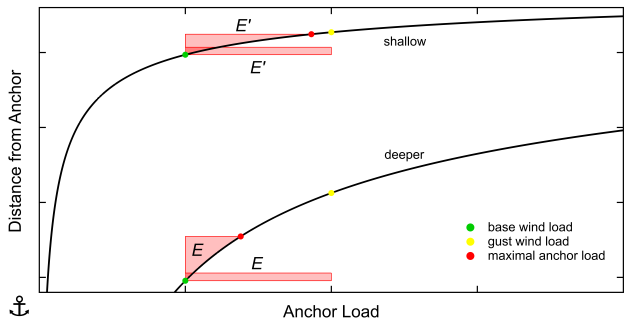
12000 kg weight, 10 m x 8 mm chain, 10 m mono hull, 26 kn wind, 0.6 kn vessel velocity at ⚓	**3 m ⚓ depth**	**5 m ⚓ depth**	**9 m ⚓ depth**
No elasticity	30 m rope ⚓: Error, Error Error	30 m rope ⚓: Error, Error Error	30 m rope ⚓: Error, Error Error
Lousy Stretch @ 8 Beaufort: 0.7 %	30 m rope ⚓: 387.8 daN, 2.7° 1.5 % stretch	30 m rope ⚓: 387.1 daN, 5.5° 1.5 % stretch	30 m rope ⚓: 387.6 daN, 11.3° 1.5 % stretch
Ok-ish Stretch @ 8 Beaufort: 3 %	30 m rope ⚓: 227.5 daN, 1.5° 3.7 % stretch	30 m rope ⚓: 227.0 daN, 4.3° 3.7 % stretch	30 m rope ⚓: 227.4 daN, 10.0° 3.8 % stretch
Excellent Stretch @ 8 Beaufort: 24 %	30 m rope ⚓: 130.2 daN, 0° 17.1 % stretch	30 m rope ⚓: 130.0 daN, 1.6° 17.1 % stretch	30 m rope ⚓: 130.1 daN, 6.8° 17.3 % stretch

Table 2: Same as Table 1, but now for a mix of 10 metres of chain and 30 metres of rope with various amounts of elasticity (defined as percentage stretch under a given working load at 8 Beaufort). Clearly, there is no benefit anymore to relocate to deeper water — in fact, it is a disadvantage, because of the increasing angle with which the chain will pull at the anchor. The anchor load is almost independent of anchor depth and much more dependent on the rope's elasticity. Ropes with poor elasticity are already stretched more than they should. In comparison to Table 1 the swinging radius is even reduced by about 10 metres.

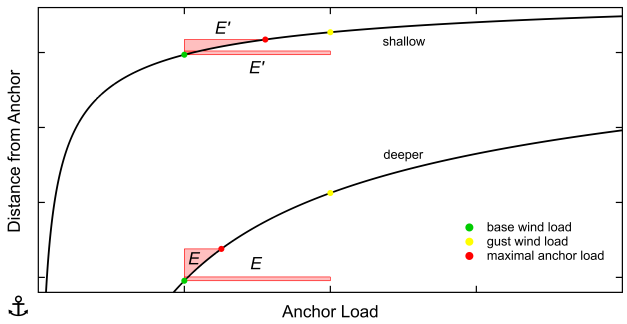
"shallow water mode" above, regardless of how shallow or deep the anchorage is. In this scenario the absorption of shock loads due to swell and gusts will be almost exclusively accomplished by the rope, and the anchor load does not vary a lot with the anchor depth. This is easy to explain: In contrast to a chain, a rope can store energy regardless of how steep the angle is at which it connects to the chain. Its elasticity does not depend on this angle. Consequently, in such a scenario it is not an advantage anymore to anchor in deeper water to reduce the anchor load. On the contrary, if the length of chain and rope remains constant, relocating to deeper water would only increase the pulling angle at the anchor shank and hence reduce the maximal holding power of the anchor.

In the app's Expert Mode, one can set some parameters even more precisely, e.g. the effective windage area and the properties of 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.

Not every vessel is equally affected by this dynamic effect!



Just Chain: Depending on the wind load, the vessel is closer or further away from the anchor. A gust lets the vessel move along the curve, starting at the green point.



Same as on the left, but now for a vessel that has the same windage area but is twice as heavy. The energy transferred is halved!

As the wind blows stronger, the vessel moves further away from the anchor and more chain is lifted off the seabed (always assuming there is enough chain on the seabed). In the graphs above, the position corresponding to the base wind is marked with a green dot. When a very strong, but only brief gust hits the vessel, the vessel is pushed further towards the yellow point. In this process energy is absorbed, some of which is stored as potential energy of the chain (dark red area), but the excess energy is causing an acceleration of the vessel (kinetic energy = light red area). After the gust has stopped, the vessel slows down again and its kinetic energy is transferred back to the potential energy of the chain. At the **red point**, the vessel has come to a standstill and has reached the **maximal anchor load** – the load we are interested in. The vessel will move towards the anchor again in a moment.

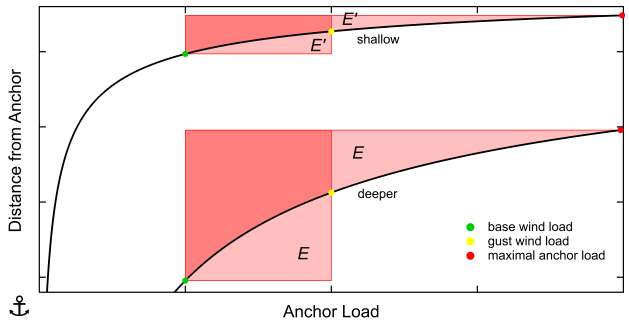
In shallow water, this maximum anchor load is significantly larger than in deep water, as the chain becomes taut faster and more “brutally" so.

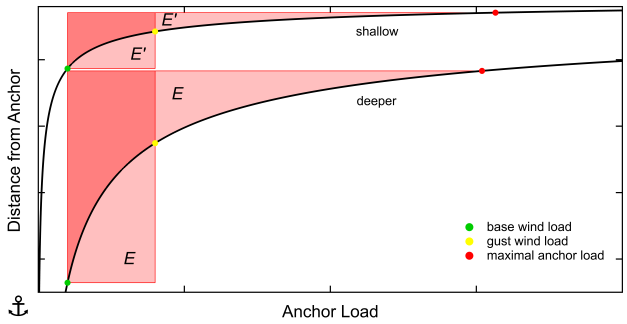
The graph on the right shows the same case, but for a vessel twice as heavy, yet with an identical windage area. Since, according to $F = m * a$, its acceleration a is only half as much as for the vessel on the left, the energy transfer is also only about half as much. Accordingly, the maximum anchor loads are significantly lower. **Conclusion:** Light-weight vessels with a large windage area are significantly more affected by this dynamic effect than heavy, compact displacement vessels.

If the gust is not short, but blows for longer (beyond the red point), then this maximum anchor load increases significantly. In this case, though, there is no longer any difference between shallow and deep water, or heavy and light-weight vessels.

A rope or a very elastic snubber / bridle has a much better elasticity property than a chain and thus leads to significantly smaller maximum anchor loads!

Extreme anchor loads can occur during gusty katabatic winds!





Just Chain: In this katabatic gust, the gust has such a long duration that the vessel had time to arrive at the point of maximum distance from anchor.

Here the situation is even more severe! Note that anchoring in deep water is only marginally better.

Gusts formed by katabatic winds can develop enormous forces. Their special feature is that they are significantly stronger than the base wind. If they then also last longer, a great deal of energy is transferred to the vessel – simply because the chain was originally dangling almost vertically and the vessel thus had a large fetch before the chain went taut. In the graph above on the left, the force of the gust is "only" twice as large as the base wind, but it leads to three times the maximum anchor load. Example: base wind is 10 kn, gust is 14.1 kn, then the maximum anchor load corresponds to a base wind of 20 kn. In the graph on the right, the situation is even more extreme: Example: base wind is 10 kn, gust is 20 kn, then the maximum anchor load corresponds to a base wind of 40 kn. And katabatic winds can be even more violent than that!

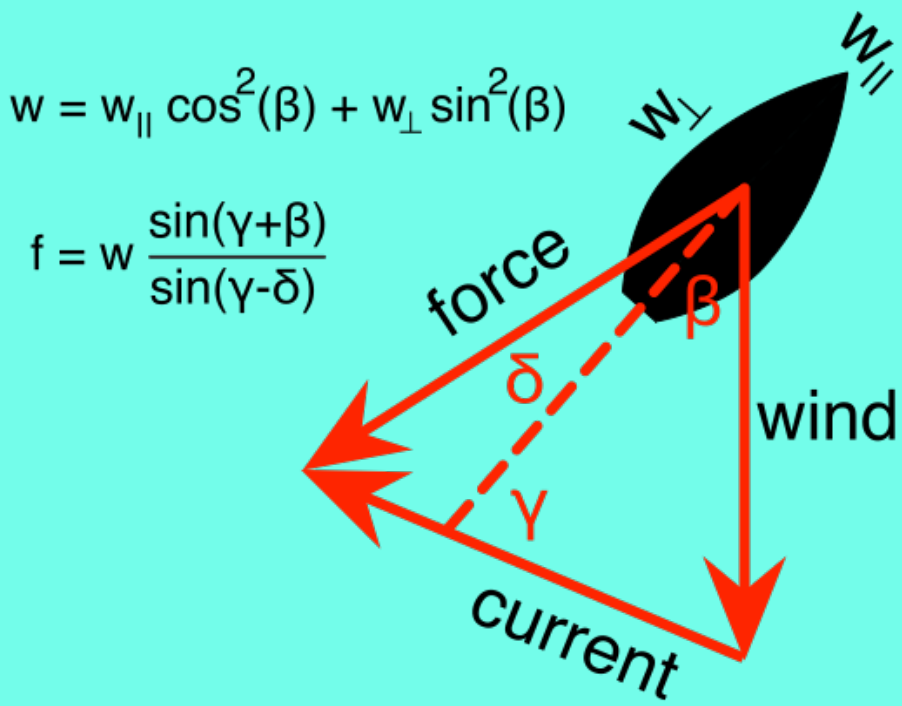
In all these cases, the weight of the vessel does not matter and the difference between anchoring in shallow and deep water is also marginal.

But an elastic anchor rope or an elastic snubber / bridle still does help!

Even this extreme scenario can be modelled with the Anchor Chain Calculator app when instead of the base wind the **gust** is used as input for the wind strength, and the velocity at anchor at the point in time when the yellow dot is reached in the graphs above — which is simply the largest velocity seen on the chart plotter whilst the gust lasts.

These graphs are very convenient to discuss energies absorbed due to forces acting on the vessel: The horizontal axis is the force and the vertical axis is the distance this force is applied. Since energy is force times distance, areas in these graphs represent energies. The solid black curves are the steady-state curves when all forces are balanced out and the vessel is at rest.

When anchoring in a **strong current** one may need to include this in the calculations as shown in the force diagram below. In this case, in addition to the frontal windage area, $w_{||}$ used so far, one needs more parameters such as the lateral windage area when viewing the vessel from the side, $w_{\perp}$, as well as the angle β between wind and vessel heading, the angle γ between current and vessel heading, and finally the angle δ between anchor rode and vessel heading. In a first instance, one calculates the effective windage area $w(\beta) = w_{||} \cos^2(\beta) + w_{\perp} \sin^2(\beta)$ which the wind sees as a weighted average and then, in a second step, a fictitious windage area $f = w \sin(\gamma+\beta)/\sin(\gamma-\delta)$ which includes the effect of the current as well. It is this fictitious windage area *f* which needs to be entered as windage area in the Expert Mode. *f* is not really a windage area, strictly speaking, but it is rather convenient to include the effect of a strong current in such a way. Please note that the angle δ of the anchor rode may actually also be negative. Whether this is the case will depend on the properties of the vessel and, in particular, on the relative lateral positions of the points where effectively the wind and current push the vessel. If — without sails — the bow tends to be pushed out of the wind, this angle δ will be negative. Example: The wind is at β = 30° with respect to the vessel's heading and its lateral windage area is three times the frontal one, $w_{\perp} = 3\, w_{||}$. With this one gets $w = 0.75\, w_{||} + 0.25\, w_{\perp} = 1.5\, w||$, so an increase by 50%. Next, we assume the angle of the current with respect to the vessel's heading as γ = 45° and the angle between anchor rode and vessel's heading as δ = 15°. With this we have $f = w \sin(75°)/\sin(30°) = 2.9\, w_{||}$, meaning that the fictitious windage area that needs to be entered in Expert Mode has almost tripled! In the case of multihulls, one also needs to consider the effect that one leg of the bridle will be much more stretched than the other one, which is not accounted for here. This will have an effect on the dynamical anchoring.



Force diagram when wind and current both pull on the vessel. The resulting net force is in line with the anchor rode at the bow.

Offline descriptions and tips in English, German, French, Spanish, Danish, Swedish, Norwegian, Dutch, Portuguese and Italian are provided for both the input and the output values, which are hidden behind the two small ℹ like info buttons at the right edge of the screen. In the top right corner is the home button, which takes you to the web page with the detailed description: https://trimaran-san.de/anchor-chain-calculator/ (Or correspondingly the German / French / Spanish description, if that is the system language in the phone / tablet). And if you prefer to calculate in kp instead of daN, you can also set this. Or imperial units such as feet and pounds, that also works. And of course all entries are saved, so that next time you only have to enter changed values. It is also possible to save different configurations under different names. Perhaps one configuration for the lunch hook, one configuration for the normal every-day snubber, and one configuration for the heavy-weather snubber.

Once you have "gotten the hang of" your vessel, 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! :)

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. Should the chain not be long enough, the app will calculate how that affects the anchor load and the angle, with which the chain will pull at the anchor. A few simple vessel 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. One can also tackle a mix of anchor chain and rope, or just a rope only. Currents are only taken into account using a small trick. But otherwise all essential factors are included in the calculations. The consideration of swell and gusts, 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 snubbers and bridles are primarily not deployed to prevent 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.

In conclusion: Vessels with very good, elastic snubbers or bridles, or a combination of chain and rope, or only rope, have no problems anchoring in shallow water, whilst vessels with only chain will be more at home in deeper water. In any case, heavy displacement vessels using chain only, which stay put even when exposed to very strong gusts and swell, are much less affected by dynamical anchoring effects compared to light-weight multi-hulls having a large windage area (compared to their weight) or simply smaller boats, which tend to move a lot at anchorage. As a result, those heavy displacement vessels may anchor in shallow water despite having only chain. However, using an elastic snubber is still highly recommended… ;)

But as always, there are several aspects to consider when anchoring and this is only one of many. In deep water, you are more often exposed to larger gusts or more swell, and then the advantages of the chain at depth are quickly gone. What I usually do is this: I look at the depth contours in my chosen anchorage and look for a deeper spot in the area still protected by the coast. So I avoid anchoring on a shallow water zone reaching out from

the shore and rather choose the opposite — a deep water zone that is reaching as close to the shore as possible. Not too close, of course! ;)

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

AnchorChainCalculator App Online (LITE with reduced functionality): https://www.anchorchaincalculator.com

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

The seminal work by Alain Fraysse (In contrast to my approach via energies, he did all the calculations in the force-time domain): http://alain.fraysse.free.fr/sail/rode/rode.htm