Comparison of mooring loads on a rubber or chain moored navigation buoy

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A numerical study, based on a simple model of a chain moored navigation buoy gives insight in the load on the chain. The same model is used to evaluate the mooring forces on a rubber moored navigation buoy. Comparison of the results explains why in shallow water rubber cords perform better than chain moorings.

Introduction

Initially mooring a navigation buoy with rubber was faced with scepticism. Experience has shown that chain moorings sometimes break. Replacing it by a stronger (or longer) chain makes the mooring survive. Based on this experience it is contra-intuitive that a rubber cord, having only a fraction of the maximum load, can handle the mooring forces equally well or sometimes even better. Now, after some 5 years of applying rubber cords on navigation buoys [**1,2,3**], this initial scepticism has changed to confidence and willingness to accept a rubber cord as a suitable mooring material. This paper deals with some background considerations concerning the mooring forces in both the chain and the rubber cord moored navigation buoy, and shows that a proper rubber cord mooring limits the mooring load well below the maximum force a rubber cord can handle.

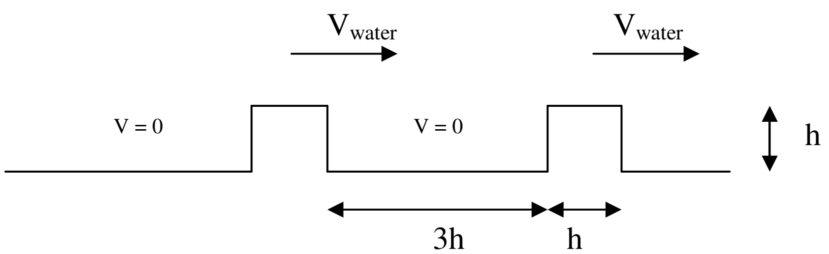
The initial conflict

Basically the mooring of a buoy serves two conflicting purposes. On the one hand it has to keep the buoy on position, while on the other hand the mooring has to allow the buoy to follow the dynamics of the waves to a certain degree in order to reduce the mooring forces. This conflict most clearly shows up when the buoy is picked up by a wave at the moment the end of the mooring line length is reached. Especially in shallow water, the chain mooring suddenly comes to its end resulting in enormous peak forces. A rubber cord can elongate, to a couple of times its original length, smoothing the stop of the buoy and thus avoiding peak forces. In the next sections of this presentation the results of a numerical simulation of a chain and rubber moored navigation buoy are presented. Finally, in the last section this topic is presented on the basis of the concept of conservation of energy.

Description of the moored navigation buoy at sea

In order to make the results as transparent as possible, the sea, the buoy and the mooring are reduced to their most essential features: The buoy is modelled as a single-pointed moored buoy which keeps perfectly upright at all times. A train of breaking wave is modelled as a

Figure 1:
A train of breaking waves



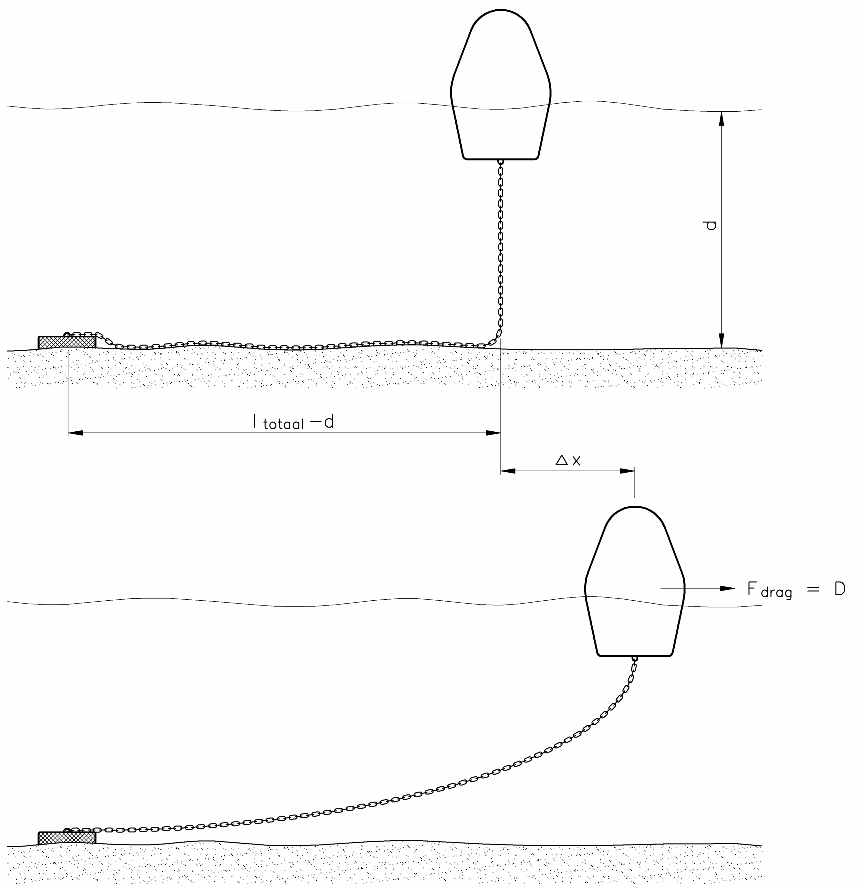


Figure 2:

The horizontal force on a buoy as a function the displacement ΔX.

wall of water having a width equal to its height. The breaking waves are separated by a still water of three times the waves width (figure 1).
Although the chain mooring is at least two dimensional, it is cast into a one-dimensional model. This is done by calculating the horizontal-force/displacement relation of a chain moored buoy. The horizontal force of the chain on the buoy is calculated as a function of the displacement (ΔX) from the zero-velocity position (see figure 2). In equilibrium this force

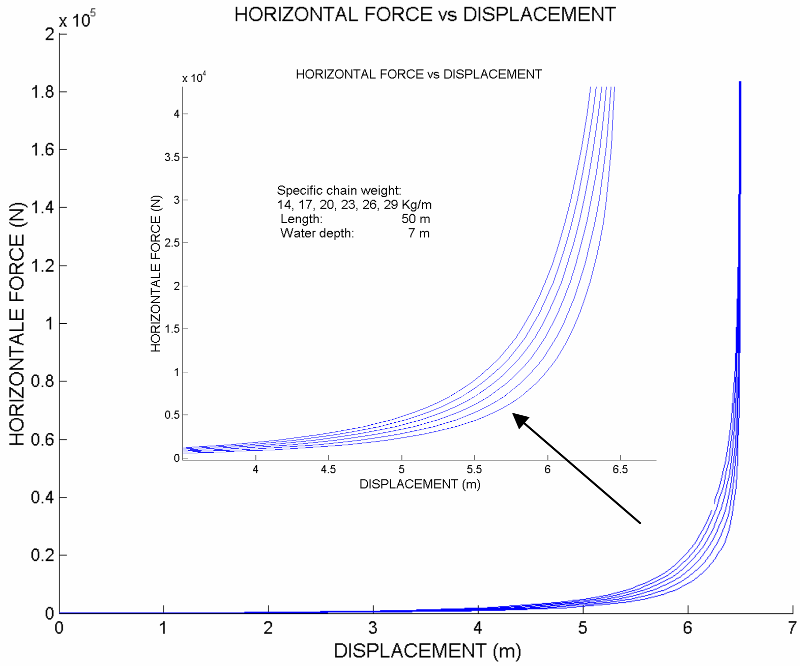


Figure 3:
The horizontal force on a buoy versus the displacement of the buoy from its zero-current position .

equals the drag force on the buoy. In a dynamic situation this force also accelerates (decelerates) the buoy. This chain-force/displacement relation depends on the specific weight (weight per meter), the length of the chain and last but not least the water depth. In figure 3 the horizontal-force versus displacement is presented for various values of the specific chain weight. As expected, the lighter the chain is, the sharper the edge in the force-displacement relation.
The impact of the varying specific chain weight can be shown by applying the chain in a mooring. The buoy, the sea and the mooring are defined as follows:

The specifications of the buoy are:

Underwater surface area:	1 m^2
Total surface area:	2 m^2
Mass incl. added mass:	300 Kg
Mass incl. added mass when flushed over:	400 Kg
Drag coefficient:	1

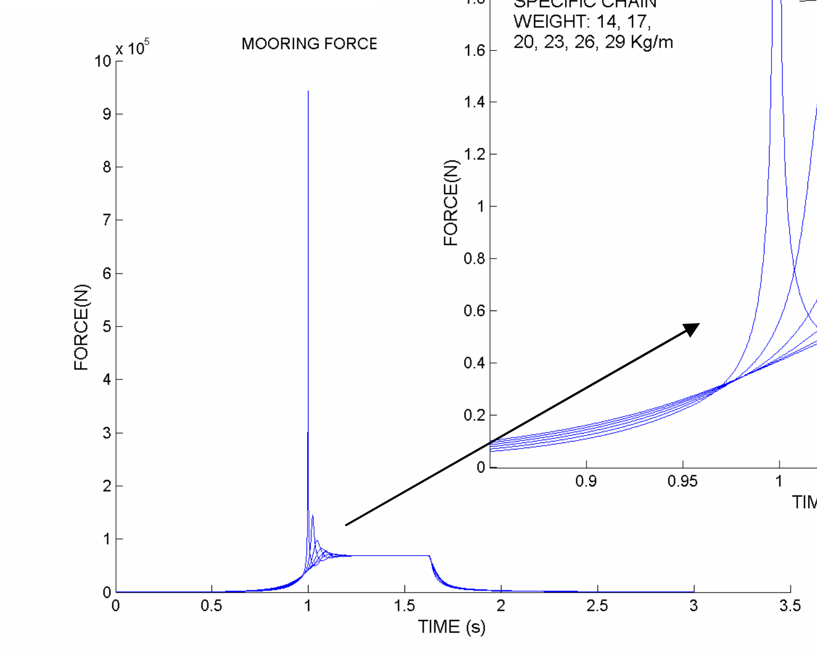
The specifications of the sea are:

Water depth:	7 m
Water velocity of the breaking wave:	8.3 m/s
Water velocity in between the breaking wave:	0 m/s
Height of the breaking wave:	7 m
Distance between two breaking waves:	21 m

The specifications of the chain mooring are:

Length	50 m
Specific weight (in water)	14, 17, 20, 23, 26, 29 Kg/m

When the breaking wave hits the buoy, the buoy is completely flushed over. Tilting of the buoy is not taken into account. The inertia of the chain itself is neglected, as is the drag of the chain. The velocity of the water in a (breaking) wave is determined by physics and depends, in shallow water, on the water depth. The standard water depth in this numerical study is 7 m. For reasons of compatibility, the velocity of the water in the breaking wave is considered constant throughout this study independent of the actual water depth.
The mooring force as a function of time when the breaking waves pass the buoy is presented in figure 4. Figure 5 zooms in on the observed peak forces. For all chains, the mooring force comes to a steady level, equal to the drag force on a steady buoy. The way this steady state force is reached depends very much on the specific weight of the chain. As can be seen in figure 5, with the most heavy chain the force smoothly increases until the equilibrium force is reached. The light-weight chains on the other hand do not slow down the buoy sufficiently when the end of the chain length is reached, and the mooring force peaks to approximately 10 times the steady state value. Here one can see what the problem is with light-weight chain: Light-weight chain is not heavy enough to keep the mooring forces small. In that case the mooring forces can reach very high peak values, with all the undesired possible consequences.



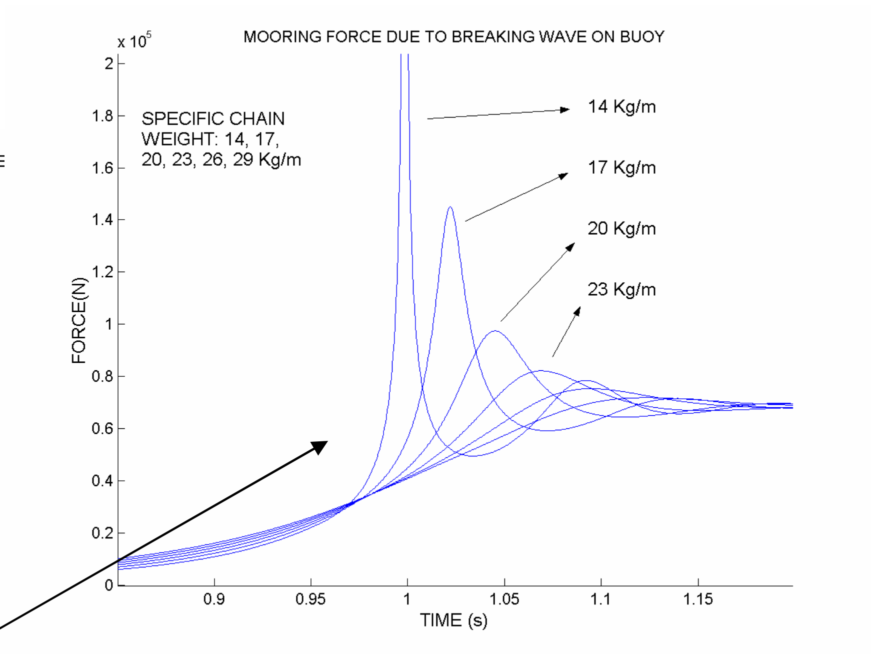


Figure 5:
The horizontal force on a buoy while a breaking wave passes.

Figure 4:
The horizontal force on a buoy while a breaking wave passes.

Shallow water

In the previous section the mooring design was completely in our hand. With a proper choice of the chain, both in specific weight and in length, the mooring forces could be kept low. In the case of shallow water the key parameter is the precise water depth and this is not controlled by man. From the configurations described in the previous section, the chain with a specific weight of 20 Kg/m is chosen, and the water level is taken 3, 4, 5, 6 and 7 m respectively. The mooring forces due to a passing breaking wave are presented in figure 6. At t = 0 the front of the breaking wave is at the buoy's equilibrium position in case of zero water velocity. With decreasing water level from 7 to 4 m, the

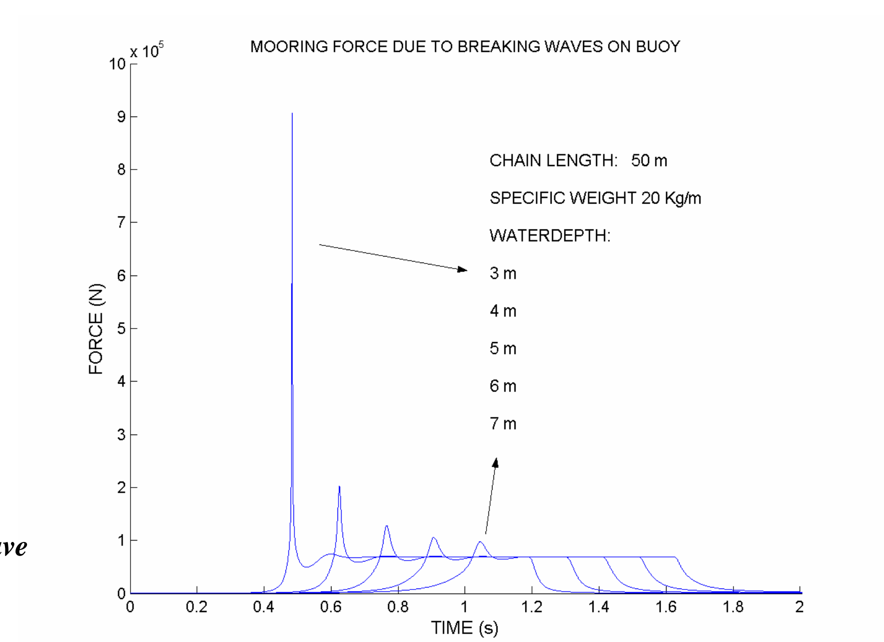


Figure 6:

The horizontal force on a buoy while a breaking wave passes.

maximum force increases dramatically. At 3 m the peak force increases to over 10 times the static force of the braking wave. The impact of this observation is that in an occasional case of lower water level than expected the mooring design is not adequate anymore and can fail.

Rubber moored navigation buoy

The sharp peaks in the mooring force in shallow water under breaking wave conditions can be avoided by applying a rubber cord in the mooring. When the buoy is picked up by the wave, and the mooring line reaches its end, the buoy has to be slowed down. The rubber cord will do this in a gradual manner, thus avoiding high peaks in the mooring force. In order to

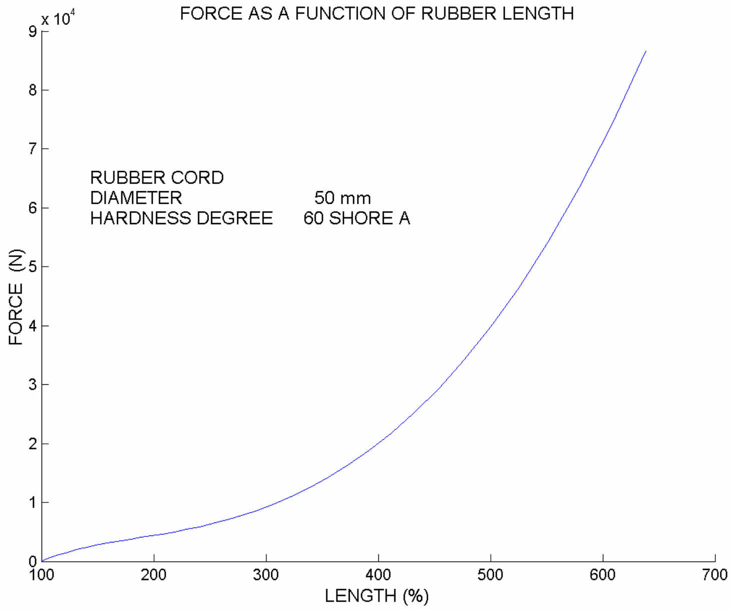


Figure 7:

The force on a rubber cord as a function of the relative length.

demonstrate this, the numerical simulation presented in the previous section has been performed with rubber cord, instead of chain. The used rubber has a diameter of 50 mm, and a hardness of 60 Shore A.

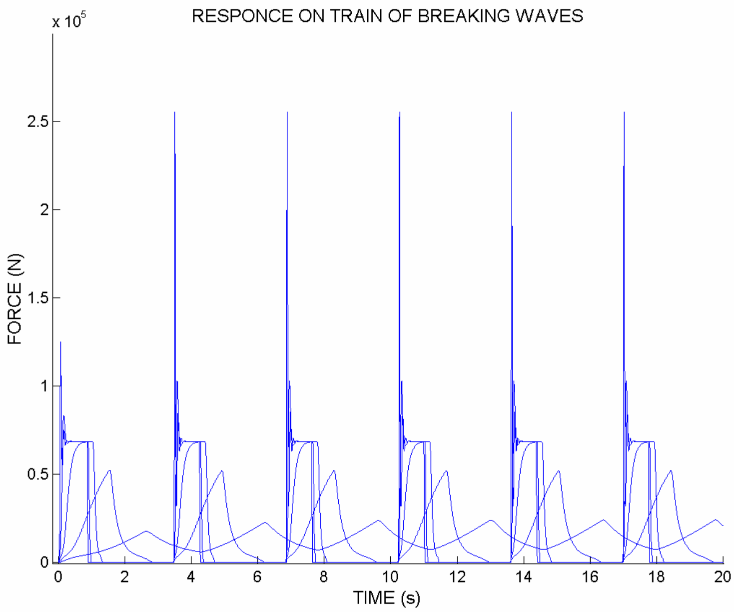


Figure 8:

The mooring force on a buoy moored with a rubber cord while breaking waves pass. Rubber cord length: 2 cm 8 cm 32 cm 1.3 m 5.1 m.

The force elongation relation of the used rubber is presented in figure 7. Elongation is presented as a percentage, 100 % corresponds to an un-stretched condition, at 200 % the rubber cord is doubled in length. For varying length of the rubber cord the simulation has been performed, see figure 8. In figure 9 is zoomed in on the second breaking wave pass. The peaked mooring forces are due to the simulation with an unrealistically short rubber cord of only 2 cm! With increasing length of the rubber cord the peak immediately disappears. Further increase of the rubber cord length results in a reduction of the maximum force to a level below the steady state level. In those cases the buoy can move along with the wave during the whole passage and is pulled back during the time in-between two breaking waves.

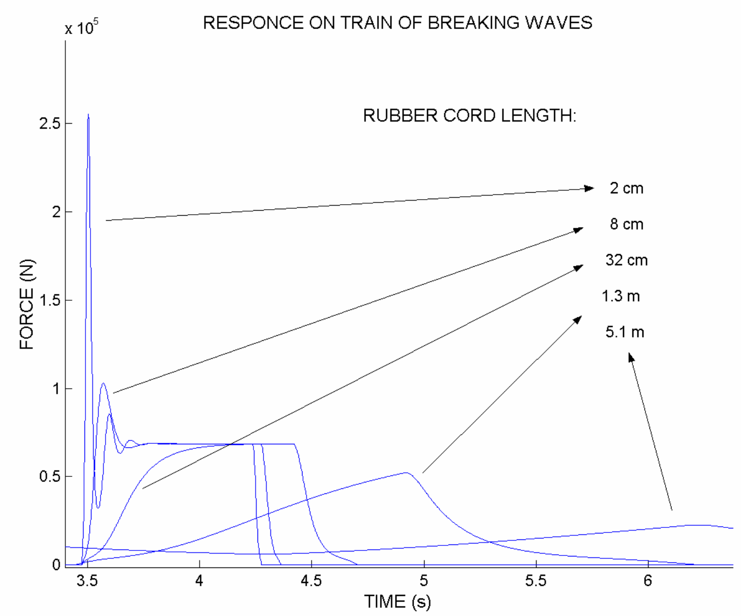


Figure 9:

The mooring force on a buoy moored with a rubber cord while breaking waves pass. Rubber cord length: 2 cm 8 cm 32 cm 1.3 m 5.1 m.

With the first breaking wave passing the buoy, the maximum forces are not as high as during the sequential waves. At t = 0 the rubber cord is in the un-stretched condition, and the front of the breaking wave just tips at the buoy. When the breaking wave passes the buoy, it is displaced in the positive direction. After this passage the buoy is pulled back by the mooring. At the time the front of the second wave hits the buoy, it may be on the left or right side of the original position point. With this new starting position the second pass will be slightly different.

Energy considerations

The applicability of the chain and rubber mooring can be considered from an energy point of view. When the buoy is picked up by a (breaking) wave it will gain kinetic energy. This energy has to be absorbed by the mooring. A chain mooring absorbs this energy by lifting up chain. The kinetic energy is transferred to potential energy. The rubber mooring transfers the kinetic energy into internal (elastic) energy. Here the difference shows up, the energy a chain mooring can absorb depends on, among others, the water depth. The energy a rubber cord can absorb only depends on the cord itself. Thus, in shallow water, elastic mooring has the greatest asset.

Conclusion

By numerical analysis it is shown that a buoy which is not adequately moored may suffer from high force peaks in the mooring line. The quality of the chain mooring depends on the length and specific weight of the chain and the water depth. If the chain is too light in weight, or not sufficiently long, peak forces can increase dramatically. The quality of the rubber moored buoy only depends on the rubber cord itself. Peak forces can be avoided independently of the water depth, making the rubber cord mooring superior in shallow water situations.

References

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