SeaTek CORP.

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DESIGN OF MOORING SYSTEMS

INTRODUCTION

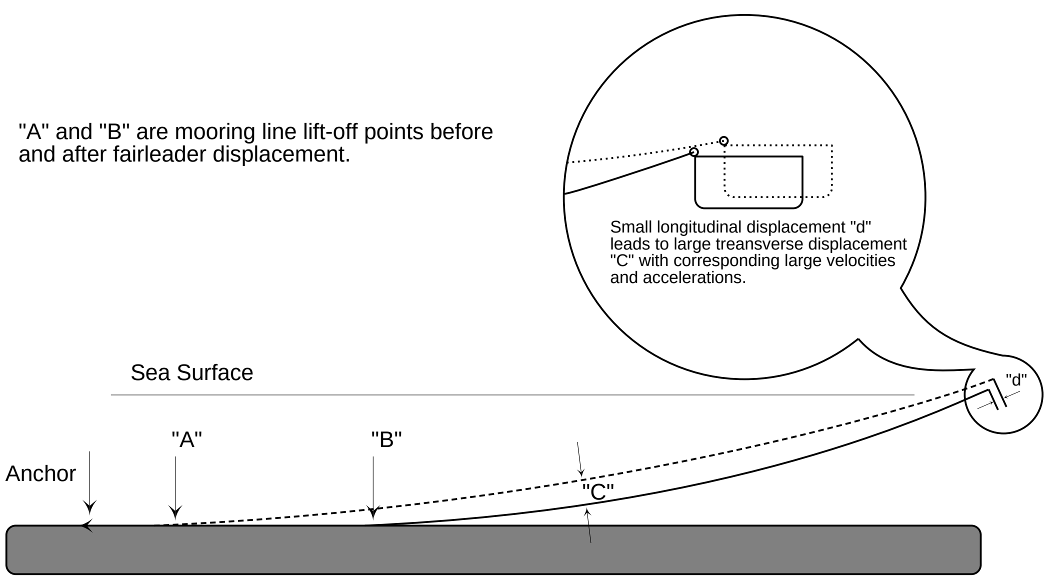
In the design of mooring systems it is customary to obtain the tensions in the mooring lines by a static catenary calculation. It is, in other words, assumed that the mooring lines are at all times at least approximately in static equilibrium.

It is pointed out in this memorandum that in the typical case of a drilling or construction vessel moored in the open sea this assumption cannot be justified. It is, in fact, possible to show that in an environment of heavy seas the peak line tensions may be as much as twice as large as those obtained in catenary calculations. An improved design procedure is very badly needed.

The reason for the failure of the catenary calculations to give the correct answers is that in the heavy sea environment the vessel, and therefore also the fairleaders, are in quite vigorous motion. It is vigorous enough to make the static equilibrium assumption completely invalid. Only when the fairleader motion is very gentle is the static equilibrium assumption approximately correct.

Figure 1

Effect of Small Change of Fairleader Location on Mooring Line Geometry (Static Equilibrium)



It is easy to see how the large dynamic forces are generated that invalidate the static equilibrium assumption. As is illustrated in Figure 1, a quite small fairleader displacement “d” can lead to a large transverse displacement “C” of the middle part of the line if it is assumed that the line is at all times in static equilibrium. Calculations show that it is not unusual for the C:d ratio to be as high as 3 to 4. Even quite modest fairleader displacements “d” occurring at some frequently occurring wave period, say 10 seconds, can therefore

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lead to substantial accelerations and velocities. There will of course be correspondingly large inertial forces and drag forces respectively. Whenever these forces are appreciable compared to the gravity force acting on the mooring lines (corrected for buoyancy of the lines) the static equilibrium assumption clearly loses its validity. Very much larger line tension oscillations will result.

While it is true that both the inertial forces and the drag forces can be large the drag forces are typically by far the largest. They are often many times greater than the gravity force acting on the line.

In summary, the static equilibrium assumption must be rejected because large dynamic forces prevent the mooring line from reaching the instantaneous static catenary configurations corresponding to the varying fairleader positions. The result is often very much increased tension oscillations and much higher peak tensions.

The effect of the dynamic forces on the response of the mooring lines will now be discussed in greater detail.

RESPONSE OF DIFFERENT KINDS OF MOORING LINES TO THE DYNAMIC FORCES

It is customary to use chain or wire rope or combinations of chain and wire rope for mooring drilling and construction vessels. On closer examination it is found that chain and wire rope typically respond quite differently to the dynamic forces. The combination lines show an intermediate response.

In examining these different responses more closely only fairleader motions parallel to the tangent to the line at the fairleader will be considered. Motions perpendicular to the tangent have, as can easily be seen, very little effect on the line tensions.

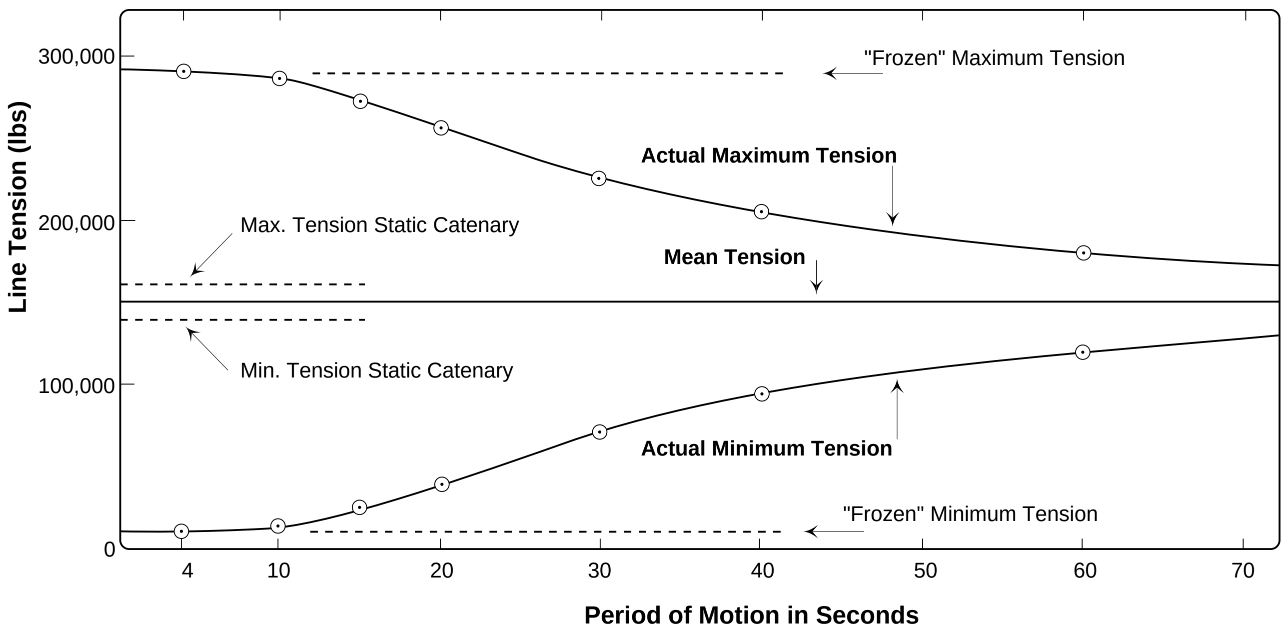
a. Wire rope. The transverse dynamic forces acting on the typical wire rope mooring line are so large that the transverse line motions are almost completely suppressed at wave heights and periods of practical interest. The line response to the fairleader motion consists then almost entirely of along-the-wire elastic stretch and contraction. This “freezing” of the transverse motion makes the calculation of the line tension very simple. The mean tension is first obtained by the static catenary method and the variable part of the tension is next obtained using only the elastic properties of the line. There is no need for additional catenary calculations for the displaced fairleader positions.

Figure 2 illustrates the behavior of wire rope lines. It shows how the maximum and minimum tensions typically vary with wave period when the amplitude of the fairleader motion is kept constant. Several things should be noted. First of all, the tension oscillations at long periods of motion (70-80 seconds) are only slightly larger than those obtained with the static catenary model. Second, at shorter periods of motion--those of naturally occurring waves--the oscillations are much larger. In this particular case they are more than ten times larger than those for the static catenary model. Third, at periods shorter than about 10 seconds the tension oscillations are essentially independent of wave period reflecting the nearly “frozen” transverse response of the mooring line. In this particular example, the maximum tensions at short wave periods are almost twice as large as the mean tension. Although this is not very unusual it should not be considered as typical.

Figure 2

Maximum and Minimum Mooring Line Tension vs. Period of Motion: Wire Rope

Water depth	1000	ft.
Amplitude of fairleader motion	7	ft.
Mean tension	150,000	lbs.
IWRC wire rope diameter	3.5	inches
Line length	4,500	ft.



A consequence of the nearly "frozen" behavior of the mooring line is that already for quite small amplitudes of the fairleader motion (5-10 ft) the line may be slack during part of the oscillatory cycle. As the motion is not completely frozen, a completely slack line is not often observed but a very nearly slack line is common in rough sea conditions as an inspection of mooring line tensiometer records will reveal. It should be noted here that for this example, when the fairleader motion is large enough for the line to just go slack at one extreme of the cycle the tension at the other extreme of the cycle will be about twice as large as the mean tension (see Figure 2). As a result the peak tensions can become very large, certainly much larger than the static catenary calculations can explain. The tension oscillations are of course increased even more by the dynamic forces. They may be as much as 10 times larger.

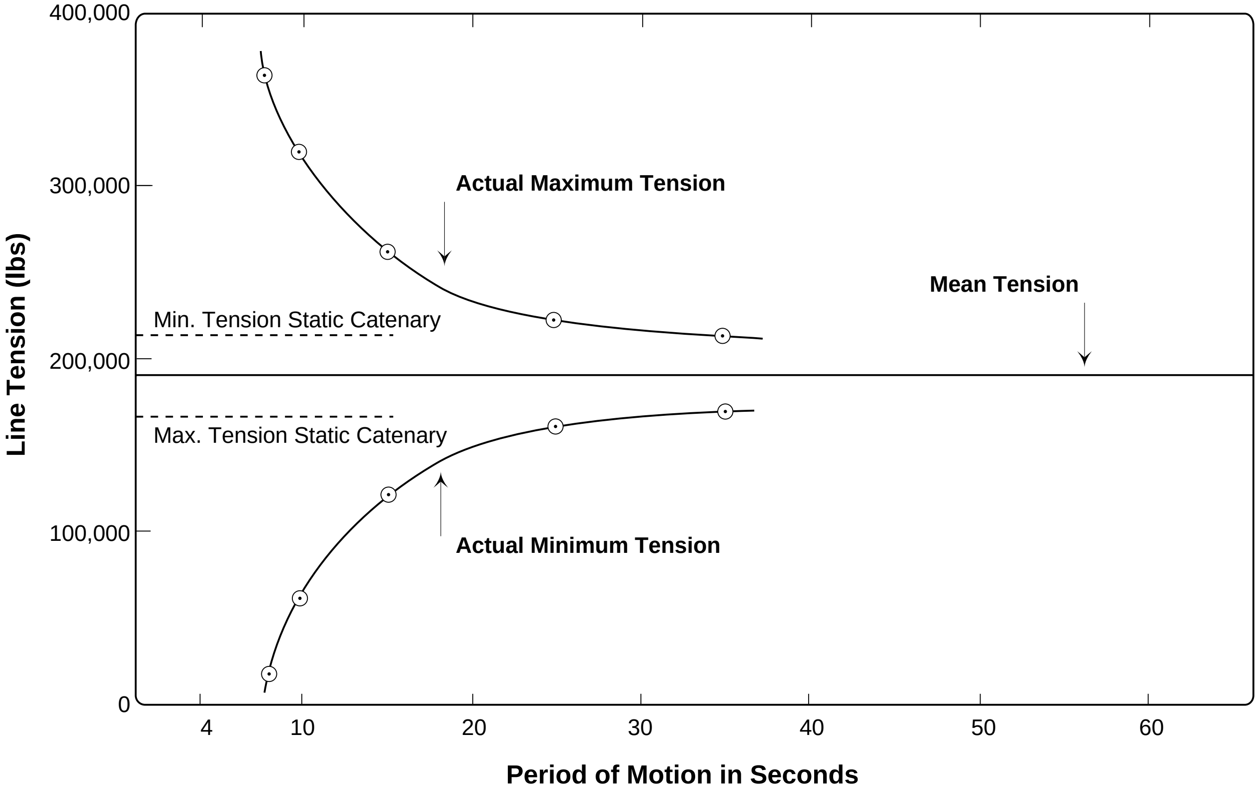
b. Chain. The properties of a typical chain mooring line are quite different from those of a wire rope line. Both the weight per unit length and the elastic stiffness are greater for chain than for wire rope for comparable lines. As a consequence an almost "frozen" chain mooring line is seldom if ever observed. The increase in peak line tension due to the dynamic forces may, however, be just as large and often is. The calculation of the peak tension is of course more complicated when the nearly "frozen" model cannot be used.

Figure 3 illustrates the behavior of chain lines. Like Figure 2 it shows how the maximum and minimum tensions typically vary with wave period when the amplitude of the fairleader motion is kept constant. The static catenary model is again quite good at long periods (25 seconds and longer) but at shorter periods it fails completely. The tension oscillations are far larger than the catenary model can account for. It should be noted that there is no evidence of a "frozen" transverse line response.

Figure 3

Maximum and Minimum Mooring Line Tension vs. Period of Motion: Chain

Water depth	500	ft.
Amplitude of fairleader motion	7	ft.
Mean tension	190,000	lbs.
Stud-link chain diameter	3	inches
Line length	2,000	ft.



Chain mooring lines can also become slack (or nearly slack) during part of the fairleader motion cycle but a larger motion amplitude is usually required for this to occur. Again, when the fairleader motion is large enough for the line to just go slack the peak tension will be about twice as large as the mean tension. The tension oscillations may be increased by as much as 10 times by the dynamic forces.

c. Chain-wire rope combinations. As can be anticipated, the dynamic properties of chain-wire rope combinations are intermediate to those of all-chain and all-wire rope lines and depend on the relative lengths of chain and rope.

STATISTICAL PROPERTIES OF THE MOORING LINE TENSIONS

In an irregular storm sea it is important to know the statistical distribution of the peak line tensions, in particular in the most exposed mooring lines. One can then for example calculate the most likely maximum line tension that can be expected in a given situation. Such statistical calculations have turned out to be very useful in describing other variables such as heave, roll and pitch in irregular storm seas. A knowledge of the r.m.s. value of these variables makes it possible to calculate the so-called significant values, the most likely maximum values in a train of 1000 waves, etc. In these calculations it is assumed that the statistical properties are adequately described by the Rayleigh distribution.

On the basis of the description given earlier in this memorandum of the typical mooring line responses to vessel motions it is clear that whenever a line is approximately "frozen" and it does not go slack during part of the motion cycle the Rayleigh distribution may again be assumed to hold. It applies of course only to the amplitudes of the tension oscillations, not to the peak tensions which must be obtained by adding the mean tension to the variable tension (which may be described by the Rayleigh distribution).

As wire rope lines usually exhibit the "frozen" behavior, it can be concluded that the usual statistical calculations are in order in the analysis of wire rope systems. For chain lines which rarely, if ever, show the frozen behavior a different kind of statistical distribution applies. This distribution is usually more nearly a simple exponential distribution. For such a distribution very large tension oscillations are more frequent than for the Rayleigh distribution. This should be kept in mind in the design of chain mooring systems.

DYNAMIC EFFECTS OF LONG PERIOD MOTIONS

The discussion given so far has been limited to the dynamic effects of importance when the vessel moves in response to the individual waves passing it (the wave frequency response). An irregular sea can however excite other vessel motions as such a sea also generates a variable drift force. This second vessel response consists almost entirely of a resonant excitation of the surge, sway and yaw motions. The natural periods of these motions are quite long, usually in the range 45 seconds to 3 minutes, so it is reasonable to assume that the static catenary approximation is appropriate for the calculation of motion responses and corresponding line tension oscillations. A closer examination reveals, however, that although this may often be the case one cannot always disregard the dynamic forces acting on the mooring lines. Their effect on the mooring line tensions is however quite different. Instead of an increase there is a decrease in the peak tension. The explanation is as follows: When the vessel moves transverse drag forces act on the mooring lines as has been pointed out earlier. The existence of these drag forces means of course that energy is being dissipated. This energy dissipation causes the amplitude of the long period oscillations to be reduced. The corresponding peak line tensions are then of course also reduced. The importance of this added damping in comparison to other damping effects due to forces acting directly on the vessel depends on the vessel characteristics, the type of mooring system, the water depth and the mooring line pretension. No simple rule can be formulated, however. The most that can be said is that wire rope lines in general cause more damping than chain lines.

IMPROVED DESIGNS OF MOORING SYSTEMS

On the basis of the discussion of the dynamic response of mooring lines given in this memorandum it may be concluded that the transverse dynamic forces acting on the line are the principal cause of mooring system failures in rough seas. It can also be concluded that such failures can often be avoided if the lines are made more elastic. This can be done by insertion of sections of synthetic fibre rope in the chain or wire rope lines. Admittedly, this complicates the handling of the mooring lines but is a solution worth considering.

It may be argued that making the lines more elastic will lead to a certain loss of station keeping capability of the system but this is not necessarily the case as a moderate increase in the pretension will in most water depths compensate for this loss.

It is of course also possible to install a second mooring system consisting of, say, four synthetic fibre ropes as a back-up for the primary chain or wire rope system. Both systems would be deployed at all times but the second one would be tensioned only in survival conditions. The primary lines would then be slacked off. Synthetic fibre rope (e.g., Nystron rope) of 7-inch diameter may be suitable in most cases. In order to avoid abrasion of the fibre rope the lower part of the line should consist of chain. Uplift on the anchors is also avoided in this way.