Flexible Mooring with Multiple Buys

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ABSTRACT

This paper discusses new mooring techniques that may improve mooring of open ocean aquaculture systems. For
multi-cage systems, the interaction between the mooring
system and the cage structure is significant, and the impact
on the cage structure must be evaluated for each system.

Helgeland Fjord A/S is the manufacturer of the well-known
Fast-Cage System. Helgeland has through the years
been involved in many projects to keep the mooring
system apart from the cage structure. In 1984 Helgeland
started MARINTEK to help them develop a
new and improved mooring system for the Fast-Cage
system.

MARINTEK and Helgeland Fjord A/S have accomplished
two major projects focusing upon improved
mooring methods. The projects have developed new
mooring techniques that give considerable reduction
in impact on the cage unit.

Present mooring methods are based upon a grid
pattern that is considered a traditional mooring system.
A traditional mooring, with
arches - mooring lines - buoy - crossfloat - and the cage,
is quite similar for all single cage systems. Recently,
the so-called system mooring, a submerged frame of
lines that acts as a base for mooring of the individual
cages, has gained popularity.

Initially, computer analysis on a fully equipped
cage unit including the mooring system was
performed. The influence of the mooring system on
cage stress is generally significant, and we also found
that the impact even from the transverse mooring lines was considerable.

By calculating the flexibility of the mooring lines by parameter variation, it was shown that the line characteristics could easily be improved by adjusting the length of the line sections of the mooring lines. Increasing flexibility implies a larger vertical displacement of the mooring buoys. The most commonly used EPS-filled buoys are hardly able to withstand any hydrostatic pressure larger than five meters water column. Other buoyancy elements, such as PVC-filled buoys, could be used, but the investment costs would increase dramatically. Looking for other solutions, it was found that small multiple floats in a row would reduce the costs compared to large single buoyancy units. Computer analyses showed that multiple floats gave large reductions of the dynamic tension in the anchor lines. This new concept was also favourable with respect to costs.

In order to verify these results, model tests were performed in MANITEX's Ocean Laboratory in December 1983. The tests were made at scale 1:20. For a range of regular and irregular sea states, the line tensions were determined in three identical mooring systems with different mooring line system mooring with two cages — one floating cage and one submerged cage, and one single cage with a multiple-buoy mooring. The cages were anchored in-line, transverse to the wave direction.

By comparing the measured line tensions from identical cages exposed to identical waves, it was found that the results from the computer simulations were realistic. The test result analyses also indicated that using a combination of the line groups may increase the dynamic excitation on the cage float. This result therefore questioned the beneficial effect of the installation of the cross-over in traditional moorings.

Introduction

The exposed location high flexibility in the mooring system is important in order to avoid high tension on the floating collar. This paper deals with mooring system geometry and buoyancy elements in the mooring, and describes the effect on the cage unit illustrated in simulation results and model tests.

Moorings system geometry and buoyancy

The purpose of a mooring line is to:
- keep the cage reasonably on-site with minimum stress on the float rings
- prevent the cage from becoming submerged in large current and wave conditions.

The mooring system must have sufficient flexibility to prevent the cage structure from being damaged. For this purpose, the flexibility from only the cages is too small, so the total flexibility is increased by adding a geometric flexibility by attaching a buoy to the mooring line.

An equilibrium consideration of a conventional mooring line, see Figure 1 given:

\[ T_x \cos \beta = T_y \cos \beta \]
\[ T_x \sin \beta + F_x = T_y \sin \beta \]
\[ d = l_1 \sin \alpha + l_2 \sin \beta \]

where
\[ l_1 = a \cdot \frac{1}{A_{ct}} \]
\[ l_2 = a \cdot \frac{1}{AE_{ct}} \]
\[ F_x = \text{bending force} \]

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Normally, \( L_b \) is on the order of 15-22 meters, and \( L_h \) is two to four times the water depth. The characteristics for different lengths of the line segments are illustrated in Fig. 2, ref 1.

These line characteristics are obtained from the formulas presented above. The buoy is treated only as a dispersive force. A correct modeling of the buoy would give a slightly different initial characteristics in the region where the buoy is partly submerged.

As can be seen from Fig. 2, increased flexibility is obtained by reducing the L/E ratio. For a traditional mooring geometry, the buoy only offers a small additional flexibility. In order to increase the flexibility, the line length between the buoy and cage, (the change), should be increased at the same time as the line length from the buoy towards the anchor should be reduced. The flexibility of the mooring line is a function of the slenderness of the buoy, see Figure 3.

Increased mooring flexibility therefore raises another problem. The traditional LPS (expanded polyurethane) filled buoys are unable to withstand higher pressure than approximately five meter submergence. We cannot therefore only adjust the length of the line segments. Such buoys will become crushed and destroyed.

![Figure 3: Mooring flexibility](image)

There are three different buoyancy materials on the market:

- continuous buoy mooring buoys (rubber, EPI, PVC)
- flexible mooring buoys (rubber, EPI, PVC)
- buoy, PVC/steel

The pressure capacity of different materials is shown in Figure 5.
The cost of different buoyancy types is illustrated in Figure 5. Prices are approximate as they vary by quality and quantity.

Figure 5: Pressure capacity for different materials

Figure 6 shows that floats are much cheaper than large single buoys. Floats are widely used in fishing and floating operations. Normally, the net buoyancy of single floats varies from one to three kg.

The floats may be threaded on the anchor line in long rows. Figure 7. Using long rows of floats is advantageous in using a heavy chain mooring, in that very smooth catenary line characteristics are obtained.

Figure 7: Two single buoys and one heavy line mooring

The two single buoy mooring lines in Figure 7 are similar in appearance, but a single vertical line up to the buoy is however less exposed to weathering. The horizontal mooring buoy has to take all the restoring force, and the wear on the eyebolt and shackles is a problem. The experience with a multiple buoy mooring is limited. However, the floats have a high durability. The float lines have a considerable material flexibility, the buoyancy is reduced to about 50 percent at 50% immersion, and they are very resistant to shock loads. The row of floats should be divided into sections of about 10 pax, separated with ladders preventing the sections from sliding on each other.

Figure 8: Cross-section of a buoy mooring line
Simulation of multiple buoy mooring

In the following example, the computer program RHLEX has been used to compare a single buoy mooring with multiple buoys having the same total buoyancy, ref 2. A circular cage structure made from polyethylene tubes together with a 60 m deep net is completely numerically modeled. The model includes short mooring lines as illustrated in Figure 8. The water depth is 201 m.

Figure 8: Multiple and single buoy mooring.

In Figure 9, the maximum line tension for the alternatives, single-buoy mooring and multiple-buoy mooring, are compared within a given wave period.

The figure shows clearly that the tensions for the single-buoy mooring are more than twice as large as compared to multiple buoys. A similar trend was also observed from other wave conditions.

One significant observation from these analyses was that even the transverse lines, 1.2 and 1.4, get very high line tensions. This is caused by the fact that the buoys are oscillating in the wave zone, and even if their net weight is low, their dynamic mass is high due to the hydrodynamic added mass. Large single-mooring buoys cause high line tensions due to their very existence. The dynamic unloading between the buoys and the cage is significant.

Figure 10 shows the equivalent stress in the float tubes for the two mooring alternatives. The stress is presented for a circumference of the cable, starting from line 1, head set. It is evident that the multiple-buoy alternative is favorable.

In this example, the ratio between the wave height and length is 1/20. For a steeper wave, the difference decreases because the bending moment about the wave surface diminishes. A ratio of 1/20 is fairly representative for a normal sea state.

Figure 10: Comparative equivalent stress.
Model tests of different mooring systems

In December 1995 we performed a model test in scale 1:3 at MARINTEK's Ocean Laboratory, cf. No! Bohmer's et al:ke definition. Two cages in a system mooring were compared with an individually multi-body moored cage, Figure 11.

![Diagram of mooring systems](image)

Figure 11: Arrangement in the laboratory

- Cage 1 was a multi-body moored single cage.
- Cage 2 and 3 were both moored in a 3m submerged frame.
- Cage 2 was floating.
- Cage 3 was submerged to app. 7m depth.

All three cages were identical with respect to floating, collars and net. Cage 3 had 30 percent heavier clamp weights than cage 1 and 2. The collar stiffness was not validated, but was equal for all the cages. The stiffness of the collars was too high.

Detailed system description is not presented here, but is described in Ref. 3. The systems mooring geometry is according to normal practice by several manufacturers.

The multi-body mooring had a net buoyancy of 5.76 kN in each line.

![Graph of significant wave height vs. tension](image)

Figure 12: Comparison between

The face tensions were measured on each occasion. The plotted results are achieved by adding the tension in both parts of the crossfoot. Due to the unequal cages, one floating and one submerged, we got a non-symmetric response on the cages in the frame. However, the coupling between responses for cage units in a system mooring will always be considerable and probably more pronounced with more cages and different seas.

The multiple moored cage gave about 50 percent reduction in significant tension (T10) compared with the floating system moored cage, and was in magnitude comparable with the submerged cage.

The submerged cage is not further discussed in this paper. The item will, however, be presented in the near future.

Analysis of the tension time series in the crossfoot showed that the variance of the tension in a single
crossfoot was greater than the variance of the sum of both, which is equivalent to the tension in the anchor line. This means that the crossfoot does not distort the dynamic response. Therefore the dynamic impact at the clamp point on the collar increases by using a crossfoot instead of a single line. On a four-line mooring, the capstan tension in an upstream line will be distributed by a crossfoot, and it is therefore preferable. On systems with more anchor lines, say six to eight, there will be at least two sandwich lines, and the advantage of the crossfoot could be debatable.

Conclusions

Traditional mooring methods using single buoys and long anchor lines are unfavourable. Only a slight increase of the flexibility is achieved. The presence of a buoy attached near to the cage causes large impacts on the cage due to the relative motion between the cage and the buoy.

A system mooring solution with a rigidly mounted frame also causes high impact on the cage during due to the relative motion between the cages.

Increased flexibility may be gained by changing the segment lengths. By increasing the segment length between the cage and the buoy in combination with a reduction of the segment length towards the anchor, the line characteristics are improved.

The geometric flexibility of a mooring line is related to the movement, submergence, of the buoy.

Increasing geometric flexibility in the mooring line necessitates high pressure capacity buoyancy elements. Replacing large single buoys with a multiple number of low pressure buoys is a favourable solution.

Multiple buoy systems reduce the stress in the cage collar. In a low static situation, a smaller part of the buoyancy is acting near the surface, and the dynamic loads in the line itself is reduced.

A crossfoot does not necessarily distribute the dynamic loads. The load variation in a crossfoot line is normally larger than in a single line. The crossfoot is necessary on a four-line mooring in order to distribute the static load. On a six-point mooring, it is probably better to choose one line instead of a crossfoot.

REFERENCES

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