Stochastic Mooring Analysis of Aquaculture Installations

Master Thesis by Malin Bjørkøy

1 BACKGROUND

Since modern commercial aquaculture begun in Norway in the early 1970's, the industry has experienced rapid development and growth. Aquaculture installations are getting larger, the environmental conditions become tougher, and the fish farms are moved to more exposed sites. This entails stricter requirements for structural design to avoid fish escape, and increased use of advanced technology is essential to meet the new challenges the industry face.

Today, the industry perform design analyses with regular waves as "best practice". As the environmental conditions at the fish farm locations get harsher, regular wave analyses will not be sufficient to describe the realistic response of the structure. Improved analyses that address the variability of the environment and uncertainty in estimation of loads should be applied.

2 OBJECTIVE

1. Perform numerical simulations of mooring line tension for different environmental conditions
2. Study the effect of interaction between current and waves in regular and irregular conditions
3. Propose a method for determining the annual distribution of extreme mooring line tension when there is lack of simultaneous environmental data
4. Compare the distribution of load and strength with different ways to calculate characteristic load:
   (i) Static analyses with current only
   (ii) Dynamic analyses in irregular waves
   (iii) Dynamic analyses in regular waves

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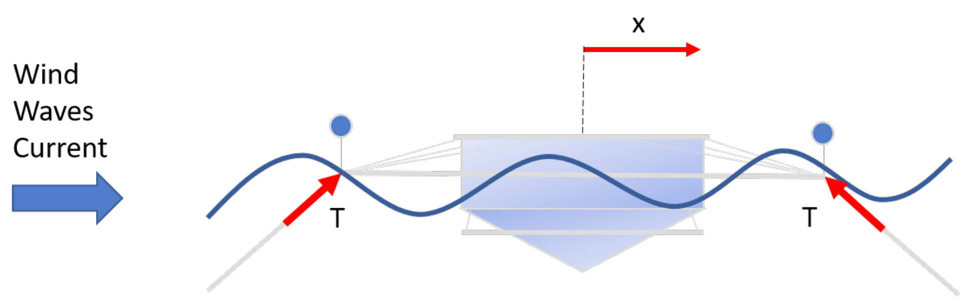

Figure 1: Aquaculture cage exposed to wind, waves and current. x indicates horizontal offset and T represents mooring line tension.

3 METHOD

Dimensioning of components in the aquaculture industry is based on the *partial coefficient method,* which requires that the maximum load effect, S, must be lower than the minimum strength of the component, R, with sufficient probability:

$$S \leq R$$

The concept is illustrated in figure 2. Distribution curves describe the uncertainty and variability of the load and strength, which is important to assess in design analyses. The probability of failure is indicated on the figure by the grey shaded area where the two distribution curves overlap.

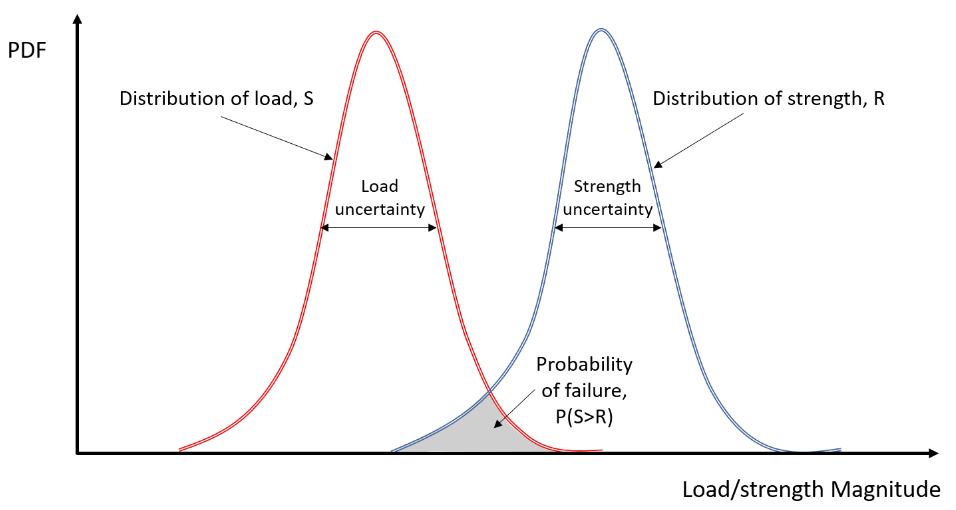

Figure 2: Illustration of the partial coefficient method

The partial coefficient method ensures that the loads imposed on the fish farm does not exceed the strength of the different components, by applying safety factors that account for uncertainties in load and response, as well as material properties. This gives:

$$S_C \times \gamma_f \leq \frac{R_C}{\gamma_m}$$

Where S_C represents characteristic load determined from simulations and γ_f is the corresponding load factor. R_C represents the characteristic strength, equal to minimum breaking load of the component, and γ_m is the appropriate material factor.

The effect of safety factors is illustrated in figure 3. S_D is the resulting design load after application of the load factor, γ_f, while R_D is the resulting design strength after application of the material factor, γ_m [1].

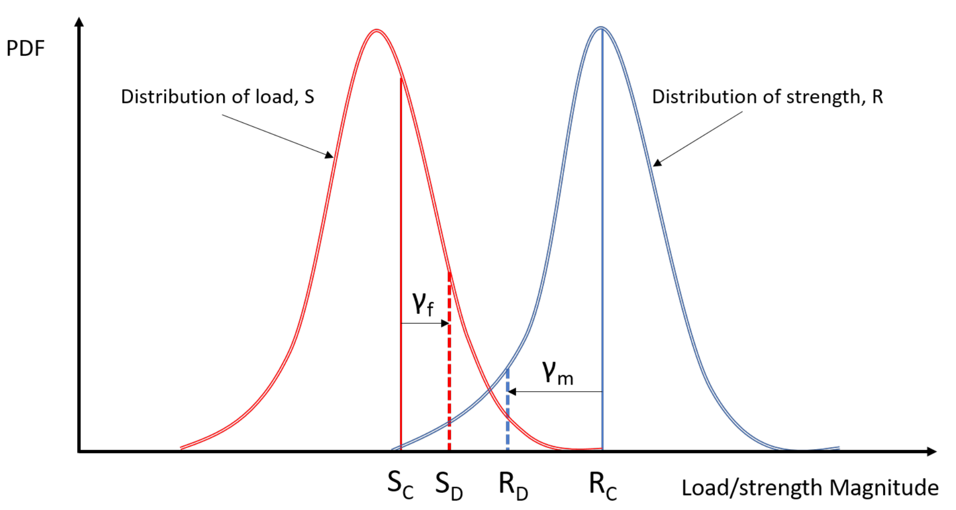

Figure 3: Partial coefficient method with variables

4 RESULTS

Resulting design load from the three approaches (i), (ii), and (iii), are presented in table 1.

Type of Analysis	Charateristic load S_C	Load factor γ_f	Design load $S_D = S_C \gamma_f$
Static	1.0251×10^5 N	1.6	1.6994×10^5 N
Irregular	1.8578×10^5 N	1.15	2.1365×10^5 N
Regular	4.9458×10^5 N	1.15	5.6877×10^5 N

Table 1: Design loads resulting from from different approaches

Characteristic load determined by the three approaches showed significant deviations in resulting design load. Simulation in regular conditions gave more than three times higher design load than static conditions, and more than twice as high as the design load in irregular conditions.

The resulting annual distribution of extreme mooring line tension and component strength are shown in figure 4, together with design strength, and design load determined from the three approaches (i), (ii), and (iii).

The results showed that the two distribution curves did not overlap at all, which indicates that the probability of failure is extremely small.

Figure 5 show probability of exceeding the specific design load for each approach. Static analyses indicate probability of exceeding the design load of about $10^{-1.5}$, which corresponds to once every 50 year. Irregular analyses show probability of load exceedance of less than once per 100 year. Regular analyses, on the other hand, which is the standard design approach, indicates probability of exceeding the design load of $10^{-9.5}$, which can be considered extremely low.

Also, regular analyses do not capture the variability in load effect, which can be seen from the distribution of load in figure 4. Irregular conditions cause second-order effects that can have significant contributions to response of the structure, but these effects cannot be seen from standard regular analyses performed according to the industry practice.

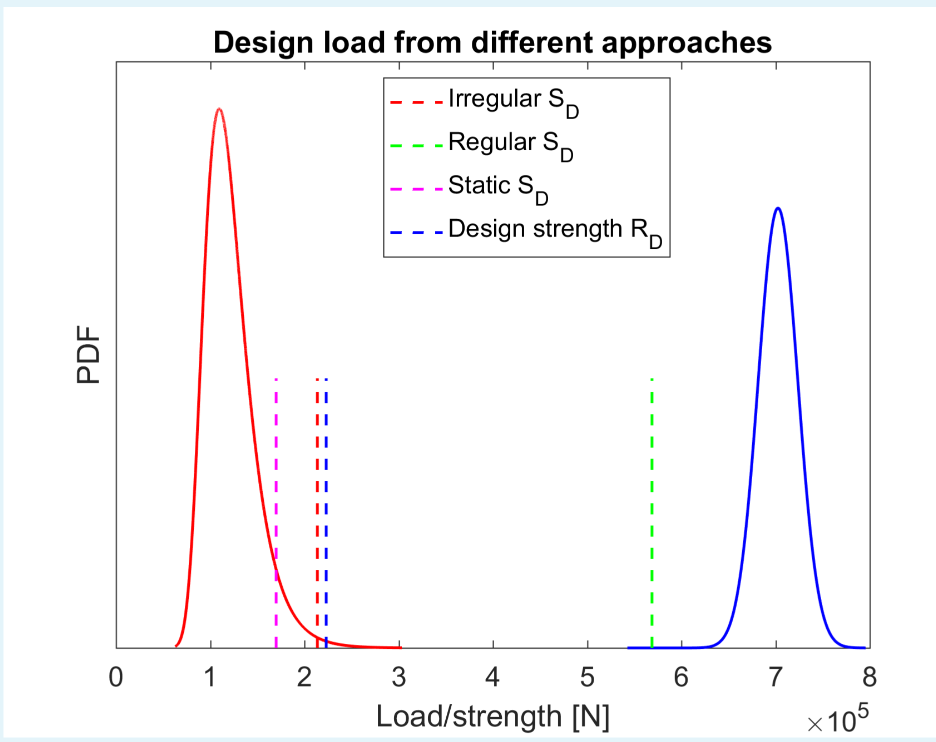

Figure 4: Distribution of load and strength with design loads

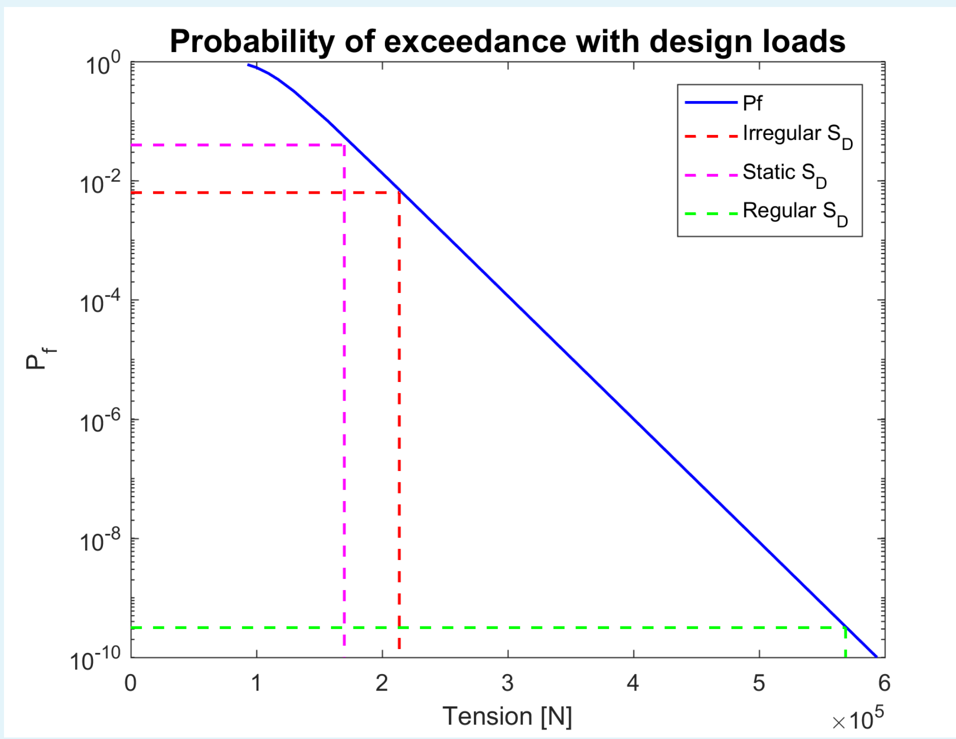

Figure 5: Probability of load exceedance with design loads

5 CONCLUSIONS

The results showed that selection of analysis approach had significant impact on the required dimensioning load. By choosing the approach that gives the lowest design load, the requirements for component strength could be significantly lowered, and money can be saved. The design approach applied in the industry today should be improved, such that selection of method does not impact the strength of the components.

This Master Thesis concludes that design analyses should be conducted with irregular environmental conditions to be able to study the behavior of fish farms in more realistic environments, and capture the variability of sea loads. The challenges that comes with more exposed sites should be modelled correctly to ensure that the installations are fit for harsher environmental conditions.

REFERENCES

[1] Standard Norway (2009). NS9415. Marine Fish Farms: Requirements for design, dimensioining, production, installation, and operation. Rev.ed.