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Fatigue Reliability and Life-Cycle Cost Analysis of Mooring Chains

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ABSTRACT

Mooring line failure is a major concern in the design of floating production and loading systems. Chain breakage may occur during a dynamically extreme loading condition or due to fatigue damage introduced by the repetitive dynamic load spectrum during long-term operation. Reliability methods can be applied by the designer to prevent a high probability of line failure and to achieve a cost-effective design. In the present work, a lognormal model is used to derive the probability of fatigue failure as a function of service time. The uncertainties in the fatigue capacity and the modeling errors of both the dynamic loading and the damage calculation are included. A parametric study is carried out, and expected life-cycle costs are estimated. The results are discussed in the light of the fatigue design factor specified in current rules and recommendations.

INTRODUCTION

The technology for floating loading and production systems for oil exploitation is growing rapidly. The systems are based on conventional catenary mooring line configurations using wire ropes and chain segments. The installations represent in most cases a safe low-cost alternative when compared to other types of structures. To ensure safe operations of the systems, reliability against line failure is a major concern in design and for in-service inspection. The wire ropes and the mooring chains are intended for long-term operation with a minimum of maintenance. Although mooring systems are redundant and can continue to operate temporarily with one line broken, the failure consequence may be unscheduled downtime and high repair costs. The present report addresses the problem of fatigue failure of mooring chains due to the fact that they are more vulnerable to fatigue damage than wire ropes. Furthermore these segments have high investment costs and are normally not accessible for in-service inspection. Normal fatigue design of chain segments is based on constant amplitude tension data. The number of cycles N to failure is given as a function of the applied tension range ratio R. These capacity data are used under variable amplitude loading by the application of the Miner summation rule. The design R-N curve is chosen as the mean curve minus two standard deviations to account for the scatter in test result. Additional safety is introduced by a Fatigue Design Factor (FDF), defined as the ratio of predicted fatigue life/target service life. This is to account for other sources of uncertainty, mainly the errors involved in modeling of the dynamic forces introduced in the mooring lines by the environment (waves, wind current) and the calculation scheme for the fatigue damage. The magnitude of FDF may vary because of different requirements and recommendations (API 1993, NPD 1992). Typically values are 3 or 10. API recommends a factor of 3, while NPD prescribes a factor of 10 if a mooring line failure is defined to have a strong bearing on structure integrity and is impossible to inspect during service. The chain dimensions according to these two values of FDF will be quite different, and so will the investment costs and expected Life-Cycle Costs (LCC). If the FDF is too low, line failure may occur with severe economical impact due to necessary intervention and repair by replacements. On the other hand, a high FDF may also be considered a waste of money, i.e., the mooring lines are too heavy and expensive. On this background the scope of the present work is twofold:

- Establishing a reliability model to calculate the probability of failure for the most heavily loaded chain segment as a function of service time. The model should account for the scatter in fatigue test data, the uncertainty in damage calculation and the error in load modeling.
- Using the reliability parameter to calculate the expected LCC and search for the optimum chain dimensions, constrained by current rules and recommendations.

CALCULATIONS ACCORDING TO RULES AND RECOMMENDATIONS

Fatigue life prediction is made by comparing the long-term cyclic tension loading in the mooring chain with the capacity given by the R-N curve. A recommended procedure is described in API (1993). The R-N curve reads:

$$N=\frac{K}{R^{M}} \tag{1}$$

where R is the force range divided by a reference breaking strength, K is the fatigue strength coefficient, and M is the fatigue strength exponent. These parameters are derived by least square analysis of experimental results in log-log scale, giving the slope

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KEY WORDS: Floating loading systems, mooring chains, fatigue reliability, life-cycle costs.