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Sensitivity Study of Extreme Value and Fatigue Damage of Line Tension in Mooring System with One Line Failure under Varying Annual Environmental Conditions

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ABSTRACT

Mooring systems are usually designed against ultimate and fatigue failure of individual lines as well as to survive a certain environmental condition with one line failed. Depending on the system configuration, failure in one mooring line could obviously increase the loads in the remaining lines, especially in the adjacent lines. Increasing extreme line tension and induced fatigue damage will also depend on the environmental conditions that the mooring system could experience after damage. The annual variation of sea wave conditions also leads to a significant variation of the predicted line tension. In this paper, annual extreme values of mooring line tension have been estimated both by full long-term analyses and by the contour line method for an intact mooring system and for a damaged one, respectively. On the average, an increase of 20% and 30% in extreme tension are obtained in the adjacent line due to a single line failure in a 16-line system and in a 12-line system, respectively. Long-term fatigue damage induced by line tension has also been summed up from the short-term contributions which are estimated by a bi-model fatigue formulation and an average increase of the annual damage by 50% and 90% are obtained due to failure for the 16-line and 12-line systems.

KEYWORDS: mooring system; line failure; extreme tension; fatigue damage

INTRODUCTION

Mooring system of floating structures is usually designed against ULS (Ultimate Limit State), FLS (Fatigue Limit State) and ALS (Accidental Limit State) by using the LRFD (Load and Resistance Factor Design) method. Partial safety factors are calibrated by detailed structural reliability analyses and specified by many design codes, e.g. API RP 2SK (1997), DNV-OS-E301 (2004), ISO 19901-7 (2005), etc.

Design checks both for ULS and for ALS are made by comparing line capacity and extreme line tension under a design environmental condition for an intact system and for a damaged system with one line failure, respectively. Compared with an intact system, it is obvious that both static and dynamic tensions in the remaining lines of a damaged system, especially in the adjacent lines, increase under the same environmental condition. Moreover, the failure rate of one mooring line due to abnormal reasons (e.g. abnormal strength due to abnormal fabrication defects/lack of quality assurance or abnormal loads, e.g. by erroneous winching operation, etc.) is shown by experience high, around 1% annually (Haver et al., 1999). This problem can not be dealt with by structural reliability analysis. In a risk analysis perspective, it is useful to know the performance of a damaged mooring system and the corresponding safety level, i.e. conditional failure probability.

At the same time, the increased dynamic line tension in a damaged system will of course induce more fatigue damage. When the failed mooring line has not been identified or has been identified but not repaired or replaced for a long time, e.g. one winter season, the increased fatigue damage could be considerable. However, the design code gives no guidance on this consideration. Safety level implied by the ultimate strength check could be recovered from a damaged system to an initial intact system when the failed line is repaired or replaced, although it is also influenced by many degrading mechanisms in sea water, like corrosion, wear, cracking, etc. On the other hand, the accumulated fatigue damage under a damaged condition becomes permanently a part of the total damage the line could experience during a service life. The effect of increased fatigue damage does not disappear after line repair.

It is interesting to see how a mooring system behaves after one line failure and what effect is on the safety level in terms of extreme line tension and induced fatigue damage. It is believed that a steady state response of a damaged system over the next few hours, days or months gives the most critical situation for the remaining lines and a transient analysis of the first few minutes might not be necessary for ALS (DNV-OS-E301, 2004). Moreover, the safety level of a damaged mooring system is quite sensitive to the relevant environmental condition and the duration when the system is kept damaged. Environmental condition is varying even for a relative large time scale, e.g. one year, and variation in the averaged statistics can be significant. Response of a damaged mooring system under these varying conditions could also be of interest.

Therefore, in this paper, steady state analyses of a mooring system of a semi-submersible with one line failed have been performed in the