Ocean Engineering 156 (2018) 550–563

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Mooring system fatigue analysis for a semi-submersible

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ARTICLE INFO

Keywords:
Semi-submersible
Fatigue assessment
T-N curves
S-N curves
Fracture mechanics (FM)

ABSTRACT

T-N curves, S-N curves, and fracture mechanics (FM) based mooring system fatigue analyses for a semi-submersible are presented. Stress ranges are calculated based on the tension ranges of mooring lines subjected to the combined loading process induced by the motions of wave frequency (WF) and low frequency (LF). A comparison between T-N curves, S-N curves, and FM based mooring fatigue analyses for the semi-submersible is made and the results show that the fatigue lives predicted by the three approaches are in general comparable if the safety factors suggested by API and DNVGL are considered in the T-N and S-N curves based approaches. In addition, the crown section of a mooring chain is prone to fatigue damage compared to bend and weld sections without considering the SCF. A parametric study to investigate the impact of initial crack shape, critical crack depth, and initial crack sizes on fatigue life of a mooring chain is also conducted and the results show that fatigue life of a mooring chain predicted by the FM approach is generally sensitive to initial crack shape and initial crack sizes, however, it is relatively insensitive to the critical crack depth.

1. Introduction

Safety is crucially important for offshore floating structures. However, over the past few decades, mooring accidents of permanent floating structures occurred at a high rate. Ma et al. (2013) reported that 23 mooring failures happened from 2001 to 2011, in which three failures were due to fatigue. Kvitrud (2014) reviewed 15 mooring failures in Norwegian sea during 2010–2013 and one third of them were fatigue failures. These accident reports clearly indicate fatigue failure has become one of critical failure modes of a mooring system. There is thus a need to develop rational methods for fatigue assessment of a mooring system during the design phase.

The attempt to understand the fatigue behaviour of offshore mooring chains was done by de Laval (1971) who conducted a series of fatigue tests on mooring chains. van Helvoirt (1982) performed experimental studies to investigate the static strength and the fatigue strength of 3-inch studlink chains and of three types of 3-inch connecting links (Kenter, Baldt, and D shackle) in high-cycle fatigue range in an artificial sea-water environment. Based on the results from a four-year DNV project on mooring lines, S-N curves for mooring chain links were summarized by Lereim (1985). A series of experiments for the mooring lines of offshore floating structures were launched by API (1993) and the T-N curves for mooring line fatigue designs were released.

Afterwards, considerable work was conducted on mooring system fatigue analysis using the T-N or S-N curves based approaches. Lassen and Syvertsen (1997) applied T-N curves to predict the fatigue damage of mooring lines. Horde and Moan (1997) carried out mooring fatigue analysis accounting for the combination of low frequency and wave frequency motions. Gao and Moan (2007) performed a frequency-domain analysis for bimodal nonGaussian fatigue damage prediction of mooring lines based on a simplified mechanical model and S-N curves. Olagnon and Guédé (2008) proposed approximate formulae for predicting mooring line fatigue damage with a combined spectrum of one or several narrow-band low frequency loads and a higher frequency load based on S-N curves. Xu et al. (2014) performed fatigue analysis for a net cage mooring system using both the spectrum analysis method and the rainflow counting method. Wu et al. (2015) conducted mooring fatigue analyses for semi-submersibles using the frequency-domain analysis based on T-N curves where low frequency and wave frequency loading and their combination are considered.

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https://doi.org/10.1016/j.oceaneng.2018.03.022
Received 18 May 2017; Received in revised form 7 February 2018; Accepted 6 March 2018

Recently, there are some attempts of the application of fracture mechanics for mooring system fatigue analysis. Mathisen and Larsen (2004) applied the linear elastic fracture mechanics to predict the mooring chain fatigue life and initial cracks are assumed to grow from the surface of a chain link with a semi-elliptical shape. Lassen et al. (2005) conducted a series of experiments to investigate the crack growth behaviour of high strength mooring chains in a corrosive environment and S-N curves based approaches and the linear elastic fracture mechanics analysis were performed to compare with experimental results. Lardier et al. (2008) performed both S-N curves and the linear fracture mechanics based fatigue analysis for mooring lines considering corrosion effects and correlation between chain links. Palin-Luc et al. (2010) and Pérez-Mora et al. (2015) conducted a number of experiments on R5 grade steel to investigate the effect of corrosion on very high cycle fatigue strength. A fracture mechanics analysis in which the stress intensity factor is estimated with hemispherical surface defects combined Paris-Hertzberg-Mc Clintock crack growth rate model was performed to compare with experimental results.

As seen from the above literature review, a mooring fatigue analysis is traditionally conducted based on T-N curves or S-N curves and there is relatively less work done on fracture mechanics analysis. This paper is to perform T-N curves, S-N curves, and fracture mechanics based mooring fatigue analyses for a semi-submersible installed in Gulf of Mexico (GoM). Stress ranges are calculated based on the tension ranges of mooring lines subjected to the combined loading process induced by the motions of wave frequency (WF) and low frequency (LF). For fracture mechanics analysis, the chain links of mooring lines are treated as round bars and initial surface cracks are assumed to propagate at the surface of chain links. The stress intensity factor ranges are then calculated based on a finite element analysis. A comparison between T-N curves, S-N curves, and fracture mechanics based mooring fatigue analyses for the semi-submersible is made and a parametric study to investigate the impact of initial crack shape, initial crack sizes, and critical crack depth on fatigue lives of mooring lines is also conducted.

2. Semi-submersible and mooring systems

A four-column ring pontoon semisubmersible with 16 mooring lines operated at the Gulf of Mexico is considered in this paper. Two types of mooring systems, namely, catenary and taut mooring systems with four cases are designed for the semisubmersible.

2.1. Semi-submersible hull

The semi-submersible hull comprises a ring pontoon and four vertical, surface piercing columns. The platform structures under main deck are symmetric in both east-west and south-north directions. The geometry of platform hull is shown in Figs. 1 and 2 and the principal dimensions of platform hull are listed in Table 1.

2.2. Mooring systems

The semi-submersible is spread moored with 16 (4 × 4) homogenous material mooring lines emanating from four corner columns. The mooring system is symmetric in both east-west and south-north directions. Mooring line 1 is 37.5° clockwise from platform north and each two neighbouring mooring lines in the same cluster lay with 5° separation. The detailed layout of mooring lines with numbering is shown in Fig. 2.

Four mooring systems (A, B, C and D) are designed for this semi-submersible. Cases A and B are taut mooring systems. Cases C and D are catenary mooring systems. For each mooring system, the operating water depth is 6000 ft and the design life is 25 years. Each mooring line consists of a 6-inch R4 grade studless bottom chain, a 267 mm polyester rope, and a 150 m long 6-inch R4 grade studless top chain. The length of bottom chain is 210 m and the top chain is 150 m long. The polyester ropes are 2600 m long with four segments. The wear and corrosion rate of mooring chains is assumed be 0.5 mm per year. The normal and longitudinal drag coefficients are set as (2.4, 1.15) for chains and (1.2, 0.1) for fibre ropes, respectively. The friction coefficient between the bottom line and seafloor is assumed to be 1.0 for catenary mooring systems. The connecting links jointing each mooring line segment are considered in Cases A and C but not accounted for in Cases B and D.

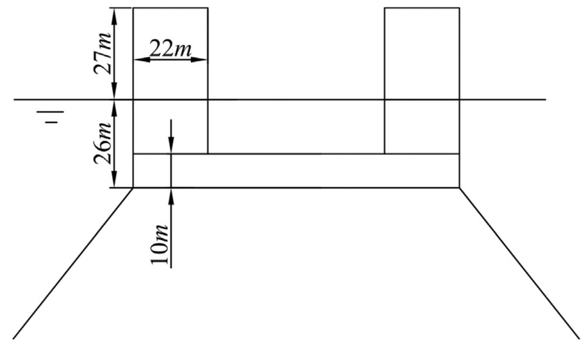

Fig. 1. Geometry of the semi-submersible.

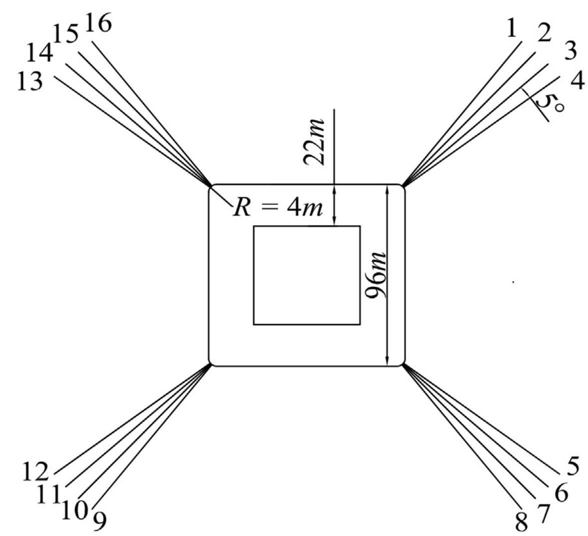

Fig. 2. Layout of mooring lines of the semi-submersible.

The details of the four mooring systems are summarized in Tables 2 and 3.

2.3. Environmental conditions

The semi-submersible is assumed to be installed and operated at the central of Gulf of Mexico. The typical wave, wind and current conditions of the central of Gulf of Mexico have been taken into account in the mooring fatigue analysis (API RP 2MET, 2014). Compared to a ship-shaped vessel, the semi-submersible is relatively insensitive to the directions of wave, wind and current. The spread mooring system is

Table 1
Principal dimensions of the semi-submersible hull.

Parameter	Value
Draft	26.0 m
Overall length	96.0 m
Column corner radius	4.0 m
Freeboard to top of column	27.0 m
Pontoon height	10.0 m
Pontoon width	22.0 m
Platform displacement	98,000 t