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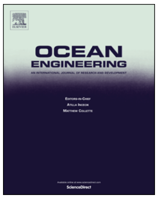

Mooring line damping due to low-frequency superimposed with wave-frequency random line top end motion

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ABSTRACT

The slow drift motions would lead to a serious influence on moored floating structures and cause the failure of mooring and riser systems. Mooring line damping which represents the transfer of energy is important for moored floating structures. In this paper, time domain finite element method was applied by using OrcaFlex. A series of mooring line top end motions was simulated to investigate the relationship between mooring line damping and low-frequency superimposed with wave-frequency random motion. A transformation method was introduced that wave-frequency random motion was transferred to an equivalent sinusoidal motion based on the spectral density of vessel motion. Then, the influence of equivalent sinusoidal motion and random motion on mooring line damping was compared. It can be found that mooring line damping could be reduced slightly if considering random motion. Finally, the influence of individual parameter which includes current speed, drag coefficient, added mass coefficient and pre-tension on mooring line damping was studied. The results showed that the significant status of drag coefficient and pre-tension on the predication of mooring line damping. But for current speed, the effect on mooring line damping cannot be overstated for considering random motion but the reverse is true for considering sinusoidal motion.

1. Introduction

The motion of moored offshore structure is mainly resulted from and dependent on the static and dynamic environmental loads. The first-order motion and second-order motion which are excited by different components of environmental loads are taking place at wave-frequency range and well below the wave-frequency range respectively. Normally, the natural frequency of the floating structure's surge motion or sway motion is close to the frequency of second-order wave loads. As a result, the low-frequency slow drift motions at resonant frequencies are one of the characteristic features of moored floating structures causing large horizontal excursions. The amount of the low-frequency surge or sway damping plays an important role in determining the maximum horizontal excursions. Generally, the main sources of the total damping which includes viscous hull damping, mooring line damping, wave drift damping, etc. are coming from the structure itself and mooring system.

It was presented that that the mooring line damping might be a main contribution to the total low-frequency damping of the system in certain circumstances (Huse and Matsumoto, 1989). It was also proved that the mooring line damping was the key component of the total damping through the comparison with other sources of damping (Matsumoto, 1991). For some ship-like structures such as FPSOs, the mooring line damping plays the key role in determining the maximum excursion and peak line tension since the inherent damping in surge motion is very low for those kinds of vessels (Webster, 1995). Through the coupled analysis of dynamics for moored floating structures, the prediction for the amount of damping from mooring line is important to predict the low-frequency motion of the vessels as it accounts for a large contribution to the total damping (Ormberg and Larsen, 1998). Therefore, the effect of mooring line damping should be taken into consideration in order to predict the motion response of moored floating structures. It was known that the mooring line damping has limited influence on the wave-frequency motion, but the influence on low-frequency motion cannot be overstated (Huse, 1986). But, the combination of wave-frequency motion and low-frequency motion would lead to an obvious increase of the low-frequency mooring line damping (Huse and Matsumoto, 1988, 1989; Dercksen et al., 1992). The explanation for this phenomenon was that the drag coefficient is enlarged owning to the variation of the drag force acting on the mooring line with relative velocity between the fluid and line itself (Huse,1991).

Brown and Mavrakos (1999) found that the superimposed wave-frequency sinusoidal motion had a significant effect on the

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low-frequency mooring line damping that it would show a dramatic upward trend compared with those under low-frequency motion only. The results showed that a wave-frequency motion of 5.4 m amplitude at 10 s period will increase the low-frequency damping by a factor of 7.1 and 2.0 for two different systems respectively. And the increasing factors were 8.8 and 2.4 respectively when amplitude of wave-frequency motion increases from 5.4 m to 8 m. Experimental model test was carried out by Kitney and Brown (2001). The tensions of the mooring line measured in the experiment were acceptable agreed with the results from dynamic analysis. According to the results described as enclosed area in indicator diagram, it was found that the combination of low-frequency and wave-frequency motions leaded to a significant increase of the low-frequency mooring line damping. Johanning et al. (2007) predicted the motion of WEC devices by using the time domain finite element method. The effect of wave-frequency top end motion was considered in a different approach that the frequency ratio (top end motion frequency over natural frequency of the mooring line) was introduced. The results suggested that the dissipated energy caused by mooring line showed an upward trend with the increase of the frequency ratio. Besides, this trend would be more obvious and significant with the increase of the mooring line pre-tension.

A fully dynamic finite element method was performed to calculate the tensions of mooring line and mooring line damping with the indicator diagram plotting according to the relevant non-dimensional parameters by Webster (1995). The parametric study showed that the pre-tension of the mooring line had a significant influence on the mooring line damping. It indicated that the mooring line damping will firstly show an upward trend with the increase of the drag coefficient and motion frequency at low pre-tensions, but the reverse was true if the pre-tensions are high. That is to say the elastic stretch of mooring line has a significant effect on the damping values since it will become domain at high pre-tensions while its effect can be neglected if the pre-tensions are low. Besides, the results showed that the current effect on the damping is very slight. It might be true if the velocity of the mooring line motion is fast. If just consider a low-frequency motion the effect might be quite different. Qiao and Ou (2010) proposed a parametric study on mooring line damping due to low-frequency motion only by using time domain finite element method. The damping resulted from friction force at seabed and drag force along mooring were both taken into consideration. It was found that the damping due to drag force constitutes the vast majority of the total damping and different seabed friction coefficient had a limited influence on the mooring line damping. Qiao and Ou (2011) also investigated the effect of current speed on mooring line damping due to low-frequency motion. The results showed that the mooring line damping had an upward trend with the increases of the current speed.

Most researches focus on the mooring line damping corresponding to pure low-frequency motion or pure wave-frequency motion. And also the parametric study was carried out in this background. In this paper, the effect of the superimposed wave-frequency random motion on the low-frequency mooring line damping will be investigated. Meanwhile, the wave-frequency random motion will be transferred to an equivalent sinusoidal motion by using an energy based method. Then, the comparison between the effects of those two kinds superimposed wave-frequency motion on low-frequency mooring line damping will be carried out. Finally, parametric study is performed to investigate the influence of each individual parameter on mooring line damping due to low-frequency superimposed with wave-frequency random motion as well as with wave-frequency sinusoidal motion respectively.

2. Methodology and modeling

2.1. Time domain finite element method for calculating mooring line damping

The top end motion of the mooring line is illustrated in a time history file to input or directly pre-defined in the program. The top end motion can be low-frequency motion, wave-frequency motion or a combination of them. The horizontal component of tension at mooring line top end will be calculated and outputted as a function of the time during one low-frequency period cycle of vessel surge motion. Then integrate the product of the horizontal component of tension multiplying with the low-frequency component of the velocity over a low-frequency period (Huse, 1991). Typically, the dissipated energy caused by the mooring line during one low-frequency period cycle can be obtained by using the indicator diagram. The horizontal displacement is plotted on the horizontal axis and the corresponding horizontal component of tension is plotted on the vertical axis. The figure obtained will be a curve that the area of it represents the dissipated energy caused by the mooring line as shown in Fig. 1.

According to Webster (1995), Brown and Mavrakos (1999), the dissipated energy caused by the mooring line during one period cycle of vessel surge motion can be defined as:

$$E = \int_0^{\tau} T_h \frac{dX}{dt} dt \tag{1}$$

where T_h is the horizontal component of tension at mooring line top end; X is the low-frequency component of horizontal displacement; τ is period of the low-frequency surge motion.

The equivalent linear damping coefficient B is introduced to express the mooring line damping. It can be assumed that:

$$T_h = B\frac{dX}{dt} \tag{2}$$

After combination of the (Eqs. (1) and 2), the dissipated energy caused by the mooring line can be represented as:

$$E = \int_0^{\tau} B\left(\frac{dX}{dt}\right)^2 dt \tag{3}$$

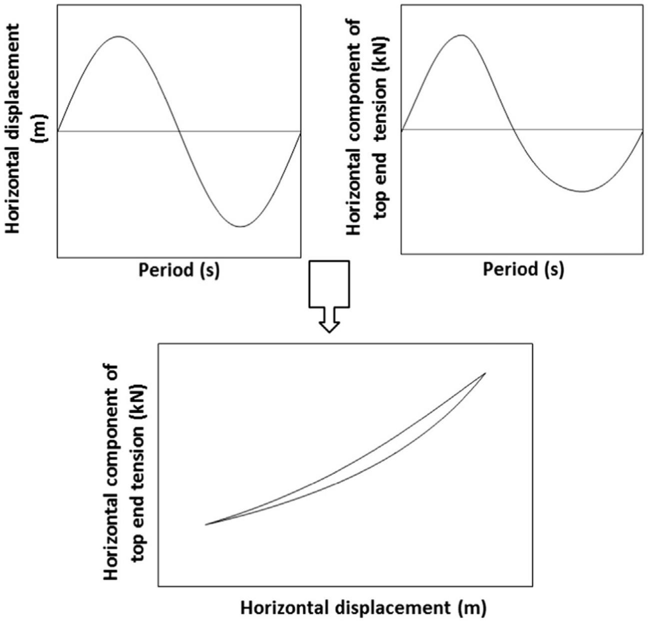

Fig. 1. Indicator diagram.