Establishment of Evaluation Method , and Extension of Knowledge for Vortex Induced Vibration of Riser

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It is believed that the use and development of marine resources will be promoted in the future in Japan and also needs of drilling risers will grow. One of the concerns for riser is Vortex Induced Vibration (hereinafter referred to as VIV). The assumed usage area of a riser tube includes seas where the marine/tidal current is strong. In this case, the Reynolds number is higher, which differs from the hydrodynamic force characteristics considered in conventional VIV design. Additionally , much of conventional researches focused on cross flow directional vibration, and the effect of inline directional vibration was not considered. This paper describes Mitsubishi Heavy Industries, Ltd.'s (MHI) efforts in these issues.

1. Introduction

Risers are roughly classified into the following two groups: drilling risers used for subsea drilling for oil development or scientific surveys of the earth, and production risers used for lifting up crude oil collected in offshore oil fields to the sea surface. In Japan, the drilling riser equipped on the D/V Chikyu is well-known. Both for drilling risers and production risers, breakage of the riser causes significant economic loss and impacts on the environment. Therefore this is one of the important themes in major international marine engineering institutes.

Because a riser string is very long and thin, its main breaking mode is local buckling. Therefore there is a need to design a riser so that it is always tensioned in order to prevent such local buckling.

In recent years, VIV (Vortex Induced Vibration), which is induced by vortexes discharged by the riser, has been attracting attention in line with the increasing use of risers under conditions where the tidal current is strong. Because a riser is very long, even vibration of high order mode may occur. If vortex shedding at a frequency of 1 to a several Hz causes resonance of a riser, safety problems such as fatigue damage may arise from VIV. VIV has recently been attracting attention, and major international oil companies such as Shell (Netherlands), BP (UK), Chevron (U.S.), and Petrobras (Brazil), as well as classification societies such as DNV (Norway) and academic institutions, have been cooperatively promoting studies. MHI has also been working on the establishment of riser VIV evaluation techniques in a joint study with Nippon Kaiji Kyokai (NK), the University of Tokyo and the Japan Agency for Marine-Earth Science and Technology. This document describes a summary of the study.

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2. Efforts in establishment of riser VIV evaluation techniques

2.1 Issues for riser VIV evaluation techniques

VIV phenomena are very complicated and scientifically interesting. In many countries, research on VIV is being studied vigorously. However, methods to accurately estimate the behavior of VIV and allow it to be reflected in design are undeveloped. It is expected that VIV estimation and design techniques of a riser will be developed in the future.

Estimation methods of riser VIV behavior developed in the past are roughly classified into the following three categories in terms of the handling of fluid:

[1] Preparing a database of hydrodynamic force characteristics and performing structural calculation in reference to the data.

[2] Performing 2D-CFD at each cross section in response to structural behavior and coupling it with structural calculation.

[3] Coupling CFD with structural calculation in a three-dimensional model.

In regard to [2], Yiannis Constantinides et al.(1) examined a method that coupled two-dimensional CFD with FEM. In regard to [3], C. Le Cunff et al.(2) examined a method that coupled three-dimensional CFD with FEM (modal method). These methods, which consider the flow field around the riser and the structural behavior of the riser directly, are very important for an understanding of detailed phenomena. However, they are not suitable for design because computation time may be very long. On the other hand, [1] is suitable for design because parametric study for flow rate, flow rate distribution, the diameter of a riser tube (rigidity), etc. can be performed in a short time, although preparation of the database requires time. For example, Nozawa et al.(3) published the original LINE-3D_VIV code based on method [1]. A database used for this method can be established based on results obtained from water tank test. However, the establishment of a database has the following issues:

(1) For an experiment assuming a high Reynolds number in seas where the marine/tidal current is strong, a large model and a high-speed towing unit are needed. There are a limited facilities where hydrodynamic force can be obtained under such conditions. In particular, a water tank test itself is impossible for Reynolds numbers in the millions.

(2) In a VIV phenomenon, not only the cross flow directional vibration, which has been generally considered, but also inline directional vibration may have an effect on hydrodynamic force. However, there is little knowledge of hydrodynamic force in consideration of this effect.

Therefore in this study, a hydrodynamic force database for conditions with higher Reynolds numbers assuming seas where the marine/tidal current is strong and in consideration of effect of inline directional vibration was established with the support of hydrodynamic force evaluation using CFD in addition to a water bath experiment.

2.2 Conditions for obtaining a hydrodynamic force database covered in this study

This section describes the conditions covered in this study. **Figure 1** shows an image of the vortex shedding around a cylindrical column. The periodical vortex shedding around a cylindrical column generates inline and cross flow directional periodically fluctuating hydrodynamic force. Because the vortex induced vibration of a riser is induced by this periodically fluctuating hydrodynamic force, it is important to understand the relationship between the vibration of a cylindrical column and periodically fluctuating hydrodynamic force.

Here, we examine the conditions for obtaining a hydrodynamic force database based on an example of the D/V Chikyu. The riser outer diameter is approximately 1.2 m including the buoyancymodule. When strong marine current of 0.5 m/s (deep water) to 3.0 m/s (surface water) is assumed, the Reynolds number ranges from approximately 600,000 to 3,600,000.

When a Reynolds number is within this range, the Strouhal number of the cylindrical column (frequency of vortex shedding x diameter of cylindrical column / flow rate) is approximately 0.2 to 0.5, and the hydrodynamic force characteristics seem to differ from the conventionally and internationally studied range where the Reynolds number is 300,000 or less (the Strouhal number is approximately 0.2). In addition to cross flow directional vibration, inline directional vibration also occurs in actual vibration and causes changes in the characteristics of the vortexes occurring around a cylindrical column, and thus the hydrodynamic force characteristics of vortex induced vibration are affected.

In this study, high Reynolds numbers of 500,000 and 3,000,000 are selected as conditions for obtaining a hydrodynamic force database in consideration of inline directional vibration in addition to cross flow directional vibration.

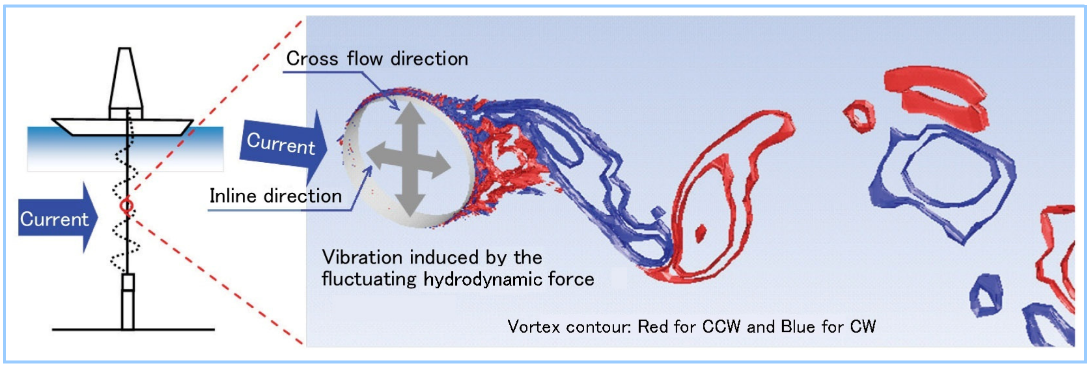

Figure 1 Image of vortexes shedding around cylindrical column (Example of CFD under conditions with higher Reynolds numbers)

2.3 Establishment of hydrodynamic force database

In this study, hydrodynamic force at a Reynolds number of 500,000 was obtained through a water tank test at MHI, and hydrodynamic force at a Reynolds number of 3,000,000, an experiment that is difficult to conduct, was obtained through CFD. In the water tank test and CFD, cross flow directional and inline directional vibration was applied to a cylindrical column element in a constant flow field in the following manner to obtain time history data of hydrodynamic force.

$$x = A_x \sin(2 \cdot 2\pi f_y \cdot t + \gamma) \quad (1)$$

$$y = A_y \sin(2\pi f_y \cdot t) \quad (2)$$

Where x and y are the inline directional displacement and cross flow directional displacement of the cylindrical column element respectively, Ax and Ay are the applied amplitude of the inline directional excitation and the cross flow directional vibrationexcitation respectively, and γ is the phase difference between inline directional and cross flow directional excitation applied. Because the frequency of inline directional hydrodynamic force is twice as large as that of the cross flow directional hydrodynamic force due to the alternating occurrence of vortexes, vibration was applied so that the frequency of inline directional vibration (2fy) would be twice as large as that of the cross flow directional vibration (fy).

Figure 2 presents an overview of the water tank test equipment created for this study. In this equipment, a relative flow field was generated by towing a cylindrical column model. A exciter that could apply forced excitation in two directions, both vertical and horizontal, was developed to obtain time history of hydrodynamic force acting on the cylindrical column.

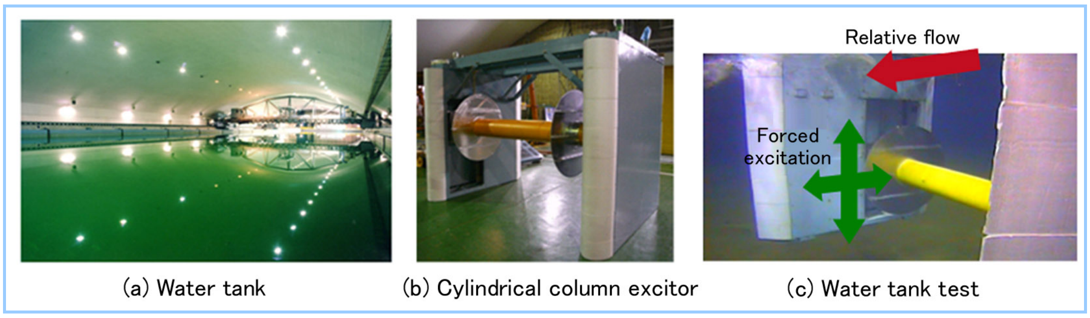

Figure 2 Overview of water water tank test equipment

For CFD, **Figure 3** shows an example of a flow field under forced excitation. A CFD method for a forced excitation in two directions to a cylindrical column element in a constant flow field was developed to obtain time history of hydrodynamic force acting on the cylindrical column.

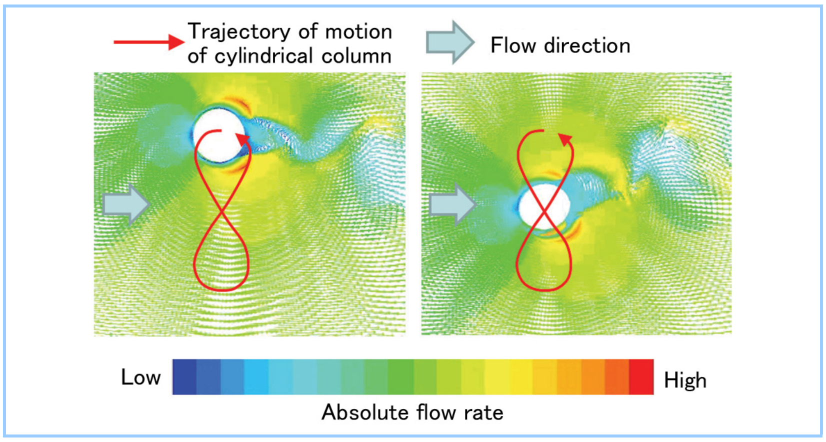

Figure 3 CFD case example (Flow rate vector diagram)

In this study, F0x and F0y, hydrodynamic force amplitude in each direction of vibration application, and φx and φy, phase against vibration application displacement, were obtained by sine wave fitting of time history of hydrodynamic force obtained by the experiment and CFD. Based on the result, hydrodynamic force was divided into a component proportional to the acceleration of the forced excitation and a component proportional to the velocity of the forced excitation, and the added mass coefficient and the attenuation coefficient were calculated as shown in **Figure 4** and arranged in a database.

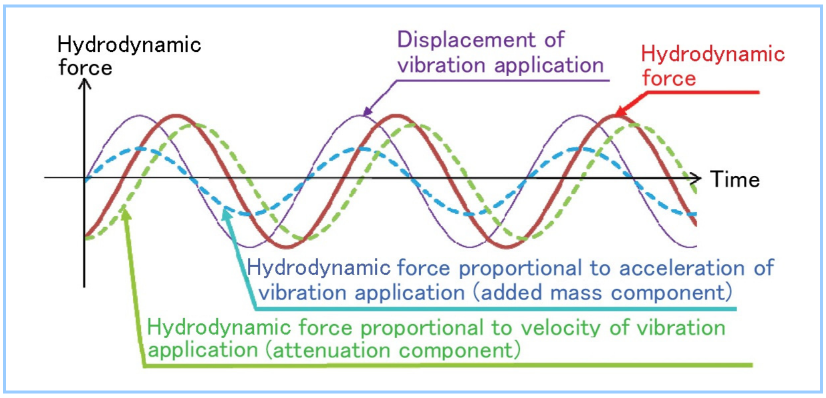

Figure 4 Image of hydrodynamic force wave

For reference, formulas for calculating cross flow directional added mass and attenuation coefficients are shown below.

<Added mass coefficient> <Attenuation coefficient>

$$\frac{F_{0y}\cos\phi_y}{\rho\frac{\pi}{4}D^2LA_y(2\pi f_y)^2} \qquad -\frac{F_{0y}\sin\phi_y}{\frac{1}{2}\rho DLUA_y(2\pi f_y)} \tag{3}$$

Where ρ is fluid density, U is flow velocity, and D and L are the diameter and length of a cylindrical column.

2.4 Knowledge about hydrodynamic force characteristics obtained in this study

In this study, a hydrodynamic force database in consideration of not only conventionally focused cross flow direction vibration, but also inline directional vibration, were obtained. Examples of obtained hydrodynamic force characteristics are presented as the following. **Figure 5** shows the difference of hydrodynamic force characteristics with and without inline directional vibration. When inline directional vibration is taken into consideration, the area with high vibratory force (red to yellow) is larger in comparison to the case without consideration of inline directional vibration. This indicates the possibility that cross flow directional vibration is amplified by inline directional vibration.

Figure 6 presents the effect of the phase difference of the forced excitation. The distribution of the cross flow directional hydrodynamic force characteristics changes depending on the phase difference of the vibration application. In Figure 6, the area with high damping force (blue to light blue) extends when phase difference of vibration application exists. This indicates the possibility that there exists in an actual phenomenon some phase difference that is likely to amplify VIV and some that is not.

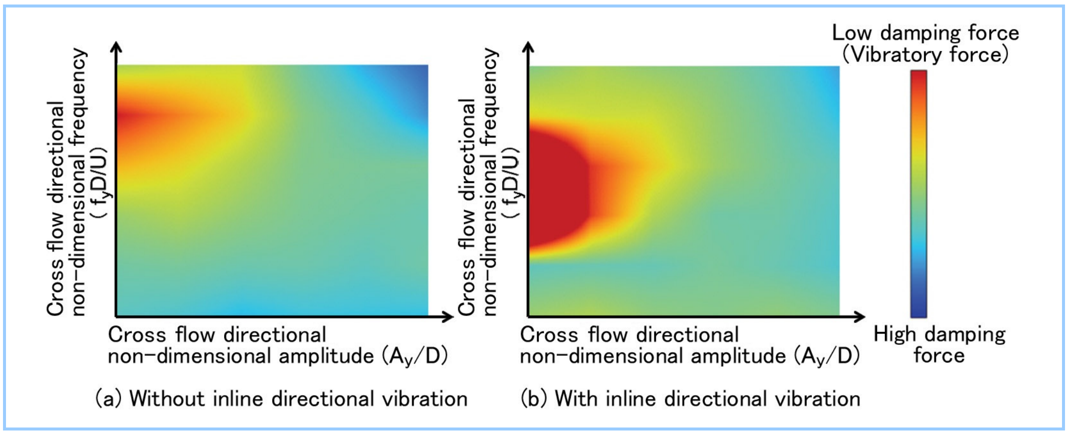

Figure 5 Cross flow directional hydrodynamic force characteristics (effect of inline directional vibration)

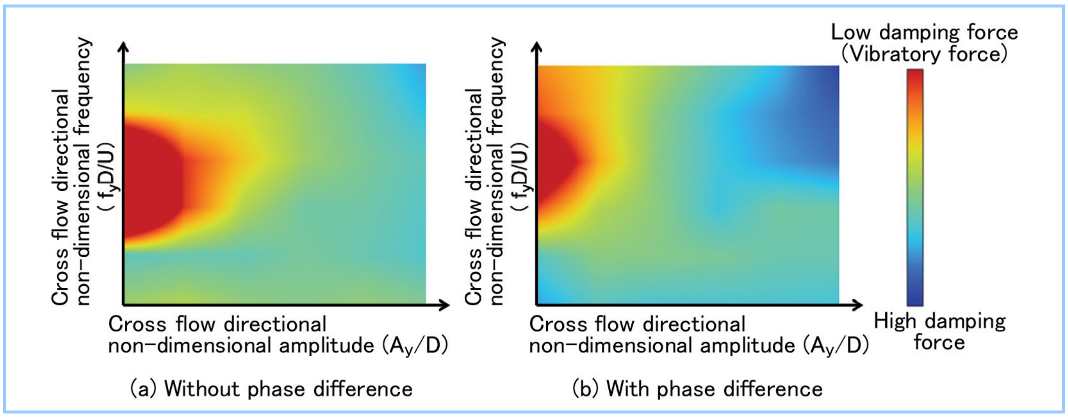

Figure 6 Cross flow directional hydrodynamic force characteristics (effect of phase difference between inline directional vibration and cross flow directional vibration)

Figure 7 presents the effect of inline directional vibration amplitude. When the amplitude of the inline directional vibration increases, the area with high cross flow directional damping force (blue to light blue) increases. This indicates the possibility that moderate amplitude growth of the inline directional vibration leads to a range where the cross flow directional vibration is suppressed.

Only part of the results obtained are described above. These hydrodynamic force data have been systematically obtained and arranged in a database.

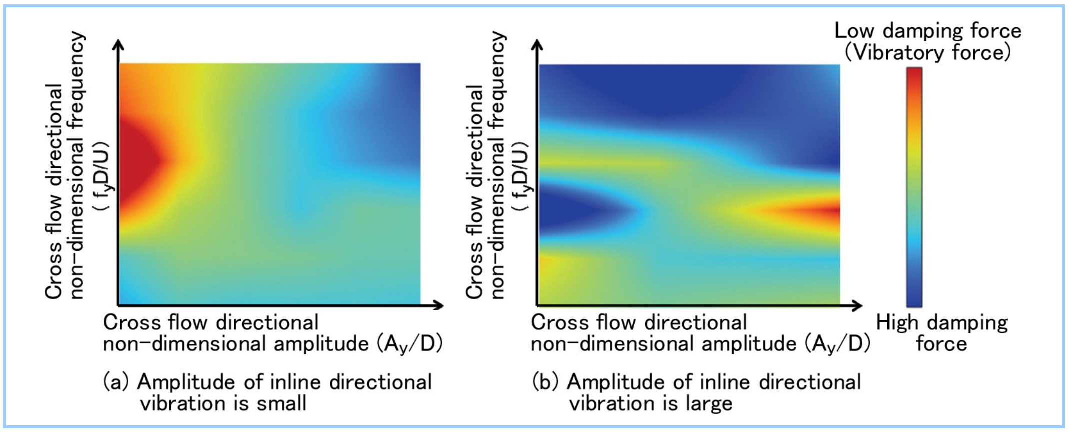

Figure 7 Cross flow directional hydrodynamic force characteristics (effect of amplitude of inline directional vibration)

2.5 Utilization of established hydrodynamic force database

The database established through this study has been incorporated in the VIV analysis code “LINE-3D_VIV” developed by Suzuki et al.(3), and maintained as a VIV evaluation method that can deal with high Reynolds numbers in consideration of the coupling of the inline direction and the cross flow direction. **Figure 8** presents its overview. MHI is willing to further enhance riser VIV estimation accuracy using this evaluation method and to contribute for evolution of risers deployed in strong marine/tidal currents and improvement of the safety of risers.

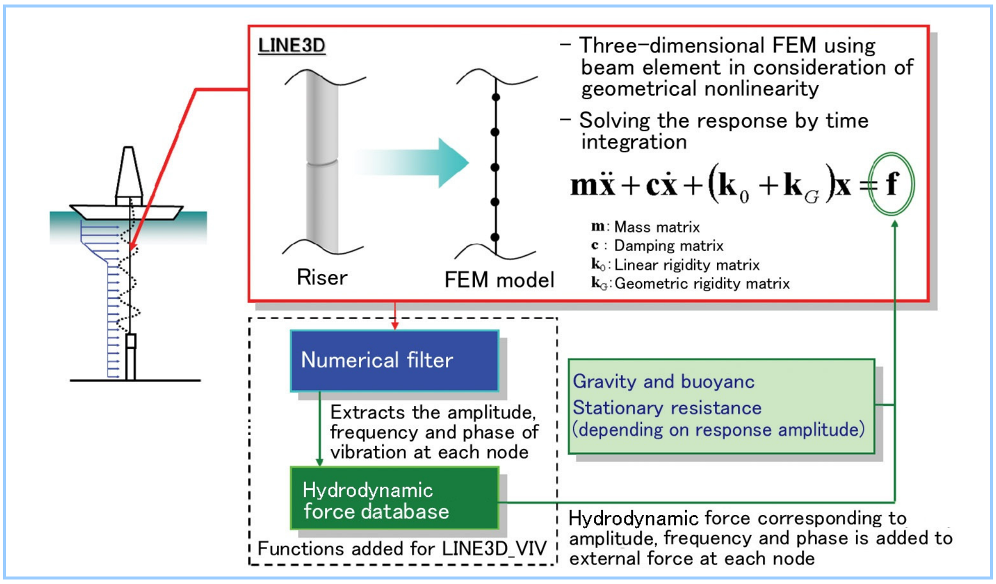

Figure 8 Outline of VIV evaluation of riser using LINE3D_VIV

3. Conclusion

Through this study, MHI targeted Reynolds numbers as high as 500,000 to 3,000,000 assuming deployed in strong marine/tidal currents not covered by conventional studies of risers, and obtained hydrodynamic force data in consideration of the coupling of the inline directional vibration and the cross flow directional vibration. The hydrodynamic force data obtained in this study allowed MHI to acquire new response characteristics of the effects of inline directional vibration and extend knowledge about the VIV characteristics of risers.

In the future, MHI is willing to utilize the results of this study for the development of technologies for the improvement of the safety of risers and to contribute to progress in Japanese marine science development.

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