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Comparison of drift force calculation methods in time domain analysis of moored bodies

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ABSTRACT

This paper compares five numerical methods for calculating drift forces in time domain analysis of moored bodies. The first method is the most basic one. It uses all terms of QTF (quadratic transfer function) matrix based on double summation. It is the most correct due to no approximation but needs large memory and cpu time. The second method uses diagonal terms of QTF matrix with Newman approximation. It reduces memory but still uses double summation. When the wave spectrum is narrow banded, the third and fourth methods with more approximated single summation are applicable. Those methods are much approximated but fast due to single summation. One uses fixed local frequency and the other uses time variant local frequency in calculating QTF. The fifth method uses interpolated local frequency of the third and fourth methods. A turret moored FPSO and a spread moored DTV (deck transportation vessel) are analyzed as numerical examples and the accuracy and cpu time are compared for each method.

1. Introduction

Effect of the 2nd order drift force is significant in responses of moored bodies especially in surge, sway or mooring line tension. So, the drift force calculation is important in design of floating body with mooring lines. Time domain calculation of drift forces is studied by many researchers (Newman, 1974; Roberts, 1981; Marthinsen, 1983; Mo, 1993) and they were extended to the multi directional case (Kim and Yue, 1989). The most conventional method for drift forces in time domain is to calculate doubled sum of wave amplitude products with full terms of QTF matrix. Since the method does not apply any approximation, it is the most correct. But, it needs large cpu time and memory due to double summation and storage for full terms of QTF. Approximate method using only diagonal terms of QTF matrix was presented (Newman, 1974). The method reduces computer memory because it uses only diagonal terms of QTF. But, it still needs large cpu time due to double summation. Further approximation was done when the wave spectrum is narrow banded (Roberts, 1981). The method uses single summation of wave amplitudes and calculates QTF only for local frequency component with peak frequency. It is very fast due to single summation but gives smaller responses when the QTF contribution is small at peak frequency. Afterwards, another single summation method was presented (Marthinsen, 1983; Mo, 1993). It uses time variant local frequency instead of fixed local frequency in calculating QTF. It can provide improved results. In some cases, the method overestimates responses. So, mixed form for local frequency is tested in this paper. It uses interpolated values of fixed and time variant local frequency.

The objective of this study is to compare the five drift force calculation methods. To do this, a FPSO with turret mooring lines and a DTV with spread mooring lines are analyzed for the comparative study. Various methods for body & line coupled analysis are available (Hong and Hong, 1997; Kim et al., 1999; Garrett, 2005; Kim et al., 2013). Among them, this study used the method by Kim et al. (2013). In the method, floating body equation is formulated by HOBEM (Choi et al., 2000; Hong et al., 2005) and convolution method (Cummins, 1962). Mooring line equation is formulated using FEM (Kim et al., 2010; Kim et al., 2013). The coupled responses are calculated by coupling the two equations. Five cases are analyzed for the five drift force methods. By comparing surge, sway, heave, roll, pitch, yaw and mooring line tension of the five cases, the accuracy and the computing efficiency of the methods are compared and discussed.

2. Equation of motion and calculation methods for drift force

Equation of motion of floating body in waves can be expressed by (1) in time domain.

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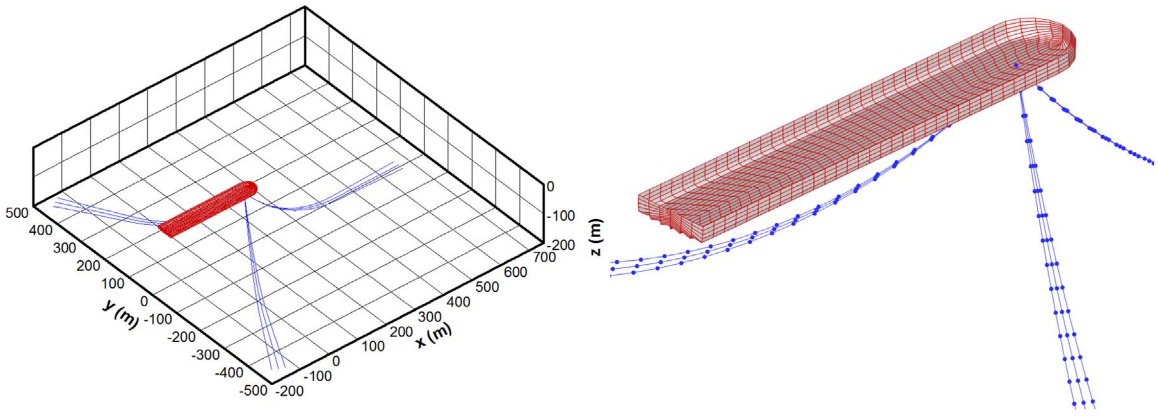
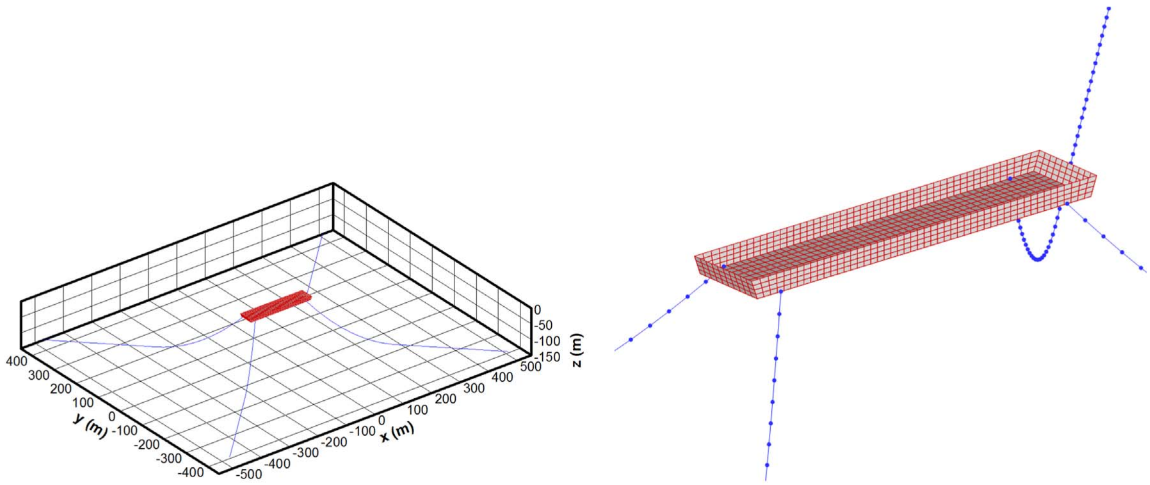


(a) Turret moored FPSO



(b) Spread moored DTV

Fig. 1. Geometry and numerical grid of sample ships.

Table 1
Main particulars of sample ships.

Particulars		(a) Sample ship I	(b) Sample ship II
Body	Length (LBP)	315 m	217 m
	Breadth	53 m	43 m
	Draft	12 m	10 m
	Displacement	194,955 m^3	91,745 m^3
	Water depth	192 m	130 m
Mooring line	Number of lines	9	4
	Length	600 m	600 m
	Weight	408.1432 kg/m	408.1432 kg/m
	Diameter	0.36 m	0.36 m
	Drag coefficient	0.7	0.7
	Mass coefficient	2.0	2.0
	Location of fairleads	(120, 0, −12)	(±90, ±21.5, −10)
Irregular wave	Heading angle	180 deg	135 deg
	Significant wave height	$H_{1/3}=11.5$ m	$H_{1/3}=11.5$ m
	Peak period	$T_p=14.5$ s ($\omega_p=0.433$ rad/s)	$T_p=14.5$ s ($\omega_p=0.433$ rad/s)

Table 2
Comparison cases for drift force calculation.

Case	Equation	Description
1	(3)	– Double summation – Full terms of QTF
2	(4)	– Double summation – Diagonal terms of QTF
3	(5)	– Single summation – QTF with fixed local frequency (peak frequency)
4	(9)	– Single summation – QTF with time variant local frequency
5	(11)	– Single summation – QTF with interpolated local frequency

$$[M_B + M_{add}(\infty)]\{\ddot{x}\} + \int_0^t [R(t-\tau)]\{\dot{x}(\tau)\}d\tau + [K_B]\{x\}$$
$$= \{f_w\} + \{f_d\} + \{f_m\} \quad (1)$$

where $[M_B]$ and $[K_B]$ are mass and hydrostatic matrix of floating body. $\{x\}$ is vector of floating body motions. $[M_{add}(\infty)]$ is added mass matrix at infinite frequency and R is retardation function. $\{f_w\}$ and $\{f_d\}$ are force vectors due to wave and drift. $\{f_m\}$ is mooring forces transmitted from fairleads of mooring lines. Equation of motion of mooring lines in time domain is

$$[M]\{\ddot{u}\} + [C]\{\dot{u}\} + [K]\{u\} = \{f\} \text{ with BC: } u = u_f \text{ at connections} \quad (2)$$

where $[M]$, $[C]$, $[K]$ and $\{u\}$ are mass matrix, damping matrix, stiffness matrix and displacement vector for mooring lines. $\{f\}$ is force vector due to Morison force of water particle motion. u_f is displacement at fairleads transmitted from floating body center. By solving (1), displacements at fairleads are obtained. With this