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# SIMULATION OF LOW FREQUENCY MOTIONS IN SEVERE SEASTATES ACCOUNTING FOR WAVE-CURRENT INTERACTION EFFECTS

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## ABSTRACT

Today's industry practice assumes wave drift forces on floating structures can be computed from zero current wave drift force coefficients for the stationary floater, while simplified correction models introduce current effects and slow drift velocity effects. The paper presents an alternative approach which overcomes some of the limitations of today's procedures. The method, to be applied together with a time domain solution of the low frequency motions, is based on pre-calculation of mean wave drift force coefficients for a range of current velocities. During the low frequency motions simulation, the wave drift forces induced by the irregular waves are computed from the mean drift coefficients corresponding to instantaneous relative velocity resulting from the current and the low frequency velocities. A simple interpolation model, based on a quasi-steady assumption, is applied to obtain the drift forces in time-domain.

Since calculation of the wave drift forces on Semi-submersibles in severe sea states with fully consistent methods is out of reach, a semi-empirical model is applied to correct the potential flow wave drift force coefficients. This model takes into account viscous effects, that are important in high seastates, and wave-current interaction effects. The paper compares the wave drift forces and the related low frequency motions computed by the proposed method, with results applying "standard" methods and with model test data. The test data was obtained in the scope of the EXWAVE JIP, with model tests designed to investigate wave drift forces in severe seastates and assess the wave-current interaction effects.

## 1 INTRODUCTION

Accurate prediction of extreme platform motions in horizontal plane, and consequently extreme line tensions, is essential in safety and reliability of floating platforms.

During recent years several mooring line failure incidents in bad weather have been reported on North Sea MODU's and FPSO's [1]. The failures are caused by a mixture of overload, fatigue and mechanical damage, and the full circumstances around the incidents are not clear. However, the occurrence of wave forces higher than predicted by standard methods could be considered as a contributing factor, at least in some of the incidents. Further descriptions could be found in [2] and [3], among others.

The low-frequency, or slowly varying motion of the platform in horizontal plane is mainly excited by second order wave drift forces. Second order mean drift forces are traditionally estimated using first-order potential flow solutions together with Newman approximation (see for instance [4]). However, importance of viscous effects on the mean drift forces is well known and sometimes included in analyses, while it does not appear to be consistently taken into account in standard industry practice. This has been discussed in [5] and [4], based on a simple Morison drag force formulation. Dev and Pinkster [6] presented a systematic study on this problem. The approach was also applied by Stansberg et.al. [7] on a semi in irregular waves. An important contribution to the slowly varying drift force for a column based floater comes from the Morison drag force in the splash zone integrated up to the instantaneous free surface. This force is proportional to the cube of the wave height. Hence for long waves the viscous contribution may become considerably higher than the potential flow drift force, and they become more and more important with increasing wave amplitude. It is known that viscous drift forces are mainly important for long and high waves. A current will further increase the viscous drift forces, as well as the potential flow contribution.

The EXWAVE Joint Industry Project (EXWAVE - Wave forces on floating units in extreme seas) objective is to investigate extreme wave forces on floating units which may lead to overloading of mooring line loads, with emphasis on slowly varying wave exciting forces and related low frequency

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[1] Earlier MARINTEK, SINTEF Ocean from 1st January 2017 through a merger internally in the SINTEF Group

motions. Dedicated model tests and data analysis has been carried out as a part of the work. Two floating units have been selected for investigations, namely a Semi-Submersible and a Floating Productions Storage and Offloading vessel (FPSO).

Wave-current interactions effects on drift forces are usually taken into account by applying simple corrections on zero current wave drift force coefficients for the stationary floater. This method is used also in time domain to calculate variation on drift forces due to platform's slowly varying horizontal velocities. Here, an alternative approach for time-domain simulations is investigated. The method, to be applied together with a time domain solution of the low frequency equations of motion, is based on pre-calculation of mean drift force coefficients for a range of current velocities. During the simulation of low frequency motions, the wave drift forces induced by the irregular wave are computed from the mean drift coefficients corresponding to instantaneous relative velocity resulting from the current and the low frequency velocities. In this way, the wave-current effects and the slow drift damping effects are simultaneously accounted for by the calculations.

The proposed approach is tested for the EXWAVE Semi. Given the EXWAVE scope – prediction methods for extreme seastates – the viscous effects need to be taken into consideration. The viscous drift effects as well as the wave-current interaction effects are taken into account using a semi-empirical formula [13]. The model test data obtained for the EXWAVE semi-submersible is used to assess the numerical predictions.

## 2 A NOTE ON MODEL TESTS

The model tests of the EXWAVE semi-submersible were conducted at MARINTEK's Ocean Basin during October 2015 with a 1:50 scaled model of the hull (Fig 1). The model may be considered representative of a drilling rig with four columns. The model's main particulars are given in Table 1. All values given here are in full scale, unless otherwise noted. The tests focused on the dynamic behavior of the platform in waves and current. The aim of the model test program was to obtain test data to identify the slowly varying wave drift forces and the related slow drift damping. The focus is on severe seastates and the vessel survival draught was used. The wave-current interaction effects on the wave drift forces is also addressed.

A simple horizontal and soft mooring system was selected for the model tests. The mooring system horizontal restoring characteristics are (almost) linear, which simplifies the analysis of results and identification of hydrodynamic properties. The mooring lines were designed to obtain natural periods of the horizontal motions above 100s, so that the system does not respond dynamically to the wave frequency forces (and still sustain the forces induced by severe seastates).

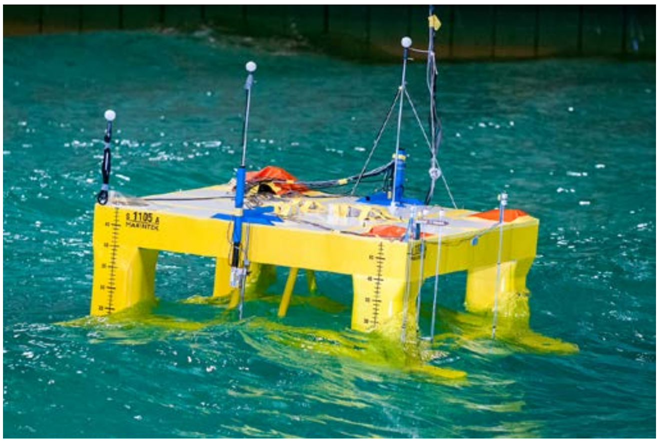

**Fig 1: Photo showing the platform model in the MARINTEK's Ocean Basin.**

The horizontal mooring system restrains the vessel heading at a mean position with respect to the incoming waves. It consists of 4 lines connected to the semi-submersible model at one end and attached to the edges of the basin (above water) at the other end. The connection to the model is located at midship on the Port and Starboard sides and the center of gravity height. The aim is to decouple the pitch motion from the mooring system forces. The angular separation between the 4 lines was 90 degrees.

**Table 1. Main particulars of the semi-submersible platform model used in model tests.**

| Parameter | Model scale | Full scale |
|---|---|---|
| **Length of pontoons** | 2.15 m | 107.5 m |
| **Breadth outside pontoons** | 1.625 m | 81.25 m |
| **Width of pontoons** | 0.2852 m | 14.26 m |
| **Height of pontoons** | 0.19 m | 9.50 m |
| **Width of columns** | 0.25 m | 12.50 m |
| **Breadth of columns** | 0.25 m | 12.50 m |
| **Long. dist. betw. columns** | 1.36 m | 68.00 m |
| **Trans. dist. betw. columns** | 1.34 m | 67.00 m |
| **Survival draft** | 0.46 m | 23.0 m |
| **Displacement** | 306 kg | 39206 ton |

From the considered vessel headings, only zero heading, i.e. head sea condition, with collinear wave and current is addressed here. The six degrees of freedom motions were measured by an optical-electronic system consisting of four light emitting diodes, strategically positioned on the model, and cameras located on the basin side.

### 2.1 Coordinate system

A right-handed coordinate system with x-axis pointing towards the wave-maker, and z-axis upward, positioned at the midship on mean water level is considered. Therefore, considering zero-heading condition, the waves are travelling towards negative x-axis. The results for surge motion is presented here, i.e. the horizontal motion along the x-axis.

## 2.2 Model test data analysis

Table 2 shows the conditions of the four model tests which are considered for the present study. Since the focus is on studying the importance of significant wave height and current velocity, two wave spectrums with equal peak period (*Tp*) and different significant wave heights (*Hs*) are considered. The spectrums are shown in Fig 2. In addition, two collinear current velocities, 0.82[m/s] and 1.58[m/s] are tested.

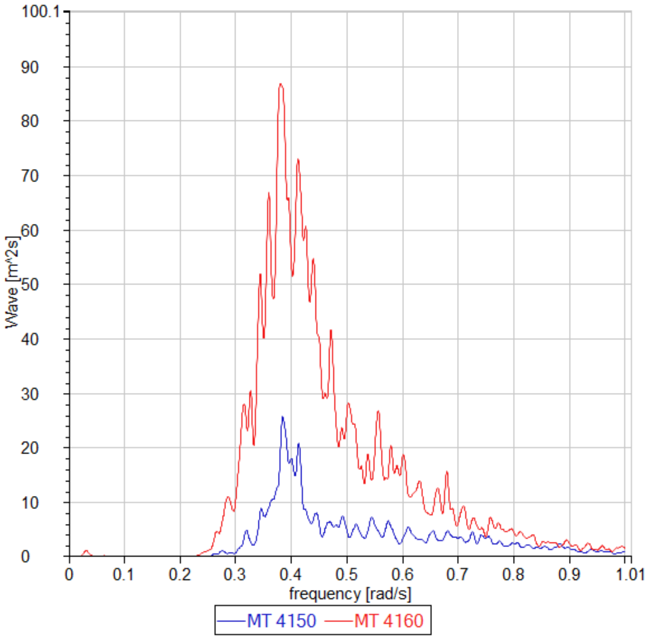

**Fig 2: Wave spectrum from model test wave time series. See Table 2 for spectrum parameters.**

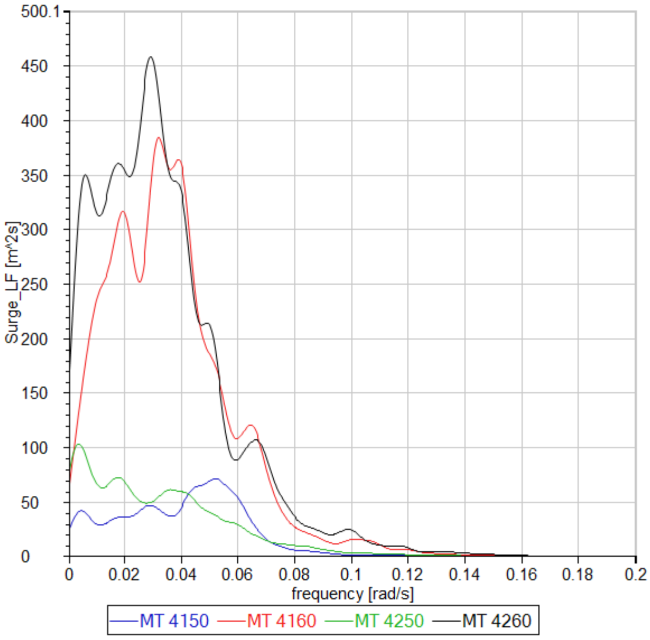

**Fig 3: Low-frequency surge spectrum from four model tests (see Table 2 for test conditions).**

As mentioned before, from the 6 degree of freedom motions recorded during experiments, only surge motion is presented here and the focus is on slowly varying motions. Fig 3 shows the low-frequency surge motion spectrum for the four test conditions presented in Table 2. Increase in the low-frequency energy by increasing *Hs* is evident in the plot. Moreover, it is interesting to point out the reduction in the maximum energy peak to a lower-frequency by increasing the current velocity. In addition to surge motions, cross bi-spectrum analysis is adopted to extract wave drift force coefficients from the model tests. These coefficients are presented and compared with the values calculated by the adopted empirical method.

**Table 2: Selected model test conditions. *Hs*: significant wave height, *Tp*: peak period, *Uc*: current velocity. All conditions are head-sea, i.e. zero heading.**

| Model Test | Hs[m] | Tp[m] | Uc[m/s] |
|---|---|---|---|
| **4150** | 7.5 | 16.0 | 0.82 |
| **4160** | 15.0 | 16.0 | 0.82 |
| **4250** | 7.5 | 16.0 | 1.58 |
| **4260** | 15.0 | 16.0 | 1.58 |

## 3 NUMERICAL MODEL

Today's industry standard methods for calculating platform motions in waves mainly consist of first-order potential flow solution for radiation/diffraction problem together with corrections for viscous effects, mainly based on the Morison equation. This means small wave steepness and platform motion are assumed. The wave-structure hydrodynamic interactions are usually calculated in the frequency domain, and used with or without memory effects in time domain simulations. This method is shown to be reasonably accurate for wave-frequency (WF) motions in most of the practical scenarios.

Considering platform's low-frequency (LF) responses, low-frequency wave forces can be obtained using a full second-order modelling (Quadratic Transfer Functions – QTF's), while in practice the much simpler "Newman's approximation" is often used where only quadratic terms of the first order quantities are included. This approximation is commonly known to be quite good in many cases for horizontal slow-drift motions in deep water, especially if the platform natural periods are long.

Low-frequency and wave-frequency motions can be solved independently, by separating first and second order excitation, or together, using retardation functions and combined excitation force time histories. The first method is simpler and it neglects the influence of low-frequency motions on the wave-frequency responses. This simple method can be adopted for solving horizontal motion responses of semi-submersible platforms if motions natural periods are outside wave frequency energy range. The wave-frequency problem is solved in the frequency-domain while the time-domain solution is adopted for low-frequency problem, i.e. slowly varying platform motion. Therefore, proper linearized viscous damping should be introduced in the frequency-domain calculations to obtain correct wave-frequency response. For semi-submersible platforms, this is particularly important for heave, roll and pitch modes of motion.

In the present study, the method of separating low-frequency and wave-frequency motion is adopted. A quadratic damping model is established based on free-decay tests in different modes of motion. The model is linearized and applied in heave, pitch and roll for the frequency domain calculations, neglecting the KC-dependency of the damping coefficients (KC: Keulegan-Carpenter number [8]).

Regarding the low frequency horizontal motions, quadratic current coefficients are the only source of damping for conditions with current. The surge, sway and yaw current coefficients were identified from current-only model tests in the Ocean Basin.

The hydrodynamic model, together with the model for mooring lines, is established using MARINTEK's time domain simulation code (SIMO® [9]). MARINTEK simulation platform, SIMA®, is used to establish workflows for systematic parameter variation, signal analysis, model test comparison, and reporting of the simulation data.

### 3.1 Wave drift force coefficients

The low-frequency excitation forces are introduced using *Newman's approximation* (see for instance [4] and [14]). The mean second-order wave drift force coefficients are obtained by solving the first-order potential-flow solution. As mentioned before, viscous effects and wave current-interaction modifies the wave drift forces, especially at lower frequency range. Here the empirical formula proposed by Stansberg et.al. [11] for modifying semi-submersibles potential-flow wave drift force coefficients is adopted. The method takes wave-current interaction and viscous effects into account in a simple manner. The wave-current interaction is modeled based on Aranha's method [10], while a Morison-based approach is used to account for viscous forces on columns. Here on, this empirical method is referred to as *Formula*.

Fig 4 shows the variation of wave drift force coefficients with current velocity, for two different significant wave heights (*Hs*) in head sea condition (zero heading). The values are for the platform presented in Sec. 2. Comparing the values for zero current velocity, the contribution of viscous drift forces predicted by the Formula is evident, which is larger for higher *Hs*. The percentage of increase is significant at lower frequencies, which is known to contribute to slowly varying horizontal motions, and consequently line tension, extreme values.

A comparison between the wave drift force coefficients extracted from model tests and the calculated values based on the presented Formula, for two different sea-states in head sea condition, is shown in Fig 5. The model test results, indicated by MT, are obtained using cross bi-spectrum analysis (CBS) [13]. The modification of the force coefficients due to viscous and wave-current interaction effects are well predicted by the Formula.

### 3.2 Wave drift force in time-domain simulation

The mean wave drift force coefficients can be used in time domain simulations applying different methods. Considering an assumed incoming wave spectrum, the most common method is to pre-calculate wave drift force time series for different directions using zero-velocity coefficients. The influence of platform's slowly varying yaw motion is accounted by interpolating between the force time series for different wave directions as shown in Equ.(1) for the force in surge.

$$F_1(t;\alpha) = \frac{F_1(t,\alpha_2) - F_1(t,\alpha_1)}{\alpha_2 - \alpha_1}(\alpha - \alpha_1) + F_1(t,\alpha_1) \qquad (1)$$

where, $\alpha$ is the platform heading.

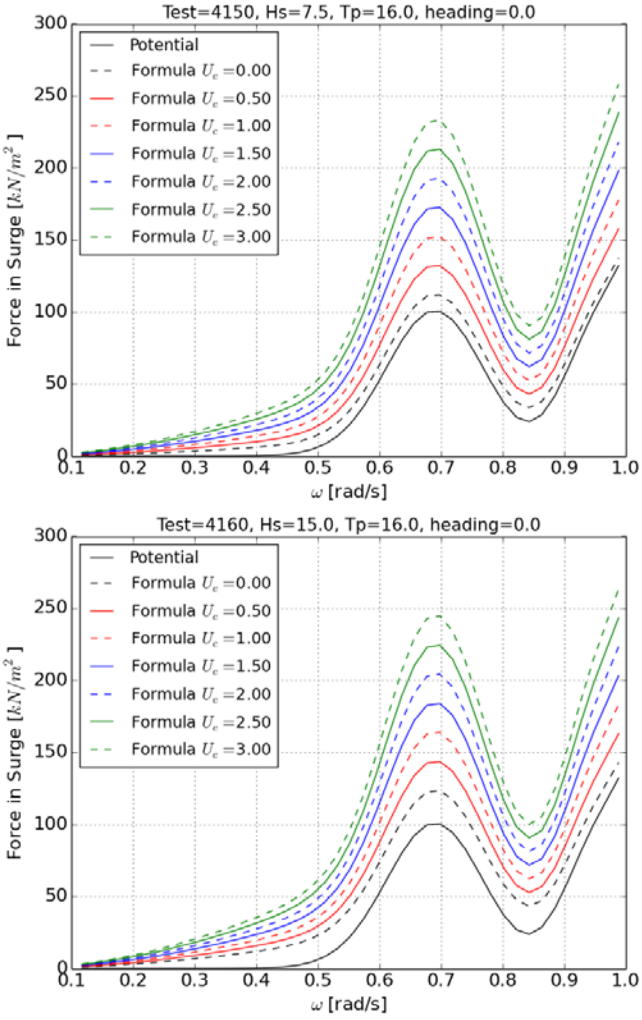

**Fig 4: Variation of the wave drift force coefficients by the current velocity. Top: Hs=7.5[m], Bottom: Hs=15.0[m].**

Moreover, the force time series must be corrected for the low-frequency relative velocity between platform and water. This includes both the current velocity and the velocity due to platform's slowly varying motion in current direction. The so-called wave drift damping model is usually used for this purpose as shown in Equ. (2) for force in surge.

$$F_1(t) = F_1^{U0}(t)(1 + C_{WDD}U_{rel}) \tag{2}$$

Here, $U_{rel} = U_c - U_b\cos(\beta)$ is the relative velocity between the platform ($U_b$) and the current ($U_c$), while $\beta$ is the angle between the two velocity vectors. $C_{WDD}$ is known as the wave drift damping coefficient, and represents the gradient of the wave drift force coefficients with respect to relative velocity. Although this coefficient is normally frequency dependent, time domain solvers often use a frequency independent constant value. For most practical cases $C_{WDD} = 0.25[\text{s/m}]$ is assumed. In this way, the dependency of the wave dirt forces to the relative velocity is linearized around zero. A similar linearization could be applied around the mean current velocity by adopting the drift force coefficients obtained for that velocity (see for example the plots in Fig 5).

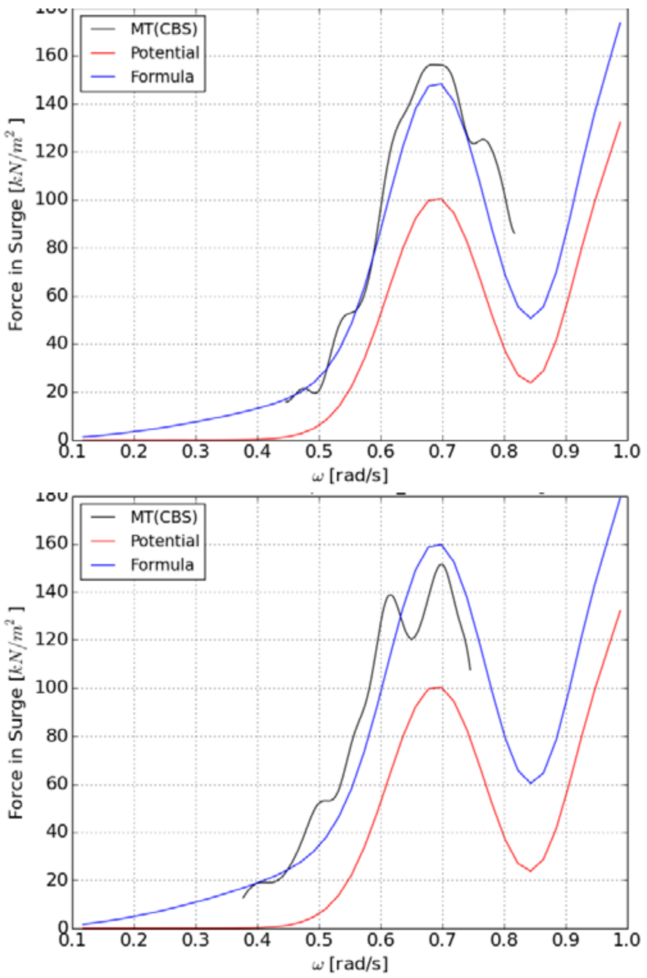

**Fig 5: Comparison of wave drift force coefficients in surge for two different Hs. Top: MT 4150, Bottom: MT 4160. MT: model test coefficients extracted using cross bi-spectrum (CBS) method.**

In addition to the two mentioned methods, a more consistent approach is investigated here. This approach is based on pre-calculation of mean drift force coefficients for a range of current velocities and body headings. The semi-empirical method described in Sec. 3.1 is applied to correct the zero current potential-flow wave drift force coefficients for different relative velocities. Adopting Newman's approximation, the drift force time-series are calculated for each heading and relative velocity prior to time-domain simulation. The wave drift forces are calculated directly for the undisturbed wave elevation measured during the model tests. A sample of pre-calculated drift force time series and their spectrums are presented in Fig 6.

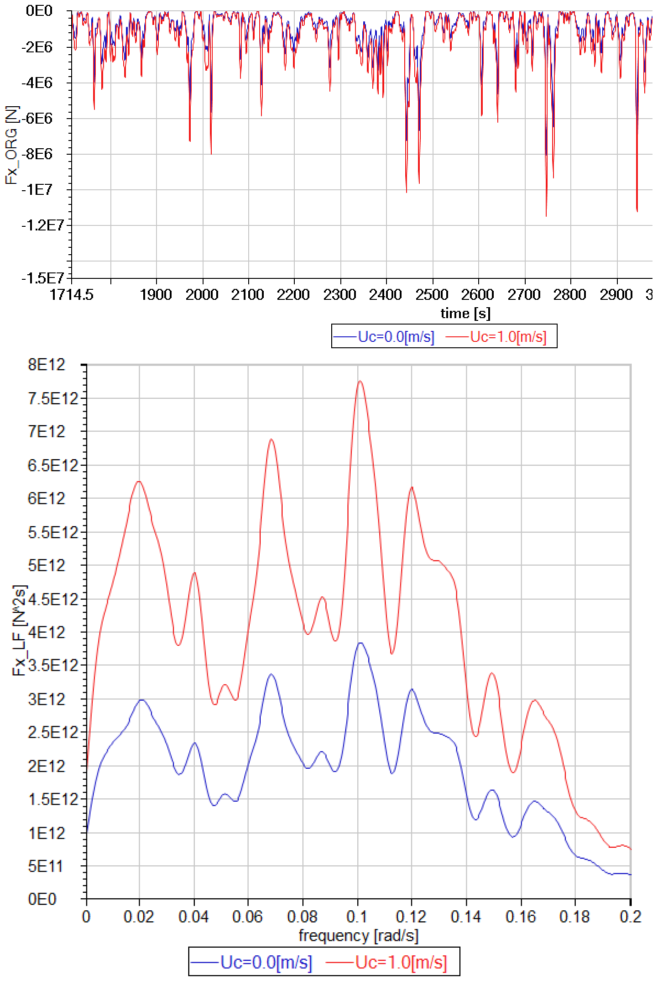

**Fig 6: Drift force time series and spectrum for MT 4160 wave condition with 0.0 and 1[m/s] collinear current velocity calculated using wave drift force coefficients based on Formula.**

During the time-domain simulation of low frequency motions, the wave drift forces induced by the irregular wave, corresponding to instantaneous relative velocity resulting from the current and the low frequency velocities, are computed from the pre-calculated drift force time-series. A simple interpolation model, based on a quasi-steady assumption, is applied to obtain the drift forces during a low-frequency time-domain simulation. Here on, this method is referred to as drift force time-series method or (TS) for short. To perform the simulations, the interpolation module is implemented as a Dynamic-Link Library (DLL) and coupled with the time-domain simulator SIMO® [9].

## 4 TIME DOMAIN SIMULATION

The results of the time-domain simulation using SIMO are presented here and compared with model test data. The focus is on slowly varying surge response of the semi-submersible platform, however, the wave-frequency surge response spectrums are presented to show the accuracy of the wave-frequency solver. The low-frequency surge response obtained from different methods described in Sec. 3 are compared against model test results for the semi-submersible described in Sec. 2.

### 4.1 Wave-frequency surge response

As mentioned in Sec. 3, the wave-frequency problem is solved in frequency domain and combined with the time-domain solution of low-frequency problem. Fig 7 shows the obtained wave-frequency surge response spectrums, extracted from the simulated total motion, together with model test results. The three methods for calculating wave drift forces presented in Sec. 3 were applied, while setting the wave drift damping coefficients to zero.

As expected the method for calculating the wave drift force has no effect on the wave frequency response. Moreover, the frequency-domain solution of wave-frequency surge response shows quite good agreement with the experimental results.

### 4.2 Low-frequency surge, wave drift damping model

This Section assesses the low frequency surge predictions by using potential flow coefficients, and formula corrected coefficients, combined with simplified wave drift damping model to account for slow drift velocity effects. The different drift force models are assessed by comparing predictions with test data.

The low-frequency surge response obtained from the potential-flow and from the Formula wave drift force coefficients are presented in Fig 8. The current velocity is 0.82 m/s. The potential-flow values (Pot.) are for zero relative velocity, while the Formula values (Form.) are calculated for the mean current velocity. The figure also shows the experimental results for the low-frequency surge response. Since the platform was horizontally moored, and negligible yaw motion was reported, the sway and yaw motions are not discussed here.

The low-frequency response energy is clearly under-predicted by the potential-flow wave drift model, while the values obtained from Formula over-predict the response. Including the wave drift damping model, i.e. *WDD* in the legend of Fig 8, increases the response energy for both methods. The reason is that the correction introduced on the zero velocity wave drift forces by the wave drift damping coefficient effectively increases the drift forces (see equation 2). In this sense, "wave drift damping" coefficient might be a misleading expression. This correction slightly improves the results from potential-flow model, but it increases the already high values from Formula model. The large over prediction by the formula is expected since the wave drift damping model in its current form is consistent only if zero relative velocity drift force coefficients, i.e. potential-flow values in this case, are adopted.

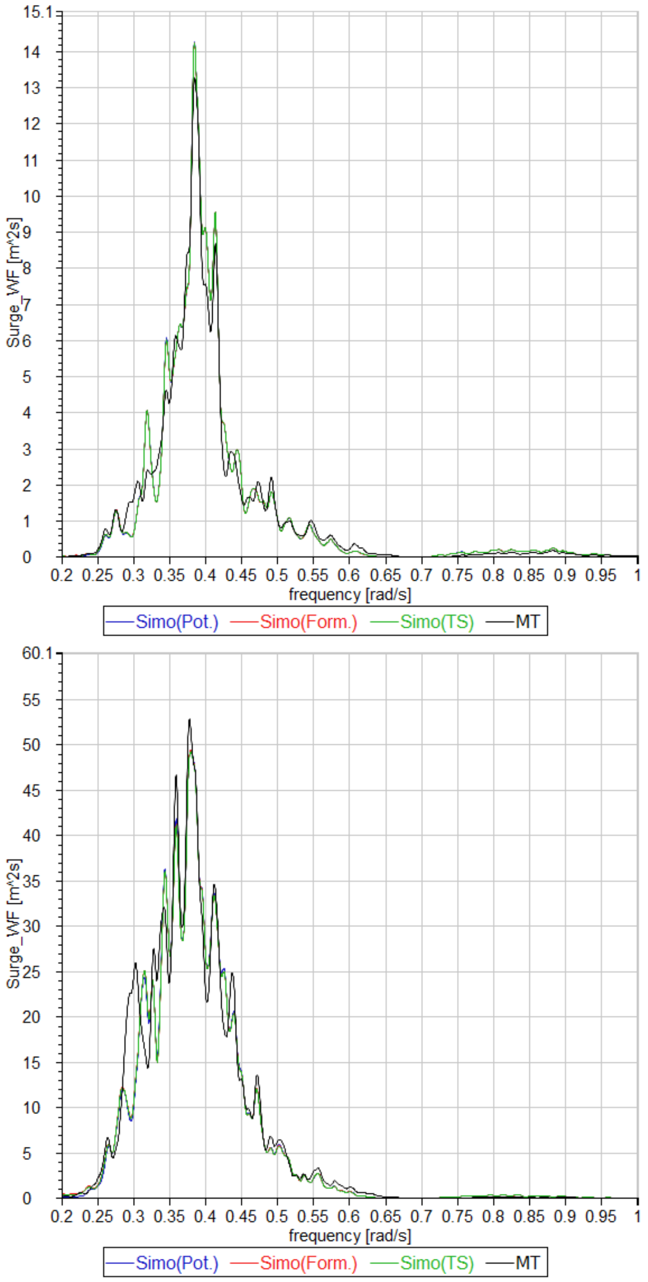

**Fig 7: Wave-frequency surge response spectrum obtained from combined frequency-domain/time-domain simulations. Pot: potential-flow wave drift force, Form.: corrected wave drift force using Formula, TS: drift force is calculated in time-domain, MT: Model test results. Top: MT 4150, Bottom: MT 4160. Please see Table 2 for test conditions.**

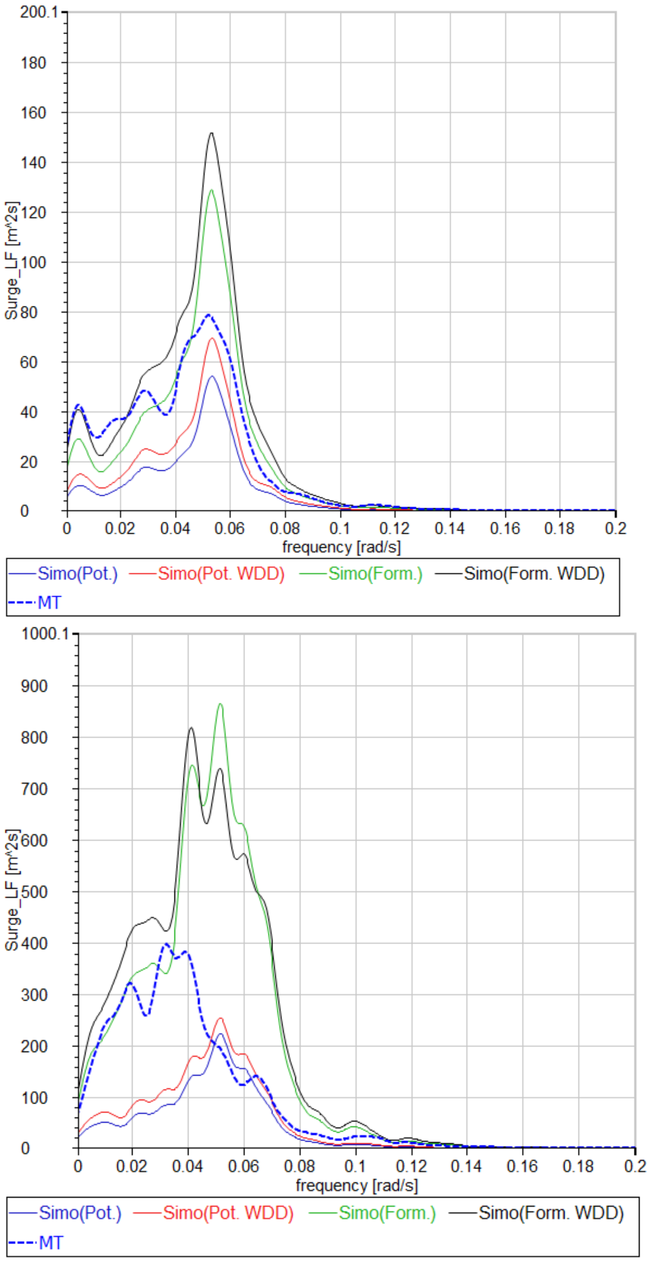

**Fig 8: Influence of simple wave drift damping model. Pot.: potential flow drift coefficients, Form.: drift force calculated using Formula, WDD: wave drift damping coefficient equal to 0.25. MT: Model test results. Top: MT 4150, Bottom: MT 4160. Please see Table 2 for test conditions.**

## 4.3 Low-frequency surge, time-series interpolation method

The simulation results based on time-series interpolation method (TS) for wave drift forces are presented in Fig 9 for two seastates with a current velocity of 0.82 m/s, and in Fig 10 for one seastate with a current velocity of 1.58 m/s. The time-domain interpolation of wave drift force time-series calculated based on Formula, using instantaneous relative velocity (i.e. the new wave drift force model), has significant effects on the obtained response spectrum. Moreover, the proposed drift force model improves significantly the low frequency spectrum from simulations as compared to the model test results.

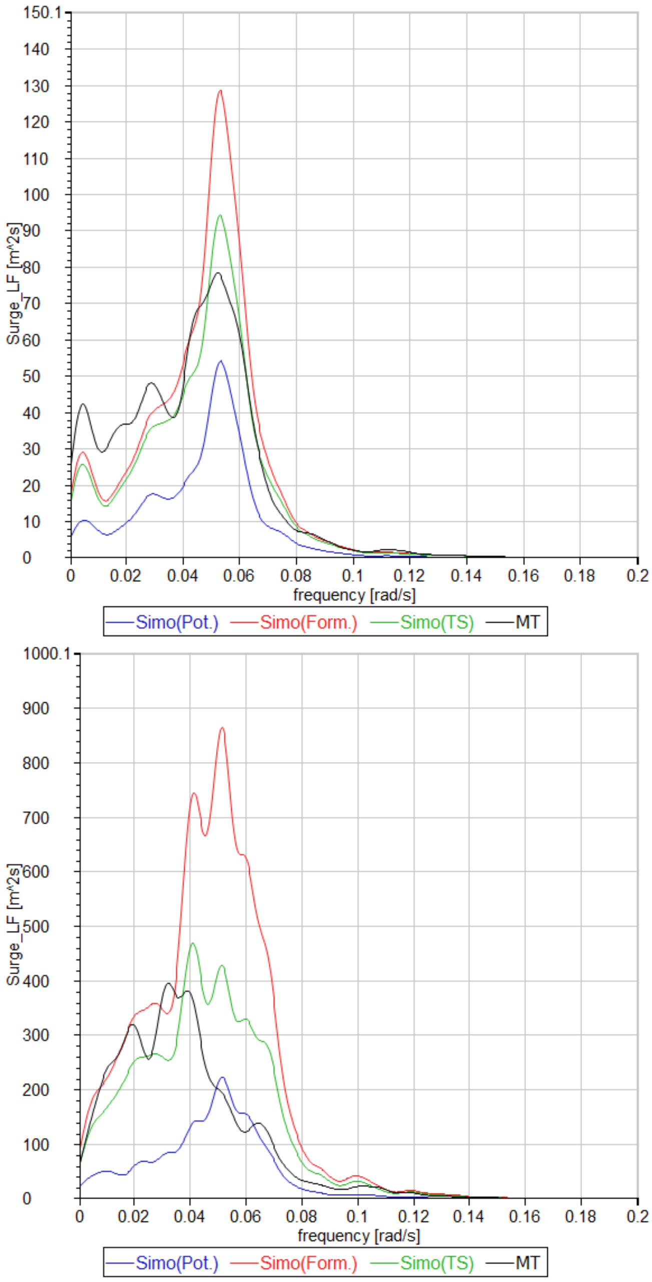

**Fig 9: Comparison of low-frequency surge response spectrum using different drift force calculation methods and model test. Top: MT 4150, Bottom: MT 4160. Pot: potential-flow wave drift force, Form.: corrected wave drift force using Formula, TS: drift force is calculated in time-domain, MT: Model test results. Please see Table 2 for test conditions.**

On the other hand, as noted before, slow drift motions simulated with zero current potential flow drift coefficients are very much under predicted. Applying the "Formula" corrected drift coefficients results on an over estimation of the slow drift motions. The reason is that the slow drift damping is not considered.

Looking at Fig 9 upper graph and comparing to the lower graph, it is possible to observe a clear shift of the experimental response spectrum peak: the low frequency response peak shifts to lower frequencies for the higher seastate. A similar shift was not captured by any of the numerical methods described here. Considering that the difference between the two tests is only in significant wave height, it is difficult to explain the reason for this shift. One possible explanation might be a modification of the surge added mass due to viscous effects induced by higher Hs. Further investigations are needed to better clarify the issue.

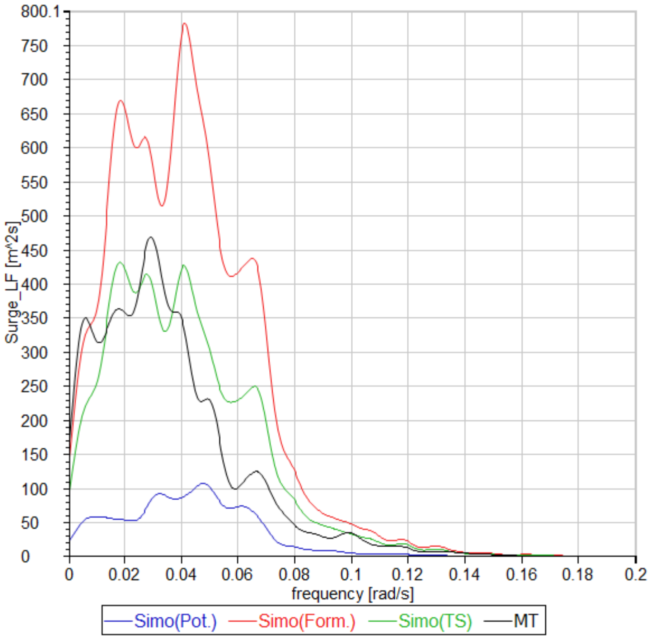

**Fig 10: Comparison of low-frequency surge response spectrum using different drift force calculation methods and model test MT 4260. See Fig 9 caption for explanation of legends.**

## 5 CONCLUDING REMARKS

The paper deals with the low-frequency surge response of a horizontally moored semi-submersible platform in severe seastates with current. The focus is on a new approach for calculating wave drift force time histories considering the influence of viscous effects, together with current and slowly varying velocity effects. The proposed method is compared with existing practical procedures and the results assessed by comparisons with selected model test data from the EXWAVE JIP test program.

The proposed model interpolates pre-calculated drift forces time histories during the simulations depending on the instantaneous relative velocity. A semi-empirical formula is applied to pre-calculate mean wave drift forces for severe seastates with current. The model was implemented as a DLL and coupled with SIMO for time domain simulations.

Comparison of surge low frequency spectrums from simulations and from model tests leads to several conclusions:

- Applying zero current potential flow wave drift force coefficients largely underestimates the slow drift motions.
- Although the semi empirical "Formula" appears to represent correctly the mean drift coefficients in severe seastates with current, use of these coefficients together with a simplified wave drift damping coefficient results on overestimation of the low frequency motions.
- Application of the drift force interpolation method proposed here, results on a significant improvement of the slow drift motion predictions as compared to test data.
- The experimental data show a decrease of the low frequency surge motion spectrum peak for the larger significant wave height. There appears to be a modification of the surge natural period, which is not captured by the numerical models. More detailed studies are needed to clarify this issue.

## 6 ACKNOWLEDGEMENTS

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## 7 REFERENCES

[1] Arne Kvitrud, “Lessons Learned From Norwegian Mooring Line Failures 2010–2013,” in *33nd International Conference on Ocean, Offshore and Arctic Engineering*, San Francisco, California, USA, 2014.

[2] A. M. Wang, P. Rong, and S. Zhu, “Recovery And Re-Hookup Of Liu Hua 11-1 FPSO Mooring System,” in *Offshore Technology Conference (OTC) 2009*, Houston, TX, USA, 2009.

[3] S. Majhi and R. D’Souza, “Application of Lessons Learned From Field Experience to Design, Installation and Maintenance of FPS Moorings,” in *Offshore Technology Conference (OTC) 2013*, Houston, TX, USA, 2013.

[4] O. M. Faltinsen, *Sea loads on ships and offshore structures*. Cambridge, UK: Cambridge University Press, 1990.

[5] S. Chakrabarti, “Drift Force on Vertical Cylinder - Viscous vs. Potential,” vol. 2, no. 6, pp. 73–82.

[6] A. Dev and J. Pinkster, “Viscous mean drift forces on moored semi-submersibles,” in *Proc. ISOPE 1995*, The Hague, The Netherlands, 1995.

[7] C. T. Stansberg, R. Yttervik, and F. G. Nielsen, “Wave Drift Forces and Responses in Storm Waves,” in *Proceedings, PRADS’98*, The Hague, The Netherlands, 1998, pp. 1005–1012.

[8] G. H. Keulegan and L. H. Carpenter, “Forces on cylinders and plates in an oscillating fluid,” *J Res Natl Bur Stand*, vol. 60, No. 5, pp. 423–40, May 1958.

[9] H. Ormberg, “SIMO Theory Manual V4.0, rev 1,” MARINTEK, Trondheim Norway, MT51 F93-0184, Sep. 2012.

[10] J. A. P. Aranha, “A Formula for Wave Damping in the Drift of Floating Bodies,” vol. 275, pp. 147–155, 1994.

[11] C.T. Stansberg, K. E. Kaasen, B. C. Abrahamsen, A. Nestegård, Y. Shao, and K. Larsen, “Challenges in Wave Force Modelling for Mooring Design in High Seas,” presented at the Offshore Technology Conference (OTC) 2015,Houston, TX, USA, 4-7 May, 2015, Houston, TX, USA, 2015.

[12] Newman N., "Second-order, slowly-varying forces on vessels in irregular waves. Proc. Symp. on the Dynamics of Marine Vehicles and Structures in Waves", London, UK, 182-186, April 1974.

[13] Fonseca, N. and Stansberg, C.T., 2017. Wave drift forces and low frequency damping on the Exwave Semi-submersible. Proceedings of the ASME 2016 36th International Conference on Ocean, Offshore and Arctic Engineering, OMAE2017, June 25-30, 2017, Trondheim, Norway, paper OMAE2017-62540 (submitted).