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EFFICIENT MODELLING OF HARSH ENVIRONMENT DISTURBANCES FOR DP AND AUTONOMOUS SHIPS SIMULATIONS

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ABSTRACT

Numerical modelling of the Arctic ocean dynamics with real-time simulation capability is useful for designing, developing, testing, and validating Dynamically Positioned (DP) and Autonomous ships/offshore platforms. However, advanced simulation technology needs to be developed to predict the expected loads on these systems due to the complex interactions with environmental disturbances. This paper presents models of waves, currents, wind, and ice that comply with the real-time simulation requirements and adequately capture the dynamic characteristics of the most relevant physical processes. A 3D dispersive numerical model is deployed to predict the wave parameters to be utilized to compute the wave loads on a ship with known Response Amplitude Operators (RAO). A uniform current load is then incorporated in a superposition manner by using a combined wave-current field dispersion relation capable of expressing the wavenumber of an interactive wave-current field. The mean and the gust wind components are added to the resultant force components. A multiple regression-based ice model is used to predict the loads caused by an ice field characterized by varied ice thickness, concentration, floe size, drift speed and directions. The interaction between the ice field and waves is assumed negligible. The stationkeeping performance of a generic DP-controlled ship subjected to the environmental disturbances defined by the time traces of the combined forces and moments obtained by the above methods for a range of environmental conditions.

The proposed models can be beneficial for designing, developing, and evaluating dynamic positioning and autonomous ship controllers' performance. Another application may be developing a realistic simulation environment to train conventional, DP-controlled and autonomous ship operators.

Keywords: Dynamic positioning, wind force, wave force, current force, ice force, 3D wave models, 3D wave-current interaction models,

1. INTRODUCTION

The offshore industry has raised its research and development endeavour to explore and extract oil and gas from Arctic and Sub-Arctic offshore regions. The physical environment in these regions presents several challenges: cold, temperatures, darkness, precipitation, fog, extreme winds, currents and waves, icing, etc. [1]. One of the greatest threats to the Dynamic Positioning (DP) and Autonomous control systems of vessels and offshore installations operating in these regions is the multi-directionality of drifting sea ice with a wide variety of types and forms, ranging from isolated first-year floes to compacted multi-year ridges [2]. In the sub-arctic, marginal ice zone (MIZ, the first ice infested area encountered from the open Ocean), wind, waves and sometimes current is present besides the broken ice-field. This creates a very complex environment for offshore operations, particularly for DP operations. The DP or autonomous control systems in the market today do not take account of the forces and movements that exist in such a highly demanding environment. Numerical modelling and validation of each interaction phenomenon in all possible environmental cases are essential and key to understanding the problem and designing both the floating and control systems.

Modelling and simulation of environmental disturbances for ocean surface vehicles have been used in ship simulators for naval training, ship hull designs, military science and entertainment activities such as computer games [3]. Numerical simulations of the Arctic ocean dynamics can help design, develop, test, and validate DP and Autonomous ships/offshore platforms in harsh environment simulations. Simulation technology needs to be developed to predict the expected loads on these systems due to the complex interactions with the disturbances. Modelling complex environmental disturbances and their loads on the systems is an essential and critical component of such simulations.

This paper presents models of waves, currents, wind, and ice that comply with the real-time simulation requirements and adequately capture the most relevant physical processes. Section 2 presents a brief review of existing models for various environmental disturbances modelling. For the wave model, the authors proposed a 3D dispersive numerical model to predict the wave parameters to be utilized to compute the wave loads on a ship with known Response Amplitude Operators (RAO). A uniform current load is then incorporated in a superposition manner by using a combined wave-current field dispersion relation capable of expressing the wavenumber of an interactive wave-current field. The mean and the gust wind components are added to the resultant force components. Multiple regression-based ice models are then used to predict the forces and moment caused by an ice field characterized by varied ice thickness, concentration, floe size, drift speed, and directions. The combined loads are assumed to be the summation of the wind loads, wave and current interaction loads, and ice loads. The interaction between the ice field and waves is assumed negligible. In Section 3, the authors present the time traces of the individual and combined loads exerted by these disturbances on a Generic DP ship for a range of environmental conditions. Section 4 presents the implementation of the environmental disturbances model to the DP vessel in a simulated environment to evaluate the DP performance. A few concluding remarks and recommendations for future work follow in Section 5.

2. ENVIRONMENTAL DISTURBANCES

A brief discussion of various existing environmental disturbance models is presented in this Section. Focus is given to the wave and current interactions and ice force models. Several wave, wind and current models are proposed in the literature, ranging from very simple empirical/analytical to complex high-fidelity numerical models; however, literature to capture their interactions is limited. Also, modelling of ice dynamics in the presence of waves is scarce in the literature.

2.1 Wind Models

The wind load at any instance is the summation of the mean and the gust load components at a given point, both of which are functions of time and space and vary on elements of a given structure. For a single-point loading method, it is assumed that mean and gusty velocities are constant at all locations on the structure. On the other hand, when the structure is quite large, distributed multiple points of wind force method might be utilized where the surface of the structure would be divided into multiple sections, and the mean and gusting wind forces are computed separately on each Section. The gusting wind load component for each small Section is evaluated separately using a correlation strategy [4], and then a superposition is made for the total wind gusting force on the structure.

The instantaneous wind force (F_w) on any structure that has r number of elements can be given by the following superposition equation [5]:

$$F_{wind}(t) = \frac{1}{2}\rho_a \sum_{j=1}^{r} C_{Daj} A_j \left(\overline{U}_{aj} + u_{gj}(t) - \dot{x}(t)\right)^2 \quad (1)$$

where ρ_a is the air density, C_{Da} is the drag coefficient in air, A is the projected area and $\overline{U}_a$ is the mean wind velocity on any element, and u_g is the wind gust; $\dot{x}$ is the structural velocity, which can be considered negligible for our cases.

The gust wind force on the structure can be predicted by the following empirical equation presented in [6]:

$$\frac{S_w(n)n}{4\kappa N} = \frac{\overline{U}_{a10}^2}{(2+N^2)^{\frac{5}{6}}} \quad (2)$$

where, n is the frequency, $S_w(n)$ the spectrum, κ (=0.003 to 0.005) the drag coefficient, $\overline{U}_{a10}$ the velocity at a height of 10 m averaged over one hour and $N = 1200n/\overline{U}_{a10}$. See also, [7] and [8] for more information.

The mean force, F_{windM}, and fluctuating force, F_{windG}, on any structure can be expressed as follows:

$$F_{windM}(t) = \frac{1}{2}\rho_a C_{Da} A \overline{U}_a^2 \quad (3)$$

$$F_{windG}(t) = \frac{1}{2}\rho_a C_{Da} A \overline{U}_a u_g(t) \quad (4)$$

For modelling DP operation in a testing facility, particularly in the presence of ice, the wind forces are sometimes modelled as a certain percentage of total thruster capacity [41]. The total thruster capacity of the DP vessel is reduced to compensate for the virtual presence of wind load.

2.2 Current Models

The magnitudes of currents vary with the location in the Ocean and also their generation mechanism. For example, a strong wind could generate a strong current over a certain water depth, but a tidal current usually moves the whole ocean water body. Wave breaking and river discharge can generate localized strong current. Current is typically modelled as uniform over depth or linearly or non-linearly varying sheared current. The current force is modelled based on the empirical formulation to account for the global and local current drag coefficients, current magnitude and direction, and projected area, as discussed below.

The computation of the current force is often done in a very straightforward manner. In general, currents impart non1inear forces on the structure and could be characterized as a drift force due to the current only case. The velocity of currents could be depth-dependent, but the current velocity is considered vertically uniform for simplicity. The force due to currents (F_C) only can be evaluated using the following equation:

$$F_C = \frac{1}{2}\,\rho_w\, C_{Dc}\, A\, U_c^2 \quad (5)$$

where U_c is the wave-particle velocity, A the projected area and C_{Dc} is the drag coefficient for current.

The above current model can be further improved if the two-dimensional current model introduced by [9] and [10] is used. The same formulation can be used for predicting the wind and current loads; we use notations for current to illustrate the method. In this method, the resultant wind or current force acting on a surface vessel is defined in terms of relative current speeds $u_{current}$ and $v_{current}$ illustrated in Figure 1.

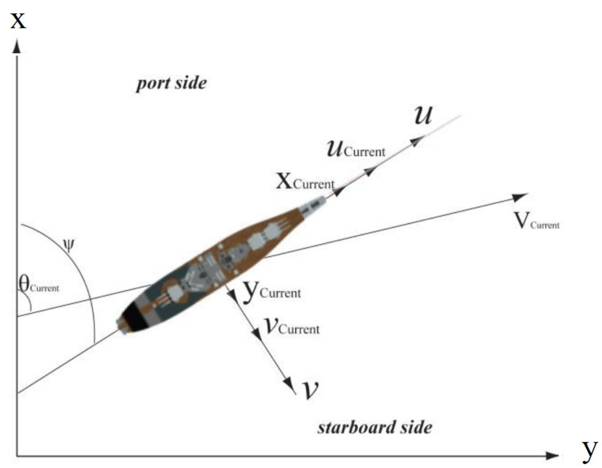

FIGURE 1: NOTATIONS FOR TWO DIMENSIONAL CURRENT OR WIND MODEL [10]

$\theta_{current}$ is the angle between X-axis and the direction of the current. Then $u_{current}$ and $v_{current}$ determined as follows:

$$u_{current} = V_{current} cos(\theta_{current} - \psi) - u \quad (6)$$

$$v_{current} = V_{current} sin(\theta_{current} - \psi) - v \quad (7)$$

The resultant current forces acting on a surface vessel with respect to the ship's fixed reference frame:

$$X_{current} = \frac{1}{2} R_{wx} \rho_w A_T u_{current}^2 \quad (8)$$

$$Y_{current} = \frac{1}{2} R_{wy} \rho_w A_L u_{current}^2 \quad (9)$$

where, R_{wx} and R_{wy} - Current drag coefficients, A_T - transverse current projected area of the vessel (underwater for current and above water for wind), A_L - lateral current projected area of the vessel. A similar yet more accurate model was proposed by [11]. We recommend the model presented in [11] as it accounts for the instantaneous vessel yawing the corresponding changes in the speed and directions of current as well as the project surface areas.

2.3 Waves Models

Of the three main environmental forces (wave, wind, and current), the horizontal wave drift force is quite important.

For the cases of regular waves and current, a 3D numerical model with the assumption of inviscid and incompressible fluid flow is developed and utilized in this work to evaluate wave kinematics. An explicit type numerical scheme is used for the simulation of the numerical model. A detailed description of this wave model can be obtained in [12, 30, 31]. On the other hand, for the irregular waves, a Boussinesq type numerical model with modified dispersion relation is developed and adopted in this simulation. The description of this numerical model is available in [12, 31]. The same model is upgraded for the interacted wave-current coexisting field. An ADI (Alternative Directional Implicit) method is employed for the solution of the non-linear equations.

The wave force on a unit length of a structure can be calculated when the wave kinematics are known using Morisons's equation as follows:

$$F_w(t) = \frac{1}{2}\,\rho_w\, C_D\, A\, u|u| + C_M \rho_w V \dot{u} \quad (10)$$

where u is the wave particle velocity, $\dot{u}$ the wave acceleration, C_D and $C_M (= 1 + C_m)$ are the drag and mass coefficients, C_m the added mass coefficient, V the volume, D the diameter and $A (= D * 1)$ is the area per unit length.

The mean drift force due to viscosity effects can be obtained by utilizing the instantaneous velocity of the water particle in the above equation and integrating the obtained expression over one wavelength [13]:

$$F_{wdrift} = \frac{2}{3\pi}\,\rho_w \omega^2\, C_{Dv}\, D\, a^3 \quad (11)$$

The viscous drift coefficient C_{Dv} can be obtained from the empirical formula by [13] and varies roughly from 1.27 to 1.62.

The prediction of wave loads due to regular and irregular waves and waves and current interactions can also be obtained using the RAO (Response Amplitude Operator) approach, as long as the instantaneous surface elevation and the RAO of the vessel for the wave environment are known. In this approach, the wave force RAOs for specific vessels for various operating conditions are calculated using commercial potential flow solvers such as ANSYS-AQWA or WAMIT or a similar solver. The RAO curves are then utilized to derive the wave force and moment spectrums in the irregular sea for the specified theoretical spectrum. The corresponding wave force/moment values were extracted directly from the force/moment RAO for the single frequency regular sinusoidal wave.

To obtain the forces and moments due to an irregular sea, the traditional linear superposition principle is used. This principle allows summing the responses of a system due to components of the irregular sea in a linear fashion to predict motions in an irregular sea state. The wave forces and moments in the mathematical model adopted in [14] also follow the same superposition principle assuming a linear system.

2.4 Ice Force Models

One of the challenging tasks in developing a real-time simulator for environmental disturbances involving ice is to develop, validate and implement a statistically reliable numerical model that can predict the ice loads in real-time and at the same time accounts for most of the relevant physical processes of the complex and dynamic ice-ice, ice-environment and ice-vessel interactions.

Several published numerical works have been used to understand and model the ice forces acting on stationary or DP-controlled or moored floating platforms or slowly manoeuvring ships in managed or broken sea ice. The authors of [16] presented an extensive literature review of various existing techniques and approaches for modelling broken ice-structure interactions. In [16], the authors categorized the existing methods into Analytical Methods, Empirical-Statistical Methods, Numerical Methods and Hybrid Methods.

Popular analytical techniques known as a “Micro” model and a “Macro” model were used for modelling and simulations of ice interaction with moored structures by [17] and [18] and [19]. [20] extended the approach to simulate 6 degrees-of-freedom motion of vessels transiting through the ice. Amongst the empirical methods, [21] developed a pioneering empirical method for predicting ice-structure interaction forces due to broken ice using the “equivalent level ice thickness” approach.

[22] developed an empirical-statistical modelling technique for predicting the ice forces on a DP vessel. The method offers a balanced combination of physical ice model tests and numerical techniques to justifiably predict statistically valid ice forces on a DP-controlled vessel due to actions of a broken ice field. The major shortcoming of the approach is its lack of details of the floe dynamics that would decrease the fidelity in visualization in the simulation. To improve the fidelity of this approach, the techniques, as outlined in Figure 14, have been implemented.

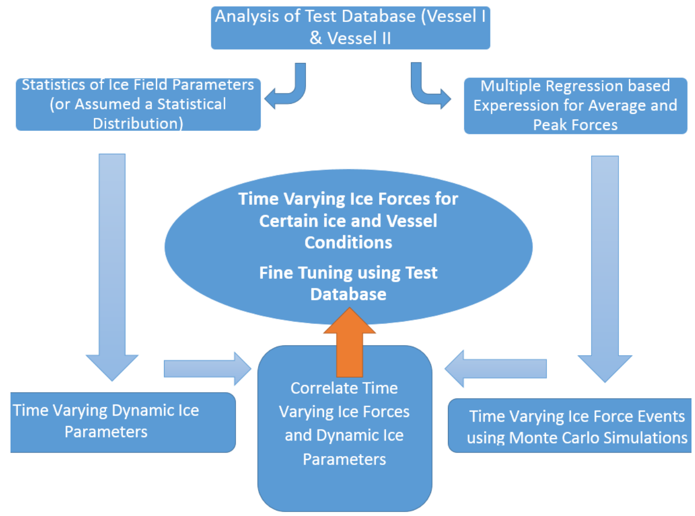

FIGURE 2: FLOW CHART OF THE EMPIRICAL- STATISTICAL TECHNIQUE [22].

In this technique, the time-average ice forces are expressed as functions of nominal managed ice variables, e.g. ice thickness and strength, floe size, floe concentration, and floe velocity and direction, using advanced multivariable statistical analysis of existing database acquired during an ice basin testing campaign. The next step is to relate the time-average to the discrete ice impact forces on the DP/Autonomous vessel using statistical distribution and Monte Carlo methods [22]. The procedure used to develop this model is outlined below. The details of the model is provided in [22].

- Developed multiple-regression based models for mean and average of peaks of thruster forces, for mean loading span and frequencies.
- Developed models for predicting force peaks and peak time for one or multiple events using Monte Carlo Simulations.
- Generated time series for thruster forces and yawing moment using idealized loading profiles.
- Applied correction factors to account for idealization and regression errors.
- Converted thruster forces to ice forces using specialized random noise.

Figure 3 compares the model testing measurements and corresponding statistical model predictions for a test case. The predicted forces/moments are statistically comparable with the corresponding measurements.

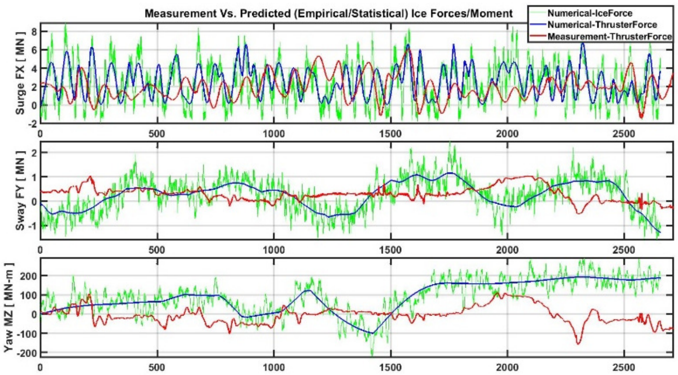

FIGURE 3: COMPARISON OF MEASURED AND PREDICTED GLOBAL FORCES (THRUSTER AND ICE) ON A DRILLSHIP, ICE THICKNESS 2M, 90% CONCENTRATION, FLOE SIZE 50M, DRIFT SPEED 0.5 KNOT AND ±2° HEADING.

2.5 Waves and Currents Interaction Models

The presence of a wave over a current field remained as an interesting research topic among ocean engineers and researchers. When a wave and a current are in the same direction, the wavelength increases, and the height decreases to accommodate extra energy. On the other hand, when the wave and current are opposite, the wavelength decreases, and as compensation, the wave height increases.

The above-mentioned wave models use a dispersion relation that contains the current parameter will account for the modified wavenumbers following equation [23,24,25] below:

$$\omega - \overrightarrow{U_c} \cdot \overrightarrow{k} = \sqrt{gk \tanh kd} \quad (12)$$

where $\vec{k}(k_x, k_y)$ is the wavenumber, d the mean water depth, $\overrightarrow{U_c}(U_{cx}, U_{cy})$ the current velocity, and g is the acceleration due to gravity. The descriptions of the wave-current interaction models can be found in many literatures, See also [28] for details.

The total force for the combined wave-current field F_{wc} can be obtained from the following relation:

$$F_{wc}(t) = \frac{1}{2}\, \rho\, C_D\, A\, u_{wc}|u_{wc}| + C_M \rho V \dot{u}_{wc} \quad (13)$$

where u_{wc} is the velocity and $\dot{u}_{wc}$ is the acceleration of the combined wave-current field can be obtained from [30] depending on the requirements of the modelling and C_M is the mass coefficient. See [30] for details.

In this paper for the regular wave and regular wave-current interaction, simulation is done following [26]. The above force expression, Eq. (13) is based on Morison's formulation. Alternatively, the total force for the combined wave-current field can be obtained by using the RAO technique using modified surface elevation and then superimpose the current load as per Section 2.2.1.

2.6 Waves and Ice Interaction Models

The ice and wave interaction is important in the marginal ice zone (MIZ) for two primary reasons: firstly, ocean waves influence the sea ice cover, which then affects large scale wind patterns and ocean currents; secondly, ice floes scatter and dampen waves, which has to be taken into account in forecasts of wave heights [32]. The grease ice and broken ice floes present in the MIZ, play an important role in damping the high-frequency waves that would otherwise lead to fast-breaking of the inner, continuous sea ice [33]. [33] presented a brief survey of the existing sea ice and wave interaction modelling, both physical and numerical and field measurements.

[34] treated the wave attenuation by interaction with sea ice with a percent transmission of wave energy through the ice as a simple linear function of ice concentration. Rogers and [35] modified a third-generation model for wind-generated surface gravity waves WAVEWATCH III® to represent the effect of ice on waves as a dissipative source function with three alternative formulations of varying complexity.

[36] reported a wave-ice interaction model for the MIZ that calculates the attenuation of ocean surface waves by sea ice and the concomitant breaking of the ice into smaller floes by the waves. The rate of attenuation is calculated using a thin elastic plate (representing ice floes) scattering model, and a probabilistic approach is used to derive a breaking criterion in terms of the significant strain. This determines if the local wave field is sufficient to break the ice cover. An estimate of the maximum allowable floe size when ice breakage occurs is used as a parameter in a floe size distribution model, and the MIZ is defined in the model as the area of broken ice cover.

[37] investigated various models of ocean wave propagation in ice-infested seas. [38] explored these models as well, however, obtained unrealistic attenuation coefficients for continuous ice sheet/high concentration ice-field. The "Transport equation models" hold a special status because they can incorporate models from the other categories as source terms in the transport equation.

Successful modelling of wave-ice interaction is challenging. In particular, both field and laboratory data are still too scarce. Several competing models exist where each model can be approximately fitted to the available observations. [32] proposed a new set of methodology and instruments to perform sea ice and wave interactions measurements and compared several datasets.

3. MODEL IMPLEMENTATION

A generic Drillship vessel is used for the present simulation cases. The full-scale vessel has an overall length of 206 m, has a 45 m beam and displaces around 100,000 MT at 12 m draught [39]. The forces and moments (environmental load on the horizontal plane) were predicted on the vessel due to the environmental disturbance cases as identified in Table 1. The time traces of the forces and moments exerted by these disturbances (individual cases as well as combined cases) on the Drillship for a range of environmental conditions are presented in this Section.

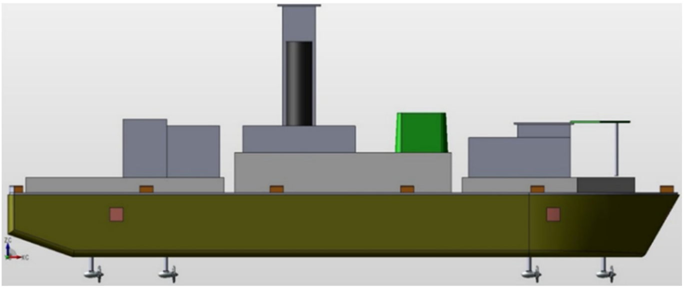

FIGURE 4: THE GENERIC DRILLSHIP HULL UTILIZED IN THE PRESENT RESEARCH.

TABLE 1: SIMULATION MATRIX FOR ENVIRONMENTAL MODELS

Case	Environment Condition	Wave			Current		Ice		
		H / Hs (m)	T / Tp (s)	Angle	U (m/s)	Angle	ConC Floe(m) Thick(m)	Drift (Kts)	Angle
1	Regular wave only	8	8	0	NA	NA	NA	NA	NA
2	Regular wave only	8	12	0	NA	NA	NA	NA	NA
3	Regular wave only	8	12	45	NA	NA	NA	NA	NA
4	Irregular waves (JONSWAP)	15	14.6	0	NA	NA	NA	NA	NA
5	Irregular waves, [16]	15	14.6	0	0	NA	NA	NA	NA
6	Regular wave with collinear current	8	12	0	-2.5	180	NA	NA	NA
7	Irregular waves [16] with collinear current	15	14.6	0	1	NA	NA	NA	NA
8	Managed Ice Field	NA	NA	NA	1.2	0	90%,50 m, 2 m	1.2	0
9	Managed Ice Field	NA	NA	NA	0.25	10	80%, 50 m, 2 m	0.5	10
10	Waves and Current, Managed Ice Field	1.5	14.6	0	1	0	90%,50 m, 2 m	1.2	0
11	Waves and Current, Managed Ice Field	1.5	14.6	0	1	0	80%, 50 m, 2 m	0.5	10

To obtain the wave loads due to wave only or wave and current field, the wave kinematics are first predicted using a vertically integrated 3D numerical model [26]. This model can efficiently compute the dynamics of ocean waves in the presence or in the absence of the ocean current. The Vessel forces and moments were then predicted using the surface elevation and RAO-based methods described above. The wave force RAOs from ANSYS-AQWA for the drillship vessel and for different practical wave conditions were obtained for 0° to 180° wave heading in an interval of 15°. The values required in between those headings were obtained by interpolation. The first-order wave loads on the vessel were then estimated using the transfer function for a given wave. The forces and moments due to the broken ice field is obtained using the regression-based model [22]. For the sake of the present simulations, the wave and ice interaction is assumed negligible.

Computations are carried out using Case 1, Case2 and Case 3. The obtained results are quite reasonable (not shown in this paper for space limitations). The validations of the 2D version of these models are reported in [25,31].

The results of irregular waves and forces for Case 4, shown in Figure 5, are simulated using. JONSWAP spectrum is used for the simulation of the wave-only case. But for the case of interaction of irregular waves [15] with a current, [43] spectrum is utilized shown by Eq. 12. Figure 6 shows results for surface elevations and forces due to a regular wave interaction with an opposite current. The computational condition is described in Case 6. In Figure 7, the predicted surface elevation is compared with the RAO-based reconstructed surface elevation for Case 6. Figure 8 describes the results for instantaneous surface elevations and force components when an irregular wave field interacts with a vertically uniform current for Case 7. Figure 9 compares the power spectrums for irregular waves without (Case 5) and with (Case 7) current.

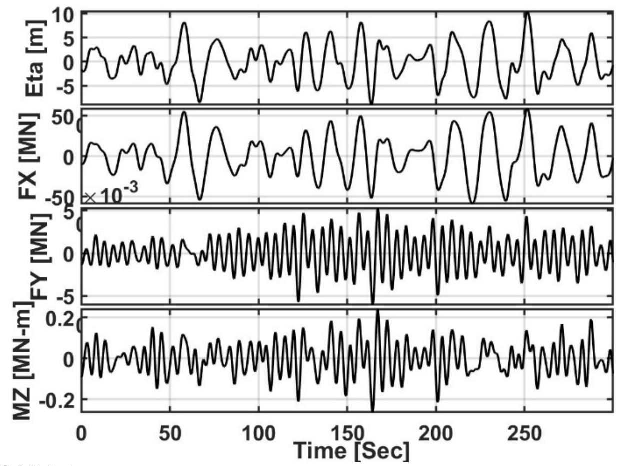

FIGURE 5: WAVE ELEVATIONS AND FORCES FOR CASE-4 WITH JONSWAP SPECTRUM ($H_s = 15\ m\ and\ T_p = 14.6\ s$)

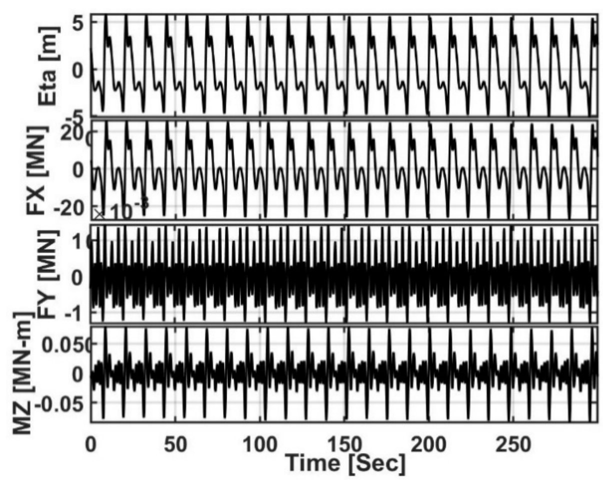

FIGURE 6: SURFACE ELEVATIONS AND WAVE FORCES FOR CASE-6, REGULAR WAVE WITH NON-COLLINEAR CURRENT ($H = 8\ m, T = 12\ s, U = -2.5 m/s, wave\ angle = 0^o\ and\ current\ angle = 180^o$)

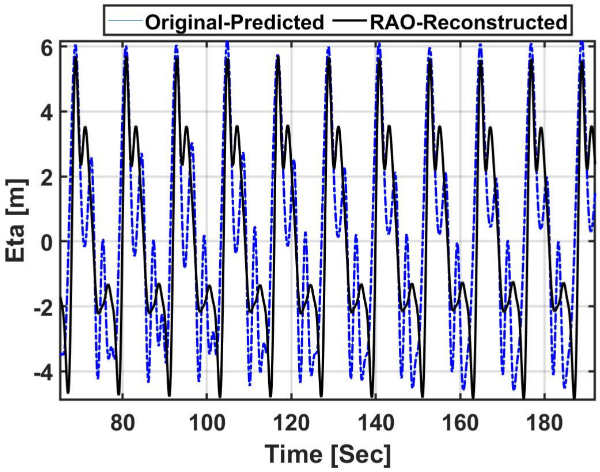

FIGURE 7: COMPARISONS OF THE SURFACE ELEVATIONS BETWEEN THE PREDICTED AND RAO-BASED RECONSTRUCTION.

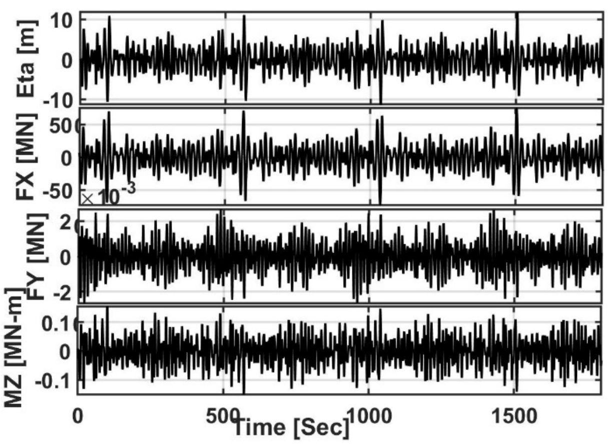

FIGURE 8: WAVE ELEVATIONS AND FORCES FOR CASE-7 WITH GODA [16] SPECTRUM ($H_s = 15\ m, T_p = 14.6\ s\ and\ U = 1.0\ m/s$)

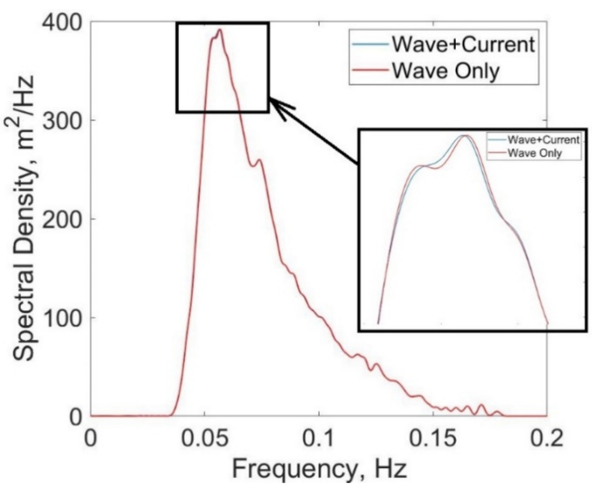

FIGURE 9: COMPARISON OF THE POWER SPECTRUMS FOR IRREGULAR WAVES WITH AND WITHOUT UNIFORM CURRENT FOR CASE 7 USING [16] SPECTRUM ($H_s = 15\ m, T_p = 14.6\ s\ and\ U = 1.0\ m/s$).

Figures 14 and 15 present the ice forces and moment in the horizontal plane on the Drillship due to cases 8 and 9, respectively, as described in Table 1. Both conditions are considered extremely harsh, whereas the first case is for a head-on condition, and the next case is in an oblique condition. Figure 12, through Figure 14, presented the simulated disturbances that include ice, waves, and current. In these predictions, the interactions between the wave and current were included. However, wave and ice-field interactions were neglected. Figure 12 shows the linear superimposition of the forces in the surge direction. A further discussion on the ice load characteristics is beyond the scope of this paper.

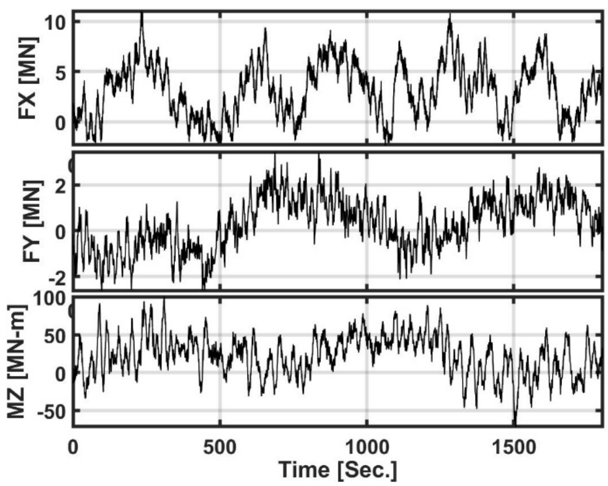

FIGURE 10: ICE LOADS IN A MANAGED ICE FIELD, ICE THICKNESS 2M, 90% CONCENTRATION, FLOE SIZE 50M, DRIFT SPEED 1.2 KNOTS AND HEAD-ON CONDITION.

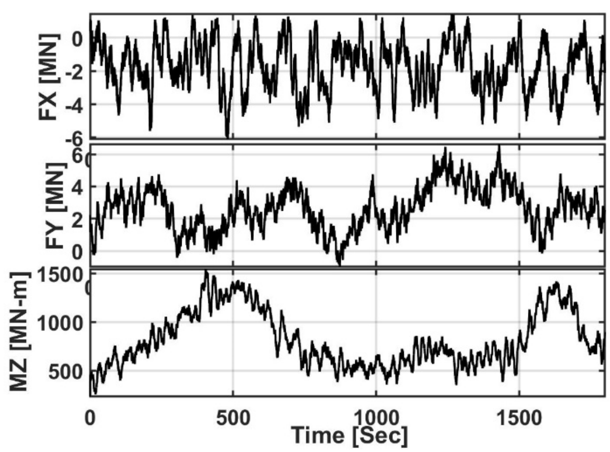

FIGURE 11: ICE LOADS IN A MANAGED ICE FIELD, ICE THICKNESS 2M, 90% CONCENTRATION, FLOE SIZE 50M, DRIFT SPEED 0.5 KNOT AND 10O OBLIQUE CONDITION.

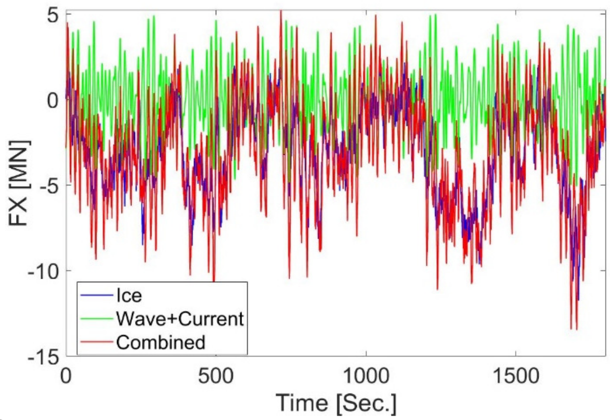

FIGURE 12: COMBINED WAVE, CURRENT AND ICE LOADS IN SURGE, ICE THICKNESS 2M, 90% CONCENTRATION, FLOE SIZE 50M, DRIFT SPEED 1.0 KNOT, WAVES WITH $H_s = 1.5\ m, T_p = 14.6\ s\ and\ Current\ with\ U = 1.0\ m/s.$

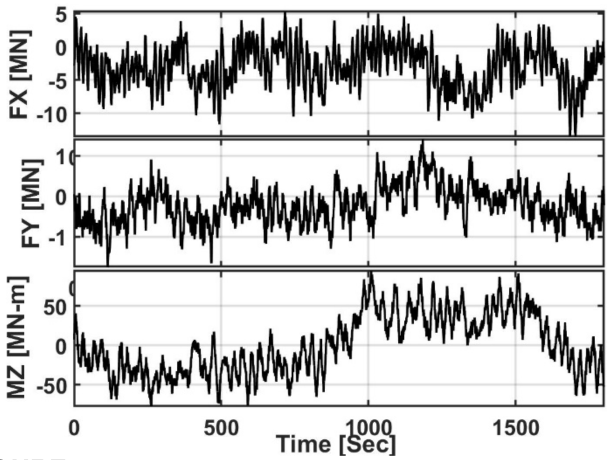

FIGURE 13: COMBINED WAVE, CURRENT AND ICE LOADS IN SURGE, SWAY AND YAW FOR CASE-10, ICE THICKNESS 2 M, 90% CONCENTRATION, FLOE SIZE 50 M, DRIFT SPEED 1.2 KNOT, WAVES WITH $H_s = 1.5\ m, T_p = 14.6\ s\ and\ current\ U = 1.0\ m/s.$

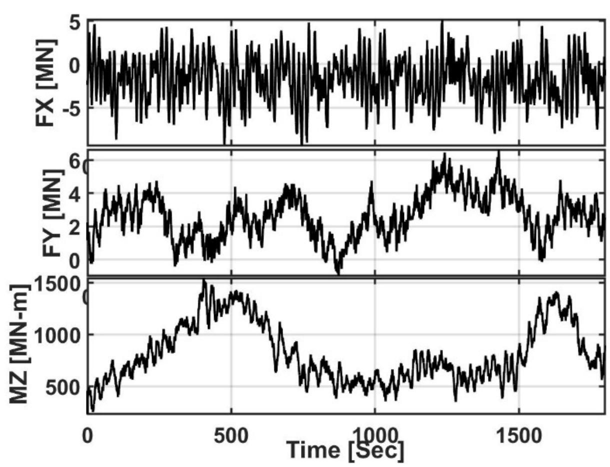

FIGURE 14: COMBINED WAVE, CURRENT AND ICE LOADS IN SURGE, SWAY, AND YAW FOR CASE-11, ICE THICKNESS 2 M, 80% CONCENTRATION, FLOE SIZE 50 M, DRIFT SPEED 0.5 KNOT, WAVES WITH $H_s = 1.5\ m,\ T_p = 14.6\ s\ and\ Current\ with\ U = 1.0\ m/s.$

4. REAL-TIME SIMULATIONS

The dynamic positioning (DP) performance of the Drillship vessel under the influence of two cases (Case 10 ad Case 11 in Table 1) of environmental disturbances comprising ice, wave and current is investigated in this Section. The vessel equipped with a non-linear proportional integral and derivative (NPID) control system with acceleration feedback type control system [42] were simulated and evaluated under the two different extreme sea conditions. Matlab/Simulink models of the full-scale ship are used, which were developed under the scope of a multi-year R & D project [42]. In the model, an unscented Kalman filter (UKF) is used to estimate vessel motions and to control low frequency (LF) motions while filtering out wave frequency (WF) motions.

Figure 15 and Figure 17 show the thruster responses during the stationkeeping of the drillship with a target 0,0,0 deg and 0,0,10 deg, respectively, for the two corresponding disturbance cases. Figure 16 and Figure 18 show the corresponding offsets. Both cases show that the vessel could not main its station in the target location and orientation. This is attributed to the extreme ice, wave and current conditions. These simulations were carried out to demonstrate the processes of environmental disturbances modelling for real-time simulation applications and not to investigate DP systems capability, no further discussion on the DP system's capability is offered.

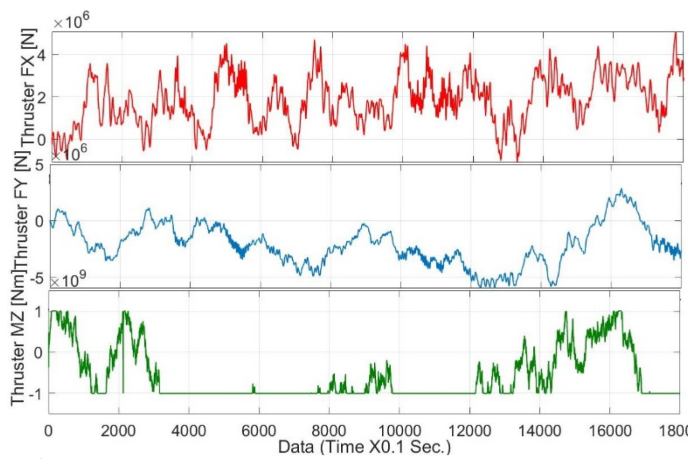

FIGURE 15: THE THRUSTER LOADS DURING THE DP OPERATIONS OF THE DRILLSHIP WITH NPID CONTROLLER SUBJECTED TO CASE-10 DISTURBANCE LOADS.

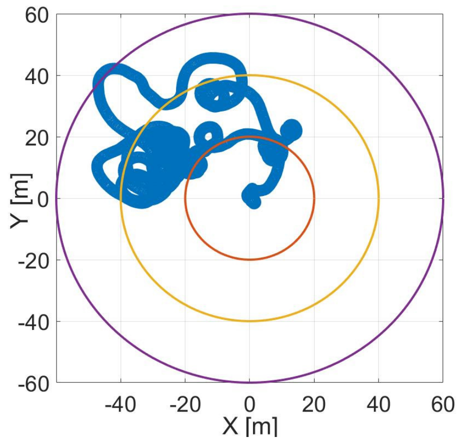

FIGURE 16: THE X, Y OFFSETS OF THE DP VESSEL WITH THE TARGET POSITION OF 0 M, 0 M, 0 DEG FOR CASE-10.

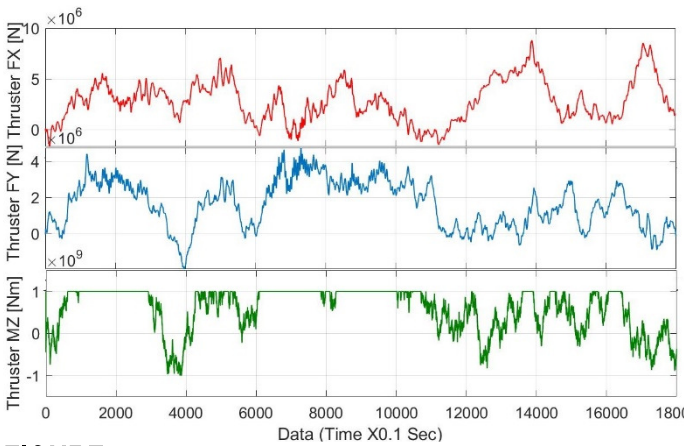

FIGURE 17: THE THRUSTER LOADS DURING THE DP OPERATIONS OF THE DRILLSHIP WITH NPID CONTROLLER SUBJECTED TO CASE-11 DISTURBANCE LOADS.

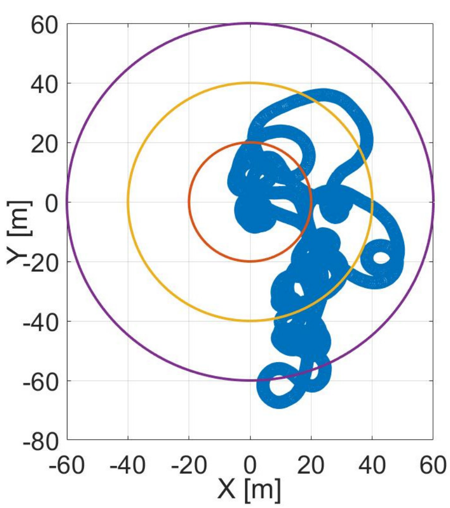

FIGURE 18: THE X, Y OFFSETS OF THE DP VESSEL WITH THE TARGET POSITION OF 0 M, 0 M, 10 DEG FOR CASE -11.

In a previous comparative study to investigate five state-of-the-knowledge control schemes, the authors found that the NMPC (non-linear model predictive control) showed the best ability to deal with extreme disturbances efficiently [67]. Although all five controllers were able to maintain the ship position under moderate conditions, only the NMPC and the MRPID (multi-resolution PID) controllers were able to stabilize the ship under extreme sea states. The authors plan to investigate further the performance of NMPC and MRPID to improve its performance to deal with several realistic external disturbances that include wind, waves, currents, and ice, including the two scenarios presented above.

Regardless of the modelling approach taken, the availability (and quality) of measured data is paramount to the success of the environment disturbance model development. For the range of environmental conditions and scenarios of interest (dictating wave characteristic and interactions with current, the presence of ice, type and characteristics), and for each vessel of interest (e.g. Drillship, supply vessel, ice breaker, etc.), the current modelling technique require the availability of a dataset that extends the range of conditions and operations expected from the models. The authors plan to carry out an extensive test program to evaluate a ship's performance with different controllers for DP and Autonomous operations in an environment consisting of wave, current and/or ice.

5. CONCLUSION AND FUTURE WORK

In the numerical simulation, the combined environmental loads due to wind, wave, current, and ice are utilized to perceive the response of the NPID controller in keeping the DP vessel at the target (0, 0, 0) position. Each of the wave, current, ice and interaction models presented can be used for real-time and faster than real-time simulations.

The wave-current models used here for various simulations are all validated for limited cases and are published in different conferences and journals. The ice force models are developed and validated using an extensive dataset of DP vessel's interactions with managed ice-field. The wave and ice interaction models are still in the development phase, and besides some rudimentary empirical techniques, the complex interactions are not well understood.

Regardless of the modelling approach taken, the availability (and quality) of measured data is paramount to the success of the environment disturbance model development. The present modelling techniques and performance of the DP-controller require further validations using basin test data.

The external disturbance models developed or recommended in this research are expected to help to develop and evaluate the most effective control scheme for different extreme sea conditions. The results also support control system development for dynamic positioning and autonomous operations of ships and offshore platforms. These models should be rigorously tested and validated for DP and autonomous operations in realistic environmental conditions.

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