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NEW APPROACH IN SHIP MANOEUVRABILITY PREDICTION

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Abstract: Nowadays there aremany computational tools that are being developed to predict the sea keeping and the dynamic stability performance of a steered ship in large waves. Ship motion forecasting is very important for the safety of ships especially when operating in large waves. It is known that the ship motions have dynamical and nonlinear characteristics in the ocean and sea environments. Our paper presents an analysis of a presently applied approach to accounting for sea keeping qualities of FPSO (Floating Production, Storage and Offloading). The motion of FPSO in ocean surface is extremely complicated and difficult to predict, and for this we used MATLAB and OCTOPUS software environmentto predict the manoeuvrability of the FPSO ship applying the predicted nonlinear wave field with the current state of the vessel motions. Different simulations were performed and made in comparison with other test simulations cases for different value of input parameters including the sea state. We tried to find the best method that can be applied to ship manoeuvrability prediction, and simulation results showed the validity computational tool to improving the prediction accuracy. We chose in our analysis the FPSO ship, because these ships are operating in arbitrary environmentalconditions without the possibility of avoidance of storm zones andcan be towed for repair.

Key words: heave, pitch and roll motions; simulation, MATLAB, OCTOPUS.

1. INTRODUCTION

The ability to reliably predict the ship motion will allow improvements in several naval operations such as cargo transfer, off-loading of small boats, ship handling during berthing and ship “mating” between a big transport ship and some small ships. For navigation safety, the ship manouevrability and course keeping in waves are a very important problem and are treated with maximum responsibility. Usually, the manoeuvrability of ships is nearly associated with seakeeping performance of them. Because these problems are very complex and depend on many parameters, many researchers have treated them separately.

In this section we present an overview of the state-of-the-art regarding the techniques used for the prediction of the manoeuvring properties of ships and floating structures. Most researchers are studying the ship manoeuvring in waves andhave made different simulation methods which are referring to dynamic stability problems. They are using various software programs for CAD design of hull and made the simulation with different software programs for the analysis of the course keeping of ships to identify the hydrodynamic forces by a seakeeping method in frequency or time domain and after that they simulate the manoeuvring motion to predict the ship manoeuvrability in waves.

These days there are different methods for predicting the manoeuvrability of ship in waves, such as prediction based on empirical methods, captive model tests methods or predictions based on system identification methods. All of these methods are followed by simulations using differents softwares programs like: ShipX, SEAWAY, GNC in Matlab envinroment.

In Fig. 1, we present a comprehensive diagram that includes all usual methods for predicting the manoeuvrability of ship in waves. Most of these tests are made on free model or captive model with the aim to identify the mathematical model and to obtain the manoeuvring coefficients. For the validation of the mathematical model, a selection of free model tests is used.Empirical methods are applicable only to ships which are similar to the ships that the method is based upon. The most important empirical methods used for prediction are: the regression methods, the cross flow drag model [6], database methods [10], or the Kijima method, [7].

The method that uses prediction of manouevrability of ships based on system identification makes a good job if there are sufficient wide ranges of rotation rates, speeds, rudder angles, drift angles for a sufficient numbers of trajectories, and that through this method we obtain a mathematical procedure that optimizes the hydrodynamic coefficients in a new mathematical model [9]. Usually the hydrodynamic

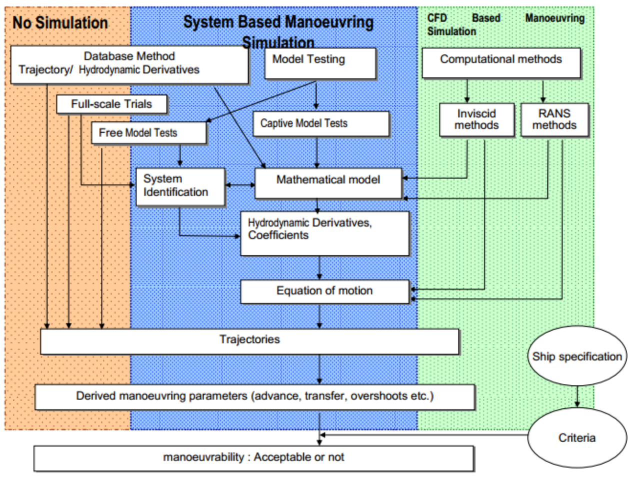


Fig. 1. Overview of manoeuvring prediction methods, [20]

coefficients are determined by seakeeping theory such as strip theory, slender body theory, sometimes used together with the cross flow drag theory [12], or a 3D panel method in frequency domain or time domain. Many researchers like Yasukawa [14, 15, 16], tankers [8], container vessels [2, 11], presented their individual investigations for specific ships and their reports.Methods using 4-DOF or 6-DOF mathematical models represent the base for simulation when we investigate the manouevring ships in waves [3, 4]. Nowadays there is an increasing trend to investigate manoeuvring and seakeeping problems in the field of ship hydrodynamics by using a unified theory. The simulation of manoeuvring is then conducted by using manoeuvring theory to predict the manoeuvrability in waves.A practical method for simulating ship manoeuvring and wave induced motions was made by Yasukawa and Nakayama [18], for a model of the container ship S-175. He also used a numerical method based on strip theory for the calculation of hydrodynamic forces and wave induced ship motions.The manoeuvring theory to predict the manoeuvrability in waves is used in numerical computer simulations and Fossen and Perez [5] demonstrate that it is very useful for a ship motion control and for a ship autopilot also.

2. SHIP DYNAMICS THEORY

In this section we specified the maneuvering governing equations for the specified ship. General equations of ship movement are based, in essence, on perturbations appreciation that appear in ship governing with the help of propulsion systems and navigation environment, apriori through sea waves actions. The experimental model and simulation model for the source program made for tanked ship transformed in a FPSO of 200 000 DWT, with zone of unlimited navigation (made to deliver oil products with different specific weights). The synthetic characterization necessary for a ship are given in Table 1.

Table 1. Main dimensions of the FPSO ship

Length between perpendicular L_{pp}	310 (m)	Transverse metacentric height $\overline{GM}$	9.48 (m)
Beam B	47.17 (m)	Longitudinal metacentric height $\overline{GM_L}$	379.26 (m)
Draft T	18.9 (m)	Roll radius of gyration in air k_{xx}	11 (m)
Block coefficient C_b	0.850	Pitch radius of gyration in air k_{yy}	72 (m)
Volume displacement∇	229201.5 (m^3)	Yaw radius of gyration in air k_{zz}	72.11 (m)
Water plane area A_w	12 878 (m^2)	Design speed u	12 (knots)
Water plane coefficient C_W	0.9164	Nominal propeller turation	80 (rpm)

The simulation program made possible the ship movement analysis; with regard at four from six degree of freedom of a free rigid solid in space. Although the simulation program results can offer multiple possibilities of interpretations and analysis of dynamic ship behavior (answering spectra in amplitude for weight ship center, information regarding the position, speed and acceleration of interest points from body ship, information regarding forces and moments that act in different transversal sections of ship, selected by user, etc.). The compared results follow the validation simulation program made; on its base we can make a significant number of simulation tests and interpretations of the dynamic behavior of ships even with the sea trials made on prototype ship in real sea.

We expres the mathematical model for large tankers in deep and confined waters and we write the speed and steering equations of motion are:

$$\begin{cases} \dot{u} - vr = gX'' \\ \dot{v} - vr = gY'' \\ (Lk_z'')^2\dot{r} - Lx_G''ur = gLN'' \end{cases} \quad (1)$$

where k_z'' is the non dimensional radius of gyration, $x_G'' = L^{-1}x_G$, u - surge velocity, v - sway velocity, r - yaw velocity, δ– rudder angle, c - flow velocity and *X", Y", and N"* are nonlinear non-dimensional functions:

$$
\begin{aligned}
X'' &= X''(\dot{u},u,v,r,T,\varsigma,c,\delta) \\
Y'' &= Y''(\dot{u},u,v,r,T,\varsigma,c,\delta) \\
N'' &= N''(\dot{u},u,v,r,T,\varsigma,c,\delta)
\end{aligned} \tag{2}
$$

and the meaning terms from equations above are established [5].
The hydrodynamic derivatives corresponding to these expressions and the non-dimensional surge, sway and yaw dynamics force were taken from references [5]. Also we define the deep and confine waters by expresion:

$$\varsigma = \frac{T}{h-T} \tag{3}$$

where T is the ship draft in meters and h > T is the water depth.
The results of the simulation of dynamic behavior of the FPSO ship are referring to the solving vectorial equation of movement (1) in MATLAB and OCTOPUS software.

3. SIMULATION AND HYDRODYNAMICS OF MOTION

For the mathematical model presented before we perform a simulation program, and we compute the velocities of surge, *u(t)*, sway, *v*(*t*), and yaw, *r*(*t*), assuming that input parameters are the rudder angle, *δ(t)*, and the FPSO ship's speed, *n*(*t*). All these data will be obtained from manoeuvrability simulations with the manoeuvrability model implemented in MATLAB and OCTOPUS as well.

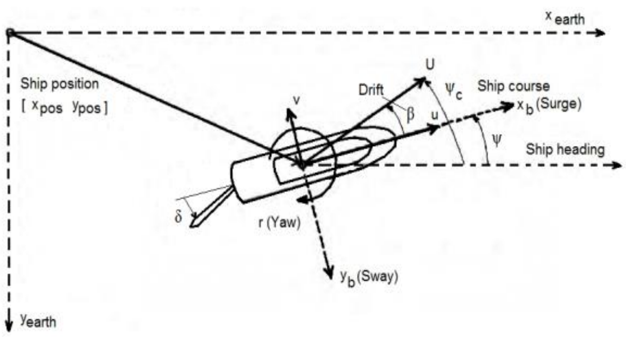


Fig. 2. Inertial earth-fixed frame and the body-fixed frame for a ship

There were also considered thenatural heave, roll and pitch periods for the FPSO ship, because it is important to limit the effects of the natural motions of the ship on the ocean surface. In the above defined simulation scenario we considered the following parameters:
- ship speed: v = 0 – 12 knots;
- wave encounter angle: β = 0 – 360 (special attention for 180^o- head wave);
- wave spectrum: JONSWAP with amplification factor:γ = 3.3;
- significant wave height H_S= 5 ÷ 17 m.

The natural periodand the wave exciting level are important parameters for estimating the amplitude ofmotion of the floating vessel. If the structures are excited with oscillation periods in thevicinity of the peak period of the wave spectrum, large motions are likely to occur.The FPSO natural heaving, rolling and pitching periods have been calculated from these relations:

$$
\begin{aligned}
T_z &= 2\pi\sqrt{\frac{\rho\nabla + A_{33}}{\rho g A_w}} = 8.47\sec T_\Phi = 2\pi\sqrt{\frac{\rho\nabla k_{xx}^2 + A_{44}}{\rho g\nabla GM}} = \\
7.16\sec T_\theta &= 2\pi\sqrt{\frac{\rho\nabla k_{yy}^2 + A_{55}}{\rho g\nabla GM_L}} = 7.42\sec
\end{aligned} \tag{4}
$$

where: T_z – natural heaving period, T_Φ – natural rolling period,T_θ – natural pitching period,
A_w – surface area of water plane,A_{33} – added mass of water for heaving, A_{44} – moment of inertia of added mass for rolling, A_{55} – moment of inertia of added mass for pitching, GM – initial transverse metacentric height, GM_L – longitudinal metacentric height,∇ – volume displacement,
ρ – water density,g – gravitational acceleration,k_{xx} – radius of gyration relative to the x axis,
k_{yy} – radius of gyration relative to the y axis.

4. RESULTS AND DISCUSSIONS

We present in figure 3 the heave motion and the area where the synchronous rolling of the FPSO ship happened and we have wave components that are close to the FPSO ship`s natural frequency in roll.

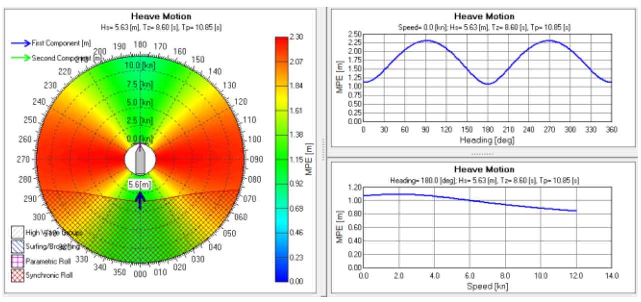


Fig.3 Heave motion of FPSO ship and area of synchronic roll

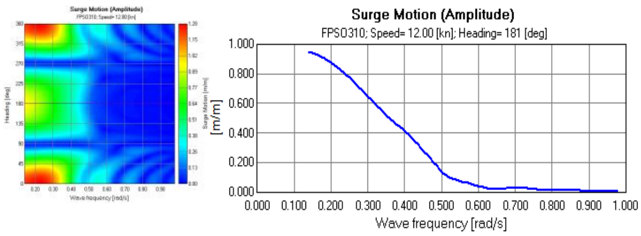
The period of maximum wave height from the met-ocean data provided, for offshore location in the West Africa in the Guineea Gulf, gives a period of maximum wave height ranging from 6.7 s to 9.3s [19]. These are produced from swells. The calculations show the FPSO ship shape will bevulnerable to larger motions in heave.

The FPSO ship sails securely

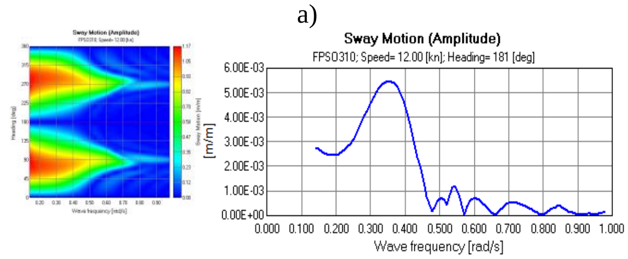
Warning about dangers – touch lower limit of the relevant criteria exceed

Threat to the safety of the FPSO ship – touch upper limit of the relevant criterion exceed

Response amplitude operators were extracted from the OCTOPUS output so as to measurethe motions of the vessel in surge, sway, heave, pitch, and yaw.
We measured RAOs for steered FPSO analysis in OCTOPUS at 12 knots, encountered wave direction 180˚, H_S=6.2 m, T_z=5.64. The nature of the RAO curves are presented in Fig.4a, 4b, 5a, 5b, and 6.To simulate the circulation manoeuvre we made a complex structure where the input values are the following: the ship length between perpendiculars, L_{PP}, ship breadth B, ship draught T, block coefficient of ship hull, hydrodinamic coefficient of ship, the speed at the beginning of the circulation manoeuvre, rudder aspect ratio, surge, sway and yaw angles. The simulation outputs were the following: transverse and head translations (transfer and advance) at ship course, tactical diameter of circulation, total decrease of ship speed at course change by 360°, as well as the surge, sway and yaw angles.



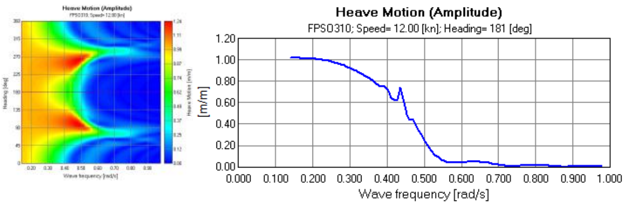
a)



b)

Fig. 4. a) Surge RAO behavior and surge motion with respect to wave frequency for FPSO; b) Sway RAO behavior and sway motion with respect to wave frequency for FPSO

Fig. 7a shows the results of simulation for initial turning test. From this simulation, we find the tactical diameter of ship is 350 m, is 1.13 times the ship length which is 310m. The tactical diameter is much smaller than the IMO criteria which is 5 times ship length. So we decided that the ship satisfies IMO criteria Turning Circle test.



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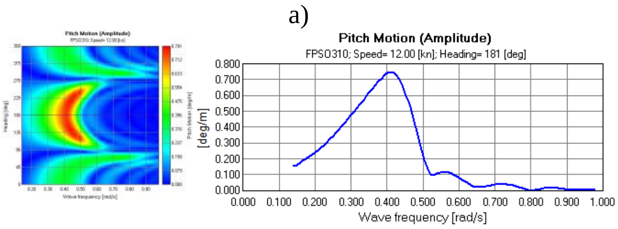

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Fig. 5. a) Heave RAO behavior and heave motion with respect to wave frequency for FPSO; b) Pitch RAO behavior and pitch motion with respect to wave frequency for FPSO

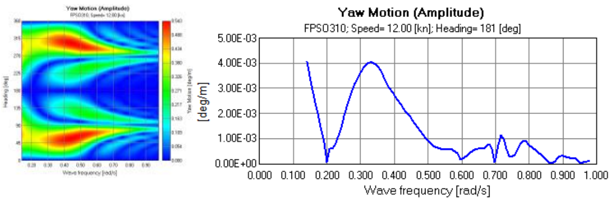
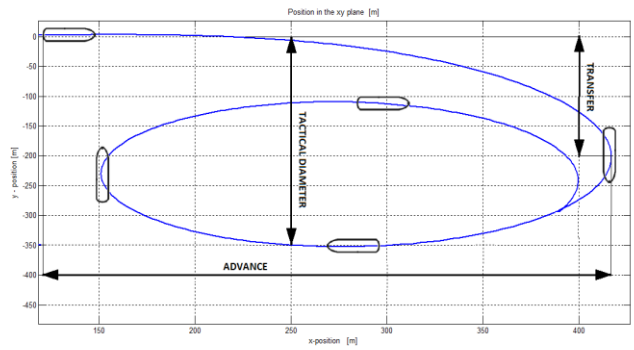


Fig. 6. Yaw RAO behavior and yaw motion with respect to wave frequency for FPSO



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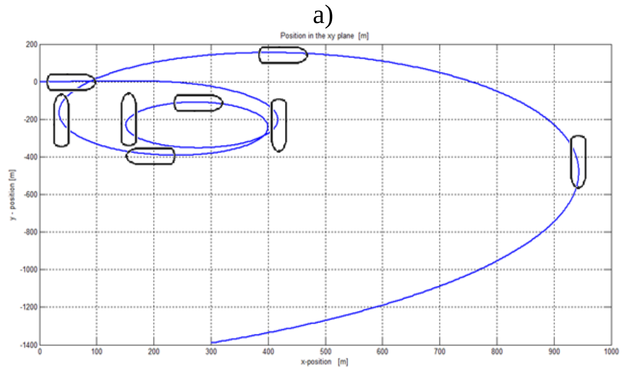

b)

Fig. 7. a) Results for circulation manouvre test and superposed with the simulation using MATLAB, withtransverse and head translations at ship course for rudder δ=35°, and v=12 knots; b) Results for circulation manouvre test and superposed with the simulation using MATLAB, considering the influence of waves and wind, at ship speed v=12 knots

5. CONCLUSIONS

We made a complex analysis to predict the manoeuvrability of the FPSO ship applying the predicted nonlinear wave field with the current state of the vessel motions and for these we used MATLAB and OCTOPUS software environment to make the simulations.We compute FPSO ship`s natural frequency and also we present the heave motion statistics with the synchronous rolling area of the FPSO ship. We find that we have wave components that are close to the FPSO ship`s natural frequency in roll.

We present the response amplitude operators as to measurethe motions of the FPSO ship in surge, sway, heave, pitch, and yaw.We measured RAOs for steered FPSO analysis in OCTOPUS at 12 knots, encountered wave direction 180˚, HS=6.2m, Tz=5.64. The simulation outputs gives transverse and head translations for ship course, tactical diameter of circulation, total decrease of ship speed at course change by 360°, as well as the surge, sway and yaw angles.

After the simulations, the obtained results of them, regarding the IMO standard tests, we established that this FPSO can be claimed to satisfy the requirements of IMO standard for maneuvrability. These results validate the numerical simulation code.

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