Analysis for the amplitude oscillatory movements of the ship in response to the incidence wave

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Abstract. Event of major accident navigation near offshore drilling rigs remains unacceptably high, known as the complications arising from the problematic of the general motions of the ship sailing under real sea. Dynamic positioning system is an effective instrument used on board of the ships operating in the extraction of oil and gas in the continental shelf of the seas and oceans, being essential that the personnel on board of the vessel can maintain position and operating point or imposed on a route with high precision. By the adoption of a strict safety in terms of handling and positioning of the vessel in the vicinity of the drilling platform, the risk of accidents can be reduced to a minimum. Possibilities in anticipation amplitudes of the oscillatory movements of the ships navigating in real sea, is a challenge for naval architects and OCTOPUS software is a tool used increasingly more in this respect, complementing navigational facilities offered by dynamic positioning systems.

This paper presents a study on the amplitudes of the oscillations categories of supply vessels in severe hydro meteorological conditions of navigation. The study provides information on the RAO (Response Amplitude Operator) response operator of the ship, for the amplitude of the roll movements, in some incident wave systems, interpreted using the energy spectrum Jonswap and whose characteristics are known (significant height of the wave, wave period, pulsation of the wave). Ship responses are analyzed according to different positioning of the ship in relation to the wave front (incident angle ranging from 10 to 10 degree from 0 to 180), highlighting the value of the ship roll motion amplitude. For the study, was used, as a tool for modeling and simulation, the features offered by OCTOPUS software that allows the study of the computerized behavior of the ship on the waves, in the real conditions of navigation. Program library was used for both the vessel itself and navigation modeling environment, for regular waves as well for the irregular waves which was modeled using Jonswap energy spectrum.

1. Introduction

Supply vessels do as their name implies; they are used to transport some materials, equipments and personnel to the offshore oil drilling platforms and of them to the land, as follows [1]:

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-goods transported to the work platform is intended for drilling platforms activities and consists of: solid cargo - drill pipes, equipments (containerized or not), anchors, chains etc.; bulk cargo - fuel, drinking water, pulverized cement, drilling mud, brine etc.

-goods transported from the platform to the shore are intended for recycling or scrapping and consists of: outworn or out of service equipments; waste oil and sanitation, various used chemicals.

Additionally, supply vessels can carry specialized personnel during crew exchanges. Also they are used for: supply platforms and other offshore installations; platforms towing and mooring; underwater construction and installation; repair and maintenance of underwater installations; mounting of submarine cables; assistance for various offshore activities etc. In general, these vessels are of medium size, with lengths ranging from 60-70 meters to 120-150 meters and are built considering certain characteristics and specific facilities. The design of supply vessels respect that they are often dedicated to operations in a particular area. A typical aspect of the design of a supply vessel is the forward location of the deck house with the large open space aft. Exposed aft deck is considered as working deck and therefore need to be more extensive and free of obstacles. According to [1], loads due to the cargo (and use for the strength calculus of the deck) are at least 1.5 tons per square meter plus 80% of design pressure of the wave. Usually, the total load taken into account is 5-10 tons per square meter. As offshore support vessels must operate even in rough weather and sea, the bow forms are optimized to have good water resistance and seakeeping both into calm water and high waves. Exposed bow deck extends over at least 2-3 superstructure storey above the main deck and forecastle of the modern ships are protected to avoid taking water on the open deck. Since these vessels operate in rough sea and near offshore oil drilling platforms (risk of collision and crash) they are provided with elements designed to increase the body strength. Offshore support vessels have good manoeuvrability thanks to powerful propulsion equipments and systems. Usually, propulsion is with nozzles propellers or azimuth thrusters. The ship steering system must be able to bring the rudder from 35 degrees port to 30 degrees starboard (and vice versa) in a maximum of 20 seconds at top speed headway ship. Modern ships are equipped with aft and bow thruster which must be able to keep fixed point positioning the ship and keeping this position (or by using anchor systems or dynamic positioning systems). Study on ship movements done while navigating on the sea waves, is of particular importance, especially for ships in the fleet serving the offshore oil and gas industry, and justified interests of authors of this paper for the topic. Among the issues that concern naval architects and engineers regarding study of the general movements of the ship, is noted [2, 3]:

- deterioration or loss of buoyancy, which may lead to sinking (unless tightness conditions are not ensured) as a consequence of deck flooding at the entrance of a board, bow or aft of the ship in wave (in terms of harsh regimes of roll and/or pitch);
- loss of transverse stability, which may lead to the overthrow of the ship caused by: a dangerous inclinations on board determined by ship gyration in terms of a rough sea; dangerous board slopes caused by displacement of the wrong mooring transported cargoes; hard roll oscillations caused by wave action at resonance;
- deterioration due to the ship steer caused by: decrease of maneuverability under unfavorable hydrodynamic wave action on the rudder; loss of stability on the way through the phenomenon of drift generated by unfavorable actions of the wind and sea currents when, for various reasons, the steering system can no longer function;
- reducing the march qualities due to: worsening of propulsion system function, throughout the entire driveline (propellers is out of the water, blade empty revolve and, when reinforce to the water, they are overburdened and cause shocks in the system); vessel speed reduction due to drag increase and malfunction of propellers in rough sea conditions; reducing autonomy of the ship by increasing the energy consumption;
- loss the nautical quality of small amplitude oscillations, on the strong impact between the hull and waves, with the consequences: the emergence of seasickness (accompanied by discomfort of passengers and crew on board); occurrence of vibration due to the effects of slamming (hitting the bow
on wave) whipping (hitting stern on wave) and slams (repeated shocks); worsening the function of equipments and systems onboard caused by dynamic actions of water on deck;
- damage of elasto-plastic behavior of hull structures due to: general and additional local loads; weakening of general strength by fatigue; the motions and accelerations on the work deck; the vertical relative motions between the waves and the deck edges (deck wetness); the effect of shipped water in pipes transported on the open deck of supply vessels.

2. Theoretical considerations
The subject of ship movements on the waves modeled as rigid body with six freedom degrees, has been addressed in the literature by various authors. Those who have the attention of authors are: Bhattacharya (1978) "Dinamics of marine vehicles" [4]; Chakrabarti (1987) "Hydrodynamics of offshore structures" [5]; Edward (1989) "Principles of naval architecture" [6]; Fossen (1994) "Guidance and Control of Ocean Vehicles" [7] and (1995) "Nonlinear modeling of marine vehicles in 6 degree of freedom" [8]; Domnişoru (2001) "Ship Dynamics. Oscillations and Vibrations of the Ship Hull" [9].

The general equation of motion of the ship, in a vector form, referred to the moving reference system is well known and is:

$$M\ddot{v}_r + C(v_r)v_r + D(v_r)v_r + g(\eta) = \tau_M + \tau$$

where:
- \(v_r = v - v_c\), relative velocity vector; \(\dot{v}_r\), relative acceleration vector;
- \(v = [v_1^T, v_1^T]^T = [u, v, w, p, q, r]^T\), overall velocity vector of the ship;
- \(v_c = [v_{2c}^T, v_{2c}^T]^T = [u_c, v_c, w_c, 0, 0, 0]^T\), overall velocity vector of marine currents;
- \(\eta = [\eta_1^T, \eta_1^T]^T = [x, y, z, \phi, \theta, \psi]^T\), position vector of an arbitrary point belonging to the vessel;
- \(g(\eta)\), generalized vector of restored forces and moments;
- \(\tau\), generalized vector of the disruptive forces and moments due to operations control and manoeuvre executed with the propulsion and steering systems;
- \(\tau_F\), generalized vector of the disruptive forces and moments generated by the currents and waves on the wetted surface of the hull respectively by the action of the wind on the sail area of the vessel;
- \(M\), the matrix of the ship mass inertia and additional water masses;
- \(C(v_r)\), complementary matrix for the ship motions and additional water masses;
- \(D(v_r)\), the damping matrix determined by the dynamic action of the water on the ship surface, caused by the moving of the vessel.

The general equation of motion of the ship, in a vector form, referred to the fixed reference system is also well known:

$$M_\eta(\eta)\ddot{\eta} - C_\eta(\eta)\dot{\eta} + D_\eta(\eta)\dot{\eta} + g_\eta(\eta) = \tau_{M_\eta}(\eta) + \tau_{\eta}(\eta)$$

3. Results and Discussions
For the case study was chosen a platform supply vessel (often abbreviated as PSV). The ship has a hull without bulbous in bow and aft in mirror. The principal dimensions are: length \(m\), width \(m\), draft \(m\); buoyancy 12537 cubic meters. Service speed, \(\text{knots}\) (maximum speed \(\text{knots}\)). Propulsion is made by two main azimuth thrusters aft mounted, plus other three azimuth thrusters, two on sides and one retractable on bow, with power 880 kW each. The vessel is equipped with a diesel-electric propulsion system with four generator units and two main engines Wärtsilä 6L34DF type with nominal power
P=2610 kW at 720 rotation per minute. The study was conducted for hydrometeorological conditions of the North Atlantic.

For the case study developed in this paper, the evolution of the most probable extreme amplitudes of roll oscillations, obtained for speeds between 0 and 15.6 knots and encountering angles between 0 and 360, is illustrated in figure1. This summative graph was obtained by superimposing detailed schedules for each rate included in the study (from 0 knots - standing ship up to the maximum speed of the ship, 15.6 knots) finding, obviously, increased range of roll motion with increasing travel speed of the ship.

![Figure 1. Envelope of roll motion most probable amplitude (speeds 0; 3.9; 7.8; 11.7; 15.6 knots).](image)

In figure 2 was exemplified the results for three speeds of the ship (5; 9.5 and 15 knots). Significant wave heights analyzed varies from 1 meter to 13.6 meters and are indicated in the figure legend.

![Figure 2. Roll motion most probable amplitude (speeds 5; 9.5; 15 knots).](image)

For the analyzed navigation conditions, it is was found that the maximum values of the amplitudes of the roll motion (most dangerous for the stability of the ship) are reached for encountering angle of
105 degrees (or 255 degrees) and are, in relation to the speed of the ship, those indicated in Table 1. The maximum values for roll motion amplitudes illustrated in table 1 are not recommended for navigation and must be avoided. The absolute maximum value of 30.1 degree was found for significant wave heights of 13.6 meters and for ship speed of 15.6 knots.

**Table 1.** Roll amplitude in respect with ship speed.

| Ship speed [knots] | Roll amplitude [deg] |
|--------------------|----------------------|
| 5                  | 13                   |
| 9.5                | 18.5                 |
| 15                 | 30.1                 |

The study of this paper show more results than those illustrated in figure 2 and table 1, being able to specify the roll amplitude for any vessel speed between 0 and 15.6 knots and encountering angles of the wave between 0 and 360 degrees with a sampling step of 1 degree. In Figure 3 is exemplified aspect of the response amplitude spectra (RAO) for the roll for motion, for the five speeds of the ship considered in the study (0; 3.9; 7.8; 11.7 respectively 15.6 knots) and calculated for significant height of waves, Hs = 2.1 meters and for zero crossing period, Tz = 4.42 sec.

![Figure 3](image-url)
4. Conclusions

World-leading shipping companies have used OCTOPUS onboard ships since 2003 for route planning and speed optimization, heading and fuel consumption in every weather condition. OCTOPUS software combines wave measurements, weather forecasts, and navigation data like speed, course, and the voyage plan, with ship characteristics, loading conditions and motion sensor measurements. [10]. One aim of this paper is to demonstrate the usefulness of OCTOPUS software as real-time analysis tool for ship movements (considered as rigid body with six freedom degrees) under various navigation conditions. OCTOPUS software is a powerful tool used in navigation to handling the ship in waves, together with other devices and facilities like dynamic positioning systems heave or roll compensator devices. OCTOPUS-onboard are use in container, LNG, offshore and many others shipping activities; the students of maritime universities should be familiar with it.

The case study presented in this paper aims is to highlight the usefulness of this program: for research studies in the field of complex interactions between body and navigation environment; for navigation as a tool for the efficient operation of vessels with functional features (work near drilling platforms, underwater work assistance, anchor handling, oversized pieces transport by sea etc.); for future navigation officers proper training.

The given limitations on enlargement of the paper resulted in partial presentation of the obtained results of the study. Those who may be interested to access the full case study results must contact authors.

5. References

[1] Ionaş O 2014 Technical ships Galaţi University Press
[2] Chiţu M G 2003 Contributions to the Ship Oscillations on the Waves Ph.D. Thesis (Politehnica University of Bucharest)
[3] Journée J M J and Massie W W 2001 Offshore Hydromechanics 1 (Delft University of Technology)
[4] Bhattacharyya R 1978 Dynamics of marine vehicles (New York: John Wiley & Sons)
[5] Chakrabarti S K 1987 Hydrodynamics of offshore structures (Southampton: Computational Mechanics Publications)
[6] Edward V L 1994 Principles of Naval Architecture SNAME (New Jersey) 1, 2, 3
[7] Fossen T 1994 Guidance and Control of Ocean Vehicles (University of Trondheim Norway: John Wiley & Sons)
[8] Fossen T and Fjellstad O E 1995 Nonlinear modelling of marine vehicles in 6 degree of freedom Journal of mathematical modeling of systems
[9] Domnişoru L 2001 Oscillations and Vibrations of the Ship Hull Ship Dynamics (Bucharest Romania: Tehnica Publishing House)
[10] *** 2010 OCTOPUS Office 6 User Manual, Amarcon B V.
[11] Chiţu M G and Zăgan R 2009 Comparative study of dynamic nautical features of turning computer assist and sea trial International Journal of Modern Manufacturing Technologies I(1) pp 21-24
[12] Maier V 1997 General loads in modern naval architecture (Bucharest Romania: Tehnica Publishing House) 1, 2, 3
[13] Voinea R 1989 Introduction to Solid Mechanics with Engineering Applications (Bucharest Romania: Academia Publishing House)