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Sensitivity of Mass Distribution with Respect to Pitch Motions of High-Speed Craft

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ABSTRACT

Beside of environmental conditions, ship characteristics also greatly affect in ship behavior when operating at sea, called seakeeping ability. The shape of the hull, appendages, damping, and the weight distribution of ship are some of the factors that determine how the ship motion response occurred. This paper examines how much the pitch motion is influenced in high-speed craft due to the changing of the gyration radius. By using the strip theory method, and by taking the irregular head sea condition and a wave height of 4 meters, then the ship speed and the wave period are varied to determine the pitch motion amplitude at 3 values of gyration radius: 0.2, 0.25 and 0.3 of the ship's length. The results of the study show that at higher ship speeds, the gyration radii greatly influence the pitch amplitude. As for changes in the wave period, the influence is significant at value of 5 second. From these two results, it is clear that the ship's gyration radii must be determined precisely to be able to predict an accurate pitch motion response on a high-speed craft.

KEYWORDS: *Seakeeping, High-speed craft, Gyration radius, Pitch amplitude.*

NOMENCLATURE

∇	Volume Displacement
k_{yy}	Gyration radius of pitch motion
x_i	Longitudinal origin distance to center of gravity
y_i	Transverse distance origin to center of gravity
z_i	Vertical distance from origin to center of gravity
w_i	Mass of each element (section)
F_n	Froude number
Hs	Characteristic wave height
$a\frac{d^2\theta}{dt^2}$	Inertial moment
$b\frac{d\theta}{dt}$	Damping moment

1.0 INTRODUCTION

The ship's response in the form of excessive motion can interfere with the performance of the ship's crew in carrying out their duties [1]. And also affects the success of the ship in carrying out its functions, including loss of stability, loss of steering, shipping water, slamming, cargo damage and decreased propulsion efficiency [2]. Some recommendations were proposed for decreasing wet deck slamming in multi-hull ship to increase safety issue for the inner bottom hull structure [3].

From the literature it is clear that the motion exposures experienced by the occupants are potentially dangerous and detrimental to successful and safe operations. This is especially of concern for military or rescue operations [4] and means to reduce or mitigate against motion exposures are required to protect the occupants. For the benchmark in seakeeping analysis, computational study has been conducted for 6750-TEU containership [5], also for Patrol Vessel at the various center of gravity and heading of wave [6] and MOB-based analysis for *Perambuan* ship-type by using wireless optical tracking system [7]. Particularly for high-speed craft, which are typically have length between 6 meter through 24 meter, and capable of speeds in excess of 25 knots, experience an uncomfortable motion that can lead to fatigue both of physical and mental [8]. For future ship motions behavior, the accurate prediction is great significance to improve the safety and efficiency of ship navigation [9].

Related to ship motions at the sea, there are six degrees of freedom direction: (1) translational motions: surging, yawing, heaving and (2) rotational motions: swaying, pitching, rolling. Each motions type influenced by internal and external factors. Ship loading conditions is one of internal factors that affected in is motion magnitude. The influence of it was investigated to an Indonesian ro-ro ferry [10]. Furthermore, the importance of accurately estimating radius of gyration was presented to predicts reliably ship roll motion with taking into account the fluid inertia in tanks [11]. In this paper, using 2D linear strip

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theory by Jacobs [12], a detailed background describing high speed marine craft motion effects with respect to determination of mass distribution is presented, especially for pitch motion due to changing of its radius of gyration.

2.0 THEORITICAL BACKGROUND

A high-speed craft is defined as a craft capable of a maximum speed V in m/s equal to or exceeding:

$$V = 3.7\, \nabla^{0.1667} \tag{1}$$

where volume displacement (m^3) corresponding to the design waterline.

Ship motion prediction require a ship's radius of gyration around the longitudinal, transverse, and vertical axes passing through its center of gravity. The gyration radius basically relates the moment of inertia about the particular axis to the area of rotation. It is defined as the square root of the ratio of total rotational inertia to mass for each axis. Gyration radius for pitch motion is formulated below:

$$k_{yy} = \sqrt{\frac{\Sigma w_i({x_i}^2 + {z_i}^2)}{\Delta}} \tag{2}$$

The pitch equation of motion of a ship without anti-pitching fin is given by

$$a\frac{d^2\,\theta}{dt^2} + b\frac{d\theta}{dt} + c\theta = M_0 cos\omega_e t \tag{3}$$

The various components of the pitch equation of motions are inertial moment, damping moment and restoring moment, where "a" is the virtual mass moment of inertia, "b" is the damping moment coefficient and c" is the restoring moment coefficient. θ is the angular displacement in pitching.

3.0 METHOD

The analysis was carried out by taking a monohull ship with a chined-hull type. Ship particular data is presented in the Table 1. With these characteristics, this ship has a Block Coefficient (Cb) value of 0.410, Wetted Surface Area (WSA) of 88 m2 and Displacement of 42.96 Tons.

Table 1: Ship characteristic

Component	Value	Unit
Length of Waterline (Lwl)	20.25	m
Breadth (B)	4.6	m
Depth (H)	3.8	m
Draught (T)	1.1	m
Max. Speed (V)	25	knots
Volume Displacement (∇)	41.91	m3

The Strip Theory method approach is used in the calculation of wave loads. In applied the theory, ship hull is divided into 61 sections with a maximum mapping of 3 for each, as shown in Figure 1. No damping factor values were used. The pitch gyration radius is taken varied. Roll gyration radius and yaw gyration radius is taken constant, namely 40% and 25% of the width and length of the ship.

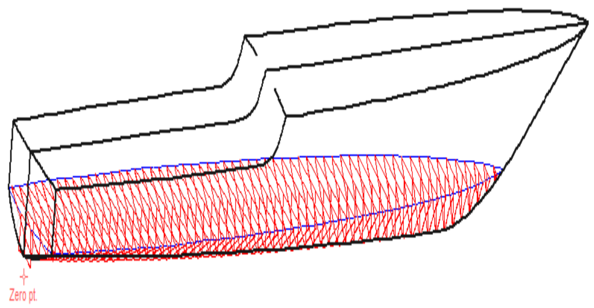

Figure 1: Strip hull along waterline

There are several variables used in this analysis: variations in ship speed, variations in pitch gyration radius, wave height, wave period and wave direction. All variables value is presented in the Table 2.

Table 2: Variable of analysis

Variable	Value					
Fn	0.7	0.75	0.8	0.85	0.9	0.95
kyy/Lwl	0.2		0.25		0.3	
Hs [m]	4					
Wave Cond.	Head Sea					

4.0 RESULT AND DISCUSSION

The first result obtained from the numerical calculations that have been carried out is regarding the effect of radius gyration on pitch amplitude. This is done at several variations of the ship's speed which are represented as froude number. The overall results regarding this are displayed in graphical form as in Figure 2. From the figure can be seen that at value of kyy=0.2 with increasing speed, the pitch amplitude increases until it reaches a maximum value of 18.1 deg. at a speed of 22 knots. After that, decreasing in amplitude is happen. Different things happened to the kyy values of 0.25 and 0.3. For both of value, the amplitude decreases while ship speed is increase.

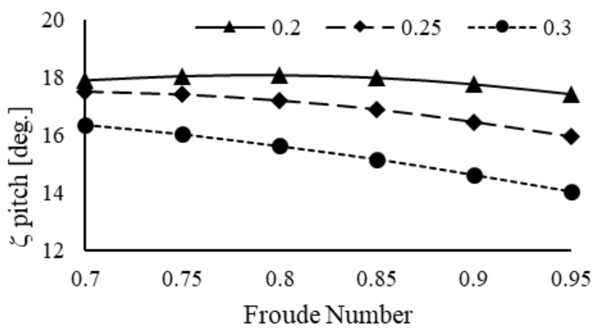

Figure 2: Pitch amplitude at various gyration radius and ship speed

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At ship speed of 19.2 knots (Fn=0.7), the pitch amplitude decreased as the value of kyy increased from 0.2 to 0.25 (Condition 1) and from kyy/Lpp 0.25 to 0.3 (Condition 2), respectively 2.1% and 6.7 %. In Condition 1, the biggest difference occurred at Fn = 0.95, which was 8.38%. The same thing happened for Condition 2 of 11.83%. The overall pitch amplitude differences for the two conditions at all speed variations are shown in Figure 3.

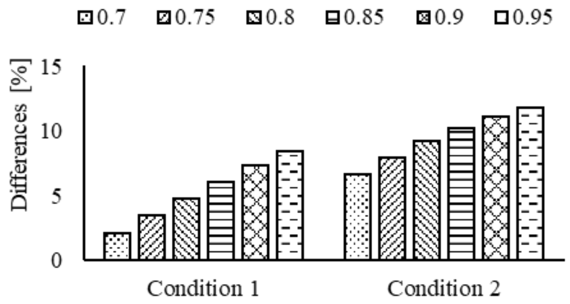

Figure 3: Pitch amplitude differences for gyration of radius changing

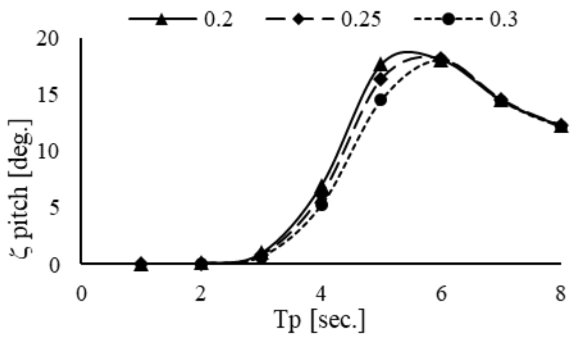

Figure 4: Pitch amplitude in various wave period

Apart from being viewed from the internal side, namely ship speed, the influence of external factors, in this case the wave period can also be seen from the results obtained, as presented in Figure 4. With a speed of 20 knots, the difference in the pitch amplitude begins to appear from the wave period of 2 seconds until it reaches its maximum value at Tp = 6 seconds. After that there was a tendency for the same value for all kyy/Lpp values. The most significant effect of gyration radius occurs at Tp=5 seconds, each of 17.72 deg., 16.38 deg. and 14.53 deg.

In all value of gyration radii, the maximum magnitude occurs at the same wave period of 6 sec. The difference that occurs is quietly small, ranging from 0.5% to 0.8%.

5.0 CONCLUSION

The effect of ship mass distribution parameter on ship motions is presented in this paper with several processes. Results showed a trend of almost linearly decreasing pitch amplitude in proportion to gyration radius. It clearly described that the pitch motion is influenced by the longitudinal radius of gyration variation as well.

The comparison between varied values of pitch gyration radius for high-speed craft is shown in figures. The obtained results ensure practical predictions of longitudinal gyration radius's parameter contribution to pitch motions with a high level of accuracy that would be useful during the concept design stage. As a future work, the other motions indices of high-speed craft will be investigated in terms of amplitude and its acceleration.

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