International Journal of Engineering and Science Applications
ISSN: 2406-9833

IJEScA

Motions Analysis of a Phinisi Ship Hull with New Strip Method

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ABSTRACT

Phinisi is the name of a renowned traditional wooden ship from South Sulawesi, Indonesia. The ship has been proven to be tough and reliable in sailing even to this very day. However, the ship is built only with a very traditional method and simple tools. There is no hydrodynamic analysis performed prior to the building of the ship. Therefore, in order to analyze the performance of the ship motion of a Phinisi ship hull, New Strip Method (NSM) is employed in the present study. With NSM, the ship hull is divided into several strips and the hydrodynamics forces are computed on each strip. Moreover, because the ship is assumed to be slender, the total forces are obtained by integrating the force on each strip. From the computation results, it can be shown that the resonant frequency of the analyzed Phinisi hull is shifted to lower frequency as the ship speed increases.

Keywords: Phinisi Ship, New Strip Method, Hull Characteristics, Hydrodynamic Forces, Ship Motion.

Article history: Received 15 May 2015, last received in revised 25 May 2015

1. INTRODUCTION

Phinisi is known to be a traditional wooden ship from South Sulawesi, Indonesia. This type of ship was originally built by Konjo tribe in 14th century [1]. It is still commonly used also by other tribes such as Bugis, Makassar and Mandar tribes mostly for inter-island transportation, fishing, and cargo purposes [2].

The ship has been known to be strong and reliable in sailing. It had made several historical journeys to several distant locations such as to Vancouver, Canada in year 1986, to Darwin, Australia in 1987, to Madagascar in 1991, and to Yokohama, Japan in 1992 [3].

Phinisi can be recognized easily from its distinct structure characteristics. It has 2 (two) masts which represents the number of basic statements of the Islamic faith known as "shahadah" [1]. Besides that, it can also be recognized from its 7 (seven) sails. 3 (three) sails named "cocoro pantara" are placed at the stem, 2 (two) sails named "cocoro tangga" at the amidships and 2 (two) sails named "terengke" at the stern [4] as shown in the following figure.

The original type of Phinisi is known as "Palari". Palari uses curved timber for both stem and stern posts. The size of this type of Phinisi is usually smaller than another type of Phinisi. Moreover, like other traditional ships, Palari relies only on natural wind to propel the ship.

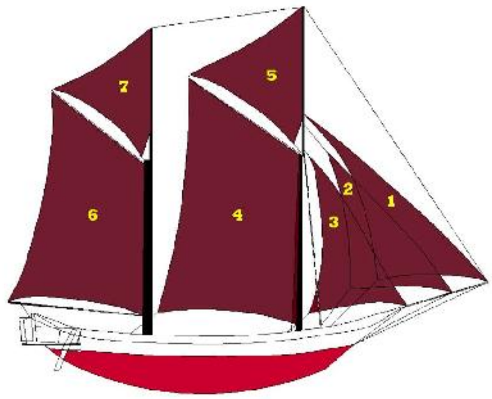

Figure 1. Phinisi sail numbers and positions

However, when the diesel engine as prime mover has become popular, Phinisi hull is modified to have straighter posts at the stem and stern parts in order to accommodate more space for the engine. This kind of Phinisi is called "Lambo" or "Lamba".

Lambo uses not only sails but also an engine to move the ship. Therefore, it is categorized as "Machine-Sail Boat" or "Kapal Layar Motor (KLM)" [5].

Another uniqueness of a Phinisi is in the construction process where there is no drawing or other technical planning made prior to the building of the ship like commonly performed when building a modern ship [6]. Dimensions (except main dimensions) and shape of the hull and other parts of the ship really depend on the instinct and experiences of the ship builder.

Instead of the technical computations and analysis, various rituals are performed throughout the building process to initiate and celebrate each stage. Several stages which are celebrated such as cutting the trees down, laying of the keel, determination of the ship navel, launching the ship, etc. [7].

Therefore, performance of the ship cannot be evaluated while and after the ship is built. Thus, employing theoretical methods in order to evaluate the performance of Phinisi hull is an interesting topic of research.

In the present study, New Strip Method (NSM) which is described in Kashiwagi [8], will be employed to analyze the performance of a Phinisi. The performances are evaluated in terms of hydrodynamic forces such as added mass, damping coefficient, and wave exciting force are computed and analyzed. Besides that, the ship motions which is one of the important performance criteria will also be evaluated in 2 (two) different ship speed conditions.

New strip method (NSM) is a numerical method based on the slender strip theory where the ship is assumed to be slender (ratio between ship length and breadth is large). With this assumption, the ship can be divided into a number of elements longitudinally called strips. The hydrodynamic forces and ship motions are evaluated in each strip. The total forces and motions are determined by integrating the forces and motions on each strip along the ship length.

2. New Strip Method (NSM)

A. Definition of Problem

In order to address problem discussed in the present study, a ship is assumed to advance with constant velocity *U* and oscillating with circular frequency μ in deep water. Moreover, a regular incident wave is also assumed to be incoming with angle degree with respect to the ship advancing direction.

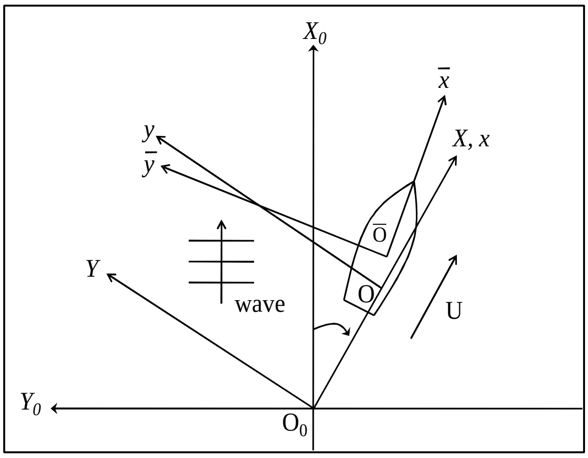

Figure 1. Coordinate system definition

With these assumptions, 2 (two) coordinates systems are used in the present study which are space-fixed coordinate system O_0-$X_0Y_0Z_0$ and ship-fixed coordinate system O_0-XYZ as shown in Figure 1. In ship-fixed coordinate system, *x*-axis is in the same direction with ship's bow direction. Moreover, the *z*-axis of both coordinate systems are assumed to be pointing downward.

Based on those coordinate systems, by adopting linear potential flow assumption, the velocity potential can expressed by the sum of steady and unsteady parts as follow [9]:

$$\Phi = -Ux + Re[\phi(x,y,z)e^{i\omega_e t}] \quad (1)$$

where the unsteady potential can be expressed as:

$$\phi = \frac{g\zeta_w}{i\omega_0}\{\phi^0(x,y,z) + \phi_7(x,y,z)\} + \sum_{j=1}^{n} i\omega X_j \phi_j(x,y,z) \quad (2)$$

$$\phi_0 = \exp\{-k_0 z - ik_0(x\cos\beta + y\sin\beta)\} \equiv \psi^0(y,z)e^{ilx} \quad (3)$$

where

$$\omega_e = \omega_0 - k_0 U\cos\beta \quad (4)$$

$$k_0 = \frac{\omega_0^2}{g} \quad (5)$$

$$l = -k_0\cos\beta \quad (6)$$

where ¤$_0$ represents the velocity potential of incident wave, g gravitation force, and ¸$_w$, µ$_0$, µ$_e$, k_0, are the regular incident wave amplitude, angular frequency, encountered wave frequency, wave number, and angle of attack, respectively.

¤$_7$ in Eq. (2) is the scattering potential and ¤$_0$ radiation potential from j-th mode of 6 degree of freedom (DOF) motions with complex amplitude X_j (j=1 for surge, j=2 for sway, j=3 for heave, j=4 for roll, j=5 for pitch, and j=6 for yaw).

B. Hydrodynamic Forces

The main aim of the hydrodynamic forces computation is to obtain the added mass (A_{ij}) and damping coefficient (B_{ij}). The hydrodynamic forces working to i-th direction can be written as follows [10]:

$$F_i = -\sum_{j=1}^{6}[(i\omega_e)^2 A_{ij} + i\omega_e B_{ij}]X_j \equiv \sum_{j=1}^{6} T_{ij}X_j \quad (7)$$

where T_{ij} is the transfer function of j-th mode of the hydrodynamic forces working to i-th direction.

C. Wave Exciting Force

The ship wave exciting forces can be divided into Froude-Krylov force and scattering force as follows [10]:

$$E_j = E_j^{FK} + E_j^{S} \quad (8)$$

The Froude Krylov force (E_j^{FK}) can be determined using the following equation:

$$E_j^{FK} = \frac{i\rho g\zeta_a}{\omega}\int_L dx \int_{S_H} n_j\left(i\omega_e - U\frac{\partial}{\partial x}\right)\varphi_0\, dl \quad (9)$$

While the scattering force (E_j^S) can be divided into symmetric and anti-symmetric forces. For anti-symmetric force, the wave exciting force can be determined with the following equations [8]:

$$E_j^S = -\zeta_a\omega\omega_e\int_L e^{k_0 z_s - ik_0 x\cos\beta}\left\{-\rho\int_{S_H}\varphi_3 n_j dl\right\}dx \quad (j = 1,3) \quad (10)$$

$$E_5^S = -\zeta_a\omega\omega_e\int_L e^{k_0 z_s - ik_0 x\cos\beta}\left(x + \frac{U}{i\omega_e}\right)\left\{-\rho\int_{S_H}\varphi_3 n_3 dl\right\}dx \quad (11)$$

While for the symmetric forces is expressed as follows:

$$E_j^S = i\zeta_a\omega\omega_e\sin\beta\int_L e^{k_0 z_s - ik_0 x\cos\beta}\left\{-\rho\int_{S_H}\varphi_2 n_j dl\right\}dx \quad (j = 2,4) \quad (12)$$

$$E_6^S = i\zeta_a \omega\omega_e \sin\beta \int_L e^{k_0 z_s - ik_0 x\cos\beta} \left(x+\frac{U}{i\omega_e}\right)\left\{-\rho\int_{S_H}\varphi_2 n_2 dl\right\}dx \quad (13)(13)$$

In Eqs. 10~13, integral in {} sign can be solved using added mass (A_{ij}) and damping coefficient (B_{ij}) which have been obtained previously, as follows:

$$-\rho\int_{S_H}\varphi_j n_i dl = A_{ij} + \frac{1}{i\omega_e}B_{ij} \quad (14)$$

D. Ship Motion

The hydrodynamic and wave exciting forces obtained previously can be used to determine the ship motions. As a preliminary step, heave and pitch motions will be determined first. Both motions can be determined by solving the following simultaneous equation [8]:

$$[-\omega_e^2(m+Z_{33}^G)+C_{33}^G]X_3^G + [-\omega_e^2 Z_{35}^G + C_{35}^G]X_5^G = E_3^G \quad (15)$$

$$[-\omega_e^2 Z_{53}^G + C_{53}^G]X_3^G + [-\omega_e^2(I_{yy}+Z_{55}^G)+C_{55}^G]X_5^G = E_5^G \quad (16)$$

where T_{ij} and Z_{ij} can be defined from the hydrodynamic forces (radiation case) as follows:

$$T_{ij} = -(i\omega_e)^2 Z_{ij} \quad (17)$$

$$Z_{ij} = A_{ij} + \frac{1}{i\omega_e}B_{ij} \quad (18)$$

In Eq. (16), I_{yy} is the moment inertia of pitch motion. After the Eqs. (15) and (16) are solved, the ship motions with respect to the ship center of gravity can be obtained. In order to transform these motions reference to be at the origin of coordinate system, the following equations are used:

$$X_3 = X_3^G + ixX_5^G \qquad X_5 = X_5^G \quad (19)$$

After both motions can be determined, other mode of motions can be determined by utilizing the normal vector *x*.

3. SHIP DATA

The evaluated ship hull in the present study is a Phinisi hull of MV. Jacuzzi Bathtubs. The ship was built at Tanah Beru, Bulukumba. The dimensions and 2D figure of the ship are shown in Table 1 and Figure 2 below

Table 1. Particulars of MV. Jacuzzi Bathups

Parameter	Length (m)
Length overall (LOA)	45.20
Length waterline (LWL)	37.50
Length between peak (LBP)	28.70
Breadth (B)	10.00
Height (H)	3.85
Draught (T)	2.76

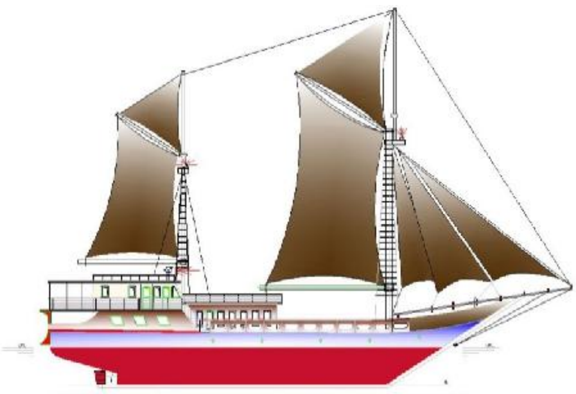

Figure 2. 2D view of MV. Jacuzzi Bathups

As shown in Fig. 2, the computed Phinisi in the present study can be categorized to be a Lamba type or the motorized version of the Phinisi. The body plan of the ship can be seen in the following Figure 3.

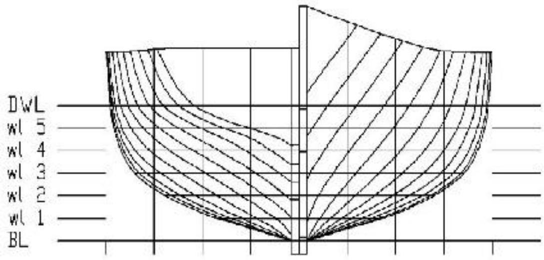

Figure 3. Body plan of MV. Jacuzzi Bathups

Based on the body plan shown above, the 3D view of the submerged hull is created. The 3D model of the hull is shown in the following figure:

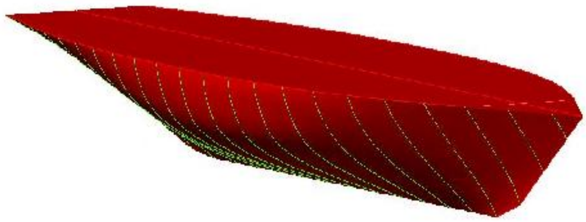

Figure 4. Submerged hull of MV. Jacuzzi Bathups

4. RESULT AND DISCUSSION

Based on the ship data shown previously, computations are performed using New Strip Method (NSM) as described in the preceding sections. The obtained hydrodynamic force components which are added mass and damping coefficient are shown in the following (figure 5 & 6).

As shown in Figs. 5 and 6, the hydrodynamic forces in terms of added mass and damping coefficient of 6 modes of motions are obtained. In the figures, the hydrodynamic forces of heave and sway are relative larger than other modes of motions.

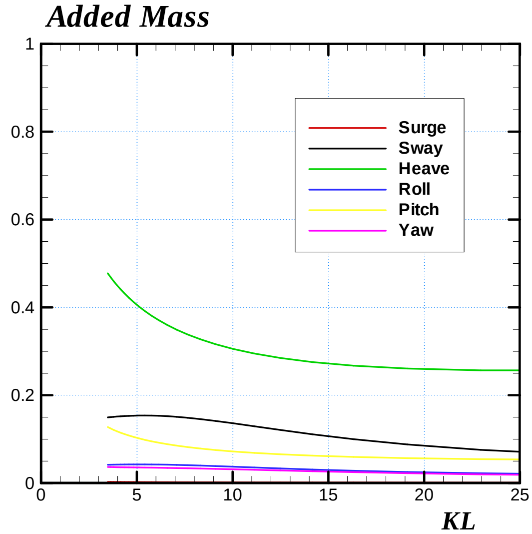

Figure 5. Added mass of MV. Jacuzzi Bathups

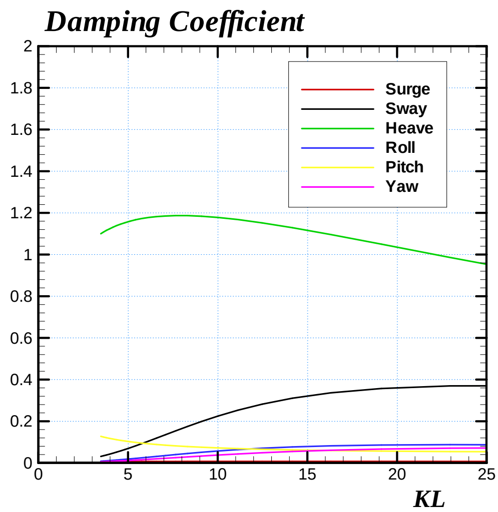

Figure 6. Damping coefficients of MV. Jacuzzi Bathups

After the hydrodynamic forces are obtained, the wave exciting force can be computed. In order to obtain the wave exciting force and motions amplitude, the angle of incident wave needs to be defined. In the present study, head wave case is considered. Therefore, $=180^{o}$ is used in the computation. The obtained wave exciting force is shown in the following figure.

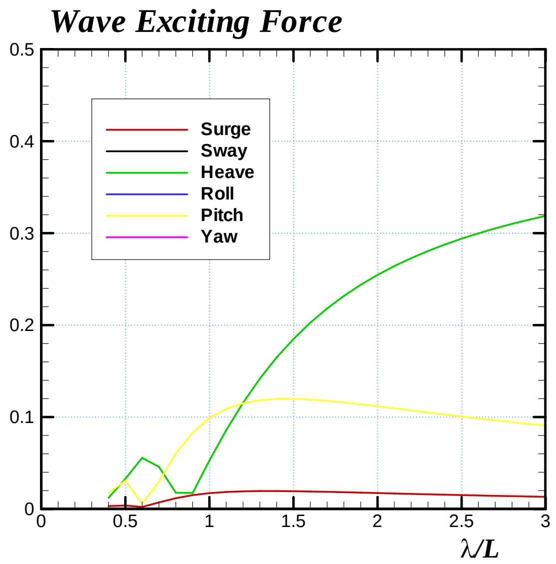

Figure 7. Wave exciting force

It can be seen from Fig. 7 that only 3 modes which appears on the graph because the wave exciting forces for other modes equal to zero in head wave case. Moreover, amongst the three modes, heave has the biggest forces compared to other modes of motions.

Moreover, as previously stated that two different ship speed condition will be analyzed in the present study. In order to represent the ship speed, Froude number is used. In the present study, two different Froude numbers are computed to analyze the performance of the ship for different speed conditions. The computed Froude numbers are *Fn*=0.1 and *Fn*=0.2. The computation results are shown in the following figure:

It can be seen from Fig. 8 that in each case, there are also only 3 modes of motions appear. This is because the present study analyze the head wave case. Moreover, it also can be shown that the pitch motion for faster speed is larger compared to other modes especially in longer wavelength region.

Besides that, it can also be noted that the heave motion for higher Froude numbers tends to be larger in all wavelength region. However, the surge motion has smaller amplitude in all wavelength region for higher Froude number.

In terms of resonance frequency, it can also be observed that the resonant frequency of the analyzed Phinisi hull especially for heave motion is shifted to lower frequency as the ship speed increases.

5. Conslusion

In the present study, New Strip Method (NSM) is employed to analyze the motions characteristics of a Phinisi hull. The head wave case is considered and 2 (two) different ship speed conditions are computed. The computation results shows that the resonant frequency of the analyzed Phinisi hull is shifted to lower frequency as the ship speed increases.

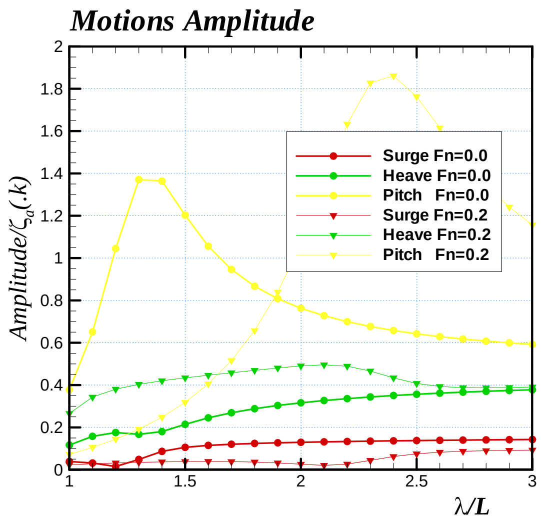

Figure 8. Motion amplitude for *Fn*=0.0 and *Fn*=0.2

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