THE EFFECT OF ASYMMETRIC WATER ENTRY ON THE HYDRODYNAMIC IMPACT

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Abstract The effect of the asymmetric water entry over a submerged part of a ship on the hydrodynamic impact is investigated numerically. A wedge body is considered to study and the problem is assumed to be two-dimensional. The Results of symmetric and asymmetric impacts are compared together. The effect is found significant in the numerical simulation. The maximum hydrodynamic pressure at a heel angle of 10 degrees becomes about 95% more than that of the symmetric entry. The result of the present work proves the importance of asymmetrical hydrodynamic impact loading for structural design of a ship. Besides, the numerical procedure is not limited to a wedge type cross section and it is possible to apply it for any real geometry of ships and high-speed crafts.

Key Words Asymmetric Water Entry, Hydrodynamic Impact

چکیده در این مقاله با استفاده از روش‌های عددی، اثر برخورد نامتقارن شناور به سطح آب بر روی ضربه هیدرودینامیکی وارد بر کف شناور بصورت دو بعدی بررسی شده است. مقطع شناور بصورت Wedge در نظر گرفته شده که یکبار بصورت متقارن و بار دیگر بصورت نامتقارن به سطح آب برخورد می‌کند. سپس نتایج ناشی از حل این دو مساله با یکدیگر مقایسه شده اند. بر اساس ارزیابی‌های فوق نتیجه می‌شود که تأثیر برخورد نامتقارن بر نیروهای وارد بر سازه شناور دارای اهمیت زیادی است و در طراحی موضعی سازه شناورها باید در نظر گرفته شود. همچنین با حل جریان بصورت عددی و در نظر گرفتن اثر اسپری آب، نیروی ثقل و لزجت نتایج بهتری نسبت به نتایج تحلیلی موجود حاصل شده است.

1. INTRODUCTION

The number of high-speed ships in commercial service has increased in the past few years and their role in marine transportation and operation is becoming very important. Besides, ship size has become larger with time. The newly designed ships about 150 m in length have been put into service and their speeds can be up to 40 knots [1]. For such ships, structural designs can strongly influence ship weight, and simultaneously building cost and cargo capacity. The slamming impact load is one important phenomenon that must be taken into consideration in the local structural design. Furthermore the slamming impact becomes more severe as ship speed increases. Because of the stochastic nature of slamming, prediction of this random process is studied in probabilistic manner [2].

Asymmetric hydrodynamic impact on a ship occurs because of bow waves. Due to the wave excitation and the wind pressure on the superstructure, roll motion of a ship in her seaway causes the ship fore body to be always asymmetrical in some degrees under water entry after it has been raised over the wave surface. Moreover the slope of wave elevation gives additional degrees of asymmetry. However the heading wave and the symmetric impact pressure are still used as design conditions. But the effect of asymmetric impact on the structural dynamic response is expected to be more serious because the hydrodynamic pressure level becomes higher, especially at a short duration.

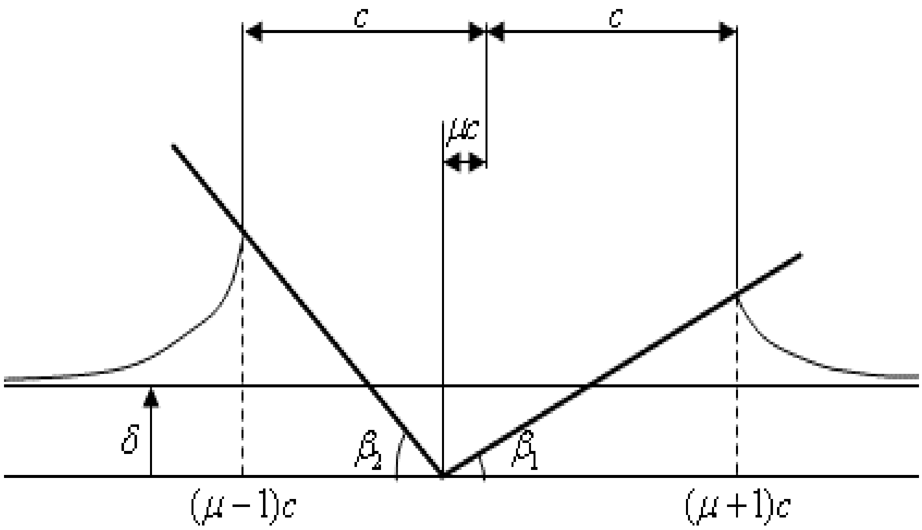

Figure 1. Asymmetric water entry of an edge body.

Also asymmetric slamming causes in a very large hydrodynamic pressure difference in port and starboard sides. In other words, symmetric model of slamming impact does not have acceptable accuracy in real conditions.

Hua [3] pointed out the importance of the asymmetric water impact when identifying the difficulties in the assessment of design loads for high-speed vessels by theoretical approaches.

Toyama [4] derived a method based on Wagner's theory [8] to calculate the transient pressure distribution on an asymmetric edged body under water entry. This method is restricted to wedge type cross sections and can not consider spray effects.

Rose and Rutersson [5] conducting full-scale measurement of hydrodynamic pressure on a planing boat in waves indicated that the bow wave gives higher pressure-level than the heading waves because of the asymmetric condition.

Hua [6] studied the effects of asymmetric impact on the dynamic responses of a plate structure by employing an orthogonal plate theory.

In this work, water entries of a wedge in symmetric and asymmetric conditions will be modeled numerically and the effects of asymmetric impact on the hydrodynamic pressures will be discussed.

2. ANALYTICAL METHOD

For the water entry of a symmetric edge body with a small dead-rise angle, the Wagner's theory gives good result in predicting the slamming pressure distribution. With a constant drop velocity V, for the slamming pressure distribution in x direction we have [6]

$$\frac{p(\varsigma)}{\rho} = \frac{\pi}{2tg\beta}\frac{V^2}{\sqrt{1-\varsigma^2}} - \frac{V^2}{2}\frac{\varsigma^2}{1-\varsigma^2} \qquad (1)$$

In Equation 1 ς is defined as:

$$\varsigma = \frac{x}{c} \qquad (2)$$

Toyama [4] derived a simple method, which is an extension of the Wagner's theory to calculate the asymmetric slamming pressure distribution. The pressure distribution along the wetted line is then determined by the following expression as:

$$\frac{p(\varsigma)}{\rho} = \frac{V\dot{c}(1+\varsigma\mu)}{\sqrt{1-\varsigma^2}} - \frac{V^2}{2}\cdot\frac{\varsigma^2}{1-\varsigma^2} + V\dot{c}\sqrt{1-\varsigma^2} \qquad (3)$$

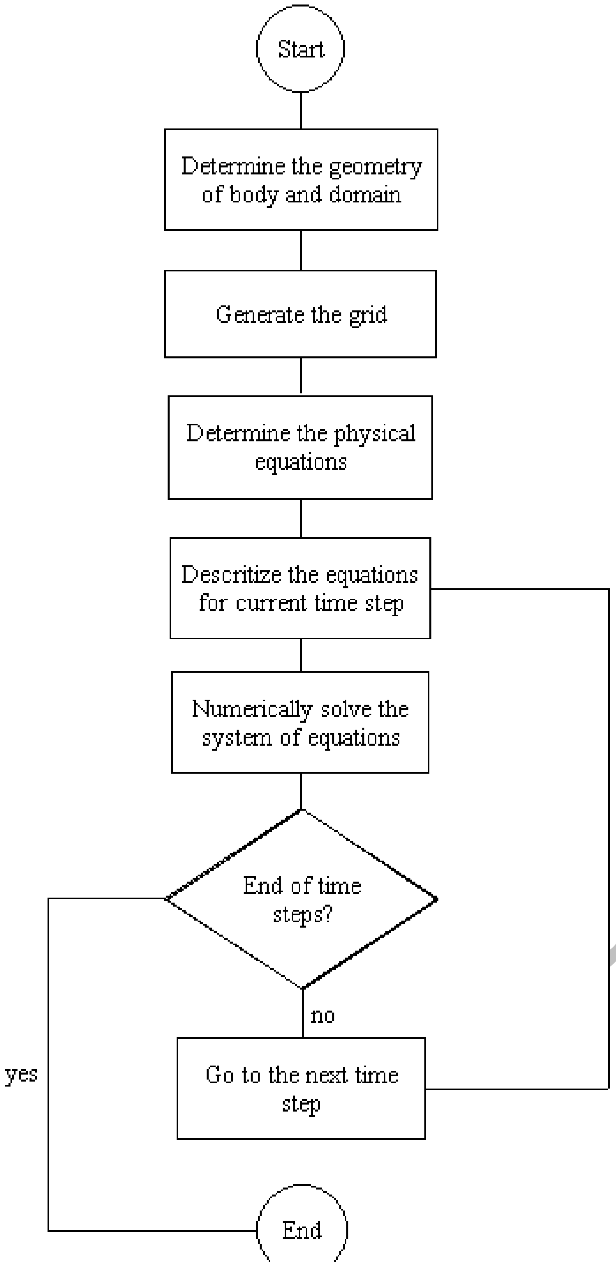

Figure 2. Flowchart of numerical modeling.

In Equation 3 ς is defined as:

$$\varsigma = \frac{x - \mu c}{c} \tag{4}$$

μ is the measure for the asymmetric condition and can be determined as followed

$$\mu = \begin{cases} f(R)(R-1)/(R+1) & for \;\; R \geq 1 \\ f(1/R)(R-1)/(R+1) & for \;\; R < 1 \end{cases} \tag{5}$$

In Equation 5 R is defined as:

$$R = \frac{tg\beta_2}{tg\beta_1} \tag{6}$$

And f(R) is defined by the following equation:

$$f(R) = \begin{cases} 0.77975 + 0.003371R + 0.001876R^2 & 1 \leq R < 3 \\ 0.76773 + 0.015024R - 0.000539R^2 & 3 \leq R < 10 \\ 0.80497 + 0.007208R - 0.000130R^2 & 10 \leq R < 20 \end{cases} \tag{7}$$

$\dot{c}$ is the time derivative of the half wetted length and is calculated according to the following expression

$$\dot{c} = \frac{\pi R V}{(R+1)^2 (1-\mu^2)\sqrt{1-\mu^2}} \left(\frac{1}{tg\beta_1} + \frac{1}{tg\beta_2} \right) \tag{8}$$

All the geometric parameters for the asymmetric slamming calculation are specified in Figure 1.

4. NUMERICAL METHOD

The approach is based on the finite volume method. RANS equations are solved for whole domain including water and air. The most important part of numerical modeling is procedure for finding out the position of water free surface during water impact. VOF (Volume Of Fluid) is a very efficient method and have used in wide applications. In this method, the volume fraction of water in each cell is calculated to determine the free surface position. Volume fraction of fluid can change from zero to one. If we denote the volume fraction of fluid q by α_q, then continuity equation in j direction is

$$\frac{\partial \alpha_q}{\partial t} + u_j \frac{\partial \alpha_q}{\partial x_j} = 0 \tag{9}$$

The values of fluid properties such as ρ and

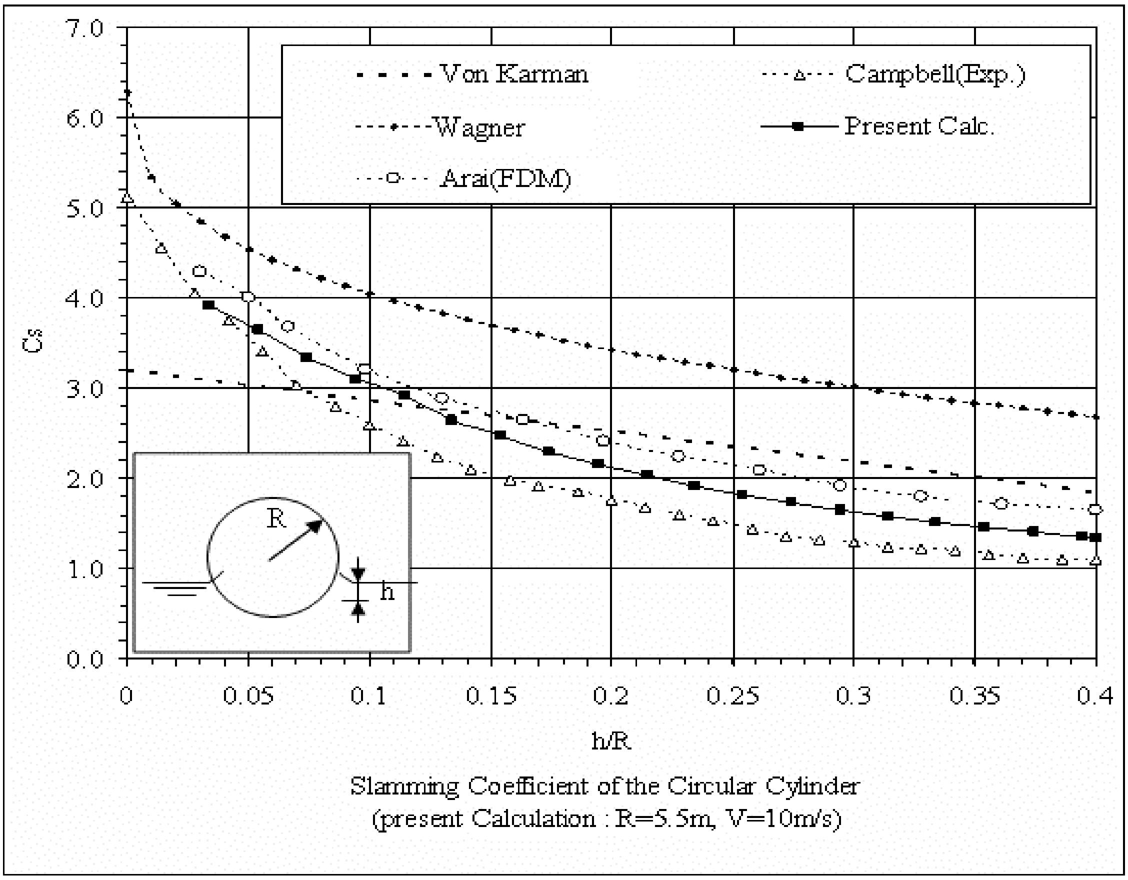

Figure 3. Slamming Coefficient of the Circular Cylinder (present Calculation : R=5.5m, V=10m/s).

μ in each cell are calculated according to the volume fraction of the computational cell as followed

$$\rho = \sum \alpha_q \rho_q \tag{10}$$

The momentum equation will be solved for all domains (air and water). Turbulent momentum equation in j direction is:

$$\frac{\partial}{\partial t}(\rho u_j)+\frac{\partial}{\partial x_i}(\rho \overline{u_i' u_j'}) = -\frac{\partial P}{\partial x_j}+\frac{\partial}{\partial x_i}\left[\mu\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)\right]+\rho g_j+F_j \tag{11}$$

Figure 2 shows a flowchart that indicates the procedure of numerical modeling.

To evaluate the accuracy of the present numerical model, a circular cylinder with radius of 5.5 m and constant drop velocity of 10 m/s is considered. Reynolds Stress Method (RSM) is applied for turbulence modeling.

The slamming coefficient is defined as:

$$C_s = \frac{F_s}{\rho R V^2} \tag{12}$$

Figure 3 compares the results of present numerical model with other available data. Von Karman theory [7] predicts the slamming coefficient at initial contact equal to π while the Wagner's theory [8] predicts it as 2π. The experimental data published by Campbell [9] are very different and vary between 5.5 and 6.5. The results of a finite difference modeling carried out by Arai [10] have better agreement with that of experimental study, but the modeling is based on

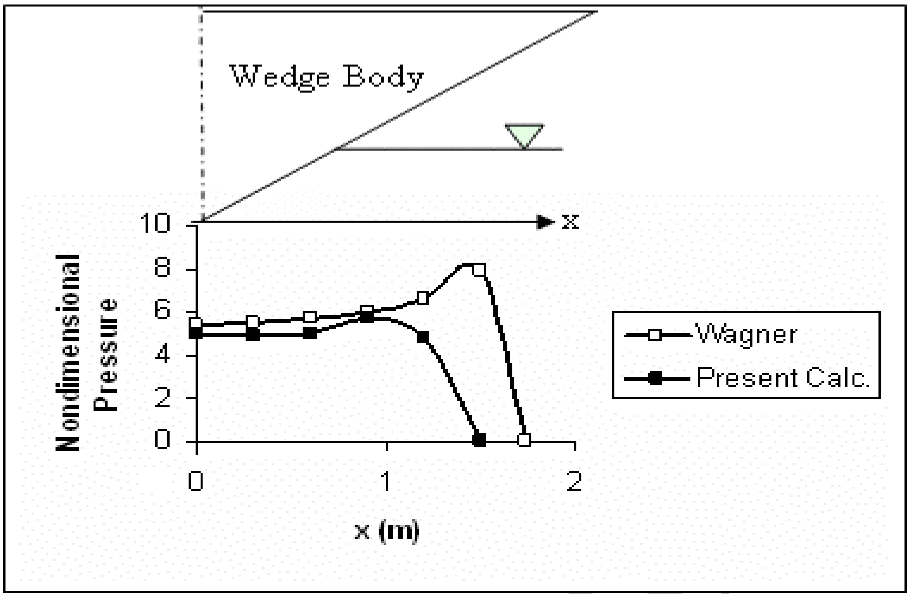

Figure 4. Comparison between analytical and numerical results of symmetric impact.

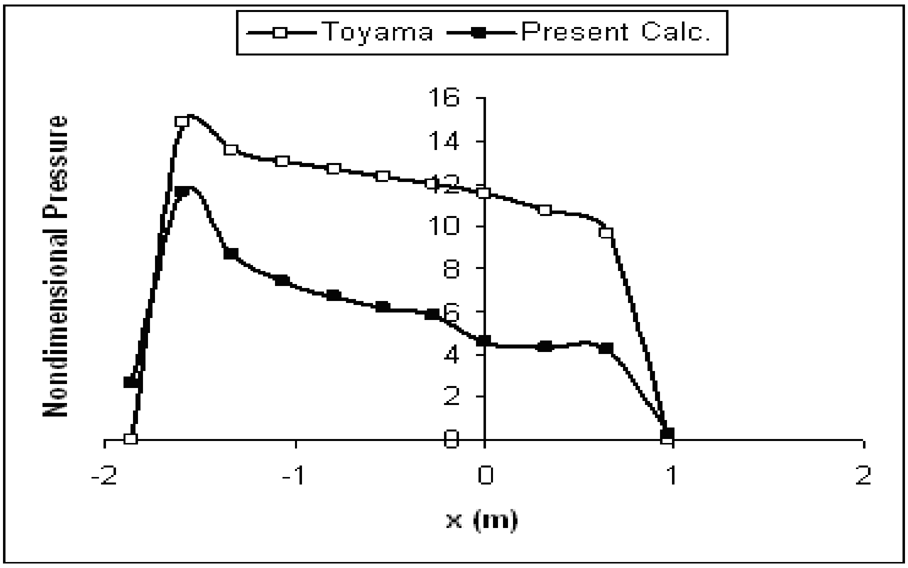

Figure 5. Comparison between analytical and numerical results of asymmetric impact.

the potential theory and neglects the viscosity effects. It is clear from the Figure 3 that the present study has more accuracy and is closer to the experimental data.

5. NUMERICAL RESULTS

Numerical study is performed for a wedge body with a dead-rise angle of 30 degrees in symmetric and asymmetric conditions. Drop velocity is 5 m/s and the heel angle of asymmetric water entry assumed to be 10 degrees. A square structured grid is used and gravity force is taken into account.

Figure 4 shows a comparison between analytical and numerical results of symmetric impact. Wagner's theory overestimates the hydrodynamic pressure and its maximum value is about 38% more than that of the numerical

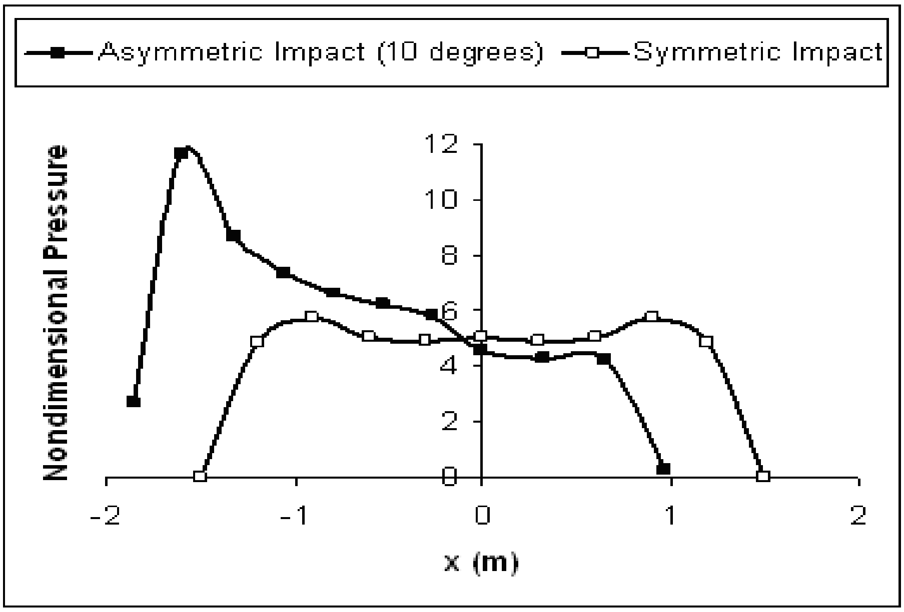

Figure 6. Comparison between numerical results of symmetric and asymmetric impacts.

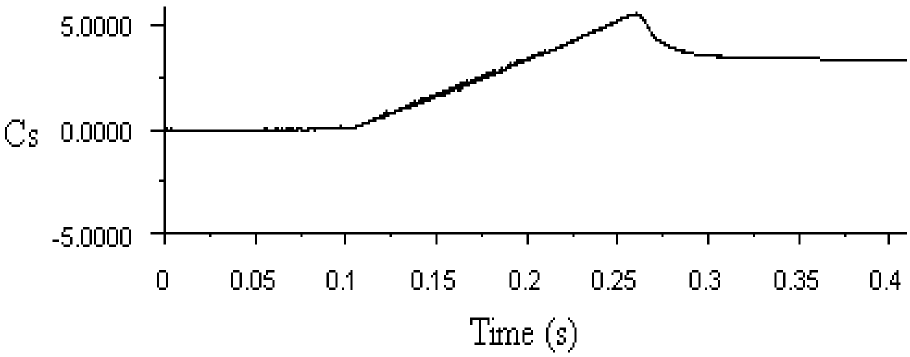

Figure 7. Time history of the non-dimensional slamming coefficient.

modeling. The difference is due to some assumptions in Wagner's theory such as neglecting water spray, viscosity and gravity. Since the difference is much more in larger values of x, where the spray takes place, the effect of spray is the most important one.

Figure 5 compares the analytical and numerical results for asymmetric water entry. Toyama's method also overestimates the hydrodynamic pressure and it is possible to get more exact values from numerical modeling.

The effect of asymmetric water entry on the hydrodynamic impact is studied in Figure 6 which shows the numerical results of non-dimensional pressure distribution for both symmetric and asymmetric impacts. The maximum pressure value becomes twice in asymmetric impact, which can be very important in optimum design of the ship structure. Besides, the asymmetric distribution of the hydrodynamic pressure will produce a twisting moment and have to be considered in global structural design of the ship.

Non-dimensional slamming coefficient is presented in Figure 7. Slamming force increases

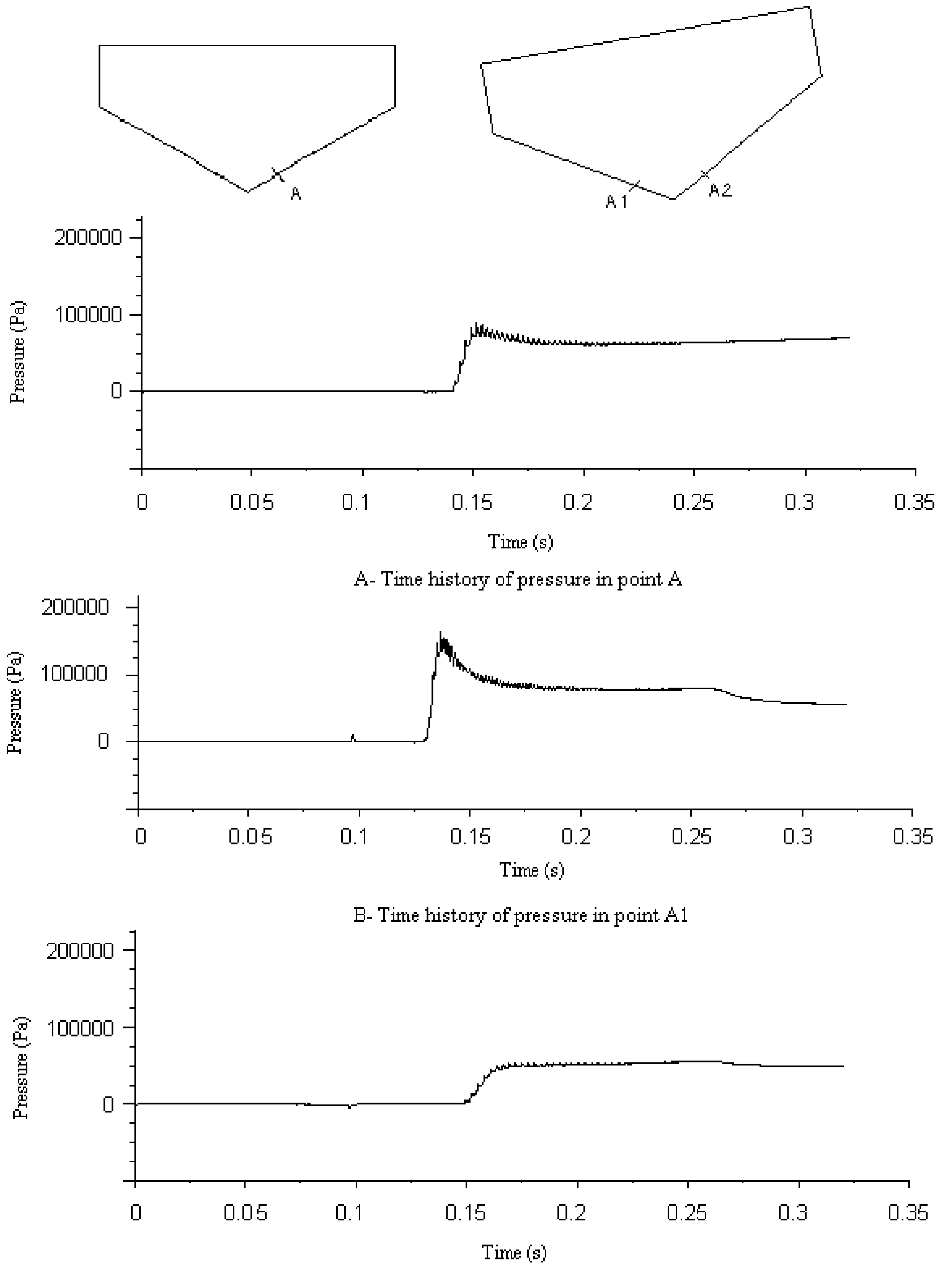

Figure 8. Time history of pressure in symmetric and asymmetric impacts.

until the water spray separates from the body. Then the force decreases to reach the hydrostatic value.

Figure 8 shows the time history of the hydrodynamic pressure for a particular point on the body during symmetric and asymmetric water entries. Asymmetric entry has a significant effect on the hydrodynamic impact and the differences between the pressure values of symmetric and asymmetric conditions are quite considerable in both sides of the body. The pressures become nearly twice along the side with the lower dead-rise angle and decrease significantly along the other side.

6. CONCLUSIONS

In this study, the asymmetric effect is investigated on the hydrodynamic impact on a ship bottom structure. The numerical results have shown that the effect is significant. Both the pressure values and the location of the maximum pressure change considerably in asymmetric condition.

Validity of the numerical results is studied and the agreement between present results and experimental data is found acceptable. Meanwhile the present modeling has no limitation for geometry, and is applicable for complex cross sections of real ships.

The present study has shown evidently that the asymmetric water entry and its effect on hydrodynamic impact loads are important in the consideration of the structural design of high-speed vessels. It has also demonstrated that the application of the present numerical simulation is a practical approach in modeling the slamming forces on ship bottom structure. The present approach provides more accurate analysis than the analytical methods and therefore is an appropriate alternative in analyzing the problem in both symmetric and asymmetric conditions.

1. NOMENCLATURES

P: Pressure

ρ : Water Density

μ : Viscosity

g: Gravity Acceleration

α_q : Volume Fraction of Fluid q

F_j : Body Forces in j Direction

u: Flow Velocity

R: Radius of the Cylinder

c : Half Wetted Length

α : Heel Angle

β : Dead-Rise Angle

V : Impact Velocity

$\beta_1 = \beta - \alpha$

$\beta_2 = \beta + \alpha$

F_s : Slamming Force

C_s : Slamming Coefficient

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