International Journal of Ocean System Engineering 2(1) (2012) 32-36
http://dx.doi.org/10.5574/IJOSE.2012.2.1.032

Comparison of Potential and Viscous Codes for Water Entry Problem

Sun-Hong Kwon [1*], Chang-Woo Park [1] and Jae-Young Shin [1]

[1] *Department of NAOE, Pusan National University, Busan, Republic of Korea*

(Manuscript Received December 15, 2011; Revised January 3, 2012; Accepted February 6, 2012)

Abstract

This paper presents a comparison of potential and viscous computational codes for the water entry problem. A po-tential code was developed which adopted the boundary element method to solve the problem. A nonlinear free surface boundary condition was integrated to find new locations of free surface. The dynamic boundary condition was simplified by taking constant potential values for every time steps. The simplified dynamic boundary condition was applied in the new position of the free surface not at the mean level, which is the usual practice for linearized theory. The commercial code FLUENT was used to solve the water entry problem from the viscosity point of view. The movement of the air-liquid interface is traced by distribution of the volume fraction of water in a computational cell. The pressure coefficients were compared with each other, while experimental results published by other researchers were also examined. The characteristics of each method were discussed to clarify merits and limitations when they were applied to the water entry problems.

Keywords: Slamming Impact, Water entry problem, Boundary element method (BEM)

1. Introduction

When a ship travels in a rough sea, it frequently experiences various types of impacts from waves. The impact of a ship striking a water surface often causes an extremely large load with high pressure, which shows transient behavior. It can result in substantial damages to the ship structures. Thus, the water entry problem has attracted much research for its practical importance in the field of naval architecture and ocean engi-neering (for a review, see SNAME, 1993; Korobkin, 1996). The pioneering work on the water impact problem was done by von Kar-man (1929): His linearized theory was able to successfully calculate the slamming coefficient. However, his theory was not able to estimate the induced free surface elevation. This limitation was improved by Wagner (1932), by taking into account of the uprise of the free surface elevation. Similarity solutions for wedges with arbitrary deadrise angles were proposed by Dobrovol'skaya (1969). The solu-tion was expressed in integral equation form, which should be solved by numerical computations. Armand and Cointe (1987), Watanabe (1986), and Howison et al. (1991) solved this problem by using matched as-ymptotic expansions. Zhao and Faltinsen (1993) developed a numerical tool based on the boundary element method (BEM). They took account of exact nonlinear free surface boundary conditions. In a later paper (Zhao and Faltinsen, 1996), they simplified the dynamic free surface condition, by taking the potential values along the free surface zero. This simplification turned out to be very useful in keeping the potential values on the free surface robust. An application of conformal mapping methods was discussed by Mei et al. (1999). This paper compared potential and viscous codes, and the potential code was developed by the present authors. This po-tential code was based on the

*Corresponding author. Tel.: +82 51 510 2347, Fax: +82-51-581-3718.
E-mail address: shkwon@pusan.ac.kr.

boundary element method (BEM). The commercial code FLUENT was used to solve the water entry problem in terms of viscosity. The present study was carried out under two assumptions. The first is a two-dimensional assumption. Most theoretical studies pertaining to water entry impact load have been done by two-dimensional analysis for complicated body geometry. The two-dimensional assumption sounds like a severe limitation when one considers complex three-dimensional ship geometry. However, three-dimensional analysis of ship slamming has not yet been realized. Therefore, in shipyards, it is the usual practice to analyze slamming for particular cross sections. It means that a two-dimensional computational tool for water entry problem needs to be developed. The present study was carried out under another assumption; that of constant body velocity. This second assumption may also seem to be a rude one to make. However, the assumption makes the computation far easier. Otherwise, one needs to solve the equation of motion of the body separately.

2. Boundary Element Method

Let us describe the boundary value problem to be solved, before we address the developed potential code. The present paper deals with two-dimensional analysis. The z-axis takes the positive direction upward and z=0 location represents the undisturbed free surface.

The fluid is assumed to be inviscid and incompressible. The additional assumption of irrotationality yields the Laplace equation as a governing equation. The mathematical expression of the governing equation is:

$$\nabla^2\phi = 0 \quad \text{in the fluid region} \qquad (1)$$

The boundary condition on the wetted body surface S_B is

$$\frac{\partial\phi}{\partial n} = V{\cdot}n \quad \text{on } S_B \qquad (2)$$

where V represents the body velocity and the outward normal into the fluid domain is denoted as n. The two boundary conditions for the free surface SF are kinematic and dynamic boundary conditions, which can be written:

$$\frac{Dx_F}{Dt} = \nabla\phi \quad \text{on } S_F \qquad (3)$$

$$\phi = 0 \quad \text{on } S_F \qquad (4)$$

The new position of the free surface can be obtained by integrating the kinematic boundary condition (3).

On the side-wall boundary and tank bottom boundary , the following boundary conditions are imposed:

$$\frac{\partial\phi}{\partial n} = 0 \quad \text{on } S_D \text{ and } S_W \qquad (5)$$

To solve the given boundary problem using BEM, let's consider the following equation:

$$\phi = \int_S \sigma(\xi,\eta)G(x,y;\xi,\eta)dS \qquad (6)$$

where denotes the position of source point; G is the Green function; and σ is its strength. The fundamental solution adopted here is the well-known logarithmic function. Its mathematical expression is:

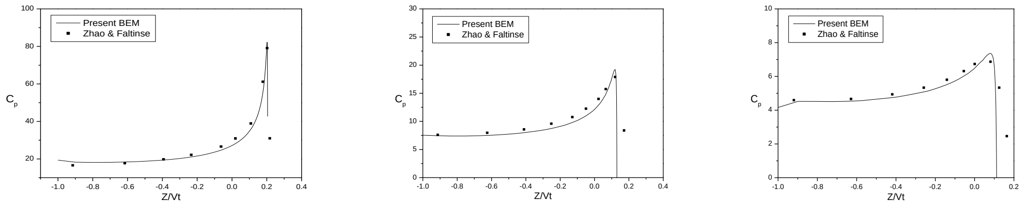
$$G = \ln\sqrt{(x-\xi)^2+(y-\eta)^2} + \ln\sqrt{(x-\xi)^2+(y+\eta+2d)^2} \qquad (7)$$

where is the tank depth.

The boundary is segmented into straight lines, over which the values of potential and its derivatives are assumed to be constant. The free surface boundary near to the body is densely segmented, so that the complex displacement of the boundary can be described. The pressure at any field point in the fluid domain can be calculated from Bernoulli's equation, which includes a nonlinear term:

$$p - p_a = -\rho\frac{\partial\phi}{\partial t} - \frac{\rho}{2}\nabla\phi\cdot\nabla\phi \qquad (8)$$

The evaluation of the $d\phi/dt$ was calculate as was done by Kim and Shin (2003) as follows



(a)10 degrees (b)20 degrees (c)30degrees

Fig. 1. Slamming pressure distribution

$$\left(\frac{\partial \phi}{\partial t}\right)_i^n = \left(\frac{\phi_i^n - \phi_i^{n-1}}{\Delta t}\right) - V_i^n \cdot \nabla \phi_i^n \qquad (9)$$

Where Δt represents size of time step, and n and n-1 represent present and previous time steps. The velocity in Eq. (9) is estimated by the usual first order forward difference scheme. The dynamic boundary condition is simplified as follows so that the computed potential values can be robust. :

$$\phi = 0 \text{ on } S_F \qquad (10)$$

Only half of the computational domain is considered, due to the symmetry of the present problem. The initial free surface is assumed to be calm. The initial potential values of the free surface are set to zero. To initiate the BEM computation, we need to submerge a small portion of the body.

3. FLUENT Code

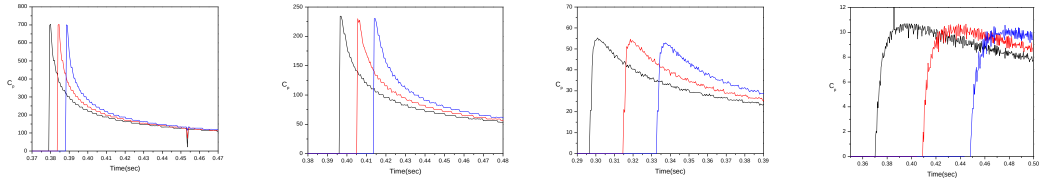
The viscous computation for water entry problem was carried out using a commercial code, FLUENT. The computational domain in FLUENT is discretiezed as finite number of tetrahedral cells. The movement of the air-liquid interface is traced by distribution of the volume fraction of water in a computational cell.

The slamming phenomenon in FLUENT was described in a way that the uniform flow approach to the body. The flow was assumed to be laminar. Any interested readers in FLUENT may visit its web site. Dense meshes are distributed near the body and the free surface. Considering the symmetry of the problem, only half of the domain was calculated, exactly the same way as was done for the BEM computation.

4. Computational Results and Discussion

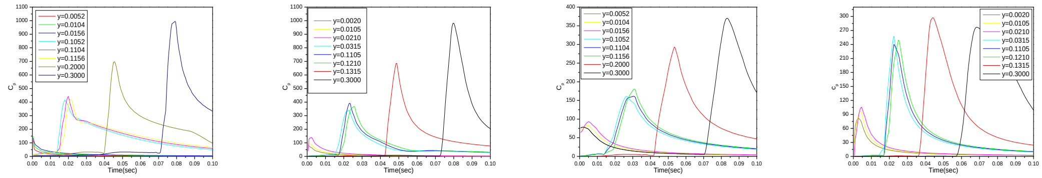
The constant body velocity was set to 1 for all computations. In this study, every scale used in this computation has been normalized. When it comes to BEM, the number of meshes on the body, free surface, and wall were 96, 304, and 20, respectively. In the case of FLUENT, the number of meshes on the body, free surface, and wall were 400, 481, and 240, respectively. The time increment for these computations was 0.0005 seconds.

Firstly, computations using BEM code were made for a two-dimensional wedge on three deadrise angles of 10, 20, and 30 degrees, respectively. Figs. 1 (a)-(c) show the results, and compare them with Faltinsen's results (Faltinsen, 1993). The BEM code developed in this study shows quite good agreement with Faltinsen's calculations. We can see that the pressures decrease rapidly when the deadrise angle exceeds 15 degrees.



(a)3 degrees (b)6 degrees (c)10 degrees (d)15 degrees

Fig. 2. Slamming pressure time history in B.E.M



(a)3 degrees (b)6 degrees (c)10 degrees (d)15 degrees

Fig. 3. Slamming pressure time history in FLUNET

The first computations being presented in Figs. 2 (a)-(d) were done for a wedge with 3, 6, 10, and 15 degrees deadrise angles respectively, by using BEM code. They represent the time series of the slamming impact.
Secondly, the computations shown in Figs. 3 (a)-(d) were done for a wedge with 3, 6, 10, and 15 degrees deadrise angles respectively, by using FLUENT code. The results of the computations show the same properties as the previous calculations of pressure change and jet flow. But maximum values at each measured point keep increasing continuously, except for the last case, Fig. 3 (d). This paper also shows the jet flow generated in slamming conditions. Figs. 4 (a)-(d) give the jet flow shape at 3, 6, 10, 15 degrees, respectively. The outstanding features of FLUENT can be seen in these figures, since the jet flow generated can be described in detail.

5. Conclusions

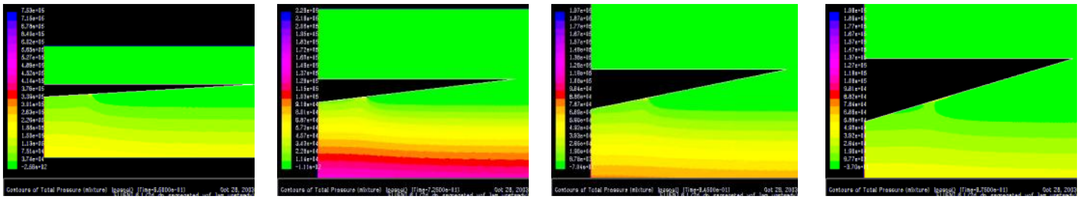
This study presents the results of numerical computation for two codes. One represents the potential code, and the other the viscous one. The potential code is written by BEM, which is the typical computational tool for the potential problem. The commercial code, FLUENT was utilized to simulate the viscosity. The developed BEM code has shown good agreement with Fatlinsen's results. It seems that the developed BEM comply with the slamming phenomenon. The required mesh generation and imposition of boundary condition seem suitable to describe the slamming phenomenon. When it comes to FLUENT code, the numerical values are higher than they should be. One promising feature derived from the FLUENT calculation is that we can see the generation of jet flow and its corresponding free surface evolution. This cannot be achieved with BEM, since BEM cannot simulate the separated flow. The results show that deadrise angle is the most important factor of slamming impact. The first computations being presented in Fig. 4 (a)-(d) were done for a wedge with 3, 6, 10, and 15 degree deadrise angles respectively, by using BEM code. They represent the time series of the slamming impact. The results show that deadrise angle is the most import factor of the slamming impact.

Acknowledgement

This work was supported by Korea Science and Engineering Foundation (KOSEF) through the Advanced Ship Engineering Research Center at Pusan National University.

References

[1] Armand. J.L, Cointe. R, Hydrodynamic impact analysis of a cylinder, *Journal of Offshore Mechanics and Arctic Engineering ASME 9*, (1987) 237-243.
[2] Dobrovol'skaya. Z.N, *On some problems of similarity flow of fluid with a free surface*,



3 degrees 6 degrees 10 degrees 15 degrees

Fig. 4. Slamming pressure distribution in FLUENT

Journal of Fluid Mechanics 36(4), (1969) 805-829.

[3] Chuang. S.L, *Experiments on flat-bottom slamming*, Journal of Ship Research, (1966) 10-17.

[4] B. Kim, Yung. S. Shin, 2003. *An efficient numerical method for a solution of two-dimensional hydrodynamic impact problems*, Proceedings of the 13th international offshore and polar engineering conference Honolulu Hawaii May, (2003) 25-30.

[5] Korobkin. A, 1996. *Water impact problems in ship hydrodynamics*, Advances in Marine Hydrodynamics (Editor: M. Okushu), (1996) 323-371.

[6] Mei. X, Liu. Y, Yue. D.K.P, *on the water impact of general two-dimensional sections*, Applied Ocean Research 21(99), 1-15.

[7] SNAME, Notes on Ship Slamming, *Technical and Research Bulletin 2-30*, The Society of Naval Architects and Marine Engineers.(1993)

[8] Von Karman, *The impact on sea plane floats during landing*, NACA Technical Note 321 (1929)

[9] Wagner, H, *Uber stoss- und Gleitvergange an der Oberflache von Flussigkeiten*, Z. Angew. Math. Mech, 12(4), (1932) 193-215.

[10] Watanabe. T, *Analytical expression of hydrodynamic impact pressure by matched asymptotic expansion technique*, Transactions of West-Japanese Society of Naval Architects 71, (1986) 77-85.

[11] Zhao. R, *Faltinsen. O.M*, *Water entry problem of two-dimensional bodies*, Journal of Fluid Mechanics 246, (1993) 593-612.

[12] Zhao. R, Faltinsen. O.M, *Aarsnes. J.V*, *Water entry of arbitrary two-dimensional sections with and without flow separation*, Proceedings 21st (1996) 408-423.