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# WAVE IMPACT ON A VERTICAL BAFFLE

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**ABSTRACT**

We consider the wave impact against a vertical baffle or a vertical wall in close proximity to the baffle for four cases: (i) a vertical baffle at free surface; (ii) a vertical baffle in front of a wall; (iii) a vertical baffle on a deck in front of a wall; (iv) a vertical baffle on the tank bottom in front of a wall. The mathematical formulation and the boundary conditions for four cases are presented for the pressure impulse. We used a basis function solution method for the pressure impulse which can then be integrated analytically to give the total impulse for each problem. These basis functions satisfy the boundary conditions except on the baffle and a matching line, where appropriate conditions give a matrix system for the unknown coefficients. The influence of the depth of baffle penetration and the size of the impact region is also studied. We find that pressure impulse with the same size of impact region on baffles of the same length are almost same for cases (i), (ii) and (iii). However the pressure impulse behind the baffles decreases when the length of the baffle increases for cases (ii) and (iii). For case (iv), the pressure impulse on the wall and behind the baffles increases when the length of the bottom-mounted baffle increases.

**Keywords:** slamming, sloshing, pressure impulse, wave impact, and naffles.

## 1. INTRODUCTION

Fluid-structure interaction resulting in wave impact is important in several engineering fields. For example, when a vehicle is braking, turning or in collision, the liquid in its partially-filled tank may slosh sufficiently violently to cause very steep, or even overturning, waves and these can cause slamming that could be important for the simulation of handling, especially on the stability for planes, rockets and spacecraft. Marine applications include impacts arising from the sloshing of LNG carriers in a seaway, and steep wave impact on coastal structures and oscillating water column wave energy devices.

The mathematical modeling of wave impact on a baffle in different conditions is studied using the pressure impulse theory. This gives a versatile and convenient way of assessing the influence of the depth of baffle penetration, and the size of the impact region, perhaps before undertaking much more expensive fully-nonlinear numerical calculations and/or model (or even full-scale) tests as in, e.g., Hattori, Arami and Yui (1994) or Hofland, Kaminski and Wolters (2010) in the coastal engineering context. To investigate these effects, vertical baffles are added, reaching down from the ceiling or up from the floor of the tank.

Cooker and Peregrine (1990) utilised a simplified model of pressure impacts on a seawall with the pressure impulse $P$ defined as the integral of pressure with respect to time

$$P(x,y)=\int_{t_b}^{t_a} p(x,y,t)\,dt \approx \frac{\Delta p_{pk}}{2} \qquad (1)$$

where $t_b$ and $t_a$ are the times at the before and after of the impact, $x$, $y$ are Cartesian coordinates of position and $p$ is measured relative to atmospheric pressure. The pressure impulse removes time from the equations of motions, but $p_{pk}$ can be estimated from a calculated value $P$ by assuming the pressure during impact is approximately triangular, during the impact time, $\Delta t$, see Cooker (1990), Cooker and Peregrine (1990, 1995) and Peregrine (2003), as given in Equation (1). The formulation for each problem is solved by using basis functions that satisfy the boundary conditions except on the baffle and the matching boundary, see Fig. 1. These conditions are satisfied using an integral method and a hybrid collocation method, see Md Noar (2002) and Md Noar and Greenhow (2014, 2015). This gives a matrix system for the unknown coefficients which is easily solved using MATLAB.

## 2. MATHEMATICAL MODELING FOR WAVE IMPACT ON A BAFFLE

The boundary-value problem described here is summarized in Figure-1, whilst the formulation of the other cases is very similar. The baffle depth of penetration is $H_b$ and the fluid filling the rectangular region $b_1 < x < b_2, -1 < y < 0$ where $b_2$ is sufficiently large to simulate open ocean in all cases and case (i) also has $b_1$ large (in practice twice the water depth is sufficient). On the right hand side of the baffle for all cases considered here we have a free surface i.e. $P = 0$ on $y = 0$. The pressure impulse $P$ satisfies Laplace's equation throughout the fluid. Since the wave comes from the right, the normal derivative of $P$ at the back of the baffle is zero and also zero below the impact region $-\mu < y < 0$. In the impact region we assume the horizontal component of the impacting wave's velocity is uniform (taken to be 1 in the non-dimensionalised problem studied here).

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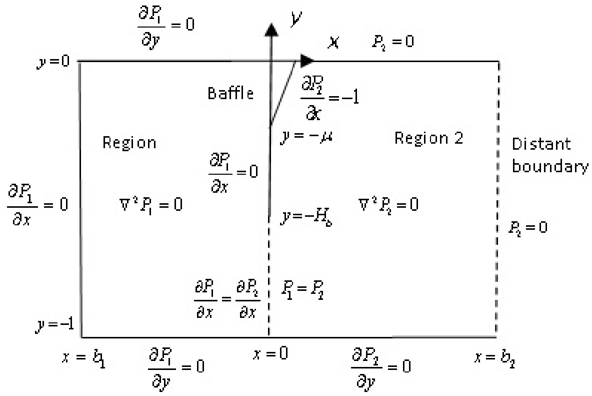


**Figure-1.** Non-dimension boundary-value problem for pressure impulse for wave impact on a baffle, for case (iii).

The region is split into two regions. In the region 1, the boundary conditions are different depending on the problem. For case (i), (ii) and (iv) the boundary condition at $y=0$ is $P_1=0$. At $x=b_1$, the boundary condition for case (i) is $P_1=0,$ and for case (ii) and case (iv) the boundary condition is $\frac{\partial P_1}{\partial x}=0.$ Because of baffle is located at the seabed, the free-surface boundary conditions for case (iv) is $P_1=0$ for both regions. The pressure impulse in region 1 can be written using eigenfunction expansion as in equation (2) for case (i), equation (3) for case (ii), equation (4) for case (iii) and equation (5) for case (iv).

$$P_1(x,y)=\sum_{n=1}^{\infty}\alpha_n\sin(\lambda_n y)\frac{\sinh(\lambda_n(x-b_1))}{\cosh(\lambda_n b_1)} \tag{2}$$

$$P_1(x,y)=\sum_{n=1}^{\infty}\alpha_n\sin(\lambda_n y)\frac{\cosh(\lambda_n(x-b_1))}{\cosh(\lambda_n b_1)} \tag{3}$$

$$P_1(x,y)=\sum_{n=1}^{\infty}\sin(\lambda_n y)\left\{\begin{matrix}\alpha_n\dfrac{\sinh(\lambda_n(x-b_1))}{\cosh(\lambda_n b_1)}\\ +\beta_n\dfrac{\cosh(\lambda_n(x-b_1))}{\cosh(\lambda_n b_1)}\end{matrix}\right\} \tag{4}$$

$$P_1(x,y)=\sum_{n=1}^{\infty}\sin(\lambda_n y)\left\{\begin{matrix}\alpha_n\dfrac{\sinh(\lambda_n(x-b_1))}{\cosh(\lambda_n b_1)}\\ +\beta_n\dfrac{\cosh(\lambda_n(x-b_1))}{\cosh(\lambda_n b_1)}\end{matrix}\right\} \tag{5}$$

where $\lambda_n=\left(n-\frac{1}{2}\right)\pi$ , $n\in(1,2,3\ldots,N)$ for $-1\le y\le 0,$ and $b_1\le x\le 0.$

The solution which satisfies the boundary conditions in region 2 for all cases is given by:

$$P_2(x,y)=\sum_{n=1}^{\infty}c_n\sin(\lambda_n y)\frac{\sinh(\lambda_n(x-b_2))}{\cosh(\lambda_n b_2)} \tag{6}$$

where $\lambda_n=\left(n-\frac{1}{2}\right)\pi$ , $n\in(1,2,3\ldots,N)$ for

$-1\le y\le 0,$ and $0\le x\le b_2.$

These expressions are truncated (typically after 20-40 terms) and are then input into the baffle and matching boundary conditions, giving a system of equations for the unknown coefficients $(\alpha_n,\beta_n,c_n)$. For details of the solution procedure and convergence checks, see Md Noar (2012).

## 3. RESULTS

Chan and Melville (1988) consider a baffle penetrating the free surface in an otherwise unbounded sea of constant depth, here denoted case (i). We find the pressure impulse on the baffle increases when $\mu$ increases. For small $\mu$ , the pressure impulse is almost the same for different length of baffle but when the $\mu$ is greater, the pressure impulse is higher the greater the length of the baffle. For case (ii), the behaviour is almost same as in case (i) but we have a wall behind the baffle. The pressure behind the baffle increases when $\mu$ increases but decreases when the length of baffle increases.

For case (iii) , there is high pressure behind the baffle when we have a rigid upper surface between the wall and baffle (i.e. we replace the free surface with a wall). For the same size of impact, e.g. $\mu=0.5$ , the pressure impulse behind the baffle is greater when the length of baffle increases. Case (iv) is different since the baffle is located on the seabed in front of the wall. We can see that pressure impulse on the wall is greater when $\mu$ increases and the pressure behind the baffle increases for higher lengths of baffle for the same impact.

Figure-2 shows the comparison of four cases for the same baffle length and $\mu$ . We can see that the pressure on the baffle for case (i) to (iii) is almost the same and show only a small increase when the length of baffle increases. For case (ii), the pressure impulse behind the baffle at the bottom is high and it decreases when length of baffle increases. For case (iii), the pressure behind the baffle under the closed region is higher when the length of baffle is smaller. It contrast with case (iv), when the pressure impulse on the wall is greater than on the baffle for case (i), (ii) and (iii) and the pressure impulse behind the baffle is greater when the baffle is higher.

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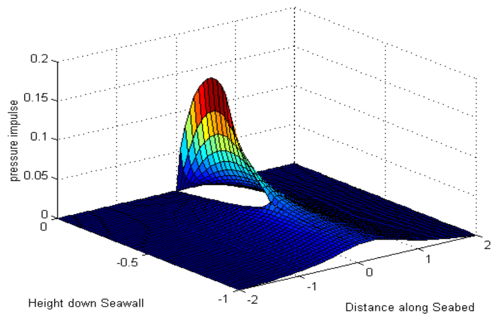
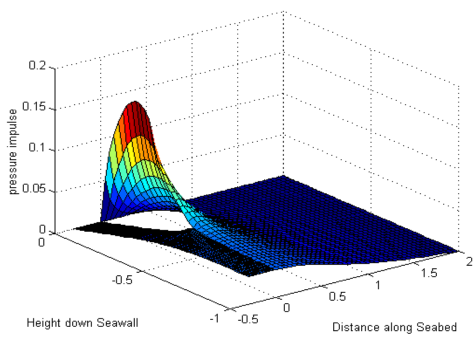
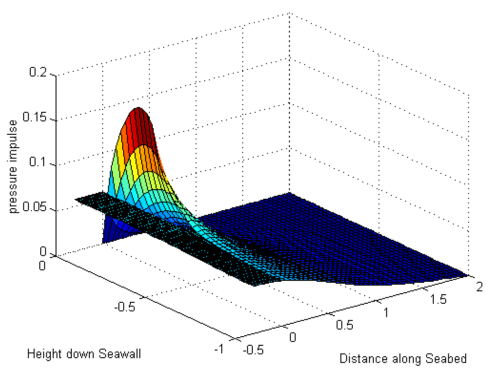


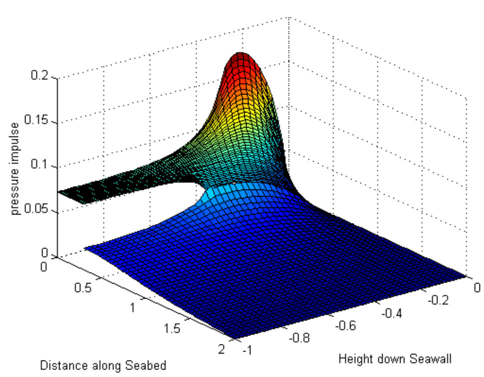

Case (i)




Case (ii)



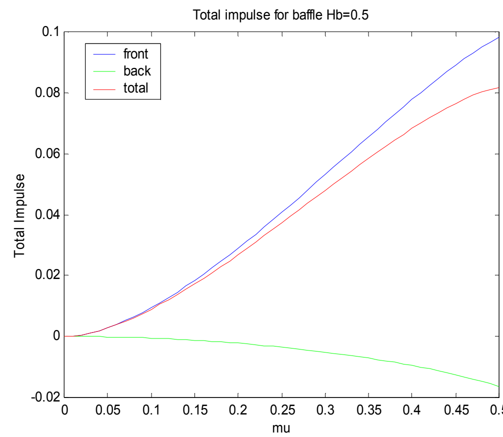

Case (iii)



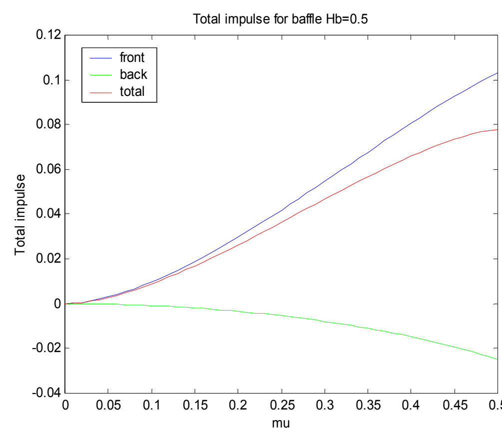

Case (iv)

**Figure-2.** Comparison between four problems for $H_b = 0.5$ and $\mu = 0.3$.

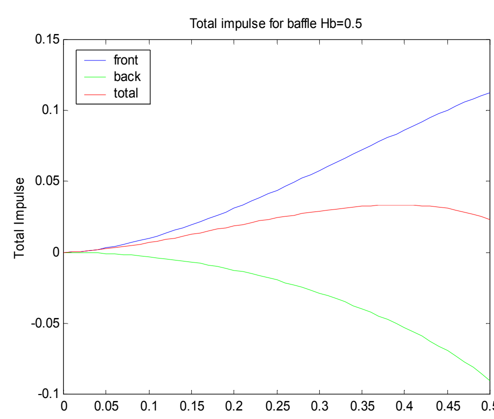
Figure-3 shows that the total impulse in front of baffle for case (i), (ii) and (iii) are higher than total impulse behind the baffle. When the length of baffle increases, the total impulse at the back is slightly higher than at the front (see Md Noar, 2012). For case (iv) we can see that the total impulse at the back is greater than at the front of baffle.




Case (i)




Case (ii)




Case (iii)

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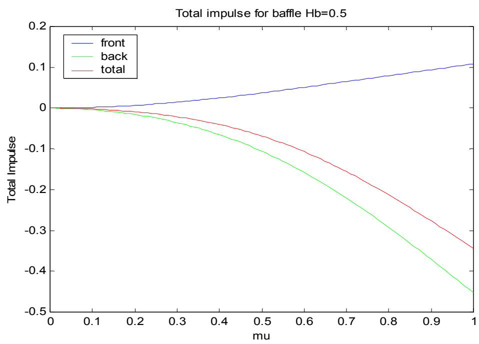
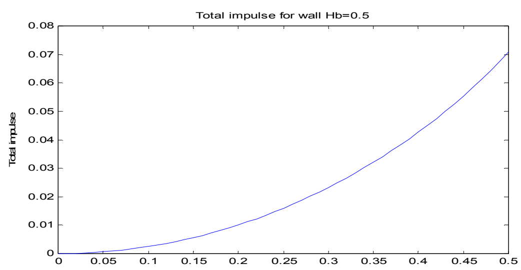


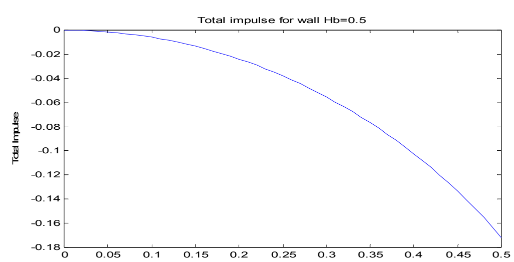

Case (iv)

**Figure-3.** Impulse on baffle for $H_b = 0.5$.

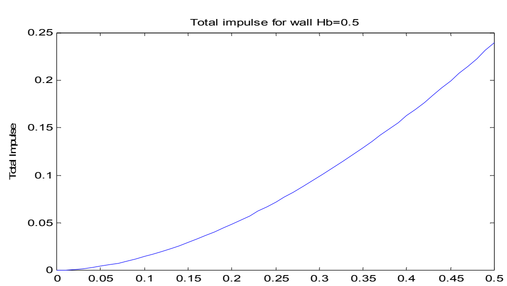
From Figure-4 we can see that the lowest total impulse on the wall is case (ii). The highest is in case (iv) as expected because the baffle is located on the seabed. The total impulse on the wall for case (iii) is higher than case (ii), and in seaward direction.




Case (i)




Case (ii)




Case (iii)

**Figure-4.** Total impulse on wall for $H_b = 0.5$.

## 4. CONCLUSIONS

The pressure impulses arising from wave impact on baffles or on a wall near a submerged baffle is given for four different cases. The pressure impulse on the baffles is almost same for case (i), (ii) and (iii) for different lengths of baffles with same size of impact. The total impulse in front of baffles is greater than that on the back of baffle for cases (i), (ii) and (iii). In contrast, for case (iv), the total impulse behind the submerged baffle is greater than the total impulse in front of the baffle. Case (iv) has the highest total impulse on the wall. The total impulse on the wall for case (iii) is higher than case (ii) and in the seaward direction. This is somewhat counter-intuitive result arises from high pressure impulses behind the baffle being trapped beneath a rigid free surface.

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