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Theoretical and Numerical Analysis of Sloshing Effect on Ballast Submarine

Luhut Tumpal Parulian Sinaga
Indonesian Hydrodynamic Laboratory- BPPT
luhuttps@yahoo.com.sg

Abstract : This study considers the analytic model for submarine. The Submarine was considered to be rigid body supported by non-permanent pole with distributed spring damper. The use of the floating body mechanisms equation is the development of the equation of force and the basic moment to obtain the pattern of submarine movement due to ballast. the development of this equation to illustrate the model performed through experiments and numerical simulations. equations of this model of analysis is one method that is quite simple, so that researchers can know earlier than the pattern of submarine motion that will be analyzed. From the results of the study, it was found that the submarine ballast has increased the effect on submarine stability that is reducing the submarine's stability.

Keywords: sloshing, floating body mechanism, global motion, model analytic, numerical, ballast, submarine

I. Introduction

Submarine is designed with the main ballast tanks fulls, the weight of water displaced will be as close as possible to the weight of the boat, see Fig.1. That is, there should be a balance between displacement and buoyancy, referred to as neutral buoyancy. If true neutral buoyancy is achieved the boat will float at whatever depth it presently is, unless something acts on it to make it rise or sink, see Fig.2. In practice, submariners prefer to maintain very slight positive buoyancy, so that if power if lost the boat may be expected to slowly rise to the surface.

The problem of water sloshing in closed tank has been the subject of many studies over the past few decades. This phenomenon can be described as a free surface movement of the contained fluid due to sudden loads. Sloshing is a liquid vibration phenomenon caused by the movement of the tank. When the liquid cargo is in transit, the sloshing would affect stability of the system severely, leading to damage or fatigue of the structure. So it is necessary to diminish the impact of sloshing and avoid large amplitude resonance. Sloshing has been studied for many years by analytical, numerical, and experimental methods.

The first approach in the modeling of sloshing liquids involves using numerical schemes based on linear and/or non-linear potential flow theory. These type of models represent extensions of the classical theories by Airy and Boussinesq for shallow water tanks. Faltinsen [1] introduced a fictitious term to artificially include the effect of viscous dissipation. Considering the importance of nonlinear effects in the sloshing response, Faltinsen [2] analyzed nonlinear sloshing by perturbation theory. Numerical simulation of sloshing waves in a 3-D tank has been conducted by Mikelis [3],Wu et al.[4].

Two experimentally derived empirical constants were included to account for the increase in liquid damping due to breaking waves and the changes in sloshing frequency, respectively. The attenuation of the waves in the mathematical model due to the presence of dissipation devices is also possible through acombination of experimentally derived drag coefficients of screens to be used in a numerical model, Hsieh [5]

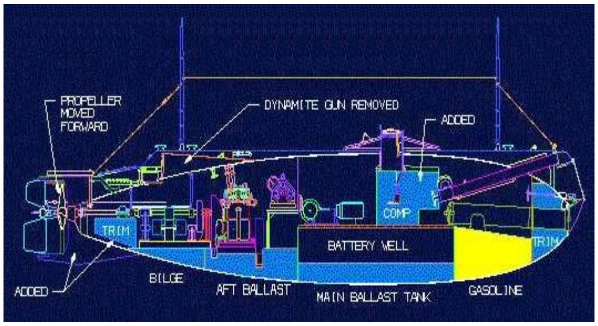

Figure 1. Ballas System at Submarine

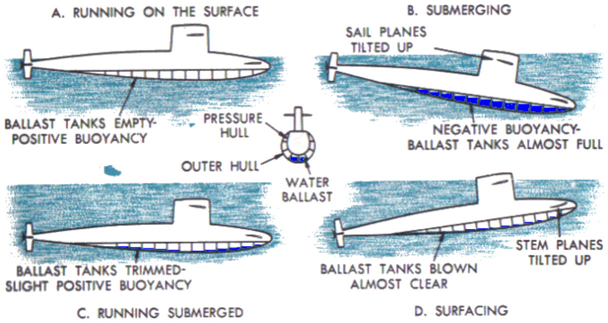

Figure 2. Submersion Proccess

In a quick dive, the negative tank is important. By flooding this tank the boat is made negatively buoyant, which gets the boat under water quicker. Once submerged, though, the negative tank is blown "to the mark." the submarine to be heavier than the water it displaced while diving, because you want to get under as quickly as possible.

The equations of motion for a submarine are similar to those for a surface ship, however they include all six degrees of freedom. For a submarine it is normal to take the origin as the longitudinal center of gravity (LCG), rather than mid- ships, as this simplifies the equations, and for a submarine this position is fixed (unlike for a surface ship). The axis system

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used is shown in the notation. Note that the origin is on the centerline, which is where the transverse center of gravity is assumed to be. Positive directions are along the positive axes, and positive rotations are clockwise as seen from the origin looking along the positive direction of the axes.

II. Material and Methodology

2.1 Floating Body Mechanism

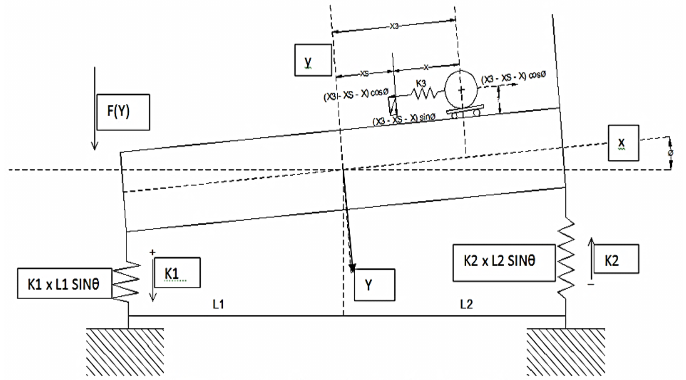

Figure 3. Floating Body Mechanism with Sloshing

In the pitching model system using 2 degrees of freedom, namely the mass beam or submarine described as the mass (M) ship and the mass of fluid in the ballast and described as two (2) spring of stiffness in the form of k_1 and k_2 for pitching motions, see Fig.3.

Mass of fluid in the tank load space is like a mass (m) in a moving train unhindered translational and 1 (one) spring of stiffness k_3 it also causes movement of the coupling to the model. If in the model gets a load (Fy) because of the influence of energy waves received by the model then the model will perform vertical and horizontal translation.

With the outside force that coordinates spring k_1 to the balance point (center of gravity) and is indicated for the spring k_2 toward the center of gravity is indicated l_2. With equation: $\sum F = m \times a$, and force coupling can be summarized as follows;

$k_1 l_1 - k_2 l_2$ So, $k_1 l_1 = k_2 l_2$

For fluid motion in the tank above the carriage modeled as a pendulum having stiffness without hindrance caused by the moving mass is equal to k_3 translansi as $(x_3 - x_s - x) sin\emptyset = (x_3 - x_s - x) cos\emptyset$.

Translation motion of fluid mass (m) will also affect the coupling pitch motion. The amount received by the vertical force spiral at an angle Ø is;

$k_1\ l_1\ \emptyset =$ F_1 has a positive direction (compressed) (1)

$k_2\ l_2\ \emptyset =$ F_2 has a negative direction (pulled) (2)

2.2 Computational Fluid Dynamic

The design model is based on a plan lines obtained from the owner. From the lines of this plan will be made for the scale model of the ship. The next stage is to use the offset table for plotting the results of the previous scale. After the scale has been determined then in print and create models. The dimension of submarine as shown table 1.

Table 1. Main Dimension submarines model

Dimension	SHIP (m)
LOA	22.00
B Total	4.29
D Total	5.13
T	2.60
dim. Press Hull	3.00
JR. FS	1.10
JR. WL	1.00
JR. BL	0.30

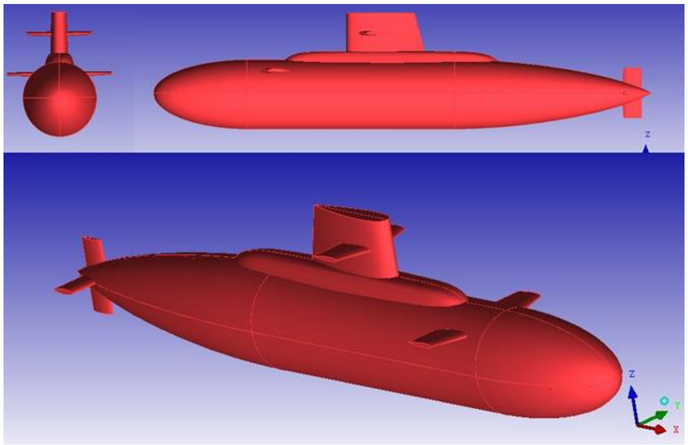

Figure 4 Design submarine

In this case the force, the left hand side of the equation, is the hydrodynamic force acting on the submarine, and the right hand side is the rigid body dynamics. This equation is transformed into body fixed axes, and the right hand side of the equation is given as follows:

$$M = I_{yy}\dot{q} + (I_{xx} - I_{zz})rp - (\dot{p} + qr)I_{xy} + \left(p^2 - r^2\right)I_{zx} + (qp - \dot{r})I_{yx} - \mathrm{m}\left[x_G(\dot{w} - uq + vp) - z_G(\dot{u} - vr + wq)\right] \quad 3$$

The origin of the axes is taken at the position of the longitudinal, and transverse centre of gravity, then both x_G and y_G will be equal to zero, simplifying these equations.

M is the total hydrodynamic pitch moments respectively. If these hydrodynamic forces and moments can be determined as functions of time for a motion submarine. In addition, if the effects of geometry on these forces and moments are understood then this can be used to assist in the design of the submarine. the equation of moment couple motion is given as follows

$$(\mathrm{M}+\mathrm{m})\ddot{\mathrm{Y}} = -2\mathrm{y}(\mathrm{k}_1+\mathrm{k}_2) - 2\emptyset(\mathrm{k}_1.l_1 - \mathrm{k}_2.l_2) - 2\mathrm{k}_3(\mathrm{x}_3-\mathrm{x}_s-\mathrm{x}).(\sin\emptyset + \cos\emptyset) \quad (4)$$

$$(J+j)\ddot{O} = -2y(k_1.l_1 - k_2.l_2) - 2\emptyset(k_1.l_1^2 + k_2.l_2^2) - k_3(x_3-x_s-x)\,[(sin\emptyset.d) - \{(x_3-x_s-x)cos\emptyset\}] \quad (5)$$

Where:
$\mathrm{k}_1.l_1 - \mathrm{k}_2.l_2$ is static Couple
$y = A\sin(\omega t+\varphi)$ serta $\emptyset = Csin(\omega t+\varphi)$ (6)
M is displasment ship
m is the mass of water in the fluid tank
$\mathrm{M}\ddot{\mathrm{Y}}$ is Fy is an external force due to wave energy
$\mathrm{m}\ddot{\mathrm{Y}}$ is the force due to sloshing
$\emptyset$ is the angle of the incident wave direction
J is moment due to an external force caused by wave
j is moment due to an internal force caused by fluids

Computational Fluid Dynamics (CFD) is the process of numerically solving fluid dynamics equations to predict resultant flow fields. It is used to model a rich variety of flow phenomena, as well as to define thermal and structural loads on bodies immersed in fluids[5].

The entire computational mesh including the submarine body is assumed to be moving with the body without any deformation. The flow field computations were performed in the inertial frame of reference, which makes the specification of boundary conditions easier. Since the body moves through infinite volume of stagnant water, the velocity specified at the far field boundaries of the computational domain is zero. Submarine run at speed 6 knots with 10^0 trim after, then external force get wave reguler with 1 m in height.

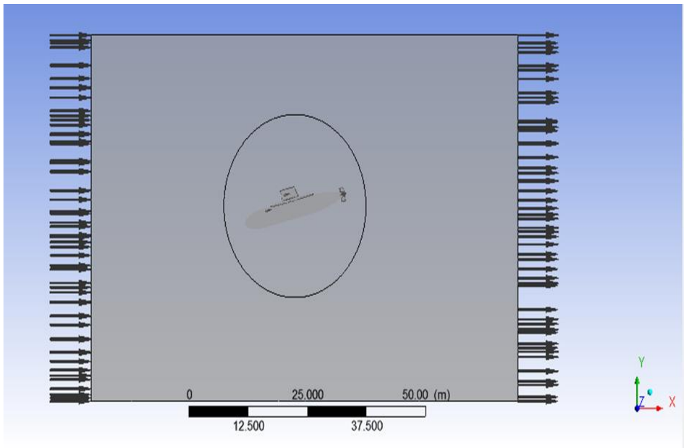

Figure 5. CFD Submarine

As described above (Figure 3), it is assumed that the global fluid motion plays the most important role in the sloshing-induced impact occurrence. The incompressible Euler equation and continuity equation are the governing equations of the present method. To solve these equations, let us consider the discretization of the tank volume into finite meshes (Table 1) and as shown in Figure 5 for meshing model. Adopting the concept of the Cartesian staggered grid, the velocity components are defined on the cell boundaries, while the pressure is computed at the center of each cell. The simulation of a motion requires the coupled solution of rigid body motion equation (in six degrees of freedom) with unsteady Reynolds-averaged Navier-Stokes equations (URANS).

The integration and rigid body mesh motion are performed automatically using CD-adapco's Dynamic Fluid-Body Interaction (DFBI). In this case submarine move forward and acquire force of the front at angle 180^0 (head seas), see figure 5.

Table 2 Generated Mesh Information

Description	Meshing Specification
Object Name	Mesh
State	Meshed
Number of Nodes	1358
Number of element	1314
Number of Nodes (Diffracting Bodies)	952
Number of Elements (Diffracting Bodies)	904

III. Results and Tables

As part of a validation of the coupled Navier-Stokes and six-degree-of-freedom method, time-accurate unsteady numerical computations were performed to predict the flow field, hydrodynamic coefficients, and the quick dive paths of submarine at an initial speed = 6 knots. Full three-dimensional computations were performed and no symmetry wall was used.

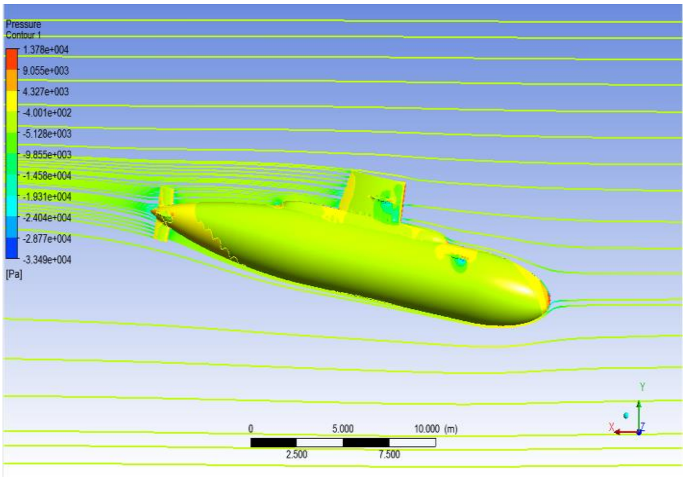

Figure 6 Trim angle at 10^0

Here, the primary interest is in the validation of coupled CFD techniques for accurate simulation of free sailing and quick dive of submarine. Numerical computations were made for the submarine configuration at an initial velocity of 6 knots. The initial angle of attack (trim) was, $\alpha = 10^0$ Figure 6 shows the computed pressure contours at a given effective motion. It clearly shows the orientation of the body at that instant in time and the resulting flow field due to the body at angle of attack

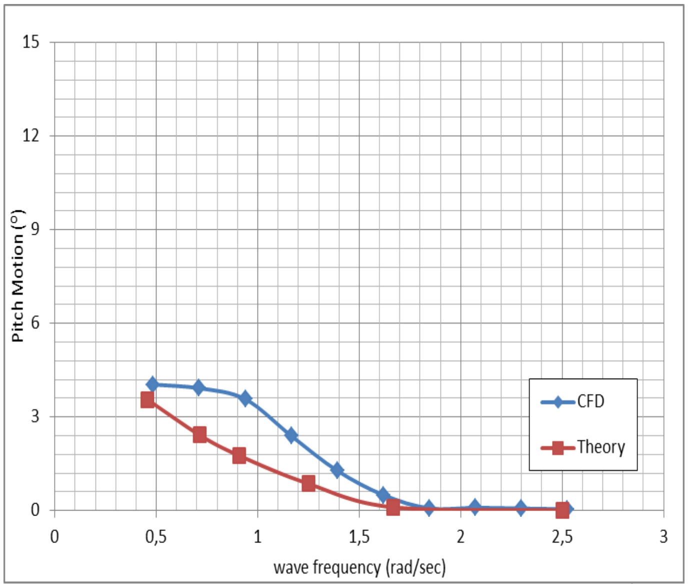

Figure 17 Comparation Pitch Motion at angle 10^0

Numerical methods, Free Floating Body Equation running by MAT-LAB version 6.5 methods, are applied to solve violent sloshing. Based on the present study

IV. Conclusion

The vessel had effective angle of inclination when diving was 10° when submerged the speed of 6 knots after the required depth had been obtained this angle became so small as to be inappreciable and had to be maintained to keep effective depth control.

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