Investigation of Buoy Hydrodynamic Damping Based on Model Testing Data Series of Indonesia Tsunami Buoy

W.H. Nugroho¹, Arifin¹, N.J.H. Purnomo¹, and B. Ali²
¹Pusat Teknologi Rekayasa Maritim, BPPT
²Balai Teknologi Hidrodinamika, BPPT

Abstract. Due to the recent Tsunami event in Indonesia in 2018, the Ina-TEWS program has been started again by the Indonesian Government. A new design has been manufactured and already deployed to the Indonesian water. This design is named Buoy G – 3. The tsunami early warning system (TEWS) consists of a tsunami buoy, an ocean bottom unit (OBU), a satellite and a ground station. The changes of the water pressure due to the seismic movement prior to the tsunami event will be acquired by OBU and sent the reading to the tsunami buoy by acoustic signal. Then, tsunami buoy transmits the signal to the ground station via satellite. The continuously link between OBU – Buoy – Satellite makes the buoy motions especially roll/pitch has to be restricted. Because of these the hydrodynamic motion damping assessment of this tsunami buoy becomes so important. This paper describes a hydrodynamic damping analysis for roll/pitch of the tsunami buoy that based on model testing data series of Indonesian Tsunami Buoy G -1 to G -3. The data analysis will be presented on graphics that show the aspect ratio of buoy diameter over draft (D/T) and form ratio of buoy displacement over weight of the cylindrical submerged form (Δ/W) against damping ratio (β). This study finds that by using the linear damping approximation the higher the aspect ratio D/T the larger roll/pitch damping ratio β, but also the higher ratio of Δ/W the smaller roll/pitch damping ratio β.

Keywords: tsunami buoy, roll/pitch damping coefficients, motion decay test
1. Introduction

Due to the recent Tsunami event in Indonesia in 2018, as well as the large potential for Tsunamis in Indonesian region, it is necessary for the Government of Indonesia to revitalize the buoy-based early warning system for tsunami disasters developed by BPPT nationally. The Tsunami Buoy system is one of the tsunami early warning systems that works based on the sea level elevation anomaly that passes above the sensor placed on the seabed in the form of the Ocean Bottom Unit (OBU). This system is placed in the open seas, far from the coast.

The concept for designing this Indonesian Tsunami Early Warning System (Ina-TEWS) buoy is to design and build a buoy that has a good buoyancy, stability and sea-keeping capability as well as a structural integrity in where electronic devices and a capable communication system to be installed inside the buoy. The buoy will be moored with a taut mooring system in deep water. In terms of function, the surface buoy subsystem is designed to be able to meet the following functional requirements such as a good stability to receive and send signals to satellites also to make sure sensors except the acoustic modem are always above sea level and be able to position the antenna at a specified minimum height.

The tsunami buoy system consists of an Ocean Bottom Unit (OBU) and a Buoy (SB) unit at sea surface. OBU actively and continuously communicates with the Surface Buoy through an underwater acoustic modem. The surface buoy acts as a data receiver from the OBU and transmits the data via satellite to the tsunami monitoring centre at the read down station (RDS). A telemetry system is needed for sending tsunami signals to a data processing centre at the ground station in real-time. These tsunami buoys will be placed on the open sea with more than 2000m water depth on 14 (fourteen) locations of Indonesian water that shown in Figure 1. Henceforth, the continuously link between OBU – Buoy – Satellite makes the buoy motion especially rolling/pitching has to be restricted and has ability to return to its equilibrium position as soon as possible. These conditions can only be predicted if the motion damping of the buoy is characterized. Because of these the hydrodynamic damping assessment of this tsunami buoy becomes so important. Some references have been found to support the importance of the roll damping analysis. The Averaging method by [3] assumes the profile of the roll decay is sinusoidal and the rate of change of the amplitude and phase is constant at their average values for each cycle, that make this method to be more applicable for light damped systems [7] has been studied this motion damping analysis to apply on the Tsunami buoy G – 1 and continue the study on Tsunami Buoy of G – 2 [8]. [2] made the roll damping characterization program (RDCP) to characterize and quantify the roll damping characteristic of a free-floating maritime platform. [6] conducted Experimental Determination of Non-Linear Roll Damping of an FPSO Pure Roll Coupled with Liquid Sloshing in Two-Row Tanks.

This paper describes a hydrodynamic damping analysis for roll/pitch of the tsunami buoy that based on model testing data series of Indonesian Tsunami Buoy G -1 to G -3 (shown in Figure 2) in Maneuvering Ocean Engineering (MOB) tank at Balai Teknologi Hidrodinamika (BTH), BPPT. The data analysis will be presented on graphics that show the aspect ratio of buoy diameter over draft (D/T) and form ratio of buoy displacement over weight of the cylindrical submerged form (Δ/W) against damping ratio (β).
2. Theoretical basis

In this section a governing equation for the buoy motion decay is presented. When the energy of the buoy motion is gradually dissipated by friction and other resistances, the motion are said to be decayed. The motion gradually reduces or changes in frequency or intensity or cease and the buoy rests in its equilibrium position. When the system behaviour is almost linear (equivalent) damping can be derived as follows: The linear rotational motion \((t)\) during a free extinction test can be described by, assuming a linear system:

\[
(I + I_A) \frac{d^2\phi}{dt^2} + B_\phi \frac{d\phi}{dt} + C_\phi \phi = 0
\]  

(1)

Where:

- \(I\) = vessel inertia for rotation
- \(I_A\) = added inertia for rotation
- \(B_\phi\) = angular damping coefficient
- \(C_\phi\) = angular spring coefficient.

The spring coefficients are a hydrostatic spring. The non-damped natural period of this system can be calculated as:

\[
T_\phi = 2\pi \sqrt{\frac{I + I_A}{C_\phi}}
\]  

(2)

For such a system the critical damping \(B_{\phi,\text{crit}}\) is defined as:

\[
B_{\phi,\text{crit}} = 2\sqrt{(I + I_A)C_\phi}
\]  

(3)
If the damping is equal to, or larger than, the critical damping, no overshoot of dynamic amplification occurs in the system. To determine the degree of damping in a system, the damping is sometimes expressed as a ratio $\beta$ of the linear damping coefficient $B$ and the critical damping $B_{\text{crit}}$:

$$\beta = \frac{B}{B_{\text{crit}}} \quad (4)$$

The method to determine a damping coefficient of the buoy above can be explained in this section. From the recorded decay curve which is presented on Figure 3 the motion decay or free extinction natural periods can be derived.

![Figure 3. Time history of a motion decay test.](image)

In Figure 3, where $\phi(t)$ is a time trace of motion $\phi$, $\phi_n$ is a motion amplitude of n-th oscillation and $T\phi$ is a natural period of motion $\phi$. The damping coefficients were derived from the decrease of motion amplitude for two successive oscillations.

The linear damping can be obtained from the decay tests as follows.

- First, a plot is made from the decay tests on logarithmic paper to determine the mean logarithmic decrement $\delta$ of the amplitudes. The logarithmic decrement $\delta$ is defined as:

$$\delta = \frac{\ln(\phi_1) - \ln(\phi_n)}{n} \quad (5)$$

Where $n$ is the number of oscillations.

- Second the logarithmic decrement is used to determine the damping $B$ or the dimensionless damping $\beta$ as a percentage of the critical damping:

$$B_\phi = \frac{2.(I + I_\lambda).\delta}{T_\phi} \quad (6)$$

$$\beta = \frac{\delta}{2\pi} \quad (7)$$

3. Motion decay test

The tsunami buoy model used in this study was made of fiber glass, before testing the model, its radius of gyration was measured by hanging the buoy model using a crane and adjusting the mass distribution of the buoy model. The motion decay test the measurement was performed by using an Optical wireless motion tracking system that can determine accurately the angle of buoy motion decay. During the decay test in the water tank has to be in a calm state. An extensive series of decay tests were performed on the buoy model. Each decay test was performed by giving the model an initial offset in one direction of freedom and, then, releasing it which presented on Figure 4. The resulting vessel motions were recorded in one degree of freedom which is roll or pitch. Some of the decay tests were repeated several times. Of these repeats the best record was analyzed to determine the natural periods
and the damping ratio. All measured data that shown on Figure 5 was recorded and stored on computer for further processing. For that purpose the analogue signals were sampled at a rate of 50 Hz. The notations of the motions were taken in relation to their directions with respect to the model system of axes (see Figure 6). Each rotation was considered positive when, from zero position, it rotated clockwise about the respective axis of the local system when looking into the positive direction of that axis.

Figure 4. Roll decay test of Buoy G-3.

Figure 5. An example of Time traces roll decay test of Buoy G 3.

Figure 6. The buoy model system of axes.

φ : roll starboard down
θ : pitch bow down
ψ : yaw bow to portside
4. Results & discussions

A number of decay tests have been performed in MOB to determine damping ratio $\beta$ as a percentage of the critical damping of the buoy models derived from these decay tests by the methods described above.

There are 6 test buoy conditions obtained in this study. These data are the result of the motion decay test on the G1 - G2 - G3 buoy models. Two plots were generated to present the damping coefficient as a function, namely the function of the ratio of diameter to draft of buoy (D/T) and the ratio of displacement of the buoy to weight of the submerged cylindrical form ($\Delta/W$). The function of the ratio of the diameter to draft of buoy (D/T) on the damping coefficient $\beta$ is shown in Figure 7. The function of the ratio of displacement of the buoy to the weight of the submerged cylindrical form ($\Delta/W$) on the damping coefficient $\beta$ is shown in Figure 8.

![Figure 7. The Diameter over Draught (D/T) vs Damping ratio $\beta$.](image1)

![Figure 8. The Displacement over weight of the cylindrical submerged form ($\Delta/W$) vs damping ratio $\beta$.](image2)

As in the theoretical basis explained when the energy of the buoy motion is gradually dissipated by friction and other resistances, the motion are said to be decayed. The motion gradually reduces or changes in frequency or intensity or cease and the buoy rests in its equilibrium position. A lightly damped harmonic motion moves with almost the same frequency, but it loses amplitude and velocity and energy as times goes on. The timescale over which the amplitude decays is related to the time constant. As the resistive force increases or damping force increases, the decay happens more quickly. If the system gradually increased the amount of damping, the period and frequency begin to be affected, because damping opposes and hence slows the back and forth motion. If there is very large
damping, the system does not even oscillate and it slowly moves toward equilibrium. In Figure 7, it can be seen that there is a tendency for the hydrodynamic damping coefficient value of the buoy to increase with the increase in the ratio value of the buoy diameter to its draft. It can also be said that in order to obtain a large hydrodynamic damping value to quickly move to the original equilibrium position a designer can choose a buoy diameter size that exceeds its draft, which seems to apply to a ratio (D / T) equal to 1 to 4, according to the results obtained in this study. However, in Figure 8 it can be seen that the damping coefficient value tends to decrease with increasing the ratio (Δ / W) 0.25 to 0.65, which means that the ability to roll the buoy to its balance position takes longer time. In case of the tsunami buoy the high damping coefficient is preferable because of the continuously link between OBU – Buoy – Satellite to meet a good stability to receive and send signals to satellites.

Concluding remarks
This study finds that by using the linear damping approximation the higher the aspect ratio D/T equal to 1 to 4 the larger roll/pitch damping ratio β, but also the higher ratio of Δ/W of approximately 0.25 to 0.65 the smaller roll/pitch damping ratio β. Results of this study clearly can be useful for a naval architect to design a buoy with a suitable damping performance to operate in the open sea.

Future Works
Some possible future works can be proposed; (1) Since the study based on the linear damping approximation based on series of model tests, to predict the motion of the buoy to be more accurate a quadratic damping approximation can be studied (2) In some studies found that a damping coefficient is also function of the excitation frequency and current speed, therefore a study of the damping coefficient of the buoy in various wave condition and current speed is also an interesting subject to be conducted.

Acknowledgements
This research was financially supported by the Agency of Assessment and Application of Technology, Ministry of Research Technology, Republic Indonesia through Program of Rancang Bangun Buoy dan OBU (Inovasi Sistem dan Teknologi INA-TEWS), PTRIM, TIRBR – BPPT FY2020

References
[1] Bhattacharya, R, “Dynamics of Marine Vehicles”, John Wiley & Sons Inc (1978).
[2] Dawson Edward and Riding Murray, “Roll Damping Characterisation Program: User Guide Maritime Division”, Defence Science and Technology Organisation, Australia, 2014.
[3] Flower, J; Sabti Aljaff, W,” Kryloff-Bogoliuboff’s solution to decaying nonlinear oscillations in marine systems”, Int. Shipbuild. Prog. 1980.
[4] Lewis E,” PNA Vol III,” Motions in Waves and Controlability”, SNAME 1988.
[5] Reddy D.V, Arockiasamy M, “Offshore Structures, Vol 1”, Krieger Publishing Company, Malabar, Florida, 1991.
[6] Igbadumhe Jane-Frances, Sallam Omar, Fürth Mirjam, and Feng Rihui, “Experimental Determination of Non-Linear Roll Damping of an FPSO Pure Roll Coupled with LiquidSloshing in Two-Row Tanks”.J. Mar. Sci. Eng. 2020, 8, 582.
[7] Wibowo HN, Samudro, Sahlan RB, “Aplikasi Teknologi Kelautan untuk Merekayasa Buoy Seawatch sebagai Buoy TEWS – Indonesia”, SENTA 2007, ITS, Surabaya-Indonesia, 2007.
[8] Wibowo HN, Samudro, Arifin, “On The Analysis Design Of Indonesian Tsunami Buoy Hull Based On The Hydrodynamic Test”, 6TH Marine Technology Conference, UI, Jakarta, Indonesia, 2008.
[9] Wibowo HN, Arifin, Buddin Hakim, “PROGRAM MANUAL 2020, Rancang Bangun Buoy dan OBU (Inovasi Sistem dan Teknologi INA-TEWS)”, (PTRIM), TIRBR – BPPT, Januari 2020.
[10] Wibowo H Nugroho, “Konsep dan Desain Rancang Bangun INA-Buoy BPPT”, Webinar Inovasi Teknologi INA – BUOY BPPT dalam Perspektif Penanggulangan Bencana Tsunami di Indonesia, 29 September 2020.