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The Stability Analysis Of Floating Buoy As A Wave Energy Harvester For Malaysian Coastal Area

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ABSTRACT

These days, the problems of the energy crisis and environmental pollution are rapidly getting worse. As a result, using renewable energy sources like solar, wind, and ocean energy serves as an alternative to the current conventional energy. The fastest-growing renewable energy source to produce electricity is ocean wave energy, which is also pollution-free. While ocean wave energy harvesting is not fully developed in Malaysia, there are some potential opportunities for it to be explored. There is a lack of stability in the wave energy harvester prototypes currently in use. Therefore, the aim of this study is to design a stable floating buoy as a wave energy harvester for the Malaysian coastal area and to conduct a stability analysis on the proposed design. In this study, the design of the floating buoy was based on the composition of previous studies done for power generation which is the NAHRIM's Coastal Defense and Energy Generator (N-CODE). Commercial software was used as a medium to evaluate the stability performance of floating buoys in terms of hydrostatic and hydrodynamic analyses. The wave amplitude was regulated between 0.1 m and 1.0 m while the wave frequency was kept constant at 0.5 Hz. This floating buoy shows a significant result for stability in static conditions since its metacentric height is greater than the centre of gravity. Finally, it has been determined that the floating buoy concept is viable in the Peninsular Malaysian coastal region, where the floating buoy can endure 1.0 m of wave amplitude.

Keywords:
Stability analysis, floating buoy, wave energy harvester, Malaysia coastal area

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1. Introduction

Nowadays, the problems of the energy crisis and environmental pollution are rapidly getting worse. Natural resources from the earth such as oil, coal, and natural gas are becoming limited. This is due to industry demand, mainly for the generation of electricity. Electricity utilization is increasing year by year based on the human population which continues to rise. The total primary energy supply is expected to increase annually, which could reach approximately 23 billion tons of standard coal by 2030, to rise to 25–27 billion tons in 2050 [1]. Human beings can not only rely on natural resources that continue to reduce instead to find another alternative to substitute the non-renewable energy. As a result, using renewable energy sources like solar, wind, and ocean energy serves as an alternative to the current conventional energy [2].

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The fastest-growing renewable energy source to produce electricity is ocean wave energy, which is also pollution-free. Based on the previous studies, Malaysia has a massive potential to fully utilize the energy from the ocean as it is mostly surrounded by coastline [3]-[6]. According to N. H. Samrat *et al.,* it can be discovered that the optimum annual wave power available in the Malaysian sea is 8.5 KW/m with the maximum capacity for annual wave power reaching 15.9 KW/m in Perhentian Island. Thus, the wave energy harvester was used to capture the ocean wave energy and convert it into electrical energy. A Wave energy harvester is the device used to transform the potential and kinetic energy related to a moving ocean wave into valuable mechanical or electrical energy. There are many types of wave energy harvesters that are used globally on a commercial basis such as point-absorber devices, attenuators, terminators, overtopping devices, and an oscillating water column [7]-[9[. A common type of wave energy harvester is a point absorber, which typically uses a submerged or floating body to retain the oscillating force of the wave. Its actuation techniques are mostly vertical translational motion. The benefit of a point absorber is that it can collect energy from waves coming from all directions at a single oceanic location.

By using the floating buoy to harvest the wave energy, another prototype wave energy harvester has been developed in Malaysia [10]. The prototype is called NAHRIM's Coastal Defense and Energy Generator (N-CODE) [11]. It has been invented by the National Hydraulic Research Institute of Malaysia (NAHRIM). The N-CODE has been deployed somewhere near Pulau Tinggi, Johor. It is anchored with a simple PVC rope on the 4000kg artificial reef named WABCORE. Based on recorded data, the N-CODE could generate up to 7.3V of electricity at a certain time. Thus, electrical power is possible to be generated on the Malaysian East Coast using N-CODE.

While ocean wave energy harvesting is not fully developed in Malaysia, there are some potential opportunities for it to be explored. There is a lack of stability in the wave energy harvester prototypes currently in use. Therefore, the aim of this study is to design a stable floating buoy as a wave energy harvester for the Malaysian coastal area and to conduct a stability analysis on the proposed design.

2. Methodology

2.1 Design of the Floating Buoy

The preliminary design of the floating buoy is based on the configurations of N-CODE. The shape of the buoy is circular which is concluded to have a good stability in the ocean wave. The circular shape of the buoy is expected to float in the ocean steadily. A simple electromagnetic system that consists of magnetic bars and copper coil will be attached on top of each pole. Figure 1 indicates the design of the floating buoy. The overall dimensions of the buoy are 1000 mm in diameter with 750 mm in height. The floating buoy design is expected to utilize fiberglass as the main material. Fiberglass is typically required for modern boat productions. Fiberglass is a reinforced plastic material made of woven material that is embedded with randomly laid glass fibers and held together with a binding agent. The low weight and high strength properties of fiberglass can be applied to the floating buoy which ensures its reliability and durability.

2.2 Mesh Construction

The simulation work is conducted using computational fluid dynamic (CFD) commercial software. The analysis is limited to hydrodynamic diffraction to test the stability of the floating buoy using simulated wave provided in the software. Meshing is the act of breaking down an object's continuous geometric space into thousands or more elements to correctly define the object's physical shape. The more complex a mesh, the more accurate the 3D CAD model, enabling for high-fidelity simulations. In this study, two parameters of mesh are involved including defeaturing tolerance and maximum element size.

The defeaturing tolerance controls how small details are treated by the mesh. If the detail is smaller than this tolerance then a single element may span over it, otherwise the mesh size will be reduced in this area to ensure that the feature is meshed. The defeaturing tolerance is set to 0.01 m with the maximum element size of 0.05 m. Figure 2 shows the mesh generated on the floating buoy.

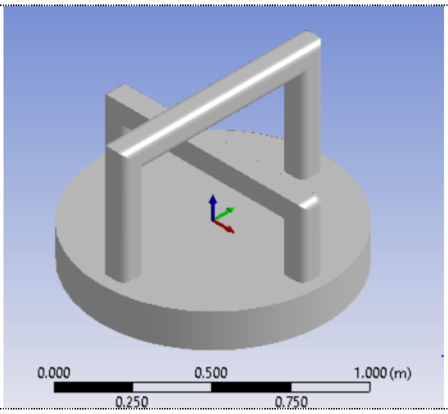

Fig. 1. Design of Floating Buoy

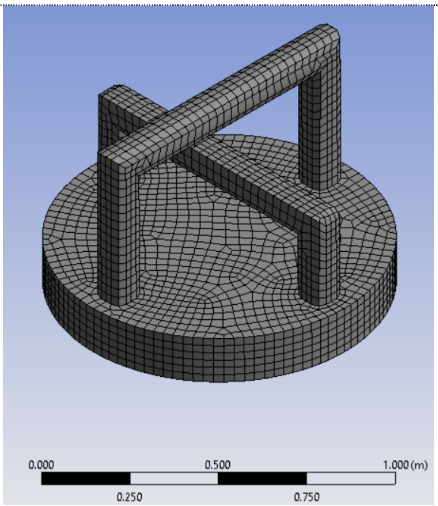

Fig. 2. Mesh Generated on Floating Buoy

2.3 Wave Direction

The Wave Directions enables the definition of a range or single wave direction to use in the analysis. If wave type was set to single direction, forward speed, a structure forward speed and a wave direction can be input. In this case, only a single wave direction can be analysed. However, in this analysis, the wave type was set to range of directions, no forward speed where waves are automatically created in -180° and +180° directions. The interval was set to 90° while the number of intermediate directions was specified to 3. If a direction range is of particular interest, additional ranges or specific directions can be added. On this analysis the range of direction was set to no forward speed. The number of intermediate frequencies and directions was set to 10 and 3, respectively. The wave direction interval is set to 90° while the wave grid size was set to 20.

2.4 Wave Frequencies

Wave frequency is the number of waves that pass a fixed point in each amount of time. The SI unit for wave frequency is the hertz (Hz), where 1 hertz equals 1 wave passing a fixed point in 1 second. In this analysis, the incident wave frequency range is manually set. The frequency values were set ranged from 0.1 Hz until 1.0 Hz with the total number of frequencies of 10.

2.5 Hydrodynamic Pressure and Motion

The pressures and motions results object enables the visualization and display of several results generated from CFD software once a hydrodynamic solve has been conducted. The incident wave amplitude can be modified to provide results that are factored from the unit 1 m wave that is the default; extreme modification may extend results beyond the capabilities of linear analysis. The response amplitude operator (RAO) also can be determined from these simulations. In this analysis, the incident wave amplitude was first set to 0.1 m while the 0.5 Hz wave frequency is kept constant. After that, the value of wave amplitude is increased until the floating buoy design is turned upside down.

3. Results

3.1 Hydrostatic Analysis

The hydrostatic result has been used to determine whether the floating buoy is stable in static condition or not. The hydrostatic result is automatically generated in CFD software. One of the important conditions to indicate the stability of the floating buoy in the static condition is the metacentric height. When the vertical position of the center of gravity is lower than the location of the metacenter, a stable equilibrium is achieved. Based on this analysis, the measured distance between the center of buoyancy and the center of gravity is 0.1125 m. While the distance between the center of buoyancy and the metacenter is 0.8329 m. This condition shows that the metacentric height is 0.7204 m. The value of the metacentric height of the floating buoy is greater than the center of gravity value Therefore, it proved that this floating buoy shows a significant result for stability in static condition.

3.2 Hydrodynamic Analysis

The simulation of the floating buoy in terms of hydrodynamic was successfully conducted in the CFD commercial software. The data of the graphical result and pressure generated by the wave were recorded and tabulated. The graph plotted in Figure 3 showed that the wave amplitude is directly proportional to the maximum pressure generated by the wave. Based on Figure 4, the graphical result showed that the floating buoy was out of stability at 1.0 m wave amplitude. Simultaneously, the maximum pressure value that is generated by the wave was 3746.6 Pa. This value showed the maximum pressure that can be applied to the floating buoy. The red line indicator specifies that any value that is equal to or beyond that line will make the floating buoy out of stability.

According to A. M. Muzathik *et al.*, it was mentioned that the significant wave height in Peninsular Malaysia was between 0.2 m and 1.2 m [12]. The result of this research showed the floating buoy design can withstand the condition of the ocean in Peninsular Malaysia. Considering that 1.0 m wave amplitude is equal to 2.0 m wave height, this condition can prove that the floating buoy can withstand the maximum pressure generated by the wave at up to 2.0 m wave height. This condition was successfully demonstrated using the simulation that was conducted in the CFD commercial software.

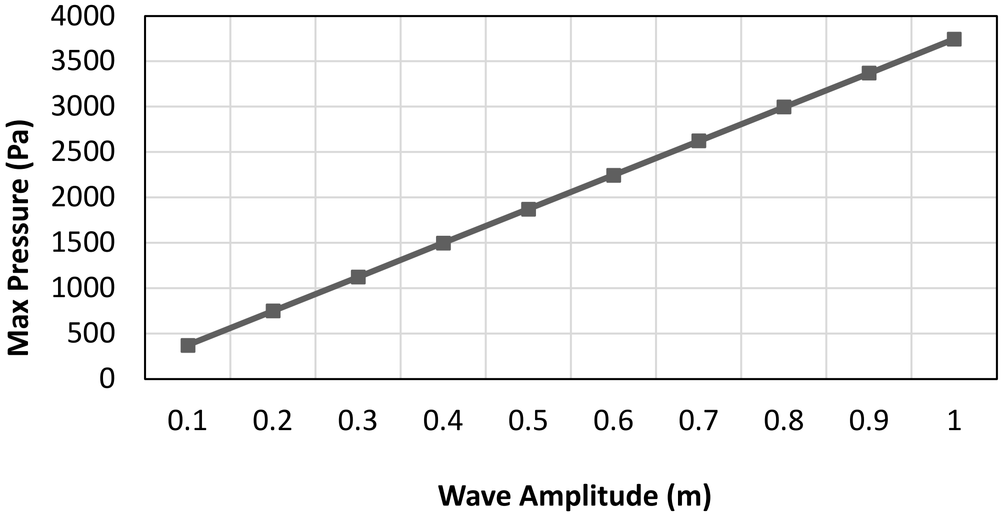

Fig. 3. Variation of maximum pressure versus variation of wave amplitude

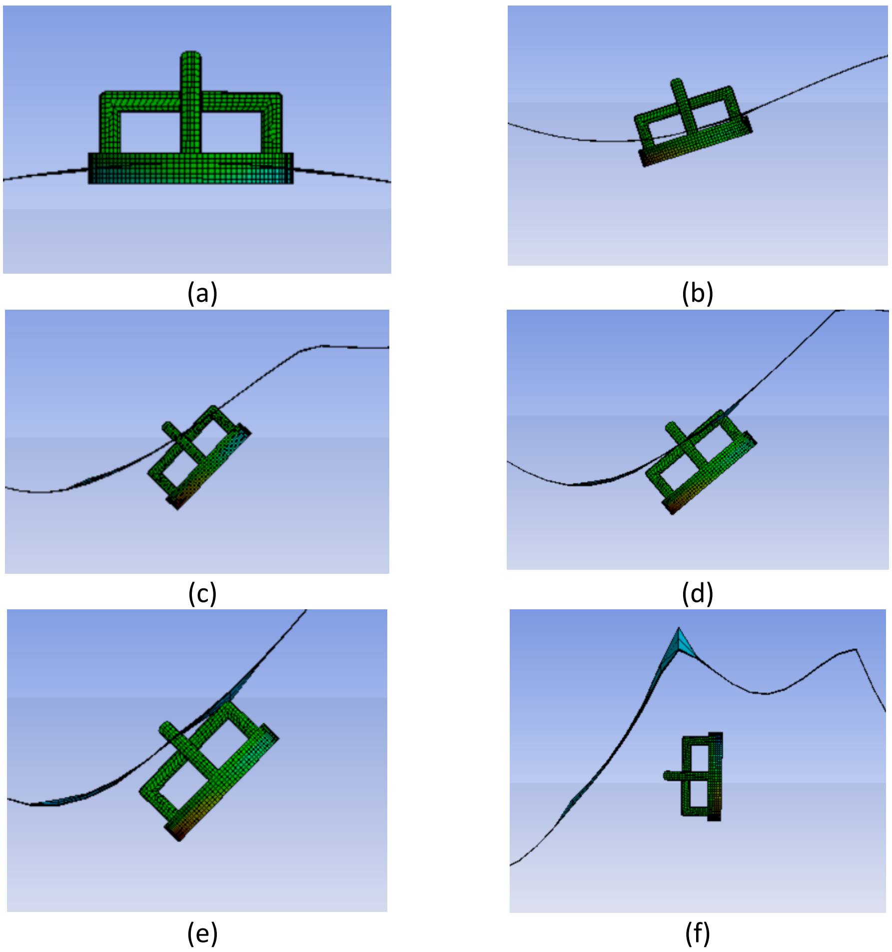

Fig. 4. Floating Buoy Stability at a) 0.2 m, b) 0.4 m, c) 0.6 m, d) 0.7 m, e) 0.8 m, and f) 1.0 m Wave Amplitude

4. Conclusions

In conclusion, developing a design of floating buoy as a wave energy harvester for coastal area was successful. This research was aimed to design and analyse the floating buoy as a wave energy harvester for coastal area especially in Peninsular Malaysian coastal conditions. The floating buoy design utilized the same configuration as the previous research because the configuration from prior tests had demonstrated its capacity to generate power in Peninsular Malaysia coastal circumstances. Besides, it can be concluded that the floating buoy design can withstand the coastal conditions in Peninsular Malaysia. This is based on the successfully conducted analysis in the CFD commercial simulation software. The analysis reported that the floating buoy is considered stable until a 1.0 m wave amplitude with 3746.6 Pa pressure is applied. Overall, this research is significant as a prospect for ocean-based electricity generation, particularly in Malaysia.

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