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Very Large Floating Structure with Stabilized Buoyancy Control Device for Photovoltaic Application

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Abstract: The increase in the global population is speculated to set a similar trend in the energy sector. However, the conventional approach of energy derivation had remained unchanged for more than a century and is causing anthropogenic pollution and climate change. Various sustainable alternative of renewable energy particularly solar energy has been developed and implemented as a part of the global effort to gradually decommission the usage of fossil fuel and in turn, reduce carbon footprint to overcome adverse environmental impacts. Nevertheless, it was reported that in 2018, only 0.37% of total energy used globally is powered by solar energy. Photovoltaic by itself is not feasible enough due to the magnified requirement of land for the installation of the modules, therefore, one of the solutions for the above statement is floating photovoltaic. However, the structure for floating photovoltaic are also restraint by certain limitation which includes but not limited the impact of tidal wave and the salinity of the sea water which will promote structural and mechanical degradation. Characterisation of the relationship between the stability of very large floating structures corresponding to the volumetric displacement of the buoyancy control device will be the focal point of this research. The significance of tidal wave impact will be empirically assessed based on a scaled-down model of buoyancy control device integrated very large floating structure by manipulating the buoyancy of buoyancy control device assisted structure to structure without buoyancy control device under a controlled environment. The fluctuation of the buoyancy control device can be reduced by up to 99.65% when tested against the highest configuration of wave transducer by displacing only 50% of air with water and neutral buoyancy is achieved up to almost 100% when the buoyancy control device is completely filled with water and total submergence is achieved.

Keywords: Buoyancy Control Device, Floating Photovoltaic, Wave, Hydrology Setting

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1. Introduction

Humans have been relying on the combustion of fossil fuel for power generation since the first industrial revolution. The increase in the global population is speculated to set a similar trend in the energy sector. However, the conventional approach of energy derivation through natural resources such as crude oil, petroleum natural gas, and coal had remained unchanged for more than a century is causing anthropogenic pollution and climate change. It was reported that as of 2018, 95.94% of the energy used by the global human population is powered by non-renewable resources as shown in Figure 1.1 [9]. The impacts of harvesting energy through the approaches resulted in a drastic increase in greenhouse gases emission such as carbon dioxide which had been approximated to rise by 35%, and methane by 148% since the first industrial revolution [7]. An increase in the global average surface temperature of 0.6 to 0.9 degrees Celsius is observed and the rate of temperature increase has doubled in the latter half of the century [6]. Measures must be taken to stop climate change before it reaches the point of no return, the world must reduce 70% of the carbon emission by 2050 [5] and the adoption of renewable energy is a necessity in this effort to curb the effect of global warming and climate change.

Photovoltaic by itself is not entirely feasible due to the magnified requirement of land for the installation of the modules, therefore, one of the solutions for the above statement is floating photovoltaic. However, the structure for floating photovoltaic are also restraint by certain limitation which includes but not limited the impact of tidal wave and the salinity of the sea water which will promote structural and mechanical degradation. The aim of this research is to investigate the significance of buoyancy control device on stabilizing very large floating structures in different hydrology settings and characterise the relationship between the volumetric displacement of the buoyancy control device and the stability of the very large floating structure.

Table 1: Summary of comparison between FPV and GMPV

	Floating Photovoltaic	Ground-Mounted Photovoltaic
Efficiency	28.20 ± 7% (Abdul Majid et al., 2014)	24.40 ± 7% (Franklin et al., 2016)
Requirement of land	Require minimal or no land	Require a large amount of land for landed PV
		Require minimal amount of land for building integrated PV
Mechanical and structural lifespan	Decreased lifespan for offshore FPV due to high salinity of seawater, or tidal wave, or combination of both	Long life span.
	Require further exploration for FPV at river, lake, and reservoir.	
Installation procedure	Tedious installation due to underwater cabling and facilities	Simpler installation relative to FPV
Environmental impact	Reduction of evaporation loss	Does not have a positive impact on evaporation lost
Implementation cost	Lower cost due to no or minimal requirement of land.	Higher cost due to the requirement of land.

Very large floating structure when integrated with stabilised buoyancy control device is capable of buoyancy alteration which could be developed for diversified engineering application including photovoltaic platform, wind-powered energy generation platform [2], oil and gas drilling platform [4], offshore hydrocarbon storage facility [3] and even residential real estate. The correlation of critical parameters such as the structure fluctuation and submergence depth of the floating platform shall be pinpointed to characterise the relationship between the volumetric displacement of the buoyancy control device and the stability of a very large floating structure before being applied in practical industrial applications.

2.0 Methodology

Research Flowchart

Preliminary studies which comprised of background probing as well as defining problem statement, purpose statement, hypotheses, research questions, objectives, scopes, and significance of this research were driven primarily by explicating relevant scientific literature particularly on the subject of the photovoltaic, very large floating platform and buoyancy control device

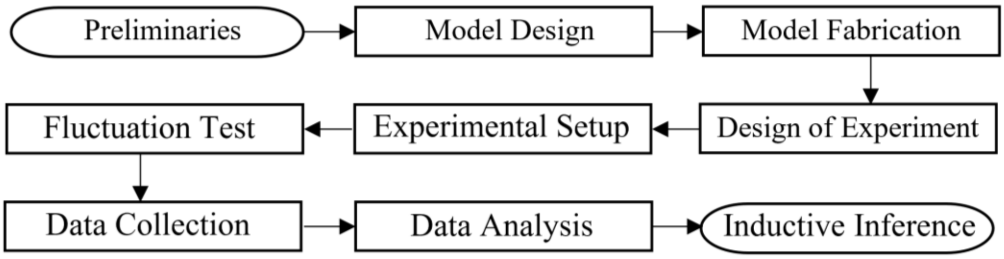

Figure 1: Research Flowchart

2.1 Model Design

The model of the buoyancy control device was designed with the dimension of 350mm x 250mm x 80mm as shown in Figure 2 by using Autodesk Fusion 360 with the intention to complement Hydrelio modular panel for floating photovoltaic structure (Patent number US9849945B2) by Ciel et Terre International as shown in Figure 3. The buoyancy control device was fabricated with a fully sealed external structure that acts as an isolated vessel integrated with a submersible water pump and a counterweight.

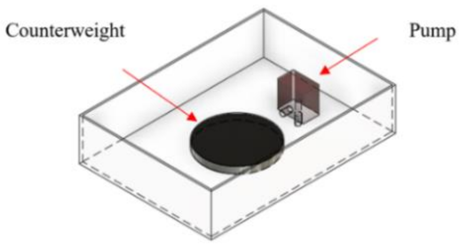

Figure 2: Isometric View of Buoyancy Control Device

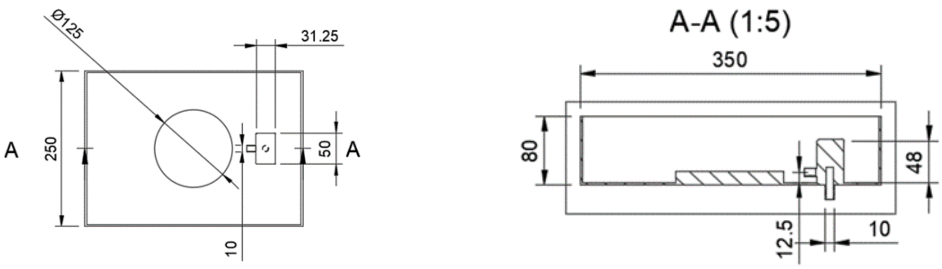

Figure 3: Cross sectional (left) and Top (right) View of Buoyancy Control Device

The buoyancy control device was designed to be installed within the boundary as outlined in the dotted box as indicated in Figure 4 for enhancement and improvement of the existing Hydrelio® Classic model (Patent number US9132889B2).

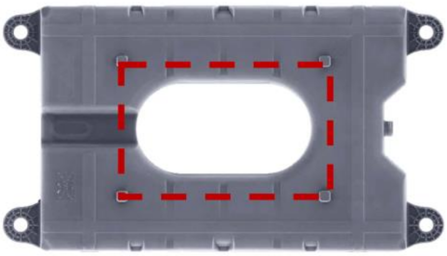

Figure 4: Ciel et Terre Hydrelio® Classic (Patent number US9132889B2)

The submersible water pump is used to displace air within the buoyancy control device and therefore alter the density of the ballast tank. The density of the buoyancy control device was manipulated by altering pump operating duration to induce water to displace the air within the vessel.

2.2 Model Fabrication

The isolated vessel of the buoyancy control device is fabricated by using Acrylonitrile butadiene styrene, an economic thermoplastic that exhibits high chemical resistance [1]. Acrylonitrile butadiene styrene also displays high tensile strength, high impact strength and excellent performance in low and high temperature (*Singh & Singh, 2020*).

2.3 Design of Experiment

After the buoyancy control device is fabricated, standard submersible water pump and power source are then assembled by using adhesive, and sealant is then applied to seal off any potential leakage prone points in order to ensure that the system is properly enclosed. The critical components of the submersible model with buoyancy control which comprised of motors and power systems are designed and set up to comply with BS-ISO-21173-2019 and BS-EN-ISO-19904:1-2019 standards. The submersible model is assessed in terms of leakage and holding time. The stability is also improved by attaching a 1200g weight to represent the average mass per unit area of commercial solar panel [10]

Figure 5: Assembled Buoyancy Control Device Model

2.4 Experimental Setup

The apparatus is set up as shown in Figure 3.8 whereby the wave transducer is used to mimic the wave pattern of any water bodies which includes the ocean, river, lake, pond and even a pool as the speed can be manipulated by changing the voltage of the wave transducer motor. The buoyancy control device that is built into the model is used to manipulate the buoyancy of the model. The model starts at positive buoyance where the density of the model is lower than the density of water. The water pump is then used to introduce water into the model until the density of the model approximates the density of water to achieve neutral buoyancy and negative buoyancy by pumping water into the tank until the density of the model exceeds the density of the water. After the test is completed, water is removed from the buoyancy control device for the preparation of the next case. For each case from the lowest wave transducer configuration to the highest wave transducer configuration, the magnitude of fluctuation of the model is pinned point by using a laser range finder. This is done to produce a graph to compare the magnitude of fluctuation of the model for the three cases across different voltage output.

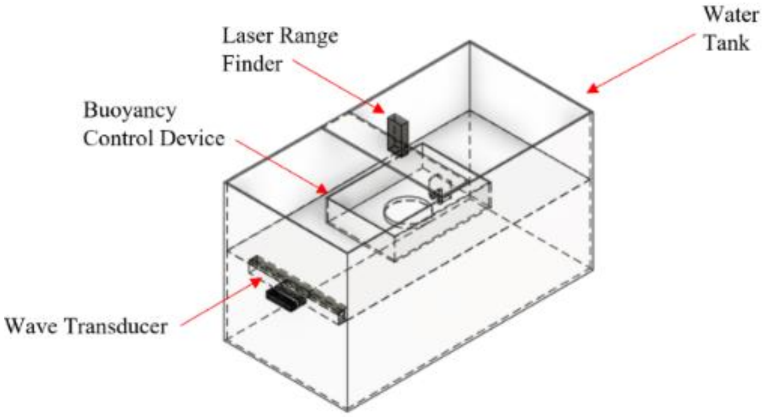

Figure 6: Isometric View of Experimental Setup

2.4.1 Wave Transducer

Before initiation of the experiment, linearity and bias study is carried out to determine the accuracy and sensitivity of the measuring gage. A BS 4372:1968 calibrated rule is used to benchmark the accuracy and consistency of the laser range finder. A datum is set, and several points were plotted from the datum. The distance between the points from the datum is labelled. The distance between the plotted points and datum is remeasured using laser range finder and the data is recorded and tabulated as shown in Table 3.2

Table 2: Voltage, Amplitude, Frequency, Wavelength and Wave speed corresponding to Configuration

Configuration	Voltage (V)	Amplitude (mm)	Frequency (Hz)	Wavelength (cm)	Wave speed (m/s)
1	5.5	15mm	78/60=1.3	15	0.195
2	10.0	18mm	79/60=1.3	20	0.260
3	16.5	22mm	78/60=1.3	25	0.325
4	22.0	27mm	78/60=1.3	30	0.390
5	27.5	31mm	79/60=1.3	35	0.455
6	33.0	34mm	78/60=1.3	40	0.520
7	38.5	39mm	78/60=1.3	45	0.585
8	44.0	43mm	78/60=1.3	50	0.650
9	49.5	47mm	79/60=1.3	55	0.715
10	55.0	51mm	78/60=1.3	60	0.780

The calibrated range finder reading is obtained by subtracting average error from the initial range finder reading. The difference of magnitude between calibrated rule and calibrated range finder is obtained by subtracting calibrated rule reading from calibrated range finder reading.

Table 3: Computed data of Calibrated Rule and Laser Range Finder

BS 4372:1968 Calibrated Rule Reading (mm)	Initial Range Finder Reading (mm)	Difference (mm)
50	138	88
100	186	86
150	225	75
200	282	82
250	335	85
300	386	86
	Average error	83.67

The r-squared value of the calibrated laser range finder is recorded at 0.9995, which is extremely close to 1 and can be concluded that the calibrated laser range finder is linear. This study also confirmed that the calibrated laser range finder is not bias.

Table 4: Computed data of Calibrated Rule and Calibrated Laser Range Finder

BS 4372:1968 Calibrated Rule Reading (mm)	Calibrated Range Finder Reading (mm)	Difference (mm)
50	54.33	4.33
100	102.33	2.33
150	141.33	8.67
200	198.33	1.67
250	251.33	1.33
300	302.66	2.66

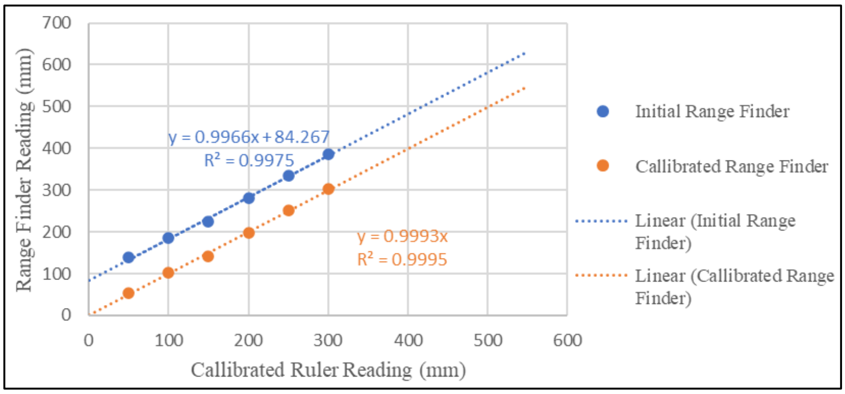

Figure 7: Linearity and Bias of Laser Range Finder Benchmarked against Calibrated Rule

3. Results and Discussion

The BCD distance relative to laser range finder was also studied against percentage of water displacement and is presented in Figure 8. It was observed that the magnitude of buoyancy control device oscillation from 0 to 18 seconds relative to pump operating duration increased with the increment of amplitude, wavelength and wave speed corresponding to the input voltage supplied to the wave transducer. During this period, the buoyancy control device is composed of 0 to 40 percent of water and is in a state known as positive buoyant where the density of the buoyancy control device is lower than that of the surrounding liquid.

It was inferred from Figure 8 that when cavity of the buoyancy control device was partially displaced and approaches neutral buoyancy, the magnitude of the oscillation decreases and first plateau region was observed on all operational conditions simulated in this study. As water was continuously added and cavity was filled to approximately 45%-55% of the vessel capacity, the buoyancy control device achieves negative buoyancy and starts to descend until it reaches the bottom where the second plateau region is observed.

However, when the ratio of water exceeds the stated limit of 40 to 55 %, the buoyancy control device started to descend and touches the bottom as the ratio of water exceed 85 %. The buoyancy control device is considered to be in negative buoyant where the density of the model exceeds the density of the surrounding liquid.

The first plateau region is a significant region where the structure is able to achieve stability while retain its position which is close to the surface water where the penetration of sunlight is high and is able to harvest slightly decreased or similar amount of sunlight relative to that when the structure is at the surface of water. While the structure is slightly submerged below the water surface, the structure will also be protected against direct sunlight with should decrease the core temperature of the solar panel which might increase the efficiency of the photovoltaic module.

Meanwhile, the second plateau region also display certain crucial aspect. This study shown that the oscillation of the buoyancy control device can be reduced by up to 94.44 % when the structure achieves total submergence. Total submergence is required in certain scenario where the surface debris is abundant, and the frequency of tidal wave is high which might lead towards structural and mechanical damage upon impact.

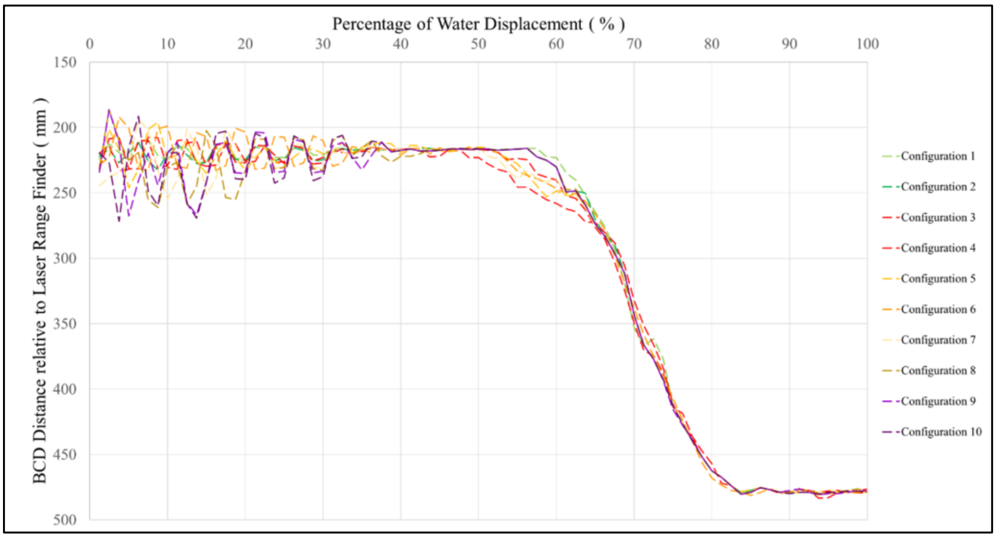

Figure 8: Graph of BCD Distance Relative to Laser Range Finder Against Percentage of Water Displacement

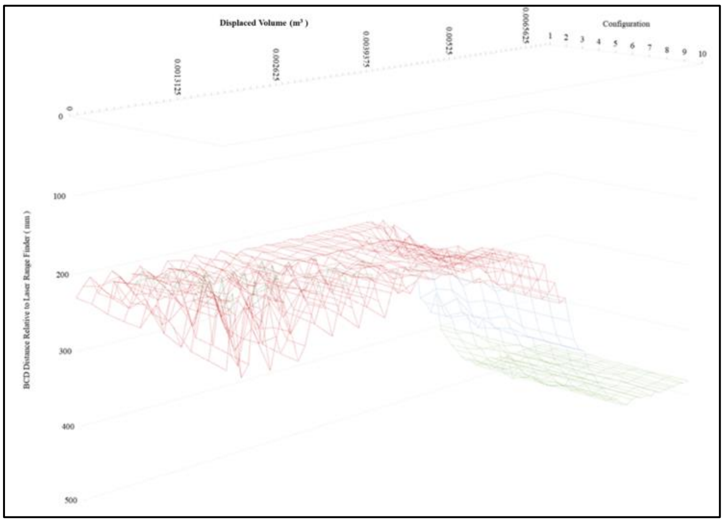

Figure 9: 3-Dimensional Graph of BCD Distance Relative to Laser Range Finder Against Water Displacement corresponding to different Configurations

The BCD fluctuation is also studied against percentage of water displaced and is presented in Figure 10. Higher configuration of wave transducer tends to set similar pattern in the fluctuation of the buoyancy control device. The fluctuation of the buoyancy control device can be stabilised by displacing the air with water to achieve neutral buoyancy and negative buoyancy. The fluctuation of the buoyancy control device can be reduced by up to 99.65% when tested against the highest configuration of wave transducer by displacing only 50% of air with water. The fluctuation can be reduced by up to almost 100% when the buoyancy control device achieves total submergence. Several unexpected interceptions across multiple distinct trendline were observed. This could be the result of low laser range finder frequency where only 2 data is logged per second. More accurate trendline with no interception is expected with the deployment of a better measurement instrument with higher frequency, sensitivity, and accuracy.

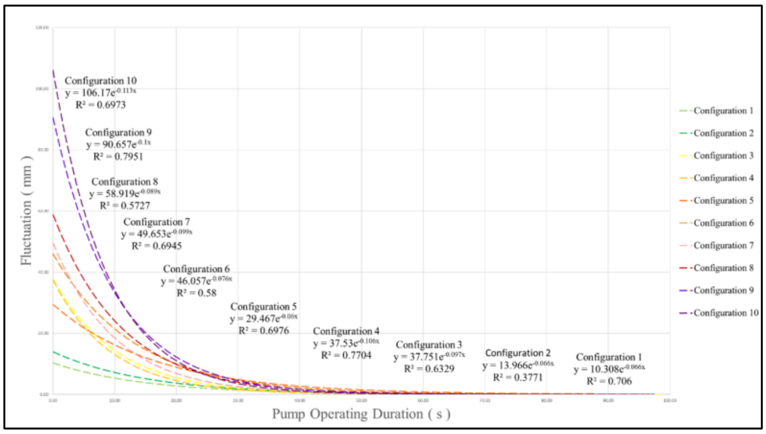

Figure 10: Graph of Fluctuation Against Percentage of Water Displaced

4. Conclusion and Recommendation

Solar energy while largely available, do have certain limitation. The photovoltaic platform is conventionally building integrated or ground mounted, thus requiring a large portion of empty space which hence deemed not viable due to the exorbitant cost and the land are usually conserved for other purposes which includes farming and developmental projects. Building integrated although is space and cost efficient, the power generated are way too less that it is not enough to support the building for daily usage. Floating photovoltaic on the other hand, require minimum or no land at all for the implementation. Floating photovoltaic despite the numerous benefits are also restricted by the types of floating platform.

In this study, a novel semi-submersible floatation device is proposed as a replacement for conventional support structure to minimise the damage that could potentially damage photovoltaic modules under unpredictable circumstances which often includes heavy storm especially during the Monsoon season in the Malaysian water. The implementation of buoyancy control device towards photovoltaic display extremely feasible characteristics which includes lower fluctuation that results in lower wearing of mechanical parts of the photovoltaic module under normal condition and could assist the photovoltaic module in partially submerging below surface wave to prevent any instant damage from debris during heavy storm.

The fluctuation of the buoyancy control device can be reduced by up to 99.65% when tested against the highest configuration of wave transducer by displacing only 50% of air with water and neutral buoyancy is achieved. The fluctuation can be reduced by up to almost 100% when the buoyancy control device is completely filled with water and total submergence is achieved. The buoyancy control device was tested and proven to be significant in stabilising floating platform under distinct hydrology setting. Laser range finder or similar instrument of higher frequency is recommended for future usage. The laser range finder used in this study is of 2Hz, with limited capability of only measuring 2 relative distances per second due to budget constraint. Hence, data obtained might not entirely represent the motion of the buoyancy control device under the influence of simulated wave.

The interception between the graphs of fluctuation against pump operating duration corresponding to wave transducer configuration are not bound to happen in theory as higher magnitude of wave should induce higher magnitude of fluctuation towards the buoyancy control device. However, the low frequency of the measuring instrument might not be able to procure the slightest change of motion of the buoyancy control device when the buoyancy control device achieve the highest and lowest point of oscillation. Measuring instrument of higher frequency should theoretically provide a better understanding regarding the full range of motion of the buoyancy device, therefore providing a better glance at the fluctuation of the buoyancy control device.

While the correlation of fluctuation corresponding to pump operating duration is clearly defined in this study, the energy efficiency can be further optimised by focusing on achieving neutral buoyancy in the future studies. This study had shown that by achieving neutral buoyant, the buoyancy control device experience reduction in the fluctuation that is similar to that of when the buoyancy control device is at negative buoyant and touches the bottom of the experimental setup tank. By inducing water into the buoyancy control device to achieve neutral buoyancy might reduce the total energy required to stabilise the entire platform and might even reduce the frequency of required maintenance.

Integration of air compressor and tension spring valve with the buoyancy control device could potentially allow the buoyancy control device to achieve both negative and positive buoyant by displacing air with water, and water with air. This will allow the platform to descend when the magnitude of wave is undesirably high and ascend when the condition of surrounding weather is in ideal state.

Apart from that, providing the very large platform with thermometer, barometer, hygrometer, and anemometer could potentially allow the platform to detect the temperature, atmospheric pressure, humidity and wind speed, hence providing data on possible magnitude of wave. Remote access capability might also be beneficial for the very large floating platform by providing the ability to transfer two way data, to and from control station hence allow remote control of the buoyancy control device and the very large platform.

The salinity of the water body should also be studied before the commission of the buoyancy control device and unique material might be required to reduce and prevent degradation towards the very large floating platform along with the buoyancy control device. Due to the limitation of the study duration and capability of the wave transducer, there is lack of data from the aspect of mechanical and structural wearing. Further evaluation is highly recommended before the commissioning of the buoyancy control device

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