Hydrodynamic Analysis of Multiple Geometric Designs of Float for Ocean Wave Energy Converter Using AQWA ANSYS

Tahir Mehmood Khan* and Muhammad Shahid Khalil

***Abstract*—This paper illustrates the hydrodynamic analysis performed on three different geometries of floats used in Ocean Wave Energy Converter (point absorbers). The basic aim of performing this analysis is to find out the most suitable geometry out of the three floats that can capture the maximum amount of ocean wave energy. Surface Force on the floats is calculated using the results of hydrodynamic analysis, which tells us which geometry of the float is more efficient. The boundary conditions used for performing this analysis are the average wave data of Pakistan. The waves are assumed to be sinusoidal and wave height is taken 1m. This paper also discusses some potential location in Pakistan for installing WEC. Modeling of the floats is done on CREO Parametric and hydrodynamic analysis is performed on AQWA module of ANSYS. The analysis results propose that the tapered cylinder type float absorbs the maximum amount of wave energy.**

***Index Terms*—Hydrodynamic, Wave Energy Converter (WEC), Wave Energy, Surface Force, Efficient, CREO Parametric, AQWA ANSYS, Potential, Boundary conditions.**

I. Introduction

The rapid development in global economy and industry has boosted the energy demands of the world, which will be on the rise for the foreseeable future. According to a study it has been estimated that by 2040 the global energy consumption will approximately increase to about 30% higher than that in 2010. The generation of electricity will also be more than 40% of the energy consumption [1,2]. It is also a realization that these traditional resources, such as fossil fuels, are becoming scarce. The changes in environment and the high levels of CO2 are shifting the global attention towards renewable and clean energy sources [3,4]. The past few decades have seen great efforts in the advancements of alternative energy sources such as solar, wind and nuclear [5]. The idea of production of energy from waves has been around for quite some time now. One of the earliest indications of utilization of ocean wave energy is the use of it to move mills in thirteenth century China, however the first presentation was obtained in France by Girard in 1799.

One of the first milestones in this field was by Yoshio Masuda who developed a navigation buoy which was powered by wave energy, it also consisted of a turbine. This later came to be known as an oscillating water column (OWC). In the late 1970s, during the oil crisis, researchers and universities focused their efforts on wave technology. During this rise in oil prices many researchers such as Stephen Salter and American Michael E. McCormick pioneered this technology [6]. Governments and private bodies began to offer help, but in the 80s the fall in oil cost made a significant reduction in the funding. This brings us to today where due to energy crisis and spreading awareness or the environment has seen this technology to re-emerge. Wave energy conversion is environmentally benign as all the impacts occur only during the installation phase and the construction of the structures. However, once operational, its eco-friendly and does not produce any greenhouse gases. Conversely it has positive impact on environment as the underwater infrastructure serves as artificial reef habitat to the native sea life. Along with all the environmental advantages wave energy conversion has many technical advantages over other renewable sources of energy. The major drawbacks of other renewable sources of energy like wind and solar energy is their unpredictability, on the other hand wave activity is far more predictable reducing the need of spinning reserve [7].

II. Problem Statement

The most important component of any ocean wave energy conversion device is the floating unit. The floats determine the power output of the WEC devices [8]. As floats are the part that are in direct contact with the ocean waves, so they heavily influence the stability, power absorption, weight, and cost of the WEC devices. In this regard it is of prime importance to select the shape of the float that is most suitable for a certain location having a unique pattern of waves. The shape of the float determines how it will behave when it faces the ocean waves [9]. Choosing the best shape increases the overall efficiency of the system. It also makes the whole system cost effective to install as one requires lesser number of floats to capture more wave energy [10]. Performing a hydrodynamic analysis on the floats help in determining the amount of wave energy that can be captured by the float in terms of surface forces, as there has not been any significant efforts made in this regard. AQWA ANSYS will be used for simulation purposes to compute the surface force on three different shapes of float. These values of force will be used to determine the amount of electric power in KW that can be produced theoretically by using the three shapes of floats.

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1. Mechanical Engineering Department, UET Taxila, Pakistan
*tahirmehmoodkhan7@gmail.com

III. Modeling the Floats

The float geometries are modeled using the 3D modeling software CREO Parametric 2.0. The dimensions of the floats are determined based on available wave potential in Pakistan. Following are the three selected geometries for floats.

Tapered Cylinder Float

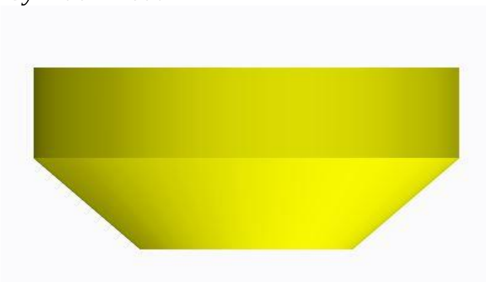

Fig 1: Side view of Tapered cylinder float

Bulb type float

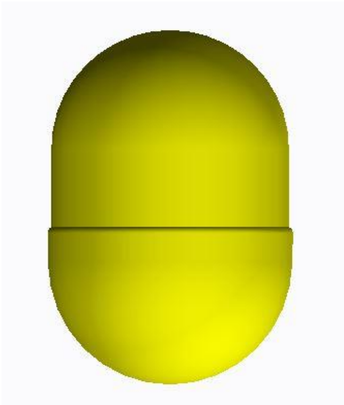

Fig 2: Side view of Bulb type float

Disc type Float

Fig 3: Side view of Disc type float

The dimensions of the floats are set to reduce the effects of the reflection and refraction so that uniformity of waves reach the floats. Since the force exerted on the floats is the Cartesian product of the effective area of the floats and the imperativeness of the waving, the diameter in this case has been selected so that the surface of the float uniformly experiences the acting wave pressure. A float with very large diameter is not capable of absorbing full potential of the waves, also as its size is increased the weight also increases reducing the maximum amplitude in case of shortstop wave wavelengths. The buoy with very small diameter also cannot absorb maximum energy in case of long wave wavelengths as it will not be able to fit on the full wave and a portion of the energy will not come in contact with it [11].

All the dimensions of the floats are in meters (m), mass in Kilograms (kg).

TABLE I
Tapered cylinder float dimensions

Name	Dimension
Upper diameter	4.00m
Lower diameter	2.00m
Height	3.00m
Chamfer	45°
Mass	1000kg

TABLE II
Bulb type float dimensions

Name	Dimension
Upper diameter	3.80m
Lower diameter	4.00m
Height	4.50m
Mass	1000kg

TABLE III
Disc type float dimensions

Name	Dimensions
Upper diameter	4.00m
Lower diameter	3.80m
Height	2.50m
Mass	1000kg

IV. Meshing of Floats

The floats that we used are mostly curved shape and are simple geometries so, we used tetrahedral mesh type for all the three geometries. Tetrahedral meshing is best suited for less complex geometries with major portions as curves [12]. The element size we used is 5mm. Lowering the element size below 5mm had no significant effect on the result but it increased the processing time. So, for efficient use the resources the element size of 5mm was selected. The number of elements for Tapered cylinder, Bulb type and Disc type float are 15489, 16137 and 14903, respectively. The results of tetrahedral mesh on the floats were very impressive and are shown in Fig 4 to 6.

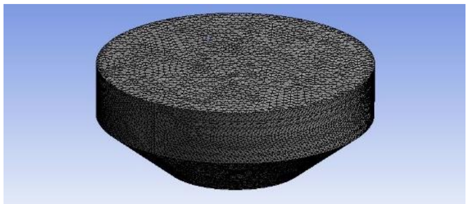

Fig 4: Tetrahedral Mesh of Tapered Cylinder Float

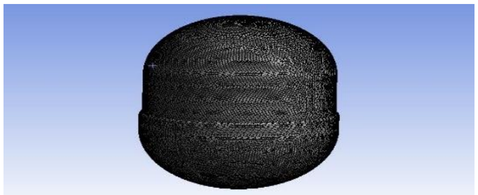

Fig 5: Tetrahedral Mesh of Bulb type float

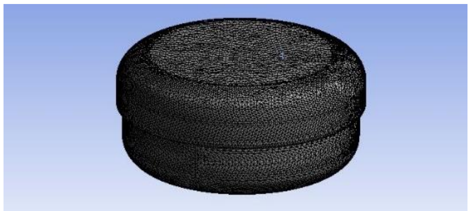

Fig 6: Tetrahedral Mesh on Disc type float

V. HYDRODYNAMIC ANALYSIS

After finalization of the design and dimensions, the next step is to perform the hydrodynamic analysis on the floats. For hydrodynamic analysis AQWA module of AYSYS software was used. AQWA provides us with the options to simulate wave condition according to the average wave condition of Pakistan by inputting the boundary conditions. The only assumption used in wave simulation is that the waves are sinusoidal in nature, this is an ideal condition. Following are the basic steps performed in the hydrodynamic analysis.

A. 3D Modeling of the floats:

3D models of all the three floats are designed on CREO Parametric 2.0. The color of all the floats in yellow. The model files are saved as .prt files. The main modeling window of CREO Parametric is shown in Fig.7.

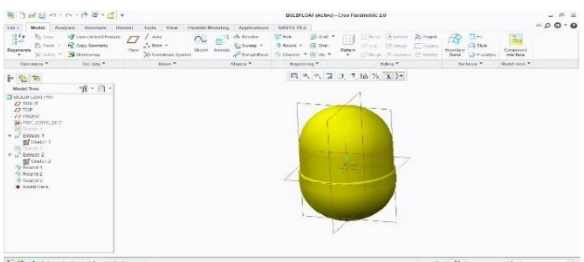

Fig 7: Main modeling window of CREO Parametric 2.0.

A. Setting up the float in ANSYS:

In the ANSYS Workbench main window hydrodynamic analysis is selected. Now the first step is to import the 3D model of the float as shown in Fig 8. then, we must apply slice to the float to differentiate the floating part and the submerged part.

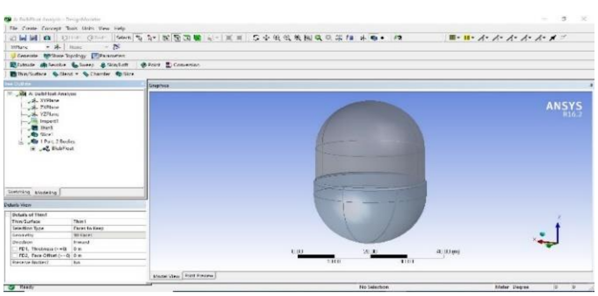

Fig 8: ANSYS design modeler window showing slice on Bulb type float

Model and Wave parameters for Analysis:

Next step in the analysis is to set the model parameters. In the analysis water depth of 100m, and volume size in X and Y direction were used as 500m. Now the wave parameters in the analysis section were assigned. Wave parameters include wave direction, wave frequency, ranges, amplitude, wave height as shown in Fig 9. In the analysis, the waves are assumed to be sinusoidal, frequency of waves is 0.2 Hz, wave interval is 45°, wave range is 180-180 and wave height is kept as 1m.

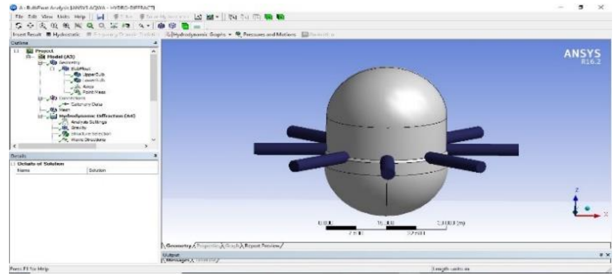

Fig 9: AQWA Solver window showing wave force on Bulb type float

Solving the Analysis:

After setting all the parameters, analysis was performed. A small window popped-up showing the real time progress of the analysis. Any faults or errors will also appear in this window. On successful completion of analysis, multiple solution could be run to find the desired results.

VI. SIMULATION RESULTS

After the successful completion of the hydrodynamic analysis now we can extract different type of results. Our main aim is to calculate the force on the upper surface of the floats so that we can find out which shape of the float absorbs the maximum amount of wave energy. The force on the surface of the float can be further utilized and converted to electric power. Simulation results are shown in Fig 10 to 12.

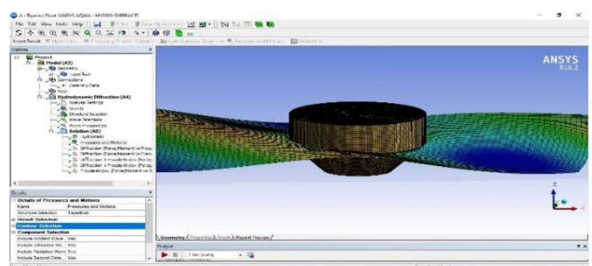

Fig 10: AQWA Solver window showing Tapered float simulation

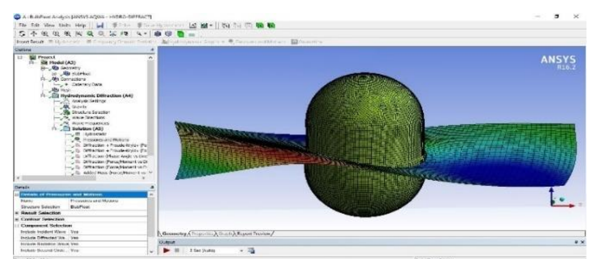

Fig 11: AQWA Solver window showing Bulb type float simulation

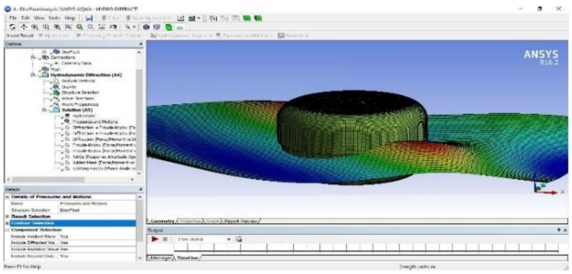

Fig 12: AQWA Solver window showing Disc type float simulation

VII. EXPERIMENTAL FINDINGS

Performing the hydrodynamic analysis on the three floats successfully means that we can now compare the results for all the three floats to find out the float which can absorb the maximum amount of wave energy. For this purpose, we used the numerical values of Diffraction + Froud-Krylov force from the analysis results for all the floats at different wave heights and compared them with help of graphs.

TABLE IV
Surface force for Tapered cylinder float with change in wave height

Significant wave height (meter)	Tapered cylinder float (Newton/m)
0	6.7041397
0.1	103741.3
0.2	315162.8
0.3	628471.4
0.4	934168.1
0.5	1326971.6
0.6	1534798.8
0.7	1853258.2
0.8	2010835.6
0.9	2468368.1
1.0	2620944.5

From the date shown in above table it is clear that the surface force increases as the wave height increases. A graph is plotted below based on this data.

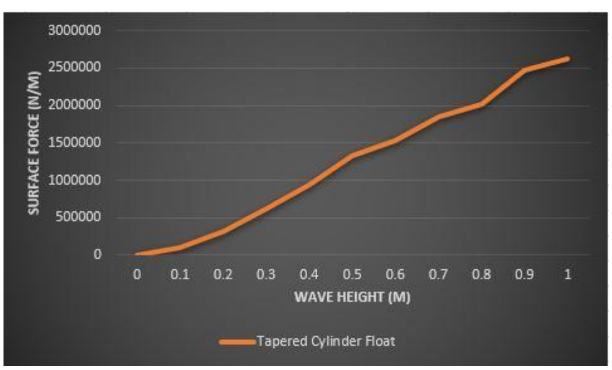

Fig 13: Surface force vs wave height for Tapered cylinder float

In Fig 13 on X-axis is the wave height in 'meters' and on Y-axis is the surface force in 'N/m'. Surface force is directly proportional to the change in wave height.

TABLE V
Surface force for Bulb type float with change in wave height

Significant wave height (meter)	Bulb type float (Newton/m)
0.0	3.7798458
0.1	101563.1
0.2	238174.3
0.3	513394.1
0.4	724638.4
0.5	1038914.6
0.6	1389589.9
0.7	1463273.7
0.8	1684381.4
0.9	1841369.6
1.0	2087813.3

From the data shown in above Table V we can clearly see that the surface force value increases with the increasing wave height, but these values of surface force are smaller as compared to the tapered cylinder float.

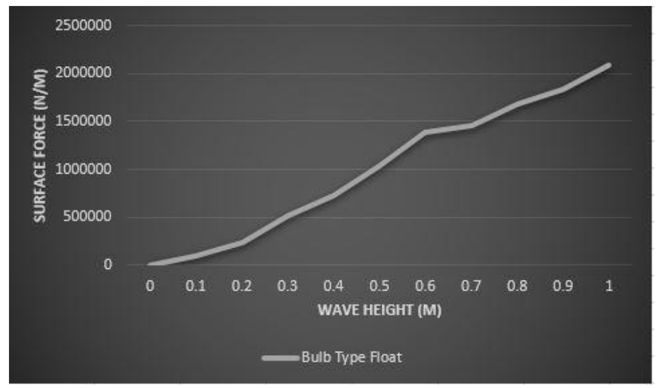

Fig 14: Surface force vs wave height for Bulb type float

In Fig 14 on X-axis is the changing wave height and on Y-axis is the absorbed surface force. The graph for the bulb type float is also linear, this shows that the surface force absorption increases with increase in wave height, but these values are smaller as compared to the Tapered cylinder float.

TABLE VI
Surface force for Disc type float with change in wave height

Significant wave height (meter)	Disc type float (Newton/m)
0.0	3.479571
0.1	103423.4
0.2	247181.7
0.3	582186.3
0.4	793473.3
0.5	948786.4
0.6	1142582
0.7	1325650
0.8	1413819
0.9	1781459
1.0	1999583

From the above table it is clear that the surface force value is increasing with the increase in wave height, but these values are small as compared to Tapered cylinder and Bulb type floats.

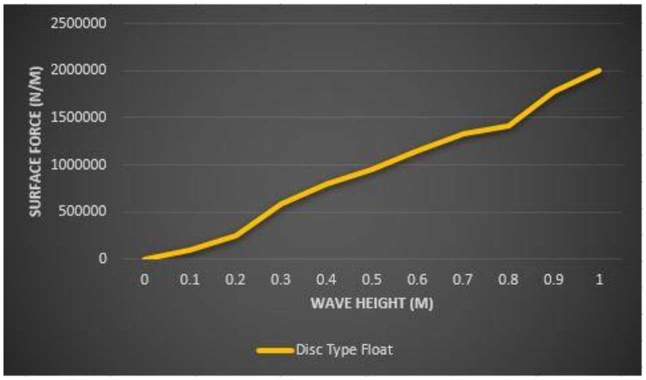

Fig 15: Surface force vs wave height for Disc type float

In Fig 15 on X-axis is the wave height and on Y-axis is the absorbed surface force. The values of surface force indicate that the disc type float is the least efficient as compared to tapered cylinder and bulb type float.

TABLE VII
Absorbed forces on the float surface with change in wave height.

Significant wave height (meter)	Tapered cylinder float (Newton/m)	Bulb type float (Newton/m)	Disc type float (Newton/m)
0.0	6.7041397	3.7798458	3.479571
0.1	103741.3	101563.1	103423.4
0.2	315162.8	238174.3	247181.7
0.3	628471.4	513394.1	582186.3
0.4	934168.1	724638.4	793473.3
0.5	1326971.6	1038914.6	948786.4
0.6	1534798.8	1389589.9	1142582
0.7	1853258.2	1463273.7	1325650
0.8	2010835.6	1684381.4	1413819
0.9	2468368.1	1841369.6	1781459
1.0	2620944.5	2087813.3	1999583

We can see from the results that the tapered cylinder float has the maximum values of force in all wave heights and these values are considerably higher than the other two floats. While bulb type and disc type floats are very much similar. Disc type float has higher value of diffraction and Froud-Krylov force than bulb type float at the midpoint of the wave height (0.5m) but its value decreases slightly than the bulb type float as the wave reaches its full height (1m). Plot shown in Fig 17 makes it easy to compare the values of all three floats. On X-axis is the wave height in meters and on Y-axis is the Surface force in N/m.

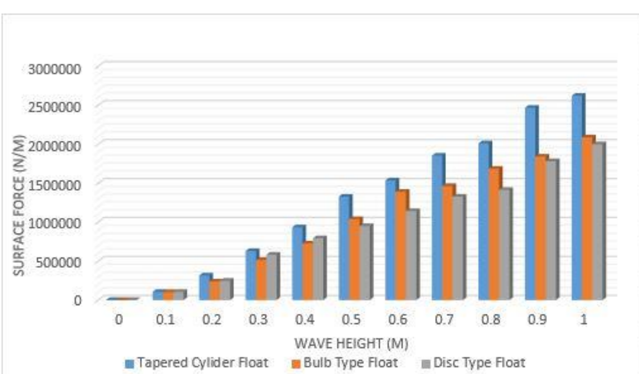

Fig 16: Graph showing Froud-Krylov force with change in wave height

VIII. Electric Power Calculation

Ocean wave energy converters are mainly used for electricity production. As the float absorbs the ocean wave energy this absorbed energy is converted to rotary motion with the help of rack and pinion mechanism and the rotary motion is converted to electricity by means of an electric generator [13]. As this conversion is not the part of our research so we will only be using the numerical values of forces absorbed by the floats to convert into electricity theocratically. Doing this will give us the numerical values of electric power that can be theoretically produced using the three-float shape that we proposed. First the force is converted to mechanical horsepower. The conversion from force to horsepower is given equation 1.

$$1\text{ hp} = \frac{Newton\ .meter}{Second} \text{ x } 0.0013 \quad (1)$$

Using the conversion, we can calculate mechanical horsepower for all the value of forces for the three floats as the distance is 1m and time-period is 5 sec.

TABLE VIII
Conversion of float absorbed force to mechanical hp

Float Type	Tapered cylinder float (Newton)	Mechanical horsepower Hp
Tapered Cylinder	2620944	681.44
Bulb type	2087813	542.83
Disc type	1999582	519.89

Now, as we know that electric power is measured in watts so we can convert the values of horsepower to watts. The conversion of horsepower to watts is given in equation 2.

$$1\text{hp} = 745.7 \text{ watt} \quad (2)$$

Using this conversion, we can convert the values of horsepower calculated in the previous table to electric power.

TABLE IX
Conversion of float mechanical hp to Electric power in KW

Float Type	Mechanical horsepower Hp	Electric Power Watt	Electric Power Kilo watt
Tapered Cylinder	681.44	508149.80	508.14
Bulb type	542.83	404788.33	404.78
Disc type	519.89	387681.97	387.68

IX. Conclusions

This research allowed us to apply the theoretical knowledge and into experimentation. Tapered Cylinder type float produces 25% more electric power than the Bulb type float and 32% more than Disc type float. This work also allows us with an innovative way to tackle the problem of environmental pollution, power crisis currently in our country and provide an alternative to the current sources of power generation. The main design criteria for such a device are life of the device, required maintenance and practical installation of the device while keeping in mind the expensive working hours and the conditions at sea. Hydrodynamic analysis was performed to determine the wave energy absorption of the floats. This analysis can help us in developing a WEC that has an efficient float installed and can absorb the ocean wave energy efficiently. As installing an efficient float in a wave energy converter decreases the number of units to install for generation of a specific amount of electricity, so the production cost of such a power plant is significantly low. One of the main conditions of designing any power generation device is cost of energy production, the best commercial device is not always necessarily the most efficient one but one which is affordable and economical. In a developing country like Pakistan where such a resource is available, such research should be used on the commercial scale to accrue maximum advantage.

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