Investigation of Wave Characteristics with Rotor Type Water Wave Generator

Badhan Saha[1], Mazharul Islam[2], Abu Torab, Dewan Hasan Ahmed[3]

[123]Ahsanullah University of Science and Technology, Dhaka Bangladesh

E-mail: dhahmed.mpe@aust.edu

Abstract: Wave energy is the most available energy associated in deep water seas and oceans. Therefore, many attempts have been applied to capture these energies. This paper describes the design, construction and testing of water wave flume. The water wave flume contains an electromechanically driven rotor type wave maker to generate water wave powers. The waves are constructed by different sizes and arrangements of blades which are connected to the rotor. The rotor is driven by an ac motor to generate wave. At the end of the tank a force measuring device is attached opposite to the rotor to measure the thrust of the wave. Experimental results are validated with available literature and wave theory. The results also show that the width of the blade play major role in generating wave sizes including frequency, amplitude and the power. Wider blade displaces much water to generate wave but reduces the blade speed.

Keywords: Water wave flume; wave power; wave height; wave frequency.

INTRODUCTION

Among the renewable energy resources, ocean energy is the one, in sufficiency around the universe. The ocean wave energy in the form of surface gravity waves are formed due to the imbalance between gravitational force and shear due to wind. Water waves are always present on the ocean surface as long as there is wind blowing over the ocean, thus offering an infinite source of wave energy. The power flow in the waves is up to five times compared to the wind that generates the waves, making wave energy more persistent than wind energy. The common factors that determine the characteristics of the wind-generated waves are the distance, the wind velocity over which the wind is in contact with the sea and for how long they are in contact. As the waves travel from deep to shallower water region, certain amount of energy (potential energy + kinetic energy) dissipates, particularly in the breaking zone. The level of dissipation as well as an increase in its amount depends on several parameters, of which, the most important being the seabed friction, bathymetry, and presence of obstructions.

CHITKARA UNIVERSITY

Saha, B.
Islam, M.
Torab, A.
Ahmed, D. H.

Several reviews, chapters and pioneer books are available on water wave generator. However, Yoshio Masuda (1925-2009), a former Japanese navy officer, may be regarded as the father of modern wave energy technology, with studies in Japan since the 1940s. He developed a navigation buoy powered by wave energy, equipped with an air turbine which was in fact what was later named as a (floating) oscillating water column (OWC). These buoys were commercialized in Japan since 1965 (and later in USA). Later, in Japan, Masuda promoted the construction, in 1976, of a much larger device: a barge, named Kaimei, used as a floating testing platform housing several OWCs equipped with different types of air turbines. Probably because this was done at an early stage when the science and the technology of wave energy conversion were in their infancy, the power output levels achieved in the Kaimei testing program were not a great success. Brown [1] carried out a study to estimate of surface wind speeds using satellite-borne radar measurements at normal incidence. Atlas et al. [2] constructed the grid based global surface stress fields from SEASAT scatter meter data and conventional meteorological data using a data assimilation method. Young [3] carried out an estimation of the Geosat altimeter wind speed algorithm at high wind speed. Offiler [4] carried out the calibration of ERS-1 satellite scatter meter winds.

Takahashi et al. [5] defined the development of wave energy extracting caisson breakwater in Japan. The wave energy extracting device is combined in the form of air chamber attached with an ordinary caisson. The dynamic pressure excited on the sloped front wall well compared with the theory of Goda (1985). The sliding tests on the caisson breakwater proved that sloped front wall have a higher stability than the other caisson types tested. It was inferred by Malmo and Reitan [6] that the natural frequency of an OWC system primarily depends on its front lip depth. McIver and Evans (1988) observed that the reaction of OWC system depends on the extent of the dynamic pressure and its excitation period, whereas, Zheng et al. [7] proved that flared harbour walls in an OWC enhanced its efficiency compared to the one with rectangular walls. Muller and Whittaker [8] tested a 1:36 physical model of the Isle of Islay to obtain the wave-induced pressures on the lip wall. It was observed that the suggestions given by the Coastal Engineering Research Center (CERC 1984) for the estimation of design pressures were conservative. Jayakumar [9] conducted experimental study on OWC caisson model and found that the wave forces on OWC caisson model were less than the conventional rectangular caisson when air damping inside the OWC model maintained is less.

Through a detailed experimental study on OWC, Thiruvenkatasamy and Neelamani [10] found that an increase in wave steepness causes a decrease in its performance in terms of its efficiency and for a/A (ratio of air hole area (a)

Investigation
of Wave
Characteristics
with Rotor Type
Water Wave
Generator

to plan area (A)) larger than 0.81 %, a considerable reduction in energy absorption capability of the device was reported. Ruo-Shan [11] reported that the experimental investigation on multi-resonant oscillating water column yields only 28.5 % of efficiency because of high-energy loss. Wang [12] studied analytically and experimentally the change in bottom slope in front of the shoreline mounted OWC model and observed that an increase in the slope of the bottom leads to a shift in the capture-width ratio at lower frequencies.

Sudheesh et al. [13] carried out the comparison of the NCEP re-analysis winds with the data of deepwater buoys to ascertain the accuracy of NCEP winds for a summer monsoon for north Indian Ocean. The result shows that NCEP winds match closely with buoy winds. However, Swail and Cox [14] used a state-of-the-art, third-generation wave model to evaluate the marine surface wind fields produced in the NCEP-NCAR reanalysis project. They found that storm peak wave height in extra tropical storms were systematically underestimated at higher sea states due to underestimation of peak wind speeds in major jets treak features propagating about intense extra tropical cyclones. In addition, in situ data were incorrectly assimilated and tropical cyclones were poorly resolved.

Ashlin et al. [15] presented a comprehensive review on the possible approaches that can make use of the OWC as part of breakwaters and coastal defence systems for the harbour formation. The concept of integration of OWC with breakwaters that can reduce the total cost significantly to bring forth economic security in project planning was highlighted. Zhang et al. [16] observed that the efficiency of OWC centred on a resonant frequency. This clearly shows the importance of phase lag between the dynamic excitation pressure and the corresponding air pressure being developed. Wilbert [17] have considered the parameters such as water depth inside the wave energy converter (d) and opening in the bottom of the wave energy converter (o) and, found that effective energy conversion capacity of OWC was found to be increasing with an increase in its bottom opening, o/d. It reached a maximum efficiency of 94 % closer to the natural frequency for o/d = 0.80. However, at the same time, the peak efficiency was found to shift towards the higher frequency with an increase in opening depth. Recently, the chamber bottom profile configuration (i.e., Flat, Circular curve, Slope 1 in 1 and Slope 1 in 5 bottom profiles) has been optimized by Ashlin et al. [15]. Faizal et al. [18] have found that in wave motion, the water particles are known to follow orbital paths. This orbital motion was studied and a five bladed Savonius rotor was built to extract energy from the orbiting particles. Experiments were performed on a rotor placed parallel to the incoming waves in a two dimensional wave channel by varying the frequency of the wave generator, which produced

Saha, B.
Islam, M.
Torab, A.
Ahmed, D. H.

sinusoidal waves. The rotor submergence below the mean level was varied. The flow around the rotor was studied with particle image velocimetry (PIV) measurements. Tutar and Veci [19] carried out experimental study on rotor type wave generator and found that placement of the rotor on the water surface and number of blades makes significant contribution on water wave energy. In another study Tutar and Veci [20] showed that the wave height and wave period along the submergible condition like shallow or deep water depth influence the wave energy conversion efficiency. However, the blade width and rotor rotation are the two issues which are not considered in their studies.

As derived by McCormick, within the sea waves there are two components of energy one of which is the potential energy and another one is the kinetic energy. The total energy for regular (sinusoidal) waves is

$$E = E_p + E_K = (\rho g H^2 \lambda)/8 \qquad (1)$$

Where, E_P = Potential energy

E_K = Kinetic energy

ρ = mass density of water

λ = the wave length

H = the wave height

The output power for deep water is also given as

$$P = (\rho g^2 H^2 T)/32\pi \qquad (2)$$

The purpose of this paper is to design and construct of a small water wave generator, which was built and instrumented with a limited budget, is described. The design feature and constructing methods are explained to investigate the general water wave properties and validate with general wave theory. The article is also tried to investigate the effect of the blade number, blade width and rotor rotation on wave formation and related energy outcome.

DESIGN AND CONSTRUCTION

The tank is designed so that it is capable of producing waves. The length of the tank is 16 ft (4.88 m), 4 ft (1.22 m) wide, 4 ft (1.22 m) high. The one side of the tank is constructed of 10 mm thick acrylic sheet which helps to examine the wave characteristics. A rotor type wave maker at one end of the tank can generate waves. The radius of the rotor is 6 inch (0.1524 m), a width of 32 inch (0.8128 m) and has three slots to which blades are attached of different arrangement. The rotor is driven by an ac motor through chain.

There are many researchers who worked on wave tank or flumes. With the general principle, water wave flume should not be too long or short in length,

width and height. The following issues need to be considered during the construction of a wave flume.

✓ The width of the flume or tank needs to be large for frictional effects to be negligible. It is suggested that wave widths be no shorter than 3 cm.

✓ The height should be such that the tank is capable of producing the desired waves. Both the still water level and wave height need to be considered in the flume's height dimension to ensure that no water spills over the tank while producing waves.

✓ The length of the tank allows at least four wavelengths to propagate prior to the waves reaching the energy dissipating structure at the end of the flume. This allows the waves to fully develop and evanescent modes, secondary waves that exist near the wave-maker due to its motion, to be not considered in the study area of interest. Long flumes also allow abnormalities that may exist in the wave motion to correct themselves.

There are normally 3 types of wave maker. They are

✓ Flap Type

✓ Piston Type

✓ Rotor Type

All the types of wave makers have advantages and disadvantages over each other. For example, piston type wave maker can be used for short wave while flap type can be introduced to make wave for deep water and rotor type can produce high torque even with low rpm. Different types of wave makers and their specifications are summarized in the Table 1.

Figure 1 and 2 shows the isometric views of the setup and the different views of constructed water wave flume respectively. The rotor is connected with a motor and the blades are placed over the rotor. Therefore, once the motor is on, the rotor starts to rotate as the chain is connected between the rotor and motor shaft. The movement of the blade initiates to displace the volume of water and wave is generated. The general pattern of the wave in the water wave flume is shown in Figure 3.

Table 1: Types of wave maker

Type of Wave Maker or Generator	Year	Dimensions of Tank	References
Piston type	1996	Length= 23 ft.-1/8 inch Width= 10 inch Height= 21-7/8inch	[21]

Saha, B.
Islam, M.
Torab, A.
Ahmed, D. H.

Type of Wave Maker or Generator	Year	Dimensions of Tank	References
Piston type	2004	Length= 14 meter Width= 25 cm Height= 50 cm	[22]
Paddle type Wave Maker	2004	Length= 10 meter Width= 890 mm Height= 300- 400mm	[23]
Flap type	2010	Length= 14 meter Width= 1 meter Height= 1.75 meter	[24]
Flap type	2010	Length= 3500 mm Width= 300 mm Height= 450 mm	[25]
Piston and hinged type	2015	Length= 72.5 meter Width= 2 meter Height= 2.5 meter	[15]
Flap type	2015	Length= 6 meter Width= 0.6 meter Height= 1 meter	[26]
Paddle type hydraulic Piston		Length= 35 meter Width= 0.9 meter Height= 1.4 meter	[27]
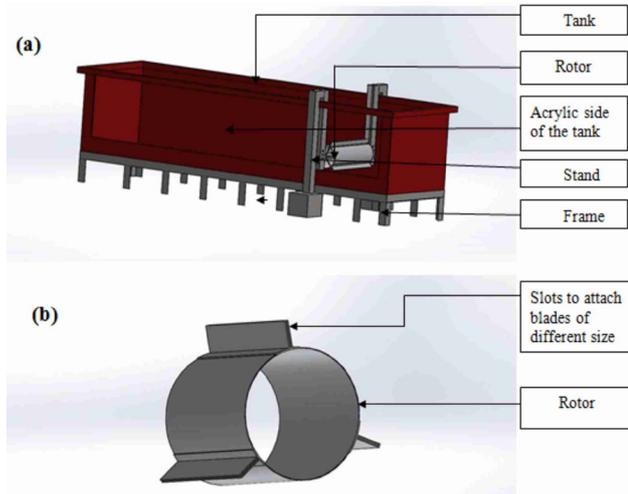
Figure 1: (a) Isometric view of the experimental setup,
(b) Isometric view of the rotor

Investigation
of Wave
Characteristics
with Rotor Type
Water Wave
Generator

Figure 2: Side view of the constructed water wave flume
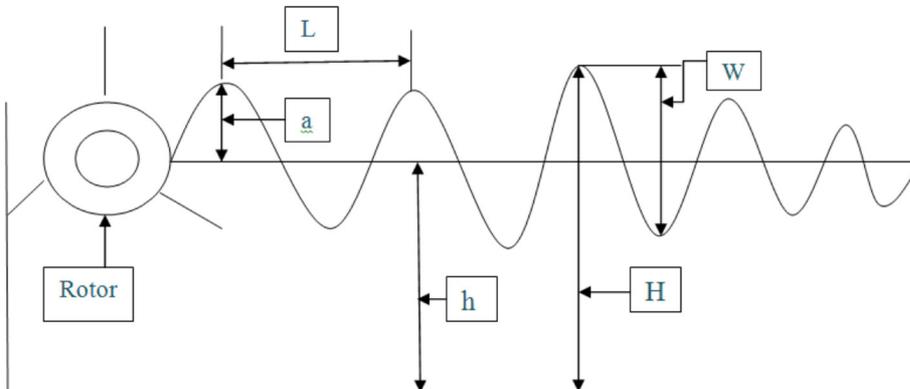

Figure 3: Schematic diagram of wave

Here,
a= Amplitude
L= Wave length
H= Highest peak from the ground
h= Water Height
W= Wave Height

EXPERIMENTAL PROCEDURE

The water wave generator is installed in the fluid dynamics lab of the Mechanical and Production Engineering Laboratory. The experiments are carried out to obtain the different wave parameters as shown in Figure 3 and calculated the forces and others. However, the general experimental procedures are explained below:

➤   Single phase AC motor of one horse power is used for this project. When this motor is connected to electric supply, it rotates the cylindrical-shaped rotor.

➤   Single blade with different widths (like 8-inch or 10-inch blade) is attached to rotor. While using double blades, lag of blades are varied (120°

129

Saha, B.
Islam, M.
Torab, A.
Ahmed, D. H.

and 240º). The changes of blade size and blade position are done several times.

➢ The blade strikes the water away and thus the wave is created. The propagation of wave is observed from one side where acrylic is used as boundary of the tank.

➢ Some scaling is used to observe wave characteristics. The scaling is done manually taking an equal amount of distance. From this scaling, some readings such as wavelength, amplitude, number of peak, frequency, velocity etc. are measured.

➢ A force measuring device is set at the end of the tank to measure the force of the wave.

➢ While working, water level is increased and decreased several times. It is done for different cases. Five different water heights are considered during the experiments ranging from 20 inches to 24 inches.

➢ While taking the readings, number of peak and wavelength are observed very carefully. Sometimes, the procedures are repeated to get correct data.

➢ While measuring force, the reverse wave (bouncing from the solid wall) are tried to avoid.

The experiments are conducted with different orientation of the blades on the rotor. The total experimental works are divided into four different cases. Table 2 shows the details of the different cases for the present study.

Table 2: Different case studies

Experiment ID	Meaning
Case 1	The rotor has single blade and The width of the blade is 8 inch.
Case 2	The rotor has single blade and The width of the blade is 10 inch.
Case 3	The rotor has double blades. The widths of the blades are 8 inch and 10 inch. The 8 inch and 10 inch blades are attached one after another at 120^0 lag.
Case 4	The rotor has double blades. The widths of the blades are 10 inch and 8 inch. The 10 inch and 8 inch blades are attached one after another at 120^0 lag.

Investigation
of Wave
Characteristics
with Rotor Type
Water Wave
Generator

RESULTS AND DISCUSSIONS

A number of experiments on water wave are carried out on the constructed water wave flume. The different case studies are briefly explained in Table 2. Case 1 and Case 2 are designated for using the blade width of 8 inch and 10 inch respectively. The amplitude variations along the distance of the water wave flume for Case 1 and Case 2 are shown in Figure 4 for three different water heights (water height is calculated from the flume bed) like 1 ft 8 inch, 1 ft 10 inch and 2 ft of water height. It is clearly visible that the wave simply follows the sine wave pattern and maintained the same amplitude as wave propagates along the flume especially when water height is 1 ft 8 inch.
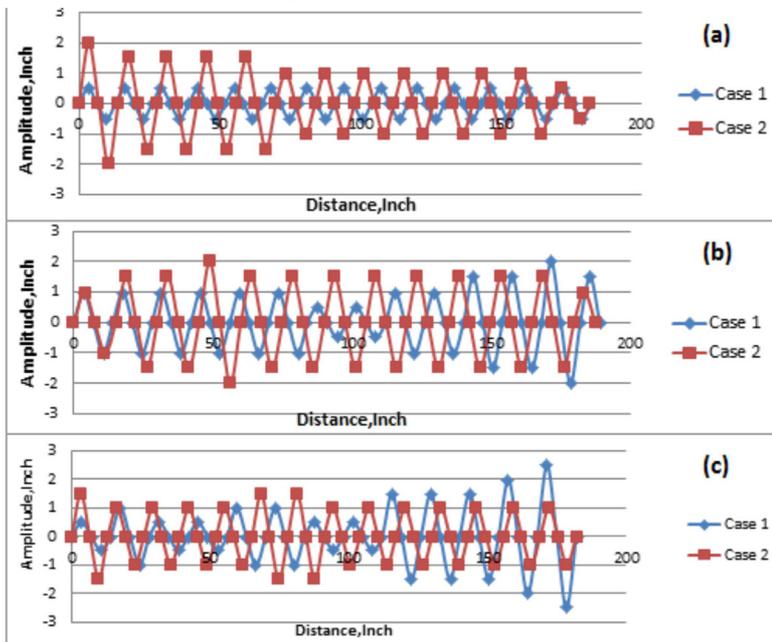
Figure 4: Amplitude variation along the distance of the wave flume for (a) 1 ft 8 inch, (b) 1 ft 10 inch and (c) 2 ft water height

However, as the water height increases the amplitude shows some irregular shapes which may be due to the disturbance by the reflected wave from the flume wall and may be some instrumental and measurement error. Li [28] numerically showed that the nonlinear effect is negligible when the ratio of the wave amplitude to the depth decreases. He also obtained the regular sinusoidal wave pattern along the length.

However, to validate the present experimental results, wave length variation on wave frequency is plotted in Figure 5a. Figure 5a shows that as the frequency increases the wave length gradually decreases and follows the usual trend. Dorrell

Saha, B.
Islam, M.
Torab, A.
Ahmed, D. H.

et al. [23] and Faizal et al. [30] also obtained that the wave length is inversely proportional to the wave frequency (as shown in Figure 5b). Similarly, Figure 6a and 6b show that the wave length increases with the time period and resembles with the usual trend. There are some discrepancies between Case 1 and Case 2 for low frequency (Figure 5a) or the high time period (Figure 6a) on wave length. Usually, wave length gradually increases with the increase of water height i.e. it moves from shallow to deep water level. However, in the shallow region, the clearance between the blade tip and bottom surface is much less as compared to deep water. Here, in Case 2, this gap is much smaller than the Case 1 as the Case 2 having 10 inch blade. This smaller gap may initiate some disturbance at bottom of the wave flume and hence influence the propagation. As the water height increases, this disturbance reduces and ultimately diminishes for higher depth of water. Moreover, according to the dispersion relation of water wave, wave needs to become squeeze or contract to keep balance the wave momentum for particular wave period.
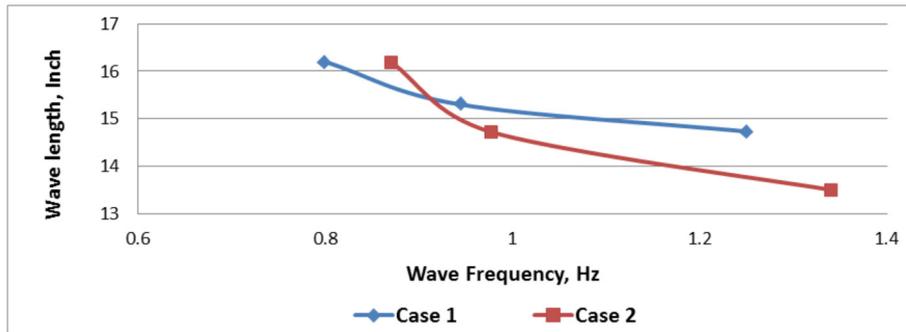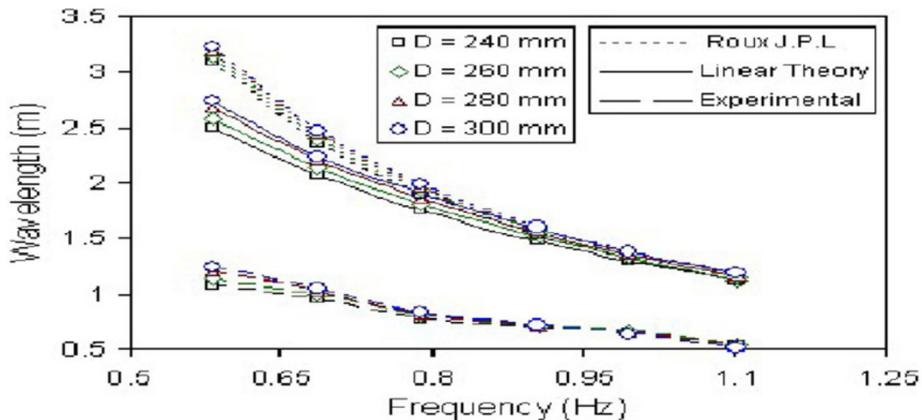

Figure 5(a): Wave Frequency vs. Wave Length

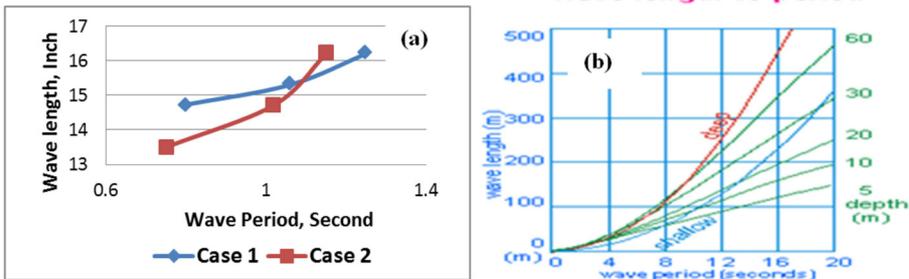Figure 5(b): Validated graph for Wave frequency vs. Wave length (Faizal et al. [29])

Investigation
of Wave
Characteristics
with Rotor Type
Water Wave
Generator

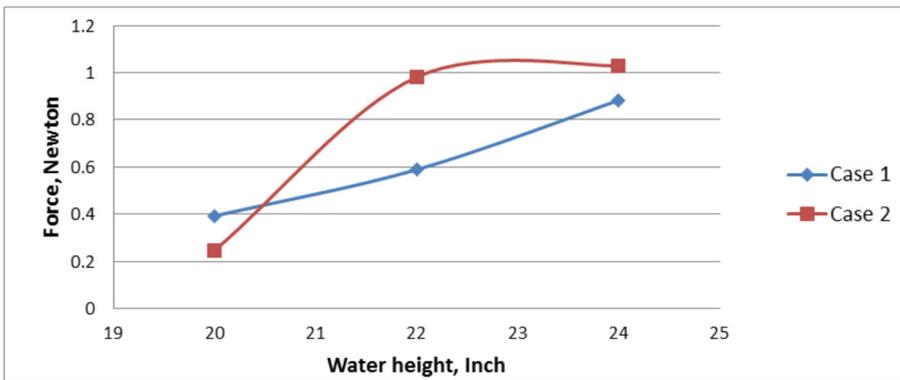Figure 6: Wavelength variation on wave period (a) Present study and (b) theoretical (Everbach et al. [21])

Figure7: Water height vs. Force (Case 1 and Case 2)

The Figure 7 represents the force exerting by the wave for different water height for Case 1 and Case 2. The force which is generated in the flume is increased with the increases of water depth that is water height. Case 1 (8 inch blade) shows the linear increment of the forces on water height, but Case 2 (10 inch blade) does not show the same trend as Case 1, though the force increases with water height. Actually, 10 inch blade displaced much volume of water in the flume leads to have higher value in force but unfortunately for the water height with 24 inch does not to show the same representation. This may due to the decrease of motor speed (as shown in Figure 8) for higher water level in the wave flume. This means that it takes more time to displace water as compared with the Case 1. Faizal et al. [18] has observed similar behaviour on motor speed for various water heights.

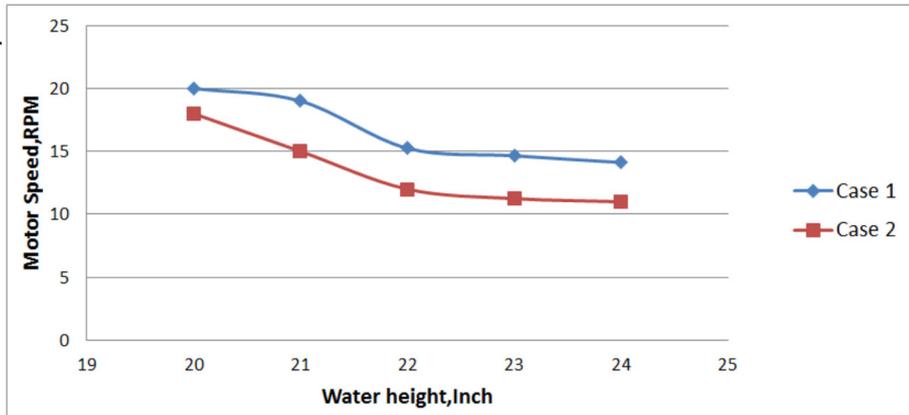Saha, B.
Islam, M.
Torab, A.
Ahmed, D. H.

Figure 8: Water Height vs. Motor Speed (Case 1 and Case 2)

The Figure 9(a) represents the time vs. force for 2 feet water height for Case 1 and Case 2. For Case 1 the force that is obtained is greater than the force for Case 2 but the time required for the first wave to propagate from the blade point to the end of the tank to hit the force measuring device is almost same (around 5 to 6 seconds) for both cases. As the time is increased the force is increased at a certain limit for both Cases. Then for further increasing of time the force is decreased for both Cases but for Case 1 it is decreased at a higher rate with respect to time than Case 2 because at 2 feet water height motor rpm is higher for Case 1 than Case 2 causes to have maximum force on later time. After having the peak value of the force, the strength of the wave gradually decreases because of the reflection of the waves from the front wall and also from the side walls. Penalba and Ringwood [30] obtained the forces over the time (see Figure 9(b) and found that the forces fluctuated and gradually decreases with the time elapsed. The differences between the two figures (i.e. Figure 9(a) and (b)) are due to the time periods.

Investigation
of Wave
Characteristics
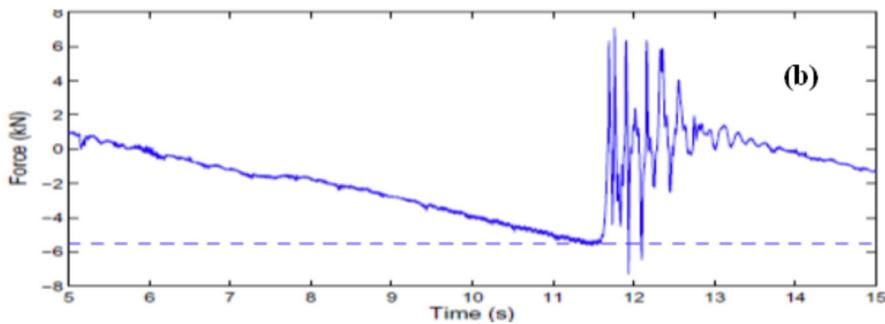with Rotor Type
Water Wave
Generator
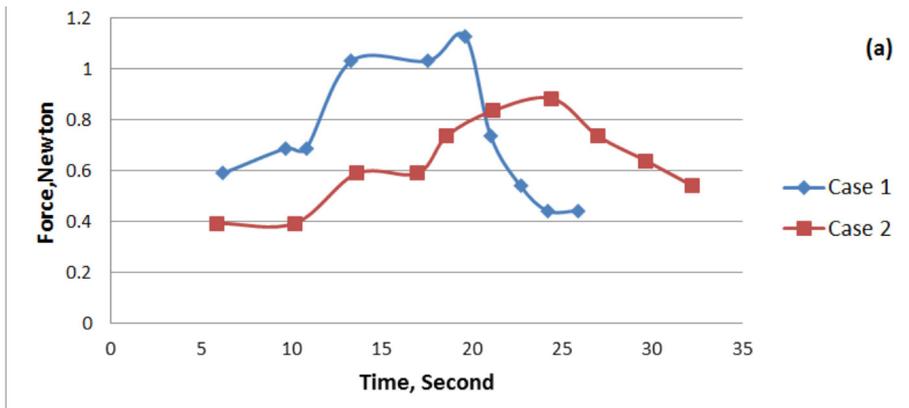
Figure 9: Force vs. Time (a) present study (b) Penalba and Ringwood [30]

The amount of wave energy which can be extracted from wave is highly influenced by the wave height. In fact, wave energy per unit area is proportional to the square of the wave height. Actually the orbital motion of the wave is much larger at the top of the water surface and gradually decreases towards the depth. For deep water, the orbital motion of the wave doesn't touch the ground, however, as long as the wave moves from deep water region to shallow water region (like: sea beach), the wave breaks and the height decreases. Therefore, the wave height significantly depends on water depth.

The Figure 10 represents wave height vs. water height for Case 1 and Case 2. It shows that with the increases of the depth of water, the height of wave is also increased. However, for higher depth, the wave heights become almost same for the both cases. This may be due to the decrease of the motor speed which causes to reduce the momentum.
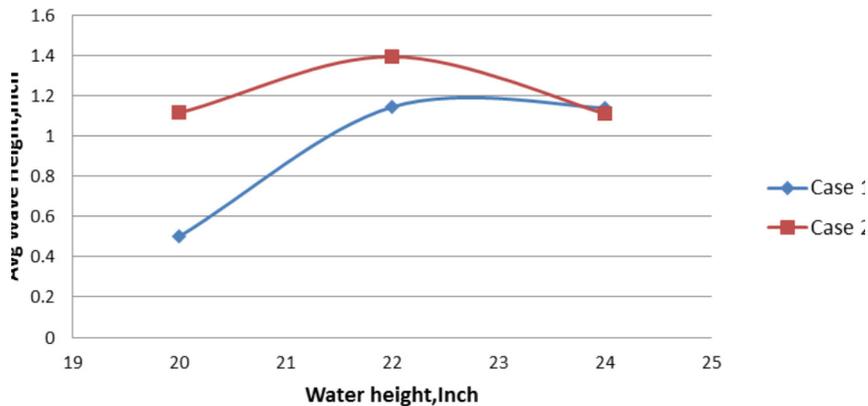

Figure 10: Water Height vs. Average Wave Height (Case 1 and Case 2)

The wave energy and power is calculated by equation (1) shown in Figure 11 for different cases. The Figure 11 represents the wave energy vs. height

Saha, B.
Islam, M.
Torab, A.
Ahmed, D. H.

of wave for Case 1 and Case 2. The wave energy is found by the equation of $E = E_p + E_K = (\rho\, g\, H^2\, \lambda)/8$ and this equation indicates the total energy of a regular sinusoidal wave. The graph is showed that as the height of the wave is increased the wave energy is also increased. Similar trend is also found by Salimullah et al [31] where water energy is proportional to the wave height.
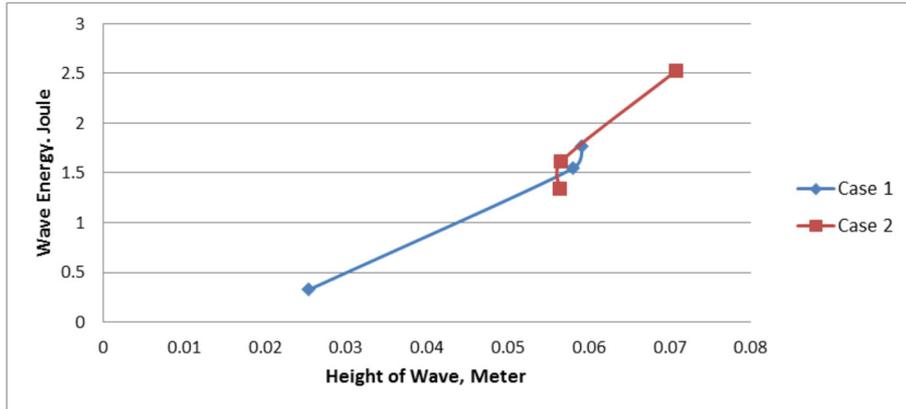

Figure 11: Wave Energy vs. Height of Wave for Case 1 and Case 2

Continuing the study on wave in the water wave flume two consecutive waves are generated with the means of two different sizes of blades which are placed on the rotor at 120° apart. Case 3 is designated in this study as 8 inch blade makes wave and with the same rotation of the rotor, 10 inch blade makes the second wave. The study is carried out for three different water depths as before. Similarly, Case 4 is considered for the 10 inch blade strike water first and then the 8 inch blade where 8 inch blade lagging of 120°. The highest peaks of the two consecutive waves generated by the two different sizes of blades for both cases are shown in Figure 12.
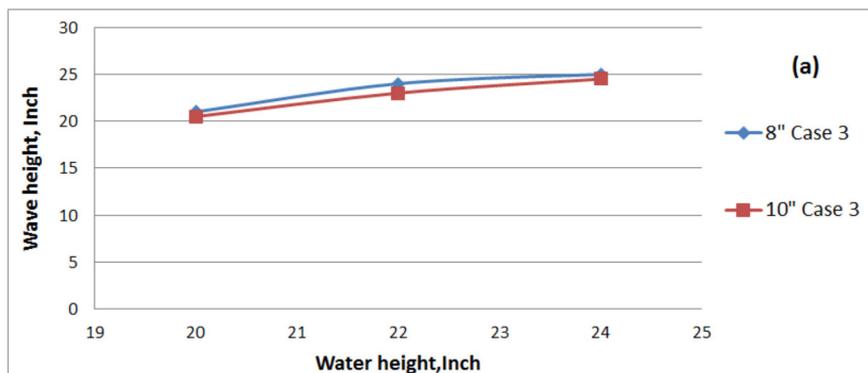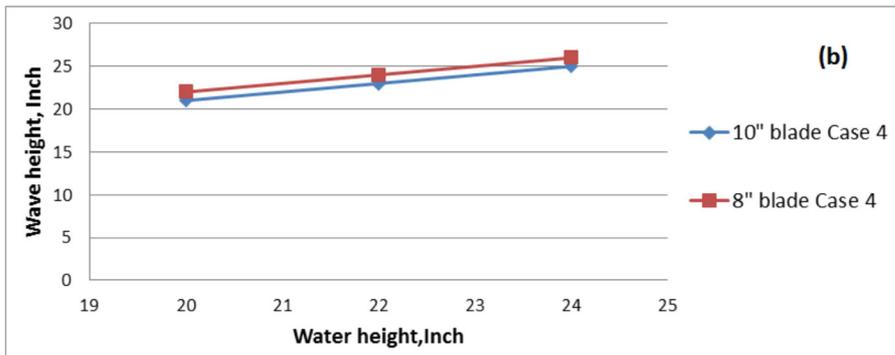
Figure 12: Wave height variation on water height (a) Case 3, (b) Case 4

It is interesting that the wave generated with strike of 8 inch blade makes bigger wave as compared with the 10 inch blade for the both cases. 10 inch blade displaces large volume of water causes to reduce the rpm and leads to have lower momentum as compared with the 8 inch blade. Tutar and Veci [19] also observed that the rotational speed of the rotor influence the water wave height, in fact, higher rotational speed leads to have higher water wave height. However, the figure shows that the wave height gradually increases with the increase of the water depth. The present experiments are conducted with the deep water consideration as the depth of water is half of the wavelength. Similar trend of wave height on water depth are also obtained by Lipa et al. [32].

The maximum forces exerted on the wall at downstream of the wave flume for different water heights are shown in Figure 13 and exhibits that the forces are gradually increased with the increasing of the water height. The Case 4 which is configured as 10 inch blade and then 8 inch blade possess higher force than that for Case 3. The results indicate that the two consecutive wave causes to decrease the force (comparing Case 1 and Case 2). The reason behind that the waves are initiated by two blades impose or superimpose of one another to reduce the effectiveness of the wave and thus causes to lower value of the forces. Considering the high tide and low tide, the second wave should be bigger and lower as compared with first wave respectively. It is true that maintaining the torque of the rotor for the different sizes of the blades could make sure the high tide and low tide. The present observation gives good insight for further studies on high tide and low tide and to obtain the wave energy.
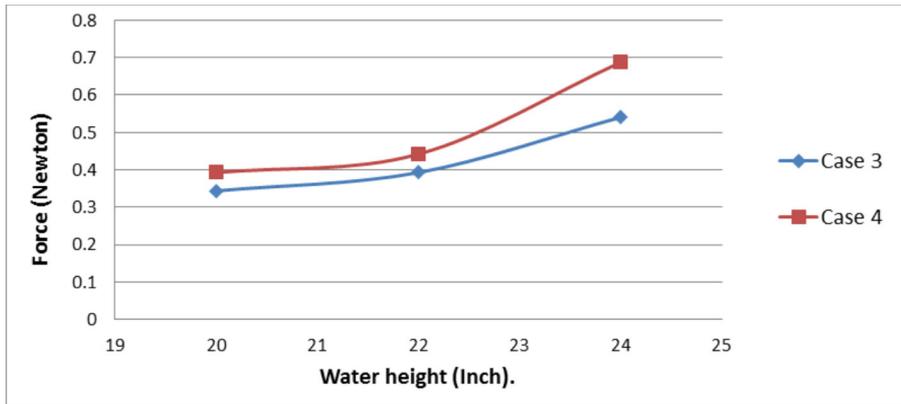
Saha, B.
Islam, M.
Torab, A.
Ahmed, D. H.

Figure 13: Force vs. Water Height (Case 3 and Case 4)

CONCLUSION

A water wave flume is constructed as a part of major project for harvesting energy from the waves and tides. The coastal line the Bay of Bangle which is at the south of Bangladesh can be useful as the source of wave energy and will be able to fulfil the demand. The wave flume is constructed with a length of 16 feet and rotor type water wave generator is used. The experiments are conducted with different sizes of the rotor blades with different combinations. The constructed wave flume gives the considerable results and validated with the available literature and the general wave theory. The results show that the blade size has significant impact on water wave generation and hence the force and the power. Wider blade displaces much water and at the same time due to the larger momentum leads to reduce the motor speed. Constant rpm is necessary to investigate the high tide and low tide effects.

ACKNOWLEDGEMENT

REFERENCES

1. Brown, G.S., 1979. Estimation of wind speeds using Satellite- Borne Radar Measurements at Normal Incidence. *Journal of Geographical Research*, 84(B8), 3974-3978.
2. Atlas, R., Hoffman R. N., Bloom, S. C., Jusem, J. C., Ardizzone, J., 1996. A Multilayer Global Surface Wind Velocity Dataset Using SSM/I Wind Observations. Bulletin of American Meteorological Society, 77(5).
3. Young, I. R., 1993. An Estimate of the Geosat Altimeter Wind Speed Algorithm at High Wind Speeds, *Journal of Geophysical Research*, 98, 20275-20285.
4. Offler D., 1994, The Calibration of ERS- 1 Satellite Scatterometer Winds. *Journal of Atmospheric and oceanic Technology*, 11, 1102-1017.

Investigation
of Wave
Characteristics
with Rotor Type
Water Wave
Generator

5. Tanimoto, K. Takahashi, S., 1994. Design and construction of caisson breakwaters - the Japanese experience. Coastal Engineering, 22, 57-77.

6. Malmo, O., Reitan, A., 1985. Wave Power Absorption by An Oscillating Water Column in a Channel, *Journal of Fluid Mechanics*, 158, 253-175.

7. Zheng, W., 1989. Experimental Research and parameters optimization of a prototype OWC wave power device. Proc. International Conference on Ocean Energy Recovery, 89, 43-50.

8. Muller, G. U., Whittaker, T., 1993. An investigation of breaking wave pressures on inclined walls, Ocean Engineering, 20(4), 349–358.

9. Jayakumar, 1994, Wave forces on Oscillating Water Column Type Wave Energy Caisson – An Experimental Study, Ph.D. Thesis, Ocean Engineering Centre, Indian Institute of Technology, Madras. India.

10. Thiruvenkatasamy, K., Neelamani, S., 1997. On the efficiency of wave energy caisson in array, Applied Ocean Research, 19, 61-72.

11. Tsenga R. –S., T., Wu, R. –H., Huang, C. –C., 2000. Model study of a shoreline wave-power system, Ocean Engineering, 27, 801-882.

12. Wang, D. J., Katory, M., Li, Y. S., 2002. Analytical and experimental investigation on the hydrodynamic performance of onshore wave-power devices, Ocean Engineering 29(8) 871-885.

13. Sudheesh, K., Vethamony, P., Babu, M. T., Jayakumar, S., 2004. Assessment of wave modeling results with buoy and altimeter deep water waves for a summer monsoon, 3rd Indian National Conference on Harbour & ocean Engineering NIO, Goa, Dec 7-9, 2004.

14. Swail, V. R., Cox, A. T., 1999. On the Use of NCEP–NCAR Reanalysis Surface Marine Wind Fields for a Long-Term North Atlantic Wave Hindcast, *Journal of Atmospheric and Oceanic Technology*, 17, 532-545.

15. Ashlin. S. J., Sannasiraj. S. A., Sundar. V., 2015. Wave forces on an Oscillating Water Column Device. 8th International Conference on Asian and Pacific Coasts (APAC 2015). Procedia Engineering 116, 1019 – 1026.

16. Zhang, Y., Zou, Q. –P., Greaves, D., 2012. Air-water two phase flow modelling of hydrodynamic performance of an oscillating water column device, Renewable Energy, 41, 159–170.

17. Wilbert R., 2013. Hydrodynamic characteristics of Double Chamber Oscillating Water Column device, Doctoral thesis, Indian Institute of Technology Madras, India, 137, 138.

18. Faizal, M., Ahmed, M. R., Lee, Y. –H., 2010. On utilizing the orbital motion in water waves to drive a Savonius rotor. Renewable Energy, 35, 164–169.

19. Tutar, M., Veci, I., 2015. Experimental wave flume study of Savonius-type multiple rotor arrays, *Journal of Renewable and Sustainable Energy*, **7**, 063125.

20. Tutar, M., Veci, I., 2016., Performance analysis of a horizontal axis 3-bladed Savonius type wave turbine in an experimental wave flume (EWF), Renewable Energy, 86, 8–25.

21. Everbach, C., Siddiqui, F., Samuelson, K., 2014. Design and Construction of an Electromechanically Driven Wave Flume, Department of Engineering, Swarthmore College.

22. Sekiguchi, T., Sunamura, T., 2004. Effects of bed perturbation and velocity asymmetry on ripple initiation: wave-flume experiments, Coastal Engineering, 50, 231–239.

23. Dorrell, D. G., Halliday, J. R., Miller, P., Findlater, M., 2004. Review of Wave Energy Resource and Oscillating water Column Modelling, Universities Power Engineering Conference, Bristol, 5-8, (on CD).

24. Khalilabadi, M. R., Bidokhti, A. A., 2010. Design and Construction of an Optimum Wave Flume, *Journal of Applied Fluid Mechanics*, 5(3), 99-103.

25. Ram, K., Faizal, M., Ahmed, M. R., Lee, Y. –H., 2010. Experimental studies on the flow characteristics in an oscillating water column device, *Journal of Mechanical Science and Technology*, 24(10), 2043-2050.

26. Sainchera, S., Banerjee, J., 2015. Design of a numerical wave tank and wave flume for low

Saha, B.
Islam, M.
Torab, A.
Ahmed, D. H.

steepness waves in deep and intermediate water, 8th International Conference on Asian and Pacific Coast (APAC 2015), Procedia Engineering, 116, 221 – 228.

27. Harry, M., Zhang, H., Lemckert, C., Colleter, G., Blenkinsopp, C., 2011. Remote sensing of water waves: wave flume experiments on regular and irregular waves, 20th Australasian Coastal and Ocean Engineering Conference 2011 and the 13th Australasian Port and Harbour Conference 2011 (COASTS AND PORTS 2011). Curran Associates, pp. 138-143. ISBN 9781622764303.

28. Bin, L., 2008. Wave Equations for Regular and Irregular Water Wave Propagation, Journal of Waterway, Port, Coastal and Ocean Engineering, 134(2), 121-142.

29. Faizal, M., Ahmed, M. R., Kim, C. –G., Lee, Y. –H., 2011. Experimental Investigation of Water Wave Characteristics in a Wave Channel, 38(2), 167-178.

30. Penalba, M., Ringwood, J. V., 2016. A Review of Wave-to-Wire Models for Wave Energy Converters, Centre for Ocean Energy Research, Maynooth University, Maynooth, Co. Kildare, Ireland. Grant No. 13/IA/1886.Energies 2016, 9(7), 506.

31. Salimullah, S. M., Rafi, M. M. E., Sheikh, M. R. I., 2014. Prospects of Wave Power in Bangladesh, *American Journal of Engineering Research,* 3(5), 29-35.

32. Lipa, B., Nyden, B., Barrick, D., Kohut, J., 2008. HF Radar Sea-echo from Shallow Water, Sensors, 8, 4611-4635.