BACHELOR THESIS & COLLOQUIUM – ME184841

PERFORMANCE ANALYSIS OF OSCILLATING WATER COLUMN BY VARIATION SHAPE OF COLUMN & NUMBER OF TURBINE

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DOUBLE DEGREE PROGRAM
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TUGAS AKHIR – ME184841

ANALISISA PERFORMA PADA OSCILLATING WATER COLUMN DENGAN VARIASI BENTUK KOLOM & JUMLAH TURBIN

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APPROVAL FORM

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BACHELOR THESIS

Submitted as one of Requirements to obtain Bachelor Degree in Engineering
on
Marine Fluid Machinery and System (MMS)
Bachelor Program in Marine Engineering Department
Faculty of Marine Technology
Institut Teknologi Sepuluh Nopember

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DECLARATION OF HONOR

I hereby who signed below declare that :

This final project has written and developed independently without any plagiarism act. All contents and ideas drawn directly from internal and external sources are indicated such as cited sources, literatures, and other professional sources.

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NRP	: 04211541000034
Bachelor Thesis Title	: Performance Analysis of Oscillating Water Column by Variation Shape of Column & Number of Turbine
Department	: Marine Engineering

If there is plagiarism act in the future, I will fully responsible and receive the penalty given by ITS according to the regulation applied.

Surabaya, July 2019

Sultan Brillianto Ardoury

PERFORMANCE ANALYSIS OF OSCILLATING WATER COLUMN BY VARIATION SHAPE OF COLUMN & NUMBER OF TURBINE

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ABSTRACT

Oscillating Water Column is the one of the most common WEC (Wave Energy Converter). This system generates electricity from rising sea levels due to ocean waves that enter into a isolation column. Sea wave will fluctuated and give impact the air inside the column to flow to the outside of the column. Sea level in the column will compress the air inside the column and generate pressure to drive the turbine. According to the basic model of owc, it only use block column as the collector and no optional shape for result a better performance. This research try to give a variation to the column by using another shape of column (Cylinder, and Rectangular pyramid) and also give variation number of turbine (1 turbine & 2 turbine) for knowing the most big power generated and the most efficient model to be applied as power plant. This research choose South Malang East Java Sea as the place to build Oscillating Water Column because the sea has a high wave rate. This research will using manual count and simulating software for resolve the case.As the conclusion from variating shape of column and number of turbine, it conclude that the sea wave level affects the amount of power generated by oscillating water column, more wider area of the column also effect the number of air capacity inside the column so the most effective column is Pyramid Column rather than Cylinder and Block Column but when heigth of the wave is very low the pyramid column is produce less power. The number of turbines with the same size is not too influential for power that generated by oscillating water column because if the amount of output area increases, the air pressure in each output area will be decrease, and even then it will also affect the torque that will be given to the turbine.

Key Word : Block, Cylinder, Oscillating Water Column (OWC), Power Plant, Rectangular Pyramid, Variation column, Variation Number of Turbine.

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ANALISA PERFORMA PADA OSCILLATING WATER COLUMN DENGAN VARIASI BENTUK KOLOM & JUMLAH TURBIN

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ABSTRAK

Oscillating Water Column adalah salah satu *WEC* (*Wave Energy Converter*) yang paling umum. Sistem ini menghasilkan listrik dari kenaikan permukaan laut akibat gelombang laut yang masuk ke dalam kolom isolasi. Gelombang laut akan berfluktuasi dan memberikan dampak pada udara di dalam kolom yang akan mengalir ke luar kolom. Permukaan laut di dalam kolom akan menekan udara di dalam kolom dan menghasilkan tekanan untuk menggerakkan turbin. Model dasar *Oscillating Water Column* hanya menggunakan kolom blok sebagai kolektor dan tidak ada bentuk opsional untuk menghasilkan kinerja yang lebih baik. Penelitian ini mencoba memberikan variasi pada kolom dengan menggunakan bentuk kolom lain (Silinder, dan Limas Segi Empat) dan juga memberikan variasi pada jumlah turbin (1 turbin & 2 turbin) untuk mengetahui daya paling besar yang akan dihasilkan dan juga model yang paling efisien untuk diterapkan sebagai pembangkit listrik. Penelitian ini memilih daerah Laut Jawa Timur, Malang Selatan sebagai tempat untuk membangun *Oscillating Water Column* karena lautnya memiliki tingkat gelombang yang tinggi. Penelitian ini akan menggunakan penghitungan manual dan aplikasi simulasi untuk menyelesaikan kasus ini. Sebagai kesimpulan dari variasi bentuk kolom dan jumlah turbin, disimpulkan bahwa tingkat gelombang laut mempengaruhi jumlah daya yang dihasilkan oleh *Oscilating Water Column*, area kolom yang lebih luas juga efek jumlah kapasitas udara di dalam kolom mempengaruhi tekanan yang akan dihasilkan sehingga kolom yang paling mengasilkan daya terbesar adalah Kolom Limas Segi Empat dibanding dengan Kolom Silinder dan Balok akan tetapi ketika gelombang laut rendah daya yang dihasilkan oleh kolom limas segi empat yang terkecil. Jumlah turbin dengan ukuran yang sama tidak terlalu berpengaruh terhadap daya yang akan dihasilkan oleh *Oscillating Water Column* karena jika jumlah area output meningkat maka besar tekanan udara di setiap area output akan berkurang, itupun juga akan mempengaruhi torsi yang akan diberikan untuk turbin.

Kata Kunci : Balok, Limas Segi Empat, Oscillating Water Column (OWC), Pembangkit Listrik, Silinder, Variasi Jumlah Turbin, Variasi Kolom.

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PREFACE

All the gratitude towards Almighty Allah SWT for all the blessings and gifts so that the author can complete this Bachelor Thesis with title of "Performance Analysis of Oscillating Water Column by Variation Shape of Column & Number of Turbine" in order to fulfill the requirements to obtaining Bachelor Degree of Engineering in Marine Engineering Department, Faculty of Marine Technology, Institut Teknologi Sepuluh Nopember, Surabaya.
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Because this work is far from perfect work, author will really appreciate for every advice suggestion and idea from all parties to correct and improve this bachelor thesis. By the completion of this bachelor thesis, author hopes this thesis can provide any knowledge for reader and give beneficial for marine technology improvement.

Surabaya, July 2019

Author

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CHAPTER I
INTRODUCTION

1.1 Background

Electrical energy needs are increasing as time goes on from year to year. This was accompanied by the pace of growth, regional development and construction. With the increase in electricity demand, it will increase the rate of exploitation of the remaining raw materials to fuel the electricity generator. Even though energy such as oil, gas and coal will run out someday. To slow down the rate of exploitation can be done by using alternative energy. Indonesia is the largest marine country in the world.The potential of ocean and ocean energy to produce electricity is one potential that is not yet widely known. Compared to solar and wind energy, this wave energy provides 90% availability with the potential area is unlimited, as long as there are waves, electricity can be obtained.

Basic on BPS Statistics Indonesia in Statistics of Marine and Coastal Resources (SMCR), the length of the entire Indonesian coastline is 68,216 km. This data is collected from the Department of Marine and Fisheries Provinces throughout Indonesia. Based on Geospatial Information Agency Missive Number B.3-4/SESMA/ IGD/07/2014, the length of Indonesia coastline in 2014 is 99,093 km (KKP, 2015). Refer to Law Number 30 in 2007 concerning energy, mandated that in order to support national development in a sustainable manner and improve national energy security, energy management is aimed at achieving energy management independence, ensuring the availability of domestic energy, ensuring optimal, integrated and sustainable management of energy resources. increasing community access, achieving the development of capabilities in the energy industry and services. Domestic energy, improve professionalism of human resources, creation of jobs, and preservation of environmental functions.

To generate electricity by fluctuative wave movement there are innovation called Wave Energy Converter (WEC). A wave energy converter is defined as a device to convert kinetic and potential energy associated with moving wave into useful mechanical or electrical energy.Of the several types of WEC (Wave Energy Converter) Oscillating Water Colomn type is the most popular type of WEC. This system generates electricity from fluctuative sea levels due to ocean waves that enter into a isollation column. The fluctuative sea level in the column will compress air inside the column and generate pressure to drive the turbine.The turbine rotation will produce power to generate electricity. According to the basic model of owc, it only use block column as the collector and no optional shape for result a better performance.

This research try to simulate and give a variation to the column by using block, cylinder, and rectangular pyramid with upsidedown position for knowing the best and better optional shape to be use in oscillating water column. The reason to choose cylinder because of the shape has largest volume to surface area ratio and less frictional effect and the reason to choose upsidedown pyramid because the input is small rather than another column and hopefully give better pressure at the outflow. This research also give variation to number of turbine (1 & 2 turbine) for knowing the most big power generated and the most efficient model to be applied as power plant. The wave data of the simulation is using in South Malang East Java Sea which has a high wave rate.

Table 1.1 Wave data in South Malang East Java
(Source : Badan Meteorologi, Klimatologi, dan Geofisika 2013)

Wave Data				
Month	H max (m)	Period (s)	H min (m)	Period (s)
January	5.1	4.7	0.9	4.8
February	3.4	4.6	0.7	4.7
March	2.7	4.9	0.1	4.8
April	1.7	4.5	0.6	5.3
May	1.6	5.5	0.5	5.3
June	1.6	5.5	0.9	5.3
July	2.8	5.7	1	5.6
August	2.2	6	1	6.3
September	2.1	5.4	0.4	5.6
October	1.9	4.7	0.3	4.7
November	1.3	4.7	0.5	4.8
December	3.1	4.6	1.1	4.6

1.2 Research Problem

This research analysis has formulation of the problem as follow :

1. How is the parameter of Oscillating Water Column in various shape of column (Block, Cylinder, Rectangular Pyramid)?
2. How is the parameter of Oscillating Water Column with various number of turbine (1 shape of column 1 turbine & 1 shape of column 2 turbine)?
3. How much the power generated by Oscillating Water Column with various shape of column and number of turbine?
4. How much the efficiency of Oscillating Water Column with various shape of column and number of turbine?

1.3 Research Objective

For answer all the question contained in the research problem, this research has following objective :

1. Obtain the parameter of Oscillating Water Column in the shape of block, cylinder, rectangular pyramid.
2. Obtain the parameter of Oscillating Water Column with various number of turbine (1 shape of column 1 turbine & 1 shape of column 2 turbine).
3. Obtain the power generated by Oscillating Water Column with various column and number of turbine
4. Obtain the efficiency of Oscillating Water Column by various shape of column and number of turbine.

1.4 Constraints

To be able to carry out this research, the limitation problem from this research are :

1. Does not discuss economic reviews in this study.
2. The researcher uses Computational Fluid Dynamic software to model and analyze.
3. Design columns used only in the form of block, rectangular pyramids and cylinders.
4. Does not calculate the material of construction.

1.5 Significance of Research

The Benenfit that can be obtained by this research are :

1. Knowing the parameter of Oscillating Water Column in various shape of column (Block, Cylinder, Rectangular Pyramid).
2. Knowing the parameter of number of turbine to use in oscillating water column.
3. Knowing the amount of power produced by variation shape of column and number of turbine for oscillating water column.
4. Knowing the most effectiveness design to generated power by wave energy through the oscillating water column (Block, Cylinder,and Rectangular Pyramid , and number of turbine).

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CHAPTER II
LITERATURE REVIEW

2.1 Wave

Waves that occur in the oceans can be classified into several types depending on the power that causes them. Sea waves can be caused by wind (wind waves) of the earth's attraction “Moon & Sun” (tidal waves, earthquakes (volcanic and tectonic) on the seabed (tsunami waves) or waves caused by the movement of the ship.Waves are the up and down movements of water in a direction perpendicular to the sea level that forms a sinusoidal curve / graph. Wind over the ocean moves its energy to the surface of the water, causing strains.

Wave basic Formulas :

$$v = \lambda .\ f \quad (2.1)$$

v: wave velocity (m/s)
λ: wavelength (m)
f : frequency

And from the above formula there are several derivative formulas such as :

$$\lambda = v / f \quad (2.2)$$

Because the frequency is reversed directly in the period f = 1 / t

$$v = \lambda / t \quad (2.3)$$
$$\lambda = v.\ t \quad (2.4)$$

v : wave velocity (m/s)
: wavelength (m)
t : period

(Georgi, 2015)

To find out the power of waves is by knowing the available wave energy. Total wave energy is the amount of kinetic energy with potential energy. Potential energy is formulated as follows:

$$PE = mg\ \frac{y(xt)}{2} \quad (2.5)$$

Where,

PE : Potential Energy (J)
m : Wave Mass (kg)
g : gravity (m/s^2)

y : y(x,t) = the heigth from surface to sea floor (d+η)

Calculating potential energy after one period can assume waves only in function x and free time, i.e. : y (x, t) = y (x) so

dPE $= 0.5\ w\rho a^2 \sin^2 (kx-\omega t)dx$

PE $=\int_0^{\lambda} d\ PE$

$=\int_0^{\lambda} \frac{1}{2} w\rho g a^2 sin^2(kx-\omega t)dx$

$=\frac{1}{2} w\rho g a^2 [\frac{1}{2}x - \frac{1}{4} sin^2(kx-\omega t)]_0^{\lambda}$

Consider k $=\frac{2\pi}{\lambda}$ dan $\omega = \frac{2\pi}{T}$ then obtained

PE $= \frac{1}{4} w\rho g a^2 \lambda$ (2.6)

Total kinetic energy after one period is the result of total potential energy,

KE $= \frac{1}{4} w\rho g a^2 \lambda$ (2.7)

So the total energy after one period is,

Ew = PE + KE $=\frac{1}{2} w\rho g a^2 \lambda$

After the unity of energy is obtained it can also add other parameters such as energy density at power and respective density.

Energy Density : $EWD = \frac{Ew}{T} = \frac{1}{2}\rho g a^2$ (2.8)

Power : Pw $=\frac{Ew}{T}$

Power Density : $P_{WD} = \frac{Pw}{\lambda w} = \frac{1}{2T} w\rho g a^2$ (2.9)

Then consider the depth of water, so the equation becomes

$$\omega^2 = kg = \left(\frac{2\pi}{\lambda} g\right) \rightarrow \lambda = \frac{g}{2\pi} T^2 \cong 1.56T^2$$

Applied : $\lambda = 1.56T^2$ on the energy equation above,

Ew = $0.78 w\rho g a^2 T^2$ (2.10)

Pw $=\frac{1}{8} w\rho g h^2 T$ (2.11)

Finally if use wave height compared to the amplitude of the wave then

$Ew = 0.195\ w\rho g h^2 T^2$ (2.12)

$$PW = 0.195 w \rho g h^2 T \tag{2.13}$$

the wave width is assumed to be equal to the column width (m)

KE = Kinetic Energy (J)
K = Wave coefficient
Ew = Wave Energy Total (J)
Pw = Wave power (W)
T = Wave period (sec)
H = Wave height (m)
w = Wave width (m)
ρ = Density (1025 $\frac{kg}{m^3}$)
g = Gravity Acceleration (9,81 m/s^2)
a = Wave Amplitude (H/2)
H = Wave Height
T = Wave Period
= Angular wave velocity 2π/T (rad/sec)

(Cormick, 1981)

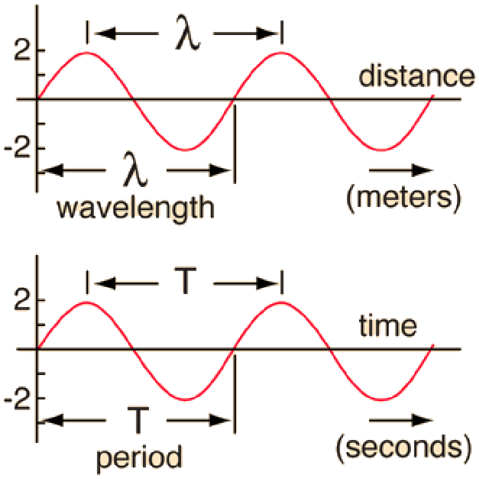

Figure 2.1 Wavelength & Period Graph
(Source : hyperphysics.phy-astr.gsu.edu)

2.2 The Potential Conversion of Ocean Wave into Electrical Energy

With the second coastline in the world, Indonesia should be able to take advantage of ocean waves and tides as alternative energy used. Even though ocean wave energy can produce electricity about 246 to 1,968,235 watts using an oscillating water column system. Based on existing observations, the waves around the coast of New Zealand with an average height of 1 meter and a period of 9 seconds have a power of 4.3 kW per meter of wave length. While the waves are similar to 2 meters high and 3 meters of power are 39 kW / meter long waves. For waves with a height of 100 meters and a period of 12 seconds it produces 600 kW / meter. (Utami, 2010)

The technique of transforming ocean energy into electricity

1. Wave Energy
   The kinetic energy contained in ocean waves is used to drive turbines. The waves rise into the generator room then the rising water pushes air out of the generator room and causes the turbine to spin when the water drops, the air blows from the outside into the generator room and turns the turbine back.
2. Ocean Thermal Energy
   Another way to generate electricity in the sea is to make use of the difference in temperature at sea. The difference in temperature at sea is caused by the difference in sea level or into the sea (sunlight). The temperature difference required a minimum of 38^0 Fahrenheit between surface temperature and submarine temperature for energy purposes or OTEC.

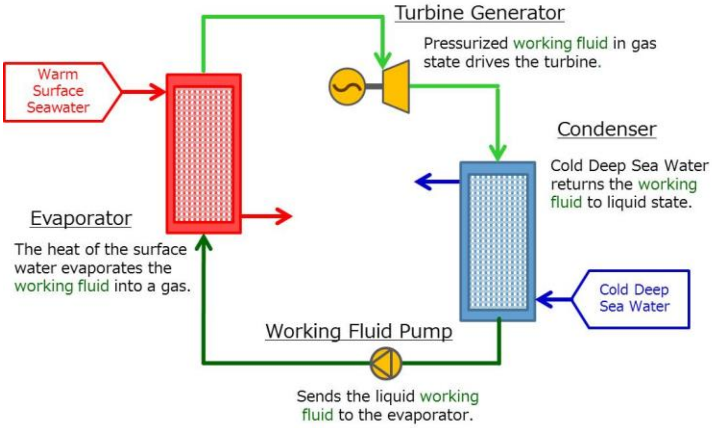

Figure 2.2 Ocean Thermal Energy Conversion
(Source : otecokinawa.com)

3. Ocean Tide & Low Tide
   As is often used in Indonesia, the use of tide is accommodated in the reservoir and then when the water recedes behind the reservoir can be flowed. Works optimally when the tidal wave is large and it takes a difference of 16 feet between tides and lows.

2.3 Wave Energy Converter (WEC)

A wave energy converter is defined as a device to convert kinetic and potential energy associated with moving wave into useful mechanical or electrical energy. WEC categorized into six type of model converter.

2.3.1 Anaconda Wave Energy

Invented by Rod Rainey and Francis Farley and further developed by the licensed manufacturers Checkmate SeaEnergy Ltd. The system essentially consists of a rubber tube filled with water which is placed in the sea. Both ends of this rubber tube are sealed and it is anchored with its head to the waves. It is squeezed or enlarged locally by waves causing pressure variations along its length. A running bulge wave is generated by squeezing the water-filled rubber tube. The bulge wave travels at a speed that is determined by the geometry and material properties of the tube. Anaconda is designed so that its bulge wave speed is close to the speed of the external water waves above. In this resonance condition the bulges grow as they travel along the tube, gathering wave energy. Inside the tube, the bulge waves are accompanied by a periodically reversing flow. Localised squeezing and enlarging effects permit energy to be extracted indirectly with a Power Take-Off (PTO). One way of extracting power from Anaconda is to use a pair of duck-bill valves to convert this power into a rectified flow past a turbine between high and low pressure reservoirs.

Figure 2.4 Anaconda wave energy converter
(Source: Checkmate SeaEnergy Ltd)

2.3.2 Oyster Hydraulic Piston System

The Oyster is a hydro-electric wave energy device uses the motion of ocean waves to generate electricity. It is made up of a Power Connector Frame (PCF), which is bolted to the seabed, and a Power Capture Unit (PCU). The PCU is a hinged buoyant flap that moves back and forth with movement of the waves. The movement of the flap drives two hydraulic pistons that feed high-pressured water to an onshore hydro-electric turbine, which drives a generator to make electricity. (Dr. Ing Ingo Ruhlicke, 2012)

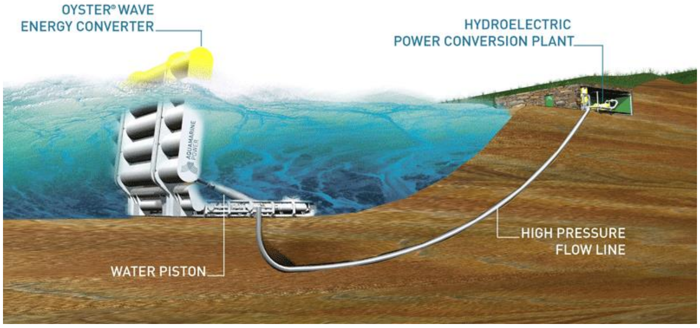

Figure 2.3 The Oyster power plant sits on the sea floor
(Source : hydraulicspneumatics.com)

2.3.3 Actuator Pelamis System

Pelamis Wave Power became the worlds first offshore wave power converter to successfully generate electricity into a national grid. The device was 120m long, 3.5m in diameter and comprised four tube sections. Concept which is designed instead primarily for survival in extreme seas. This is accomplished by its end-on orientation to the waves, which enables the WEC negotiate breaking waves safely, and by its relatively small diameter (3.5m), which non-linearly limits power output in extreme conditions. (Gobato, 2015)

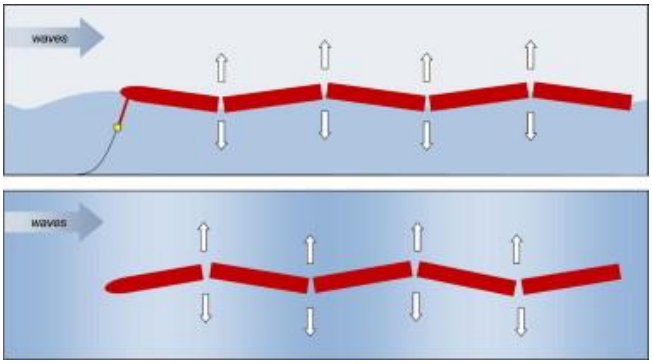

Figure 2.5 Actuator Pelamis System
(Source : researchgate.net/wave-energy-converter)

2.3.4 Archimedes Wave Swing System

The Archimedes wave swing is a solution to tidal power generation. This wave energy converter is a cylindrical shaped buoy which is submerged and tethered to the ocean floor. Moored to the seabed, this generation unit has got only one moving part, the floater unit. The floater unit is an air-filled device which is connected to a lower fixed cylinder. In the fixed cylinder, a uniquely designed linear generator converts the up and down motion into energy. The wave action powers the floater which moves up and down, generating a reciprocating movement. When the wave crest approaches, pressure on the top of the floater increases, which pushes mechanism inside the cylinder downwards, compressing the gas within the cylinder to balance the pressure. When the wave trough passes over the floater, the reverse process takes place , moving the floater upwards and decompressing the gas inside the cylinder. This reciprocating motion generated by the floater is converted into electricity by means of a hydraulic system or a motor-generator set. Having only one moving part makes the sytem more reliable with less need for maintenance.

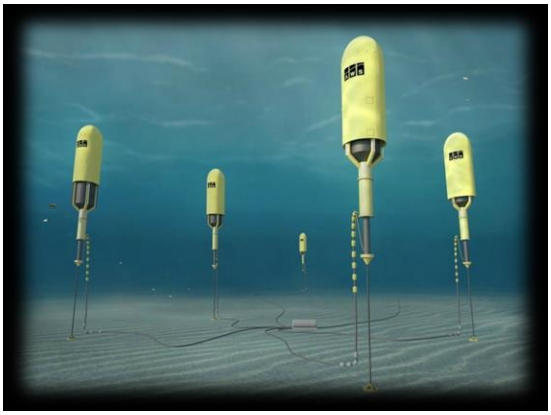

Figure 2.6 Archimedes Wave Swing System
(Source : awsocean.com)

2.3.5 Wave Dragon

Wave Dragon is a wave energy converter of the over-topping type a floating hydro-electric dam and represents a unique, innovative development of a state of the art technology within the field of Wave Energy converters. Wave Dragon achieves exceptional wave energy conversion efficiencies with very few moving parts. The heart of the Wave Dragon unit is a large floating reservoir. Two reflector wings concentrate the power of oncoming waves which pass up a curved ramp and into the reservoir. The water returns back to sea through a battery of low-head turbines connected directly to permanent magnet generators. The reservoir and wings are connected to a forward mooring buoy by hawsers. The wholestructure weather-vanes to face oncoming waves naturally. The forward buoy is moored toanchors on the sea floor. Multiple redundancies ensure structural integrity. (Friis-Madsen, 2015)

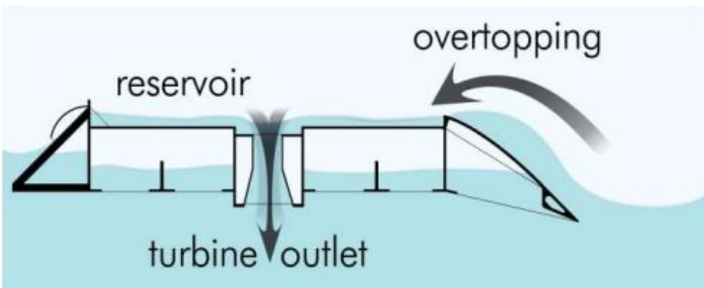

Figure 2.7 Wave Dragon
(Source:Wave Dragon North Sea Demosntrator 1.5 MW Report)

2.3.6 Oscillating Wave Column (OWC)

Of the several types of WEC (Wave Energy Converter) Oscillating Water Colomn type is the most popular type of WEC. This system generates electricity from rising sea levels due to ocean waves that enter into a isollation column. The fluctuative sea level in the column will compress air inside the column and generate pressure to drive the turbine.The turbine rotation will produce power to generate electricity.

Figure 2.8 Oscillating Water Column
(Source : Researchgate.net/figure/principle-operation-of-fixed-structure-OWC)

2.4 Oscillating Wave Column (OWC)

WEC (Wave Energy Converter) type Oscillating Water Column is the most popular type of WEC, Oscillating water column has several advantages compared to other types of WEC technology. It is a simple technology by utilizing wave fluctuations which goes into the isolation collector to produce energy for turbine rotation. The power plant system consists of air collector chamber which serves to drive turbines, the columns function is accomodate water moves up and down through inside the column The movement of water fluctuative with ocean waves causes air flow through the column and rotate the turbine. The turbine is designed to work with a two-way flow.

2.4.1 Component Of Oscillating Water Column (OWC)

a. Collector

Collector is a building or construction with functions to collect as many waves as possible. Based on its function, the shape of the collector is planted into the seabed. From the data obtained, namely the height of the sea wave, the period of ocean waves and the width of the collector column can be calculated the amount of power that enters the collector. The collector has an orifice hole that connects the collector to the wind turbine. In the orifice there is a force and wind pressure used to rotate the turbine.

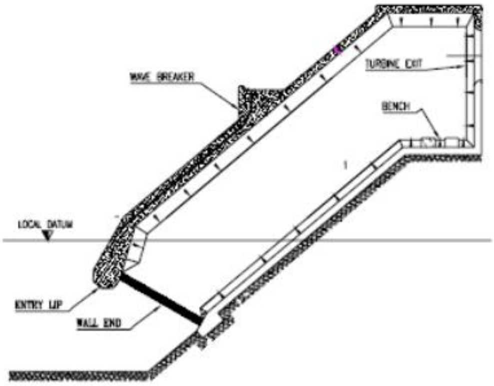

Figure 2.9 OWC Collector
(Source: Publishable Report of Islay LIMPET Wave Power Plant)

b. Orifice & Turbine

Wind turbines on Oscillating Water Colomn function is to change the air pressure produced by the collector into motion energy. The working principle of a wind turbine is to change the mechanical energy from the air pressure to the rotating energy in the turbine, then spin the turbine is used to rotate the generator which ultimately produces electrical energy. Generally the effective power that wind turbines can produce is only 20% -30%.

Table 2.1 Wind Turbine Parameter
(Source: Publishable Report of Islay LIMPET Wave Power Plant)

Turbine Diameter	2.6 m
Nominal Operating Speed	1050 rpm
Number of Turbines	2
Arrangement	In Line Contra-rotating
Blade Form	NACA0012
Number of Blades	7
Blade Chord	320mm
Hub to Tip Ratio	0.62

Orifice is the hole where the turbine is placed. The turbine in the orifice can rotate because the air in the OWC column is pushed out and the air outside is sucked into the OWC column.

2.4.2 OWC Basic Theory

To calculate the OWC output power, the Bernoulli equation can be used, taking into account several parameters.

$$Pu = (P_2-P_1)\ v_1\ A_1 \quad (2.14)$$

Pu : OWC Power (watt)
p_2 : Air Pressure on Orifice (Pa)

p_1 : Air pressure on Column (Pa)
v_1 : Air Velocity on Column OWC (m/sec)
A_1 : Column area (m^2)

(Cormick, 1981)

The stages are as follows,

1. Calculate the wavelength

$$\lambda = \frac{g}{2\pi} T^2 \quad (2.15)$$

λ : Wavelength (m)
g : Gravity Force (m/s^2)
T : Wave Period (sec)

2. Calculates the frequency in a column

$$f = \frac{1}{T} \quad (2.16)$$

fc : Resonant frequency of the rotation in column (Hz)
T : Wave Period (sec)

3. Calculates the angular velocity of a wave

$$\omega = 2\Pi f \quad (2.17)$$

fc : Resonant frequency of the rotation in column (Hz)
: Angular wave velocity (rad/sec)

4. Calculates the speed of air flow around the column

$$v1 = -\frac{\omega}{2} H \sin(\omega t) \quad (2.18)$$

v_1 : Air Velocity on orifice (m/sec)
c : Angular wave velocity (rad/sec)

5. Calculates Air Velocity on orifice

$$v2 = \frac{A1}{A2} v1 \quad (2.19)$$

v_2 : Air Velocity near column OWC (m/sec)
v_1 : Air Velocity on orifice (m/sec)
A_1 : Colomn Area OWC (m^2)
A_2 : Orifice Area (m^2)

6. Calculates Air Capacity

$$P = (P2 - P1)\, Q \quad (2.20)$$

From continuity equation can get,

$$Q_1 = v_1 A_1$$
$$Q_2 = v_2 A_2 \quad (2.21)$$

Q_1 : Air Capacity in column OWC (m^3/sec)
Q_2 : Air Capacity in orifice (m^3/sec)
A_1 : Colomn Area OWC (m^2)
A_2 : Orifice Area (m^2)
v_1 : Air Velocity near column OWC (m/sec)
v_2 : Air Velocity on orifice (m/sec)

(Cormick, 1981)

7. Calculate Potential Velocity

$$\varphi_2 \cong v_2 \eta_2 = -\left(\frac{A1}{A2}\right) v_1 \frac{\omega H^2}{4} \sin(\omega t)\cos(\omega t) \quad (2.22)$$

v_1 : Air Velocity near column OWC (m/sec)
v_2 : Air Velocity on orifice (m/sec)
: Angular wave velocity (rad/sec)
A_1 : Colomn Area OWC (m^2)
A_2 : Orifice Area (m^2)
Q_1 : Air Capacity in column OWC (m^3/sec)
Q_2 : Air Capacity in orifice (m^3/sec)
φ_2 : Potenrial Velocity (rad.m/s)

8. Calculate Air Pressure on Orifice

$$P2 - P1 = \rho \left(\frac{A1}{A2}\right) \frac{d\varphi 2}{dt} \quad \frac{Q}{A2}\,(v2 - v1) \quad (2.23)$$

$P2$: Air Pressure on orifice (Pa)
$P1$: Air Pressure on column (Pa)
Q : Air Capacity in orifice (m^3/sec)
φ_2 : Potenrial Velocity (rad.m/s)
v_1 : Air Velocity near column OWC (m/sec)

v_2 : Air Velocity on orifice (m/sec)

(Cormick, 1981)

To calculate the power in the turbine requires the value of force and air pressure on the collector's oriface and the torque of the turbine. To calculate turbine torque, the equation is:

$$Q = F\, x l \tag{2.24}$$

Q : Turbine Torque (Nm)
F : Force on Orifice (N)
l : Turbine Radius (m)

To calculate the power generated by the turbine with the equation of,

$$Pt = \omega Q = 2\pi n Q \tag{2.25}$$

Pt : Power generated by turbine (W)
Q : Turbine Torque (Nm)
n : Turbine Rotation (Rpm)

For calculate the power of OWC and turbine, the efficiency of OWC and Turbine performance can be calculate by the equation of,

$$\eta\text{owc} = \frac{Pt}{Pw} x\ 100\% \tag{2.26}$$

ηowc : Efficiency of OWC
Pt : Turbine Power (w)
Pw : Wave Power (w)

2.5 Solidworks

The Solidworks software is a mechanical design automation application that lets designers quickly sketch out ideas, experiment with features and dimensions, and produce models and detailed drawings. Parts are the basic building blocks in the Solidworks software (SolidWorks, 2015). Assemblies contain parts or other assemblies, called subassemblies. A Solid model consists of 3D geometry that defines its edges, faces, and surfaces. The Solidworks software can use for design models quickly and precisely. Solidworks models are defined 3D design and based on component. Solidworks can use for a 3D design approach. Design a part, from the initial sketch to the final result and create a 3D model. From this model, we can create 2D drawings or mate components consisting of parts or subassemblies to create 3D assemblies. Solidworks also create 2D drawings of 3D assemblies. When designing a model using Solidworks it can visualize in three dimensions, the way the model exists once it is manufactured.

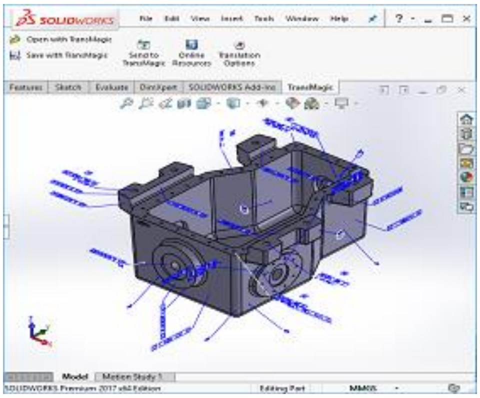

Figure 2.10 Solidworks
(Source: solidworks.com)

2.6 Computational Fluid Dynamic

CFD is a method of calculating, predicting, and approaching fluid flow numerically with the help of computers. Fluid flow in real life has many types and certain characteristics that are so complex, CFD approaches the numerical method and uses fluid equations. CFD is a method of calculation with a control of dimensions, area and volume by utilizing computer computing to calculate the dividing elements. The principle is that a space that contains fluid to be calculated is divided into several parts, this is often called a cell and the process is called meshing. The divided parts are a calculation dick that will be done by the application or software. These calculation controls and other calculation controls are the mentioned division of space or meshing. (ANSYS, 2007).

At each calculation control point, the application will be calculated with the boundary domain and boundary conditions specified. This principle is widely used in the calculation process using computer computing assistance. CFD is a calculation that specializes in fluid, starting from fluid flow, heat transfer and chemical reactions that occur in fluid. Based on the basic principles of fluid mechanics, energy conservation, momentum, mass, and species, calculations with CFD can be done. In simple terms the calculation process carried out by the CFD application is with the calculation controls that have been made, the calculation control will be involved by utilizing the equations involved. These equations are the equations that are generated by entering any parameters involved in the domain. For example, when a model to be analyzed involves temperature, it means that the model involves the energy or conservation equation of that energy.

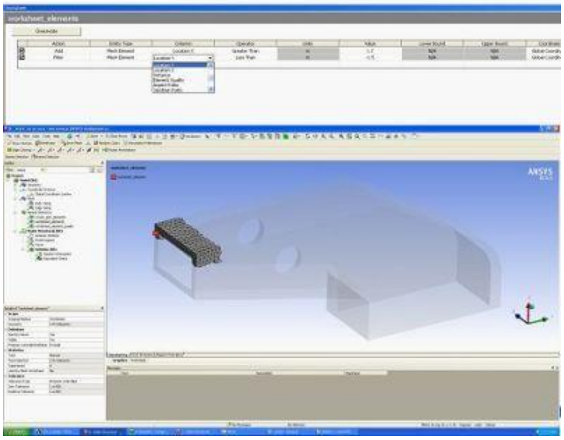

Figure 2.11 CFD Program
(Source : Simutechgroup.com)

CHAPTER III
METHODOLOGY

3.1 Flowchart

Research method is a reference or foundation used in research activities. In general, research methods are the stages and processes used to achieve the objectives of the research in the thesis. The methodology used in this final project is calculation and simulation method, which will be tested using software for validation.

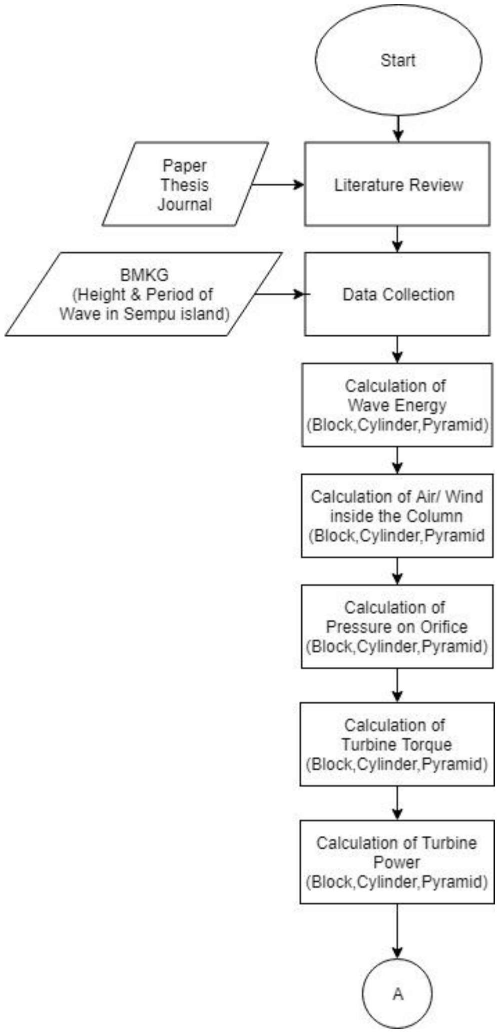

Figure 3.1 Methodology Flowchart

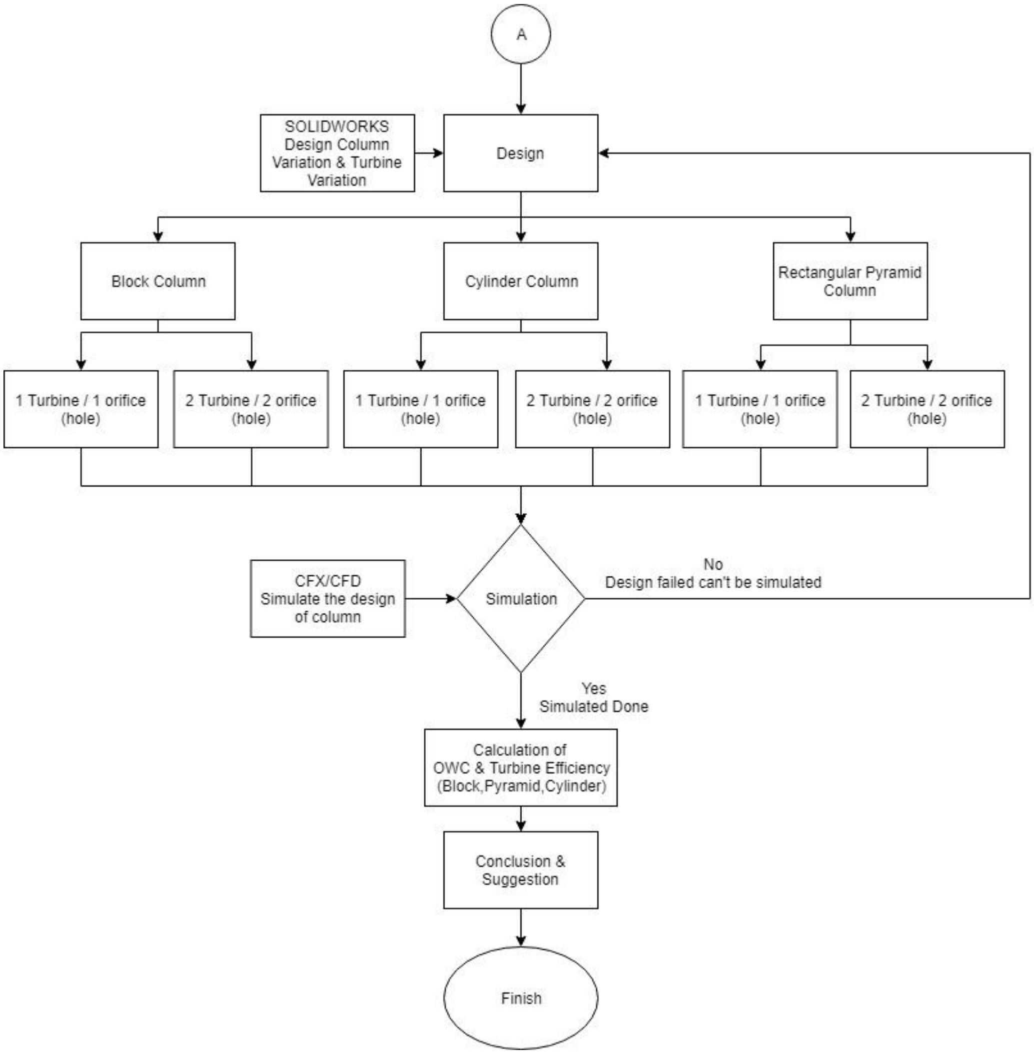

Figure 3.2 Methodology Flowchart

3.2 Detail Flowchart Explanation

This is a detailed description of the Flowchart of research writing:

1. Literature Review

Literature studies are conducted to study theories that can support solving existing problems. Literature studies are obtained from several sources such as books, journals, thesis, and also the internet. Where the literature refers to wave theory and also optimization of Oscillating Water Column (OWC), and several other materials that can support the work of this research.In this section the author looks for sources of information and references from various media that are assured of truth.

2. Data Collection

Data collection was carried out from Badan Meterorologi dan Geofisika. The data is talk about wave current on South Malang East Java (Sempu Island).

3. Calculation of Wave Energy and Power

Based on the sea wave height data throughout 2013 obtained from BMKG, Wave energy and power can be calculated by knowing the characteristic of the wave.

4. Calculation of Air inside the column

After get the value of the power and energy produce by the column, the next step is to calculate the air velocity value on the OWC for knowing the air pressure on the orifice.

5. Calculation of Pressure on Orifice

Before calculate the torque value in the turbine is to calculate the value of air pressure on the orifice. It affect the number of torque that can be produce for the Turbine.

6. Calculation of Turbine Torque

For the calculation of the turbine power, a force value is needed in column dimensions, torque will be produce for rotating the turbine.

7. Calculation of Turbine Power

This step is to calculate the power of turbine the power produce by each column (Block, Cylinder, and Pyramid) and the affect of variation number of turbine (1 Turbine and 2 Turbine).

8. Design

By using SolidWorks the next step is Design the variation of column (Block, Cylinder, and Pyramid). The dimensions of the columns are varied with the shape and width of each column. The assumption is :

Block Column

Size data:
Length (m) : 3 m
Width (m) : 3 m
Heigth (m) : 6 m
Diameter Orifice: 2.6 m

Cylinder Column

Size data
Diameter : 3.5 m
Radius : 1.75 m
Heigth : 6 m
Diameter Orifice : 2.6 m

Rectangular Pyramid

Size Data :
Length (m) : 4 m
Width (m) : 2.5 m
Heigth (m) : 6 m
Diameter Orifice : 2.6 m

9. Simulation

The numerical simulation process in Computational Fluid Dynamic starts from making dimensions of the Oscillating Water Column model. Modeling using Solidworks program, then the file is exported to be opened in ANSYS. In general, the CFD calculation process consists of 3 main parts: 1. Pre-processor 2. Processor 3. Post Processor.

a. Pre Processor

This is the first step to using ansys, the process are as follows:

1. Open the AnsysCFD application Workbench.
2. Import the design files that have been created in SolidWorks into the Ansys workbench.
3. Geometry or design processing.
4. The next step is the process of meshing. At this stage the object or space to be analyzed is divided by a certain number of grids.

b. Processor (Setup)

At this stage the process of calculating input data is carried out with equations that are involved iteratively. This means that the calculation is done until the results lead to the smallest error or to reach a convergent value. The input value used as input is the wave propagation speed, while the output value is the value of wind pressure on the orifice (Hole for turbine). After entering the desired input and output values, the next step is to run the calculation.

c. Post Processor (Result)

The final stage is the postprocessor stage where the calculation results are interpreted into image in order to obtain a clear interpretation of the results of the calculation by entering the contour that want to observe.

10. Calculation of OWC & Turbine Efficiency

After simulation and mechanical power produced by the turbine is known, it used to know the efficiency of Oscillating Water Column and turbine. The better option of the OWC Column and Number of turbine can be known.

11. Conclusion & Suggestion

After all the step has been done the research result can know the most efficient column & turbine to be applied in oscillating water column (OWC) so the conclusion from the research can be conduct and give suggestion for improving the research.

CHAPTER IV
RESULTS AND DISCUSSION

4.1 General Description

The south coast of East Java is a beach with potential that is quite capable for Wave energy conversion development (Oscillating water column), one of which is in the area of south malang sea.

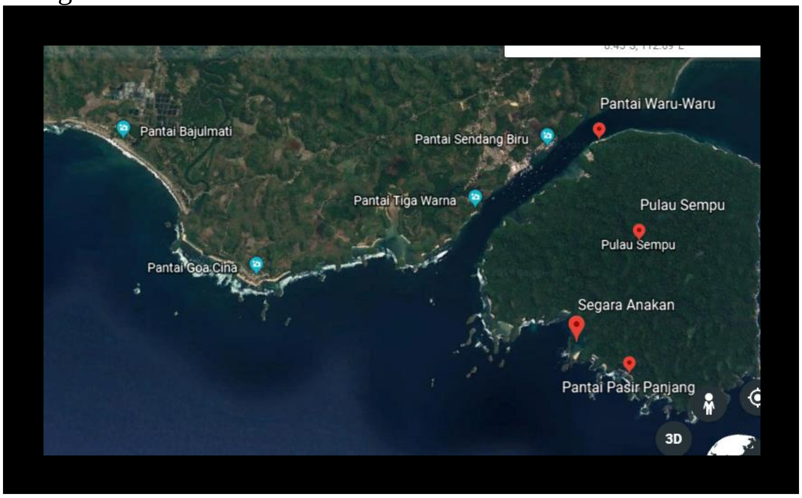

Figure 4.1 South Malang Ocean
(Source : Googleearth.com)

Figure 4.2 South Malang Ocean
(Source : Googleearth.com)

Located near the sempu island and Indian ocean. The area has a potential wave to generate electricity..

4.2 Wave Height Data

Based on the sea wave height data throughout 2013 obtained from BMKG, the wave characteristic obtained as follows :

Table 4.1 Wave Charateristic in South Malang East Java

Wave Characteristic			
Month	H (meter)	T (second)	Wave Frequent (Hz)
January	0.90	4.80	0.21
February	0.70	4.70	0.21
March	2.70	4.90	0.20
April	1.70	4.50	0.22
May	1.60	5.50	0.18
June	1.60	5.50	0.18
July	2.80	5.70	0.18
August	2.20	6.00	0.17
September	2.10	5.40	0.19
October	1.90	4.70	0.21
November	1.30	4.70	0.21
December	1.10	4.60	0.22

4.3 Wave Power

Based on the Publishable Report of LIMPET Islay Power Plant, the column width is varied to 5m, 6m and 7m, for this thesis the column is varied to the form of a Block (3m width), Cylinder (3.5m width) and Pyramid (2.5 m width). After obtain the value of sea wave height, the energy and power calculations are generate by the equation of :

$$Ew = 0,195 w \rho g h^2 T^2 \quad (2.12)$$
$$Pw = 0.195 w \rho g h^2 T \quad (2.13)$$

Where,

Ew : Wave Energy (J)
Pw : Wave Power (W)
w : Column Width (m)
: Ocean Density (1025 kg/m^3)
g : Gravity acceleration (m/s^2)
h : Ocean Wave Height (m)
T : Wave period (s)

Wave width can be assumed from each column, from the calculations data of block column is obtained as follows:

Table 4.2 Block Column Wave Power

Block (Wave Energy & Power)					
Month	H (meter)	T (second)	Ew (J)	Wave Width (m)	Pw (w)
January	0.9	4.8	109778.23	3	22870
February	0.7	4.7	63670.83	3	13547
March	2.7	4.9	1029599.75	3	210122
April	1.7	4.5	344248.15	3	76500
May	1.6	5.5	455526.96	3	82823
June	1.6	5.5	455526.96	3	82823
July	2.8	5.7	1498354.28	3	262869
August	2.2	6	1024935.65	3	170823
September	2.1	5.4	756440.63	3	140082
October	1.9	4.7	469085.12	3	99805
November	1.3	4.7	219599.41	3	46723
December	1.1	4.6	150608.60	3	32741

From the calculations above the most high wave energy produce by block column is 1.498.354 J. The most high wave power produce by block column is 262.869 W. The data of cylinder column is obtained as follows:

Table 4.3 Cylinder Column Wave Power

Cylinder (Wave Energy & Power)					
Month	H (meter)	T (second)	Ew (J)	Wave Width (m)	Pw (w)
January	0.9	4.8	128074.60	3.5	26682
February	0.7	4.7	74282.64	3.5	15805
March	2.7	4.9	1201199.70	3.5	245143
April	1.7	4.5	401622.84	3.5	89250
May	1.6	5.5	531448.12	3.5	96627
June	1.6	5.5	531448.12	3.5	96627
July	2.8	5.7	1748079.99	3.5	306681
August	2.2	6	1195758.26	3.5	199293
September	2.1	5.4	882514.07	3.5	163429

Cylinder (Wave Energy & Power)					
Month	H (meter)	T (second)	Ew (J)	Wave Width (m)	Pw (w)
October	1.9	4.7	547265.97	3.5	116440
November	1.3	4.7	256199.31	3.5	54510
December	1.1	4.6	175710.03	3.5	38198

From the calculations above the most high wave energy produce by Cylinder column is 1.748.079 J. The wave power can be calculated as follow :From the calculations above the most high wave power produce by cylinder column is 306.681 W. The data of pyramid column is obtained as follows:

Table 4.4 Pyramid Column Wave Power

Pyramid (Wave Energy & Power)					
Month	H (meter)	T (second)	Ew (J)	Wave Width (m)	Pw (w)
January	0.9	4.8	91481.86	2.5	19059
February	0.7	4.7	53059.03	2.5	11289
March	2.7	4.9	857999.79	2.5	175102
April	1.7	4.5	286873.45	2.5	63750
May	1.6	5.5	379605.80	2.5	69019
June	1.6	5.5	379605.80	2.5	69019
July	2.8	5.7	1248628.57	2.5	219058
August	2.2	6	854113.05	2.5	142352
September	2.1	5.4	630367.19	2.5	116735
October	1.9	4.7	390904.27	2.5	83171
November	1.3	4.7	182999.50	2.5	38936
December	1.1	4.6	125507.17	2.5	27284

From the calculations above the most high wave energy produce by Pyramid column is 857.999 J. From the calculations above the most high wave power produce by pyramid column is 175.102 W.

From table 4.3,table 4.4, and table 4.5 with different sea wave heights (H), varying energy and power can be obtained. Increasing the value of kinetic energy causes the value of the resulting power to increase as well.

a. The highest kinetic energy produced by the Block column is 1.498.354 J with the power produced 262.869 W with a wave height of 2.8 m.

b. The highest kinetic energy produced by the Cylinder column is 1.748.079 J with the power produced 306.681 W with a wave height of 2.8 m.
c. The highest kinetic energy produced by the Pyramid column is 857.999 J with the power produced 175.102 W with a wave height of 2.8 m.

The width of the column affects the amount of energy produced.

4.4 Air Speed on Oscillating Water Column

After getting the value of the power and energy produced, the next step is to calculate the air speed value on the OWC. The formula is,

$$v1 = -\frac{\omega}{2} H \sin(\omega t) \qquad (2.18)$$

Where,

v_1 : Air Speed on the column (m/sec)

: Angular Wave Velocity (rad/sec)

H : Wave Height (m)

From these calculations the data is obtained as follows:

Table 4.5 Air Speed on Column

Air Speed on Column (Wind Speed "V1")						
Month	H (meter)	T (second)	Frequent (Hz)	Omega W	Sin wt	V1 (m/s)
January	0.9	4.8	0.21	1.31	-0.39	0.23
February	0.7	4.7	0.21	1.34	-0.39	0.18
March	2.7	4.9	0.20	1.28	-0.38	0.65
April	1.7	4.5	0.22	1.40	-0.41	0.49
May	1.6	5.5	0.18	1.14	-0.34	0.31
June	1.6	5.5	0.18	1.14	-0.34	0.31
July	2.8	5.7	0.18	1.10	-0.33	0.51
August	2.2	6	0.17	1.05	-0.31	0.36
September	2.1	5.4	0.19	1.16	-0.34	0.42
October	1.9	4.7	0.21	1.34	-0.39	0.50
November	1.3	4.7	0.21	1.34	-0.39	0.34
December	1.1	4.6	0.22	1.37	-0.40	0.30

The wave height influences the speed of air flow in the OWC column, the higher wave height, the faster air flow at OWC. The greater Air speed on column is in March (0.65 m/s).

4.5 Air Speed and Capacity in Orifice

The next calculation step is to calculate the air velocity and capacity values in the orifice, using the following formula:

$$v2 = \frac{A1}{A2}\, v1 \tag{2.19}$$

v_2 : Air Speed on the orifice (m/s)
A_1 : Area in column (m^2)
A_2 : Area in orifice (m^2)
v_1 : Air Speed on the column (m/s)

The values of the area A1 and A2 are obtained by calculating the area of the column and orifice (cylinder). From these calculations the data is obtained as follows:

Table 4.6 Air Speed on Orifice of Block (1 Orifice)

Air Speed on Orifice (Wind Speed "V2") Block				
Month	V1 (m/s)	Area 1 (m^2) Block	Area 2 (m^2) Cylinder	V2 (m/s)
January	0.23	90.00	18.79	1.09
February	0.18	90.00	18.79	0.88
March	0.65	90.00	18.79	3.13
April	0.49	90.00	18.79	2.33
May	0.31	90.00	18.79	1.48
June	0.31	90.00	18.79	1.48
July	0.51	90.00	18.79	2.42
August	0.36	90.00	18.79	1.72
September	0.42	90.00	18.79	2.02
October	0.50	90.00	18.79	2.39
November	0.34	90.00	18.79	1.64
December	0.30	90.00	18.79	1.44

The values of the area A1 and A2 are obtained by calculating the area of the column and orifice (cylinder). The area of Block is 90 m^2 and the area of orifice is 18.79 m^2 for 1 orifice and 37.58 m^2 for 2 orifice. The figure and the calculation of 2 orifice as below,

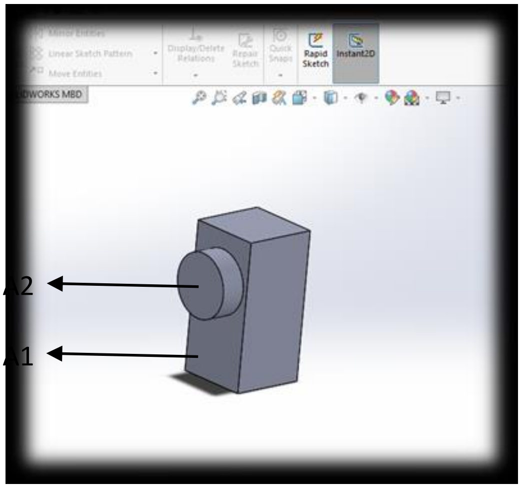

Figure 4.3 Area of Block (1 Orifice)

Table 4.7 Air Speed on Orifice of Block (2 Orifice)

Air Speed on Orifice (Wind Speed "V2") Block				
Month	V1 (m/s)	Area 1 (m^2) Block	Area 2 (m^2) Cylinder	V2 (m/s)
January	0.23	90.00	37.58	0.54
February	0.18	90.00	37.58	0.44
March	0.65	90.00	37.58	1.57
April	0.49	90.00	37.58	1.16
May	0.31	90.00	37.58	0.74
June	0.31	90.00	37.58	0.74
July	0.51	90.00	37.58	1.21
August	0.36	90.00	37.58	0.86
September	0.42	90.00	37.58	1.01
October	0.50	90.00	37.58	1.20
November	0.34	90.00	37.58	0.82
December	0.30	90.00	37.58	0.72

The fastest Block column air speed on orifice is in March (1 Orifice : 3.13, 2 Orifice 1.57 m/s). The slowest air speed on orifice is in February (1 Orifice : 0.88, 2 Orifice : 0.44 m/s). The Speed of air in cylinder column orifice are as follow,

Table 4.8 Air Speed on Orifice of Cylinder (1 Orifice)

Air Speed on Orifice (Wind Speed "V2") Cylinder				
Month	V1 (m/s)	Area 1 (m^2) Cylinder	Area 2 (m^2) Cylinder	V2 (m/s)
January	0.23	85.22	18.79	1.03
February	0.18	85.22	18.79	0.83
March	0.65	85.22	18.79	2.97
April	0.49	85.22	18.79	2.20
May	0.31	85.22	18.79	1.40
June	0.31	85.22	18.79	1.40
July	0.51	85.22	18.79	2.29
August	0.36	85.22	18.79	1.63
September	0.42	85.22	18.79	1.91
October	0.50	85.22	18.79	2.26
November	0.34	85.22	18.79	1.55
December	0.30	85.22	18.79	1.37

The values of the area A1 and A2 are obtained by calculating the area of the column and orifice (cylinder). The area of cylinder is 85.22 m^2 and the area of orifice is 18.79 m^2 for 1 orifice (1 Turbine) and 37.58 m^2 for 2 orifice (2 Turbine). The figure and the calculation of 2 orifice as below,

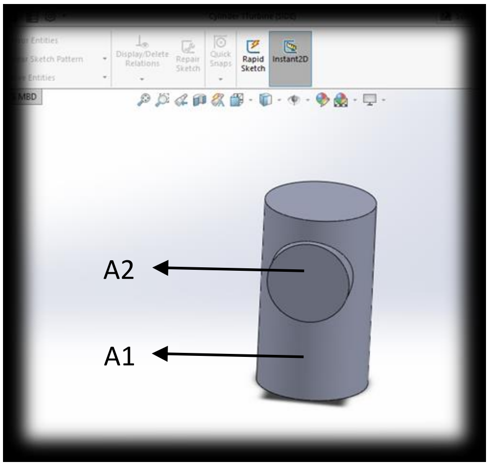

Figure 4.4 Area of Cylinder (1 Turbine)

Table 4.9 Air Speed on Orifice of Cylinder (2 Orifice)

Air Speed on Orifice (Wind Speed "V2") Cylinder				
Month	V1 (m/s)	Area 1 (m^2) Cylinder	Area 2 (m^2) Cylinder	V2 (m/s)
January	0.23	85.22	37.58	0.51
February	0.18	85.22	37.58	0.42
March	0.65	85.22	37.58	1.48
April	0.49	85.22	37.58	1.10
May	0.31	85.22	37.58	0.70
June	0.31	85.22	37.58	0.70
July	0.51	85.22	37.58	1.15
August	0.36	85.22	37.58	0.81
September	0.42	85.22	37.58	0.95
October	0.50	85.22	37.58	1.13
November	0.34	85.22	37.58	0.77
December	0.30	85.22	37.58	0.68

The fastest Cylinder column air speed on orifice is in March (1 Orifice : 2.97, 2 Orifice 1.48 m/s). The slowest air speed on orifice is in February (1 Orifice : 0..83, 2 Orifice : 0.42 m/s). The Speed of air in pyramid column orifice are as follow,

Table 4.10 Air Speed on Orifice of Pyramid (1 Orifice)

Air Speed on Orifice (Wind Speed "V2") Pyramid				
Month	V1 (m/s)	Area 1 (m^2) Pyramid	Area 2 (m^2) Cylinder	V2 (m/s)
January	0.23	45.00	18.79	0.54
February	0.18	40.00	18.79	0.39
March	0.65	113.37	18.79	3.95
April	0.49	108.47	18.79	2.80
May	0.31	85.33	18.79	1.41
June	0.31	85.33	18.79	1.41
July	0.51	108.50	18.79	2.92
August	0.36	93.50	18.79	1.79
September	0.42	101.00	18.79	2.26

Air Speed on Orifice (Wind Speed "V2") Pyramid				
Month	V1 (m/s)	Area 1 (m^2) Pyramid	Area 2 (m^2) Cylinder	V2 (m/s)
October	0.50	108.48	18.79	2.88
November	0.34	89.80	18.79	1.63
December	0.30	85.32	18.79	1.37

The values of the area A1 and A2 are obtained by calculating the area of the column and orifice (cylinder). The area of pyramid is fluctuative because of height of the wave that fill the area is different because of the shape of pyamid. The area of orifice is 18.79 m^2 for 1 orifice (1 Turbine) and 37.58 m^2 for 2 orifice (2 Turbine). The figure and the calculation of 2 orifice as below,

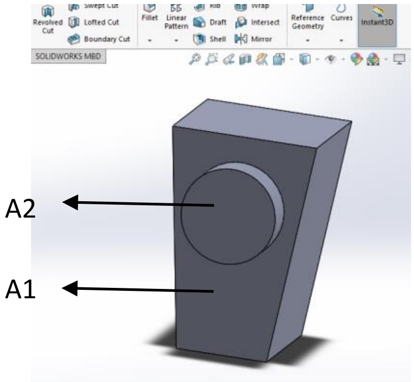

Figure 4.5 Area of Pyramid (1 Turbine)

Table 4.11 Air Speed on Orifice of Pyramid (2 Orifice)

Air Speed on Orifice (Wind Speed "V2") Pyramid				
Month	V1 (m/s)	Area 1 (m^2) Pyramid	Area 2 (m^2) Cylinder	V2 (m/s)
January	0.23	45.00	37.58	0.27
February	0.18	40.00	37.58	0.20
March	0.65	113.37	37.58	1.97
April	0.49	108.47	37.58	1.40
May	0.31	85.33	37.58	0.70
June	0.31	85.33	37.58	0.70
July	0.51	108.50	37.58	1.46

Air Speed on Orifice (Wind Speed "V2") Pyramid				
Month	V1 (m/s)	Area 1 (m^2) Pyramid	Area 2 (m^2) Cylinder	V2 (m/s)
August	0.36	93.50	37.58	0.89
September	0.42	101.00	37.58	1.13
October	0.50	108.48	37.58	1.44
November	0.34	89.80	37.58	0.82
December	0.30	85.32	37.58	0.68

The fastest Pyramid column air speed on orifice is in March (1 Orifice : 3.95, 2 Orifice 1.97 m/s). The slowest air speed on orifice is in February (1 Orifice : 0.39, 2 Orifice : 0.20 m/s).

After calculate the speed of air (v_1 & v_2) air capacity can be calculate by the equation of,

$$Q_2 = v_2 A_2 \tag{2.21}$$

Q_2 : Air Capacity in orifice (m^3/s)
v_2 : Air Speed on the orifice (m/s)
A_2 : Area in orifice (m^2)

From these calculations the data is obtained as follows:

Table 4.12 Air Capacity in Orifice

Air Capacity in Orifice				
Month	T (second)	Block (m^3/s)	Pyramid (m^3/s)	Cylinder (m^3/s)
January	4.8	20.42	10.21	19.34
February	4.7	16.55	7.35	15.67
March	4.9	58.87	74.15	55.74
April	4.5	43.71	52.68	41.39
May	5.5	27.86	26.41	26.38
June	5.5	27.86	26.41	26.38
July	5.7	45.47	54.82	43.06
August	6	32.32	33.58	30.60
September	5.4	37.90	42.53	35.89
October	4.7	44.91	54.13	42.53

Air Capacity in Orifice				
Month	T (second)	Block (m^3/s)	Pyramid (m^3/s)	Cylinder (m^3/s)
November	4.7	30.73	30.66	29.10
December	4.6	27.11	25.70	25.67

From the calculations above the most high Air capacity produce by Block, Pyramid and Cylinder column is 58.87 m^3/s, 74.15 m^3/s, 55.74 m^3/s. The calculation above can be describe by graph as below,

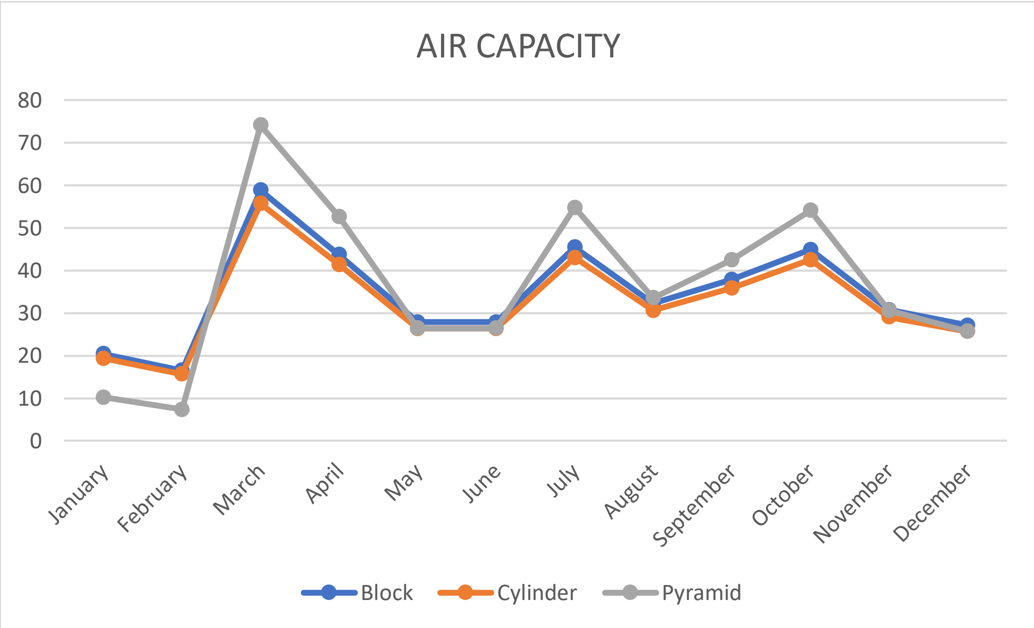

Figure 4.6 Air Capacity Graph

The amount of air speed in the orifice is influenced by column area, orifice area and air speed in the column. The amount of air capacity in the orifice is influenced by two factors, namely air speed in the column and area of orifice. The greater air speed in the column let the greater air capacity in the orifice.

4.6 Potential Air Velocity in Orifice

After calculated the air capacity value on the orifice, the potential value of air velocity can be calculate to get the pressure on orifice so for calculate the potential air velocity using the equation as follows :

$$\varphi_2 \cong v_2\eta_2 = -\left(\frac{A1}{A2}\right) v_1 \frac{\omega H^2}{4} \sin(\omega t)\cos(\omega t) \qquad (2.22)$$

$_2$: Potential Air Velocity (rad m/s)

V_2 : Air velocity on the orifice (m/s)
A_1 : Area in column (m^2)
A_2 : Area in orifice (m^2)
H : Wave Height (m)

From the calculations above, block column data is obtained as follows:

Table 4.13 Potential Velocity In Block Colomn (1 Orifice)

Potential Velocity in Orifice (Block)							
Month	H (meter)	T (second)	Frequent (Hz)	Area 1 (m^2) Block	Area 2 (m^2) Cylinder	V1 (m/s)	Potential $\phi 2$ (rad.m/s)
January	0.9	4.8	0.21	90	18.79	0.23	0.0010
February	0.7	4.7	0.21	90	18.79	0.18	0.0005
March	2.7	4.9	0.20	90	18.79	0.65	0.0248
April	1.7	4.5	0.22	90	18.79	0.49	0.0080
May	1.6	5.5	0.18	90	18.79	0.31	0.0037
June	1.6	5.5	0.18	90	18.79	0.31	0.0037
July	2.8	5.7	0.18	90	18.79	0.51	0.0176
August	2.2	6	0.17	90	18.79	0.36	0.0073
September	2.1	5.4	0.19	90	18.79	0.42	0.0087
October	1.9	4.7	0.21	90	18.79	0.50	0.0098
November	1.3	4.7	0.21	90	18.79	0.34	0.0031
December	1.1	4.6	0.22	90	18.79	0.30	0.0020

Table 4.14 Potential Velocity In Block Column (2 Orifice)

Potential Velocity in Orifice (Block)							
Month	H (meter)	T (second)	Frequent (Hz)	Area 1 (m^2) Block	Area 2 (m^2) Cylinder	V1 (m/s)	Potential $\phi 2$ (rad.m/s)
January	0.9	4.8	0.21	90	37.58	0.23	0.0005
February	0.7	4.7	0.21	90	37.58	0.18	0.0002
March	2.7	4.9	0.20	90	37.58	0.65	0.0124
April	1.7	4.5	0.22	90	37.58	0.49	0.0040
May	1.6	5.5	0.18	90	37.58	0.31	0.0018
June	1.6	5.5	0.18	90	37.58	0.31	0.0018
July	2.8	5.7	0.18	90	37.58	0.51	0.0088

Potential Velocity in Orifice (Block)							
Month	H (meter)	T (second)	Frequent (Hz)	Area 1 (m^2) Block	Area 2 (m^2) Cylinder	V1 (m/s)	Potential ϕ2 (rad.m/s)
August	2.2	6	0.17	90	37.58	0.36	0.0037
September	2.1	5.4	0.19	90	37.58	0.42	0.0044
October	1.9	4.7	0.21	90	37.58	0.50	0.0049
November	1.3	4.7	0.21	90	37.58	0.34	0.0016
December	1.1	4.6	0.22	90	37.58	0.30	0.0010

The Potential Air Velocity in block column is influenced by the area of the orifice, column area, air velocity in the column, wave height, angular wave velocity, sin ωt and cos ωt. The highest potential velocity is in March (1 Orifice: 0.0248 rad.m/s, 2 Orifice: 0.0124 rad.m/s) and the lowest potential velocity is in February (1 Orifice: 0.0005 rad.m/s, 2 Orifice: 0.0002 rad.m/s). For Cylinder column data obtained as follow:

Table 4.15 Potential Velocity In Cylinder Column (1 Orifice)

Potential Velocity in Orifice (Cylinder)							
Month	H (meter)	T (second)	Frequent (Hz)	Area 1 (m^2) Cylinder	Area 2 (m^2) Cylinder	V1 (m/s)	Potential ϕ2 (rad.m/s)
January	0.9	4.8	0.21	85.22	18.79	0.23	0.0009
February	0.7	4.7	0.21	85.22	18.79	0.18	0.0005
March	2.7	4.9	0.20	85.22	18.79	0.65	0.0235
April	1.7	4.5	0.22	85.22	18.79	0.49	0.0076
May	1.6	5.5	0.18	85.22	18.79	0.31	0.0035
June	1.6	5.5	0.18	85.22	18.79	0.31	0.0035
July	2.8	5.7	0.18	85.22	18.79	0.51	0.0166
August	2.2	6	0.17	85.22	18.79	0.36	0.0069
September	2.1	5.4	0.19	85.22	18.79	0.42	0.0083
October	1.9	4.7	0.21	85.22	18.79	0.50	0.0093
November	1.3	4.7	0.21	85.22	18.79	0.34	0.0030
December	1.1	4.6	0.22	85.22	18.79	0.30	0.0019

Table 4.16 Potential Velocity In Cylinder Column (2 Orifice)

Potential Velocity in Orifice (Cylinder)							
Month	H (meter)	T (second)	Frequent (Hz)	Area 1 (m^2) Cylinder	Area 2 (m^2) Cylinder	V1 (m/s)	Potential $\phi 2$ (rad.m/s)
January	0.9	4.8	0.21	85.22	37.58	0.23	0.0005
February	0.7	4.7	0.21	85.22	37.58	0.18	0.0002
March	2.7	4.9	0.20	85.22	37.58	0.65	0.0118
April	1.7	4.5	0.22	85.22	37.58	0.49	0.0038
May	1.6	5.5	0.18	85.22	37.58	0.31	0.0017
June	1.6	5.5	0.18	85.22	37.58	0.31	0.0017
July	2.8	5.7	0.18	85.22	37.58	0.51	0.0083
August	2.2	6	0.17	85.22	37.58	0.36	0.0035
September	2.1	5.4	0.19	85.22	37.58	0.42	0.0041
October	1.9	4.7	0.21	85.22	37.58	0.50	0.0046
November	1.3	4.7	0.21	85.22	37.58	0.34	0.0015
December	1.1	4.6	0.22	85.22	37.58	0.30	0.0010

The Potential Air Velocity in cylinder column is influenced by the area of the orifice, column area, air velocity in the column, wave height, angular wave velocity, sin ωt and cos ωt. The highest potential velocity is in March (1 Orifice: 0.0235 rad.m/s, 2 Orifice: 0.0118 rad.m/s) and the lowest potential velocity is in February (1 Orifice: 0.0005 rad.m/s, 2 Orifice: 0.0002 rad.m/s). For Pyramid column data obtained as follow:

Table 4.17 Potential Velocity In Pyramid Column (1 Orifice)

Potential Velocity in Orifice (Pyramid)							
Month	H (meter)	T (second)	Frequent (Hz)	Area 1 (m^2) Pyramid	Area 2 (m^2) Cylinder	V1 (m/s)	Potential $\phi 2$ (rad.m/s)
January	0.9	4.8	0.21	45.00	18.79	0.23	0.0005
February	0.7	4.7	0.21	40.00	18.79	0.18	0.0002
March	2.7	4.9	0.20	113.37	18.79	0.65	0.0313
April	1.7	4.5	0.22	108.47	18.79	0.49	0.0096
May	1.6	5.5	0.18	85.33	18.79	0.31	0.0035
June	1.6	5.5	0.18	85.33	18.79	0.31	0.0035
July	2.8	5.7	0.18	108.50	18.79	0.51	0.0212
August	2.2	6	0.17	93.50	18.79	0.36	0.0076

Potential Velocity in Orifice (Pyramid)							
Month	H (meter)	T (second)	Frequent (Hz)	Area 1 (m^2) Pyramid	Area 2 (m^2) Cylinder	V1 (m/s)	Potential $\phi 2$ (rad.m/s)
September	2.1	5.4	0.19	101.00	18.79	0.42	0.0098
October	1.9	4.7	0.21	108.48	18.79	0.50	0.0118
November	1.3	4.7	0.21	89.80	18.79	0.34	0.0031
December	1.1	4.6	0.22	85.32	18.79	0.30	0.0019

Table 4.18 Potential Velocity In Pyramid Column (2 Orifice)

Potential Velocity in Orifice (Pyramid)							
Month	H (meter)	T (second)	Frequent (Hz)	Area 1 (m^2) Pyramid	Area 2 (m^2) Cylinder	V1 (m/s)	Potential $\phi 2$ (rad.m/s)
January	0.9	4.8	0.21	45.00	37.58	0.23	0.0002
February	0.7	4.7	0.21	40.00	37.58	0.18	0.0001
March	2.7	4.9	0.20	113.37	37.58	0.65	0.0156
April	1.7	4.5	0.22	108.47	37.58	0.49	0.0048
May	1.6	5.5	0.18	85.33	37.58	0.31	0.0017
June	1.6	5.5	0.18	85.33	37.58	0.31	0.0017
July	2.8	5.7	0.18	108.50	37.58	0.51	0.0106
August	2.2	6	0.17	93.50	37.58	0.36	0.0038
September	2.1	5.4	0.19	101.00	37.58	0.42	0.0049
October	1.9	4.7	0.21	108.48	37.58	0.50	0.0059
November	1.3	4.7	0.21	89.80	37.58	0.34	0.0016
December	1.1	4.6	0.22	85.32	37.58	0.30	0.0010

The Potential Air Velocity in pyramid column is influenced by the area of the orifice, column area, air velocity in the column, wave height, angular wave velocity, sin ωt and cos ωt. The highest potential velocity is in March (1 Orifice: 0.0313 rad.m/s, 2 Orifice: 0.0156 rad.m/s) and the lowest potential velocity is in February (1 Orifice: 0.0002 rad.m/s, 2 Orifice: 0.0001 rad.m/s).

The higher wave let the greater air potential velocity. The faster air flows in the column and in the orifice will let the greater air potential velocity. The area of the orifice and the area of the column also affect the potential of the air velocity, small orifice and big area of column let greater potential velocity.

4.7 Air Pressure On Orifice

The step that needs to be known before calculate the torque value in the turbine is to calculate the value of air pressure on the orifice. The equation is,

$$P2 - P1 = \rho \left(\frac{A1}{A2}\right) \frac{d\varphi 2}{dt} \quad \frac{Q}{A2} \, (v2 - v1) \qquad (2.23)$$

P2 : Air Pressure on orifice (Pa)
P1 : Air Pressure on column (Pa)
v_2 : Air velocity on the orifice (m/s)
v_1 : Air Speed on the column (m/s)
A_1 : Area in column (m^2)
A_2 : Area in orifice (m^2)
: Air Density (1.293 kg/m^3)

From the calculations above, block column data is obtained as follows:

Table 4.19 Pressure on Orifice Block Column (1 Orifice)

Air Pressure on Orifice (Block)							
Month	Area 1 (m^2) Block	Area 2 (m^2) Cylinder	Potential Velocity (rad.m/s)	V1 (m/s)	Block Capacity Q (m^3/s)	V2 (m/s)	Pressure on Orifice P2 - P1 (pa)
January	90	18.79	0.0010	0.23	20.42	1.09	1.13
February	90	18.79	0.0005	0.18	16.55	0.88	0.74
March	90	18.79	0.0248	0.65	58.87	3.13	9.46
April	90	18.79	0.0080	0.49	43.71	2.33	5.18
May	90	18.79	0.0037	0.31	27.86	1.48	2.11
June	90	18.79	0.0037	0.31	27.86	1.48	2.11
July	90	18.79	0.0176	0.51	45.47	2.42	5.66
August	90	18.79	0.0073	0.36	32.32	1.72	2.85
September	90	18.79	0.0087	0.42	37.90	2.02	3.91
October	90	18.79	0.0098	0.50	44.91	2.39	5.48
November	90	18.79	0.0031	0.34	30.73	1.64	2.56
December	90	18.79	0.0020	0.30	27.11	1.44	1.99

Table 4.20 Pressure on Orifice Block Column (2 Orifice)

Air Pressure on Orifice (Block)							
Month	Area 1 (m^2) Block	Area 2 (m^2) Cylinder	Potential Velocity (rad.m/s)	V1 (m/s)	Block Capacity Q (m^3/s)	V2 (m/s)	Pressure on Orifice P2 - P1 (pa)
January	90	37.58	0.0005	0.23	20.42	0.54	0.21
February	90	37.58	0.0002	0.18	16.55	0.44	0.14
March	90	37.58	0.0124	0.65	58.87	1.57	1.75
April	90	37.58	0.0040	0.49	43.71	1.16	0.96
May	90	37.58	0.0018	0.31	27.86	0.74	0.39
June	90	37.58	0.0018	0.31	27.86	0.74	0.39
July	90	37.58	0.0088	0.51	45.47	1.21	1.05
August	90	37.58	0.0037	0.36	32.32	0.86	0.53
September	90	37.58	0.0044	0.42	37.90	1.01	0.72
October	90	37.58	0.0049	0.50	44.91	1.20	1.01
November	90	37.58	0.0016	0.34	30.73	0.82	0.47
December	90	37.58	0.0010	0.30	27.11	0.72	0.37

The biggest Pressure of block column is in March (1 Orifice: 9.46 pa, 2 Orifice: 1.75 pa) and the smallest Pressure is in February (1 Orifice: 0.74 pa, 2 Orifice: 0.14 pa). For Cylinder column data obtained as follow :

Table 4.21 Pressure on Orifice Cylinder Column (1 Orifice)

Air Pressure on Orifice (Cylinder)							
Month	Area 1 (m^2) Cylinder	Area 2 (m^2) Cylinder	Potential Velocity (rad.m/s)	V1 (m/s)	Cylinder Capacity Q (m^3/s)	V2 (m/s)	Pressure on Orifice P2 - P1 (pa)
January	85.22	18.79	0.0009	0.23	19.34	1.03	1.00
February	85.22	18.79	0.0005	0.18	15.67	0.83	0.65
March	85.22	18.79	0.0235	0.65	55.74	2.97	8.36
April	85.22	18.79	0.0076	0.49	41.39	2.20	4.58
May	85.22	18.79	0.0035	0.31	26.38	1.40	1.86
June	85.22	18.79	0.0035	0.31	26.38	1.40	1.86
July	85.22	18.79	0.0166	0.51	43.06	2.29	5.00
August	85.22	18.79	0.0069	0.36	30.60	1.63	2.52

Air Pressure on Orifice (Cylinder)							
Month	Area 1 (m^2) Cylinder	Area 2 (m^2) Cylinder	Potential Velocity (rad.m/s)	V1 (m/s)	Cylinder Capacity Q (m^3/s)	V2 (m/s)	Pressure on Orifice P2 - P1 (pa)
September	85.22	18.79	0.0083	0.42	35.89	1.91	3.46
October	85.22	18.79	0.0093	0.50	42.53	2.26	4.84
November	85.22	18.79	0.0030	0.34	29.10	1.55	2.26
December	85.22	18.79	0.0019	0.30	25.67	1.37	1.76

Table 4.22 Pressure on Orifice Cylinder Column (2 Orifice)

Air Pressure on Orifice (Cylinder)							
Month	Area 1 (m^2) Cylinder	Area 2 (m^2) Cylinder	Potential Velocity (rad.m/s)	V1 (m/s)	Cylinder Capacity Q (m^3/s)	V2 (m/s)	Pressure on Orifice P2 - P1 (pa)
January	85.22	37.58	0.0005	0.23	19.34	0.51	0.18
February	85.22	37.58	0.0002	0.18	15.67	0.42	0.12
March	85.22	37.58	0.0118	0.65	55.74	1.48	1.51
April	85.22	37.58	0.0038	0.49	41.39	1.10	0.82
May	85.22	37.58	0.0017	0.31	26.38	0.70	0.34
June	85.22	37.58	0.0017	0.31	26.38	0.70	0.34
July	85.22	37.58	0.0083	0.51	43.06	1.15	0.90
August	85.22	37.58	0.0035	0.36	30.60	0.81	0.45
September	85.22	37.58	0.0041	0.42	35.89	0.95	0.62
October	85.22	37.58	0.0046	0.50	42.53	1.13	0.87
November	85.22	37.58	0.0015	0.34	29.10	0.77	0.41
December	85.22	37.58	0.0010	0.30	25.67	0.68	0.32

The biggest Pressure of cylinder column is in March (1 Orifice: 8.36 pa, 2 Orifice: 1.51 pa) and the smallest Pressure is in February (1 Orifice: 0.65 pa, 2 Orifice: 0.12 pa). For Pyramid column data obtained as follow:

Table 4.23 Pressure on Orifice Pyramid Column (1 Orifice)

Air Pressure on Orifice (Pyramid)							
Month	Area 1 (m^2) Pyramid	Area 2 (m^2) Cylinder	Potential Velocity (rad.m/s)	V1 (m/s)	Pyramid Capacity Q (m^3/s)	V2 (m/s)	Pressure on Orifice P2-P1 (pa)
January	45.00	18.79	0.0005	0.23	10.21	0.54	0.21
February	40.00	18.79	0.0002	0.18	7.35	0.39	0.10
March	113.37	18.79	0.0313	0.65	74.15	3.95	15.82
April	108.47	18.79	0.0096	0.49	52.68	2.80	7.87
May	85.33	18.79	0.0035	0.31	26.41	1.41	1.87
June	85.33	18.79	0.0035	0.31	26.41	1.41	1.87
July	108.50	18.79	0.0212	0.51	54.82	2.92	8.59
August	93.50	18.79	0.0076	0.36	33.58	1.79	3.11
September	101.00	18.79	0.0098	0.42	42.53	2.26	5.07
October	108.48	18.79	0.0118	0.50	54.13	2.88	8.32
November	89.80	18.79	0.0031	0.34	30.66	1.63	2.54
December	85.32	18.79	0.0019	0.30	25.70	1.37	1.76

Table 4.24 Pressure on Orifice Pyramid Column (2 Orifice)

Air Pressure on Orifice (Pyramid)							
Month	Area 1 (m^2) Pyramid	Area 2 (m^2) Cylinder	Potential Velocity (rad.m/s)	V1 (m/s)	Pyramid Capacity Q (m^3/s)	V2 (m/s)	Pressure on Orifice P2-P1 (pa)
January	45.00	37.58	0.0002	0.23	10.21	0.27	0.01
February	40.00	37.58	0.0001	0.18	7.35	0.20	0.003
March	113.37	37.58	0.0156	0.65	74.15	1.97	3.18
April	108.47	37.58	0.0048	0.49	52.68	1.40	1.56
May	85.33	37.58	0.0017	0.31	26.41	0.70	0.34
June	85.33	37.58	0.0017	0.31	26.41	0.70	0.34
July	108.50	37.58	0.0106	0.51	54.82	1.46	1.71
August	93.50	37.58	0.0038	0.36	33.58	0.89	0.58
September	101.00	37.58	0.0049	0.42	42.53	1.13	0.98
October	108.48	37.58	0.0059	0.50	54.13	1.44	1.65

Air Pressure on Orifice (Pyramid)							
Month	Area 1 (m^2) Pyramid	Area 2 (m^2) Cylinder	Potential Velocity (rad.m/s)	V1 (m/s)	Pyramid Capacity Q (m^3/s)	V2 (m/s)	Pressure on Orifice P2-P1 (pa)
November	89.80	37.58	0.0016	0.34	30.66	0.82	0.47
December	85.32	37.58	0.0010	0.30	25.70	0.68	0.32

The biggest Pressure of pyramid column is in March (1 Orifice: 15.82 pa, 2 Orifice: 3.38 pa) and the smallest Pressure is in February (1 Orifice: 0.10 pa, 2 Orifice: 0.003 pa).

The amount of air pressure in the orifice, is influenced by column area, orifice area, derivative of potential velocity. The density of seawater, the air capacity of the orifice, the air velocity in the column and the air velocity at the orifice. The air pressure on the orifice will be greater if the column is wider, and the air capacity is getting bigger. The pressure will be low if the area of orifice is big.

4.8 OWC Power (Column)

After calculate the Pressure on orifice the OWC Power can be calculate. The formula is,

$$Pu = (P_2 - P_1)\, v_1\, A_1 \qquad (2.14)$$

Pu : OWC Power (W)
P2 P1 : Air Pressure (Pa)
A_1 : Area of Column (m^2)
V_1 : Air Velocity on The Column (m/s)

From the calculations above, block column data is obtained as follows:

Table 4.25 OWC Block Power (1 Orifice)

OWC POWER (BLOCK)				
Month	Pressure on Orifice P2 - P1 (pa)	V1 (m/s)	Area 1 (m^2) Block	Pu (w)
January	1.13	0.23	90	23.02
February	0.74	0.18	90	12.23
March	9.46	0.65	90	556.99
April	5.18	0.49	90	226.64
May	2.11	0.31	90	58.74
June	2.11	0.31	90	58.74

OWC POWER (BLOCK)				
Month	Pressure on Orifice P2 - P1 (pa)	V1 (m/s)	Area 1 (m^2) Block	Pu (w)
July	5.66	0.51	90	257.42
August	2.85	0.36	90	92.13
September	3.91	0.42	90	148.28
October	5.48	0.50	90	246.16
November	2.56	0.34	90	78.59
December	1.99	0.30	90	53.88

The biggest Block Column Power with 1 orifice is in March (1 Orifice: 556.99 W) and the smallest power is in February (1 Orifice: 12.23 W). For block column 2 orifice data is obtained as follows:

Table 4.26 OWC Block Power (2 Orifice)

OWC POWER (BLOCK)				
Month	Pressure on Orifice P2 - P1 (pa)	V1 (m/s)	Area 1 (m^2) Block	Pu (w)
January	0.21	0.23	90	4.24
February	0.14	0.18	90	2.25
March	1.75	0.65	90	103.06
April	0.96	0.49	90	41.84
May	0.39	0.31	90	10.85
June	0.39	0.31	90	10.85
July	1.05	0.51	90	47.68
August	0.53	0.36	90	17.05
September	0.72	0.42	90	27.41
October	1.01	0.50	90	45.47
November	0.47	0.34	90	14.50
December	0.37	0.30	90	9.94

The biggest Block Column Power with 2 orifice is in March (2 Orifice: 103.06 W) and the smallest power is in February (2 Orifice: 2.25 W). The calculation from 2 table above can be describe by graph as below,

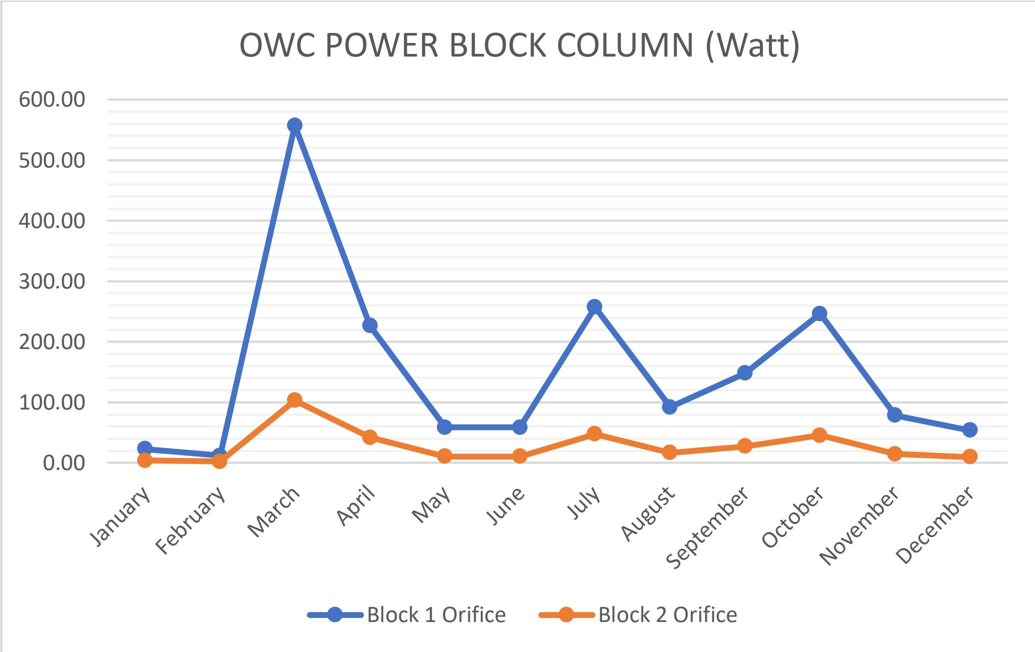

Figure 4.7 OWC Block Power Graph

From the graph above can conclude that the block power from 1 Orifice (556.99 W) is bigger than 2 orifice (103.06 W).

For cylinder column data is obtained as follows:

Table 4.27 OWC Cylinder Power (1 Orifice)

OWC POWER (CYLINDER)				
Month	Pressure on Orifice P2 - P1 (pa)	V1 (m/s)	Area 1 (m^2) Cylinder	Pu (w)
January	1.00	0.23	85.22	19.26
February	0.65	0.18	85.22	10.23
March	8.36	0.65	85.22	465.98
April	4.58	0.49	85.22	189.59
May	1.86	0.31	85.22	49.14
June	1.86	0.31	85.22	49.14
July	5.00	0.51	85.22	215.37
August	2.52	0.36	85.22	77.08
September	3.46	0.42	85.22	124.05
October	4.84	0.50	85.22	205.92
November	2.26	0.34	85.22	65.74

OWC POWER (CYLINDER)				
Month	Pressure on Orifice P2 - P1 (pa)	V1 (m/s)	Area 1 (m^2) Cylinder	Pu (w)
December	1.76	0.30	85.22	45.07

The biggest Cylinder Column Power with 1 orifice is in March (1 Orifice: 465.98 W) and the smallest Power is in February (1 Orifice: 10.23 W).

For cylinder column 2 orifice data is obtained as follows:

Table 4.28 OWC Cylinder Power (2 Orifice)

OWC POWER (CYLINDER)				
Month	Pressure on Orifice P2 - P1 (pa)	V1 (m/s)	Area 1 (m^2) Cylinder	Pu (w)
January	0.18	0.23	85.22	3.46
February	0.12	0.18	85.22	1.84
March	1.51	0.65	85.22	84.05
April	0.82	0.49	85.22	34.11
May	0.34	0.31	85.22	8.84
June	0.34	0.31	85.22	8.84
July	0.90	0.51	85.22	38.89
August	0.45	0.36	85.22	13.90
September	0.62	0.42	85.22	22.35
October	0.87	0.50	85.22	37.07
November	0.41	0.34	85.22	11.82
December	0.32	0.30	85.22	8.10

The biggest Cylinder Column Power with 2 orifice is in March (2 Orifice: 84.05 W) and the smallest power is in February (2 Orifice: 1.84 W). The calculation rate from 2 table above can be describe by graph as below,

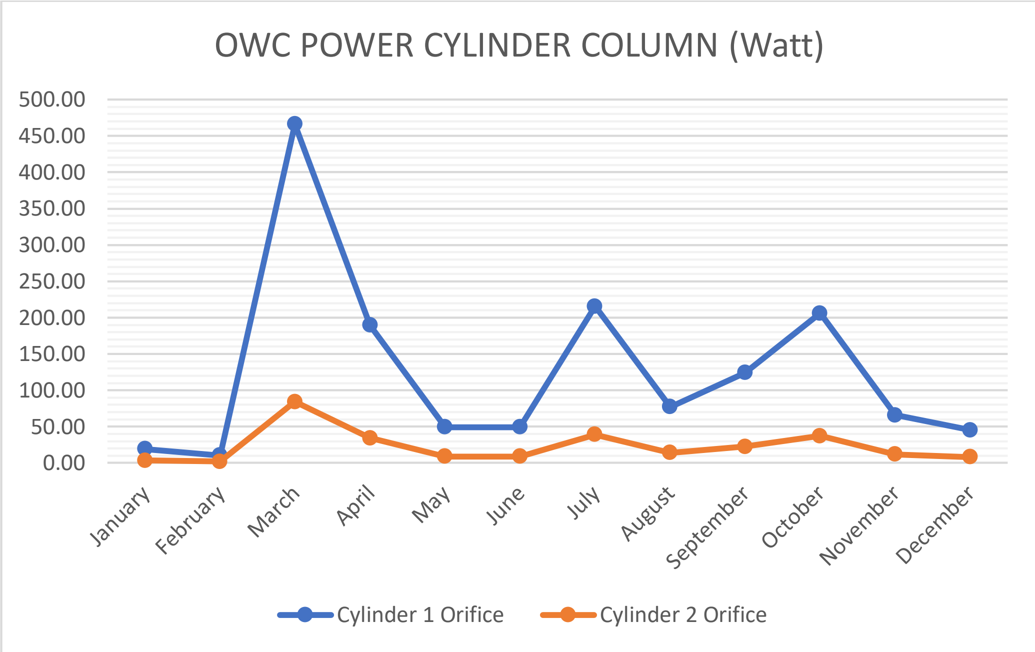

Figure 4.8 OWC Cylinder Power Graph

From the graph above can conclude that the cylinder power from 1 Orifice (465.98 W) is bigger than 2 orifice (84.05 W).

For pyramid column data is obtained as follows:

Table 4.29 OWC Pyramid Power (1 Orifice)

OWC POWER (PYRAMID)				
Month	Pressure on Orifice P2 - P1 (pa)	V1 (m/s)	Area 1 (m^2) Pyramid	Pu (w)
January	0.21	0.23	45.00	2.12
February	0.10	0.18	40.00	0.72
March	15.82	0.65	113.37	1172.95
April	7.87	0.49	108.47	414.43
May	1.87	0.31	85.33	49.34
June	1.87	0.31	85.33	49.34
July	8.59	0.51	108.50	470.97
August	3.11	0.36	93.50	104.31
September	5.07	0.42	101.00	215.52
October	8.32	0.50	108.48	450.24

OWC POWER (PYRAMID)				
Month	Pressure on Orifice P2 - P1 (pa)	V1 (m/s)	Area 1 (m^2) Pyramid	Pu (w)
November	2.54	0.34	89.80	78.02
December	1.76	0.30	85.32	45.25

The biggest Pyramid Column Power with 1 orifice is in March (1 Orifice: 1172.95 W) and the smallest power is in February (1 Orifice: 0.72 W).

For cylinder column 2 orifice data is obtained as follows:

Table 4.30 OWC Pyramid Power (2 Orifice)

OWC POWER (PYRAMID)				
Month	Pressure on Orifice P2 - P1 (pa)	V1 (m/s)	Area 1 (m^2) Pyramid	Pu (w)
January	0.01	0.23	45.00	0.15
February	0.00	0.18	40.00	0.02
March	3.18	0.65	113.37	235.82
April	1.56	0.49	108.47	82.08
May	0.34	0.31	85.33	8.89
June	0.34	0.31	85.33	8.89
July	1.71	0.51	108.50	93.50
August	0.58	0.36	93.50	19.61
September	0.98	0.42	101.00	41.72
October	1.65	0.50	108.48	89.21
November	0.47	0.34	89.80	14.38
December	0.32	0.30	85.32	8.14

The biggest Pyramid Column Power with 2 orifice is in March (2 Orifice: 235.82 W) and the smallest power is in February (2 Orifice: 0.02). The calculation rate from 2 table above can be describe by graph as below,

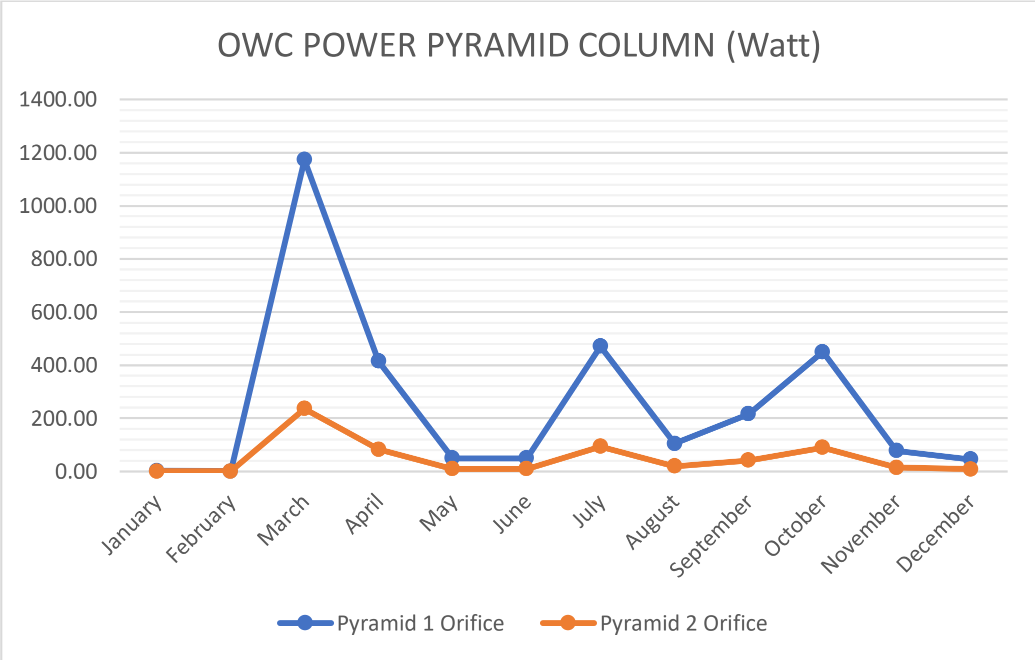

Figure 4.9 OWC Pyramid Power Graph

From the graph above can conclude that the pyramid column power from 1 Orifice (1172.95 W) is bigger than 2 orifice (235.82 W). From all calculation above can conclude that OWC Power from 1 Orifice is bigger than 2 Orifice so for the calculation of Block, Cylinder and Pyramid Column for 1 Orifice can be rate as as graph below,

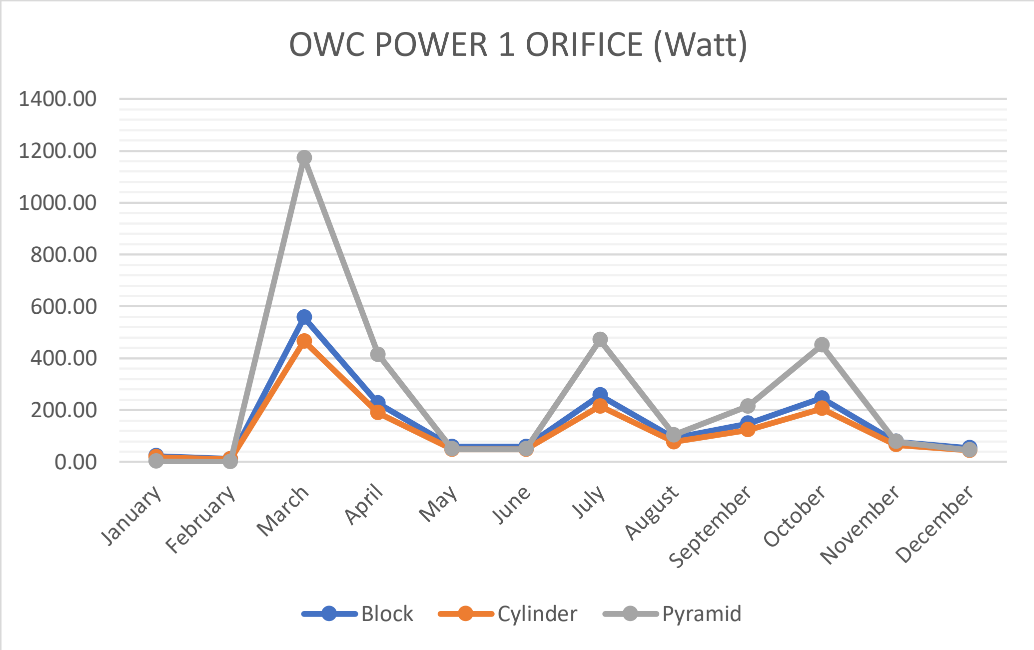

Figure 4.10 OWC Power 1 Orifice Graph

From the graph above can conclude that the most big power generated by Pyramid column rather than Block & Cylinder column, but the smallest power generated is by pyramid column also (In Month February when the wave is not high it affect by the area of water inside the column).

4.9 Turbine Torque

To calculate power in turbine requires the value of force and wind pressure on the collector's orifice and the torque of the turbine. The data pressure on orifice has already calculated and the number of orifice has same meaning with the number of turbine (1 Orifice/1 Turbine, 2 Orifice/2 Turbine). To calculate turbine torque, the formula is:

$$Q = F \times l \tag{2.24}$$

Q : Turbine Torque (Rpm)
F : Force on Orifice (N)
l : Turbine Radius (m)

From the calculations above, block column data is obtained by 2 table as follows:

Table 4.31 Turbine Torque in Block Column (1 Turbine)

Turbine Torque for Each Turbine (Block)				
Month	Pressure on Orifice P2 - P1 (pa)	Area 2 (m^2) Cylinder	F	Torque Q (Nm)
January	1.1	18.79	21.2	27.54

Turbine Torque for Each Turbine (Block)				
Month	Pressure on Orifice P2 - P1 (pa)	Area 2 (m^2) Cylinder	F	Torque Q (Nm)
February	0.7	18.79	13.9	18.05
March	9.5	18.79	177.8	231.12
April	5.2	18.79	97.4	126.65
May	2.1	18.79	39.6	51.50
June	2.1	18.79	39.6	51.50
July	5.7	18.79	106.4	138.29
August	2.9	18.79	53.6	69.64
September	3.9	18.79	73.5	95.57
October	5.5	18.79	103.0	133.88
November	2.6	18.79	48.1	62.47
December	2.0	18.79	37.4	48.56

Table 4.32 Turbine Torque in Block Column (2 Turbine)

Turbine Torque for Each Turbine (Block)				
Month	Pressure on Orifice P2 - P1 (pa)	Area 2 (m^2) Cylinder	F	Torque Q (Nm)
January	0.2	37.58	7.8	10.15
February	0.1	37.58	5.1	6.65
March	1.8	37.58	65.8	85.53
April	1.0	37.58	36.0	46.76
May	0.4	37.58	14.6	19.02
June	0.4	37.58	14.6	19.02
July	1.0	37.58	39.4	51.22
August	0.5	37.58	19.8	25.77
September	0.7	37.58	27.2	35.34
October	1.0	37.58	38.0	49.46
November	0.5	37.58	17.7	23.05
December	0.4	37.58	13.8	17.91

From the 2 table above can conclude that the block column torque from 1 Turbine (Most High : 231.12 Nm) is bigger than 2 Turbine (Most high : 85.63 Nm).

The Cylinder column data is obtained by 2 table as follows:

Table 4.33 Turbine Torque in Cylinder Column (1 Turbine)

Turbine Torque For each Turbine (Cylinder)				
Month	Pressure on Orifice P2 - P1 (pa)	Area 2 (m^2) Cylinder	F	Torque Q (Nm)
January	1.0	18.79	18.7	24.33
February	0.7	18.79	12.3	15.95
March	8.4	18.79	157.1	204.20
April	4.6	18.79	86.1	111.88
May	1.9	18.79	35.0	45.50
June	1.9	18.79	35.0	45.50
July	5.0	18.79	94.0	122.19
August	2.5	18.79	47.3	61.53
September	3.5	18.79	65.0	84.44
October	4.8	18.79	91.0	118.28
November	2.3	18.79	42.5	55.19
December	1.8	18.79	33.0	42.89

Table 4.34 Turbine Torque in Cylinder Column (2 Turbine)

Turbine Torque For each Turbine (Cylinder)				
Month	Pressure on Orifice P2 - P1 (pa)	Area 2 (m^2) Cylinder	F	Torque Q (Nm)
January	0.2	37.58	6.7	8.74
February	0.1	37.58	4.4	5.73
March	1.5	37.58	56.7	73.66
April	0.8	37.58	31.0	40.26
May	0.3	37.58	12.6	16.38
June	0.3	37.58	12.6	16.38
July	0.9	37.58	33.9	44.13
August	0.5	37.58	17.1	22.19
September	0.6	37.58	23.4	30.43

Turbine Torque For each Turbine (Cylinder)				
Month	Pressure on Orifice P2 - P1 (pa)	Area 2 (m^2) Cylinder	F	Torque Q (Nm)
October	0.9	37.58	32.8	42.59
November	0.4	37.58	15.3	19.85
December	0.3	37.58	11.9	15.42

From 2 table above can conclude that the cylinder column torque from 1 Turbine (Most High: 204.20 Nm) is bigger than 2 Turbine (Most High : 73.66 Nm).

The Pyramid column data is obtained by 2 table as follows:

Table 4.35 Turbine Torque in Pyramid Column (1 Turbine)

Turbine Torque For Each Turbine (Pyramid)				
Month	Pressure on Orifice P2 - P1 (pa)	Area 2 (m^2) Cylinder	F	Torque Q Nm
January	0.2	18.79	3.91	5.08
February	0.1	18.79	1.84	2.39
March	15.8	18.79	297.22	386.39
April	7.9	18.79	147.81	192.15
May	1.9	18.79	35.10	45.63
June	1.9	18.79	35.10	45.63
July	8.6	18.79	161.43	209.86
August	3.1	18.79	58.38	75.89
September	5.1	18.79	95.21	123.78
October	8.3	18.79	156.28	203.16
November	2.5	18.79	47.81	62.16
December	1.8	18.79	33.08	43.01

Table 4.36 Turbine Torque in Pyramid Column (2 Turbine)

Turbine Torque For Each Turbine (Pyramid)				
Month	Pressure on Orifice P2 - P1 (pa)	Area 2 (m^2) Cylinder	F	Torque Q Nm
January	0.0	37.58	0.56	0.73
February	0.0	37.58	0.11	0.14
March	3.2	37.58	119.51	155.36
April	1.6	37.58	58.55	76.12
May	0.3	37.58	12.64	16.44
June	0.3	37.58	12.64	16.44
July	1.7	37.58	64.10	83.33
August	0.6	37.58	21.95	28.54
September	1.0	37.58	36.86	47.92
October	1.6	37.58	61.93	80.51
November	0.5	37.58	17.63	22.91
December	0.3	37.58	11.90	15.47

From 2 table above can conclude that the pyramid column torque from 1 Turbine (Most High: 386.39 Nm) is bigger than 2 Turbine (Most High : 155.36 Nm).

4.10 Turbine Power

Data from torque calculation can be used for calculate the turbine power. To calculate the power generated by turbine with the equation of,

$$Pt = \omega Q = 2\pi n Q \tag{2.25}$$

Pt : Power generated by turbine (W)
Q : Turbine Torque (Nm)
n : Turbine Rotation (Rps)

From the calculations above, block column data is obtained as follows:

Table 4.37 Turbine Power in Block Column (1 Turbine)

Turbine Power (Block)			
Month	Torque Q Nm	Turbine Rotation (n) RPS	Pt w
January	27.54	1050	3026.41
February	18.05	1050	1984.16
March	231.12	1050	25400.53
April	126.65	1050	13918.29
May	51.50	1050	5659.78
June	51.50	1050	5659.78
July	138.29	1050	15197.87
August	69.64	1050	7653.09
September	95.57	1050	10503.62
October	133.88	1050	14713.58
November	62.47	1050	6865.70
December	48.56	1050	5336.25

The biggest Block Column Turbine Power is in March (1 Turbine: 25400.53 W) and the smallest Turbine Power in February (1 Turbine: 1984.16 W). For Block column 2 Turbine data is obtained as follows:

Table 4.38 Turbine Power in Block Column (2 Turbine)

Turbine Power (Block)			
Month	Torque Q Nm	Turbine Rotation (n) RPS	Pt W
January	10.15	1050	2231.82
February	6.65	1050	1462.60
March	85.53	1050	18799.25
April	46.76	1050	10278.30
May	19.02	1050	4181.21
June	19.02	1050	4181.21
July	51.22	1050	11259.18
August	25.77	1050	5663.42
September	35.34	1050	7767.57

Turbine Power (Block)			
Month	Torque Q Nm	Turbine Rotation (n) RPS	Pt W
October	49.46	1050	10871.07
November	23.05	1050	5066.86
December	17.91	1050	3936.45

The biggest Block Column Turbine Power is in March (2 Turbine: 18799.25 W) and the smallest Turbine Power is in February (2 Turbine: 1462.60 W). The calculation rate from 2 table above can be describe by graph as below,

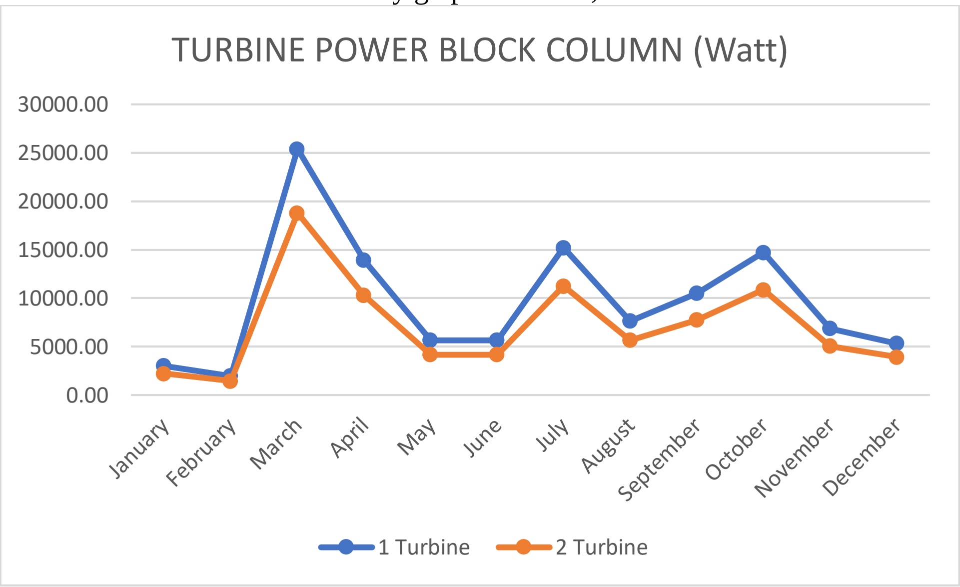

Figure 4.11 Turbine Power of Block Column Graph

From the table and graph above can conclude that the highest power generated of block column is in March and the lowest power generated is in February. By the comparison of power generated between 1 turbine and 2 turbine, 1 Turbine is produce more power.

The Cylinder column data is obtained as follows:

Table 4.39 Turbine Power in Cylinder Column (1 Turbine)

Turbine Power(Cylinder)			
Month	Torque Q Nm	Turbine Rotation (n) RPM	Pt w
January	24.33	1050	2673.51
February	15.95	1050	1752.77

Turbine Power(Cylinder)			
Month	Torque Q Nm	Turbine Rotation (n) RPM	Pt w
March	204.20	1050	22442.10
April	111.88	1050	12296.07
May	45.50	1050	5000.19
June	45.50	1050	5000.19
July	122.19	1050	13428.31
August	61.53	1050	6761.69
September	84.44	1050	9279.93
October	118.28	1050	12998.93
November	55.19	1050	6065.31
December	42.89	1050	4714.08

The biggest Cylinder Column Turbine Power is in March (1 Turbine: 22442.10 W) and the smallest Turbine Power is in February (1 Turbine: 1752.77 W).

For Cylinder column 2 Turbine data is obtained as follows:

Table 4.40 Turbine Power in Cylinder Column (2 Turbine)

Turbine Power(Cylinder)			
Month	Torque Q Nm	Turbine Rotation (n) RPM	Pt W
January	8.74	1050	1921.13
February	5.73	1050	1258.91
March	73.66	1050	16191.42
April	40.26	1050	8849.40
May	16.38	1050	3600.15
June	16.38	1050	3600.15
July	44.13	1050	9698.81
August	22.19	1050	4877.69
September	30.43	1050	6689.20
October	42.59	1050	9360.51
November	19.85	1050	4362.01
December	15.42	1050	3388.62

The biggest Cylinder Column Turbine Power is in March (2 Turbine: 16191.42 W) and the smallest Turbine Power is in February (2 Turbine: 1258.91 W). The calculation rate from 2 table above can be describe by graph as below,

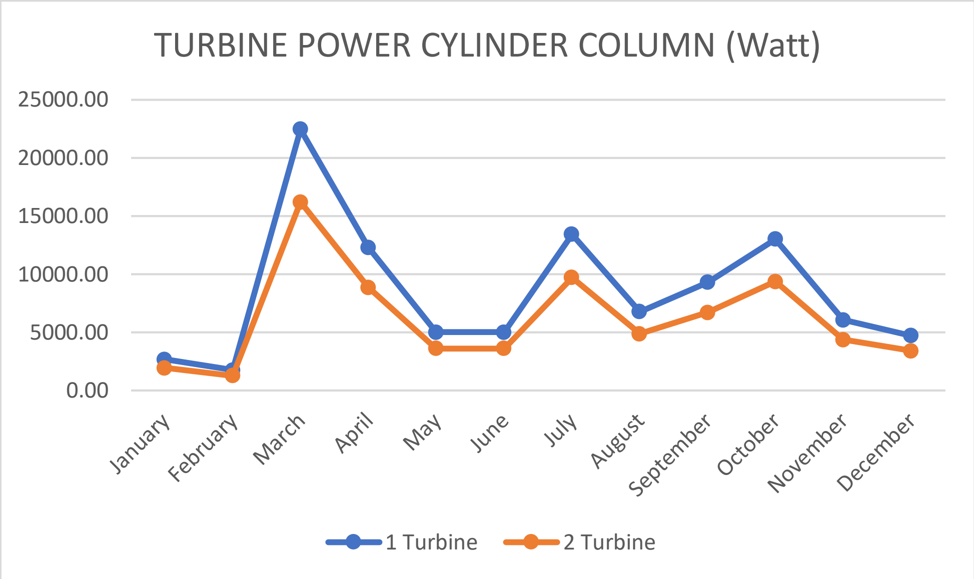

Figure 4.12 Turbine Power of Cylinder Column Graph

From the table and graph above can concude that the highest power generated of cylinder column is in March and the lowest power generated is in February. By the comparison of power generated between 1 turbine and 2 turbine, 1 Turbine is produce more power.

The Pyramid column data is obtained as follows:

Table 4.41 Turbine Power in Pyramid Column (1 Turbine)

Turbine Power (Pyramid)			
Month	Torque Q Nm	Turbine Rotation (n) RPM	Pt W
January	5.08	1050	557.96
February	2.39	1050	263.15
March	386.39	1050	42463.79
April	192.15	1050	21117.47
May	45.63	1050	5014.92
June	45.63	1050	5014.92
July	209.86	1050	23064.08

Turbine Power (Pyramid)			
Month	Torque Q Nm	Turbine Rotation (n) RPM	Pt W
August	75.89	1050	8340.29
September	123.78	1050	13603.35
October	203.16	1050	22327.30
November	62.16	1050	6831.23
December	43.01	1050	4726.70

The biggest Pyramid Column Turbine Power is in March (1 Turbine: 42463.79 W) and the smallest Turbine Power is in February (1 Turbine: 263.15 W).

For Cylinder column 2 Turbine data is obtained as follows:

Table 4.42 Turbine Power in Pyramid Column (2 Turbine)

Turbine Power (Pyramid)			
Month	Torque Q Nm	Turbine Rotation (n) RPM	Pt W
January	0.73	1050	160.66
February	0.14	1050	31.35
March	155.36	1050	34148.37
April	76.12	1050	16730.48
May	16.44	1050	3613.07
June	16.44	1050	3613.07
July	83.33	1050	18315.77
August	28.54	1050	6273.25
September	47.92	1050	10532.90
October	80.51	1050	17695.81
November	22.91	1050	5036.39
December	15.47	1050	3399.70

The biggest Pyramid Column Turbine Power is in March (2 Turbine: 34148.37 W) and the smallest Turbine Power is in February (2 Turbine: 31.35 W). The calculation from 2 table above can be describe by graph as below,

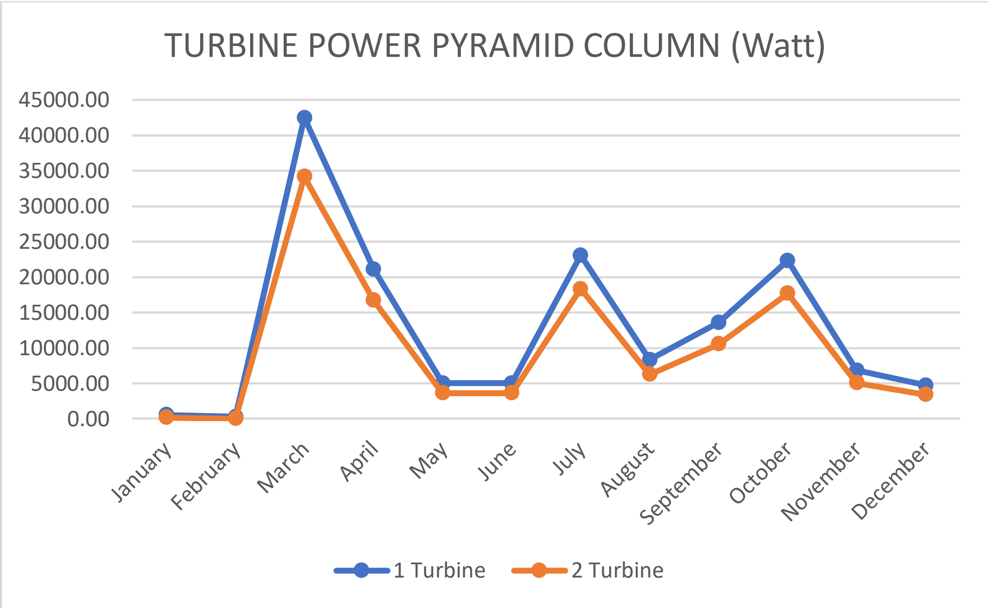

Figure 4.13 Turbine Power of Pyramid Column Graph

From the table and graph above can conlude that the highest power generated of pyramid column is in March and the lowest power generated is in February. The most high power generated is by 1 turbine,from the comparison of power generated between 1 turbine and 2 turbine. The summary power of 1 turbine by the variation of column is :

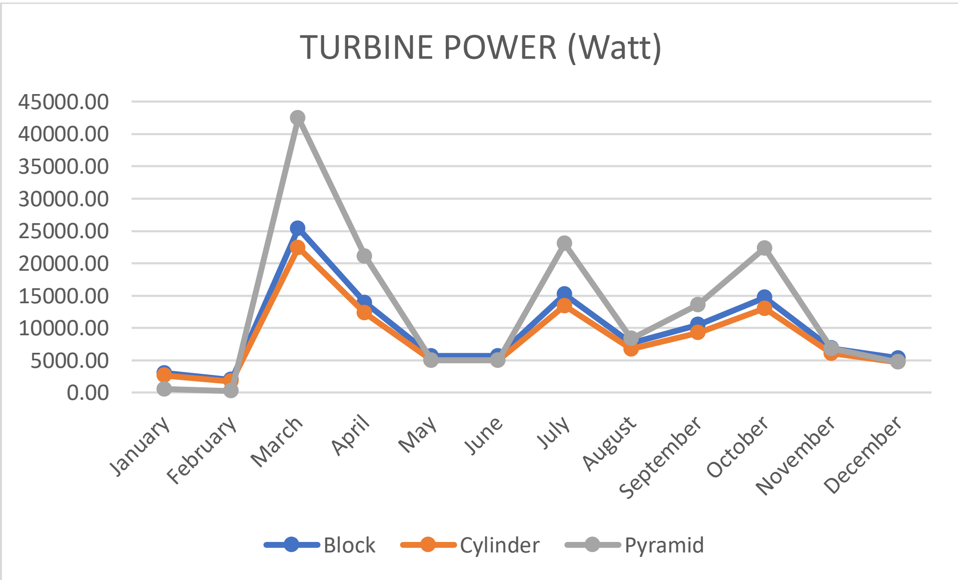

Figure 4.14 Turbine Power (1 Turbine) Graph

From the graph above we can know that the power from 1 Turbine in Pyramid column is bigger than Block & Cylinder column but the smallest power generated is by pyramid column also (In Month February when the wave is not high it affect by the area of water inside the column).

4.11 Design of Oscillating Water Column

After manual calculation process of oscillating water column the next step analysis is simulate model in Ansys CFX. The Model is created on SolidWorks. The Figure of Block column design as follow,

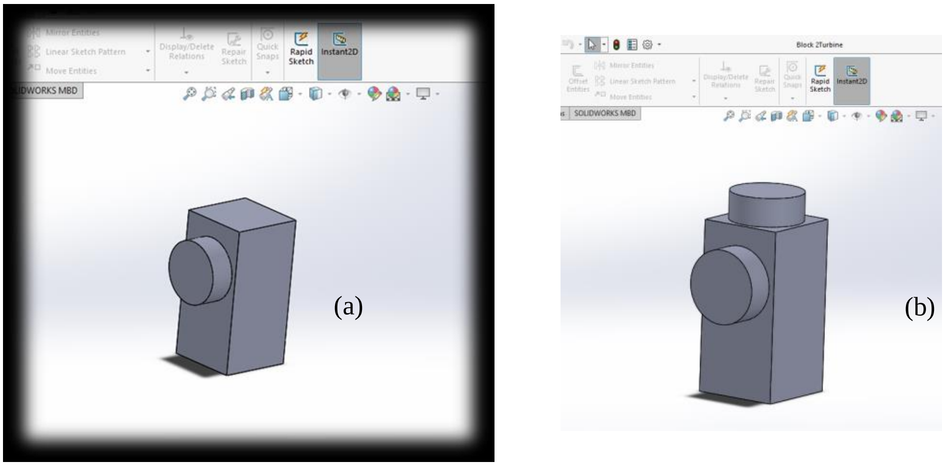

Figure 4.15 Block Column 1 Orifice (a) & 2 Orifice (b)

The figure above show the design of Oscillating Water Column variation of block column with 1 orifice and 2 orifice. The dimension is Length (m): 3 m Width (m): 3 m Heigth (m) : 6 m. The Figure of Cylinder column design as follow,

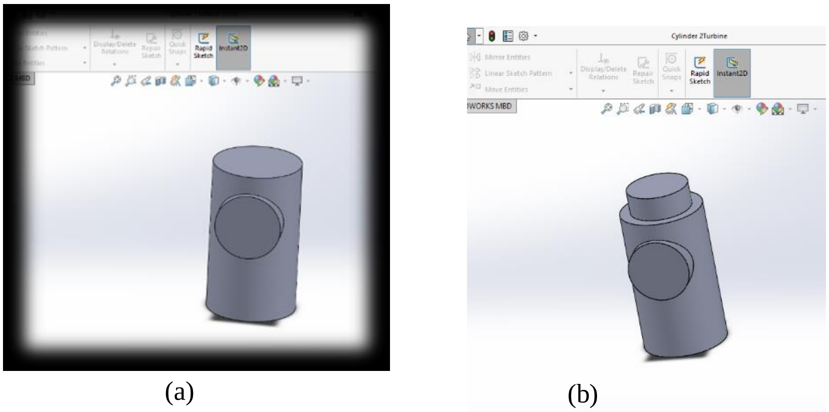

Figure 4.16 Cylinder Column 1 Orifice (a) & 2 Orifice (b)

The figure above show the design of Oscillating Water Column variation of cylinder column with 1 orifice and 2 orifice. The dimension is Diameter: 3.5 m Radius : 1.75 m Heigth : 6 m. The Figure of Pyramid column design as follow,

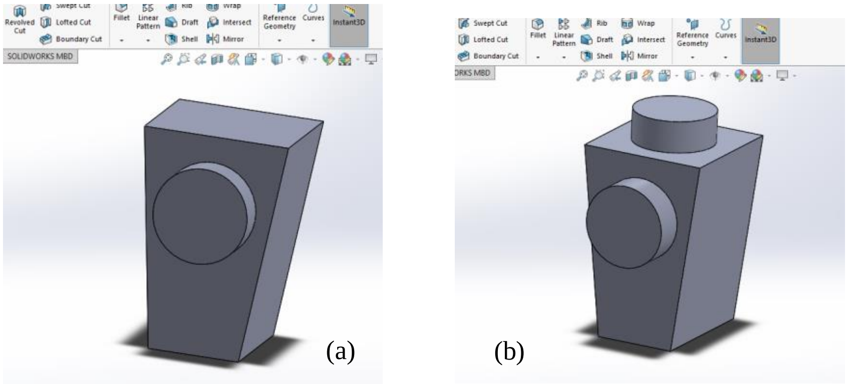

Figure 4.17 Pyramid Column 1 Orifice (a) & 2 Orifice (b)

The figure above show the design of Oscillating Water Column variation of pyramid column with 1 orifice and 2 orifice. The dimension is Length (m): 4 m Width (m): 2.5 m, Heigth (m) : 6 m

4.12 Simulation of Oscillating Water Column

In this stage the model will be simulated in Ansys CFX, the input is from manual calculation. From the simulation we can get velocity of air come from owc column. The simulation is used the great velocity from Wave (v_1 : 0.65 m/s) as input to all type of column and number of orifice. The result of the simulation can be seen on the figure as follow :

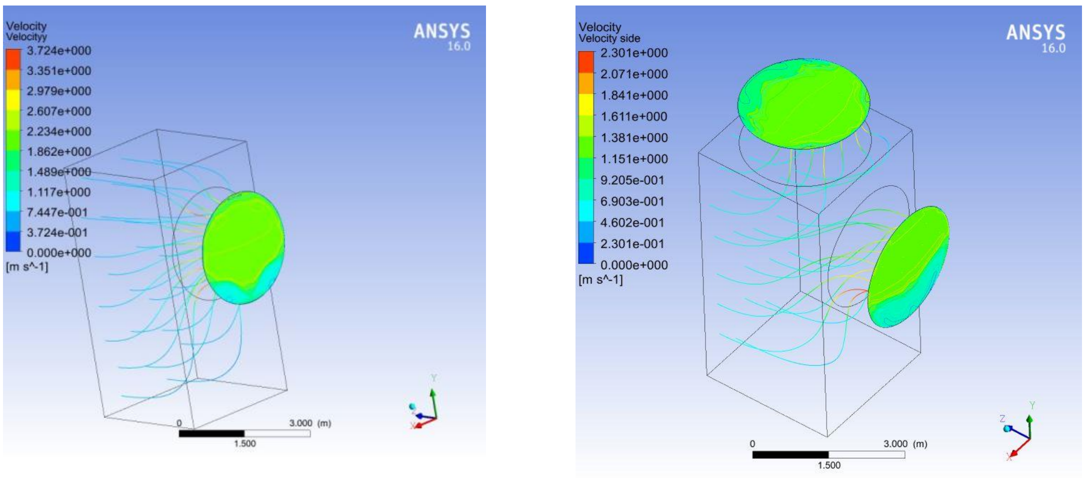

Figure 4.18 Block Column 1 Orifice & 2 Orifice Simulation

From the simulation of block column 1 orifice & 2 orifice the result show that the velocity of v_2 is 3.1 m/s for 1 orifice and 1.5 m/s for 2 orifice.

The cylinder column figure as follow,

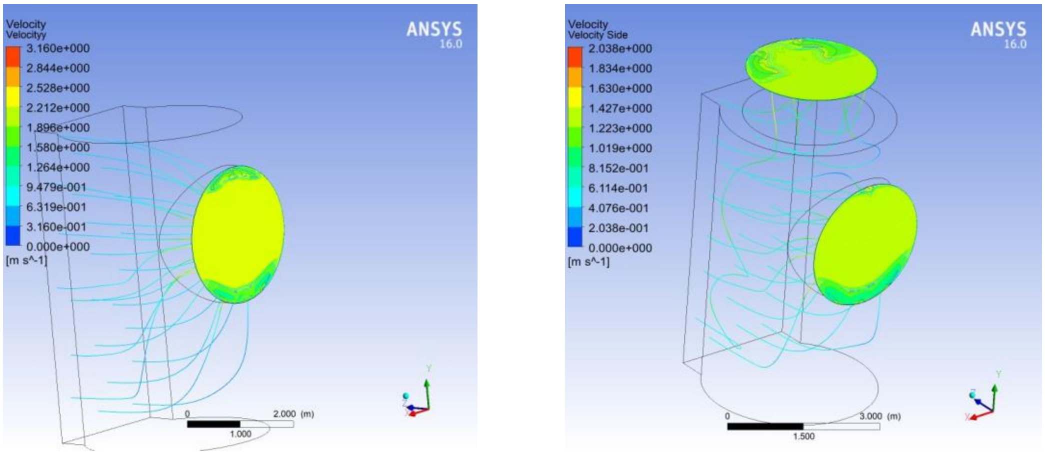

Figure 4.19 Cylinder Column 1 Orifice & 2 Orifice

From the simulation of cylinder column 1 orifice & 2 orifice the result show that the velocity of v_2 is 2.9 m/s for 1 orifice and 1.4 m/s for 2 orifice.

The Pyramid column figure as follow,

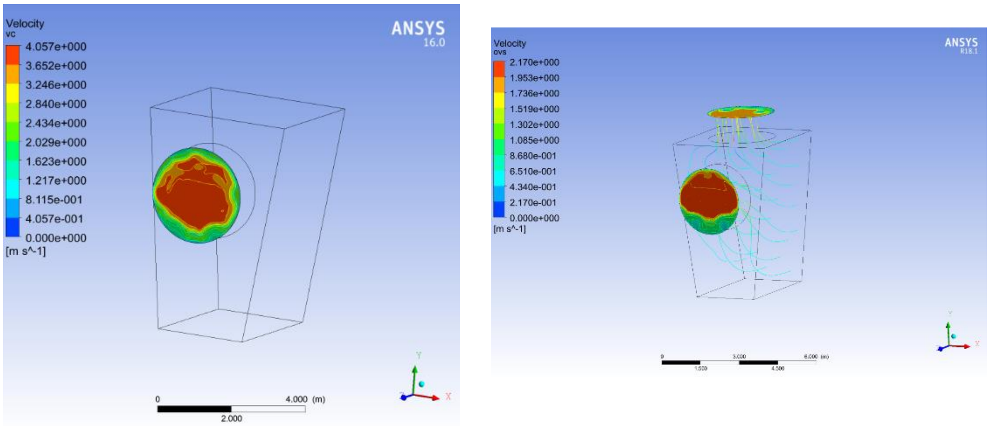

Figure 4.20 Pyramid Column 1 Orifice & 2 Orifice

From the simulation of cylinder column 1 orifice & 2 orifice the result show that the velocity of v_2 is 3.9 m/s for 1 orifice and 2 m/s for 2 orifice. From all simulation results it can be concluded that the results velocity of manual counts are not far proportional to the simulation.

4.13 Calculation of OWC & Turbine Efficiency

From the simulation can conclude that the model is available to produce and generate electrical power. From the variation of column and number of turbine we can get the efficiency of owc & turbine, The equation is :

$\eta owc = \frac{Pt}{Pw} x\ 100\%$ (2.26)

ηowc : Efficiency of OWC & Turbine
Pt : Turbine Power (w)
Pw : Wave Power (w)

From the calculations above, block column efficiency obtained as follows:

Table 4.43 OWC & Turbine Efficiency (Block Column 1 Turbines

OWC &Turbine Efficiency (Block)			
Month	Pt (w)	Pw (w)	Efficiency %
January	3026	22870	13.23
February	1984	13547	14.65
March	25401	210122	12.09
April	13918	76500	18.19
May	5660	82823	6.83
June	5660	82823	6.83
July	15198	262869	5.78
August	7653	170823	4.48
September	10504	140082	7.50
October	14714	99805	14.74
November	6866	46723	14.69
December	5336	32741	16.30

The most high efficiency of Block Column for 1 Turbine is 18.19 % in April. From the table above can be obtained the value of average efficiency, the average efficiency is 11.28 %.

For Block column with 2 Turbine the efficiency obtained as follow :

Table 4.44 OWC & Turbine Efficiency (Block Column 2 Turbine)

OWC &Turbine Efficiency (Block)			
Month	Pt (w)	Pw (w)	Efficiency %
January	2232	22870	9.76
February	1463	13547	10.80
March	18799	210122	8.95
April	10278	76500	13.44

OWC &Turbine Efficiency (Block)			
Month	Pt (w)	Pw (w)	Efficiency %
May	4181	82823	5.05
June	4181	82823	5.05
July	11259	262869	4.28
August	5663	170823	3.32
September	7768	140082	5.55
October	10871	99805	10.89
November	5067	46723	10.84
December	3936	32741	12.02

The most high efficiency of Block Column for 2 Turbine is 13.14 % in April. From the table above can be obtained the value of average efficiency, the average efficiency is 8.83 %. So the most efficiency model for Block column is using 1 Turbine.

For Cylinder column with 1 Turbine the efficiency obtained as follow :

Table 4.45 OWC & Turbine Efficiency (Cylinder Column 1 Turbine)

OWC & Turbine Efficiency (Cylinder)			
Month	Pt (w)	Pw (w)	Efficiency %
January	2674	26682	10.02
February	1753	15805	11.09
March	22442	245143	9.15
April	12296	89250	13.78
May	5000	96627	5.17
June	5000	96627	5.17
July	13428	306681	4.38
August	6762	199293	3.39
September	9280	163429	5.68
October	12999	116440	11.16
November	6065	54510	11.13
December	4714	38198	12.34

The most high efficiency of Cylinder Column for 1 Turbine is 13.78 % in April. From the table above can be obtained the value of average efficiency, the average efficiency is 8.54 %.

For Cylinder column with 2 Turbine the efficiency obtained as follow :

Table 4.46 OWC & Turbine Efficiency (Cylinder Column 2 Turbine)

OWC & Turbine Efficiency (Cylinder)			
Month	Pt (w)	Pw (w)	Efficiency %
January	1921	26682	7.20
February	1259	15805	7.97
March	16191	245143	6.60
April	8849	89250	9.92
May	3600	96627	3.73
June	3600	96627	3.73
July	9699	306681	3.16
August	4878	199293	2.45
September	6689	163429	4.09
October	9361	116440	8.04
November	4362	54510	8.00
December	3389	38198	8.87

The most high efficiency of Cylinder Column for 2 Turbine is 9.92 % in April. From the table above can be obtained the value of average efficiency, the average efficiency is 6.15 %. So the most efficiency model for Cylinder column is using 1 Turbine.

For Pyramid column with 1 Turbine the efficiency obtained as follow :

Table 4.47 OWC & Turbine Efficiency (Pyramid Column 1 Turbine)

OWC & Turbine Efficiency (Pyramid)			
Month	Pt (w)	Pw (w)	Efficiency %
January	558	19059	2.93
February	263	11289	2.33
March	42464	175102	24.25
April	21117	63750	33.13
May	5015	69019	7.27

OWC & Turbine Efficiency (Pyramid)			
Month	Pt (w)	Pw (w)	Efficiency %
June	5015	69019	7.27
July	23064	219058	10.53
August	8340	142352	5.86
September	13603	116735	11.65
October	22327	83171	26.85
November	6831	38936	17.54
December	4727	27284	17.32

The most high efficiency of Pyramid Column for 1 Turbine is 33.13 % in April. From the table above can be obtained the value of average efficiency, the average efficiency is 13.91 %.

For Pyramid column with 2 Turbine the efficiency obtained as follow :

Table 4.48 OWC & Turbine Efficiency (Pyramid Column 2 Turbine)

OWC & Turbine Efficiency (Pyramid)			
Month	Pt (w)	Pw (w)	Efficiency %
January	161	19059	0.84
February	31	11289	0.28
March	34148	175102	19.50
April	16730	63750	26.24
May	3613	69019	5.23
June	3613	69019	5.23
July	18316	219058	8.36
August	6273	142352	4.41
September	10533	116735	9.02
October	17696	83171	21.28
November	5036	38936	12.94
December	3400	27284	12.46

The most high efficiency of Pyramid Column for 2 Turbine is 26.24 % in April. From the table above can be obtained the value of average efficiency, the average efficiency is 10.48 %. So the most efficiency model for Pyramid column is using 1 Turbine.
By the all efficiency calculation it can be summary as the table below,

Table 4.49 OWC & Turbine Efficiency 1 Year

Column & Turbine Efficiency 1 Year	
Block 1 Turbine	11.28 %
Block 2 Turbine	8.83 %
Cylinder 1 Turbine	8.54 %
Cylinder 2 Turbine	6.15 %
Pyramid 1 Turbine	13.91 %
Pyramid 2 Turbine	10.48 %

From the results from table above it can be concluded that the Efficiency of Columns and Turbines is better when using 1 Turbine. The maximum results are obtained by using Pyramid Column.

CHAPTER V
CONCLUSION & SUGGESTION

5.1 Conclusion

From the research that has been done, conclusions can be drawn as follows:

1. From the research calculation of Oscillating Water Column shape variations, the results show that there are several factors that affect the pararmeter performance of OWC itself, one of the factors is:
   a. The width of the column effect the number of wave that enter the column and effect the ocean wave power through OWC. From the research calculation results it was found that the Cylinder column produces more wave power because of the larger width of the column.
   b. The area of the column affects the amount of power produced by the OWC. From the research calculation results it was found that the Pyramid column produces more OWC power because of the larger area of the column.
2. From the research calculation of Oscillating Water Column shape variations and number of orifice (Turbine), the results show that there are several factors that affect the parameter of OWC itself, one of the factors is:
   a. The amount of air speed in the orifice is influenced by column area, orifice area and air speed in the column. The amount of air capacity in the orifice is influenced by two factors, namely air speed in the column and area of orifice. The greater air speed in the column let the greater air capacity in the orifice.
   b. The higher ocean wave let the greater air potential velocity. The faster air flows in the column and orifice will let the greater air potential velocity. The area of the orifice and the area of the column also affect the potential of air velocity, smaller orifice and bigger area of column let greater air potential velocity.
3. From the research calculation of Oscillating Water Column shape variations, the results show the most effective shape of column is Pyramid Column, wide area of the column is the most important factor that affects the amount of air in the column which affects the amount of power generated by the OWC. But pyramid column have different area because the shape not always same in each area so if the wave is short the power produce by Pyramid column is smaller than block and cylinder column.
4. From the research calculation of number of turbine, the results show the most effective number of turbine to be used is 1 Turbine. The number of turbine affects the area of the outflow path of air, it also effect the torque for turbine so the power generated by 2 Turbine is less than 1 Turbine.

Table 4.50 OWC & Turbine Power Summary

Month	Block Column		Cylinder Column		Pyramid Column	
	1 Turbine Pt (w)	2 Turbine Pt (w)	1 Turbine Pt (w)	2 Turbine Pt (w)	1 Turbine Pt (w)	2 Turbine Pt (w)
January	3026	2231	2674	1921	557	160
February	1984	1462	1753	1258	263	31
March	25401	18799	22442	16191	42463	34148
April	13918	10278	12296	8849	21117	16730
May	5660	4181	5000	3600.	5014	3613
June	5660	4181	5000	3600	5014	3613
July	15198	11259	13428	9698	23064	18315
August	7653	5663	6762	4877	8340	6273
September	10504	7767	9280	6689	13603	10532
October	14714	10871	12999	9360	22327	17695
November	6866	5066	6065	4362	6831	5036
December	5336	3936	4714	3388	4726	3399

5. From research calculation, the most efficient design to generate power from wave energy through the oscillating water column is Pyramid shape with 1 Turbine.

Table 4.51 OWC & Turbine Efficiency Avarage

Column & Turbine Efficiency 1 Year	
Block 1 Turbine	11.28 %
Block 2 Turbine	8.83 %
Cylinder 1 Turbine	8.54 %
Cylinder 2 Turbine	6.15 %
Pyramid 1 Turbine	13.91 %
Pyramid 2 Turbine	10.48 %

5.2 Suggestion

From the results of this final project, the suggestions that the authors can give are as follows:

1. Develop research on ocean that have more evenly elevated or high waves and periods.
2. Search for another simulation software method to simulate 2 fluid (Air & Water) in the same way or create prototype of oscillating water column with pyramid and block variation shape.
3. Search for another type of turbine, use a large number of turbines with a small diameter on each turbine.

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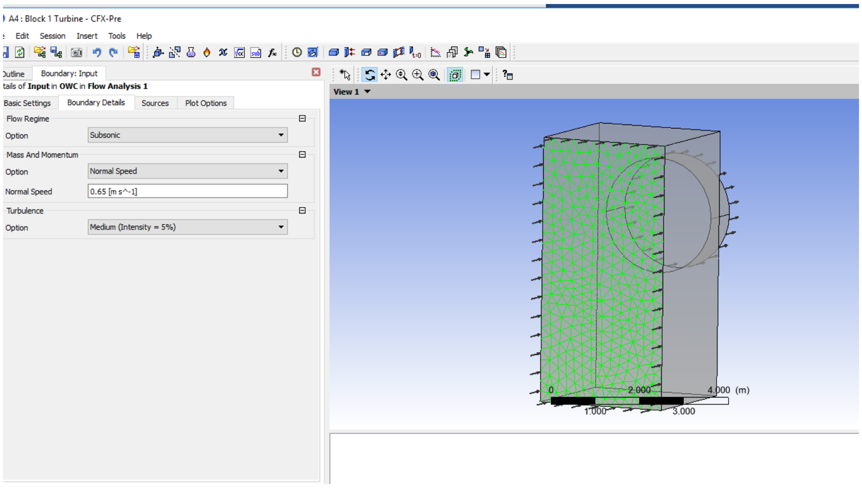
ATTACHMENT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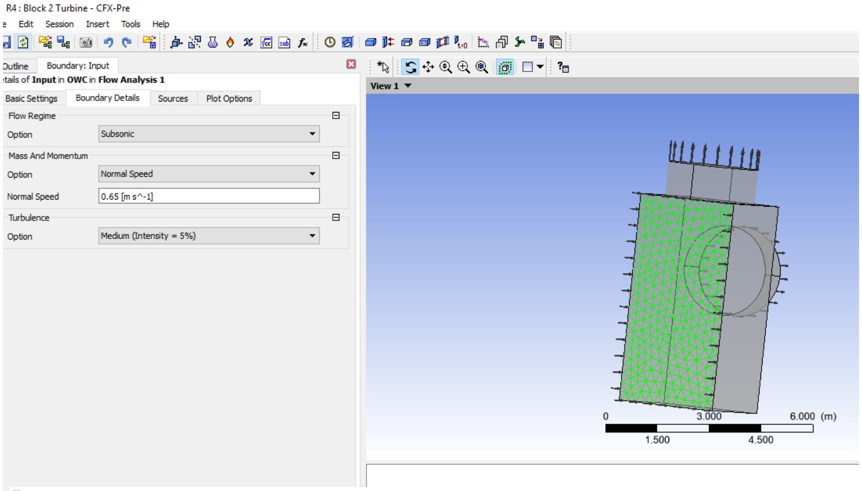
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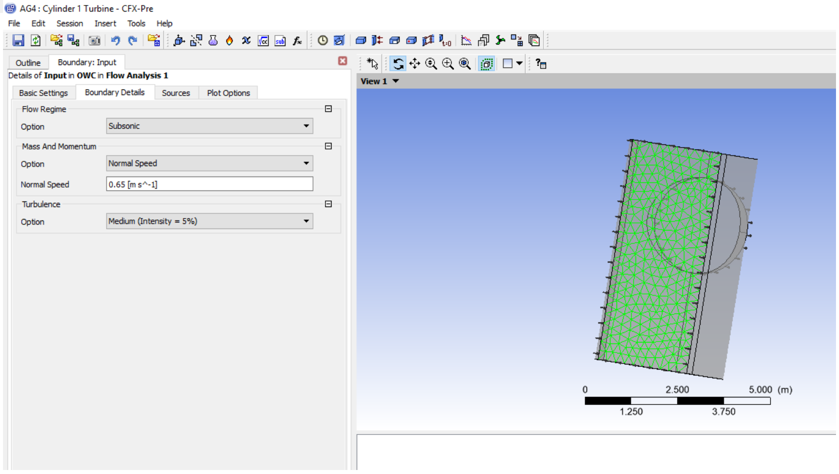
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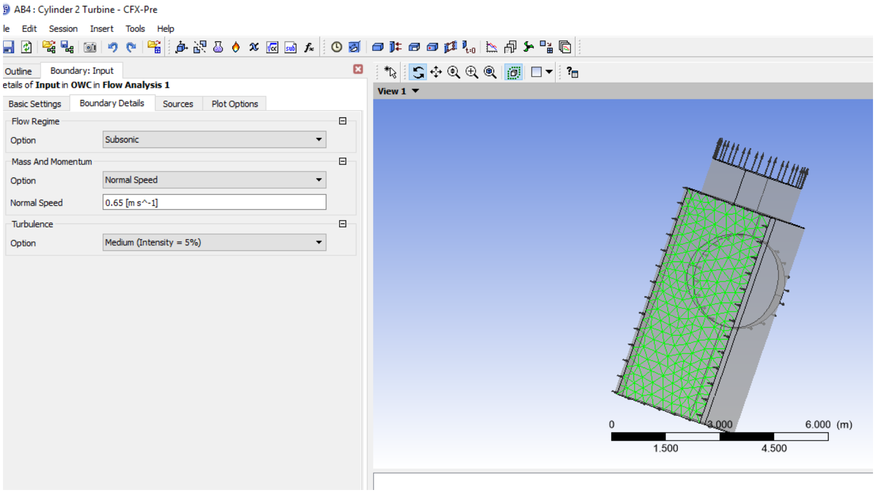
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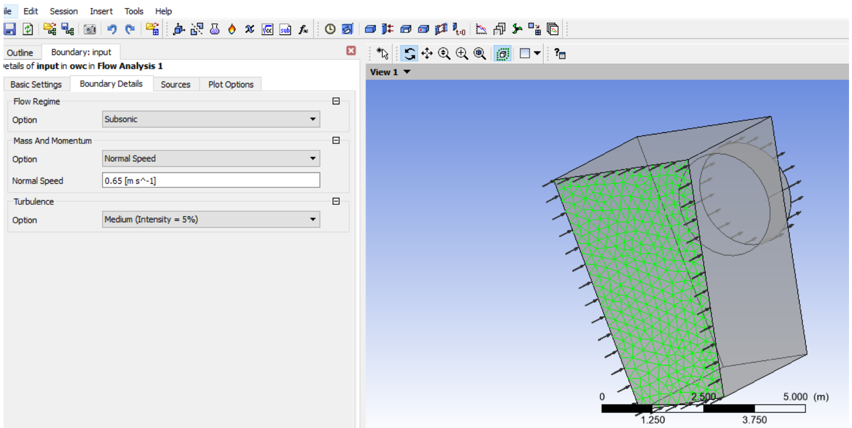
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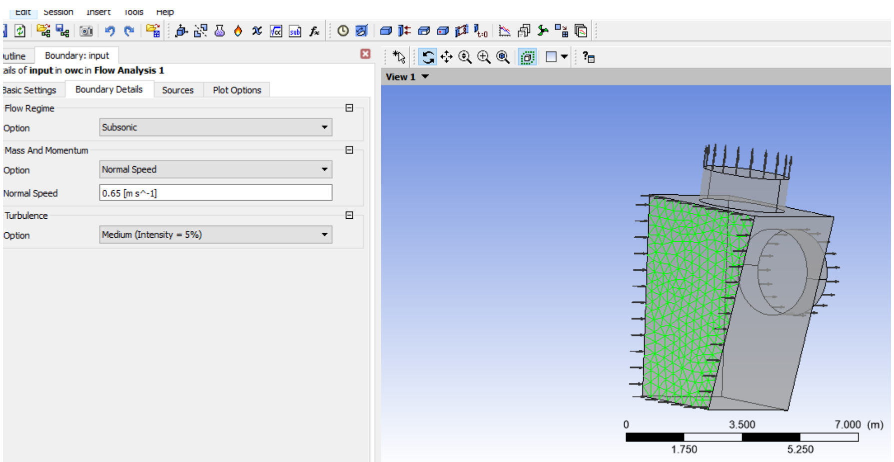
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AUTHOR BIOGRAPHY

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