

# Design and fabrication of wave generator using an oscillating wedge

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## ABSTRACT

This paper describes the design and fabrication of a wave flume. The wave maker is made by a triangle wedge. Wave flume size is 0.75(m) in width, 1.3(m) in height and 11(m) in length. The characteristic of a generation wave is also conducted in this research. An experimental results of the crated wave is considered by two operation parameters (Eccentricity and Rotation speed). Wave flume is equipped with a triangle wedge which located at one end of the wave flume, and it can be move along the rail of the wave flume. The passive wave absorber which is made of honey comb which is located at the other end of the wave flume for absorbing energy waves generated from the wave maker. The wedge is controlled by a desktop computer via Matlab Simulink. The wedge is controlled move up and down at a prescribed speed, hence the wave amplitude leading to change the height and frequency. At the middle flume is equipped micro laser distance sensor which provides data-logging capability. A Micro laser distance sensor can collect wave height and wave period through a small ball which is motioned in the tube. The ball is very light to avoid inertia. The wave maker is equipped by a cable sensor to measuring the eccentricity. Wave flume can generate the largest wave energy such as: wave-amplitude is 0.2 (m), wave-length is 1.5(m) and frequency is 1 (Hz). The waves generated by a oscillating wedge have been measured, analyzed to consider the generated wave energy.

**Key words:** Wave Energy, Wave Flume, Wave Generation, Wave Maker

## INTRODUCTION

Ocean wave energy is the natural resource to be exploited as a renewable source of energy, while also coinciding with the aim of reducing our reliance on fossil fuel sources. The concept of harnessing ocean wave energy is by no means a new idea. Modern research into harnessing energy from waves was stimulated by the emerging oil crisis of the 1970s<sup>1</sup>. With global attention now being drawn to climate change and the rising level of CO<sub>2</sub>, the focus on generating electricity from renewable sources is once again an important area of research. At present, many countries in the world use wave energy as a source of clean and renewable energy<sup>2,3</sup> (Figure 1).

Therefore, experimental wave flumes are very useful to test the performance of wave energy conversions. The wave generation is made through a wave-maker animated with a prescribed motion with specified amplitude and frequency<sup>4</sup>. Three main classes of mechanical type wavemakers are utilized in laboratory: The first is the movable wall type generators<sup>5</sup>, including piston and paddle-type wavemaker, which generates waves by a simple oscillatory motion in the direction of wave propagation (Figure 2). The movable wall type generators are used where the water

is shallow compared to the wavelength of the waves. Here the orbital particle motion is compressed into an ellipse and there is significant horizontal motion on floor of the tank. This type of paddle is used to generate waves for modelling coastal structures, harbours and shore mounted wave energy devices.

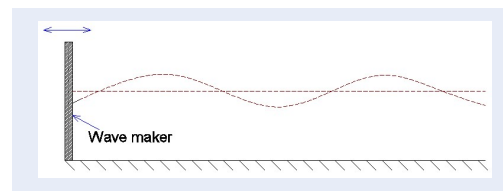


Figure 2: The movable wall type generators.

The second is the plunger-type wavemakers<sup>5</sup>, which generates waves by oscillating vertically in the surface of water (Figure 3). The plunger-type wavemakers are commonly used in wave flumes because they can be fabricated as fairly long wave machines and they easily relocated within the flumes. The machine is very compact, furthermore, as the shape is wedge, the flume can be designed to work with water behind the wave maker with almost no generation of back waves<sup>4</sup>.

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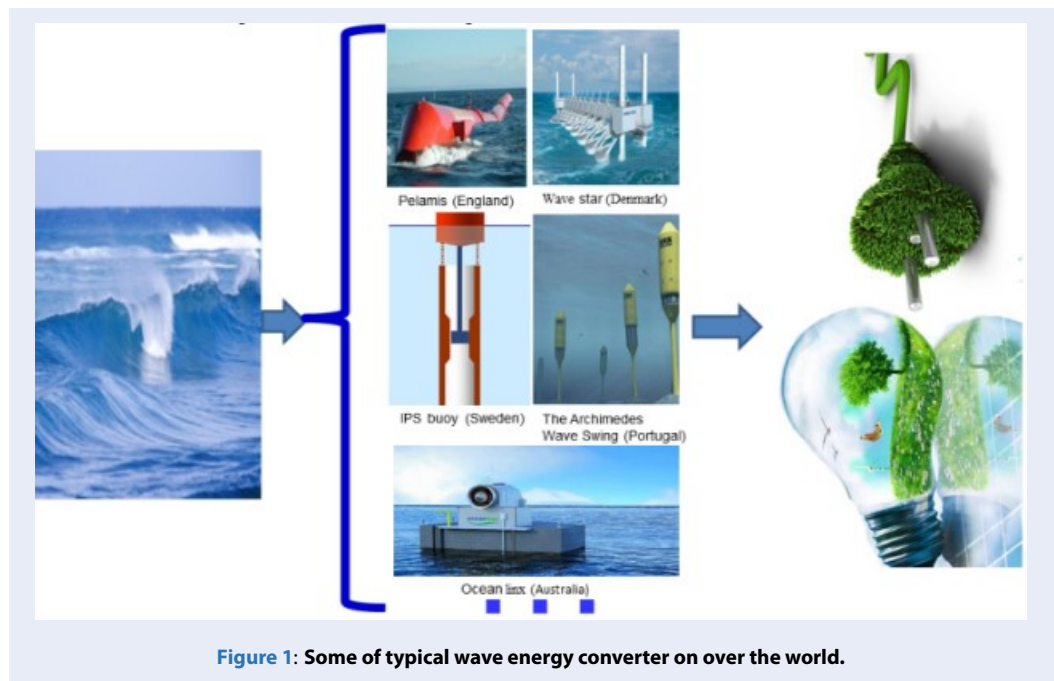


Figure 1: Some of typical wave energy converter on over the world.

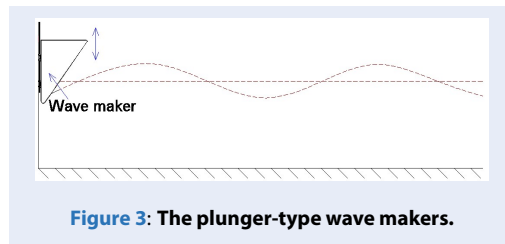


Figure 3: The plunger-type wave makers.

The third is the flap-type wave-maker, which is located at one end of the tank<sup>6</sup>, and hinged on a sill (Figure 4), waves are generated by oscillation of the flap about the sill, flap-type wave-maker is used to produce deep water waves where the orbital particle motion decays with depth and there is negligible motion at the bottom.

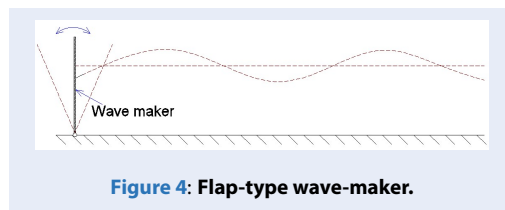


Figure 4: Flap-type wave-maker.

This paper describes the design and fabrication of a wave flume with the plunger-type wavemakers and associated equipment, the waves generated by a sinusoidal oscillating wedge have been measured and analyzed.

## DESIGN AND FABRICATION

### Wave Flume

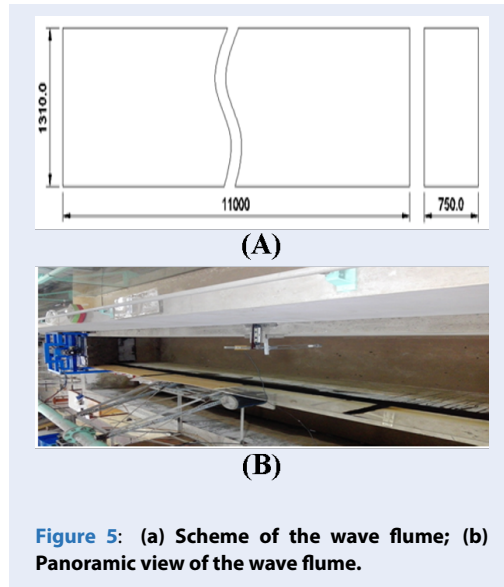
Experiments were performed in a concrete wave flume which is 0.75-meter-wide, 1.3-meter-tall and 11 meters long (Figure 5a). The water depth was maintained at 0.97 meters. The one side of the flume is made of 1-cm-thick clear mica sheets for observe the water waveform, mica sheets are supported by steel structural frames, the other side is the concrete wall (Figure 5b).

### Wave Gauges and Data Acquisition

A Micro Laser Distance Sensor (HG-C1400-Panasonic) is used for measuring the wave height. This sensor is located at the middle of the tank and it isn't contacted with water so not affect parameters of the wave. This is also the advantage of this design. Additionally, an Eccentricity Sensor is used to measure the wedge position (Figure 6a).

### Wave-Maker

Waves were generated using a wedge shaped plunger device, the 35 degree wedge has been chosen for the wave-maker because 35 degree wedge is so good for wave-maker performance in<sup>7</sup>. It is set at one end of the tank (Figure 6b) and is made of 1-mm-thick Inox sheets, it can generate regular waves. The wedge has a 0.418 m base and 0.566 m height, with a mean submergence height of 0.375 m (Figure 7). The wedge is



operated by 1 kW electric linear servo motor, which is controlled by computer. The installed wave-maker is capable of generating regular waves from 0.7s up to 3s period and 0.7m up to 14m wave length (case by case). The servo motor is programmed to provide sinusoidal input motion to the Wave-Maker<sup>8</sup>.

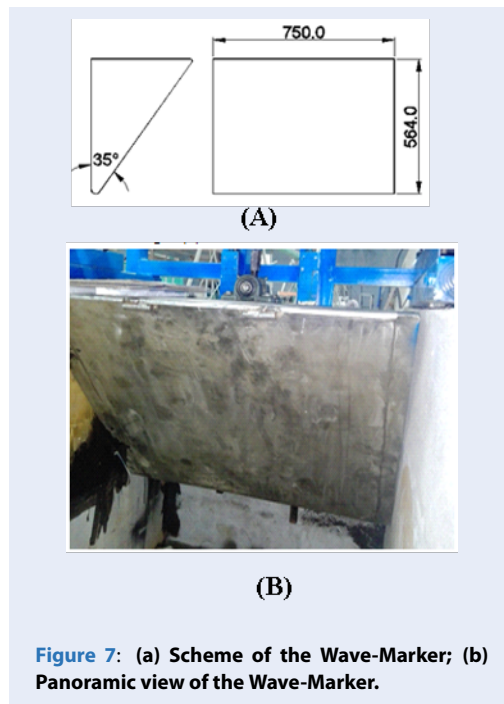


Figure 7: (a) Scheme of the Wave-Maker; (b) Panoramic view of the Wave-Maker.

### Wave Absorber

Wave absorber is the most important part in a wave flume. A great variety of designs and materials have been used throughout the world for the construction of wave absorbers. Wave absorbers could be classified into two main categories: active and passive absorbers. Active absorbers owing to its high cost is still very limited, except in a few cases where the wave board itself is programmed to absorb the reflected wave. In this design uses passive absorbers, the wave absorber has 1:4 slopes<sup>9</sup>. It is located at the end of the tank opposite to the wave-maker (Figure 6c). The waves generated are absorbed using a honey comb which is set at the other one end of the tank (Figure 8).

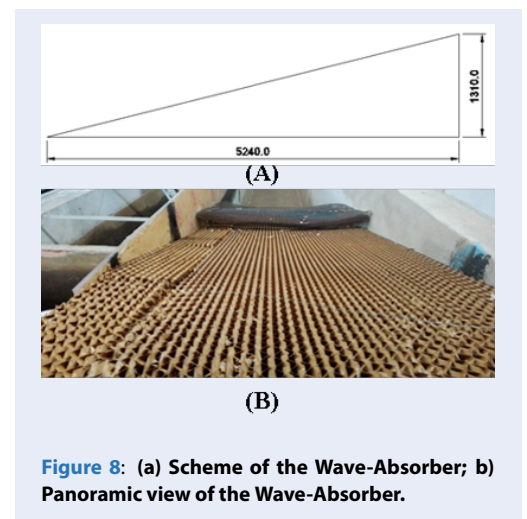


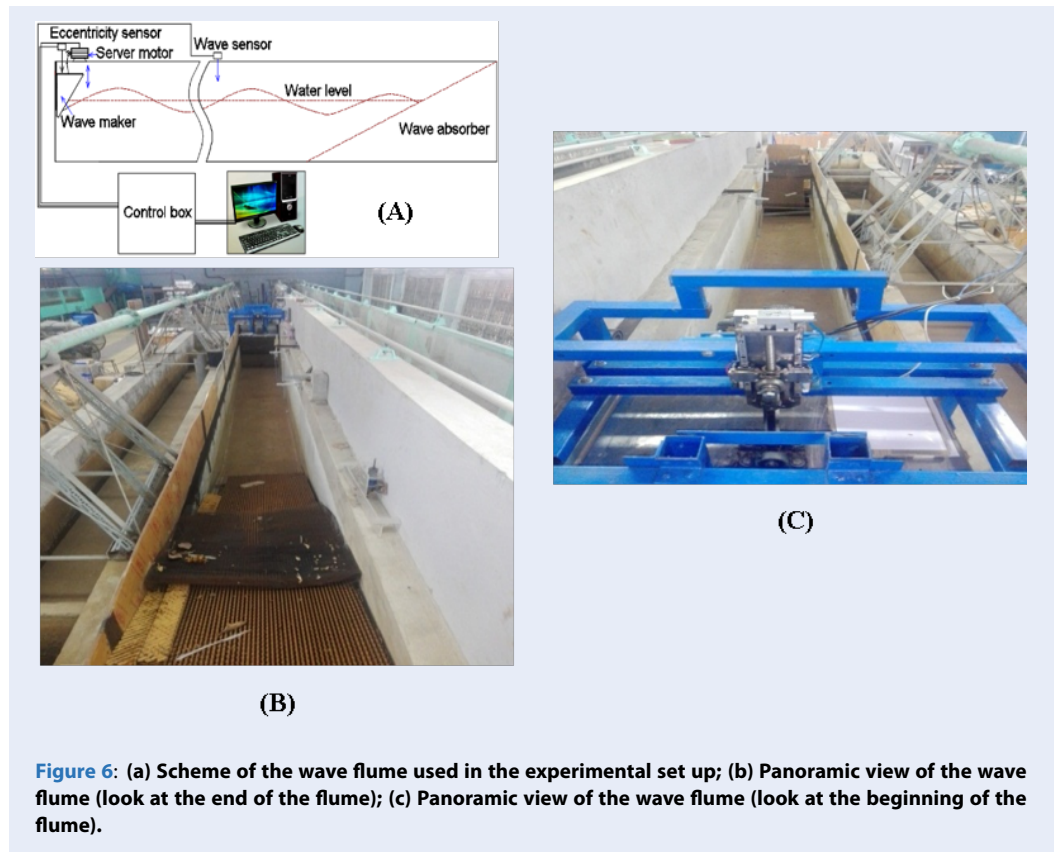
Figure 8: (a) Scheme of the Wave-Absorber; (b) Panoramic view of the Wave-Absorber.

### THEORETICAL APPROACH

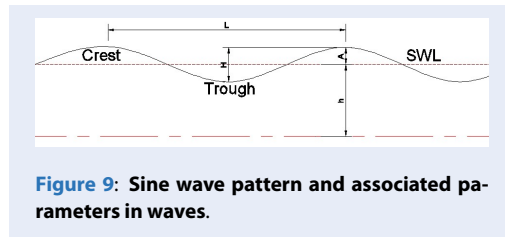
Many models can be used to try to describe the evolution of the surface elevation in time and space. One of the most used, because of the simplicity that results of assuming linearity of the potential flow function, is the one related to the linear wave theory<sup>10</sup>.

$$\eta(x;t) = A \cos(\omega t - kx) \quad (1)$$

The main parameters that define a wave are amplitude (A), period (T) and wavelength (L), represented in Figure 9. The amplitude corresponds to half of the wave height (H), the vertical distance between the highest and the lowest surface elevation in a wave. The time interval between the start and the end of the wave is what is known as the period of a wave. Finally, the wavelength is the distance between two successive peaks or two consecutive troughs. Table 1 and Figure 9 summarize a commonly used wave energy nomenclature.



**Figure 6:** (a) Scheme of the wave flume used in the experimental set up; (b) Panoramic view of the wave flume (look at the end of the flume); (c) Panoramic view of the wave flume (look at the beginning of the flume).



**Figure 9:** Sine wave pattern and associated parameters in waves.

Energy and power density: The energy density of a wave is the mean energy flux crossing a vertical plane parallel to a wave’s crest. The energy per wave period is the wave’s power density and can be found by dividing the energy density by the wave period.

$$E_{density} = \frac{\rho g H^2}{8} = \frac{\rho g A^2}{2} \tag{2}$$

$$P_{density} = \frac{E_{density}}{T} = \frac{\rho g H^2}{8T} = \frac{\rho g A^2}{2T} \tag{3}$$

Power per meter of wave front: A wave resource is typically described in terms of power per meter of wave front (wave crest). This can be calculated by multiplying the energy density by the wave front velocity.

$$P_{wave\ front} = C \cdot E_{density} = \frac{L \rho g H^2}{8T} \tag{4}$$

$$E_{wave\ front} = P_{wave\ front} \cdot T \tag{5}$$

## RESEACH METHOD, RESULT AND DISCUSSION

The research method is used in this paper is experiment method. We experiment with many difference parameters of system to consider the generated wave energy.

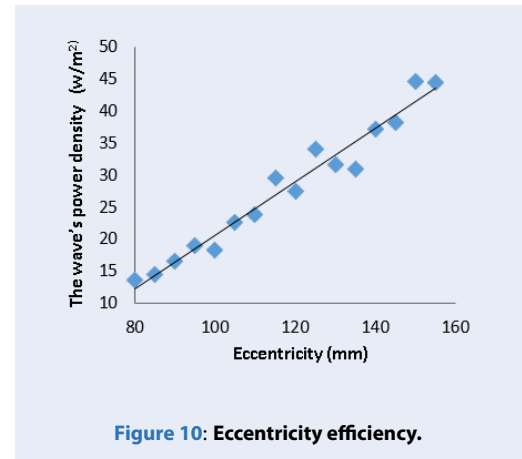
The list of experimental tests are presented in **Table 2**. These tests were chosen to show the wave height range of 12 mm to 200 mm, wavelength range of 0.7m to 14m. The water depth was maintained at 0.97 meters. From **Table 2**, we draw **Figure 10**. According to **Figure 10**, we find that the wave’s power density is related to eccentricity, which can be predicted linearly. Maybe, the experimental system is not good. So, there are many places that do not follow the linear relationship. **Table 3**, we draw **Figure 11**. According to **Figure 11**, we see that the wave’s power density is related to the RPM, which can predict as a second order. When RPM is greater than 68r/m; the waves are interrupted. **Table 4**, we draw **Figure 12**. According to **Figure 12**, when increasing eccentricity (e = 100mm); the wave’s

**Table 2: List of experimental tests (RPM=50 r/m)**

e (mm)	T (s)	H (mm)	L (m)	Pdensity (w/m <sup>2</sup> )
80	0.895	99.656	1.250	13.606
85	0.895	102.661	1.251	14.434
...	...	...	...	...
145	0.896	167.101	1.254	38.197
150	0.896	180.486	1.254	44.562
155	0.894	180.023	1.249	44.430

**Table 1: Wave Nomenclature**

Name	Description	Units/Value
$\eta$	The water surface	m
t	Time	
x	Space	m
w	Wave frequency	rad/s
k	The wavenumber	rad/m
$E_{density}$	Wave energy density	J/m <sup>2</sup>
$E_{wave\ front}$	Energy per meter wave front	J/m
$P_{density}$	Wave power density	W/m <sup>2</sup>
$P_{wave\ front}$	Power per meter wave front	W/m
SWL	Mean water level (surface)	
h	Depth below SWL	m
L	Wavelength	m
$\rho$	Sea water density	1000 kg/m <sup>3</sup>
g	Gravitational constant	9.81 m/s <sup>2</sup>
A	Wave amplitude	m
H	Wave height	m
T	Wave period	
C	Celerity (wave front velocity)	m/s
RPM	Round per minute	r/m
e	Eccentricity	mm



**Figure 10: Eccentricity efficiency.**

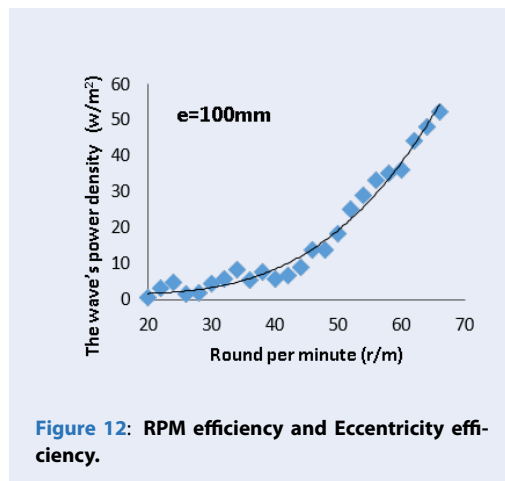
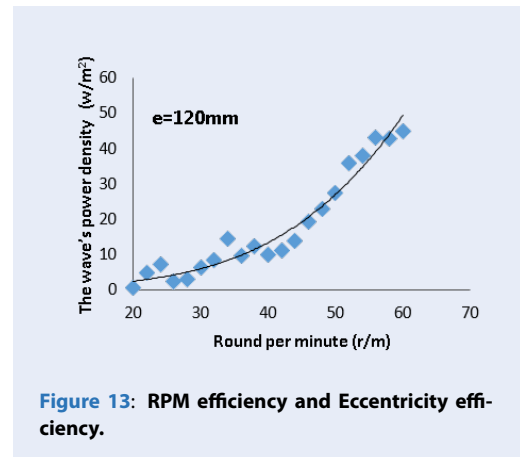
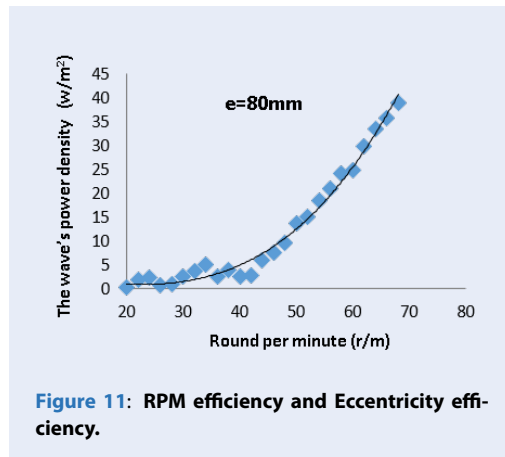
**Table 3: List of experimental tests (e=80mm)**

RPM	T (s)	H (mm)	L (m)	Pdensity (w/m <sup>2</sup> )
20	2.221	35.669	7.704	0.702
22	2.069	88.884	6.686	4.681
...	...	...	...	...
64	0.697	137.94	0.758	33.473
66	0.681	141.10	0.725	35.827
68	0.659	144.77	0.678	38.997

**Table 4: List of experimental tests (e=100mm)**

RPM	T (s)	H (mm)	L (m)	Pdensity (w/m <sup>2</sup> )
20	2.217	28.202	7.673	0.439
22	2.069	74.062	6.684	3.250
...	...	...	...	...
62	0.723	161.510	0.816	44.224
64	0.698	165.402	0.761	48.034
66	0.682	170.754	0.726	52.409





**Table 6: List of experimental tests (e=140mm)**

RPM	T (s)	H (mm)	L (m)	Pdensity (w/m <sup>2</sup> )
20	2.215	40.556	7.660	0.910
22	2.067	102.937	6.675	6.283
...	...	...	...	...
54	0.827	178.080	1.068	46.999
56	0.798	181.131	0.995	50.377
58	0.767	185.804	0.919	55.155

power density increases. When RPM is greater than 66 r/m; the waves are interrupted.

**Table 5: List of experimental tests (e=120mm)**

RPM	T (s)	H (mm)	L (m)	Pdensity (w/m <sup>2</sup> )
20	2.221	35.669	7.704	0.702
22	2.069	88.884	6.686	4.681
...	...	...	...	...
56	0.8	167.965	1.001	43.198
58	0.773	164.519	0.933	42.914
60	0.749	165.567	0.877	44.828

Table 5, we draw Figure 13. In Figure 13, when e=120, the graph has more fluctuation, due to the influence of reflectivity. When RPM is greater than 60r/m; the waves are interrupted

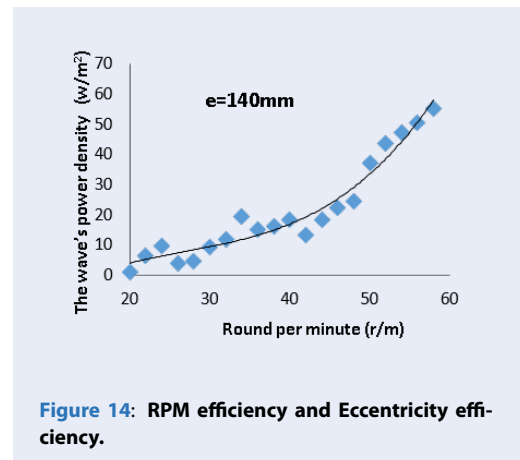
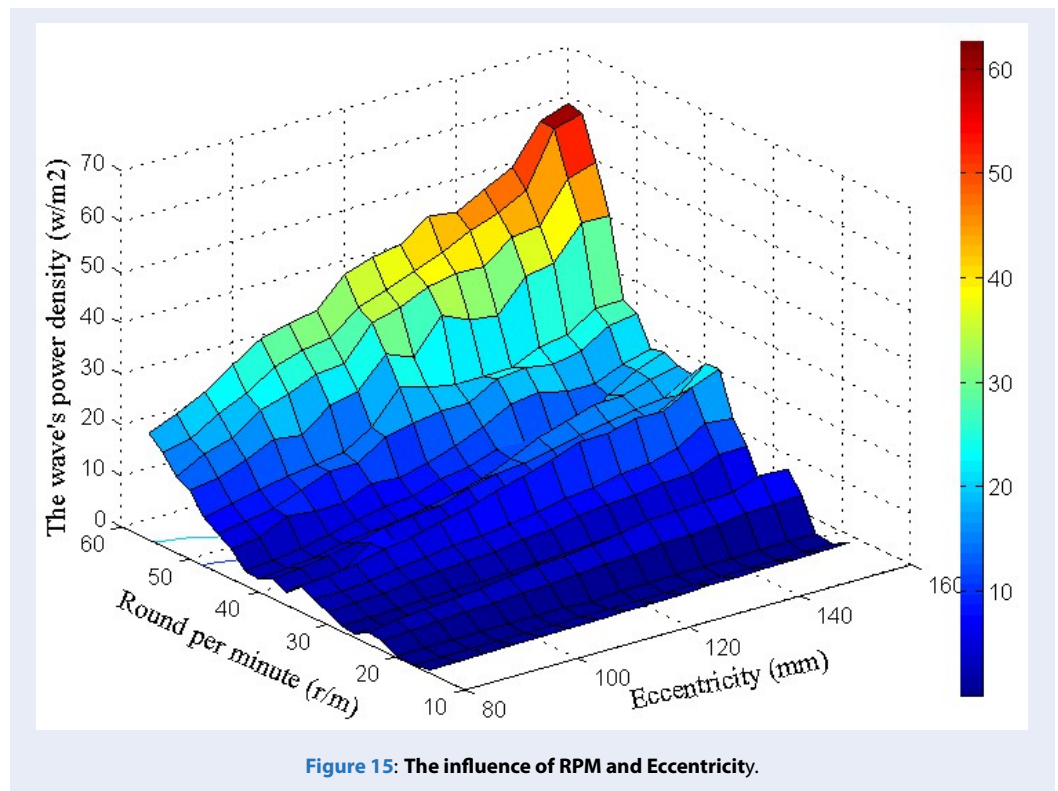


Table 6, we draw Figure 14. In Figure 14, when increasing eccentricity longer; fluctuation as much, due to the influence of reflectivity so much. When RPM is greater than 58r/m; the waves are interrupted.

Figure 15 illustrate how RPM and eccentricity affect the wave's power density. The wave's power density is significantly affected by RPM and Eccentricity.



## CONCLUSION

In this paper, the system wave flume is described and fabrication for a study and built with a limited budget, however, it is well-suited to educational and research studies about wave energy. The performance of the physical wave maker and wave absorber was evaluated over a range of frequencies and eccentricity. The results also show that the wave's power density significantly affected by RPM and Eccentricity. The affected of reflectivity is so much, further work, we will improve the performance of the wave absorber in the wave flume to minimize the reflected waves.

## CONFLICT OF INTEREST

The authors hereby warrant that this paper is no conflict of interest with any publication.

## AUTHOR'S CONTRIBUTION

Ms. Lu Thi Yen Vu played a role as an executer, analyzed experimental data and wrote the paper.  
 MSc. Ha Phuong fabricated mechanical equipment and managed all experimental process.  
 Dr. Dao Thanh Liem and Dr. Ho Xuan Think suggested the mechanical design.  
 Dr. Truong Quoc Thanh contributed for writing paper.

Ass. Prof Tran Doan Son played a role as a corresponding author.

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# Thiết kế và chế tạo thiết bị tạo sóng sử dụng nêm dao động

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## TÓM TẮT

Nội dung chính của bài báo này trình bày về thiết kế và chế tạo một thiết bị tạo sóng dạng nêm cùng với các thiết bị phụ trợ. Kênh tạo sóng được xây dựng bằng bê tông với chiều rộng 0.75 mét, 0.3 mét chiều cao, và chiều dài là 11 mét. Một bên thành của kênh tạo sóng được làm bằng bê tông, bên thành còn lại được làm bằng tấm mica trong suốt để quan sát biên dạng sóng. Kênh tạo sóng được trang bị hình nêm tam giác được đặt ở cuối kênh, hình nêm này có thể di chuyển dọc theo thành kênh. Bộ hấp thụ sóng thụ động được làm bằng các tấm tổ ong nằm ở phía đầu đối diện để hấp thụ năng lượng sóng nhằm ngăn sóng phản hồi. Nêm có thể di chuyển lên xuống và được điều khiển bởi một máy tính thông qua phần mềm matlab để tạo ra được biên độ dao động và tần số mong muốn nhằm tạo ra các thông số sóng khác nhau. Tín hiệu thông số sóng được thu thập thông qua một quả banh nhỏ, rất nhẹ để tránh sự ảnh hưởng của lực quán tính, trái banh này được di chuyển trong một ống nhựa được lắp trên mặt nước. Tại hình nêm tạo sóng được lắp một cảm biến đo độ lệch tâm để đo vị trí của hình nêm và phản hồi về máy tính điều khiển. Thiết bị tạo sóng có thể tạo ra sóng với biên độ sóng lớn nhất khoảng 0,2 (mét), chu kỳ khoảng 1 (giây), và bước sóng khoảng 1,5 (mét). Sóng tạo ra bởi nêm dao động đã được đo, và phân tích để xem xét năng lượng sóng.

**Từ khóa:** Năng lượng sóng, Mương nước tạo sóng, Tạo sóng, Máy tạo sóng

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