Preliminary Wave Energy Assessment to Setup a Breakwater Type Oscillating Water Column Ocean Wave Energy Converter at Hambantota Port, Sri Lanka

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Abstract *— Oscillating Water Column (OWC) is a type of Wave Energy Converter (WEC) that transforms the energy of ocean waves into low-pressure pneumatic power. Subsequently, this pneumatic power is taken out by a turbine and converted to electric energy through a generator. The Sri Lankan wave energy resources were assessed and revealed that the 12-15 kW/m average wave power can be generated annually and is appropriate to establish large-scale, offshore wave energy converters. The wave climate off the South-East coast of Sri Lanka has been encompassed with two different wave types such as long period swell waves and locally wind propagated short period waves due to monsoons. Therefore, Hambanthota Harbor is selected as a research study area and the most appropriate place to fix a breakwater-type OWC. As per the annual and seasonal wave climate of the South-East coast of Sri Lanka, this research focuses on extreme wave occurrences in July and August. In this investigation, firstly a directional, roll, and pitch 'Wave Rider Bouy' was placed inside the Hambanthota Harbour to collect wave climate data from July to August 2019. Then, the same 'Wave Rider Bouy' was placed 4 NM away outside the harbour and obtained wave measurements. Finally, an analytical study was conducted and revealed that swell wave height and significant wave height were sufficient to generate wave power and feasible to set up a breakwater type OWC ocean wave energy converter at Hambanthota harbour. Recommends to carry out another study to collect swell wave and significant wave data for the next three years, to confirm the sustainability of this project.*

Keywords **— Hambanthota Harbour, Sri Lanka, Break Water Type Oscillating Water Column, Wave Rider Buoy.**

I. INTRODUCTION

An Oscillating Water Column (OWC) is a type of Wave Energy Converter (WEC) that transforms the energy of ocean waves into low-pressure pneumatic power. Subsequently, this pneumatic power is taken out by a turbine and converted to electric energy through a generator. Former Japanese naval officer, Yoshio Masuda is regarded as the father of modern wave energy technology. He conducted many investigations on this wave energy harnessing since 1940 and developed a navigation buoy powered by oscillating waves. Later it was identified as OWC technology. This wave energy was harnessed through an air turbine. Then, these buoys were commercialized in Japan in 1945 in Figure 1 (Amarasekara, et al., 2014).

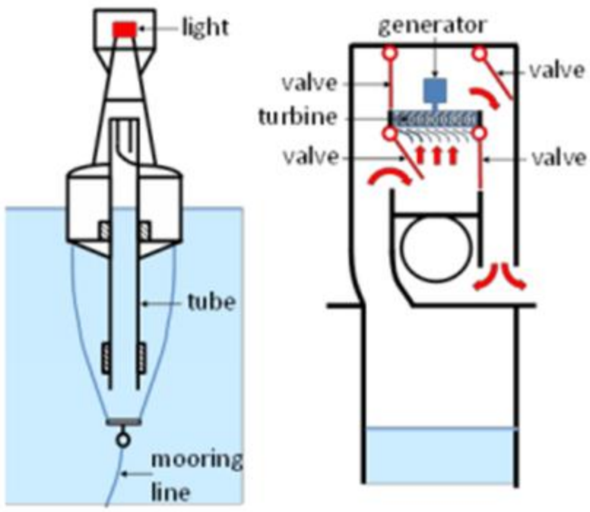

Figure 1. Buoy integrated with an air turbine made by Japanese Source:

OWC consists of a semi-submerged hollow chamber partially open to the sea, then maintains an air pocket above water level. Due to waves, the water column height fluctuates (up and down) and the trapped air volume pressures vary simultaneously. This continuous movement forces a bidirectional stream of high-velocity air, which is led through a circular duct inside and a Power-Take Off (PTO) exists. The PTO system converts the airflow into energy using an air turbine in Figure 2 (El Marjani, et al.,2006)

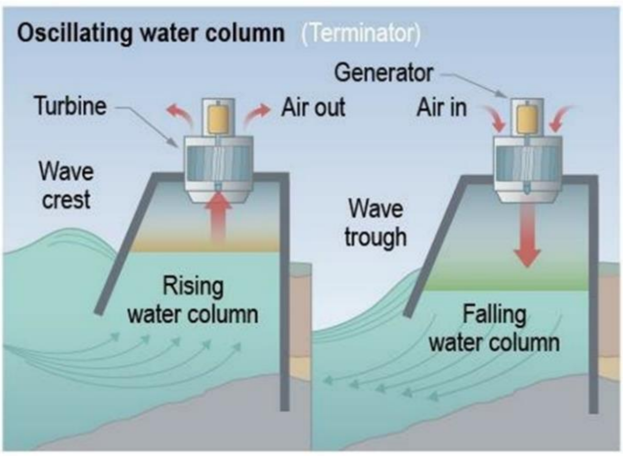

Figure 2. Conventional type Oscillating Water Column Wave Energy Converter

Source:

A comprehensive study of OWC technologies has been recognized, some were investigated at the prototype level, and others were tested at full scale in realistic scenarios. In this OWC technology, two types are commonly used to harvest wave energy such as fixed and floating structures. A breakwater integration OWC is a fixed structure that has provided several advantages such as access for construction, lesser construction costs, and cost-effectiveness of daily functions and maintenance of the wave energy converter compared to floating structure OWCs in Figure 3 (Falcão, A.F. and Henriques, J.C., 2016).

Figure 3. Multi-chamber OWC plant integrated into a breakwater, Spain

Source:

A. Wave Climate off the South-East Coast of Sri Lanka

The Sri Lankan wave energy resources were assessed and revealed that the 12-15 kW/m average wave power can be generated annually and is appropriate to establish large-scale, offshore wave energy converters. The wave climate off the South-East coast of Sri Lanka has been encompassed with two different wave types such as long period swell waves and locally wind propagated short period waves due to monsoons. Further, it is revealed that swell waves are propagated in the Southern Indian Ocean in deep water and flow direction towards more or less Southworth. Moreover, the most significant waves are locally propagated due to wind effects of the South-West monsoon. However, the Hambantota coastal area is not directly impacted by North East monsoon weather, and the generated wind field affects to South-East coast in Figure 4 (Karunarathna, et al., 2021).

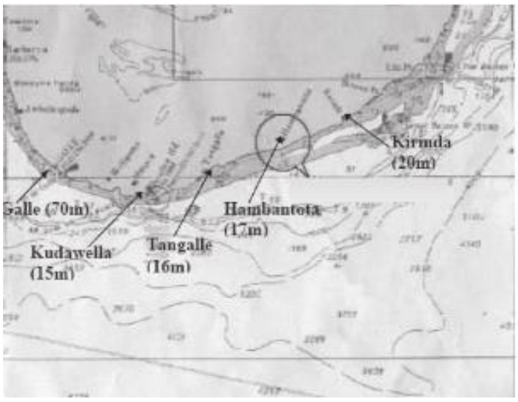

Figure 4: Analyzed wave data on the South-East coast of Sri Lanka

Source:

Table 1. Percentage dominance of swell on a monthly basis

Month	Swell (%)
January	59.1
February	67.9
March	66.8
April	74.4
May	57.6
June	61.9
July	68.2
August	68.8
September	67.5
October	60.5
November	77.6
December	62.9

Source: Luo et al. (2018)

To find a suitable location to fix a breakwater-type OWC, a group of researchers from the Department of Marine Engineering, Faculty of Engineering, General Sir John Kotelawala Defence University, Sri Lanka decided to study and assess wave climate inside and outside the Hambanthota Harbour. In this investigation, the KDU technical team paid attention to selecting the most appropriate location, safe design, and economic viability for this project. Then, they realized that the OWC structure needs to withstand extreme wave conditions. Subsequently, they focused on the annual and seasonal wave climate of the South-East coast of Sri Lanka and made the experimental set-up to study extreme wave occurrences only for one month due to financial limitations. In this investigation, firstly a directional, roll, and pitch 'Wave Rider Bouy' was placed inside the Hambanthota Harbour to collect wave climate data from July to August 2019. Then, the same 'Wave Rider Bouy' was placed 4 NM away outside the harbour and obtained wave measurements. Finally, an analytical study was conducted to check the feasibility of setting up breakwater-type OWC at Hambantota harbour with the assistance of the Sri Lanka Navy Hydrography Service and Lanka Hydraulics Institute in Figure 5.

Figure 5. Breakwater of Hambanthota harbour

II. METHODOLOGY

This directional, roll, and pitch 'Wave Rider' bouy is used to collect data on wave energy studies, harbour monitoring, environmental monitoring, and subsea engineering pre-surveys. Further, this particular buoy was equipped with a weather transmitter, tide sensor, speed sensor, pressure sensor, environmental sensor, and accelerometer. Therefore, it was understood that this buoy was a stabilized platform to get proven and accurate data and called 'Datawell'. Subsequently, the accelerometer of this bouy enabled real-time wave height measurements with a half-hourly heave and updated directional ranges. Then, Datawell was fixed with an LED flashlight along with an antenna to increase the buoy's visibility. The GPS receiver facilitated the existing location of the buoy. In addition, it was connected to the HF link and gathered data up to 50 km over the sea in Table 2.

Table 2. Specifications of Datawell

Resolution & Precision	**Direction**	**Time** (Free Floating): 1.6 s to 30 s **Range**: 0º to 360º (resolution 14) **Heading Error:** 0.4º to 2º
	Heave	**Time:** 1.6 s to 30 s **Range:** -20 m to +20 m (resolution 0.01 m) **Accuracy:** < 0.5% measured value just after calibration < 1.0% measured value after 3 years
	Water Temperature	**Range:** -5 ºC to +46 ºC resolution 0.05ºC **Accuracy:** < 0.1 ºC
Sensor	**Type**	'Datawell'
	Processing	32 bits Microprocessor
	Sampling	8 Channel, 14 bits, 3.84 Hz
Standard Features	**Integrated Data Logger**	512Mb Compact Flash Module
	LED Flash Light	Antenna type yellow (590 nm), pattern 5 flashes every 20 s, standard length 35 cm

Figure 6. Wave Rider Bouy at Hambanthota Harbor

A. *Wave Energy Calculation*

The amount of wave energy (E) generated in a particular location of the sea can be measured by a Fourier analysis after an investigation of wave data for a long period. In this context, the 'E' can be quantified by calculating the mechanical energy availability of the wave in equations (1, 2, 3, and 4).

Potential Energy: E_p
Kinetic Energy: E_k
Total Energy: E_T

$$E_P = mgh \quad \textit{Equation 1}$$

$$E_k = \frac{1}{4}\rho g a^2 \lambda \quad \textit{Equation 2}$$

$$E_T = E_P + E_k \quad \textit{Equation 3}$$

Mean Energy Density = Total energy per sea surface area
E: Wave Energy
ρ: Density
g: Gravitational Force
H: Wave Height

$$E = \frac{1}{8}\rho g H^2 \quad \textit{Equation 4}$$

III. RESULTS AND DISCUSSION

In this comprehensive study, data on swell wave height and significant wave height were gathered through the wave rider buoy from 07/08/2019 to 08/08/2019 indicated in Table 3.

Table 3. Mean Swell Wave Height and Significant Wave Height from 07/08/2019 to 08/08/2019

Date	Swell Wave Height	Significant Wave Height
07/08/2019	1.57	2.51
07/092019	1.48	2.48
07/10/2019	1.43	2.43
07/11/2019	1.34	2.31
07/12/2019	1.31	2.25
07/13/2019	1.29	2.25
07/14/2019	1.51	2.51
07/15/2019	1.56	2.43
07/16/2019	1.34	2.29
07/17/2019	1.57	2.23
07/18/2019	1.62	2.27
07/19/2019	1.53	2.55
07/20/2019	1.28	2.39
07/21/2019	1.54	2.48
07/22/2019	1.31	2.44
07/23/2019	1.43	2.43
07/24/2019	1.34	2.31
07/25/2019	1.31	2.25
07/26/2019	1.29	2.63
07/27/2019	1.51	2.51
07/28/2019	1.56	2.43
07/29/2019	1.34	2.29
07/30/2019	1.57	2.23
07/31/2019	1.62	2.58
08/01/2019	1.53	2.55
08/02/2019	1.28	2.39
08/03/2019	1.34	2.27
08/04/2019	1.57	2.23
08/05/2019	1.62	2.27
08/06/2019	1.53	2.55
08/07/2019	1.28	2.39
08/08/2019	1.57	2.51

It was revealed that the maximum mean swell wave height and significant wave height were 1.62 m and 2.63 m respectively. Subsequently, it was indicated that the minimum mean swell wave height and significant wave height were 1.28 m and 2.25 m congruently in Table 3 & Figure 7. In addition, it was shown that the mean temperature was 26.72°C and the mean pressure was 17.25 N/m^2. Consequently, the wind speed was varying from 1.4 m/s to 17.4 m/s. The heading, pitch, and roll are also read through the wave rider buoy in Annex A.

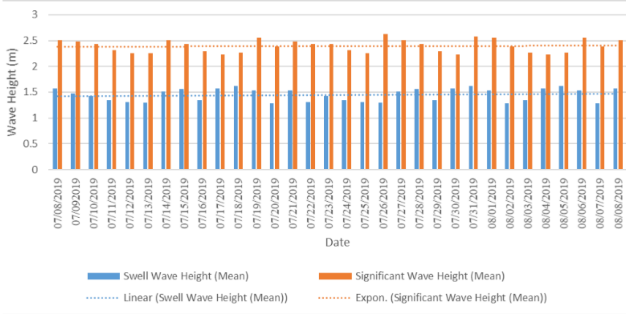

Figure 7. Mean Swell Wave Height and Significant Wave Height

The 8-10 kW/m of monthly average wave power can be generated through this project by Equations (3 & 4). Further, long-period swell waves and locally wind-propagated short-period waves were assessed in this investigation. Subsequently, it was identified that the depth of the inside harbour (17 m) and outside harbour (40 m) in Figure 8.

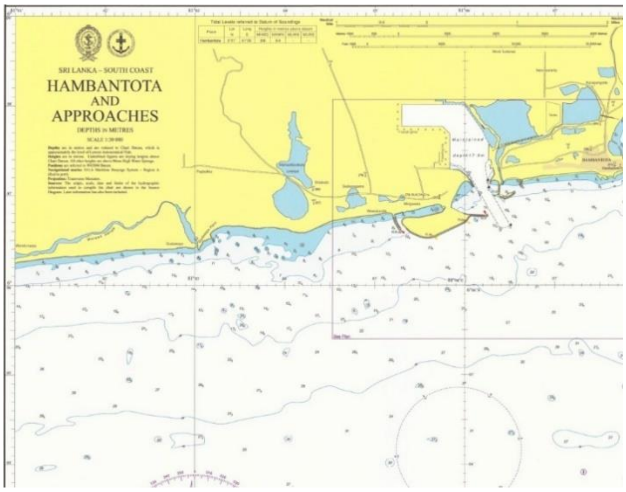

Figure 8. Depth of Hambanthota Habour

IV. CONCLUSION

It was very clear that swell wave height and significant wave height were sufficient to generate wave power and feasible to set up a breakwater type OWC ocean wave energy converter at Hambanthota harbour in Figure 5. Recommends to carry out another study to collect swell wave and significant wave data for the next three years, to confirm the sustainability of this project. Further recommends setting up an OWC model vent test rig at General Sir John Kotelawala Defence University simulating similar conditions and carrying out more studies related to turbines, valves, and optimization works with an economy of effort (Dissanayake, M.C.P., 2021).

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AUTHOR BIOGRAPHIES

Cmde (E) MCP Dissanayake, CEng (UK), CEng (India), FRINA, MIE (India), AMIE (SL) is currently performing as the Head of Department (Marine Engineering) and holds 2 No's patents for his research papers published so far. He is an inventor and published 15 No's publications on Brackish Water Reverse Osmosis applications, Fan Boat Building and Oscillation Water Column, and Ocean Wave Energy Converter. He was the Director of Research and Development at the Sri Lanka Navy and has received commendations on several occasions from the Commander of the Navy, HE the President of Sri Lanka for his innovation. Further, he was awarded the prestigious, Japanese, Sri Lanka Technical Award for his own developed low-cost Reverse Osmosis Plant, to eliminate Chronic Kidney Disease in Sri Lanka. Moreover, he has vast exposure to marine diesel engines and possesses a Masters's degree in Naval Engineering from Australian Maritime College, University of Tasmania, Australia.

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