DEVELOPMENT OF FRUGAL WAVE SIMULATOR FOR COASTAL EROSION STUDY

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ABSTRACT

Wave energy has destructive potential. Coastal erosion study should cover bigger geographical area. However, cost of the equipment limits the coastal erosion study especially in the developed countries. Lab scale frugal wave simulator has been developed to assist coastal erosion study. The system consists of wave generator and buoy reader. The system is equipped with Adruino UNO R3 and sensors to measure wave amplitude, A and wave velocity, V. The developed system has been tested in 3.5m length of flume channel. The raw data of wave amplitude and wave velocity from the system were applied to get the wave energy attenuation and total sediment deposition rate. Similar numerical model of experimental flume channel has been developed and simulate in FLOW-3D HYDRO. The results from these two methods were compared and showed acceptable range of errors between 6.35% to 7.8%. The developed wave simulator will enable inclusive and equitable quality education opportunities for all.

Keywords: *Wave energy, coastal erosion, wave simulator, Adruino, FLOW-3D HYDRO*

1.0 INTRODUCTION

Wave phenomenon contributes to the coastal erosion. Offshore breakwater is the current innovation that is used to control the coastal erosion. However, the offshore breakwater innovation is considered as costly and not sustainable [1]. Extensive studies are needed for coastal erosion control. There are lots of interrelated factors involved in coastal erosion control study that make it more challenging [2]. Wave is a complex phenomenon as a result of the wind's activity [3]. Wave have various sizes, frequencies, amplitude, speed, directions and behavior as shown in Figure 1 [4]. The amplitude of ocean waves is the most interesting attribute because it indicates the amount of energy hence its destructive potential [5]. As a result, impact of the wave form geometry of beaches, transfer of sand and other materials in the nearshore zone, and the stresses and strains on coastal buildings are all influenced by wave forces. Many interrelated parameters involved namely hydrodynamic, sediment transport condition, sediment composition and energy dissipation at coastal zone [6]. Analytical studies have to create many assumptions due to the complexity of developing the mathematical model [4]. On site experiment potentially able to provide accurate results but it is costly and life risky [7]. Therefore, there is a need for wave simulator in order to imitate the actual behavior of the phenomena. Triangulation using different methods in the research will increase the credibility and validity of the developed simulator.

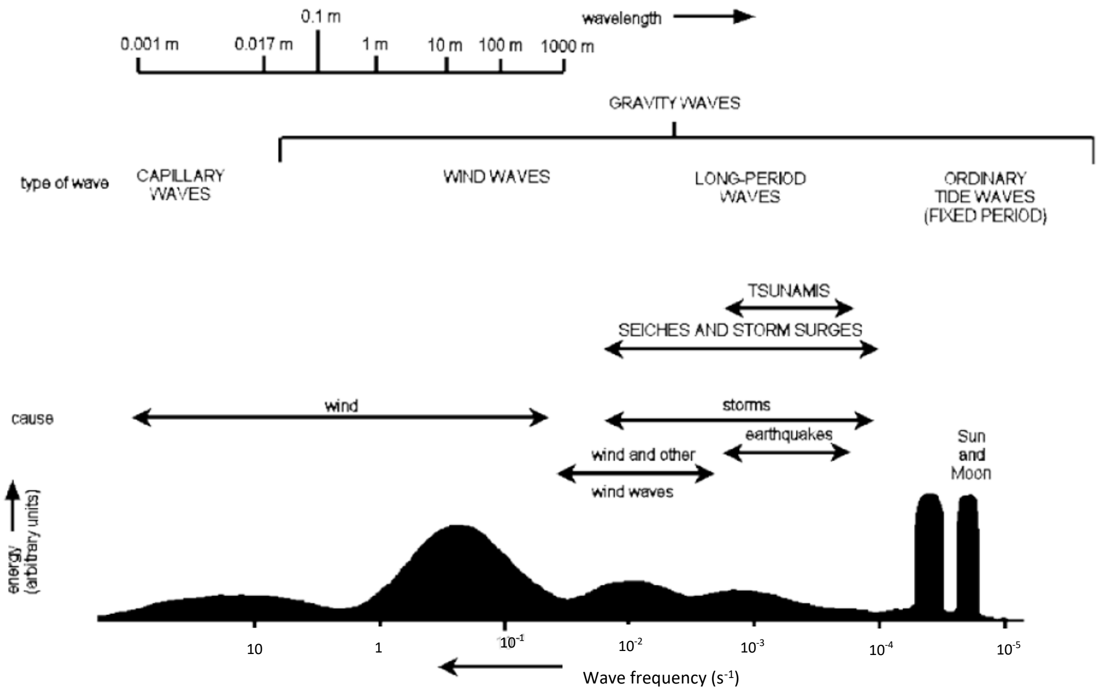

Figure 1: Ocean wave spectrum [4]

Conventionally, wave measurement technique is based on visual observation and estimation that consequently produce unreliable and inaccurate data. Currently, the techniques and technologies have been improved. Basically the technologies can be divided into two categories namely in-situ and remote sensing instruments. The in situ instruments are physically fixed at specific location or on the surface of the sea. There are varieties of instrument being used to measure ocean surface namely pressure gauges, step gauges (resistance or relay-activated), wire gauges (resistance or capacitance), altimeter and accelerometer [8]. Meanwhile, remote sensing extensively relies on satellites and aircraft. The innovation utilizes the radio wave propagation to assess wave height and slope. Likely, in situ technique combined with mathematical theories is able to provide more accurate data compare to remote sensing which gives low-resolution input [4].

Buoys are widely used for in-situ technique. Top manufacturer of data buoys is Waverider by Datawell. Waverider used accelerometer to measure vertical acceleration. However, there are factors that may affect the accuracy of the data as the buoy do not exactly follow the wave surface because the response varies with the wave frequency. Usually the buoy is tethered to the ocean floor to prevent it from drifting away. The mooring constraint consequently affect the buoy and accelerometer response [4].

The wave simulator is a sophisticated device that involved with high precision electronic devices and microcontroller. Usually the system is expensive in nature [9]. Due to Movement Control Order (MCO) enforcement in order to control the spread of the COVID 19 pandemic, there is urgency to develop an economical and reliable wave simulator for home and lab scale channel application.

2.0 PROPOSED SYSTEM MODEL

This section discussed the development of software and hardware of the frugal wave simulator. Figure 2 shows a schematic diagram of the system that consist of wave generator and two sets of buoy reader that were attached to the channel before and after the position of erosion control device. Sensory data that was collected from the system will be utilized for investigation of coastal erosion. The system will continuously measure the parameters that can give information on wave amplitude, A and wave velocity, V. Measuring such parameters continuously using sensors will assist in prediction of actual status of erosion in coastal area.

Software development of the system consists of two sub-systems namely wave generator and buoy reader. Figure 3 shows flowchart of the wave generator. The desired frequency can be set manually. The paddle continuously moves at the specified frequency until the operator decided to end the experiment by pressing the “stop” button.

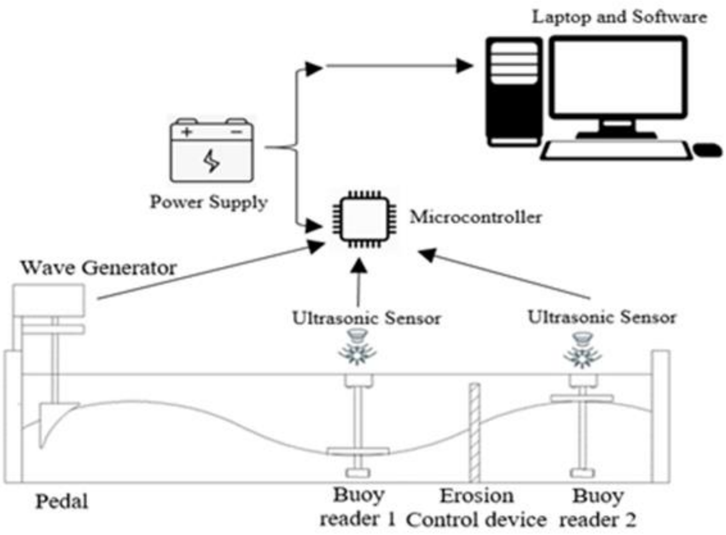

Figure 1: Schematic diagram of the frugal wave simulator system

Meanwhile, Figure 4 shows the flowchart of the buoy reader. The buoy reader designated to read and record the wave amplitude, A and wave velocity, V. The wave amplitude is measured based on the height difference. The raw sensor measurements are logged by Adruino UNO R3. The Arduino UNO R3 is the most basic and robust. It is also compatible with ATmega328P microcontroller. The boards feature serial communications interfaces, including Universal Serial Bus (USB) which is easier for loading programs. The microcontrollers can be programmed using C and C++ programming languages, a standard API which is also known as the "Arduino language".

Hardware development describes the arrangement of electronic devices and component in order to perform the intended function. Figure 3 and Figure 4 show the schematic diagram of the wave generator and buoy reader followed by Table 1 and 2 that summarize the component and its function. The desired frequency setting in Figure 3 can be done by adjusting the motor PWM in the control panel as shown in Figure 5. The motor of the wave generator can produce frequency up to 6.6 Hz.

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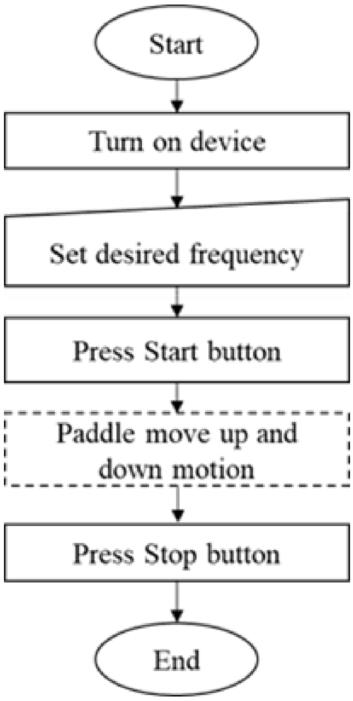

Figure 2: Flowchart of wave generator

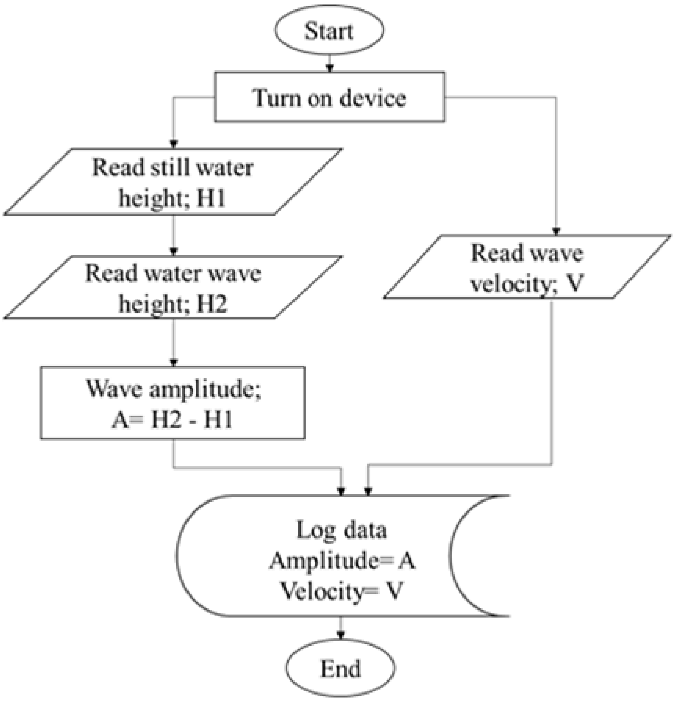

Figure 3: Flowchart of buoy reader

Table 1: Wave generator components and its function

Components	Description of functions
Tank flume	Tank filled with sand and flowing water at controlled rate to replicate the hydrodynamic condition.
Paddle	Device that is attached to the connecting rod and crank mechanism. The paddle movement creates wave.
Crank mechanism	The rotating movement of motor is converted to a repetitive up-and-down linear motion with attached mechanism.
Control box	Interface which allows users to control speed of motor/ wave generated

Table 2: Buoy reader components and its function

Components	Description of functions
Ultrasonic sensor	The sensor uses ultrasonic sound waves to detect the distance between the target item and transforms the reflected sound into an electrical signal.
Water flow sensor	It is made out of a plastic valve that allows water to pass through. The water flow is detected and measured using a water rotor and a hall effect sensor. The rotor turns as water runs through the valve. The change in the motor's speed may be seen this way.
Floating platform	It is made from polystyrene as solid based for ultrasonic sensor to reflect the generated sound.

Configuration of the wave reader is shown in Figure 6. Water surface is not solid that tend to reflect a portion of the sound and create a false echo. The sensor would misinterpret the surface's distance and gave an erroneous level measurement [10]. Retrieval of sea surface wave parameters from motion of floating bodies technique has widely applied for in situ ocean wave measurements [11]. Therefore, a solid floating platform is used in order to measure accurate distance of the platform change due to the wave effect. The floating platform can move up and down freely depending on the water level. The ultrasonic sensor HC-SR04 is used to detect the platform height. The sensor determines the distance by measuring the time taken for the emitting sound wave at certain frequency to rebound [12].

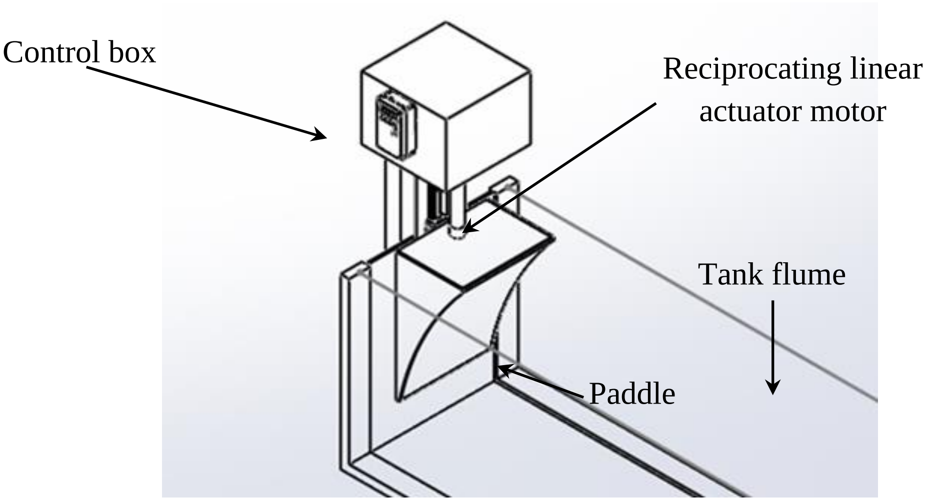

Figure 4: Schematic diagram of wave generator

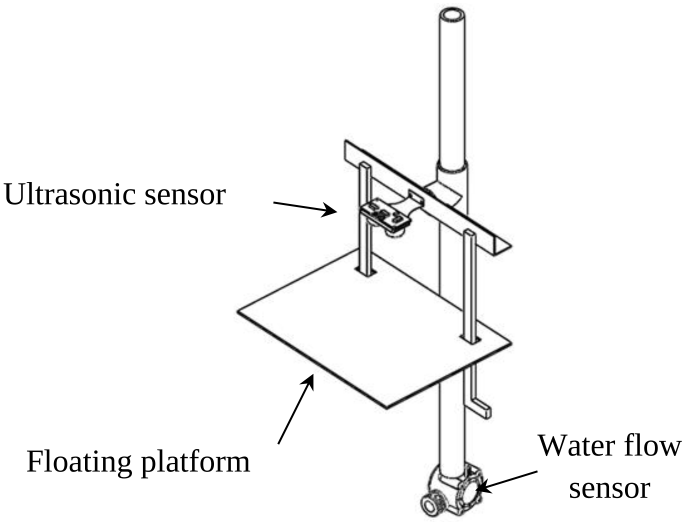

Figure 5: Schematic diagram of the buoy reader

Buoy reader is developed to measure the wave height based on displacement the platform measured by the ultrasonic sensor. The significant wave height, Hsig or H1/3 in the time domain is defined as the average height of that one third of the N measured waves having the greatest heights as shown in equation (1).

$$H_{1/3} = \frac{1}{\frac{1}{3}N}\sum_{m=1}^{\frac{1}{3}N} H_m \quad (1)$$

Where H_m represents the individual wave heights, sort into descending order of height as m increase from 1 to N and only the highest one third is used. Meanwhile, flow rate of the water at specific point can be determined by the Water Flow Sensor-YF-S201. Based on the flow meter reading, the velocity can be substituted from the equation (2)

$$Q = VA \qquad (2)$$

Where Q is the liquid flow rate, V is the velocity and A is the cross-sectional inlet of the flow meter. Total wave energy per unit area of wave system is simply calculated using equation (3)

$$E = \frac{1}{8}\rho g H^2 \qquad (3)$$

Where H is the wave height.

3.0 EXPERIMENTAL SETUP

The schematic diagram of the experimental setup is shown in Figure 7. The dimension of the flume is 3.5 m long with 0.3 m width and 0.4 m depth. The one end of the flume is installed with the wave paddle and absorbing material was placed at another end of the flume mimicking the real shore. The erosion control device was installed in the flume at 2.5 m gap from the wave paddle. Two sets of buoy readers were used to capture the wave height at 0.5 m before and 0.5 m after the installed erosion control device. The wave generator is used to generate wave from the installed motor. The motor can produce frequency of 6.6 Hz (maximum output frequency).

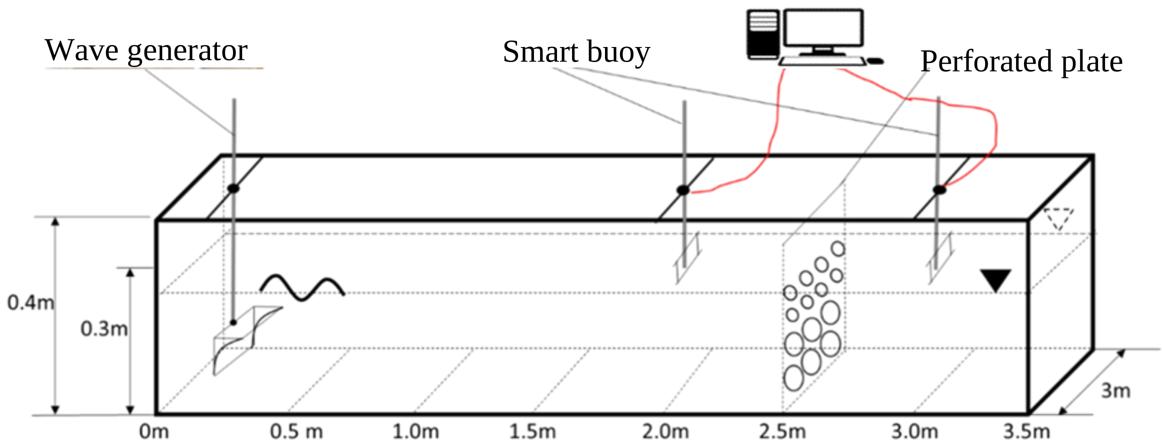

Figure 6: Experimental setup

In this study, a wave height of 0.1 m was selected based on 1m wave height. Ratio of 1:10 is used in order to fit with home-made channel scale. In order to achieve the wave height of 0.1 m, only 20 % from the maximum output frequency of the motor needed which is 1.32 Hz as shown in equation (4) and (5).

$$\text{Frequency} = 1/T_p \qquad (4)$$

$$\text{Wave steepness} = H/L \qquad (5)$$

where T_p is the wave period. Wave steepness is the steepness of waves,
where L is wavelength, calculated as $L = 1.56T_p$.

The wave's amplitude is inversely proportional to frequency. Thus, the frequency must be lowered in order to enhance the amplitude. As wavelength decreases, the steepness of wave increases. Meanwhile, the buoy reader functions to measure and record the wave height and velocity of the water at certain location over time. The results were measured at points 2.0m and 3.0m from the wave generator.

A 3 kilogram of fine sand bought from a nearby local supplier was poured into the flume. Once the sediment is poured into the flume channel, the wave generator is then turned on. After the experiment was conducted for 60 seconds, the flume was left about 7 minutes until the sediment was settled down at the bottom of the channel. The water in the channel was drained out through the valve pipe that is located at one end of the channel. After the water was completely drained, the sediment was scooped out from the channel. Sediment volume collected at every interval of 0.5m from the flume start. Measuring cylinder was used to measure the sediment volume. The sediment is poured into the measuring cylinder containing 1 liter of water. The remaining water volume in the measuring cylinder is then subtracted with the initial water volume in order to get the volume of the sediment. Little trapped fine particle at the side wall of the flume can be neglected. The experiment was repeated three times. The percentage rate of sediment is calculated by dividing the sediment volume at each point by the total sediment volume.

4.0 NUMERICAL MODELLING

Numerical modelling using FLOW-3D HYDRO version 1.0 (ID: 9-3626c206) was conducted in order to validate the data gathered from the developed wave simulator system. The process begun with model set-up. The same geometrical of home-made channel applied in the setup. Mesh cell size determines accuracy of the results. Smaller mesh cell provides more accurate result but more powerful computer processor required to run the simulation. Equidistance mesh cell of 0.02m size is used in the model. A wave height of 0.1m was used similar to home-based experimental setup. Sediment size of 0.000125m and sediment concentration of 100 mol/L was used representing the fine sediment. The water depth was set at 0.3m and simulation time was 60 sec. The flow determined as viscous and the non-slip or partial slip wall shear boundary was turned on. Other than that, wave forcing and absorbing layer type of boundary conditions were applied at the start and end of the flume respectively. The absorbing layer was meant for reducing the wave reflection. Results of the numerical setting, was extracted at the same location as the experimental setup.

5.0 RESULTS AND DISCUSSION

Comparison between experimental and numerical results aims to validate the accuracy of the developed wave simulator system. Table 3 shows the percentage of wave energy attenuation and sediment deposition. The percentage rate of wave energy attenuation for experiment and numerical is 3.46% and 3.25% respectively. While, the percentage of difference of wave energy attenuation between numerical and experiment is 6.46%. Table 4 shows the rate of total sediment deposition before and after the plate. The percentage of difference between numerical and experiment for rate of total sediment deposition before and after the plate is 6.35% and 7.80% respectively. The percentage of difference (error) between experiment and numerical are acceptable which is lower than 10% [13]. The percentage of error can be written as;

$$\delta = \left|\frac{v_A - v_E}{v_E}\right| \cdot 100\% \quad (6)$$

Where δ is the percentage of error, v_A is the actual value from experiment and v_E is the expected value from the numerical.

Table 3: Rate of wave energy attenuation for experiment and numerical

Methodology	Wave Height [m]		Rate of Wave Energy Attenuation [%]
	Before Plate	After Plate	
Experiment	0.0203	0.0196	3.46
Numerical	0.0123	0.0127	3.25

Table 4: Rate of total sediment deposition for experiment and numerical

Methodology	Rate of Total Sediment Deposition [%]	
	Before Plate	After Plate
Numerical	0.0123	0.0127
Experiment	0.0203	0.0196

4.0 CONCLUSION

As a conclusion, the developed wave simulator system is able to produce reliable measurement of wave height and flow velocity. Triangulation using numerical and experimental is able to enhance the credibility and validity of the developed simulator. Small error difference which is below than 10% (6.35% to 7.8%) have been recorded between experimental and numerical results that indicates the developed system has reliable performance. The development of frugal wave simulator system is expected to be useful in providing institutions in the developing countries to have reliable budgetary laboratory facilities. Thus, in line with Sustainable Development Goal (SDG) 4 towards ensuring inclusive and equitable quality education and promote lifelong learning opportunities for all.

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