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The Characterization of Wave Parameters in Laboratory Scale of Wave Simulator Using Video Tracking Analysis

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Abstract

Understanding the wave parameters in the ocean wave phenomenon is necessary to learn and develop the potential of ocean wave energy. Therefore, this study created a simple laboratory-scale of wave simulator that was developed using an electric motor. The various wave parameters obtained by different treatments were carried out using variations in the angle of the wedge inclination and the rotational speed of the wave generator. In this system, two pulleys of different sizes were used, a large pulley with a diameter of 20 cm and a small pulley with a diameter varying between 1.25 cm and 1.98 cm. Changing the size of the pulleys uses the principle of axial rotational motion to produce different rotational speeds. Moreover, the video tracker analysis application was used to characterize the parameters of the waves generated in the simulator that has been designed. The parameters obtained include wave height, amplitude, frequency, wave period, wavelength, and wave propagation speed. In the examination and analysis that have been carried out, it has been found that increasing wave height and amplitude correlates with increasing the inclination of wedges. The frequency and speed of the waves are linearly related to changes in the rotation speed of the wave generator. For the characteristic wavelength, there is inverse relation to the rotational speed. Based on this study, the wave simulator system and video tracking analysis application can be used to increase the understanding of wave parameters. In addition, this research can also be used as preliminary research on developing a prototype for an ocean wave energy converter on the laboratory scale.

Keywords: wave simulator, wave parameter, laboratory scale, video tracker analysis

INTRODUCTION

Bengkulu is a province of Indonesia located along the coast of the western part of Sumatra, which is direct to the Indian Ocean (Rizal & Ningsih 2020). This condition causes Bengkulu to be prone to various sea wave disasters (Hasanudin & Kusmanto 2018; Lubis et al. 2020). On the other hand, Bengkulu has a vast ocean wave energy potential (Alifdini et al. 2018; Sugianto et al. 2017; Rizal & Ningsih 2020). Therefore, the support and participation of all parties are necessary to reduce disaster risks or to use the existing potential. One of the active participation of the physics study program as one of the study programs of Bengkulu University in the city of Bengkulu is to provide specific fields related to coastal areas. The existence of this field of excellence has an impact on the availability of courses related to coastal areas and sea waves and their characteristics. Therefore, various learning facilities are needed in learning related to ocean waves.

In several practicum activities, not all parameters of sea waves can be measured directly by using available equipment in our laboratory. Therefore, it required other measurement techniques to facilitate students' observation of different forms of sea wave parameters. Developing a laboratory-scale ocean wave simulator is one way to understand the characteristic of the ocean wave. A wave simulator can be a fundamental experimental tool to understand the characteristics of each wave parameter (Supardi & Suhendri 2015; Tafonao 2018). The experimental activities are crucial in establishing an understanding of physics concepts. Therefore, a simulation system can be used in the teaching and learning process to improve the quality of learning (Rismaningsih et al. 2022).

During its development, various lab-scale ocean wave simulators were developed, such as Vionita et al. (2022) developed a simulator using an AC motor; Rifai & Hendrowati (2012) developed a simulator using the plunger type; Mikkola (2006) developed a wave simulator using a variation of wedge inclination; Parjiman et al. (2015) developed a sea wave simulator for an ocean wave power plant. Various lab-scale simulators developed by various researchers have specific purposes so that the designs and mechanisms made are specific (Gervelas et al. 2011; Olveira Pinto et al. 2019; Parkinson et al. 2015).

Generally, a wave has parameters such as wavelength, amplitude, period, frequency, and wave propagation velocity, as shown in FIGURE 1. The wavelength (λ) is the distance between two wave crests, and the amplitude (A) is the maximum deviation from the balance point. In comparison, wave height is the vertical change in height between the wave's crest and its trough. The time interval between two successive crests or two troughs passing through the equilibrium point is called the wave period. In utilizing a wave simulator in learning, the parameters of sea waves, such as wave height, amplitude, wavelength, wave frequency, wave period, and wave propagation velocity, are required (Bonnefoy et al. 2010; Ardhuin et al. 2015). Moreover, in the ocean wave energy converter system, these different wave parameters are linked in a mathematical formulation to calculate the amount of energy that can be generated from a wave.

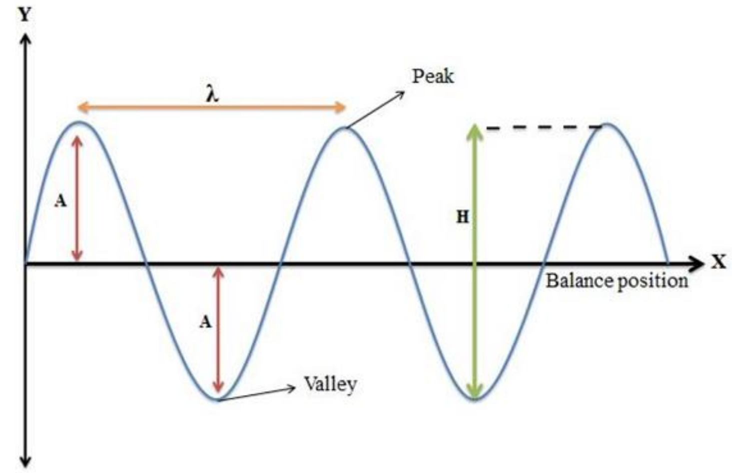

FIGURE 1. Wave Parameters

An understanding of these parameters is needed to analyze the impact and potential of the wave (Pedersen et al. 2016; Zheng 2021). To observe each of these parameters, different equipment and sensors are required. On the other hand, these measurements could not be performed due to the limitations of the equipment. Based on the existing problems and the available open-source software that can be used, in this study, we used the video tracking analysis application to obtain the parameters of waves in the developed wave simulator.

In general, video tracking analysis has been used in various cases, including physical phenomena, as done by Khotijah et al. (2019) developed a practicum about momentum; Fitriyanto & Sucahyo (2016) designed a tracker video analysis for motion kinematics; Anissofira et al. (2016) analyzed the motion of a roller coaster using a tracker with a multi-mode representation approach as a way for students to understand the concept of kinematics; Nurfadilah et al. (2020) applied video tracking analysis to determine moments of inertia in video labs to increase student learning activities. This application is popular due to its open source, easy-to-use, and complete functionality. In addition, the processing data in the tracker will greatly facilitate student observations (Wee et al. 2015; Figueroa et al. 2013). This condition relates to the feature that can display data in graphs and tables depending on the desired parameters (Wee et al. 2012; Asrizal et al. 2018). The use of technology has great potential if used and applied to the teaching and learning process, to improve the quality of learning, including learning physics (Rismaningsih et al. 2022). Based on the various uses and benefits of the video tracking application, this application has the potential to be used to obtain wave characteristics in a lab-scale ocean wave simulator.

METHODS

In this research, the design and development of a prototype wave simulator and the analysis of wave parameters using tracking software were carried out. The design of this prototype aims to make it easier for students and practitioners to analyze the parameters of ocean waves. The video tracker analysis application allows students and practitioners to obtain various wave parameters for each frame. Furthermore, this knowledge can also be developed to use ocean wave energy as renewable energy. A simulator system was designed to obtain multiple wave parameters using a wedge and an electric motor, as shown in FIGURE 2.

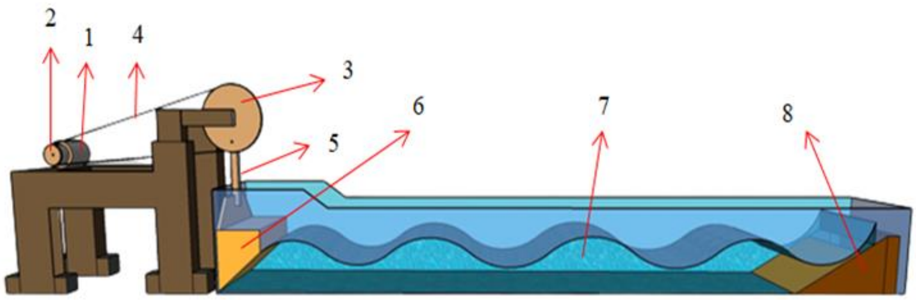

FIGURE 2. Design of a prototype of a lab-scale ocean wave simulator

where:

1. Electrical motor	4. Fan belts	7. Wave
2. Small diameter of pulley	5. Connector to wedge	8. Wave simulator
3. Large pully	6. Wedge	

In this study, the simulator is a rectangular box with a size (120 x 20 x 25) cm and a maximum water depth of 10 cm. To generate waves, this system is equipped with an alternating current motor which allows the wedge to move. The fan belt is used to connect the large pulley and the small pulley in order to vary the speed of the wedge. The wedge is a crucial element for triggering waves with various characteristics. This wedge is in the form of a triangular-shaped load with a variation in the inclination angle that can be moved up and down to produce thrust so that a wave occurs. The movement of the AC motor causes this up-and-down movement of the wedge. Pulleys of several sizes are used to produce different speeds of the wedge. The use of various pully sizes corresponds to EQUATION 1 (Amirudin et al. 2020).

$$n_1 = \frac{n_1 \times d_1}{d_2} \tag{1}$$

where :
n_1 : rotational speed for small pully (RPM)
d_1 : diameter of small pully (cm)
n_2 : rotational speed for large pully (RPM)
d_2 : diameter of large pully (cm)

In general, the variations done in this study were variations in the movement speed of the wedge and variations in the angle of inclination of the triangular wedge. The movement speed variations used are 76 RPM, 86 RPM, 96 RPM, 106 RPM, and 116 RPM. The choice of this speed, due to the rates below 76 RPM, cannot move the triangular wedge. In comparison, at higher rotational speeds at 116 RPM, the simulator cannot accommodate the artificial waves generated. The variation of movement speed was produced by varying the diameter of the small pully. The small sizes of pulleys used are 1.25 cm, 1.41 cm, 1.57 cm, 1.72 cm, and 1.89 cm. At the same time, the size of the big pulley is 20 cm. Moreover, this variation was conducted to generate variation in wave parameters, including amplitude, wavelength, wave frequency, wave period, and wave propagation speed (Habibbulloh & Madlazim 2014).

In this research, the inclination of the wedge was also varied to obtain characteristics of waves (Weber & Wilhelm 2020). Variations in the angle of inclination of the wedge will produce different waveforms, both in amplitude and wavelength (Mikkola 2006). The variations of the angle of inclination of the wedge that will be used are 35º, 40º, 45º, 50º, and 55º, as shown in FIGURE 3.

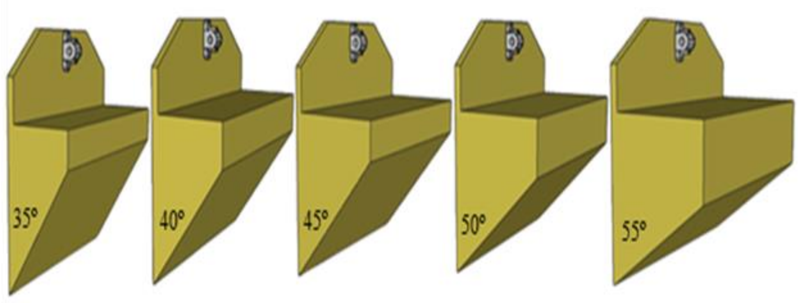

FIGURE 3. Variation of angle inclination of wedge

FIGURE 4. shows the tracking process using video data for variations of the 45º wedge angle and movement speed of 116 RPM. These data obtain the relationship between the waves' height and velocity. The process of measuring wave height is done by drawing a vertical line from the bottom of the pond. The left view is one of the ocean wave video simulation data that will be tracked, while the right side shows the plot and table of data tracking results of a wave simulation based on the parameters we need. In this application, some features can slow waves' movement, facilitating proper analysis.

Moreover, in this study, five-movement speed variations and five wedge angle variations were used to observe various wave parameters and the relationship between each of these parameters. A record is made for each variation to obtain the wave parameters for each variation. To facilitate the video's analysis, the water used is colored, as shown in FIGURE 5.

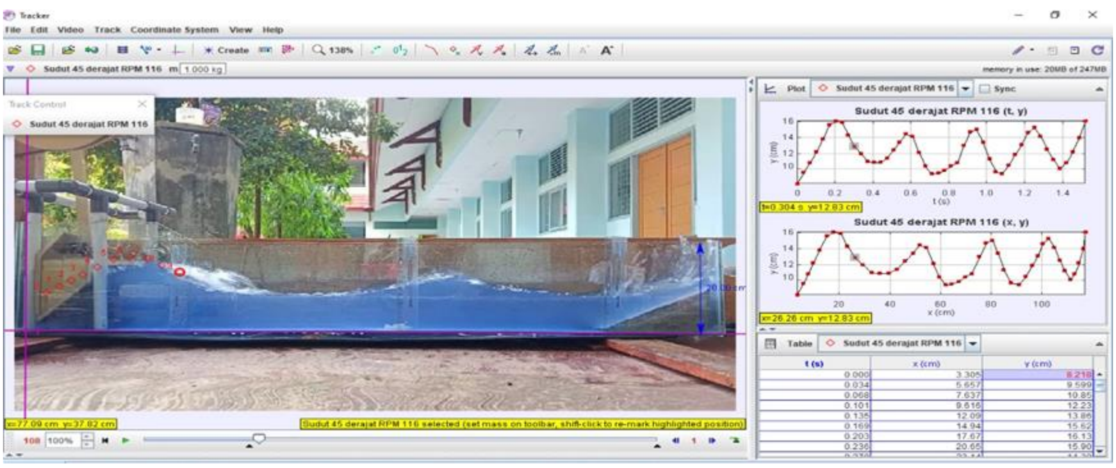

FIGURE 4. The wave simulation tracking process uses an application

RESULTS AND DISCUSSION

To obtain the wave parameters, examinations were performed using five movement speed variations and five wedge angle variations. This variety aims to get the different parameters of the waves and the relationship of each parameter. Based on the examination and analyses carried out, two main groups of analyzes are produced: the relationship between rotational speed and wedge angle with wave parameters and the relationship of each parameter obtained.

The effect of movement speed

To obtain the relationship between the movement speed and the wave parameters, a wedge with a 45º slope was used. The results for variations in movement speed versus wave height are shown in FIGURE 5. For this measurement variation, the highest wave height of 17 cm is obtained for a rotational speed of 86 RPM. The 86 RPM movement speed also produces the highest average wave height of 13.9 cm.

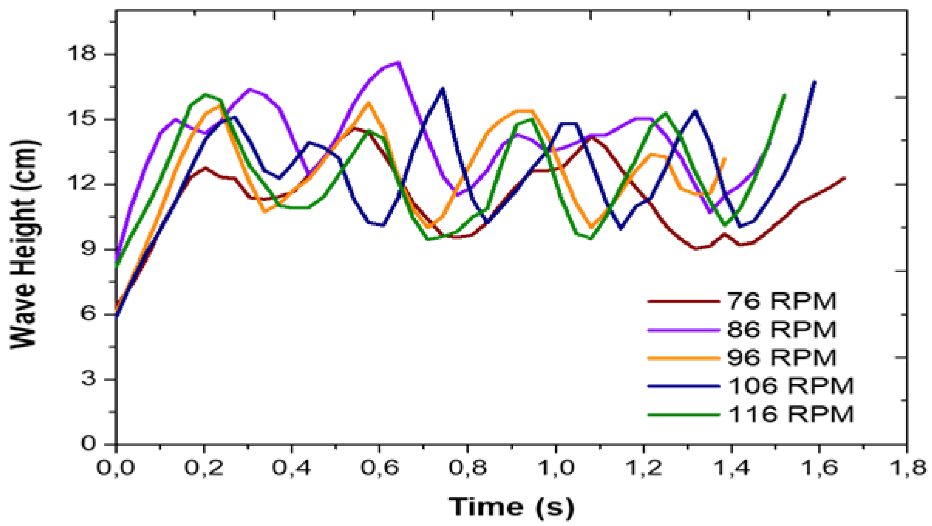

FIGURE 5. The relation between movement speed and wave height

Then, the variation of the movement speed affects not only the waves' height but also the speed and amplitude of the propagation of the waves. A low movement speed also tends to produce a low propagation speed. Additionally, the changes will vary (Amirudin et al. 2020). The wave propagation speed in waves is strongly influenced by the rotational speed of the drive or electric motor used (Jumadin et al. 2017), for a detailed discussion of each parameter discussed after this section.

FIGURE 6. The wave in laboratory scale of wave simulator with wedge angle of 45º

FIGURE 6. shows the wave conditions in the developed system when the wedge angle is at 45º. In general, variation in rotational speed produces waves with variations in wave height, amplitude, wavelength, wave period, wave frequency, and wave propagation speed.

The effect of wedge angle and movement speed of wedge on each parameter of wave

In the analysis of movement speed versus wave height, it is found that changes in movement speed cause changes in each wave parameter. This section discusses the relationship between movement speed and each wave parameter for each wedge slope, as shown in FIGURE 7, In FIGURE 7 the square symbol represents a wedge angle of 35º, a round sign for 40º, a triangular symbol for a 45º angle, a diamond symbol for 50º, and a hexagon for an angle of 55º. FIGURE 7 (a) shows the relationship between wave height for each change in movement speed and wedge angle. For a wedge angle of 35º, the wave height shows an increasing trend up to a rate of 96 rpm with a wave height of 15.35 cm and then decreases. The angle of the wedge with a slope of 45º and 55º shows an upward trend with increased movement speed. The irregularity of the relationship between wave height and changes in wedge speed and inclination is also indicated by Anissofira et al. (2017), where the prototype simulator of a wave generator (Plunger Type WaveMaker) can produce certain wave heights at certain variations in the wedge angle. FIGURE 7. (b) shows the relationship between rotational speed and wave amplitude for each variation of the wedge angle. Examination and analysis results show the same trend with wave height. This relates to the relationship between wave height and amplitude, where the wave height is twice the amplitude.

FIGURE 7 (c) depicts that the greater the variation in the speed of movement of the drive, the more the wavelength obtained decreases. These results are valid for all variations of the wedge angle. These results are consistent with research conducted by Martinez et al. (2018). In the figure, the longest wavelength is obtained for the wedge angle, which is an angle of 45º with a wavelength of 31.14 cm when the rotational speed of the electric motor is 76 RPM. The subsequent decrease in wavelength happened at the variation of the movement speed 16 RPM; the wavelength is only 22.09 cm. Using different wedge angles at the same rotational speed in this wavelength parameter has no significant effect (Lowell, Mcphee & Irani 2022). Indeed, the wavelength is more influenced by the frequency and speed of propagation of the waves caused by an increase in the electrical motor's rotation speed.

Then, in FIGURE 7 (d), there is the wave period change resulting from the rotational speed variation, which results in a linear decrease between speed and period (Drew et al. 2009). When the movement speed is high, the resulting period narrows and vice versa. Also, using different wedge angles has no significant effect. Moreover, at a variation of the wedge angle of 45º, the movement speed is 76 RPM, and the resulting wave period value reaches 0.45 seconds. Then it decreased by 0.26 seconds at a variation in the movement speed at 116 RPM. Variation of the wedge angle of 55º, the value of the wave period also continues to decrease, going from 0.42 seconds to 0.29 seconds at a variation in the movement speed at 116 RPM.

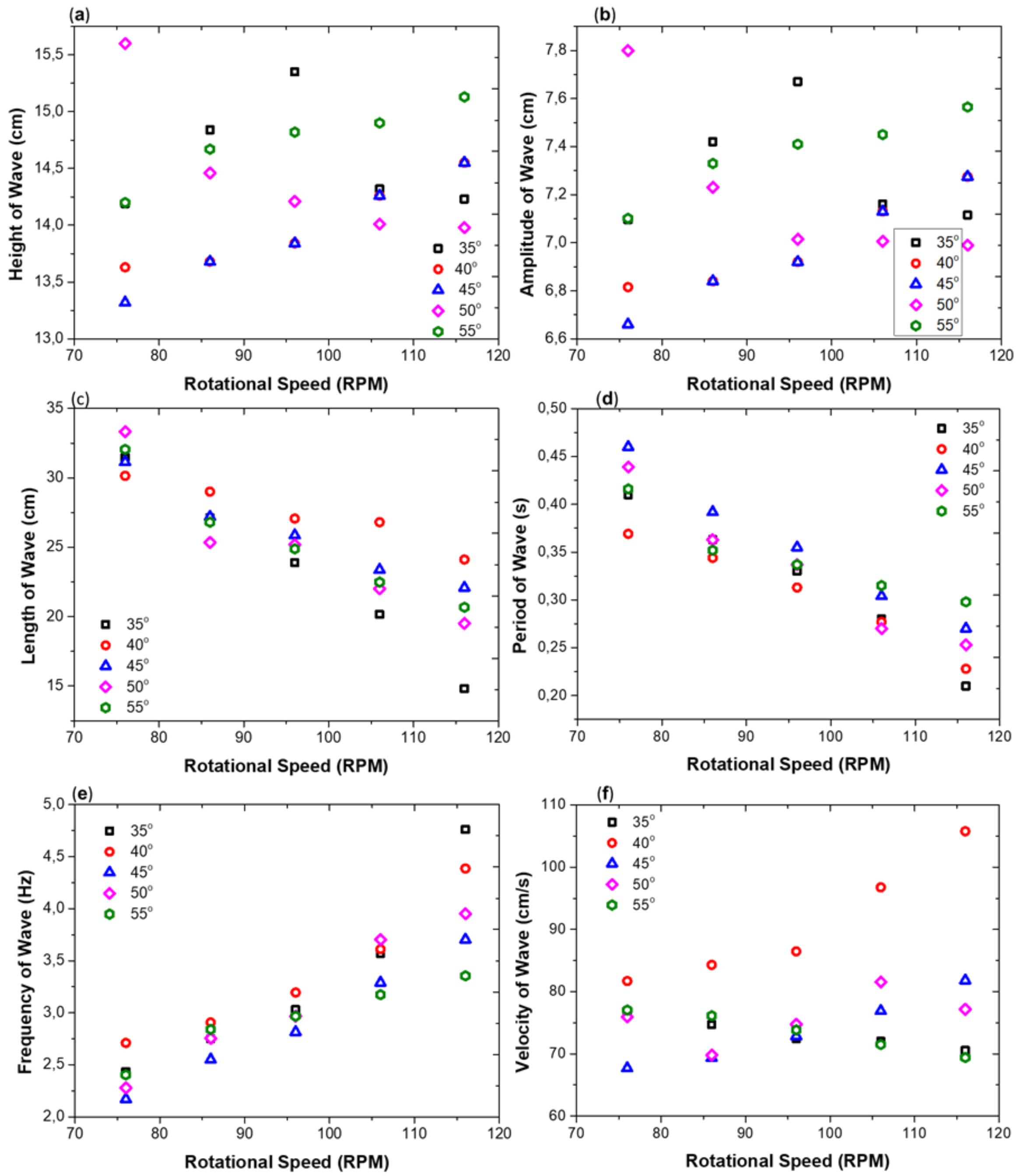

FIGURE 7. The relationship between movement speed to wave parameters in each wedge angle (a) Height of wave, (b) Amplitude, (c) wavelength (d) Period, (e) Frequency of wave, (f) wave propagation speed

For the effect of movement speed on wave frequency, an increase in wave frequency is obtained as movement speed increases, as shown in FIGURE 7 (e). We can observe in a variation of the wedge angle, namely the wedge angle of 35º, we can see that the initial wave frequency is 2.3 Hz at the variation of the movement speed of 76 RPM, which continues to increase the value of the wave frequency until it reaches 4.8 Hz at the variation of the 116 RPM. At variations in the 45° wedge angle, different frequency values are based on variations in the movement speed of the electric motor drive. When the movement speed is in variation first 76 RPM, the wave frequency successfully analyzed using the tracker is 2.17 Hz. The frequency of linear waves increases the speed of rotation of the electric motor used; the faster the rotation of the electric motor used, the higher the value of the resulting wave frequency (Choi et al. 2002). In a laboratory scale experiment using a prototype sea wave simulator

(Plunger Type WaveMaker), the maximum wave frequency reached 4.76 Hz; the success of this study exceeded the maximum frequency limit of vague in previous studies such as the study by Mikkola (2007) & Rifai et al. (2012).

FIGURE 7 (f) shows a trend of wave propagation speed on all five wedge angle variations. At wedge angles of 35º and 55º, wave propagation speed from variations in the movement speed of 76 RPM until 116 RPM looks relatively stable and only slightly decreases that range between 78 cm/s reduces to 70 cm/s. At a wedge angle of 40º fast propagation speed, the wave increases when its movement speed is accelerated. At a movement speed of 76 RPM, the rapid propagation of the wave reaches 80 cm/s and continuously increases to 105 cm/s at a variation in the movement speed of 116 RPM. Similarly, with the variation in the wedge angle of 45º at this angle, the rapid increase in wave propagation is not so significant. At first, the wave propagation speed only reaches a rate of 67.69 cm/s and continues to increase until it goes to 81.81 cm/s. The wave rises when its movement speed accelerates at a wedge angle of 40º fast propagation. At a driving speed of 76 RPM, the rapid propagation of the wave reaches 80 cm/s, then continuously increases to 105 cm/s at a variation in the movement speed of the electric motor drive of 116 RPM.

Similarly, with the variation in the wedge angle of 45º at this angle, the rapid increase in wave propagation is not so significant. At first, the wave propagation speed only reaches a rate of 67.69 cm/s and continues to increase until it goes to 81.81 cm/s. This proves that the faster the movement speed used, the greater the value of the propagation speed of the resulting wave (Alegre 2011; Abdullah et al. 2017). However, in the research that has been carried out, there is an anomaly in the 50º wedge angle variation where the wave propagation decreases, then increase at the movement speed of 116 RPM.

Based on the results obtained in FIGURE 7, increasing the wave simulator's movement speed will increase the wave's frequency; however, wavelength and period decrease. This corresponds to the situation in nature where the frequency is inversely proportional to the period. Moreover, high-frequency waves tend to have short wavelengths (Pamungkas et al. 2019). The movement speed at the height of the waves has a trend with a specific value. Variation of wedge angle also influences the characteristics of the resulting parameters; the more significant the wedge angle used, the greater the wave's amplitude and wavelength.

Moreover, the wave simulator and use of this tracker software can provide convenience in observing wave parameters and is effective for understanding wave characteristics. Based on the results obtained, appropriate parameters can be used to utilize a simulator in developing renewable energy based on ocean wave energy. For ocean wave power plants, the main factors that determine the magnitude of energy are height and wavelength. Therefore, selectable use of wedge angle and movement speed simulator used.

Furthermore, several research using wave simulators have developed such as Wahyudi (2016); Rifai & Hendrowati (2012) & Vionita (2022). However, these research are limited in the frequency of triggering the wave manually in the measurement system and limited in the parameters of the wave formed. In our research, the system simulator can produce various wave parameters. Also, the use of tracking analysis video software to analyze the characteristics of wave parameters in the form of video recordings. It can facilitate the process of analyzing the characteristics of the wave parameters of each variation of the test performed. A video tracker analysis allows various wave parameters to be measured on a measurement sample. Moreover, observing wave parameter characteristics using video tracking software is more efficient than manual or digital observations (Dewi et al. 2020).

CONCLUSION.

The design, examination, and analysis of wave parameters were performed in a laboratory-scale ocean wave simulator. Additionally, the tracker analysis video application is used to obtain wave parameters for variations in movement speed and wedge angle. Based on the test results, there are changes in the wave parameters for each variation used. In this system, two pulleys of different sizes were used, a large pulley with a diameter of 20 cm and a small pulley with a diameter varying between 1.25 cm and 1.98 cm. Changing the size of the pulleys uses the principle of axial rotational motion to produce different rotational speeds. Moreover, using a tracker is beneficial for obtaining the parameters of the waves and improving the understanding of these parameters. This prototype can also be used as learning media for wave simulators for high school and college students. Besides, for better experimental results, this can be done with a larger simulator size to minimize the friction that occurs.

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