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Effect of Drive Tilt in DC Motor-Based Wave Simulation on Ocean Wave Characteristics

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A R T I C L E I N F O

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A B S T R A C T

This study aims to analyze the effect of actuator inclination angle in a DC motor-based wave simulation system on the characteristics of artificial ocean waves, specifically wave height, wavelength, and wave period. The simulation was conducted in a laboratory wave channel using a flap-type actuator driven by a DC motor controlled via a PWM system. The treatments tested included variations in actuator angles (30°, 45°, and 60°), and motor speed is tested at 12 cm water depth, the procedure is repeated for 15 cm depth. Overall, the results at 12 cm and 15 cm water depths indicate a strong positive relationship between the actuator inclination angle and the resulting wave height. Water depth was also found to be a significant factor influencing wave height, where shallower depths tend to produce higher waves. These findings offer valuable insights into wave dynamics in simulation tanks and can serve as a reference for the design of actuator systems and other wave engineering applications

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INTRODUCTION

Ocean waves are a natural phenomenon that plays a vital role in the fields of oceanography and marine engineering. These waves significantly influence coastal dynamics, the development of renewable energy, and disaster mitigation efforts such as coastal erosion and tidal flooding. Therefore, a comprehensive understanding of wave characteristics—including wave height, wavelength, frequency, and period—is essential to support the advancement of technology and the formulation of sustainable marine resource management policies.

Laboratory-scale wave simulation is an effective approach to studying wave behavior under controlled conditions. This method allows researchers to replicate real ocean wave conditions on a smaller scale, enabling the systematic testing of various parameters and variables affecting wave formation. A key component in this simulation system is the DC motor, which functions as the mechanical driver that generates the back-and-forth motion required to produce waves. DC motors are preferred in laboratory-scale wave generators due to their ability to convert electrical energy into mechanical motion and their reliable speed control via devices such as dimmers. The motor speed directly affects the generated wave characteristics; previous studies indicate that wave height increases with water depth, while wavelength decreases as motor speed increases (Vionita, et al., 2022).

In addition to motor speed, mechanical aspects such as the inclination angle of the wave driver (e.g., the blade or paddle) may also have a significant impact on wave characteristics. However, this aspect has received limited attention in previous research. The inclination angle is a geometric parameter that affects how water is pushed by the wave-generating system. Different angles can alter flow patterns, energy distribution, and the stability of the resulting waveforms. For instance, a steeper angle may enhance water displacement efficiency, producing higher amplitude and more stable waves. In contrast, a suboptimal angle may lead to wave distortion or unwanted wave breaking in simulations.

The inclination angle also has practical implications in the construction and operation of wave simulators. A system that allows adjustable driver angles provides greater flexibility for experiments and adaptation to various simulation conditions. This opens opportunities for developing more efficient wave generator technologies that are adaptable to both research and industrial marine applications.

Based on this background, the present study aims to experimentally investigate the effect of varying the driver's inclination angle in a DC motor-based wave simulation system on the characteristics of the generated waves. The findings are expected to contribute to the optimization of wave simulation systems and provide empirical data useful for oceanographic studies and coastal engineering applications.

LITERATURE REVIEW

Ocean Wave Simulation

Laboratory-scale ocean wave simulation is a crucial approach for understanding wave dynamics and their interactions with coastal structures, buoys, and floating systems. This system enables controlled manipulation of wave variables such as height, wavelength, and period to represent real sea conditions at a smaller scale (Dean & Dalrymple, 1991). In practice, wave simulation systems are typically equipped with actuating mechanisms driven by electric motors that move flaps or paddles to generate waves.

DC Motor as a Wave Actuator

DC motors are widely used in wave simulation systems due to their stable torque and precise controllability. Pulse Width Modulation (PWM) technology enables accurate control of motor speed and rotation direction, allowing the actuator (flap) to move in a controlled manner and generate specific wave profiles (Bolton, 2015). In a study by Amini et al. (2012), DC motors were shown to generate stable sinusoidal waves with adjustable amplitude and frequency based on input voltage and duty cycle settings.

Effect of Actuator Inclination on Wave Characteristics

One of the key parameters in DC motor-based wave simulation systems is the inclination angle of the actuator (flap). This angle determines the direction and magnitude of the force vector applied to the water. A larger inclination angle directs the force more vertically, increasing wave height but tending to produce shorter and sharper waves (Huang et al., 2018). Conversely, a smaller angle generates flatter and longer waves. Adjusting this angle is critical for achieving the desired wave characteristics.

Hudspeth et al. (2000) found that varying flap angles from 20° to 60° resulted in wave height differences of up to 30% under constant motor speed. Therefore, examining the effect of flap inclination angle is a key experimental parameter in the study of artificial wave characteristics.

Observed Wave Characteristics

The artificial wave characteristics observed in this study include:

- Wave height (H): the vertical distance between a wave crest and the adjacent trough.
- Wavelength (λ): the horizontal distance between two successive crests (or troughs).
- Wave period (T): the time required for one complete wave cycle to pass a fixed point.

These parameters are commonly used in evaluating wave simulation system performance (Massel, 1996) and are highly influenced by input parameters such as flap inclination, motor speed, and water depth.

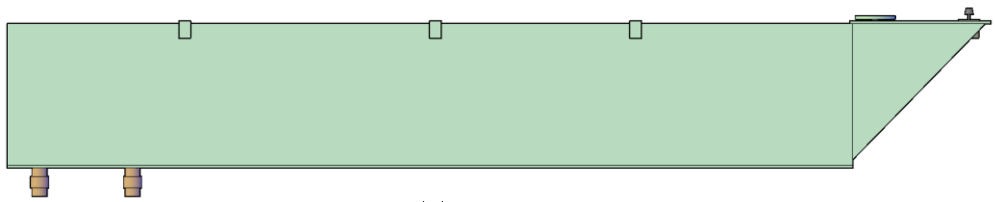
METHODOLOGY

This study employed an experimental method by constructing a laboratory-scale wave simulation system consisting of a simulation tank and a wave generator system powered by a DC motor. The simulation tank was made of acrylic with dimensions of 130 cm (length) x 25 cm (width) x 25 cm (height) and a glass thickness of 5 mm to ensure structural strength during the operation of the generator system.

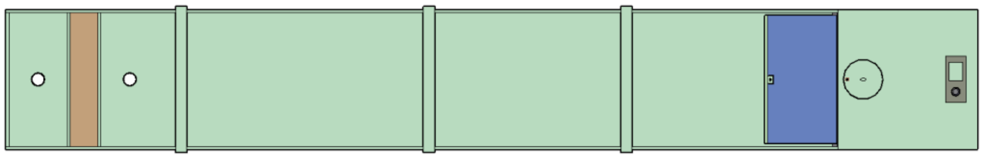
The wave generator system consisted of a DC motor as the main actuator, which moved a forward-and-backward pushing blade to generate sinusoidal waves in the tank. The DC motor used had a 12 V capacity with a rotational speed that could be adjusted using a dimmer as a speed controller (Vionita, et al., 2022; Hidayat.I, 2004).

The drive inclination, defined as the blade's tilt angle that moves the water, could be set at several levels: 15°, 30°, and 45°. The tilt was adjusted using hinges and a locking mechanism to maintain the angle throughout the test. This variation in inclination angle served as the main variable in the study to examine its effect on the characteristics of the simulated sea waves, specifically focusing on wave height as the measured parameter.

The testing procedure involved preparing the simulator tank and the generator system. The tank was filled with water to the predetermined depths (12 cm and 15 cm). The wave generator system with the DC motor and blade at a specific inclination angle was installed and connected to the speed controller. Variable settings: the blade inclination angles were set at 30°, 45°, and 60°, while the DC motor speed was set to 45%. After testing all combinations of blade angles and motor speed at a water depth of 12 cm, the procedure was repeated for a depth of 15 cm. Wave height was measured through direct observation using a measuring ruler installed at three different points along the simulation tank: near the wave generator, at the center, and at the end of the tank. Wave height data were recorded in real time and analyzed to obtain the average and variation in wave height. The design of the simulation tank to be used is shown below.



(a)



(b)

Figure 1. (a) Front View (b) Top View of Wave Simulation Pool Design

RESULTS AND DISCUSSION

Based on the experiments that have been carried out by direct observation in the wave simulation pool which aims to determine the effect of the drive slope on the average wave height measurement results at a depth of 12 cm and 15 cm with three slope variations of 30°, 45°, and 60°, with each 30 measurements at three different points.

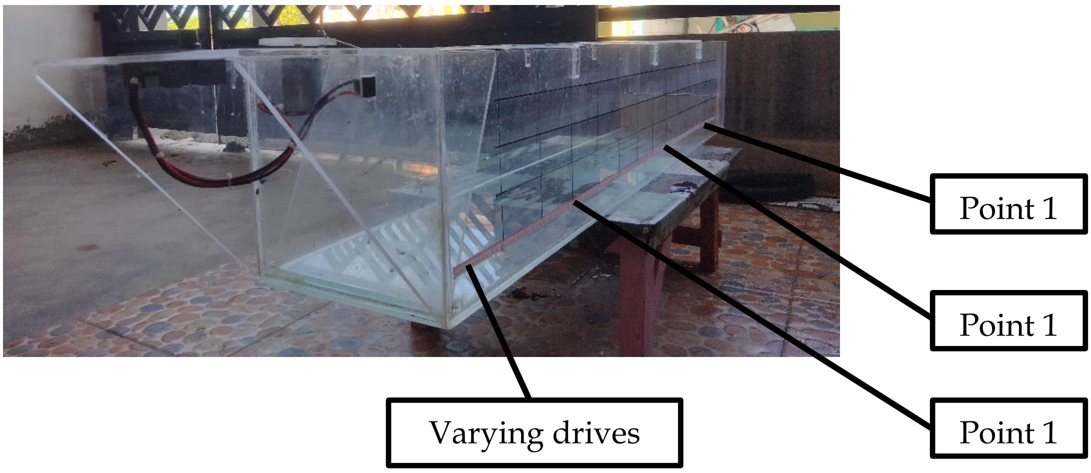
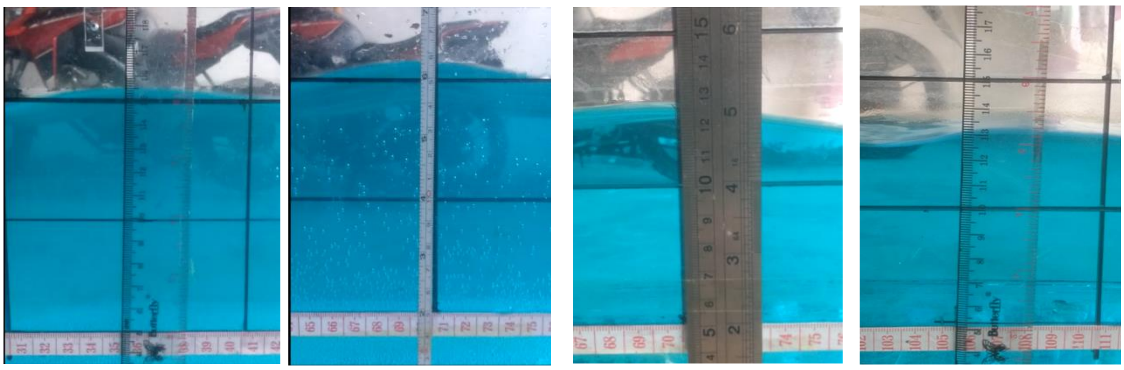


Figure 2: Measurement Points



(a) (b) (c) (d)

Figure 3. (a)(b) Point 1 & 2 Observation of 15 cm Depth, (c)(d) Point 1 & 2 Observation of 12 cm Depth

The observation results of the 30° tilt variation with 30 trials of 15 cm depth can be seen in Figure 4 which shows the graph of the relationship between the nth trial and the average wave height generated from three observation points.

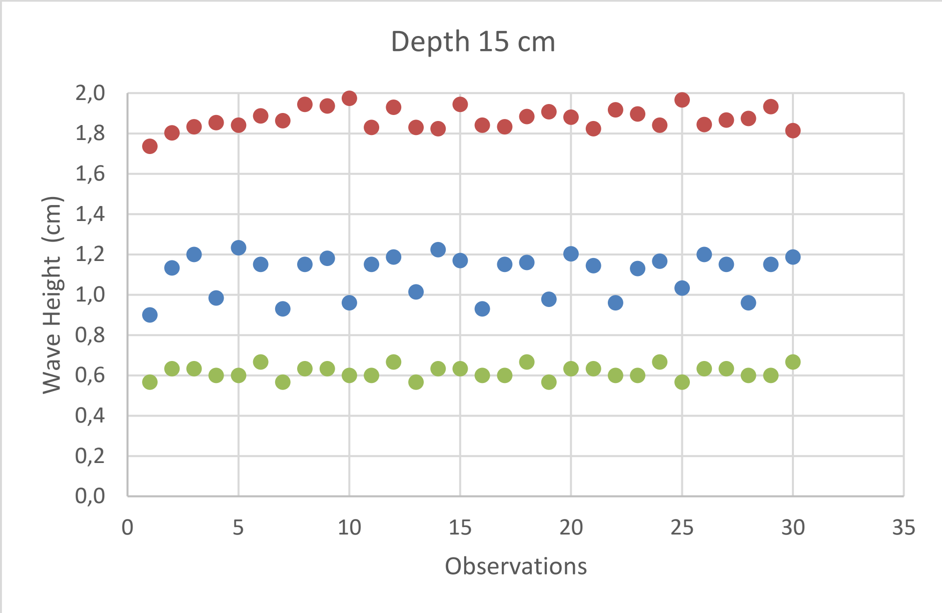


Figure 4. Observation Results at a Depth of 15 cm

The graph above shows the results of wave height observations in a simulated pond with a water depth of 15 cm and three variations of driving slope, namely 30°, 45°, and 60°, for 30 observations each. The x-axis shows the observation sequence, while the y-axis shows the wave height in centimetres (cm).

From the graph, there is a clear difference between the three tilts: At 30° tilt, the wave height ranges from 0.5 cm to 0.7 cm. This value is stable throughout the 30 observations, indicating that the system runs consistently at low inclinations. At 45° inclination the wave height increased, ranging from 1.0 cm to 1.2 cm. The data also showed stability, with small fluctuations that were still within reasonable limits. 60° inclination had the highest wave height, ranging from 1.8 cm to 2.0 cm. Although there are slight variations, the data still shows a stable and consistent pattern.

Increasing the tilt angle significantly increases the height of the waves generated. At an inclination of 30°, the potential energy converted into waves is still low so the wave height formed is also small. As the angle is increased to 45°, there is an increase in energy, resulting in higher waves that remain stable. At 60°, the maximum potential energy in the system produces the highest waves, and the stability of the data shows the system is able to adapt to extreme conditions.

These results confirm that the drive tilt angle is the main factor affecting wave height in the simulated pond with a depth of 15 cm. The stable data at each tilt also shows that the test method used is appropriate and reliable. These findings can be an important reference for practical applications in wave engineering, canal design, or further research with other depth and slope variations.

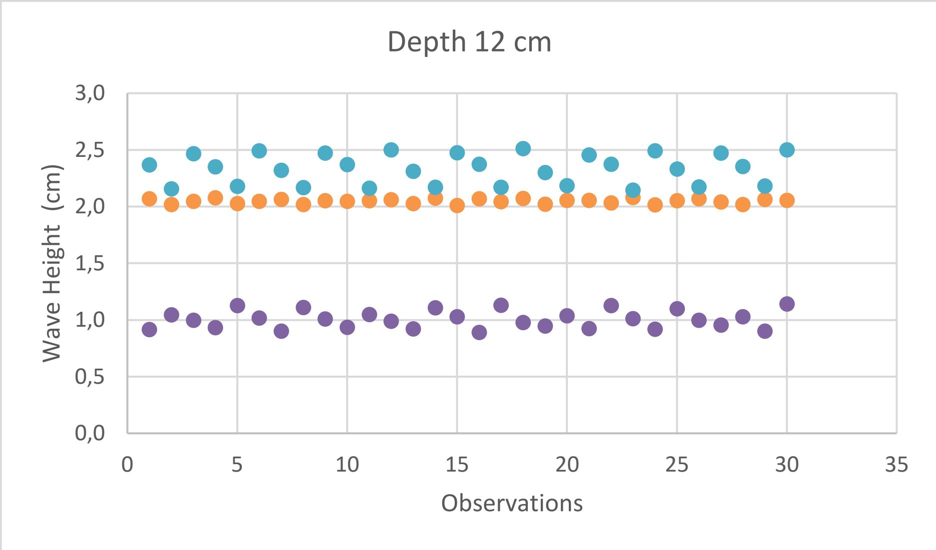


Figure 5. Observation Results at a Depth of 12 cm

The graph shows the relationship between plane inclination (30°, 45°, and 60°) and wave height at 12 cm water depth. Data were taken for 30 observations for each slope. The y-axis shows the wave height (cm), while the x-axis is the order of observation. Based on the observation results at 30° inclination, the average wave height is around 1 cm, at 45° inclination the average wave height is around 2 cm at 60° inclination, the average wave height is around 2.4-2.5 cm. It can be seen that the greater the inclination of the plane, the higher the wave height formed. This is consistent across all observations, where the trend of increasing wave height is in line with increasing tilt angle.

The increase in wave height at larger slopes can be explained through the wave energy mechanism. The steeper the slope, the greater the wave energy accumulated and focussed on the plane, resulting in waves with greater height. This phenomenon is in line with the theory of wave steepness, where the steeper the wave (the ratio of height to wavelength increases), the higher the amplitude of the wave formed (Sugianto, et al., 2023). In addition, the results show that water depth also has a significant effect on wave behaviour. At greater depths, waves tend to have greater energy, so the height of the waves formed also increases (Rahman, et al., 2005). However, in this graph, the depth is kept at 15 cm so that the main influencing factor is the slope of the plane.

Based on the research conducted at depths of 12 cm and 15 cm, there is a consistent relationship between the angle of inclination of the drive and the height of the waves formed in the simulated pond. Both graphs show a similar trend, i.e. the greater the inclination of the plane, the higher the waves generated. Comparison of Results at Depths of 15 cm and 12 cm: At a depth of 15 cm, the wave height at 30° inclination ranges from 0.5 cm to 0.7 cm, increases to 1.0 cm to 1.2 cm at 45° inclination, and reaches 1.8 cm to 2.0 cm at 60° inclination. While at a depth of 12 cm, the average wave height at 30° slope is about 1 cm, at 45° about 2 cm, and at 60° about 2.4-2.5 cm.

The difference in wave height values between 12 cm and 15 cm depth indicates that water depth also affects the energy of the waves formed. At a smaller depth (12 cm), waves tend to have more energy and produce higher wave heights compared to a greater depth (15 cm) at the same slope.

The relationship between slope and wave energy The significant increase in wave height as the slope angle increases can be explained through the mechanism of wave energy accumulation. The steeper the slope, the greater the potential energy accumulated and focussed on the plane, resulting in waves with higher amplitudes. This phenomenon is consistent with the theory of wave steepness, where an increase in the ratio of height to wavelength increases the amplitude of the wave.

In addition to slope, water depth also plays an important role in wave behaviour. Smaller depths tend to increase the wave energy, resulting in larger wave heights. This can be seen from the comparison of the results at a depth of 12 cm and 15 cm, where the wave height at a depth of 12 cm is greater at the same slope.

CONCLUSION

Overall, the results at depths of 12 cm and 15 cm showed a strong positive relationship between the angle of inclination of the drive and the wave height formed. Water depth is also a significant factor affecting the magnitude of wave height, where smaller depths tend to produce higher waves. These findings provide an important insight into the understanding of wave dynamics in simulated ponds and can be used as a reference in the design of drive systems and other wave engineering applications.

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