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Hydrodynamic Assessment of Seashell Blocks for Coastal Protection

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ABSTRACT

Traditional coastal protection strategies frequently depend on man-made structures that may have negative environmental impacts and have limited long-term sustainability. There is a pressing need to develop a new approach to address the issues. This study aims to investigate the stability of seashell blocks when exposed to wave forces, the behaviour of seashells when partially submerged, fully immersed, and exposed, and how seashells react to regular and irregular waves. Multiple experiments with varied wave amplitude and frequency are performed using a wave flume maker to evaluate the attenuation of waves. In this study, seashells were used as models with the application of a flume wavemaker in UiTM Shah Alam's laboratory. The models reproduce the effects of ocean waves. However, the research is restricted by the flume wavemaker's dimensions, which are 20 meters in length with the generating equipment and a maximum water depth of 0.4 meters. Parameters including frequency, wavelength, and amplitude were measured using pressure sensors and wave probes. The findings show that the partially submerged seashells performed better in regions with shorter coastal waves. The width of a submerged breakwater's crest can be cut in half by using seashell blocks. The findings can significantly facilitate the development of long-lasting and efficient coastal protection measures, as well as the design, construction, and monitoring of seashell block structures. Additional research is required to determine the cost, lifespan, and effectiveness of shell blocks in different coastal environments.

Keywords: Wave flume; seashells; regular wave; irregular wave; submerged wave

INTRODUCTION

Erosions on coastlines have far-reaching consequences for ecosystems, infrastructure, and human populations around the world. The coastal erosion problem in Malaysia was addressed by the construction of many submerged and emergent breakwaters (Rashidi et al. 2021). Nevertheless, it resulted in negative environmental impacts by compromising the potential of beaches to adapt to shifting conditions, thereby imposing ripple effects. Breakwaters also substantially disrupt nearshore hydrodynamic regimes and sediment transport (Amalan et al. 2018; Le Xuan et al. 2022), which in turn affects the structures of the surrounding ecosystem (Martins et al. 2009).

Recently, seashell blocks have been suggested as a sustainable and effective coastal protection approach due to their abundance and accessibility. Seashells are a suitable choice due to their high calcium content and hardness. Using physical model tests, Almaghraby et al. (2022) examined seashell-based breakwaters in wave flumes to determine their reflection, wave transmission, stability, and dissipation qualities. Additionally, Evans et al. (2019) discovered that the application of such ecological enhancement methods has the potential to increase biodiversity, particularly when implemented in large-scale coastal engineering defence programs. The findings can help build cost-effective, eco-friendly coastal safety measures, provide a sustainable alternative to traditional coastal defences, and improve the knowledge of coastal erosion mitigation strategies.

The study aims as follows: (i) to investigate the condition of seashell structures under both regular and irregular waves, (ii) to determine the behaviour of seashells under various submersion depths, including fully submerged, partially submerged, and emerged, and (iii) to evaluate the stability of seashell blocks against waves. The objectives were developed to provide additional information about the innovative use of seashells as a solution to coastal erosion problems.

METHODOLOGY

Using the Flume Wave Maker, which bends in the direction of the horizontal particle velocity, tests were conducted at the Hydraulic Laboratory of the School of Civil Engineering, College of Engineering, UiTM Shah Alam, to determine the submerged seashell along with passing waves. This research evaluated the effects of a model seashell on wave setup and run-up or rundown pattern in a controlled laboratory setting. The average water level at each probe demonstrated the extent of setup, and the variance measured the difference between the average water level and the height of the water surface. The efficiency of seashell blocks as a

formed of coastal protection has been studied extensively (Wang et al. 2008). Spectral analysis has been used to examine the wave energy distribution at each probe over the frequency range. Figure 1 displays the flow chart that served as the study's framework.

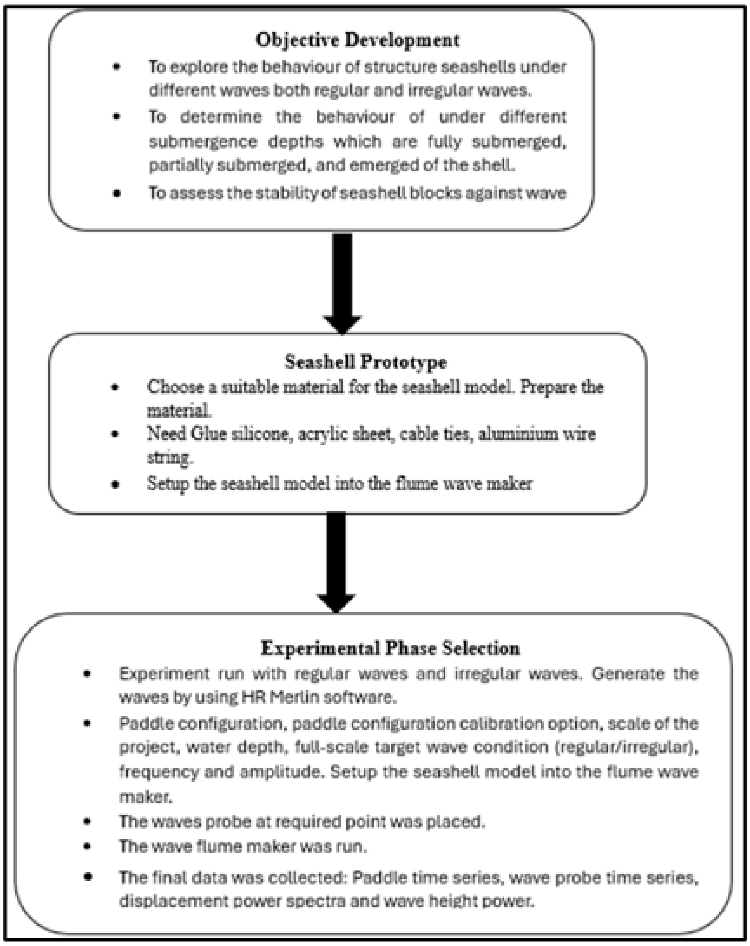


FIGURE 1. Framework of study.

EXPERIMENT DESIGN AND PROCEDURE

Figure 2 shows the seashell model, which has dimensions of 4.5cm in height, 3cm in width, and 2cm in length. It is glued to two 50cm and 52.3cm wide acrylic sheets. The silicone glue allows seashells to move freely as they would in natural surroundings. The acrylic sheet was fastened to the bottom of the ramp in the wave flume maker's setup (Figure 3) using cable ties and aluminium wire string. It is further demonstrated that resistive wave instruments are sensitive, and the water must be changed three times per week. The porosity found in seashells can be often well-defined and regulated pore structure for experimental (Laju et al. 2011) Table 1 displays the dimensions of the proposed prototype seashell, including its height, breadth, length, and thickness.

FIGURE 2. The experiment studied seashells on acrylic sheets.

FIGURE 3. Setting up a seashell with a wave maker in the flume.

TABLE 1. Shown the prototype variables of the proposed seashell.

Variable	Symbol	Prototype value	Unit
Wave depth	h1	0.20-0.30	m
Shells weight	W	3.65	kg
Wave height	Hi	0.010-0.045	m
Wave period	T	300	sec
Shells height	hs	0.02	m
Shells width	bs	0.045	m
Shells length	ls	0.03	m
Shells thickness	ts	0.05	m
Base slope angle	θ	25	-

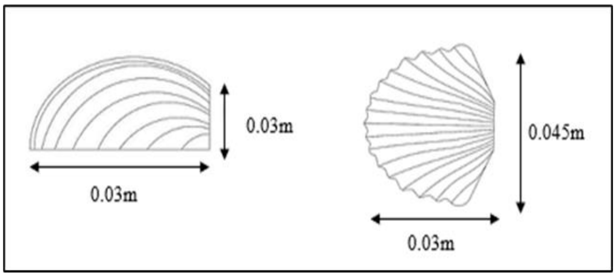


FIGURE. 4. Staggered formation dimension on the seashell

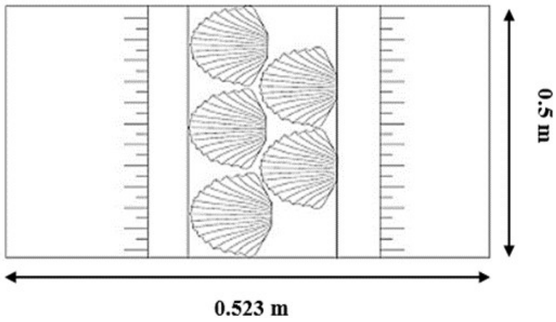


FIGURE 5. The seashell dimension.

Figure 4 displays the cross-section and dimensions of the staggered development of the seashells. The breakwater is composed of a sequence of shells stacked in a staggered configuration, leaving spaces between them. Figure 5 shows the proposed dimension for the seashell's side view. Since the supporting structures were impermeable, the waves only made up the back of the building through overtopping (Vicinanza et al. 2019)

FLUME WAVE PREPARATION

The studies involved the use of a hydraulic flume wavemaker to generate waves. These waves were controlled by a computer using HR Merlin wave production software. The software adjusts the paddle movement according to user-defined input voltage signals, following the parameters outlined in Table 1. The HR DAQ program enabled the collecting of data. Wave parameters were confirmed through direct observation, as there was no previous experimental data about the correlation between paddle displacement and wave height. A housing was installed to accommodate the dynamic wave absorption monitoring system. Additionally, four wave probe gauges were placed at intervals of 4 meters, beginning 8 meters away from the neutral point of the wave producer (Figure 6). The parameters of the flume are 20m in length, 0.5m in width, and a water depth (h) of 0.3m.

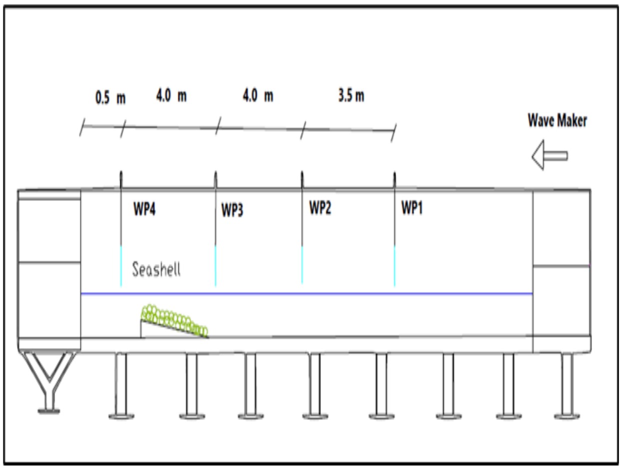


FIGURE 6. Details of Experiment Setup

The laboratory experiment utilised the SOLTEQ® Flume Wave Maker (Model: FM 27-K), an experimental setup connected to open channel flow engineering structures. This equipment is specifically developed to teach the fundamental principles of fluid mechanics, such as wave characteristics. The flume had dimensions of 20m in length, 0.5m in width, and 0.7m in height. Figure 7 depicts the construction of the flume wave maker, which consists of an open channel with spacious windows for clear visual inspection. The working section is securely installed on a sturdy framework composed of a durable steel frame and longitudinal rail. The wave generator is operated by a solitary electrical servo-driven motor actuator that uses a rack-and-pinion configuration. The device can generate waves with a maximum amplitude of 0.6 meters and a maximum velocity of 0.5 meters per second. The wave generator control system incorporates active wave absorption hardware and a dedicated control cabinet designed for a safety system.

FIGURE 7. Flume wave.

WAVE ABSORPTION

It is common practice to install a wave absorption system in the allocated area of laboratory wave-current flumes and basins (Figure 8). This will lessen the amount of wave reflection in the downstream portion of the flume, which is important for coastal research. The wave absorption device comprises a meticulously engineered structure intended to attenuate a portion of the wave energy effectively (Straub et al. 1957). It consists of materials with varying levels of porosity and impermeable surfaces. Highly porous materials, such as wire mesh screens, can greatly reduce the length of an absorption system by effectively absorbing waves. Crushed rock beaches with gentle slopes were also discovered to be efficient in absorbing the force of waves. The majority of passive wave absorption systems are designed to have an increasing absorption rate at a certain point.

FIGURE 8. A porous wave absorption system in the laboratory

WAVE AND DATA ACQUISITION

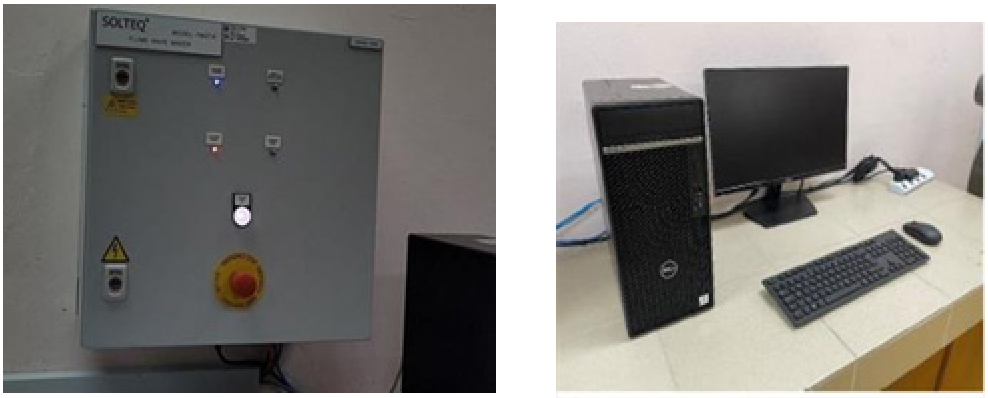
For both regular and irregular waves, several testing runs were carried out, each lasting five minutes, to demonstrate a good correlation between input voltage and wave height (Table 2). Time series of sinusoidal voltage were employed to evaluate the duration required for achieving a stable and consistent waveform state. The flume produced a single regular wave at a time, and the resulting output was compared to the desired input to calculate correction factors. This process was repeated for different frequencies. While the regular wave technique is accurate, it can be time-consuming since it calibrates only one frequency component at a time. Several experimental trials consistently showed a significant relationship between the input voltage and the resulting wave height. The probes were linked to a wave monitor, which outputs voltage data as output signals. The probes are calibrated daily (Almaghraby et al. 2022).

TABLE 2. Type of experiment cases.

Simulation	Wave Condition		Submerged Depth		
	Regular Wave	Irregular Wave	Fully Submerged	Partially Submerged	Emerged
Case 1	✓		✓		
Case 2		✓	✓		
Case 3	✓			✓	
Case 4		✓		✓	
Case 5	✓				✓
Case 6		✓			✓

DATA ACQUISITION

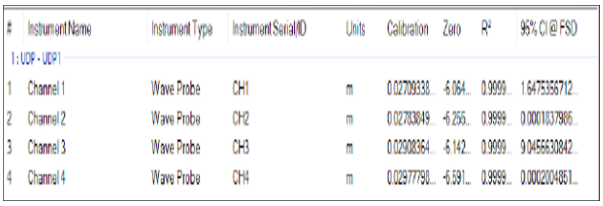
UiTM supplied the software for the wave flume generator and comprises two applications: Merlin and HR Data Acquisition (DAQ) (Figure 9). The wave flume maker can be turned on and off using the main power switch for the computer, transducer, power supply, and wave gauge system. HR DAQ, which stands for data acquisition, incorporates a calibration procedure specifically designed for wave probes, a real-time data visualisation feature, and analytic tools.



(a) (b)

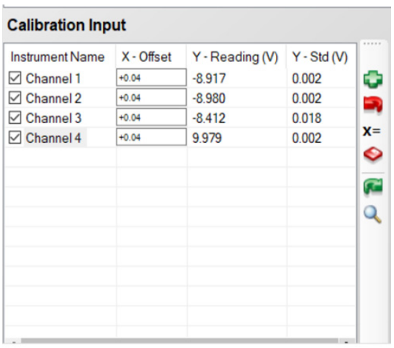
FIGURE 9. Illustrate the on the PC: (a) Control panel of wave flume maker, (b) PC to connect to the wave flume.

An R^2 value greater than 0.9 is necessary for calibration, especially for wave probes used in this evaluation (Figures 10 and 11). The next step is to utilise the HR Merlin software to create waves. This software requires certain inputs, including scale, tank depth, water depth, and study characteristics like amplitude and frequency (Figure 12).



#	Instrument Name	Instrument Type	Instrument Serial/ID	Units	Calibration	Zero	R²	95% CI @ FSD
1 : UDP - UDP1								
1	Channel 1	Wave Probe	CH1	m	0.02709338...	-6.064...	0.9999...	1.6475356712...
2	Channel 2	Wave Probe	CH2	m	0.02783849...	-6.255...	0.9999...	0.0001837986...
3	Channel 3	Wave Probe	CH3	m	0.02908364...	-6.142...	0.9999...	9.0456630842...
4	Channel 4	Wave Probe	CH4	m	0.02977798...	-6.591...	0.9999...	0.0002004851...

FIGURE 10. Calibration that needs to be filled in the SOLTEQ



Calibration Input

Instrument Name	X - Offset	Y - Reading (V)	Y - Std (V)
☑ Channel 1	+0.04	-8.917	0.002
☑ Channel 2	+0.04	-8.980	0.002
☑ Channel 3	+0.04	-8.412	0.018
☑ Channel 4	+0.04	9.979	0.002

FIGURE 11. Need to key in the calibration setup on the HR Merlin.

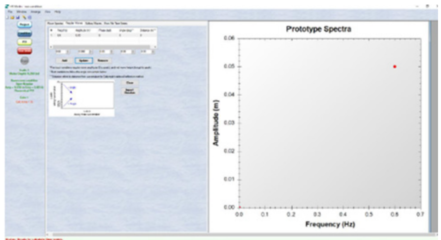


FIGURE 12. The display for parameter input in HR Merlin Software

RESULTS AND DISCUSSION

CASE 1: REGULAR WAVE (FULLY SUBMERGED CONDITION)

Due to the seashells being 0.30 meters below the water surface, the efficiency of the structure in reducing the impact of waves crashing on the seashell appears to decrease. A waveform spanning 300 seconds is depicted in Figure 13, which shows the progressive reduction of a regular wave on a submerged surface. The wave transmission has reached its peak value of 0.49. Consequently, the wave reflection coefficient would exhibit reduced values in comparison to the reflection coefficient, declining from -0.38. Run-up is the vertical distance between the still water level (SWL) and the highest point reached by a wave as it moves upwards on the slope of a breakwater.

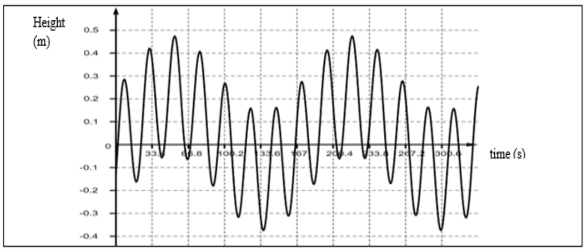


FIGURE 13. Case 1 regular wave on the fully submerged, frequency 0.7Hz.

Figure 14 shows the difference between the desired submerged depth of the water surface wave and the actual observed wave water surface. This disparity occurs over 80 seconds. The wavelength remains consistent across all channels throughout both runs. Therefore, the wave reflection coefficient exhibited reduced values.

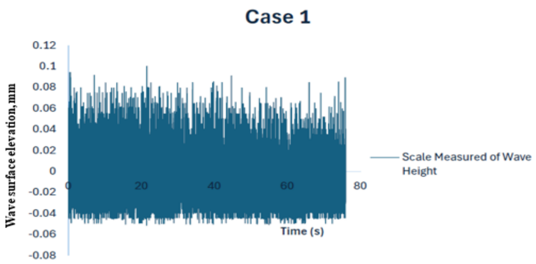


FIGURE 14. Graph wave is shown wave surface.

The interaction between the wave and structure is shown in Figure 15 for regular waves that completely submerge on the seashell. The size, shape, and orientation of the shell affect these forces, which include buoyancy, drag, and lift. The depth of the water influenced the way seashells reacted to the movements caused by waves.

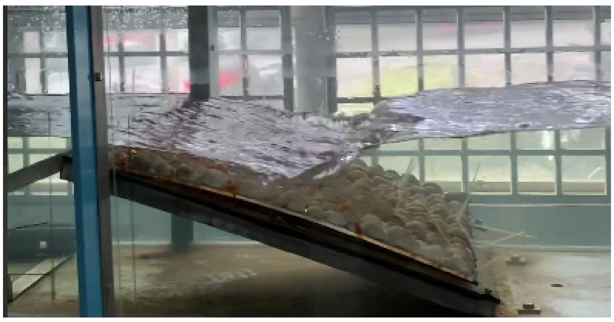


FIGURE 15. Shot reveal demonstrates the wave-structure interaction for regular wave fully submerged. (T=0,08sec)

CASE 2: IRREGULAR WAVE (FULLY SUBMERGED CONDITION)

Case 2 refers to situations where there is an irregular wave with a depth that is completely submerged. The total energy distribution within an irregular wave system and dominating wave components were revealed by spectrum analysis. Figure 16 displays the oscillating line that represents the variation in wave height as a function of time. The wavelength is determined by the distance between the peaks or troughs of a wave, representing the distance over which the wave shape repeats. In this case, the wave with a wavelength of 0.30m had the maximum amplitude.

Furthermore, the graph indicates that the recorded wave height of -0.29m consistently falls below the desired wave height of 0.30m. This could be attributed to various variables, including measurement inaccuracies, imperfections in the wave probe, and potential errors in its measurements. As shown in Figure 17, the gap between the target wave height on the red line, which is not fully targeted for submerged depth, and the measured wave height on the blue line takes 80 seconds. Every channel has the same wavelength for both runs of irregular waves. Initially, there is a noticeable decrease in amplitude, indicating the possibility of a damping effect or energy loss. However, near the end, there is a rise in amplitude, which may be attributed to an increase in energy or a modification in the wave-generating mechanism.

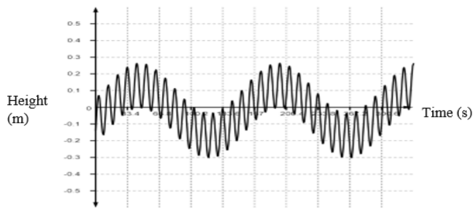


FIGURE 16. Case 2 irregular wave on the fully submerged, frequency 0.07Hz, amplitude 0.095m.

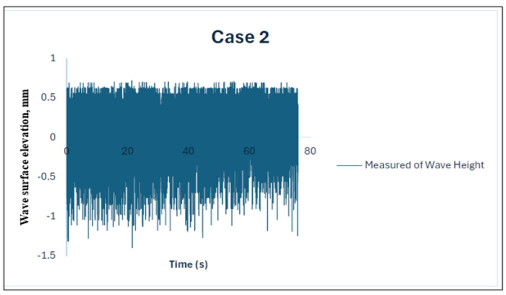


FIGURE 17. Shown of graph wave the wave surface.

CASE 3: REGULAR WAVE (PARTIALLY SUBMERGED CONDITION)

During this phase, the shell is partially submerged up to a height of approximately 0.24m, with consistent water pressure under it. The predicted outcome of the testing is expected to demonstrate the significance of the planned seashell layer. The spatial arrangement of the shells relative to the water level provides insight into the direct correlation between the shells and the incoming waves, thus revealing the true dynamics of shell production. Figure 18 demonstrates a clear relationship between an increase in wave steepness and a large decrease in the wave reflection coefficient. The graphic shows a low level of reflection and a high level of transmission. The water's depth in the shell's centre reduced the base's influence while revealing the shell's true performance, which was to decrease reflection and allow relatively high values of transmission.

FIGURE 18. Shot reveal demonstrates the wave-structure.

Figure 19 suggests that this coefficient decreased from 0.25 to 0.10, indicating that the shells effectively absorbed most of the energy from the incident waves. A significant drop in the reflection coefficient would arise from the smooth curve and the asynchronous shell formation. The arrangement of the shells permits the development of weak points or gaps between them. As a result, there would be less reflection and incident waves would have less energy to escape the shielded area.

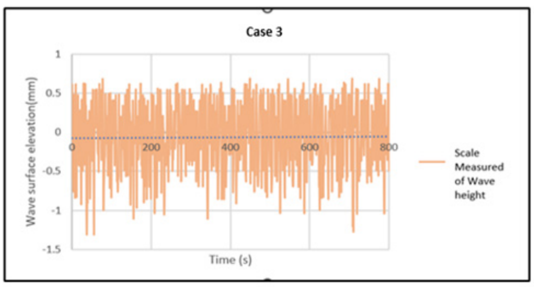


FIGURE 19. Case 3 regular wave on the partially submerged, frequency 0.07Hz, amplitude 0.090m.

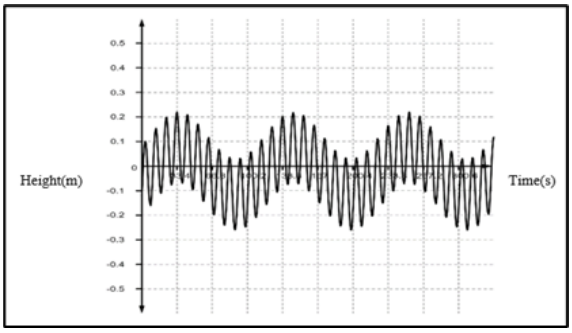


FIGURE 20. Shown of graph wave the wave surface.

Upon analysing the wave flume maker, it was found that the partially submerged example demonstrated the highest efficiency among the other cases under normal conditions. The pattern of oscillations indicates a dynamic system that could be influenced by factors such as seashells, water currents, or wind speed on the wave flume. According to Figure 20, the graph displays heights ranging from around -1.5mm to 1mm. Additionally, the wave height exhibits significant variation during the recorded period. Waves with longer periods propagate faster through the seashell model compared to waves with shorter periods because of dispersion and reduced frequencies. This was attributed to the fact that the presence of more vacancies in deeper water leads to a higher number of transmissions.

CASE 4: IRREGULAR WAVE (PARTIALLY SUBMERGED CONDITION)

Based on case 4, involving irregular waves at partially submerged depths, the wave transmission values are higher. This is related to the higher number of transmissions occurring in deeper water as a result of the increased availability of empty spaces. Figure 21 displays a time series graph depicting wave heights, with the oscillating line representing the wave's ascent and descent. Unlike in Case 2, where irregular waves were considered under full submersion, the peaks in Case 4 correspond to the highest points of the waves, also known as wave crests. In both situations of irregular waves, the wavelength remained consistent across all channels. At first, the magnitude seemed to decrease, indicating a damping effect or loss of energy. However, in the end, there was a rise in amplitude, either caused by an escalation in energy or a modification in the wave-generating process.

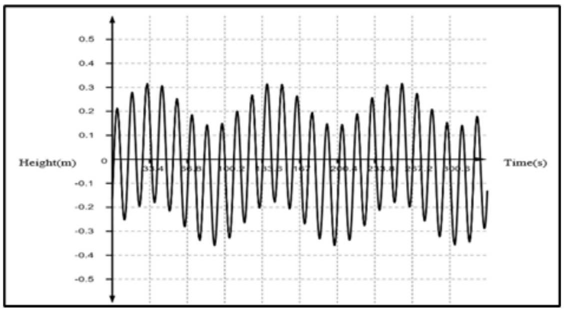


FIGURE 21. Case 4 irregular wave on the partially submerged, frequency 0.08Hz, amplitude 0.095m

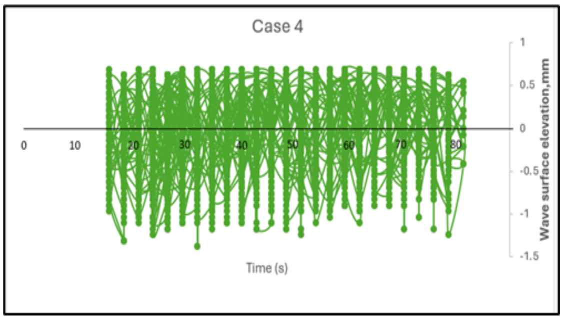


FIGURE 22. The graph shows the wave surface irregular case

The oscillations represent the increase and decrease in the height of the wave surface over time due to the wind speed on the wave flume. The graph in Figure 22 shows that the wave height varies significantly throughout the recorded period, with heights ranging from around -1.35mm to 0.5mm. Waves with longer periods propagate faster through the seashell model compared to waves with shorter periods because of dispersion and reduced frequencies. Since there are more gaps in deeper water, transmissions increase.

CASE 5: REGULAR WAVE (EMERGED CONDITION)

In Case 5, the crest of the base is visible above the surface, and the water level is 0.20m. Figure 23 exhibits the impact of the structure on the different wave conditions. An increase in wave steepness leads to a drop in the wave reflection coefficient. The gradient of a wave intensifies as its duration decreases and its amplitude increases. Based on the data provided, it can be shown that there was a decline from 0.359 to -0.25, showing a decreasing trend. The direct interaction between the waves and the seashell breakwater can create high wave reflection.

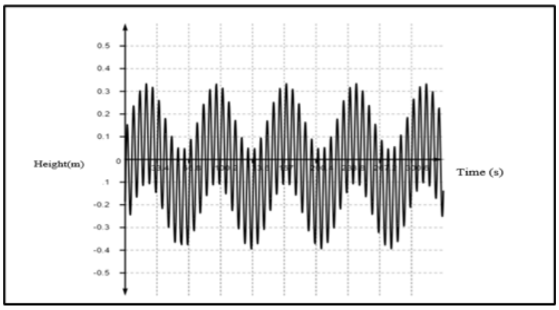


FIGURE 23. Case 5 regular wave on the emerged, frequency 0.07Hz amplitude 0.90m.

The transmission coefficient fluctuates within a small range of values, approximately 0.25m, as a result of the influence of base height, such as the sea depth and the capacity of seashells to withstand incident waves. The wave dissipation coefficient is directly proportional to the wave's steepness and is influenced by factors such as the base slope, shell shape, staggered formation, and friction (Figure 24).

FIGURE 24. Shot reveal demonstrates the wave structure on the regular wavAe emerged condition. (T=0.10s).

The lowest values of wave transmission were found in incoming waves with a high wave steepness low water depth, whereas the highest values of wave transmission were found in waves with a lower wave steepness and a higher depth on the (Fig. 25). Moreover, the direct contact between incident waves and the foundation seashell breakwater was the caused of the blatant high wave reflection. The experiment's transmission coefficient, which was influenced by the base height in relation to the water's depth and the shells capacity to withstand incoming waves, fluctuates between certain bounds.

CASE 6: IRREGULAR WAVE (EMERGED CONDITION)

The wave dispersion coefficient experienced an 89% increase. The new approach's capacity to absorb the majority of the incoming wave energy on the wave flume is a substantial factor contributing to the high dissipation values. The term "emerged depth" denotes the portion of a structure and the slope that is 0.20m above the waterline. Irregular waves are distinguished by their unpredictable and fluctuating height, period, and trajectory. The staggered shell construction would result in an extended travel time from upstream to downstream, which would further attenuate and dissipate the incident waves. The wave was expected to disintegrate when the wave steepness, which is the ratio of wave height to length, reached 0.06. The wave transmission increased to 0.40 by the breaking waves (Figure 26). Alternating water levels at an emerged depth can result from irregular waves, causing the structure to be intermittently submerged and reemerge This could lead to a diverse array of phenomena, including wave run-up and wave striking, all of which could exert substantial forces on the structure.

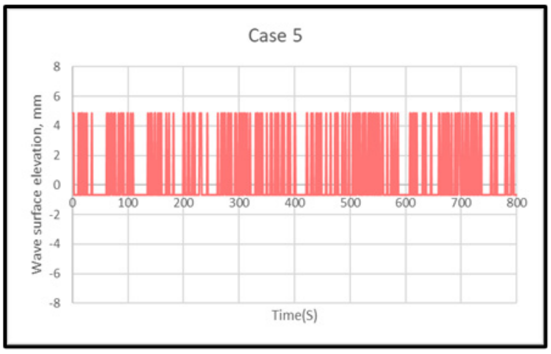


FIGURE 25. Wave surface elevation on the submerged case.

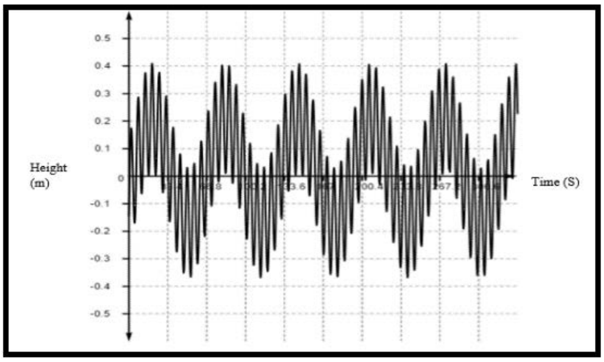


FIGURE 26. Case 6 irregular wave on the emerged, frequency 0.08Hz, amplitude 0.095m

The analysis of these interactions and the prediction of the structural responses to the intricate wave patterns would necessitate data from wave sensors that captured the wave height over time, including peak and trough dynamics. The graph displays a stark contrast between the objective wave height and the measured wave height over 300 seconds. Throughout the time series, the target wave height was represented as a solid red block, indicating that it is intended to remain constant for irregular waves (Figure 27). This could be a control scenario in a wave tank in which the target height is maintained without variation, potentially for calibration purposes or to establish a baseline.

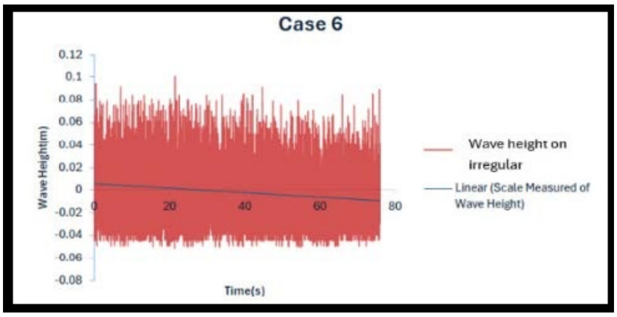


FIGURE 27. Demonstrate of the wave height on irregular wave emerged.

The research results indicate that the scenario for regular and irregular waves does not adequately represent the seashells on the wave flume. It suggests that the range of -0.25 to 0.40 is characterised by low transmission and higher values of reflection. Wave reflection decreases when the water level is fully submerged, while transmission increases as the water level decreases. The reflection coefficient ranges from -0.29 to 0.39. This is due to the interaction between the water and the shells.

In comparison to the other scenarios, the partially submerged case exhibits the highest efficiency, with a coefficient range of 0.19 to 0.45. Seashell breaks achieve dissipation values that are higher than those of other varieties of breaks, capable of dispersing up to 0.25 of the incident waves. There is also a comparison of the efficacy of the suspended open-type breakwater and the fluctuating water levels.

CONCLUSION

The six cases of simulation and wave condition have been analysed based on laboratory investigation. In comparison to other conditions, the partially submerged case in a regular wave has demonstrated the highest efficiency at the submerged depth. This serves as a comparison to some of the most remarkable breakwaters constructed in recent years. Both the observed and predicted dissipation and transmission coefficients for wave reflection were favourable in contrast to the other scenarios. The dissipation values of seashell breaks are higher than those of different varieties of breaks as a result of the shell's dissipation. The dissipation reached 0.25 of the incident waves. This innovative type of structure is widely acknowledged as a cost-effective, environmentally friendly, multifunctional, and aesthetic coastal structure, particularly for recreational coastal areas. It will help achieve specific significance in the development of sustainable coastal management strategies.

The JONS WAP spectrum was applied for both seashell runs with the following parameter. The initial incident spectrum was identical to the calculated incidence spectrum. Nevertheless, reflection coefficients that were deemed unrealistic were discovered for exceedingly low frequencies. This was due to the fact that numerical instabilities that were negligible within the pertinent domain may be the result of very low-value divisions. Consequently, it has been determined that the anticipated reflection coefficient differs for each simulation.

RECOMMENDATION

The suggestion for this study is to conduct testing at various wave characteristics to compare the results effectively and to add variation in seashell density, which was medium density. Nevertheless, the current study was unable to conduct this due to time constraints. Testing a variety of wave characteristics would offer a more comprehensive comprehension of the correlation between wave characteristics and wave reduction. Furthermore, wave flumes may contain errors in technical machinery that are intended to ensure safety.

Following are examples of research from which conclusions could be derived through a combination of field observations and laboratory experiments. It is anticipated that the utilisation of seashell blocks will be a successful approach to reducing the destructive potential of waves. This could potentially mitigate the force of the waves and safeguard the coastline from erosion by weakening them prior to their arrival at the coast. Previous research has determined that the configuration and arrangement of seashell blocks are essential for regulating the reflection and transmission of waves. Through modifications to the design specifications, engineers could optimise the amount of wave energy dissipated through the blocks and reduce the amount reflected.

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DECLARATION OF COMPETING INTEREST

None.

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