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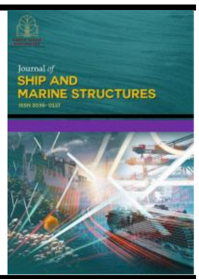

Bamboo Wave Screen for Mangrove Protection in Tanjung Kepah

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ABSTRACT

Since 2004, Pantai Tanjung Kepah has struggled with significant coastal erosion, which hurts the ecosystem of the mangrove forest and marine biodiversity. Unfortunately, despite previous repeated attempts at replanting, the mangrove plants did not thrive. Pantai Tanjung Kepah is currently highly vulnerable to the destructive force of storms as a result of the vital coastal ecosystems and assets that have been significantly lost or degraded as a result of the mangrove decline in the area. In response, an environmentally friendly approach is recommended to assist Pantai Tanjung Kepah's mangrove restoration by constructing a permeable bamboo wave screen. This solution aims to restore the natural sediment in Tanjung Kepah as well as function as a wave breaker to protect the young mangrove trees. A 25-meter-long, 0.8-meter-wide, and 2-meter-high permeable bamboo wave screen will be built and the construction will make use of bamboo poles with a diameter of 100 mm that can reach up to 6 meters for vertical piles, reinforced concrete (RC) piles for extra stability, and a geotextile scour apron to prevent scouring at the base. Tree branches will also be included in the geotextile bag as filler, improving the structure's ability to attenuate waves. To comprehend the site conditions, assessments were carried out, including mangrove sampling and coastal data collection. Geotechnical, structural, and hydrodynamic factors are all taken into account in engineering design calculations. To assess wave attenuation performance and post-construction hydrodynamics, respectively, numerical and physical modeling were done. The Department of Irrigation and Drainage Malaysia (JPS) will supervise appropriate coordination and regulatory compliance throughout the mid-August 2024 construction of the bamboo wave screen. The Kampung Tanjung Kepah local community will be part of both the construction and the post-construction activity, which will include maintenance and monitoring. This will encourage the empowerment of the community. Additionally, this initiative contributes to the achievement of the Sustainable Development Goals (SDGs), particularly SDG 14 (Life Below Water) and SDG 15 (Life on Land).

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1. Introduction

In Malaysia, the loss of mangrove forests is a major environmental issue that presents both ecological and socioeconomic problems. Over the past fifty years, Malaysia's mangrove area has decreased by thirty percent, from 800,000 hectares in the 1950s to the current size of 575,000 hectares in 2013. The states with the largest mangrove area declines are Penang, Johor, Sarawak, Negeri Sembilan, Perlis, and Selangor [1]. Located in the coastal region of Lekir, Sitiawan, Pantai Tanjung Kepah is well known for being a little fisherman's haven, where the sea's bounty—including clamps—plays a key role in local culinary traditions and economic subsistence. The current condition of Pantai Tanjung Kepah is shown in Figure 1.

Fig. 1. Current state of Pantai Tanjung Kepah

Significant coastal erosion has been a problem for Pantai Tanjung Kepah since 2004, negatively affecting the marine biodiversity and mangrove forest environment. Logging, urbanization, aquaculture growth, and agricultural land conversion are mentioned as the causes of mangrove declination [2]. Few replantation attempts have been made by the Forestry Department at Pantai Tanjung Kepah, but regretfully, the mangrove trees did not. The local community, which depends on fishing, clamps, and shrimp farming for both money and subsistence, is directly impacted by this circumstance. Furthermore, due to the significant mangrove declination as shown in Figure 2, Pantai Tanjung Kepah is now extremely exposed to the devastating power of storms. In response, an environmentally friendly approach is suggested to support mangrove restoration in Pantai Tanjung Kepah. This involves building a permeable bamboo wave screen. It is essential to develop environmentally friendly strategies that reduce negative impacts and ensure the long-term sustainability of ecosystems. Achieving a lasting solution requires establishing a compromise between the residents' socioeconomic interests and the mangroves' conservation objectives.

Fig. 2. Mangrove depletion at Pantai Tanjung Kepah

The main objective of this project is to construct a permeable wave screen to restore natural sediment dynamics and improve soil conditions at Pantai Tanjung Kepah while serving as a wave breaker to shield newly planted mangrove trees. It is anticipated that the permeable wave screen may lessen the effects of powerful waves, allowing mangrove saplings that had previously failed to survive and develop. The initiative aims to restore the once-thriving mangrove forest and its related biodiversity by establishing a more stable environment.

This project comprises several significant efforts, including fieldwork and data collection for mangrove sampling and coastal data collection to comprehend the site conditions. Subsequently, soil sampling from mangrove sampling and the coastal data collection is conducted to determine the soil classification. Geotechnical, structural, and hydrodynamic factors are all taken into account in engineering design calculations. Physical modeling is used to assess the effectiveness of wave attenuation, while numerical modeling is used to assess the site conditions prior to and following the permeable bamboo wave screen. The construction of the permeable bamboo wave screen will commence by mid of September by the contractor appointed by JPS. Post construction, the community will participate in a monitoring and maintenance program to ensure the structure's condition. The project scope flowchart is displayed in Figure 3.

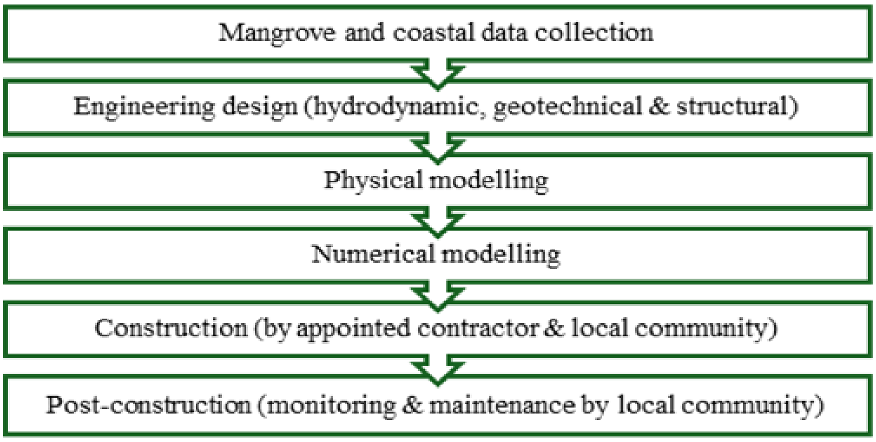

Fig. 3. Flowchart of the project scope

By restoring the mangrove environment and biodiversity, this initiative contributes to the achievement of the Sustainable Development Goals (SDGs), particularly SDG 14 (Life Below Water) and SDG 15 (Life on Land). In addition to restoring the mangrove forest, the successful completion of this project would enhance local populations' standard of living by reducing coastal erosion and encouraging the sustainable use of natural resources. The initiative at Pantai Tanjung Kepah hopes to use this innovative method to demonstrate to other coastal regions facing similar challenges that the effectiveness of nature-based solutions can be in restoring and safeguarding important ecosystems.

2. Case Studies

In Central Java (Indonesia), the Mekong Delta (Vietnam), and near Paramaribo (Surinam), mangrove recolonization with permeable structures is currently being implemented [3]. Using a building with nature approach, Wetlands International has restored deteriorating tropical muddy coastlines through implementing the structure depicted in Figure 4 into practice. In order for mangroves to recover over a period of two to five years, a permeable structure must minimize wave reflection, reduce wave energy and turbulence, and allow sediment to pass through for deposition

[3]. Table 1 shows a number of alternative materials for every part of a permeable, derived from Demak expertise.

Fig. 4. Permeable bamboo wave screen at Demak, Indonesia [3]

Table 1
Materials for every part of a permeable, derived from Demak expertise

Aspects	Specification	Description
Vertical poles	Wooden poles, bamboo & PVC-concrete	Diameter 0.12m -0.15m Length at least 4m
Filling material	Branches	Diameter 0.02m – 0.10m
Net + rope	Nylon	Mesh size: 0.10m Diameter rope net: 3mm
Horizontal beam	Wooden poles, bamboo & PVC-concrete	Diameter 0.10m Length at least 4m

Bamboo T-fences have been effectively employed for the muddy mangrove coasts along the east coast of the lower Mekong Delta. Two rows of bamboo poles are used to build the fences, with multiple layers of brushwood bundles placed in between. The construction's top is designed in line with the mean high-water level. The distance between the two rows is 0.40 m for cross-shore sections and 0.50 m for longshore sections. More details on the design are as follows [4]:

- The mean diameter of vertical bamboo poles is 8 cm.
- For cross-shore sections, the distance between the two rows is 0.40 meters; for longshore sections, it is 0.50 m. The estimated distance between two poles in a row is 0.30 m.
- The vertical poles on each side are joined to two rows of horizontal poles.
- Brushwood bundles consist of bamboo branches.
- To ensure a strong and reliable connection, stainless steel wire is utilized to lash the joints.
- The bottom was protected against scour with a double covering of nypa palm leaves.
- The vertical bamboo poles in Vinh Tan have an embedment depth of 3.40 m and a length of roughly 4.70m.

The plan was applied, however slightly modified, to the Bac Lieu Province coast as in Figure 5, where 500 meters of bamboo fencing were built in May 2012. A further 2000 m were built in a second phase in October and November along the shores of Bac Lieu and Soc Trang [4]. This implementation has improved sedimentation and decreased wave energy, which in turn has minimized erosion. It took about six months for the *Avicennia marina* to begin to naturally regenerate following the T-fence installation in Soc Trang [4].

Fig. 5. T-shaped bamboo fences on the coast of Bac Lieu Province [2]

3. Methodology

3.1 Mangrove Sampling and Coastal Data Collection

The purpose of mangrove sampling is to identify the mangrove species inhabiting the site and to estimate their age. Estimation of a tree's age requires specific tree measurement data, i.e., the species, height and diameter of the tree trunk. The site was partitioned into 12 plots to facilitate the sampling. This study adopted the NAMRIA's procedures in establishing plots within the study area [5]. The adopted procedures are schematically presented in Figure 6.

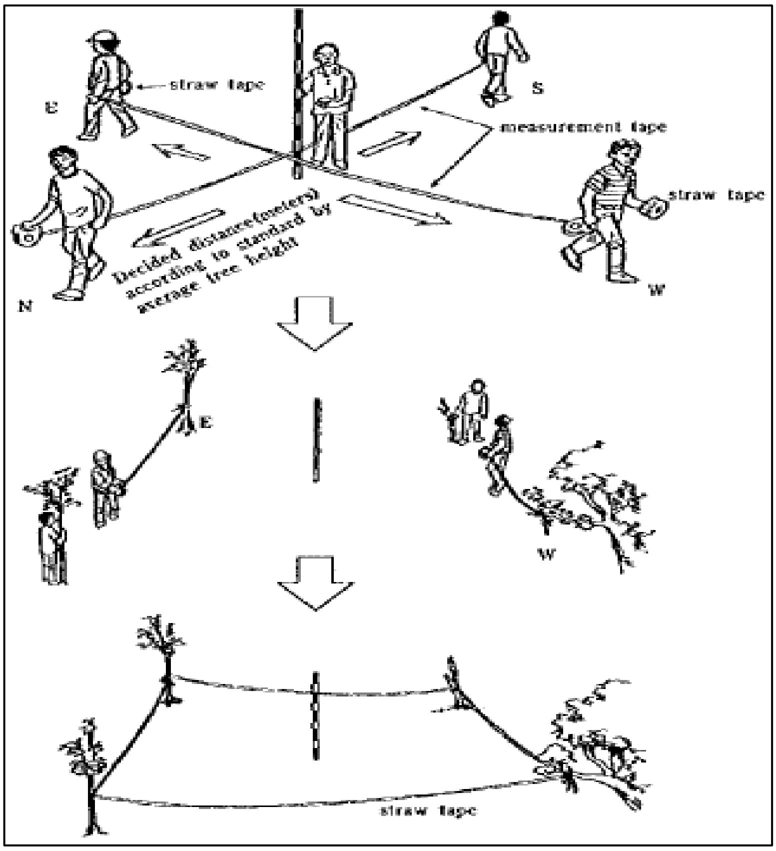

Fig. 6. Procedures for establishing a plot [5]

Coastal data collection is conducted to determine the data on the wave dynamics and currents, and sediment transport. This method was conducted by National Water Research Institute of Malaysia (NAHRIM) and the activity consisted of the installation of 2 units of Acoustic Wave and Current Profiler (Nortek – US) for 14 days, the installation of 2 units of Tide Gauge for 14 days, and a bathymetry survey of the study area pre-construction for 125km and 50km transects line. Figure 7 shows the photo during the data collection.

Fig. 7. Coastal data collection by NAHRI

Additionally, UTP conducted soil sampling to investigate the correlation between mangrove species and soil conditions within the study site, as well as to classify the soil. Samples were collected from both open areas and mangrove areas in mangrove sampling plots using scoops and a hand auger, as in Figure 8. The collected samples were then analyzed for moisture content, sieve analysis, and plasticity index to determine soil classification and characteristics.

Fig. 8. Hang auger used during soil sampling

3.2 Engineering Design

The design revolves around the development of a nature-based permeable bamboo wave screen. This design incorporates various materials, each serving specific functions, as detailed in Table 2. Additionally, Table 3 outlines the desired parameters for the permeable wave screen. The hydrodynamic design was calculated using data collected by NAHRIM. The results of the hydrodynamic calculations were integrated into the geotechnical design, which included determining the bearing capacity, vertical load on each effective area of bamboo piles, and the spacing and embedment depth of the piles. All geotechnical calculations were performed as referenced in [6]. Based on the pile spacing and embedment results, structural analysis was conducted using Staad.Pro software. Upon completing the engineering design, engineering drawings were produced for construction.

Table 2
Proposed material for the permeable wave screen

Material	Function
Bamboo RC piles	As a pile to anchor the structure to the seabed.
Tree branches	Filing material
Geotextile layer and bag	To prevent scouring and to contain the filing material respectively

Table 3
Proposed parameter for the permeable wave screen

Parameter	Details
Length	25 m
Height of the structure	2 m from the ground level
Width of the structure	0.8 m
Diameter of the bamboo	10 cm
Size of RC pile (square)	10cm x 10cm

3.3 Physical Modelling

This experiment is conducted to identify the parameters that provide the most effective wave attenuation. This involves analyzing transmission, reflection, and energy loss coefficients across different wave conditions, including variations in wave period and steepness, while accounting for water depth and the spacing between piles for wave screen components. Experiments were conducted using a model of a breakwater structure placed in the small-scale wave flume as in Figure 9, employing wave probes to gather data on incoming and reflected waves.

Fig. 9. Breakwater structure in a wave flume with attached wave probes stationed at the back and front of the model

3.4 Numerical Modelling

Numerical modeling was conducted by NAHRIM to calibrate and verify the design by comparing existing conditions with permeable wave screen conditions by using the collected coastal data. Additionally, an assessment of potential impacts was conducted. Figure 10 shows the two proposed locations for the installation of the permeable bamboo wave screen, which have been analyzed using numerical modeling.

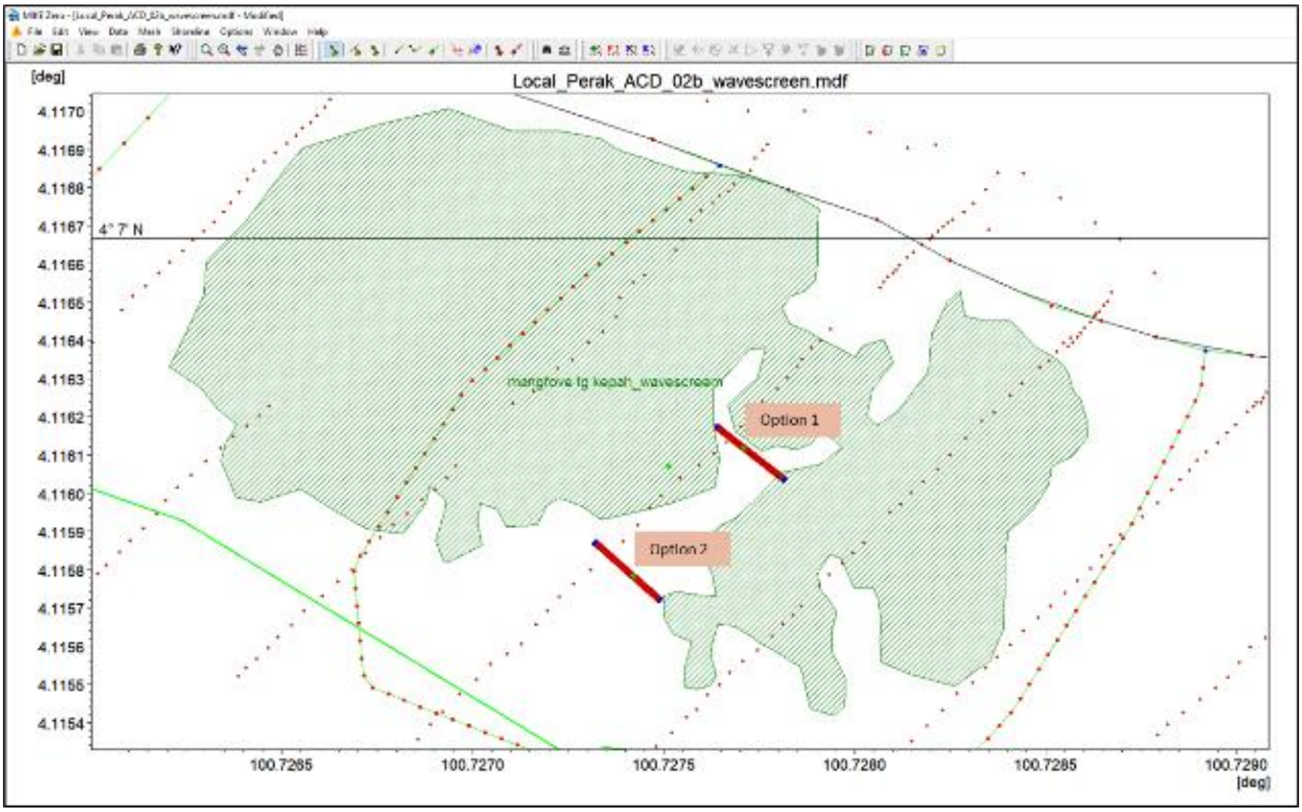

Fig. 10. Proposed locations for the installation of a permeable bamboo wave screen at Pantai Tanjung Kepah

3.5 Construction

The construction of the permeable bamboo wave screen will commence in mid-August 2024. JPS will appoint a contractor to carry out the work, and the local community will assist during the construction by preparing tree branches and sandbags.

3.6 post-construction

After the construction, the contractor and the local community will perform monitoring and maintenance for six months to ensure the bamboo wave screen's condition. Training for both the contractor and the local community will be conducted to standardize the monitoring process and maintenance works by transferring knowledge and skills.

4. Findings and Discussion

4.1 Mangrove Sampling and Coastal Data Collection

Figure 11 summarizes the distribution of mangrove trees according to their species, and the results are expressed in terms of percentage. *Avicennia officinalis* is the most dominant mangrove species at Pantai Tanjung Kepah, contributing 59%; while *Avicennia alba* becomes the second most dominant species, contributing 30%. Sonneratia alba, *Brugueira cylindrica,* and *Rhizophora apiculata* are the minority species in the sampling area, giving 6, 3 and 2%, respectively. *Avicennia officinalis* is the predominant species among old and mid-aged trees in the research region. Conversely, *Avicennia alba* has shown itself to be the most resilient species among young trees. From the soil sampling, most of the area in Pantai Tanjung Kepah is classified as poorly graded sand.

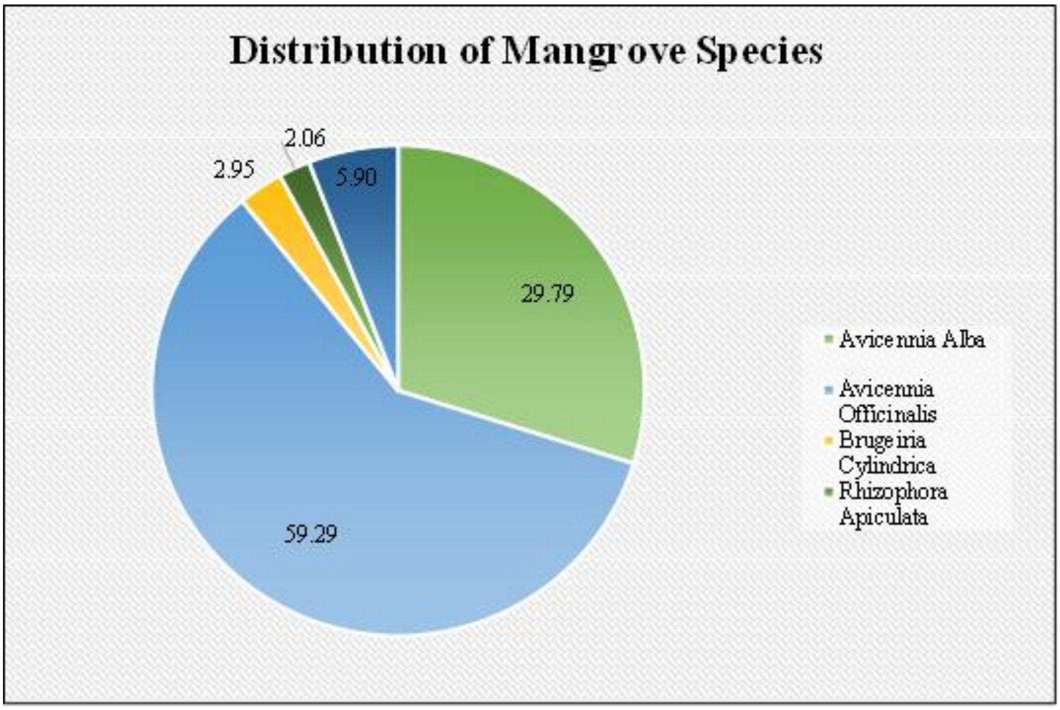

Fig. 11. Distribution of mangrove species

NAHRIM reported that Pantai Tanjung Kepah features low topography and a gently sloping mudflat. The beach profile displayed in Figure 12 shows an increase in elevation near the coast due to sand deposition and the presence of a revetment structure along the shoreline.

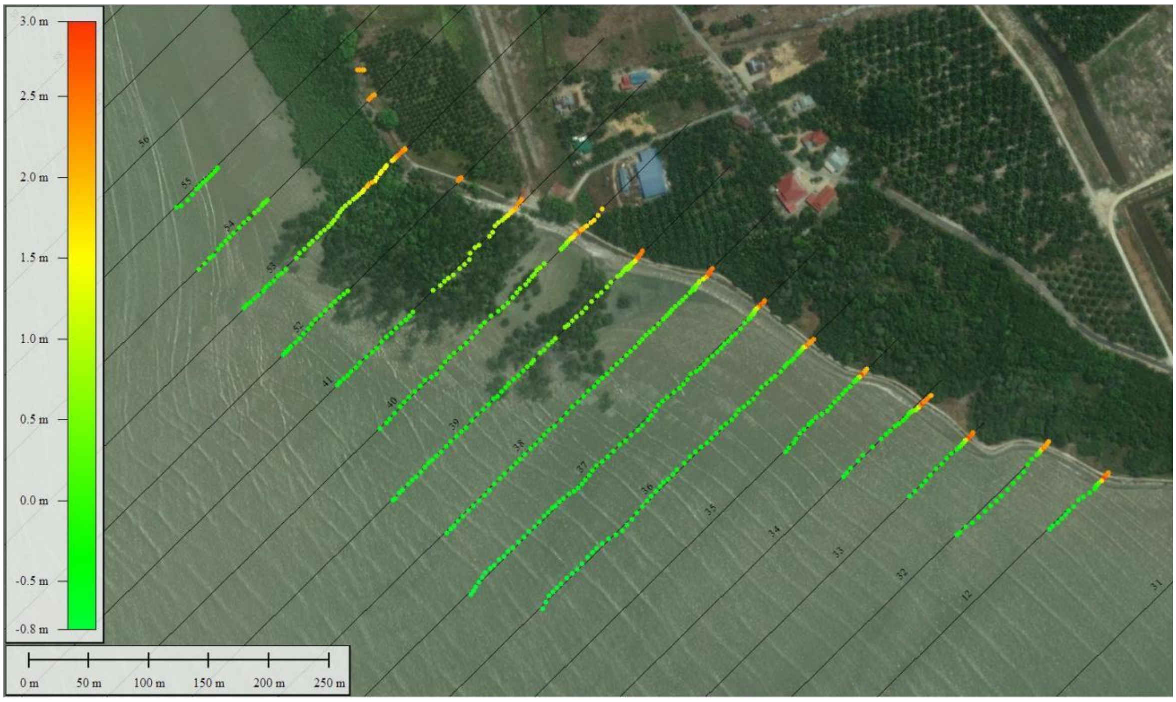

Fig. 12. Location of Beach Profile Transect along Pantai Tanjung Kepah

4.2 Engineering Design

Based on the hydrodynamic, geotechnical, and structural design calculations, the design of the permeable bamboo wave screen is as follows:

- Two rows of 6m vertical bamboo poles with 100mm diameter, each facing the sea and land.
- One row of 6m long square reinforced concrete (RC) piles (100mm x 100mm) as a supporting structure. These RC piles are spaced at 3-meter intervals along the row.
- Seven horizontal support bamboo poles, each 25 meters long and 100mm in diameter, are used: five are attached to the front row and two are attached to the second row of bamboo.
- A geotextile layer serves as a scour apron to prevent scouring, with tree branches placed inside geotextile bags to prevent them from washing away.
- Bamboo of varying lengths is used as supporting members.
- All the supporting members are tied together using nylon rope and the tripod lashing method.

Figure 13 shows the isometric view of the permeable bamboo wave screen at Tanjung Kepah.

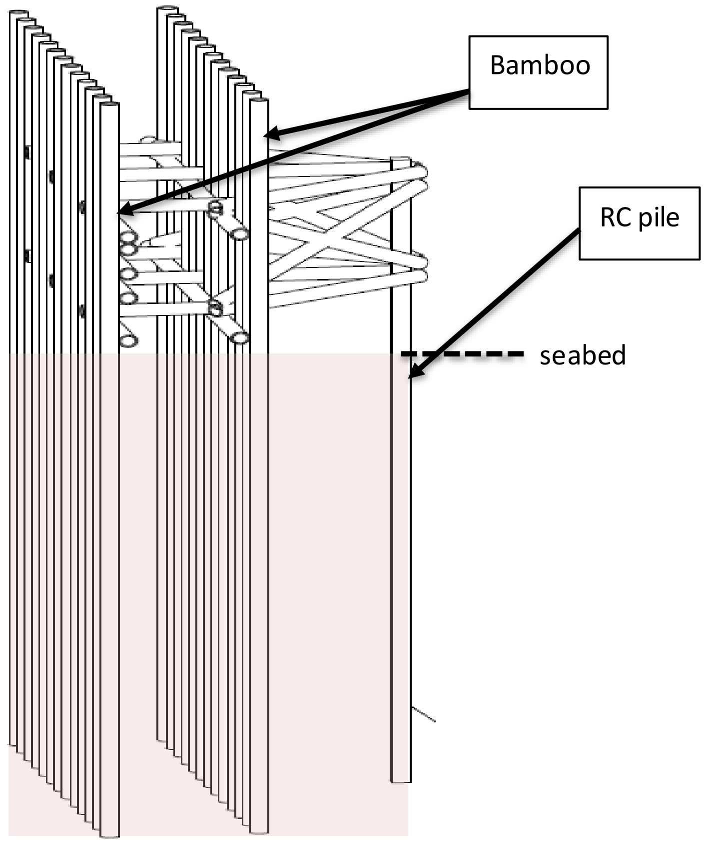

Fig. 13. Isometric view of permeable bamboo wave screen at Tanjung Kepah

4.3 Physical Modelling

From the experiment, pile spacing S/B=0.19 at d/B=1.43 gives the best wave transmission. This suggests that a significant portion of the wave energy is transmitted through the wave screens, effectively protecting the mangroves by reducing the impact of the waves that reach them. Figure 14 shows a good wave transmission produced during the experiment.

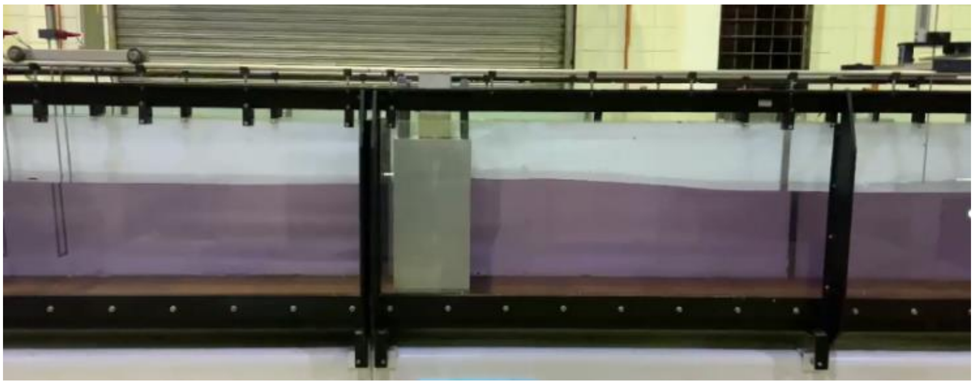

Fig. 14. The experiment shows a good example of wave transmission

4.4 Numerical Modelling

The numerical modeling results indicate that Option 1 is a suitable location for installing the permeable bamboo wave screen, as it significantly reduces wave height and current, particularly in the area designated for mangrove restoration, as shown in Figure 15.

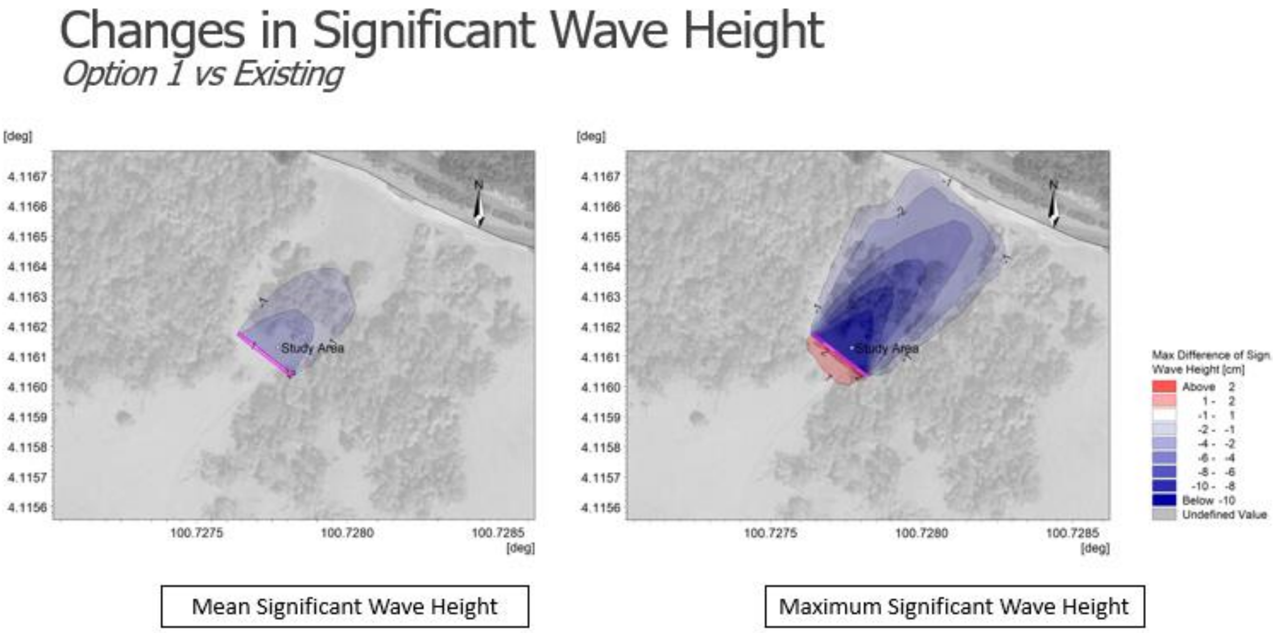

Fig. 15. Changes in significant wave height for Option 1

4.5 Construction

The construction of the permeable bamboo wave screen will take place at Pantai Tanjung Kepah. The appointed contractor will handle all the required work with assistance from the local community in filling sandbags (to provide weight to the structure and the geotextile layer), collecting tree branches, and managing logistics. The construction work will be overseen by JPS and UTP (as the consultant) to ensure the project's quality, adherence to design specifications, and timely completion. Figure 16 shows the photo taken during a site visit for a tender briefing by JPS and UTP to the local contractors. Prior to the construction, the contractor will liaise with the head village, local community, and stakeholders to coordinate efforts, ensure community involvement, and address any concerns or requirements specific to the site. This collaboration will help facilitate the smooth execution of the project, aligning it with local needs and expectations. The construction of the permeable bamboo wave screen is expected to be completed within two weeks.

Fig. 16. Ir Shamimi from JPS Manjung briefs the contractors for the project

4.6 post-construction

Following the construction, the local community will initiate a monitoring program, conducting weekly inspections to assess the condition of the wave screen. A monthly maintenance program will also be implemented to address any necessary repairs or adjustments. During the six-month defect liability period, the contractor will be responsible for performing the maintenance work, with the assistance of the local community. To ensure effective monitoring and maintenance, a series of training sessions will be provided to the local community. Figure 17 shows the previously conducted training on the monitoring program with the local community. These sessions will enhance their understanding of the scope of work, equipping them with the knowledge and skills needed to manage and maintain the wave screen effectively. This collaborative approach aims to foster community engagement and ensure the long-term success of the project.

Fig. 17. Previous monitoring training conducted with the local community

5. Conclusion

The degradation of mangroves at Pantai Tanjung Kepah has posed significant environmental and socio-economic challenges for the local community. In response, the construction of a permeable bamboo wave screen has been initiated as a proactive measure to mitigate coastal erosion and restore the mangrove ecosystem. This project is based on extensive research on structural, hydrodynamic, and geotechnical aspects, guaranteeing the resilience and effectiveness of the wave screen. The utilization of bamboo is consistent with ecological principles, contributing to the conservation of the surrounding ecosystem and strengthening its natural defenses against erosion. Moreover, by restoring the mangrove environment and biodiversity, this initiative contributes to the achievement of SDG 14 (Life Below Water) and SDG 15 (Life on Land). The project highlights community empowerment through the participation of the local community in both the construction and maintenance stages. In addition to strengthening local capacity for future conservation activities, this hands-on involvement promotes a stronger connection to the environment. The project in Pantai Tanjung Kepah is an example of how nature-based solutions may be implemented to conserve the environment and empower the community, ensuring sustainability and long-term resilience through the use of a collaborative approach.

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