


Decision Making on Breakwater Type Selection on Tidung Island, Thousand Islands

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ABSTRACT

Tidung Island, a major tourist destination in the Thousand Islands, faces coastal erosion caused by wave energy, tidal currents, and anthropogenic activities, which threaten coastal ecosystems, marine tourism quality, and residential areas. Coastal protection measures have been implemented through wave protection structures. However, their performance has been suboptimal due to limited maintenance, design incompatibility with local hydro-oceanographic conditions, and the absence of a systematic approach for selecting breakwater types. **This study aims to** identify the criteria and sub-criteria influencing breakwater selection and determine the most suitable structure for Tidung Island **using the Analytic Hierarchy Process (AHP)**. The AHP model integrates technical, environmental, socio-economic, field condition, and construction method aspects, based on secondary hydro-oceanographic data (tides, wind, wave height, and effective fetch) and expert judgments through pairwise comparisons. **The results show that** technical aspects have the highest priority (0.312), followed by environmental aspects (0.268), field conditions (0.201), socio-economic factors (0.127), and implementation methods (0.092), with all consistency ratio values below 0.10. **The selected structure is** a hollow cube breakwater with a filter-coated rockfill foundation, as it provides an optimal balance between technical performance, cost efficiency, ease of implementation in shallow waters, and manageable environmental impacts. This AHP-based model can support sustainable coastal protection decision-making.

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1. INTRODUCTION

Tidung Island is one of the main tourist destinations in the Thousand Islands, DKI Jakarta, known for its coastal landscapes and marine ecosystems, while also functioning as a residential area and a center of economic activity for local coastal communities. In recent years, however, this area has faced serious challenges in the form of progressive coastal abrasion and coastal ecosystem degradation caused by ocean waves, tidal currents, and anthropogenic activities. Several small islands in the Thousand Islands have experienced abrasion rates exceeding 1 meter per year, posing significant threats to residential areas, tourism infrastructure, and environmental sustainability [1].

The coastline of Tidung Island is highly dynamic due to continuous interactions between marine and terrestrial processes, particularly tidal fluctuations and wave action. Variations in hydro-oceanographic conditions, sediment characteristics, coastal morphology, and human activities play an important role in shaping

shoreline changes [2]. Additional factors such as wind, waves, ocean currents, beach materials, land subsidence, land clearing, surface runoff, and sediment transport from rivers further contribute to erosion and accretion processes along the coast [3]. The propagation and breaking of ocean waves near the shoreline generate longshore currents capable of transporting sediments, leading to ongoing changes in coastline position [4, 5].

Various coastal protection measures have been implemented on Tidung Island, including rubble mound breakwaters, simple revetments, and tetrapod structures. However, the effectiveness of these structures has remained limited. In several locations, structural deterioration has occurred due to inadequate maintenance and exposure to wave loads exceeding design capacities. In other areas, breakwater installations have altered local hydrodynamic patterns, resulting in excessive sedimentation and new coastal management problems such as siltation. These conditions indicate a mismatch between existing breakwater designs and the hydrodynamic and morphological characteristics of the study area [6, 7, 8].

To date, the selection of coastal protection structures on Tidung Island has largely relied on technical considerations and empirical experience, without the support of a systematic and integrated decision-making framework. Economic aspects, environmental sustainability, and socio-economic interests of local communities have often not been comprehensively evaluated within a unified assessment approach. As a result, implemented solutions tend to be suboptimal and less adaptable to long-term coastal dynamics.

Coastal protection planning must also align with national spatial planning regulations. Government Regulation of the Republic of Indonesia No. 21 of 2021 concerning Spatial Planning Implementation emphasizes that spatial utilization in coastal and marine areas shall be conducted in accordance with designated spatial plans to ensure environmental sustainability and integrated regional development. Therefore, breakwater selection on Tidung Island should be consistent with this regulatory framework to support sustainable coastal management [9].

Recent studies highlight the importance of using Multi-Criteria Decision-Making (MCDM) approaches to address complex coastal engineering problems. Methods such as the Analytic Hierarchy Process (AHP), TOPSIS, and PROMETHEE have been successfully applied to evaluate breakwater alternatives based on technical performance, cost efficiency, environmental impacts, and socio-economic considerations [10, 11]. In particular, AHP has been widely used to assess breakwater stability, wave energy reduction effectiveness, and life-cycle costs, while also allowing the integration of ecological criteria in environmentally sensitive coastal areas. Therefore, applying a systematic MCDM-based approach is highly relevant for determining appropriate and sustainable breakwater solutions for Tidung Island.

2. LITERATURE REVIEW

Coastal abrasion is a dynamic process influenced by hydro-oceanographic conditions such as wave energy, tidal currents, sediment transport, and wind patterns, and is often intensified by human activities, particularly in small island environments. Limited sediment supply, shallow coastal waters, and continuous wave action make small islands highly vulnerable to shoreline erosion. Previous studies indicate that wave breaking in nearshore areas generates longshore currents that transport sediments along the coast, resulting in persistent shoreline changes that require effective coastal protection measures [12, 13].

Breakwaters are widely used to reduce wave energy and mitigate coastal erosion, with various types such as rubble mound structures, revetments, and prefabricated concrete units developed according to site-specific conditions. Their effectiveness depends on factors including wave characteristics, water depth, soil bearing capacity, and erosion potential. However, inadequately designed or poorly maintained breakwaters may disrupt local hydrodynamic patterns, induce excessive sedimentation, or suffer structural degradation, emphasizing the importance of appropriate design, construction methods, and maintenance [14].

In recent years, coastal protection planning has increasingly integrated environmental and socio-economic considerations, as breakwater construction can affect sediment transport, marine ecosystems, and water quality, while economic factors such as construction and maintenance costs influence project sustainability [15]. To address this complexity, Multi-Criteria Decision Making (MCDM) approaches, particularly the Analytic Hierarchy Process (AHP), have been widely applied to support systematic breakwater selection by integrating expert judgment with multiple evaluation criteria. Nevertheless, the application of comprehensive AHP-based frameworks in small island contexts remains limited, highlighting the need for integrated decision-support models tailored to local coastal characteristics [16, 17, 18, 19].

3. RESEARCH METHODOLOGY

This section outlines the overall research framework, including the description of the study area, data collection, and analytical methods employed to support the evaluation and selection of appropriate coastal protection structures.

3.1. Description of Research Location

Tidung Island consists of Tidung Besar Island and Tidung Kecil Island. Tidung Besar Island has an area of 50.13 hectares, which functions as a residential area located in the west. Tidung Kecil Island has an area of approximately ± 18 hectares located at coordinates 5°10'00" to 5°57'00" South Latitude and 106°19'30" to 106°44'50" East Longitude. The research location has topographic conditions including the land of Tidung Island dominated by lowlands. The maximum height ranges up to approximately 8 meters above sea level [20, 21]. The lowest point is around 0 to less than 1 meter (including parts that may be right on the coastline or slightly below during high tide). The spatial configuration of the research area is illustrated in Figure 1.



Figure 1. Research location

3.2. Data Collection

The data used in this study are as follows:

- Tidal data for 30 days obtained from the Tanjung Priok Kolinamil Station.
- Climatological data for 12 years, from 2012 to 2023 obtained from BMKG.
- Previous research data related to effective fetch values and criteria for selecting coastal protection are as follows:

Table 1. Criteria for Selecting Coastal Protection

Criteria	Sub Criteria	Source
Technical Aspects	Wave height	[22]; [23]; [24]; [25]
	Direction of waves and currents	
	Tides and water depth	
	Type and bearing capacity of soil	
	Erosion potential	
	Level of protection	
Implementation Method	Operational depth	[26]; [27]; [28]; [24]; [25]
	Suitability to soil conditions	
	Time efficiency	
	Cost efficiency	
	Implementation risk	
	Job security	
	Availability of tools and materials	

Criteria	Sub Criteria	Source
Economy	Initial investment costs	[29]; [30]
	Material costs	
	Labor costs	
	Job costs	
	Maintenance and correction costs	
Environmental Impact	Availability of local resources	[31]; [32]; [33].
	Air pollution	
	Noise pollution	
	The impact of the building on the surrounding project	
	Hydrodynamic pattern	
	Disturbance of marine ecosystems	
	Construction waste	
Carbon emissions		
Field Conditions	Topography	[34]; [35]; [36]; [37]
	Location access	
	Geotechnical conditions	
	Weather and climate	
	Land availability	
	Potential for environmental or social disruption	

As summarized in Table 1, the criteria and sub-criteria for selecting coastal protection structures were compiled from established literature and serve as the basis for evaluating technical, environmental, economic, implementation, and field condition aspects in this study.

3.3. Data analysis stages

The collected data is then processed, which includes:

- Tidal analysis to obtain the Highest High Water Level (HHWL), Mean High Water Level (MHWL), Mean Low Water Level (MLWL), and Mean Sea Level (MSL) values.
- Wind analysis to obtain significant influence values on wave generation and hydrodynamic conditions of waters, so that it becomes one of the key parameters in coastal protection structure planning.
- Fetch analysis to determine design wave height, dominant wave direction, and evaluation of coastal protection structure requirements at the research location.
- Wave return period analysis to determine the potential extreme wave heights that may occur in the study area, so that it can be used as a basis for evaluating and planning coastal protection structures.
- Analysis of peak water level elevation to prevent/reduce water overflow behind building structures where overflow is not permitted (non-overtopping) is calculated from the sum of the planned water level elevation, wave creep height and additional height for the free boundary.
- AHP analysis to determine the type of coastal protection structure suitable for the study location. At this stage, the respondents had more than 15 years of work experience, with a minimum of a Master's degree, so they were still considered competent as experts.

These analyses were conducted sequentially to characterize the hydrodynamic conditions, determine design parameters, and support the decision-making process for selecting an appropriate coastal protection structure at the study location.



Figure 2. Types of coastal protection

Several types of coastal protection structures considered in this study are illustrated in Figure 2 as alternative solutions for mitigating wave energy and coastal erosion.

4. RESULT AND DISCUSSION

This section presents the results of the data analysis and discusses their implications for coastal protection planning at the study location, particularly in relation to hydro-oceanographic conditions and structural selection.

4.1. Tide

Table 2. Tide

Reference Elevation	Previous research (m)	Research (2025) (m)
Highest High Water Level (HHWL)	0.81	1.25
Mean High Water Spring (MHWS)	–	1.25
Mean High Water Level (MHWL)	–	0.88
Mean Sea Level (MSL)	0.44	0.69
Mean Low Water Level (MLWL)	–	0.47
Mean Low Water Spring (MLWS)	–	0.17
Lowest Low Water Level	0.00	0.00

As presented in Table 2, differences are observed in several tidal elevation parameters between the 2019 study and the 2025 observations [38, 39]. The Highest High Water Level (HHWL) increased from 0.81 m to 1.25 m, while the Mean Sea Level (MSL) increased from 0.44 m to 0.69 m.

However, these differences cannot be directly interpreted as a long-term sea level rise trend without rigorous statistical analysis, such as time-series trend testing or harmonic tidal analysis over extended observation periods. Variations in tidal parameters may be influenced by short-term oceanographic conditions, seasonal variability, measurement reference differences, or data processing methods.

According to the Intergovernmental Panel on Climate Change (IPCC), global mean sea level rise is typically observed at millimeter-per-year scales under long-term monitoring scenarios. Therefore, further statistical trend analysis using multi-year continuous datasets is required to confirm whether the observed differences reflect long-term sea level change or short-term variability.

Other parameters in Table 2, including the MHWL of 0.88 m, MLWL of 0.47 m, and MLWS of 0.17 m, provide essential design references for characterizing both average and extreme tidal conditions at the study site.

4.2. Climatology (Wind)

The analysis results of this study indicate that the dominant winds originate from the northeast (NE) sector, with the highest frequency of occurrence reaching 32.6%. The east (E) and southeast (SE) directions also contribute significantly to the annual wind distribution. The maximum recorded wind speed reached 10

m/s, while the most frequent wind speeds were in the range of 1.5–2.0 m/s, indicating that wind conditions in the region are generally weak to moderate [40, 41, 42].

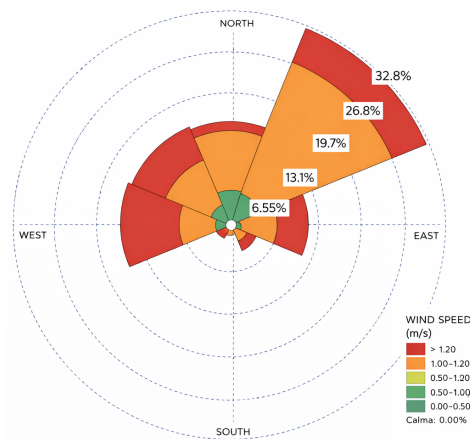


Figure 3. Windrose conditions 2012-2023

As shown in Figure 3, the windrose diagram illustrates the distribution of wind direction and speed in the study area during the period 2012–2023. The dominant wind direction is from the northeast (NE), which also exhibits the highest frequency of occurrence. Winds from the east (E) and southeast (SE) directions are also observed with notable frequencies. In terms of intensity, most wind speeds fall within the range of 1.5–2.0 m/s, while higher wind speeds occur less frequently, indicating generally moderate wind conditions in the area.

4.3. Fetch

The calculations show that the longest fetch occurs in the northeast and east directions, each reaching approximately 200 km, as presented in Table 3. Therefore, these two directions are estimated to be the primary contributors to waves propagating toward the study site. High fetch values were also identified in the northwest (107.76 km) and west (61.03 km) directions. In contrast, the south and southeast directions exhibit relatively shorter fetch distances due to the presence of surrounding land and island barriers, which limit wave development [43, 44].

Table 3. Effective fetch

Directions	Feff (m)	Distance (km)
North	164585.54	164.59
Northeast	200000.00	200.00
East	200000.00	200.00
Southeast	28853.76	28.85
South	26416.78	26.42
Southwest	31312.69	31.31
West	61033.07	61.03
Northwest	107755.84	107.76

4.4. Wave Return Period

The analysis shows that using a wave height of 1.4 m as a design reference is an appropriate and conservative approach, as summarized in Table 4. This value is derived from extreme value statistical analysis using the Weibull distribution and is supported by consistent field observation data. The selection reflects a balance between structural safety and practical design efficiency, ensuring that the adopted parameter is neither underestimated nor excessively overdesigned. By incorporating probabilistic considerations of wave occurrence, this approach enhances the reliability of the design basis under varying hydrodynamic conditions.

Therefore, it provides a robust foundation for determining the design parameters of coastal protection structures and supports long-term evaluation and performance improvement of the structure [45].

The estimation of extreme wave heights was performed using the Weibull distribution, which is commonly applied in extreme value analysis for coastal and ocean engineering. The cumulative distribution function (CDF) of the Weibull distribution is expressed as:

$$F(H) = 1 - \exp \left[- \left(\frac{H}{\alpha} \right)^\beta \right] \quad (1)$$

where H is the wave height, α is the scale parameter, and β is the shape parameter. The return period T is related to the exceedance probability P by:

$$T = \frac{1}{P} = \frac{1}{1 - F(H)} \quad (2)$$

The regression values presented in Table 4 were obtained from linearization of the Weibull distribution in logarithmic form. The standard deviation (σ) and standard error were calculated to evaluate the dispersion of the fitted model. The confidence interval for significant wave height was estimated using:

$$H_{sr} \pm 1.28\sigma_r \quad (3)$$

where H_{sr} represents the regression-based significant wave height and σ_r is the regression standard deviation, corresponding approximately to a 90% confidence interval.

Table 4. Wave height with Weibull method return period

Return period	Regression		Stdev normal	Standard deviation	Standard error	Regression	
	The	Hsr (m)				σ_{xr}	σ_{H_s}
2	0.833	1.348	1.598	0.164	0.262	1.013	1.684
5	1.269	1.299	2.146	0.164	0.352	0.848	1.749
10	1.517	1.271	2.481	0.164	0.407	0.750	1.792
25	1.794	1.239	2.865	0.164	0.470	0.638	1.841
50	1.978	1.219	3.125	0.164	0.513	0.562	1.875
100	2.146	1.200	3.364	0.164	0.552	0.493	1.906

As summarized in Table 4, the significant wave heights for different return periods were estimated using the Weibull extreme value model. The results indicate increasing wave height with longer return periods, with intermediate values ranging around 1.27–1.30 m. Based on the regression results and associated confidence bounds, a design wave height of 1.4 m was selected as a conservative yet technically justified parameter, providing an adequate safety margin without leading to excessive structural overdesign.

4.5. Peak Water Level Elevation

The top elevation of coastal protection structures needs to be designed to prevent/reduce water overflow behind the structure of the building that is not permitted to occur (non-overtopping) calculated from the sum of the planned water level elevation, wave creep height and additional height for the free boundary [46]. Based on the conditions of the research area, the layout of the building is behind the edge (not in the deep sea area) so that the determination of the elevation is based on the MHWL for the breakwater structure. Deep sea waves experience breaking waves due to the presence of the breakwater structure so that the determination of the elevation is based on the MSL [47].

4.6. Selection of Breakwater Structure Types on Tidung Island

The selection of a breakwater type in a coastal area is a strategic technical decision because it directly affects shoreline stability, environmental sustainability, and long-term investment efficiency. In Tidung Island, the presence of significant waves, shallow waters, soft subgrade conditions, and environmentally sensitive coastal ecosystems requires a decision-making framework that integrates technical, economic, environmental, and site-specific considerations [48].

To address this complexity, the breakwater type was evaluated using the Analytical Hierarchy Process (AHP) [49]. The AHP model structures the decision problem into hierarchical levels consisting of the objective, criteria, sub-criteria, and design alternatives, enabling systematic weighting of five main criteria: technical aspects, implementation methods, economic factors, environmental impacts, and field conditions [50].

Table 5. Expert Assessment of the Main Criteria

No	Criteria Aspects	Criteria	Score	Level of Importance
1	Technical	Design wave height	4.8	Very important
2	Technical	Dominant direction of waves and wind	4.7	Very important
3	Technical	Tides and sea level elevation	4.6	Very important
4	Technical	Soil conditions and bearing capacity	4.5	Very important
5	Technical	Potential for erosion and sedimentation	4.3	Very important
6	Implementation Method	Suitability of the method to soil conditions	4.2	Important
7	Implementation Method	Risks of marine work	4.1	Important
8	Implementation Method	Availability of tools and materials	4.0	Important
9	Implementation Method	Occupational safety (K3)	4.0	Important
10	Economy	Initial investment costs	4.2	Important
11	Economy	Long-term maintenance costs	4.1	Important
12	Economy	Availability of local resources	3.9	Quite important
13	Environment	Changes in hydrodynamic patterns	4.3	Very important
14	Environment	Coastal ecosystem disturbance	4.2	Important
15	Environment	Impact on surrounding areas	4.0	Important
16	Environment	Construction waste	3.8	Quite important
17	Field Conditions	Geotechnical conditions	4.4	Very important
18	Field Conditions	Project location access	4.0	Important
19	Field Conditions	Topography	3.9	Quite important
20	Field Conditions	Potential for social and environmental disruption	3.8	Quite important

As shown in Table 5, expert assessments indicate that technical aspects, particularly design wave height and dominant wave and wind direction, are considered the most important criteria in the breakwater selection process.

Table 6. Priority assessment based on criteria groups

Aspect	Average score	Ranking
Technical	4.58	1
Environment	4.08	2
Implementation Method	4.08	2
Economy	4.07	3
Field Conditions	4.03	4

As shown in Table 6, technical aspects obtained the highest average score and therefore ranked first in priority. Environmental aspects and implementation methods share the same ranking because their average scores are identical when calculated from expert evaluations. In this study, a tie-ranking approach was applied when equal scores occurred, and the subsequent ranking positions were adjusted accordingly. The ranking is based on the aggregated mean scores prior to AHP weight normalization.

Table 7. Summary of Criteria Weights

No	Criteria	Weight
1	Technical Aspects	0.2450
2	Environmental Impact	0.1970
3	Implementation Method	0.2040
4	Economy	0.1910
5	Field Conditions	0.1630
Total		1.0000

As shown in Table 7, technical aspects have the highest priority, followed by environmental impact and implementation method criteria, indicating the dominant role of technical and sustainability considerations in breakwater selection. Aspects of implementation methods include the suitability of construction methods to field conditions, time and cost efficiency, job risk level, occupational safety, and the availability of tools and materials. Tidung Island's relatively remote location limits the mobilization of heavy equipment, making modular building types that are easy to manufacture on-site and don't require specialized equipment superior.

Economic aspects include initial investment costs, material costs, labor costs, overall construction costs, maintenance costs, and the availability of local resources. These criteria are crucial given that development in island regions requires efficient financial planning to ensure the long-term operational viability of the building.

Environmental impacts include disruption to marine ecosystems, changes in hydrodynamic patterns, carbon emissions, construction waste generation, and potential impacts on coastal tourism activities. As a marine tourism area, Tidung Island requires coastal protection structures that are not only technically stable but also environmentally friendly.

Field conditions include topography, site access, geotechnical conditions, weather and climate, land availability, and potential social disruption. These factors determine the ease of construction and the success of implementation on the ground. In applying the AHP method, ten experts were asked to perform pairwise comparison assessments of criteria and alternatives. Assessments were given using a numerical scale indicating the relative importance of each element in the hierarchy. These scores were then compiled into a comparison matrix, and eigenvector values were calculated to determine the priority weights for each criterion.

To ensure the reliability of the results, consistency testing was performed using the Consistency Ratio (CR) calculation. All comparison matrices showed CR values below the tolerance limit, indicating consistent expert assessments and valid use of the data in decision-making. The overall alternatives are then calculated by multiplying the criteria weights by the local alternative weights. This calculation yields a final ranking of breakwater type alternatives according to priority level. The AHP calculation results show that the hollow cube alternative obtained the highest overall score compared to the seawall, tetrapod, and Accropode II. The advantages of the hollow cube are mainly seen in technical, economic, and environmental impact criteria.

Table 8. Selected Alternatives

No	Building Type	Weight
1	Hollow Cube	0.366090
2	Tetrapod	0.292800
3	SeaWall	0.173670
4	Accropode II	0.167440

Based on Table 8, the hollow cube breakwater ranks as the most preferred alternative with the highest weight, followed by the tetrapod, seawall, and Accropode II. This result confirms that the hollow cube offers superior overall performance, particularly in terms of technical reliability, economic feasibility, and environmental considerations for the conditions of Tidung Island.

Table 9. Local Priority Weights of Hollow Cube Alternative Under Each Criterion

No	Criterion	Local Weight
1	Technical Aspects	0.40
2	Environmental Impact	0.35
3	Implementation Method	0.33
4	Economy	0.40
5	Field Conditions	0.34

Based on the local priority weights presented in Table 9, the hollow cube alternative demonstrates strong performance under technical and economic criteria, each obtaining a local weight of 0.40. These values represent the relative performance of the alternative within each individual criterion and are not global criteria weights. Technically, the hollow cube's open structural configuration allows wave energy dissipation through internal cavities, reducing reflection and hydrodynamic pressure while improving adaptability to sea level rise and shallow-water conditions. The modular configuration enhances tolerance to settlement on soft subgrades

by allowing load redistribution and structural adjustment. Economically, local fabrication using simple molds reduces transportation and equipment dependency, thereby lowering initial and maintenance costs. From an environmental perspective, the cavity system provides potential habitat space for marine organisms, supporting ecosystem functionality alongside coastal protection performance.

Based on the results of the analysis of geotechnical conditions and the characteristics of the waters of Tidung Island, the most suitable type of foundation to use is a rock embankment foundation (rubble mound foundation) with a filter layer system. This foundation can distribute the load evenly on the relatively soft subgrade and reduce the risk of differential settlement. Furthermore, the use of a geotextile layer and a graded stone layer acts as a filter to prevent the movement of subgrade particles that can cause structural failure. The suitability of this foundation is also supported by ease of construction, material availability, and flexibility to changing field conditions. Thus, the rockfill foundation is considered the safest, most economical, and most realistic for implementation on Tidung Island.

5. MANAGERIAL IMPLICATIONS

The results of this study provide important managerial implications for coastal planners, local governments, and project managers involved in coastal protection on small islands. The AHP-based framework developed in this research offers a systematic and transparent decision-support tool that integrates technical, environmental, economic, construction, and field condition criteria, enabling more objective and evidence-based breakwater selection. The identification of a hollow cube breakwater as the preferred alternative highlights the managerial need to prioritize modular, adaptive, and cost-efficient structures that are compatible with shallow waters, limited access, and local material availability. Furthermore, the findings emphasize that environmental considerations should be embedded as a core managerial priority throughout the planning and implementation stages to ensure long-term coastal resilience, protect marine ecosystems, and support the sustainability of coastal communities and marine tourism activities.

6. CONCLUSION

The selection of a hollow cube-type breakwater with a filter-coated rockfill foundation provides an evidence-based solution for coastal protection on Tidung Island. The structure demonstrates technical reliability in reducing wave energy and mitigating coastal abrasion while maintaining cost efficiency and adaptability to shallow waters and soft subgrade conditions. The integration of structural performance, environmental considerations, and economic feasibility confirms that the hollow cube alternative achieves the highest priority within the AHP framework.

This study contributes scientifically by developing a systematic multi-criteria decision-making model that integrates hydro-oceanographic analysis and expert judgment for breakwater selection in small island contexts. The proposed framework offers a replicable decision-support approach for coastal regions with similar physical and environmental characteristics, strengthening the methodological foundation for sustainable coastal infrastructure planning.

This research has strong potential for replication on other small islands in Indonesia that experience similar challenges related to coastal abrasion and limited resources. Common characteristics such as shallow waters, weak subsoil conditions, and sensitive coastal ecosystems make the AHP-based decision-making approach and the selection of modular structures like hollow cubes highly relevant. Therefore, this study not only provides a contextual solution for Tidung Island but also serves as a conceptual and practical reference for developing integrated and sustainable coastal management policies in other island regions with comparable conditions.

7. DECLARATIONS

7.1. About Authors

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7.2. Author Contributions

Conceptualization: BS; Methodology: EK; Software: EK; Validation: BS; Formal Analysis: BS and EK; Investigation: BS and EK; Resources: BS; Data Curation: BS and EK; Writing Original Draft Preparation: BS and EK; Writing Review and Editing: EK; Visualization: BS; All authors, BS and EK, have read and agreed to the published version of the manuscript.

7.3. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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7.5. Declaration of Conflicting Interest

The authors declare that they have no conflicts of interest, known competing financial interests, or personal relationships that could have influenced the work reported in this paper.

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