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The Evaluation of the Coastal Protection Structure at Rangkan Beach, Gianyar Regency

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ABSTRACT: Pantai Rangkan is one of the beaches that has been experiencing abrasion year after year, with a beach length of ±485 meters. Pantai Rangkan has suffered significant damage in the form of shoreline retreat due to continuous wave impacts throughout the year, causing erosion and wave overtopping on revetment structures. In 2022, a tidal flood occurred, with overflow reaching the temple area and the surrounding rice fields. Along a stretch of ±92 meters, there are revetment structures that have been covered by sedimentation, reducing the performance of these revetment structures. Based on these issues, an evaluation was carried out on the coastal protection structures at Pantai Rangkan. The results of the physical condition and performance evaluation of the revetment structures indicate that segments 1, 3, 4, and 5 need to be re-assessed with the current revetment crest elevation (+5.000 m), using wave transformation results with SMS 10.1 software by inputting HWL data (+2.659), H25 (4.057), T25 (6.762), and the dominant wind direction (southeast). The evaluation results for segments 1, 2, 3, 4, and 5 show that the existing revetments are still experiencing wave overtopping necessitating the planning of wave breaker structures.

KEYWORDS: Rangkan Beach, Coastal Protection Structure, Evaluation

I. INTRODUCTION

Bali Island is a province located between Java Island and Lombok Island, with an area of 5,636.66 km² [1]. Bali Island consists of several regencies: Buleleng, Tabanan, Jembrana, Karangasem, Badung, Bangli, Gianyar, Klungkung, and Denpasar as the city [2]. Gianyar Regency is one of the regencies in Bali, with an area of 364.36 km², or about 6.52% of the total area of Bali Island [3]. Gianyar is renowned for its cultural heritage, arts, and scenic landscapes, attracting numerous visitors each year. However, the regency faces significant environmental challenges, particularly coastal abrasion. Coastal abrasion refers to the erosion or reduction of the coastline due to natural forces such as waves, currents, and tides. This phenomenon is notably affecting Gianyar's coastline, with an average of 22.41 km undergoing changes due to abrasion. Rangkan Beach in Ketewel Village is a prime example, experiencing a coastline change rate of 3.57 meters per year [4]. Abrasion is defined as the erosion or reduction of land (coastline) due to wave, current, and tidal activity [5].

Rangkan Beach, situated in Gianyar Regency, stretches over 485 meters. The beach is surrounded by picturesque rice fields owned by local residents, adding to the serene and traditional ambiance of the area. Additionally, Rangkan Beach is home to a Hindu place of worship known as Pura Dalem Rangkan, which holds cultural and religious significance for the local community. To mitigate the impact of coastal abrasion, a coastal protection structure called a revetment has been constructed along Rangkan Beach. A revetment is a slope reinforcement structure built along the coastline to shield the shore from the erosive forces of waves. This structure is designed to absorb and deflect wave energy, thereby preventing further erosion and protecting the land behind it from wave attacks. The implementation of the revetment at Rangkan Beach aims to safeguard both the natural landscape and the local infrastructure, ensuring the preservation of this important coastal area for future generations. [6].

The strong wave impact is one of the factors causing the area to experience abrasion and wave overtopping [7]. Wave overtopping occurs because the wave run-up exceeds the crest elevation of the structure, meaning the crest elevation is lower than the wave run-up [8] [9]. In 2022, a tidal flood reached the temple area and the surrounding rice fields [10]. causing sedimentation to cover 92 meters of the revetment. Sedimentation is the addition of land due to the deposition of sediment carried by currents [11], reducing the performance of the revetment. To address these challenges, ongoing maintenance and potentially redesigning the coastal protection structures may be necessary to ensure they can withstand the dynamic coastal environment and continue to protect the land and infrastructure behind them. Based on these issues, it is necessary to evaluate the revetment structure to determine whether a review or mere monitoring is needed [12]. This evaluation process also uses the Surface-Water Modeling System (SMS) 10.1 software, developed by the Environmental Modeling Research Laboratory (EMRL), to understand wave transformation [13].

Figure 1. The condition of the revetment at Rangkan Beach

II. RESEARCH METHODS

Study Area : Rangkan Beach is located on Jalan Pantai Rangkan, Ketewel, Sukawati District, Gianyar Regency. In this evaluation, it will be divided into 5 segments as shown in Figure 2.

Figure 2. Research location

Research Data: The data used in this research includes, Bali Island map obtained form Google Earth Pro, topographic and bathymetric data obtained from BWS Bali-Penida, wind data obtained from the Era5 website, and tide data obtained from PUPR Department.

Data Analysis Methods : The data used for the evaluation of the revetment at Rangkan Beach consists of both primary and secondary data. This evaluation is divided into 5 segments, with the stages shown in Figure 4. Primary data includes documentation and existing conditions useful for identifying beach damage and assessing the condition and performance of the coastal protection structure. Secondary data used for analyzing waves, wave transformation, fetch, and wind speed.

No	Priority Types	Guidelines
1	Priority A (Extremely prioritized - emergency)	Weigt > 300 (more than three hundred)
2	Priority B (Highly prioritized)	Weight 226 to 300 (two hundred twenty-six to three hundred)
3	Priority C (Prioritized)	Weight 151 to 225 (one hundred fifty-one to two hundred twenty-five)
4	Priority D (Less prioritized)	Weight 76 to 150 (seventy-six to one hundred fifty)
5	Priority E (Not prioritized)	Weight < 75 (less than seventy-five)

Table 1**.** Coastal management priorities

Identification of Beach Damage Assessment and Evaluation of Coastal Protection Structures : The purpose of beach damage assessment is to determine the actual level of damage so that it can serve as a basis for identifying which sections of the coastline should be prioritized for intervention. This is done by weighting the level of damage for each type of damage on a scale from 50 to 250 [12]. With the determination of priority for coastal management, the beach sections are grouped as shown in Table 1.

The evaluation of the condition and performance of the structure is conducted after identifying the beach damage assessment, with the aim of determining the next steps needed for the relevant structure. The evaluation includes assessing two main aspects: the physical condition and the functional performance of the structure. The results will indicate whether the structure is effective or not and will significantly influence the final decision for managing the structure. The weighting of physical components is adjusted based on the type of structure being evaluated, using Table 2.

Table 2. Weighting of the physical components of the structure

Type of structure	Physical component			
	A (Crest)	B (Body)	C (Foundation)	D (Material)
Revetment	30	20	10	40
Toothed revetment/3B	10	30	20	40
Seawall	20	10	30	40
Sheet pile	10	10	40	40
Breakwater	20	20	20	40
Groin	10	10	40	40
Jetty	10	10	40	40

After calculating the index of the physical components, the next step is to calculate the building condition index using equation (1).

$$\text{Building Condition Index} = \frac{\text{Component Value}}{\text{Overall Weight}} \quad (1)$$

In addition to the physical condition of the structure, its functional performance is also evaluated. The functional value can vary but is simplified as 'good' or 'poor, the subsequent actions to be taken are based on two factors: the building condition index and the functional performance of the building. The options include monitoring, maintenance, rehabilitation, and review.

Wave generation : To determine wave height, it is necessary to calculate the wind stress factor (U_A), effective fetch, and sea wind speed, which are plotted into a wind rose. The wind stress factor (U_A) is calculated using equation (2).

$$U_A = 0.71\ x\ U_w{}^{1,23} \quad (2)$$

Fetch is the length of the area over which the wind blows with constant speed and direction [14]. Fetch is calculated using equation (3).

$$Feff = \frac{\sum x_i \cos\alpha}{\sum \cos\alpha} \quad (3)$$

Significant wave height (Hs) and significant wave period (Ts) are calculated using equations (4) and (5).

$$Hs = \frac{0{,}0016\ x \sqrt{\frac{gFeff}{{U_A}^2}}\ x\ {U_A}^2}{g} \quad (4)$$

$$Ts = \frac{0{,}2857\ x \left(\frac{gFeff}{{U_A}^2}\right)^{\frac{1}{3}} x\ U_A}{g} \quad (5)$$

Wave Transformation Simulation using Software 10.1.
After obtaining the wave calculations, the next step is to perform a simulation using SMS 10.1 software with tide data, topographic and bathymetric data, and the results of wave analysis. The final result of the simulation is to determine the wave height at Rangkan Beach. This result will be used as a comparison with the crest elevation of the existing revetment based on the analysis results.

Sea Level Fluctuations: Several parameters are considered in calculating sea level fluctuations, including the rise in water level due to waves, rise in water level due to wind, and global warming. The rise in water level due to waves is calculated using equation (6).

$$S_w = 0{,}19\left[1 - 2{,}82\sqrt{\frac{H_b}{gT^2}}\right] H_b \quad (6)$$

The rise in water level due to wind is calculated using Equation 7.

$$\Delta h = F_c \frac{V^2}{2gd} \quad (7)$$

Global warming is determined based on the graph of projected sea level rise due to global warming, as shown in Figure 3.

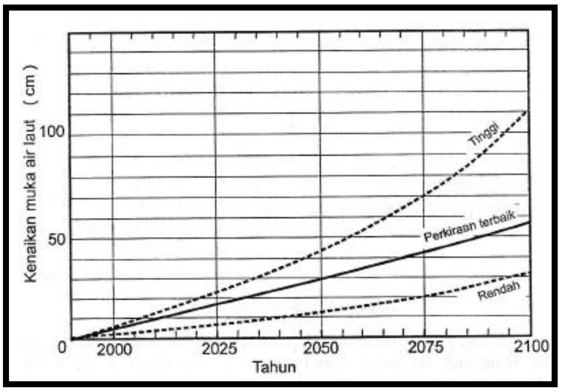

Figure 3. Projected sea level rise due to global warming

Design Water Level (DWL) : Design Water Level (DWL) elevation is calculated to determine the design water level for selecting seawall or revetment structures [15].

$$DWL = \text{Tides} + S_w + \Delta h + sea\ level\ rise \quad (8)$$

Wave Run-Up (Ru) : Wave run-up occurs when the wave run-up exceeds the crest elevation of the structure. The wave run-up is calculated using equation 9.

$$I_r = \frac{tg\theta}{(\frac{H}{L_0})^{0,5}} \quad \text{.......(9)}$$

Revetment Crest Elevation
The crest elevation of the revetment is calculated using Equation 10.

Elevation Revetment = DWL + Ru + Fb ....(10)

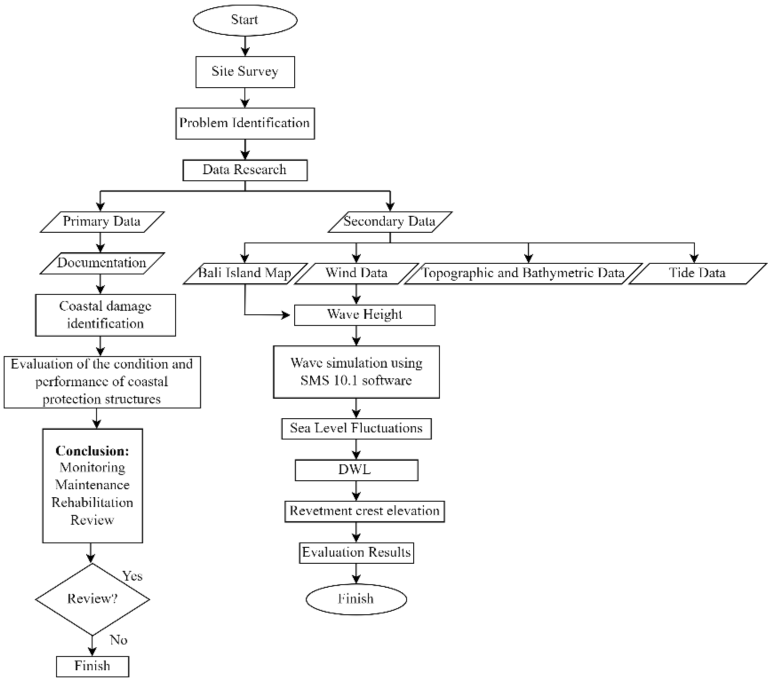

Figure 4. Research flow diagram

III. RESULT AND DISCUSSION

The results of the revetment evaluation through beach damage assessment and the evaluation of physical condition and performance of the structure will be presented in the following table.

Beach Damage Assessment : Based on the Table 3, each damage weight was multiplied by the importance coefficient of 1.00. As a result, the priorities for handling based on environmental damage are as follows: Segments 1 (0-90 m), segment 4 (291-388 m), and segment 5 (388-485 m) have a priority of D (low priority), Segments 2 (97-194 m) and segment 3 (194-291 m) have a priority of C (moderate priority). For erosion/abrasion damage: Segments 1 (0-90 m), segment 4 (291-388 m), and segment 5 (388-485 m) have a priority of B (high priority). Segment 2 (97-194 m) has a priority of C (moderate priority). Segment 3 (194-291 m) has a priority of A (very high priority).

Table 3. Beach damage assessment

Damage Weight	Type of Damage		Total	Priority Handling Scale
	Environment	Erosion/Abrasion and Building Damage		
250		Segment 1-5	300	B
200		Segment 3	250	C
150	Segment 3		450	A
100	Segment 1,3,4,5		300	B
50	Segment 1,2,4,5	Segment 1,4,5	300	B

Evaluation of Physical Condition and Functional Performance of the Structure : The evaluation of the building's condition and performance (Table 4) reveals varied results across different segments. Segment 1 is assessed to be in good physical condition, while segments 3, 4, and 5 are all deemed to be in fairly good physical condition. However, the functional performance across all segments is consistently rated as poor. Due to these findings, the recommended action for all segments is to conduct a review to address the identified issues. This suggests that while the structural integrity of most segments is relatively stable, there are significant functional deficiencies that need to be addressed to improve overall performance.

Table 4. Evaluation of physical performance structure

Evaluation of Building Condition and Performance	**Segment**			
	1	**3**	**4**	**5**
Physical Condition	Good	Fairly Good	Fairly Good	Fairly Good
Function Performance	Poor	Poor	Poor	Poor
Recommended Actions	Review	Review	Review	Review

Wave Analysis Results : The first step in wave analysis is to create a wind rose to identify the dominant wind direction at the study location.

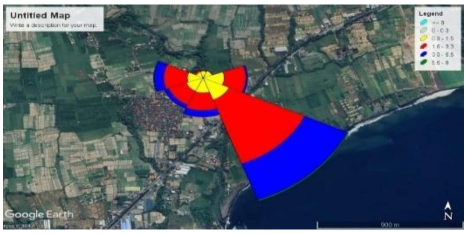

Figure 5. Windrose

Based on the wind rose results, it can be observed that the constant wind direction at Rangkan Beach is from the southeast. As shown in Figure 5, the wind direction is referenced at 0°, increasing every 6° up to 42°. If the fetch angle does not encounter land or islands, the fetch length at that angle is considered to be 1000 km.

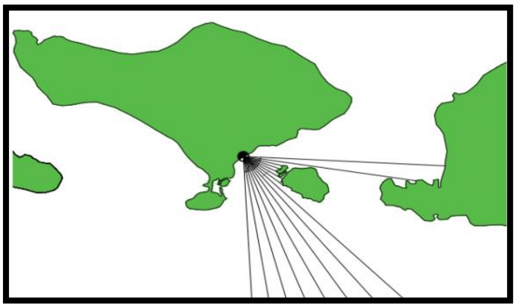

Figure 6. Fetch at Rangkan Beach

$$F_{eff} = \frac{\sum Xi.\cos\alpha}{\sum \cos\alpha}$$

$$F_{eff} = \frac{7463{,}68}{13{,}510}$$

$$F_{eff} = 552{,}42 \text{ km} = 552418{,}58 \text{ m}$$

Afterwards, the significant wave height and significant wave period, calculated using Equations (4) and (5), are presented in Table 5.

Table 5. Recapitulation of significant wave height and period

No	Year	Direction	U10 (m/dt)	UA (m/dt)	F_{eff} (m)	Hs (m)	Ts (dt)
1	2014	Southeast	6.314	9.775	552418.6	3.712	11.534
2	2015	Southeast	6.203	9.632	552418.6	3.657	11.231
3	2016	Southeast	5.714	9.006	552418.6	3.419	10.884
4	2017	Southeast	5.729	9.036	552418.6	3.431	10.643
5	2018	Southeast	5.815	9.142	552418.6	3.48	11.168
6	2019	Southeast	7.17	10.802	552418.6	4.101	10.899
7	2020	Southeast	6.527	10.043	552418.6	3.813	11.308
8	2021	Southeast	5.598	8.899	552418.6	3.379	11.001
9	2022	Southeast	6.006	9.384	552418.6	3.563	10.927
10	2023	Southeast	6.147	9.59	552418.6	3.641	10.79
Total (∑)						**36.196**	**110.385**

Results of Wave Simulation Using SMS 10.1 Software :

After inputting the data: highest water level elevation (HWL) = +2.659 m, wave height = 4.107 m, wave period = 6.759 s, and wind direction = southeast, Figure 7 shows the results of wave transformation using the CMS-Wave model. Observation lines are created at each segment to analyze the wave transformation.

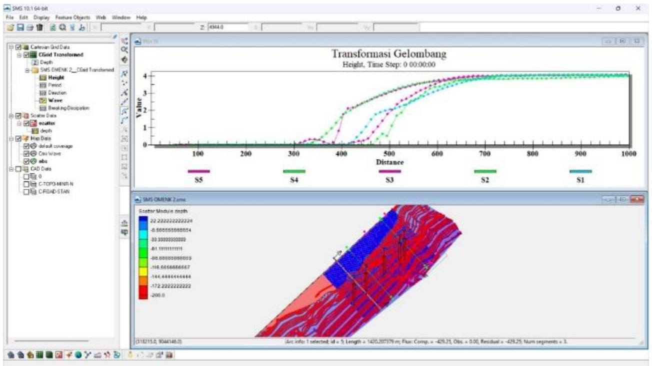

Figure 7. Wave transformation results

The results of the wave transformation in Figure 7 show the wave height at the existing revetment. This data is summarized in Table 6.

Table 6. Wave height at the existing revetment structure

Segment	Wave Height (m)
S5	1.460
S4	1.264
S3	1.384
S2	1.685
S1	1.454

The existing wave height results will be used to calculate the wave run-up using Equation (9). The run-up results will then be applied to calculate the crest elevation of the revetment, as shown in Table 7.

Table 7. Recapitulation of the crest elevation of the revetment for each segment

Segment	Sw	Ah	SLR	DWL	Ru	Fb	Revetment Elevation
S1	0.11	0.53	0.29	3.589	1.709	0.5	5.798
S2	0.11	0.53	0.29	3.589	1.853	0.5	5.942
S3	0.11	0.53	0.29	3.589	1.660	0.5	5.749
S4	0.11	0.53	0.29	3.589	1.567	0.5	5.656
S5	0.11	0.53	0.29	3.589	1.679	0.5	5.768

Table 8. Results of the existing evaluation

Segment	Revetment Crest Elevation		Result
	Existing	Recalculation	
S1	5.000	5.798	Overtopping
S2	5.000	5.942	Overtopping
S3	5.000	5.749	Overtopping
S4	5.000	5.656	Overtopping
S5	5.000	5.768	Overtopping

Based on Table 8, it can be seen that overtopping occurs in segments 1, 2, 3, 4, and 5 because the crest elevation of the existing revetment is at +5.000.

IV. CONCLUSION

The evaluation of the revetment structure at Rangkan Beach in Gianyar Regency, Bali, indicates several critical findings. Despite the physical condition of the segments being generally good to fairly good, the functional performance of all segments is consistently rated as poor. This discrepancy highlights significant functional deficiencies in the existing coastal protection measures. Wave analysis and subsequent simulations reveal that the crest elevation of the existing revetment is insufficient to prevent overtopping, with all segments experiencing overtopping due to wave run-up exceeding the crest elevation. The calculated revetment crest elevations needed to prevent overtopping are significantly higher than the existing +5.000 meters. Given the consistent poor functional performance and the occurrence of overtopping across all segments, it is recommended that a comprehensive review and subsequent actions be undertaken. This review should focus on enhancing the revetment structure to improve its functional performance and prevent overtopping, thereby ensuring better protection for the coastline, surrounding agricultural lands, and religious sites.

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