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Characteristics of Seawall Design for Coastal Protection At Laompo Beach, Indonesia

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ABSTRACT: This research presents an evaluation of the design and stability of a seawall at Laompo Beach, Sulawesi, Indonesia, to protect a nearby highway from coastal erosion. Preliminary dimensions with some secondary data on wind, tidal, and soil bathymetric data have been carried out. This includes a wall height of 4 m, foundation width of 2.8 m, foundation height of 0.7 m, and top embankment width of 1 m. The stability analyses using the limit equilibrium method indicate that the embankment satisfies the safety criteria under static, dynamic, and scour conditions. The research highlights the importance of precise design considerations, including wave forecasting and stability analysis, for constructing durable seawalls. This paper emphasizes overall coastal engineering to reduce the effects of erosion on critical infrastructure and the need for high-quality construction and maintenance to ensure the long-term efficacy of these structures, providing valuable guidance for developing safe and effective coastal protection measures. This work is singular, as the advanced geotechnical analysis tools have been implemented in the context of a real-world coastal protection scenario in a developing region.

KEYWORDS: Abrasion, Seawall, coastal erosion, coastal engineering, coastal protection, Laompo Beach

I. INTRODUCTION

Ocean engineering is a pivotal sub-discipline in the field of civil engineering, which emphasizes structures and systems that function in marine environments in terms of designing, developing, and maintenance (Agustan et al., 2024). Coastal abrasion, a process driven by the mechanical wearing down of coastal areas due to factors like waves, wind, and currents, has significant implications for society. Human activities can exacerbate coastal abrasion, further contributing to the loss of coastal resources and the need for sustainable coastal management practices (Hamid et al., 2021). Dynamic phenomena such as wind-driven sea waves are major contributors to coastal erosion and abrasion, highlighting the importance of understanding and mitigating these processes to safeguard coastal environments (Ruby et al., 2023). Coastal abrasion can also be influenced by factors such as coastal geometry, wave parameters, soil sediment, and vegetation cover, highlighting the complex interactions that shape coastal landscapes (Gianluigi et al., 2023; Margarita et al., 2021). The seasonality of coastline retreat and the impact of environmental factors underscore the need to consider the simultaneous processes of thermo-denudation and thermo-abrasion in understanding coastal erosion dynamics (Alisa et al., 2021; S. Alberti et al., 2022).

Designing an effective and stable seawall involves addressing various challenges to ensure durability and performance. One critical aspect is considering load factors, ecological impact, and recent advancements in materials science when designing concrete seawalls (Hosseinzadeh et al., 2021). The choice of materials and construction methods significantly influences the stability and longevity of seawalls (Nima et al., 2022). Safety factors against overturning are vital in the design and stability analysis of concrete seawalls, particularly concerning earthquake forces (Mohit & Chatterjee, 2022). Ensuring adequate safety margins is crucial for the seawalls to withstand external forces and maintain stability over time (Maryam et al., 2023).

Laompo Beach is one of the beaches located in Laompo Village (Figure 1), Southeast Sulawesi, Indonesia. The highway at Laompo Beach is threatened by abrasion due to extreme waves and does not yet have a safety structure. If not handled immediately, abrasion can damage the road body. The construction of effective coastal structures is very necessary to overcome abrasion or erosion. This study was conducted to determine the dimensions of the Laompo Beach safety structure that are appropriate to protect the function of the road and the stability of the coastal building due to the workload. It is expected that this study will be one of the alternatives that can be used by the government and related parties regarding the type of safe and effective coastal abrasion protection.

II. RESEARCH METHOD

A. ***Data collection***

In conducting the analysis, several supporting data are needed to obtain optimal analysis results, these data include:

1. wind data,
2. tidal data,
3. bathymetry map,
4. and soil data.

B. ***Preliminary analysis***

1. Wave forecasting:

Wind data (direction and speed), wave height, and breaking wave height are used to forecast waves. Effective fetch can be calculated using Saville’s Method. Wave forecasting is conducted by entering the fetch and wind stress factor (UA) into the wave forecast graph to determine the wave height and period (Triatmodjo, 2001).

2. Seawall crest elevation:

The elevation of the sea wall crest is determined based on the bathymetric map and wave forecast results.

C. ***Load Calculation***

The types of loads that work on the seawall structure and will affect stability are active earth pressure, passive earth pressure, seawall structure weight, wave load, and uplift pressure. All loads will work in static and dynamic conditions. (Das & Ramana, 2011; Raswitaningrum, 2019).

D. ***Stability Analysis***

Among several commonly used slice methods (Bishop, 1955; Janbu, 1973; Morgenstern & Price, 1965; Spencer, 1967), this study used the Spencer method because it accommodates the balance of forces and moments in calculating the safety factor (Ngii et al., 2023).

E. ***Location & Existing Condition***

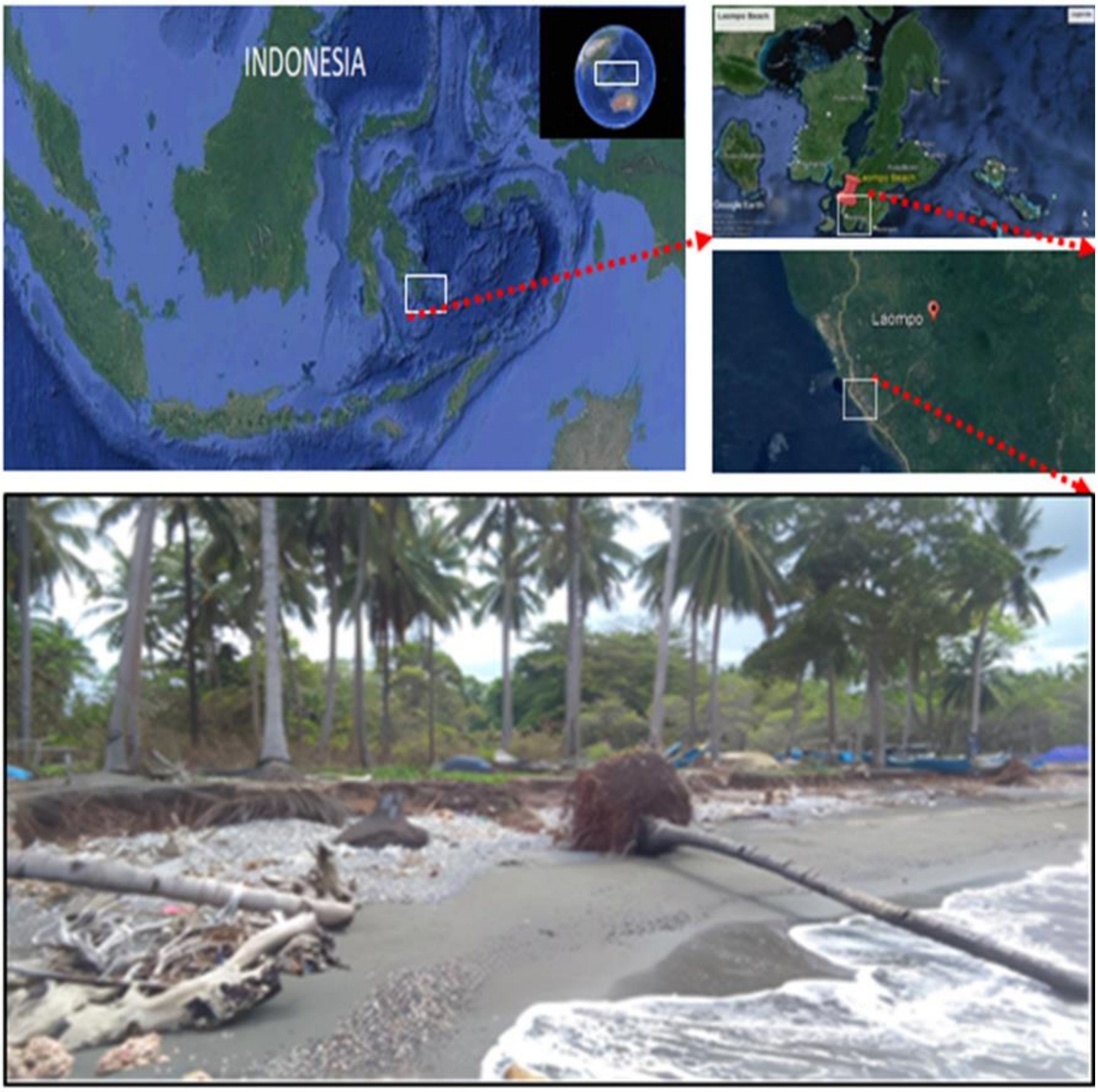

Figure 1. The existing condition of Laompo Beach

III.RESULT AND DISCUSSION

A. Analysis of Wind Data and Wave Forecasting

1. Windrose

In analyzing and drawing the wind rose, wind speed and direction data from 2013-2022 will be used, obtained from NOAA wind data at the BMKG (Indonesian Meteorology, Climatology and Geophysics Agency) Class III Betoambari Meteorological Station. Windrose is used to determine the velocity and direction of the dominant wind acting on the seawall. Shown in Table 1 & Figure 2

Table 1. Wind Data

Number and Percentage of Daily Maximum Wind Occurrences at Class III Betoambarai – Baubau Meteorological Station 2013 - 2022												
Wind direction	Number Of Wind Events						Percentage Of Wind Events (%)					
	Wind Speed Interval (m/s)					amount	Wind Speed Interval (m/s)					amount
	≤ 2	2.1-4	4.1-6	6.1-8	≥ 8.1		≤ 2	2.1-4	4.1-6	6.1-8	≥ 8.1	
North	3	0	0	0	0	3	0,08	0,00	0,00	0,00	0,00	0,08
Northeast	11	26	1	0	0	38	0,30	0,71	0,03	0,00	0,00	1,04
East	81	568	513	3	0	1165	2,22	15,55	14,05	0,08	0,00	31,90
Southeast	153	657	300	2	0	1112	4,19	17,99	8,21	0,05	0,00	30,45
South	138	90	0	0	0	228	3,78	2,46	0,00	0,00	0,00	6,24
Southwest	146	150	7	0	0	303	4,00	4,11	0,19	0,00	0,00	8,30
west	136	376	134	4	1	651	3,72	10,30	3,67	0,11	0,03	17,83
Northwest	33	88	30	1	0	152	0,90	2,41	0,82	0,03	0,00	4,16
There is Wind						3652						100
No Wind (Calm)						0						0
Amount						3652						100

2. Effective Fetch

One of the factors causing waves is caused by wind speed and the direction of the wave generation. Fetch is the length of the area where the wind blows at a constant speed and direction. This fetch will be used to determine the wave height (H) and wave period. The fetch at the research location is shown in Figure 3. From the analysis results, the Fetcheff is 25,716 m and the wind speed value is 5.297 m/s

3. Breaking Wave

The seabed slope is obtained m = 0.041644; H_0 = 0.516 m; T_p = 5.132 sec; and K_r = 0.982; L_0 = 41.0863 m; wave height (depth -1 m) H_1 = 0.798 m. The breaking wave height (H_b) based on Equation 9 = 0.6523 m and the breaking wave depth (d_b) based on Equation 10 = 0.6396 m.

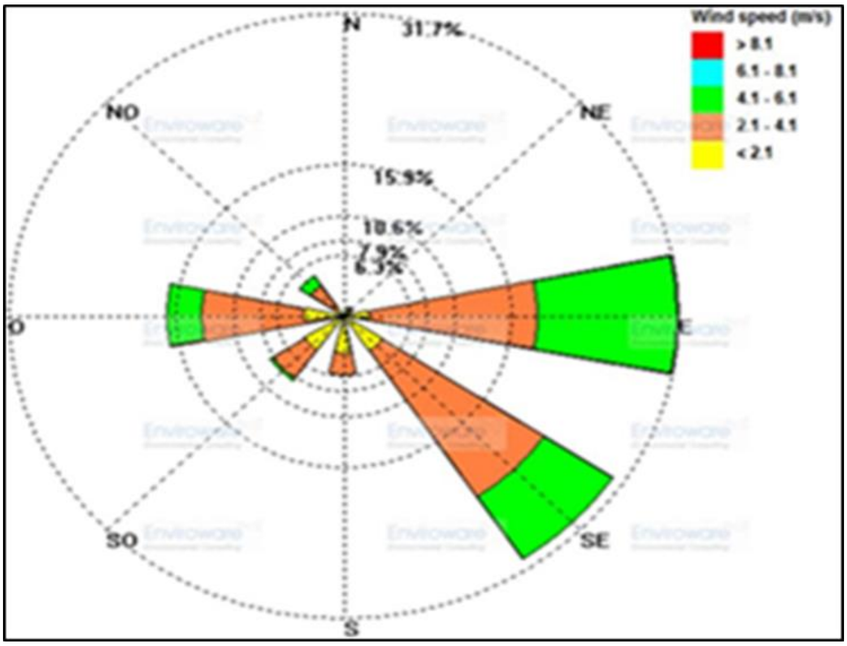

Figure 2. Windrose

B. *Designed Sea Level Elevation*

The factors that influence the design of seawater level elevation are the results of the tidal survey. The seawall crest elevation is 4 m and the breakwater height from the seabed is 3 m (seabed elevation -1 m).

C. *Stability Analysis*

The preliminary dimensions and forces on the seawall can be seen in Figure 4. The results of the soil investigation at the seawall location obtained a cohesion (c) value of 0.52 kPa; an internal friction angle (ϕ) of 25.7° and a unit weight (γ) of 14 kN/m3. Based on these data, the value of the coefficient of lateral earth pressure are $K_a = 0.30$; $K_{ae} = 0.58$; $K_p = 3.32$; $K_{pe} = 2.34$. Stability analysis was conducted under several conditions, namely non-earthquake conditions (static), earthquake conditions (dynamic), and conditions when erosion occurs both in static and dynamic conditions. The erosion was simplified by removing the soil in front of the seawall so that the passive earth pressure became zero. The entire analysis was conducted at MSL water level conditions. The results of the internal stability analysis can be seen in Table 2. The results of the analysis show that all safety factors in all analysis conditions meet the required safety factor. The scouring condition during the earthquake experienced a significant decrease in the safety factor of up to 64%. This shows the importance of taking scouring into account in the analysis of water structures located in the sea or rivers. Scouring will eliminate passive earth pressure that will reduce the resisting force, which can cause a decrease in the safety factor (Nayono et al., 2020).

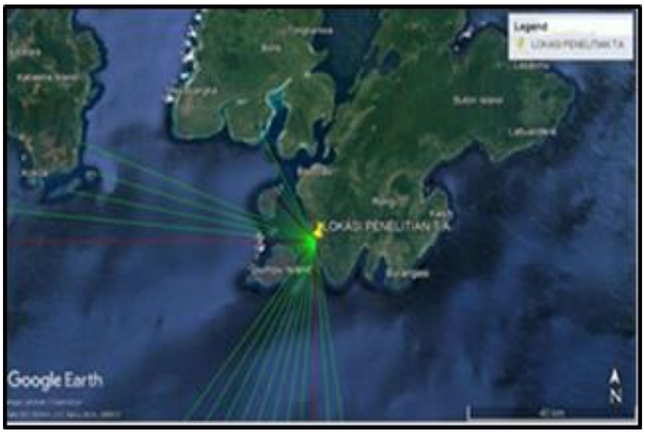

Figure 3. Fetch

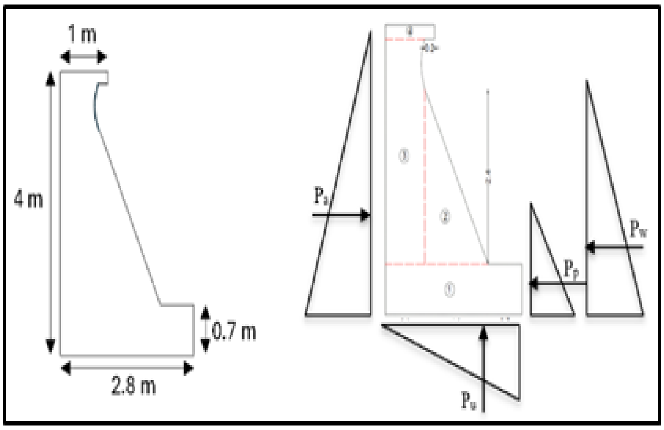

Figure 4. Seawall dimension

Table 2. Stability Analysis Result

Analysis type	Description	Force (kN)	Moment (kN.m)	Safety factor		
				Sliding	Overturning	Bearing capacity
Static	Active force	33.71	44.94	4.65 > 1.5	4.11 > 2	5.65 > 3
	Passive force	9.64	3.21			
	Water pressure	5.01	9.16			
	Uplift pressure	21.53	20.09			
	Self-weight	136.40	255.20			
Dynamic	Active force	57.26	76.34	1.90 > 1.1	2.76 > 1.1	3.1 > 1.1
	Passive force	5.94	1.98			
	Water pressure	5.01	9.16			
	Uplift pressure	21.53	20.09			
	Self-weight	136.40	255.20			
Scouring - Static	Active force	33.71	44.94	3.07 > 1.5	4.06 > 2	3.40 > 3
	Passive force	0	0			
	Water pressure	5.01	9.16			
	Uplift pressure	21.53	20.09			
	Self-weight	136.40	255.20			
Scouring - Dynamic	Active force	57.26	76.34	1.69 > 1.1	2.74 > 1.1	1.75 > 1.1
	Passive force	0	0			
	Water pressure	5.01	9.16			

	Uplift pressure	21.53	20.09			
	Self-weight	136.40	255.20			

Table 3. Result of Overall Stability Analysis

Water level	Static	Dynamic	Static - Scouring	Dynamic - Scouring
LWL	2.127	1.294	1.637	1.267
MSL	2.544	1.541	1.972	1.325

Overall stability analysis was performed under LWS and MSL conditions. The results of the slope safety factor analysis under various conditions can be seen in Table 2 & Table 3. The analysis results show a decrease in the safety factor during earthquake conditions with scouring. The safety factor value at MSL conditions tends to be greater than at LWL conditions. This is because the water pressure on the seawall surface becomes an additional retaining force for the seawall, which increases the overall safety factor. Although MSL conditions increase the safety factor, the long-term effect of water impact on the seawall surface can cause a decrease in the strength of the seawall material, which can affect the stability of its structure. Therefore, good quality work is very important to ensure that the seawall can survive according to its planned life.

IV. CONCLUSION

Coastal abrasion, driven by natural forces like waves, wind, and currents, is a significant threat to coastal areas, exacerbated by human activities. This study underscores the complexity of coastal erosion dynamics, influenced by factors such as coastal geometry, wave parameters, and sediment composition. Understanding these interactions is crucial for effective coastal management and the design of protective structures. At Laompo Beach, the research highlights the importance of precise design considerations, including wave forecasting and stability analysis, for constructing durable seawalls. While seawalls can effectively protect against erosion, challenges like scouring during earthquakes can compromise their stability. The study emphasizes the need for high-quality construction and maintenance to ensure the long-term efficacy of these structures, providing valuable guidance for developing safe and effective coastal protection measures.

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