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Study of Kintom Coastal Safety *Structure*, Central Sulawesi, Indonesia

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ABSTRACT: Kintom Beach is one of the beaches in Banggai Regency, Central Sulawesi, which directly faces the Peling Strait. The problems that occur are the retreat of the coastline and high tidal waves that endanger residents and damage existing public facilities. The purpose of this study is to plan a coastal protection structure in the form of a sea wall. The methodology used with several stages as follows: The Least Square Method is used to obtain tidal constants. Wind data is used to predict wave height and direction . Based on wind speed, wind duration and effect, wave forecasting is carried out. The design wave is calculated using the Gumbell Method. The coastal protection structure in the form of a sea wall is designed based on the results of data analysis. The results of this study are: design wave (Hs)25 = 2.51 and design wave period (Ts)25 = 6.16; breaking waves at a depth of 4.0 to 5.3 m; design sea level elevation (DWL) = +0.92; elevation of the sea wall crest face = +3.75; seawall slope 1:1.5; seawall made of river stone masonry covered with reinforced concrete; seawall toe protection made of bare stone/rip rap at elevation -1.77

KEYWORDS: Wind, Waves, Tides, Sea Wall, Kintom Beach

I. INTRODUCTION

Indonesia is the largest archipelagic country in the world with a potential territory consisting of 17,480 islands with a sea area of 5.8 million km ^{2} and has the fourth longest coastline in the world, namely 95,181 km, has a very high level of risk of abrasion, especially considering that more than 60% of the Indonesian population lives in coastal areas [1], [2]. Kintom Beach is a beach in Banggai Regency, Central Sulawesi, facing the Peling Strait. The problems include shoreline retreat and high tides, endangering residents and damaging public facilities.

The Kintom Beach area is home to Tangkiang Harbor, which is used by local residents for transportation between the surrounding islands. It also serves as a mooring point for fishing boats. Parallel to Kintom Beach is the Luwuk-Palu provincial road, which is strategically located for land transportation. Therefore, Kintom Beach needs to be protected from the dangers of tidal waves and shoreline retreat. Selecting the type of coastal protection structure based on aesthetic, technical, and environmental considerations is essential for optimal results. Therefore, a sea wall was chosen, made from locally sourced materials. The use of local materials is highly feasible due to their availability in sufficient quantities and their technical requirements.

The aim of this research is to plan a coastal protection structure in the form of a sea wall at Kintom Beach, Banggai Regency.

II. MATERIAL AND METHODS

A. Description of Study

The research location is at Kintom Beach, Kintom District, Banggai Regency, Central Sulawesi Province, with coordinates 122 ˚ 37'43.1" east longitude and 1 ˚ 12'08.0" south latitude. The research location is shown in the following image:

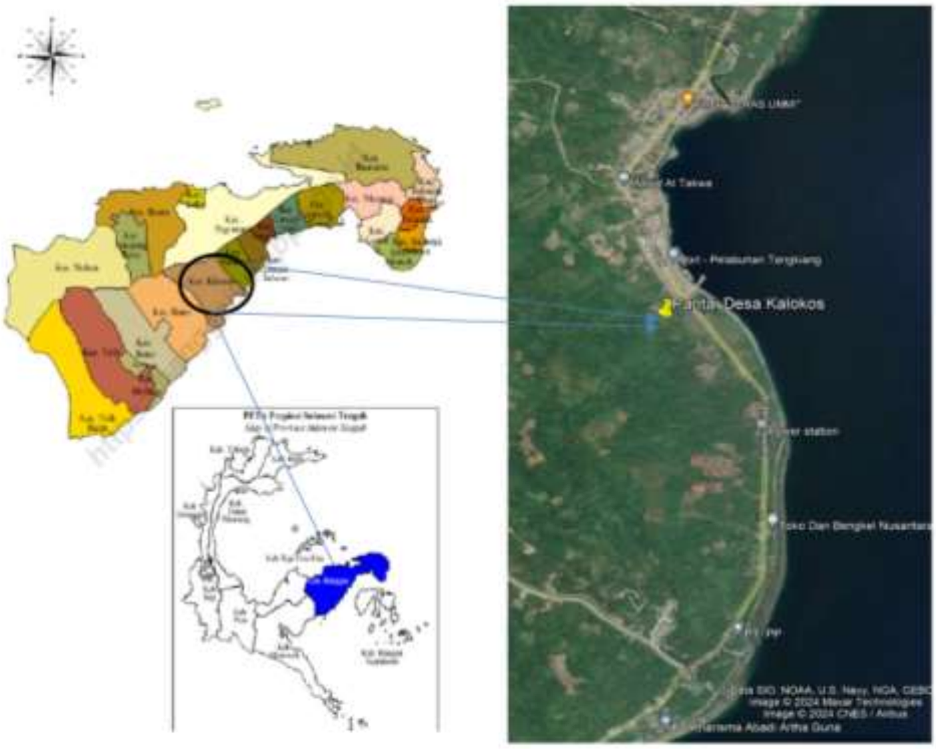

Figure 1. Research location

B. Data Sources

Topographic and bathymetric data were obtained from the Public Works and Spatial Planning Office of Banggai Regency. Tide data were obtained from (https://srgi.big.go.id/tides/tgkg), this data was obtained from the Tangkiang Port tidal station . Complete data is available from August 15, 2023, to August 29, 2023. Wind data was obtained from the Syukuran Aminudin Amir Airport Station, Luwuk, with an observation period of 2014 to 2023.

C. Research Methods

The Least Squares Method was used to obtain tidal constants. Wind data was used to predict wave height and direction . Based on wind speed, wind duration, and effect, wave forecasting was performed. Design waves were calculated using the Gumbell Method. Coastal protection structures in the form of sea walls were designed based on the results of the data analysis. The complete research method is presented in the following figure:

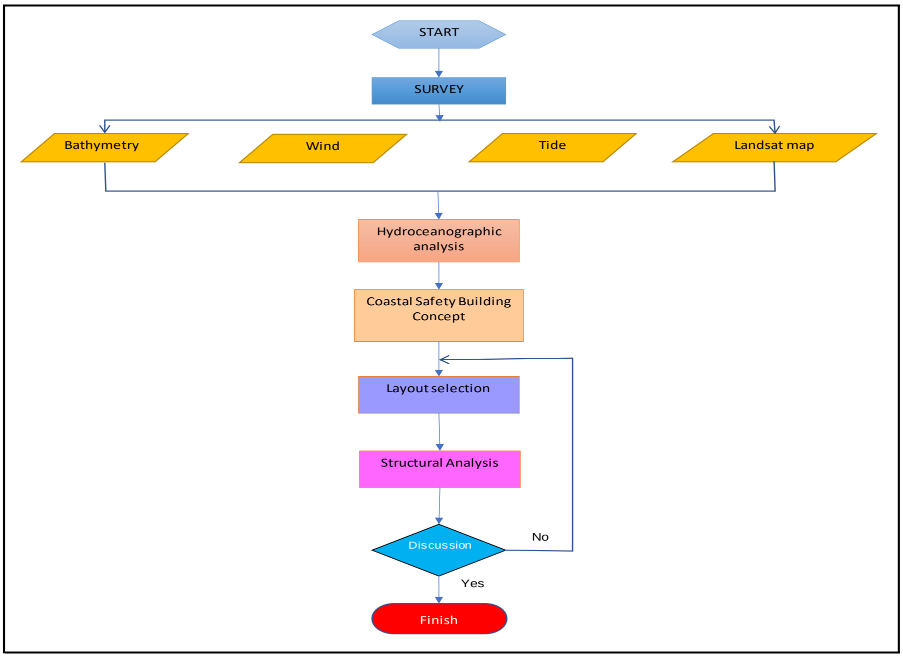

Figure 2. Research Flowchart

Tidal

The Least Square Method is used to obtain tidal constants used in determining tidal types and sea level [3]elevation [4]

Wind velocity

For wave forecasting purposes, wind speed is used at a height of 10 m. If the wind speed is not measured at this height, it must be corrected using the following formula [5]:

$$U(10) = U(y)\left(\frac{10}{y}\right)^{\frac{1}{7}} \quad (1)$$

Wind measurements on land are usually conducted at airports (airfields). Therefore, it is necessary to transform the wind data over land closest to the study location to wind data over sea level. The relationship between wind over sea and wind over the nearest land is given by RL = Uw/UL as shown in Figure 3 .

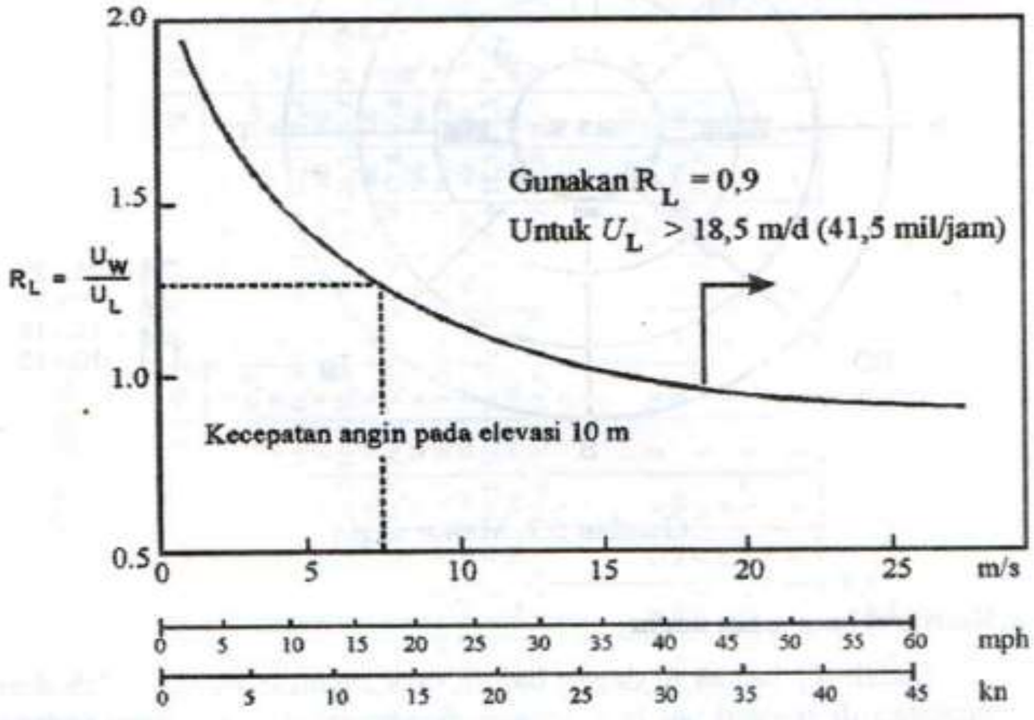

Figure 3. Relationship between wind speed at sea and on land
Source: [5]

After carrying out various wind speed conversions as explained above, the wind speed is converted to a wind stress factor using the following formula:

$$U_A = 0.71\, U^{1.23} \quad (2)$$

Where U is the wind speed in m/s.

Fetch

In the study of wave generation at sea, the effective frequency is limited by the shape of the land surrounding the sea. In the wave-forming zone, waves are generated not only in the same direction as the wind but also at various angles to the wind direction. The average effective frequency is given by the following equation: [6].

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

Wave Plan

Based on wind speed, wind gust duration and frequency, wave forecasting is carried out using the graph in Figure 4 .

In addition, significant waves and significant wave periods can be calculated with the following equation [7]:

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

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

To determine the return period, analysis of extreme wave height values is used, typically taking the highest wave each year. One way to analyze this data is to use the Gumbel method as follows:

$$H = \frac{\sum Hs}{n} \quad (6)$$

$$\sigma H = \sqrt{\frac{\sum (Hs - Hs)^2}{n-1}} \quad (7)$$

$$HT = Hs + (\sigma H/\sigma n)\,(YT - Yn) \quad (8)$$

$$T = 0.33 \times (HT / 0.0056)^{0.5} \quad (9)$$

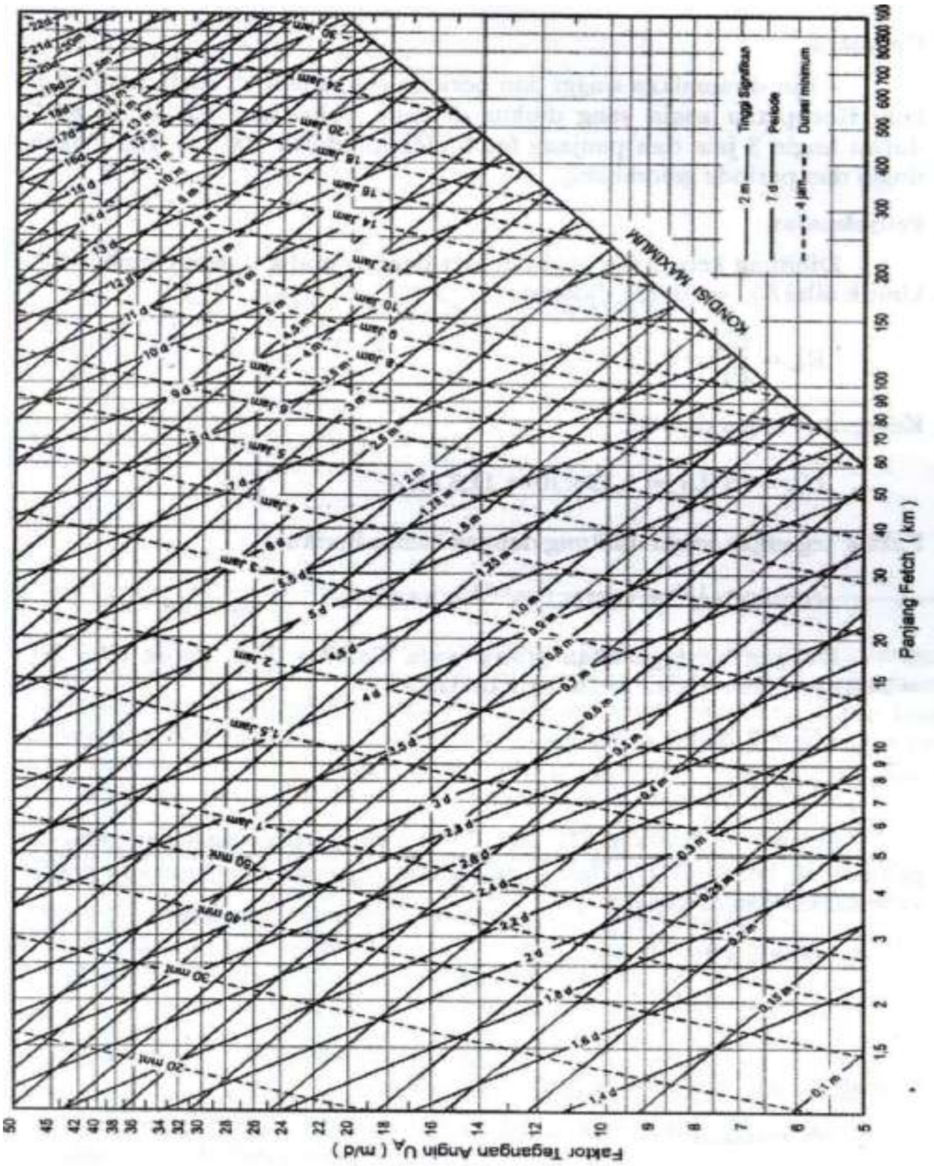

Figure 4. Wave Forecasting Graph

Waves at the Structure Site

When waves travel from the sea to the beach, where the coastal protection structure will be built, the wave height changes. This change is caused by, among other things: the process *of refraction. Shoaling, Diffraction* and *Wave Breaking.* These four processes cause wave heights to increase or decrease. Therefore, the design wave height to be used at the research site must be reviewed in light of these processes. The selected design wave height is the maximum wave height possible at the research site.

To determine the wave height caused by this process, it can be calculated using the following formula:

Kr = Refraction coefficient = (Cos α0 / Cos α1)^0.5 (10)

Ks = Shoaling Coefficient = ((no x Lo) / (nx L))^0.5 (11)

Where :

α_0 = angle of incidence of wave (^{0}), α_1 = angle of incidence of shallow wave (^{0}), Co = Wave speed (m/sec), C_1 = Shallow wave speed (m/sec), Co = Lo/Ts, $C_1 = L_1$ /Ts, L_1 = wavelength in shallow water (m), Ts = significant wave period (seconds)

Design wave height

At relatively shallow depths, the design wave is determined based on the maximum wave height occurring in the area. To determine this wave height, the breaking wave height is approximated. The calculation is as follows [5]:

1). The beach is considered horizontal

This method is less precise and is crude, because it does not take into account the slope of the beach, the planned wave height is calculated as follows:

$$Hd = 0.78\ db \qquad (12)$$

Where: Hd = Planned wave height (m), db = Depth at Structure location (m)

2). Take into account the beach slope

Compared to the first one, this method is more precise where the planned wave is calculated as follows:

$$Hd = Hb = \frac{ds}{\beta - m.\sigma p} \tag{13}$$

Where: Hd = design wave height (m), Hb = breaking wave height (m), ds = depth of Structure toe (m), β= db/Hb, σp = 4.0 to 9.25 m , m = slope (V : H)

The values βused in the equation above cannot be used directly before the Hb value is obtained. Using the values βin Figure 5 and the graph in Figure 6 , the Hb value can be determined. To simplify the calculation, a graph is provided for calculating Hb directly, namely using the graph in Figure 7.

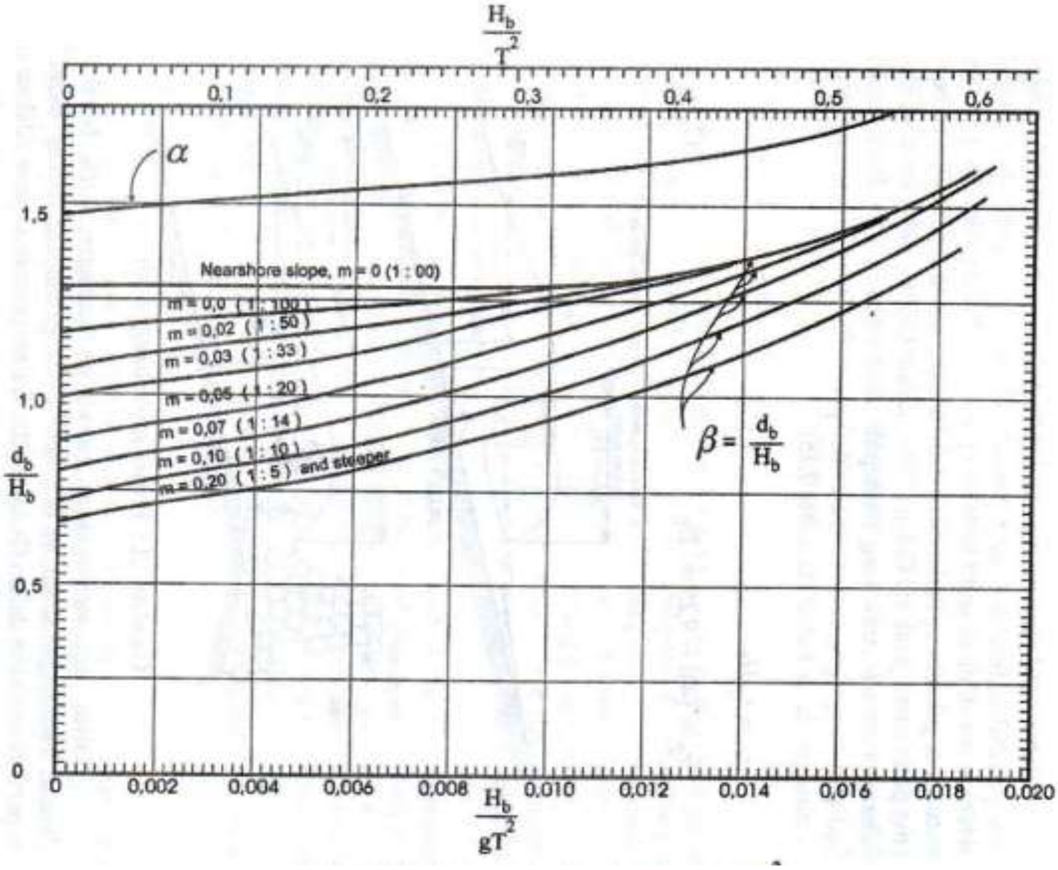

Figure 5. Values αand βversus Hb/gT [2]

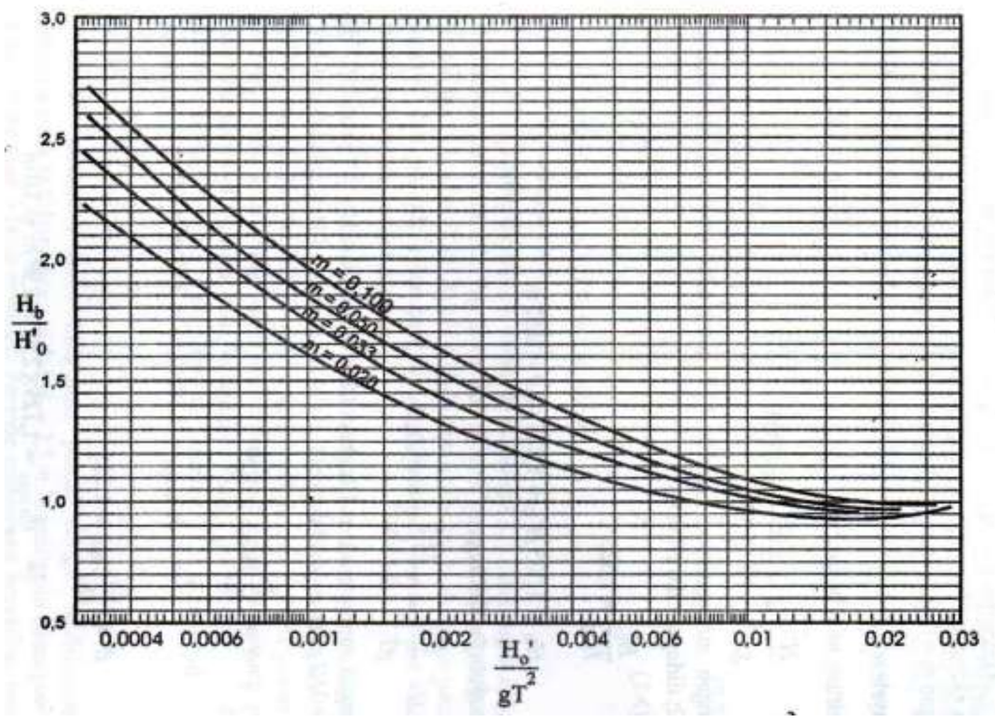

Figure 6 Hb/Ho' versus Ho'/gT [2 values]

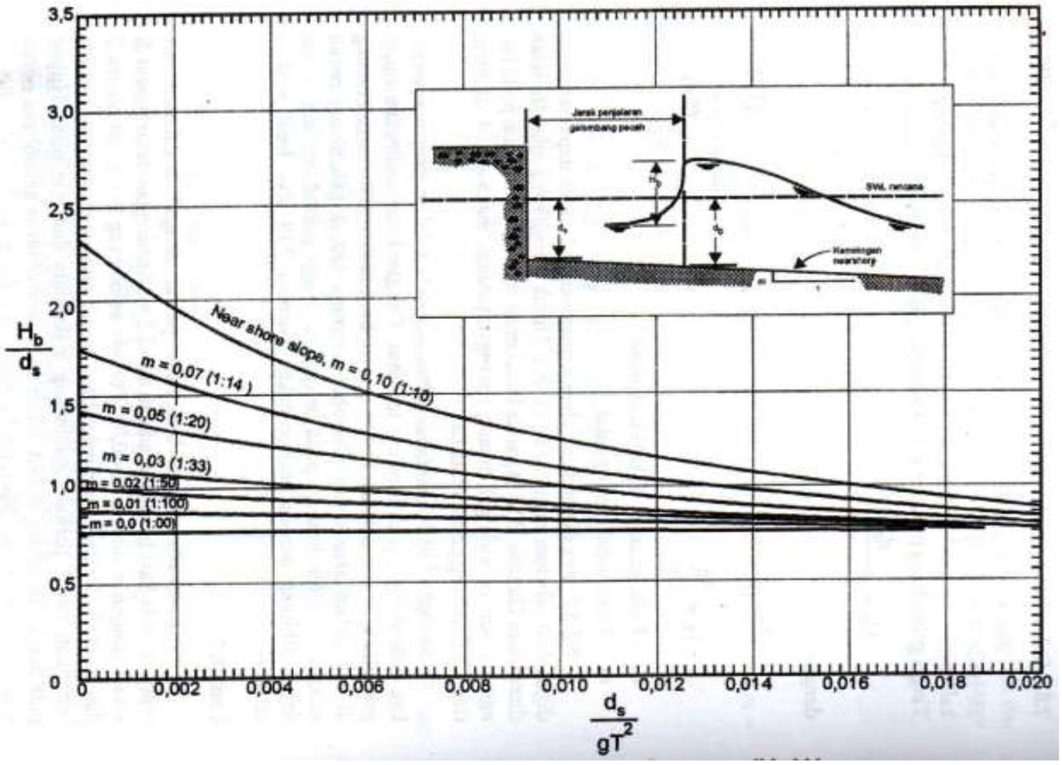

Figure 7. Hb/ds versus ds/gT ^{2} values

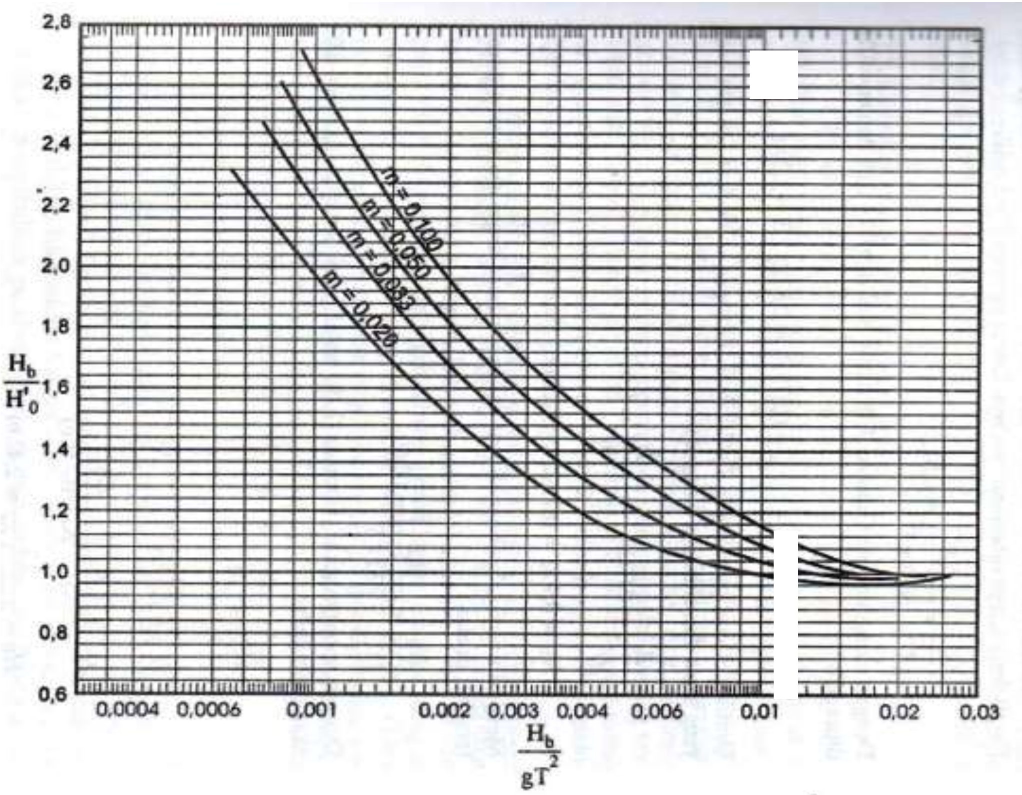

Figure 8. Wave Break Index Hb/Ho' versus Hb/gT ^{2}

Breaking Wave

Waves traveling from the sea toward the shore undergo changes in shape, with the wave crests becoming sharper until they finally break at a certain depth [8]. Some equations used to calculate breaking waves are as follows [9]:

The slope of the incoming wave Hb/gT ^{2} is as shown in Figure 8

Comparison of db/Hb with base slope m in Figure 5

The α curve is the upper limit of the db/Hb value so that α = (db/Hb) max

The β curve is the lower limit of db/Hb so that β = (db/Hb) min

Design Water Level (DWL)

Coastal Structure design must take into account varying sea level conditions. These variations in sea level are primarily due to tidal influences. However, the effects of *wind set-up* and *storm surge* must be considered in the design [10]. Because data on *wind set-up* and *storm surge* are not readily available in the field, specific values must be adopted to provide greater safety for the planned structure.

to [11]select a water level condition that produces the largest waves or highest *run-up* , *and as a guideline* the following equation can be used [12]: [13]

ds = (HHWL – BL) + storm surge or wind set-up + SLR (14)

where: ds = depth of the foot of the coastal Structure, HHWL = *Highest High Water Level* or highest high tide level, BL = *Bottom Level* or elevation of the beach base in front of the Structure, SLR = *Sea Level Rise* or rise in sea level

Run-Up and Run-Down

Run-Up and *Run-Down* are crucial for coastal Structure design. When waves hit a Structure, they rise (*run-up*) on the Structure's surface. The planned Structure elevation depends on the allowable *run-up and overtopping. Run-Up* depends on the shape and roughness of the Structure, the water depth at the Structure's toe, the slope of the seabed in front of the Structure, and the wave characteristics. *Run-up* is the rise of waves when they hit a Structure, while *run-down* is the fall in sea level at its lowest point. *Run-up* is used to determine the landmark of a coastal Structure, while *run-down* is used to calculate the stability of a revetment. The formulas used to calculate *run-up* and *run-down* on a smooth, impermeable surface are [14]:

1) *Run-up (Ru)*

$$Ru = Ir \text{ (for Ir < 2.5)} \qquad (15)$$

$$\frac{Ru}{Hi} = -0.31 \times Ir + 3.275 \text{ (for 4.25 > Ir > 2.5)} \qquad (16)$$

$$\frac{Ru}{Hi} = 2 \text{ (for Ir > 4.25)} \qquad (17)$$

2). Run-down (Rd)

$$\frac{Rd}{Hi} = -0.45 + 0.225 \text{ (for Ir < 4.25)} \qquad (18)$$

$$\frac{Rd}{Hi} = -1.7 \text{ (for Ir > 4.25)} \qquad (19)$$

$$Ir = \frac{\tan\theta}{(HsxLo)^{0.5}} \qquad (20)$$

Where: Hs = design wave height (m), Ir = Irrabaren number, θ= angle of inclination of the breakwater side (degrees), Lo = wavelength in deep sea (m).

For construction with rough and water-permeable surfaces, the above values must still be corrected by a factor of 0.5 to 0.8.

Structure Dimensions

Seawall

The height of concrete seawalls, especially those protecting critical facilities (roads, industrial areas, housing complexes, etc.), must be designed to prevent waves from overflowing the wall. Therefore, the height of the crest must be equal to or greater than the run-up. Repeated wave impacts on the seawall can weaken the soil structure. This occurs due to the vibrations generated by the waves. To address this situation, a sufficient safety factor must be established.

III. RESULTS AND DISCUSSIONS

A. Tidal

Using the Least Square Method, the sea level elevation is obtained as follows:

HHWL	: + 1,050 m
MHWS	: + 0.570 m
MHWL	: + 0.810 m
MSL	: + 0.000
MLWL	: - 0.810 m
MLWS	: - 0.570 m
LLWL	: - 1,070 m
CD (LAT)	: -0.020

B. Wind

Wind data obtained from measurements on land were converted to wind data for those above sea level. The results are presented in Table 4.1.

Table 4.1. Results of Land Wind Data Transformation and Wind Stress Factors

No.	Year	U_L m/s	R_L (Chart)	$U_{w=} R_L . U_L$ m/s	$U_A = 0.71 . U_W{}^{\wedge 1.23}$ m/s
1	2014	21.0	0.90	18.90	26.38
2	2015	16.0	1.00	16.00	21.49
3	2016	11.0	1.15	12.65	16.10
4	2017	14.0	1.02	14.28	18.69
5	2018	12.0	1.05	12.60	16.02
6	2019	9.0	1.20	10.80	13.25
7	2020	16.0	1.00	16.00	21.49

8	2021	11.0	1.15	12.65	16.10
9	2022	11.0	1.15	12.65	16.10
10	2023	10.0	1.19	11.90	14.93

C. Significant Waves in the Deep Sea

From the wave forecast graph, with the effect length (F) and wind stress factor (U_A) obtained from the calculation results, the significant wave height and period can be calculated.

Table 4.3. Wave Height and Period

No.	Year	UA m/s	Kintom Beach Hi (m)	Ti (dt)
1	2014	26.38	2.60	6.20
2	2015	21.49	2.10	5.80
3	2016	16.10	1.60	5.40
4	2017	18.69	1.90	5.40
5	2018	16.02	1.60	5.40
6	2019	13.25	1.30	5.00
7	2020	21.49	2.15	5.90
8	2021	16.10	1.60	5.40
9	2022	16.10	1.60	5.40
10	2023	14.93	1.50	5.25

The design waves that will be used in the planning of the Kintom Beach Structure are the result of calculations using the Gumbell Method.

Table 4.4. Design Wave Height Calculation

No.	Year	Hi (m)	Hi - H	(Hi - H)^2	T (Year)	YT	Yn	Sn	Hs (m)
1	2014	2.60	0.81	0.6480	2	0.366	0.4952	0.9496	1.74
2	2015	2.10	0.31	0.0930	5	1,510			2.21
3	2016	1.60	-0.20	0.0380	10	2,250			**2.51**
4	2017	1.90	0.11	0.0110	20	2,970			2.81
5	2018	1.60	-0.20	0.0380	25	3,199			2.90
6	2019	1.30	-0.50	0.2450	50	3,900			3.19
7	2020	2.15	0.36	0.1260	100	4,600			3.48
8	2021	1.60	-0.20	0.0380					
9	2022	1.60	-0.20	0.0380					
10	2023	1.50	-0.30	0.0870					
Amount		17.95	0.00	1.36					
Average		1.80							
Standard Deviation		0.389							

Table 4.5. Calculation of Design Wave Period

No.	Year	Ti (m)	Ti - T	(Ti - T)^2	T (Year)	YT	Yn	Sn	Ts (m)
1	2014	6.20	0.69	0.469	2	0.366	0.4952	0.9496	5.47
2	2015	5.80	0.29	0.081	5	1,510			5.89
3	2016	5.40	-0.11	0.013	10	2,250			**6.16**
4	2017	5.40	-0.11	0.013	20	2,970			6.43
5	2018	5.40	-0.11	0.013	25	3,199			6.51

6	2019	5.00	-0.51	0.265	50	3,900	6.77
7	2020	5.90	0.39	0.148	100	4,600	7.03
8	2021	5.40	-0.11	0.013			
9	2022	5.40	-0.11	0.013			
10	2023	5.25	-0.26	0.070			
Amount		55.15	0.00	1,100			
Average		5.52					
Standard Deviation		0.350					

D. Refraction Coefficient and Shoaling Coefficient

To predict waves at a Structure site, it is necessary to calculate wave deformation in the form of refraction and shoaling.

It is known:

- Significant wave height at 10-year return period, Hs_{10th} = 2.51 m, (Table 4.4)
- The significant wave period at the 10-year return period, Ts_{10th} = 6.16 seconds (Table 4.5)
- Water depth, d = 5 meters
- Angle of incidence of the wave, $\alpha = 45^{o}$

Calculation:

a. Determining wavelength in deep sea, Lo

$Lo = 1.56 (T_S)^2$

$Lo = 1.56(6.16)^2$

Lo = 59.20 m

b. Determining the wavelength in shallow water, L_1

d/Lo = 5 / 59.20

d/Lo = 0.084

for the d/Lo value above, using the d/L function table, we obtain:

$d/L_1 = 0.12683$, so $L_1 = 5 / 0.12683 = 39.42$ m

c. Wave speed in deep water, Co

Co = Lo/Ts

Co = 59.20 / 6.16

Co = 9.61 m/sec

d. Wave speed in shallow water, C1

$C_1 = L_1/Ts$

$C_1 = 39.42 / 6.16 = 6.40$ m/sec

e. Shoaling Coefficient, Ks

To calculate the shallowing coefficient, find the value of n using the d/l function table, based on the d/Lo value above. Based on the value of d/Lo = 0.084, the value of n = 0.8377 is obtained, while for deep water, the value of $n_o = 0.5$. Therefore, the value of the shallowing coefficient is:

$$Ks = \sqrt{\frac{noxLo}{nxL1}} = \sqrt{\frac{0.5x59,20}{0,8377x39,42}} = 0,947$$

f. Refraction Coefficient, $Kr = \sqrt{\frac{Cos\alpha o}{Cos\alpha}}$

Angle of incidence of waves at a depth of 5 m (α)

$\sin\alpha = (L_1/L_0)\sin\alpha_o$

$\sin\alpha = (39.42/ 59.20) \sin 45^0$

$\sin\alpha = 0.471$, this means the value $\alpha = 28.09^o$

So the refraction coefficient is:

$$Kr = \sqrt{\frac{Cos45}{Cos28,09}} = 0,895$$

g. Wave height at a depth of 5 m

$H = Ks \times Kr \times Hs_{10} = 0.947 \times 0.895 \times 2.51 = 2.13$ m

E. Run-Up and Run-Down

The calculation procedure is as follows:

a. Run-Up Calculation

It is known that:

- Wave height at a depth of 5 m H = 2.13 m
- Wavelength in shallow sea L1 = 39.42 m
- The planned Structure slope is 1:1.5

thus, tan θ= 0.67

Wave Calculation :

Calculate the magnitude of *the Irribaren number* (Ir) as follows:

$$Ir = \frac{Tan\theta}{\sqrt{\frac{H}{L1}}} = \frac{0.67}{\sqrt{\frac{2,13}{39,42}}} = 2,88$$

For Ir ……..4.25 > Ir > 2.5 then

Ru / H = -0.30 Ir + 3.275

Thus obtained:

Ru/H = -0.30 x 2.88 + 3.275 = 2.41

Ru = 2.41 x 2.13 = 5.13 m

In this planning, a construction with a rough surface is used so that this value still has to be corrected by a factor of 0.5 and the Run-up value obtained is:

$Ru^* = 0.5 \times 5.13 = 2.57$ m

b. Run-down Calculation

For Ir < 4.25, then:

Rd/H = - 0.45 Ir + 0.225

Rd = H (-0.45 Ir + 0.225)

Rd = 2.13 [-0.45 (2.88) + 0.225] = -2.28 m

The Run-down value after being corrected by a factor of 0.5, in this planning the Run-Down value obtained is:

Rd* = 0.5 x (-2.28) = - 1.14 m ≈ 1.20 m

F. Breaking Wave

The water depth at which the wave begins to break can be calculated as follows:

It is known:

- Significant wave height at 10-year return period, Hs_{10th} = 2.51 m, (Table 4.4)
- The significant wave period at the 10-year return period, Ts_{10th} = 6.16 seconds (Table 4.5)
- Base slope, m = 0.10

Calculation:

$Hs_{10}/(g \times Ts_{10}^2) = 2.51 / (9.81 \times 6.16^2) = 0.007$

Based on Figure 3.8, Hb/H = 1.4
So Hb = 1.4 x 2.51 = 3.51 m
Hb / gx Ts $_{10}$ ^{2} = 3.51 / (9.81 x 6.16 ^{2}) = 0.009
Based on Figure 3.5, db/Hb = 1.0
So db = 1 x 3.51 = 3.51 m
α = (db/Hb) $_{max}$ = 1.5
db $_{max}$ = 1.5 x 3.51 = 5.265 ≈ 5.3 m
β = (db/Hb) $_{min}$ = 1.125
Then db $_{min}$ = 1.125 x 3.51 = 3.95 ≈ 4.0 m
Thus, the waves at Kintom Beach will start to break at a Structure depth of 4.0 m to 5.3 m.

G. Design Wave

The results of the Gumbell method's design wave predictions, based on wind data, represent design waves located in deep water. Considering that the planned Structure is not located in deep water, the design wave magnitude must be transformed to the Structure's location. This planning process takes into account the effects of refraction and shoaling, using the following equation:
Hd = Ho x Kr x Ks
Where: Hd : wave height at location (m), Ho: significant wave height in deep sea (Hs) $_{10}$ = 2.51 m, Kr: refraction coefficient (calculation result, Kr = 0.895), K s: shoaling coefficient (calculation result, Ks = 0.947).
So Hd = 2.51 x 0.895 x 0.947 = 2.13 m

H. Planned Sea Level

In determining the planned water level, variations in sea level, in addition to tidal influences, also include the influence of *wind set-up* and *storm surge,* as well as the influence of rising sea levels due to the greenhouse effect (*Green House Effect*), which are taken into account in this planning. To determine the DWL, the following equation is used:
DWL = MHWS + (WS or SS) + SLR
= + 0.57 + 0.25 + 0.1 = + 0.92 m

I. Wave of Sea Wall Plan

The breaking wave height (maximum height) at a Structure location can be determined based on the depth of the Structure location. The planned depth (ds) can be determined using the equation:
ds = DWL – Lowest ground elevation of the location
So :
ds = 1.97 – (- 0.443) = 2.413 m
Wave period (T $_{10}$) = 6.16 seconds

$$\frac{ds}{gT^2} = \frac{2{,}413}{9{,}81x6{,}160^2} = 0{,}.0065$$

Coastal slope , m = 0 , 10 (bathymetric map)
From Figure 3.7 we get:

$$\frac{Hb}{ds} = 1{,}49$$

Hb = 1.49 x 2.413 = 3.595 m
Meanwhile, the design wave based on statistical calculations, shoaling analysis and refraction is Hd = 2.13 m. This wave will break at a depth of ds = 2.413 m and the maximum breaking wave height used as the design wave is Hb = 3.595 m.

J. Sea Wall Construction

The seawall construction is planned from river stone masonry, as shown in Figure 9.
Lighthouse elevation:
El. Mercu = DWL + Ru* + guard height
= 0.92 + 2.57 + 0.25 = + 3.74 m ≈ 3.75 m

Toe protection :
The foot protector is planned from a pile of stones with a depth of Rd* = 1.20 m below the MLWS, so - 0.57 – 1.20 = - 1.77 m with a width of 1.0 m.

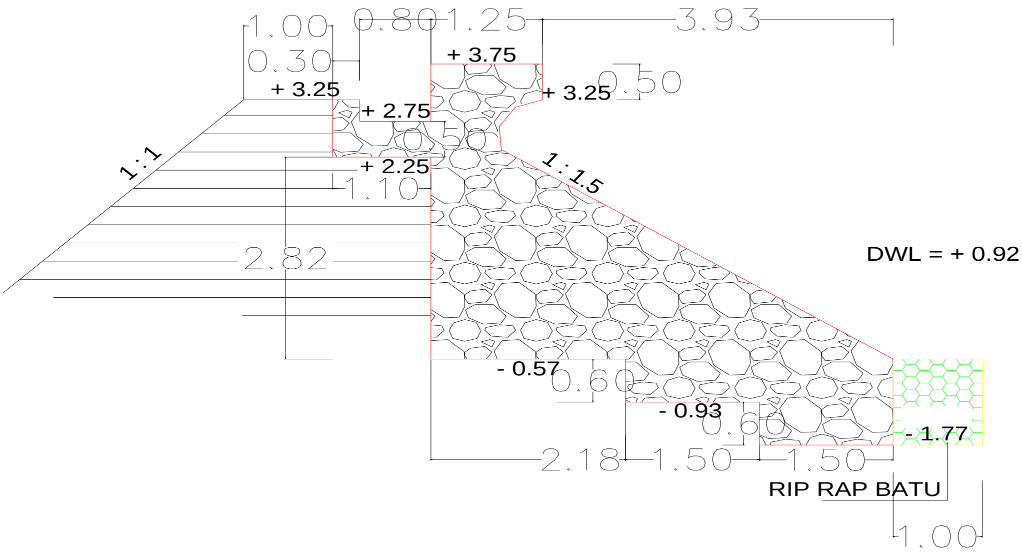

Figure 9. Sea Wall Construction

IV. CONCLUSIONS

Based on the results and discussions carried out, the following conclusions were drawn:

1. The design wave (Hs) $_{25}$ = 2.51 and the design wave period (Ts) $_{25}$ = 6.16
2. Waves break at a depth of 4.0 to 5.3 m

3. Design sea level elevation (DWL) = +0.92
4. Seawall lighthouse face elevation = +3.75
5. Sea wall slope 1:1.5
6. Sea wall made of river stone masonry covered with reinforced concrete
7. Rip rap seawall toe protection at elevation -1.77

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