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# Study Re-Analysis of High Wave Deformation in Re-Design Coastal Revetment Protection of Rajabasa Beach Kalianda

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**Abstract**: The eruption of Mount Krakatau in 2018, along with high waves, has impacted the coastal conditions of Kalianda Beach. The parameters for planning the revetment include significant wave height, highest high water level (HHWL), refraction and shoaling coefficients, wave set-up, and SLR. Wave data processing was conducted using the FT Type I. The extreme wave 50-year period has a height (Hr) of 2.22 m and a period (Tr) of 14.67 s. The wave transformation coefficients for refraction and shoaling, which are 0.74 and 1.44 respectively, lead to a deformation wave height of 2.19 m at a depth of 5 m. Admiralty tide analysis yielded a tidal range element at MSL of 0.94 m, which serves as the datum for elevation point 0. The HHWL from MSL is 0.73 m, wave set-up is 0.58 m due to breaking waves at 3.43 m, and SLR is 0.16 m, leading to a DWL of 1.46 m. The wave run-up varies according to the type of revetment, boulder type elevations id 4.60 m, tetrapod type is 3.80 m, and dolos type is 4.40 m. Differences elevation are attributed to different wave run-up every type of revetment material, run-up of the type material boulder is 2.83 m, run-up of tetrapod is 2.08 m, and dolos is 2.67 m.

**Keywords:** *revetment, significant wave, deformation wave, tidal element, design water level*

## Introduction

The coastal area in Kalianda consists of a coastline that stretches along the Sunda Strait and directly faces Mount Krakatoa. The tsunami disaster caused by the eruption of Mount Krakatoa in 2018 resulted in various damages to buildings such as places of worship, facilities, and settlements located along the coastal area, which became one of the reasons for the construction of coastal protection infrastructure in the form of a revetment [1]. High waves that occur due to massive changes have the potential to disrupt activities and increase the danger of wave impact on the settlements. Inaccurate planning regarding how waves are formed and propagate from deep sea to shallower waters, the highest tidal level during the new moon, design water level resulting from wave set-up and sea level rise, these have become rooted issues when there are planning model errors concerning the planned elevation of the revetment building.

### Objective

The following is the objective of the conducted research:

1. Determining the significant wave height and the probability distribution period of the planned waves, as well as the equivalent wave height deformation due to refraction coefficients and sedimentation, and the wave height at the 50-year recurrence interval.
2. Determining the design water level elevation based on the higher high water level, wave set-up, and sea level rise.
3. Determining the crest elevation, width, thickness, number of layers, and volume of the revetment structure resulting from the reassessment analysis of the 50-year recurrence interval for types of protection layers such as boulder, tetrapod, and artificial dolos stones, in accordance with the parameters of the actual calculation data.

**Previous Studies**

The results of the previous studies obtained and adapted are as follows:

1. In the research titled "Comparison of Accuracy in Tidal Prediction Between Admiralty Method and Least Square Method," it discusses the method of tidal analysis, comparing the accuracy of data length and the types of methods used in generating tidal harmonic constants. The study revealed that the Admiralty method, with a data length of 15 days, produced a root mean square error ranging from 25.98 cm to 30.54 cm, which is greater than when using the same method with a data length of 29 days, resulting in a smaller root mean square error of 15.69 cm to 25.77 cm [2].
2. In the research [3] it explains that the waves used in this study are significant wave height data obtained from the Copernicus Climate Change Service. C3S is a climate change observation system service with information depicting past, present, and future climate conditions in Europe and worldwide. The modeling used to determine wave height in deep sea areas involves the use of the Coupled Model Intercomparison Project (CMIP5). CMIP5 is a realistic model evaluation project that simulates the past, including hindcasting individual wave models into accurate representative significant waves. The data is then output by ERA5, one of several climate data products developed and managed by the European Union's C3S [3].
3. In the research by Maratus Khasanah Humairah, Sugeng Widada, and Rikha Widiaratih [10] titled "Simulation of the Physical Model of the Effectiveness of Tetrapod and Dolos Wave Breakers," it discusses the effectiveness of wave breakers such as tetrapods and dolos in attenuating wave energy. The study suggests that physical models of tetrapod and dolos armor layers have high effectiveness in attenuating wave energy. The research results indicate that the percentage of attenuation obtained for the 15 cm depth tetrapod model is 87.45%, while for the 15 cm depth dolos model, it is 87.75%. Based on this study, it is possible that these types of armor layers can attenuate wave energy for both non-breaking waves and smaller breaking waves. This is attributed to the ability of dolos and tetrapod to interlock more strongly between one armor layer and another protective element [4].

## Methods

### Wave Frequency Distribution

The type of frequency distribution is used to determine whether a dataset is suitable for a specific distribution and is not suitable for another distribution. To determine the suitability for a particular type of distribution, the existing conditions need to be examined first, including mean (log x̄) standard deviation (s), skewness coefficient (cs), variansi coefficient (cv), curtosis coefficient (ck).

$$S = \sqrt{\frac{1}{n-1} \sum (\log (X_i - \bar{X}))^2} \quad [1]$$

$$Cv = \frac{S}{\bar{X}} \quad [2]$$

$$Cs = \frac{\sum_{i=1}^{n} [\log(X_i) - \log(\bar{X})]^3}{(n-1)(n-2)S^3} \quad [3]$$

$$Ck = \frac{\sum_{i=1}^{n} [\log(X_i) - \log(\bar{X})]^4}{(n-1)(n-2)S^4} \quad [4]$$

The test of conformity or data proficiency is conducted on the distribution of significant wave height and peak wave period data to observe the differences in the magnitude of wave height data H33 that leads to the annual coastal observation location. The tests conducted are the Chi-Square test and the Smirnov-Kolmogorov test. In addition to using equations to determine the Chi-Square test and Smirnov-Kolmogorov test, testing was conducted with the assistance of the SPSS (Statistical Package for the Social Sciences) software.

### Design Water Level

When a wave is about to break, the sea level elevation at the breaking wave location will decrease compared to the sea level elevation before. The Longuet-Higgins and Stewart formula can be used to calculate wave set-down on the coast [5][6].

$$S_b = -\frac{0{,}536\, H_b^{\,2/3}}{g^{1/2} T} \quad [5]$$

$$S_w = \Delta S - S_b \quad [6]$$


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With a value of ΔS equal to 0.15 of db, and the value of db is 1.28 times Hb, then the magnitude of Sb can be determined using the following equation:

$$S_w = 0{,}19\ [\ 1 - 2{,}82 \sqrt{\frac{H_b}{gT^2}}\ ]\ H_b \qquad [7]$$

The impact of global warming leads to a rise in sea levels. Based on the research, the study revealed a sea level rise of 2.9 ± 0.31 mm per year in the southern waters of Banten Province [7].

To predict the height and timing of tidal sea level, an analysis was conducted using the Admiralty method. This method involves collecting sea level data from various sea level observation stations distributed worldwide. This data is then used to create a tidal chart that illustrates the relationship between time and sea level. The tidal chart is then employed to predict the future HHWL and times of high tide [7].

To ensure that the construction is capable of withstanding the water pressure generated by changes in water levels over time, including during floods or large waves. The formula used to determine the Design Water Level (DWL) is as follows:

$$DWL = HHWL + Sw + SLR \qquad [8]$$

**Fisher-Trippet Type I Method**

The method to estimate waves at specific time intervals can be done through the analysis of the Gumbel Fisher-Trippet Type I frequency distribution. This method involves decomposing the frequency distribution of wave data to find the values of specific wave height and period over several years. As follows equation:

$$P\ (H_s \le H_{sm}) = 1 - \frac{m - 0{,}44}{N_T + 0{,}12} \qquad [9]$$

$$P\ (H_s \le \hat{H}_s) = e^{-e^{-\left(\frac{\hat{H}_s - B}{A}\right)}} \qquad [10]$$

With P being the probability that the wave height representing the data does not exceed a certain value m. Calculation of scale and location parameters is performed using the least squares method for each type of distribution [8]

$$H_{sm} = Ay_m + B \qquad [11]$$

$$y_m = -\ln \{ -\ln P\ (H_s \le H_{sm})\ \} \qquad [12]$$

$$A = \frac{n\ \Sigma H_{sm}\ y_m - \Sigma H_{sm}\ \Sigma y_m}{n\ \Sigma {y_m}^2 - (\Sigma\ y_m)^2} \qquad [13]$$

From the probability distribution function, the wave height can be determined.

$$H_r = A\ y_r + B \qquad [14]$$

$$y_r = -\ln \left\{ -\ln \left(1 - \frac{1}{L\,T_r}\right) \right\} \qquad [15]$$

With $H_{nr}$ being the wave of height with a frequency of $T_r$ period (m). In the analysis of extreme wave height, confidence intervals can be utilized. Confidence intervals heavily depend on the data distribution and the value of the standard deviation [5]. The normalized standard deviation value can be found using the following equation:

$$\sigma_{nr} = \frac{1}{\sqrt{N}} \left[1 + \alpha\ (y_r - c + \varepsilon \ln v)^2\right]^{1/2} \qquad [16]$$

$$\alpha = \alpha_1\ e^{\alpha_2\ N^{-1,3} + k\sqrt{-\ln v}} \qquad [17]$$

With $\sigma_{nr}$ being the normalized standard deviation of the wave height with a frequency of Tr period.

**Wave Transformation**

Wave refraction occurs when a portion of the wave changes its direction upon entering shallower waters, as the wave speed remains constant as in deep-sea conditions. This phenomenon is caused by the difference in the refractive index between deep-sea and shallow waters [8].

$$K_r = \sqrt{\frac{\cos \alpha_0}{\cos \alpha}} \qquad [18]$$

$$K_s = \sqrt{\frac{n_0 \times L_0}{n_L}} \qquad [19]$$

The shoaling coefficient is an indicator that reflects changes in wave form as it moves from deep to shallow waters. Factors influencing shoaling include wave length and water depth. When waves move into shallow waters, the dimensions of wave height, length, and speed undergo changes [8].

Transformation occurs in waves moving from deep to shallow waters, resulting in changes in wave height, wave speed, and direction. As waves move towards shallower depths, various phenomena occur within the waves [8].

$$H'_0 = K_s \times K_r \times H_0 \qquad [20]$$

Waves propagating towards shallow waters from deep waters will form wave crests that become sharper before eventually breaking at a certain depth. The breaking process of the waves begins from an unstable state until the waves break entirely at a distance represented as xp [8].

$$\frac{H_b}{H'_0} = \frac{1}{3{,}3\left(\frac{H'_0}{L_0}\right)^{1/3}} \quad [21]$$

### Wave Run Up

The height of the revetment crest is determined by the amount of allowed overtopping. The building height is calculated by considering the maximum wave elevation (run-up), wave characteristics, structure slope, porosity, and the hardness of protective layers that affect wave propagation on the revetment structure [8].

$$I_r = \frac{\text{tg}\,\theta}{\left({}^{H}/_{L_0}\right)^{0,5}} \quad [22]$$

As follows $I_r$ is Irribaren notation.

### Stability of Revetment

The stability of the revetment is influenced by several factors, including the configuration of the protective layer stones, stone size, the type of material used, and environmental conditions such as waves and currents. The Hudson formula is used to calculate the weight of the protective layer stones.

$$W = \frac{\gamma_r \times H^3}{K_D \times (S_r - 1)^3 \cot\theta} \quad [23]$$

$$S_r = \frac{\gamma_r}{\gamma_a} \quad [24]$$

The width of the revetment's crest is determined based on the allowable water runoff capacity.

$$B = n\,k_\Delta \left[\frac{W}{\gamma_r}\right]^{1/3} \quad [25]$$

To determine the thickness of the protective layer and the number of units of the protective layer per meter square needed, the following equation is:

$$t = n\,k_\Delta \left[\frac{W}{\gamma_r}\right]^{1/3} \quad [26]$$

$$N = A\,n\,k_\Delta \left[1 - \frac{P}{100}\right] \left[\frac{\gamma_r}{W}\right]^{2/3} \quad [27]$$

## Results And Discussions

### Wave and Significant Period

Wave data consists of the significant height. Wave period data includes the peak wave period. Meanwhile, the mean wave direction represents data used to determine the dominant direction of wave height to the observed research location. The data is recorded daily per hour over a data length of 15 years (**Table 1**) [3].

**Table 1.** Wave height and significant period data for 15 years

| N | Years | Peak Wave Period (s) | Significant Wave Height (m) |
|---|---|---|---|
| 1 | 2007 | 10,15 | 1,76 |
| 2 | 2008 | 12,93 | 1,97 |
| 3 | 2009 | 9,61 | 1,81 |
| 4 | 2010 | 9,46 | 1,78 |
| 5 | 2011 | 11,30 | 1,78 |
| 6 | 2012 | 9,76 | 2,05 |
| 7 | 2013 | 10,04 | 2,02 |
| 8 | 2014 | 10,65 | 1,66 |
| 9 | 2015 | 12,19 | 1,77 |
| 10 | 2016 | 11,17 | 1,78 |
| 11 | 2017 | 9,56 | 1,89 |
| 12 | 2018 | 9,58 | 1,91 |
| 13 | 2019 | 15,08 | 1,57 |
| 14 | 2020 | 10,30 | 1,78 |
| 15 | 2021 | 11,20 | 1,74 |

### Wave and Period Distribution Test

In the frequency distribution analysis, calculations are conducted to determine the type of distribution used based on the values of Cs and Ck.

**Table 2.** Frequency analysis of sea wave height log-normal

| Data | Value |
|---|---|
| Mean (log $\bar{X}$) | 0,26 |
| Standard deviation (S) | 0,03 |
| Skewness coefficient (Cs) | 0,56 |
| Variance coefficient (Cv) | 0,11 |
| Kurtosis coefficient (Ck) | 3,12 |

Based on the calculation results in **Table 2**, the Cs value for the Gumbel method is 0.56, thus, the skewness coefficient meets the requirement because Cs (0.56) ≤ 1.1396. Meanwhile, the Ck value is 3.18, meeting the requirement as Ck (3.12) ≤ 5.4002. In the frequency


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analysis of the Log Pearson III distribution, the Cs value is 0.56, which satisfies the condition since Cs ≠ 0 for the Log Pearson III distribution. Normal and log-normal distributions do not specifically meet the criteria, and it is better to use the Gumbel distribution or Log Pearson III distribution for regression analysis. Next, the Gumbel or FT Type I method is used to analyze the peak wave height for a return period of 50 years.

### Smirnov-Kolmogorov and Chi Square Test

Here is the Smirnov-Kolmogorov test for peak wave period data, where $D_s$ represents the Smirnov-Kolmogorov distribution resulting from Gumbel frequency analysis, while $D_1$ represents the normal frequency analysis. From the calculations conducted, the $D_{max}$ value obtained from the maximum $D_2$ is 0.17. Meanwhile, the critical value ($D_{critical}$) is 0.338, obtained from the table of critical values of the Smirnov-Kolmogorov test with a 95% probability. Therefore, the conclusion of the calculation meets the Smirnov-Kolmogorov test because the $D_{max}$ value is less than the critical value, that is, 0.17 < 0.338. Based on the calculations in **Table 3**, the calculated Chi-Square ($X^2$calculate) value is 7.333, and the critical

Chi-Square ($X^2$critical) value is 7.815 from the Chi-Square table for a significance level (α) of 0.05 or a 95% probability. Since the calculated Chi-Square (7.333) is less than the critical Chi-Square (7.815), it can be concluded that the significant wave height data is valid and follows the expected distribution.

### Extreme Waves Fisher-Trippet Type I Method

In this method, predictions are made to estimate the planned wave height and planned period for various return periods, and the Fisher-Trippet Type I method is used as an approach to determine the probability distribution [9]. The calculations are presented in **Table 4** for the calculation of planned wave height.

**Table 3.** Chi-Square test for significant wave height over 15 years

| Years | Xi | Log Xi | The Boundary Values for Each Class | | | EF | OF | EF-OF | $(EF-OF)^2$ | $(EF-OF)^2/EF$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 2014 | 1,659 | 0,2198 | | | | | | | | |
| 2019 | 1,667 | 0,2220 | 0,2198 | <X< | 0,2428 | 3 | 3 | 0 | 0 | 0 |
| 2021 | 1,737 | 0,2397 | | | | | | | | |
| 2007 | 1,762 | 0,2461 | | | | | | | | |
| 2015 | 1,768 | 0,2474 | | | | | | | | |
| 2016 | 1,780 | 0,2503 | | | | | | | | |
| 2020 | 1,781 | 0,2506 | 0,2428 | <X< | 0,2657 | 3 | 7 | -4 | 16 | 5,333 |
| 2011 | 1,782 | 0,2508 | | | | | | | | |
| 2010 | 1,785 | 0,2515 | | | | | | | | |
| 2009 | 1,807 | 0,2569 | | | | | | | | |
| 2017 | 1,886 | 0,2756 | 0,2657 | <X< | 0,2887 | 3 | 2 | 1 | 1 | 0,333 |
| 2018 | 1,909 | 0,2807 | | | | | | | | |
| 2008 | 1,971 | 0,2947 | 0,2887 | <X< | 0,3117 | 3 | 2 | 1 | 1 | 0,333 |
| 2013 | 2,024 | 0,3062 | | | | | | | | |
| 2012 | 2,050 | 0,3117 | 0,3117 | <X< | 0,3346 | 3 | 1 | 2 | 4 | 1,333 |
| Σ | | | | | | 15 | 15 | 0 | 22 | 7,333 |

**Table 4.** Planned wave height Fisher-Trippet Type I method

| No Sequence of m | $H_{sm}$ | P | $y_m$ | $H_{sm}.y_m$ | $y_m^2$ | $H_{sm}-\bar{X}_{Hsm}$ | $(H_{sm}-\bar{X}_{Hsm})^2$ | $\sigma H_s$ | $\hat{H}_{sm}$ | $H_{sm}-\hat{H}_{sm}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2,05 | 0,96 | 3,28 | 6,72 | 10,74 | 0,23 | 0,05 | 0,06 | 2,09 | -0,04 |
| 2 | 2,02 | 0,90 | 2,22 | 4,49 | 4,92 | 0,20 | 0,04 | 0,05 | 1,98 | 0,04 |
| 3 | 1,97 | 0,83 | 1,68 | 3,32 | 2,84 | 0,15 | 0,02 | 0,04 | 1,93 | 0,04 |
| 4 | 1,91 | 0,76 | 1,32 | 2,51 | 1,73 | 0,08 | 0,01 | 0,02 | 1,90 | 0,01 |
| 5 | 1,89 | 0,70 | 1,02 | 1,93 | 1,05 | 0,06 | 0,00 | 0,02 | 1,87 | 0,02 |
| 6 | 1,81 | 0,63 | 0,78 | 1,41 | 0,61 | -0,02 | 0,00 | 0,00 | 1,85 | -0,04 |
| 7 | 1,78 | 0,57 | 0,56 | 1,01 | 0,32 | -0,04 | 0,00 | 0,01 | 1,83 | -0,04 |
| 8 | 1,78 | 0,50 | 0,37 | 0,65 | 0,13 | -0,04 | 0,00 | 0,01 | 1,81 | -0,03 |
| 9 | 1,78 | 0,43 | 0,18 | 0,32 | 0,03 | -0,04 | 0,00 | 0,01 | 1,79 | -0,01 |
| 10 | 1,78 | 0,37 | 0,00 | 0,00 | 0,00 | -0,04 | 0,00 | 0,01 | 1,77 | 0,01 |
| 11 | 1,77 | 0,30 | -0,18 | -0,32 | 0,03 | -0,06 | 0,00 | 0,02 | 1,75 | 0,01 |
| 12 | 1,76 | 0,24 | -0,37 | -0,65 | 0,14 | -0,06 | 0,00 | 0,02 | 1,74 | 0,03 |
| 13 | 1,74 | 0,17 | -0,57 | -1,00 | 0,33 | -0,09 | 0,01 | 0,02 | 1,72 | 0,02 |
| 14 | 1,67 | 0,10 | -0,82 | -1,37 | 0,67 | -0,16 | 0,02 | 0,04 | 1,69 | -0,03 |
| 15 | 1,66 | 0,04 | -1,19 | -1,98 | 1,42 | -0,17 | 0,03 | 0,04 | 1,66 | 0,00 |
| Σ | 27,37 | 7,50 | 8,27 | 17,04 | 24,96 | | | 0,38 | | |

**Table 5.** Design wave Hsr recurrence period Fisher-Trippet Type I method

| Recurrence Period (years) | yr (years) | Hsr (m) | σnr | σr | Hsr-1.28σr (m) | Hsr+1.28σr (m) |
|---|---|---|---|---|---|---|
| 2 | 0,37 | 1,81 | 0,22 | 0,01 | 1,80 | 1,81 |
| 5 | 1,50 | 1,92 | 0,66 | 0,02 | 1,89 | 1,94 |
| 10 | 2,25 | 1,99 | 1,07 | 0,03 | 1,95 | 2,02 |
| 25 | 3,20 | 2,08 | 1,74 | 0,04 | 2,02 | 2,13 |
| 50 | 3,90 | 2,14 | 2,34 | 0,06 | 2,07 | 2,22 |
| 100 | 4,60 | 2,21 | 3,03 | 0,08 | 2,11 | 2,31 |

With the average value of the standard deviation of wave height data $\bar{X}\sigma Hs$ at 0.026, the absolute magnitude of the standard deviation of the planned wave height can be determined. The standard error of the planned wave height of 50 years period (**Table 5**).

$$\sigma_r = \sigma_{nr} \times \bar{X}\sigma H_s = 2{,}34 \times 0{,}026 = 0{,}06$$

The planned wave for an 80% confidence level with a return period of 50 years is as follows.

$$H_r = H_{sr} + 1{,}28 \times \sigma_r = 2{,}15 + 1{,}28 \times 0{,}06 = 2{,}22 \text{ m}$$

### Wave Transformation

The wave direction is obtained from the Copernicus Climate Change Service ECMWF Mean Wave Direction data, which is the average observation data of the wave direction from 2007 to 2021, recorded daily every hour. The wave arrival direction is the dominant direction of the wave height coming from the wave observation point location toward the research area. The Mean Wave Direction based on the $H_{33}$ significant wave is 66.14° (**Figure 1**). Next, the creation of the wave arrival lines towards the research area is done by passing through different contour lines [3].



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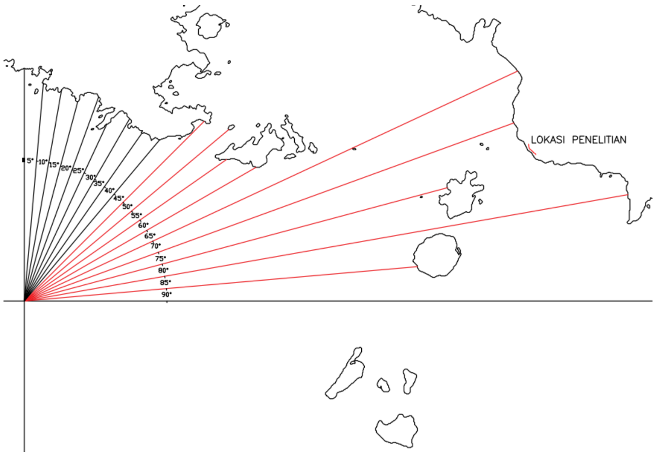


**Figure 1.** The Dominant High Wave Direction Toward the Research Location

Based on the results of the wave refraction or bending illustration towards the coastal area of the research location due to changes in the underwater contour, the angle $\alpha_0$ for each contour point that the wave passes through is obtained (**Figure 2**).

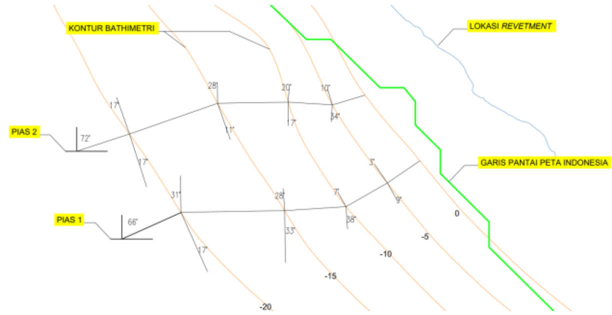


**Figure 2.** Wave Refraction Piers 1 and Piers 2

Based on the calculation results in **Table 6**, the equivalent deformation transformation wave height due to the refraction of waves traveling towards the shoreline, namely wave refraction based on piers 2, where it is an ideal pier location located at the research observation point with a depth of 5 meters, the refraction coefficient obtained is 0.737. Then, based on the value of $d/L_0$ of 0.0149, the shoaling coefficient or shoaling coefficient value of 1.435 is obtained. Thus, the value of the deformation wave height is determined to be 2.19 meters, and this wave height is used in the calculation of the wave height at breaking and the elevation of the planned revetment building/.

**Table 6.** Wave height of transformation pias 2

| d (m) | $d/L_0$ | d/L | L (m) | C (m/s) | sin α | α (°) | cos α | Kr | Ks | $H'_0$ (m) |
|---|---|---|---|---|---|---|---|---|---|---|
| 20 | 0,0596 | 0,10430 | 191,75 | 13,07 | 0,27 | 15,5 | 0,97 | 0,953 | 1,042 | 2,21 |
| 15 | 0,0447 | 0,08883 | 168,86 | 11,51 | 0,50 | 28,6 | 0,94 | 0,349 | 1,993 | 1,54 |
| 10 | 0,0298 | 0,07135 | 140,15 | 9,55 | 0,35 | 20,0 | 0,38 | 1,196 | 1,125 | 2,07 |
| 5 | 0,0149 | 0,07629 | 65,54 | 4,47 | 0,18 | 10,1 | 0,81 | 0,737 | 1,435 | 2,19 |

## Breaking Waves

Waves propagating from the deep sea towards the shore will undergo a change in shape, with the wave crest becoming sharper until it eventually breaks at a certain depth. Calculating $H'_0/gT^2$ for the 50-year return period as follows [8]. Using the following data:

$H'_0 = 2{,}19$

$$\frac{H'_0}{gT^2} = \frac{2{,}19}{(9.81 \times 14{,}67)^2} = 0{,}001$$

With the value of $\frac{H_b}{H'_0}$ being 1,57. the height of the breaking wave is:

$$\begin{aligned} H_b &= 1{,}57 \times H'_0 \\ &= 1{,}57 \times 2{,}19 \\ &= 3{,}43 \text{ m} \end{aligned}$$

**Table 7.** Breaking wave height for a 50-year return period

| Repeat Time (years) | $T_r$ (s) | $H'_0$ (m) | $H'_0/gT^2$ | $H_b/H'_0$ | $H_b$ (m) |
|---|---|---|---|---|---|
| 50 | 14,67 | 2,19 | 0,001 | 1,57 | 3,43 |

### Admiralty Tidal Method

The processing of tidal data using the Admiralty method is carried out to obtain the highest high tide value during the full moon or higher high water level, which is one of the parameters in determining the planned water level elevation in revetment building planning (**Figure 3**) [10].

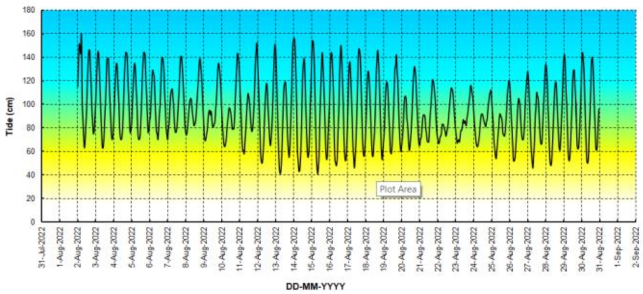


**Figure 3.** Tidal Range Data Chart for Pulau Sebesi Station Over 29 Days

Here are the tidal generation components from the tidal description calculation using the Admiralty method.

**Table 8.** Nine harmonic constants for tidal generation

| Constant | $S_0$ | $M_2$ | $S_2$ | $N_2$ | $K_1$ | $O_1$ | $M_4$ | $MS_4$ | $K_2$ | $P_1$ |
|---|---|---|---|---|---|---|---|---|---|---|
| A (cm) | 94 | 32 | 14 | 6 | 11 | 7 | 1 | 0 | 4 | 4 |
| G (°) | 0 | 329 | 54 | 287 | 146 | 116 | 310 | 64 | 54 | 146 |

Using the results of the calculation of nine harmonic constants for tidal generation, the value of the higher high water level is obtained as follows:

$$\begin{aligned} HHWL &= S_0 + (M_2 + S_2 + K_2 + K_1 + O_1 + P_1) \\ &= 94 + (32 + 14 + 4 + 11 + 7 + 4) \\ &= 166{,}90 \text{ cm} \\ &= 1{,}67 \text{ m} \end{aligned}$$

**Table 9.** Values of tidal generation components Admiralty method

| Symbol | Water Level Values (m) | |
|---|---|---|
| | Original Analys | *Adjust* MSL |
| HHWL | 1,67 | 0,73 |
| MHWS | 1,40 | 0,46 |
| MHWL | 1,45 | 0,50 |
| MSL | 0,94 | 0,00 |
| MLWL | 0,44 | -0,50 |
| MLWS | 0,49 | -0,46 |
| LLWS | 0,22 | -0,73 |
| LAT | 0,14 | -0,81 |

**Table 10.** Breaking wave condition against revetment position datum MSL

| Symbol | Description | Value (m) |
|---|---|---|
| MSL | *Mean sea level* | 0 |
| $d_{kaki}$ | Water depth at the base from MSL | -1,20 |
| $d_{HHWL}$ | Depth of HHWL to the base of the structure | 1,93 |
| $d_{LLWS}$ | Depth of LLWL to the base of the structure | 0,48 |
| $d_{MSL}$ | Depth of MSL to the base of the structure | 1,20 |
| $d_b$ | Depth of breaking waves from MSL | 4,81 |
| Cek | $d_b > d_{HHWL}$ | Breaking wave |
| | $d_b > d_{LLWL}$ | Breaking wave |

Based on the calculation in **Table 10**, the wave height before breaking is 3.43 meters. The depth of the wave at maximum breakage from MSL is 4.81 meters. It is known that the revetment building is planned at a depth of -1.20 meters, so the waves that hit the revetment building are waves that have broken.

### Design Water Level

Calculating the planned water level due to the highest tidal range, sea level rise due to wave set-up, and wave set-down with the following parameters:

$H_b$ = 3,43 m
$T_r$ = 14,67 s
g = 9,81 m/s

Calculating wave set-down as follows:

$$\begin{aligned} S_b &= -\frac{0{,}536\ H_b^{\ 2/3}}{g^{1/2}T} \\ &= -\frac{0{,}536 \times 3{,}43^{2/3}}{9{,}81^{1/2} \times 14{,}67} \\ &= -0{,}03 \text{ m} \\ &= -3{,}00 \text{ cm} \end{aligned}$$

Calculating wave set-up as follows:

$$\begin{aligned} S_w &= 0{,}19\left[1 - 2{,}82\sqrt{\frac{H_b}{gT^2}}\right] Hb \\ &= 0{,}19\left[1 - 2{,}82\sqrt{\frac{3{,}43}{9{,}81 \times 14{,}67^2}}\right] \times 3{,}43 \\ &= 0{,}58 \text{ m} \end{aligned}$$

Determining the magnitude of sea level rise due to global warming. Based on the research [7] by examining the


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correlation coefficient between the total water level envelope (TWLE) and tide gauge data, the research found a sea level rise of 2.9 ± 0.31 mm/year in the southern part of Banten Province. Considering the research location at Rajabasa Beach, Kalianda Regency, this sea level rise data represents field conditions and can be used in this study.

SLR = (2,9 + 0,31) × 50
= 0,16 m
= 16,10 cm

Thus, the increase in sea level due to sea level rise is estimated to be 0.16 meters over the next 50 years. Calculating the planned sea level height. DWL calculation is based on the values of HHWL, Sw, Sb, and SLR. HHWL is obtained from the Admiralty tidal analysis, which has been adjusted to the MSL zero point, with a value of 0.73 meters.

DWL = HHWL + Sw + SLR
= 0,73 + 0,58 + 0,16
= 1,46 m

**Table 11.** The increase in DWL sea level due to wave set-up and wave set-down

| $H_b$ (m) | $T_r$ (s) | g (m/s²) | $S_b$ | | $S_w$ | |
|---|---|---|---|---|---|---|
| | | | m | cm | m | cm |
| 3,43 | 14,67 | 9,81 | -0,030 | -3,00 | 0,58 | 57,8 |

**Table 12.** Planned sea level design water level

| Symbol | Description | Value (m) |
|---|---|---|
| HHWL | Highest water level during neap tide from MSL | 0,73 |
| Sw | Increase in DWL due to waves (wave set-up) | 0,58 |
| SLR | Increase in sea level due to global warming | 0,16 |
| DWL | Planned sea level, design water level | 1,46 |

Therefore, as seen in **Table 12**, the height of theplanned sea level, design water level used for elevation calculations and adjustments to the dimensions of the planned structure is 1.464 meters.

**Revetment Building Elevation**

The calculation of the elevation of the revetment building is the height adjusted based on the wave height conditions and the planned sea level, as well as the type of protective layer used [8].

The elevation calculation for the revetment building is done for the type of protective layer, boulder stone with a return period of 50 years.

$H_r$ = 2,19 meter
$T_r$ = 14,67 detik
$L_0$ = 1,56 × $Tr^2$
= 1,56 × 14,672
= 335,65 m

$$Ir = \frac{\tan\theta}{\left(\frac{H}{L_0}\right)^{0,5}}$$
$$= \frac{\tan 0,67}{\left(\frac{2,19}{335,65}\right)^{0,5}}$$
$$= 9,75$$

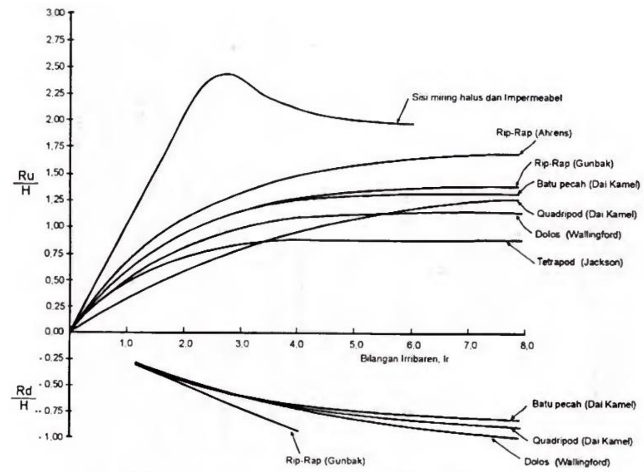


**Figure 4.** Wave Propagation Graph According to the Type of Protection Layer

If the Irribarren number is 9.75, based on **Figure 4**, the value of Ru/H is obtained as:

$R_u/H$ = 1,30
$R_u$ = $R_u/H \times H_r$
= 1,30 × 2,19
= 2,84 m
W = 0,25 m
DWL = 1,46 m
Therefore, the calculation of the revetment elevation is obtained with the following equation:
Elv. $P_{50}$ = Ru + W + DWL
= 2,84 + 0,25 + 1,46
= 4,56 m ≈ 4,60 m

**Table 13.** Elevation of boulder, tetrapod and dolos revetment protective layer

| Description | Symbol | Value | | | Unit |
|---|---|---|---|---|---|
| | | Boulder | Tetrapod | Dolos | |
| Recurrence Interval | | 50 | 50 | 50 | Years |
| Planned Wave Height | $H'_0$ | 2,19 | 2,19 | 2,19 | m |
| Slope 1:1.5 | θ | 0,67 | 0,67 | 0,67 | |
| Slope Angle | tan θ | 0,79 | 0,79 | 0,79 | |
| Planned Wave Period | Tr | 14,67 | 14,67 | 14,67 | s |
| Wavelength in Deep Water | $L_0$ | 335,65 | 335,65 | 335,65 | m |
| Irri barren Number | Ir | 9,75 | 9,75 | 9,75 | |
| Run Up/Wave Height | Ru/H | 1,30 | 0,95 | 1,22 | |
| Run Up | Ru | 2,84 | 2,08 | 2,67 | m |
| | | | | | |
| A. Run Up | Ru | 2,84 | 2,08 | 2,67 | m |
| B. Freeboard Height | W | 0,25 | 0,25 | 0,25 | m |
| C. Design Water Level | DWL | 1,46 | 1,46 | 1,46 | m |
| Revetment Elevation (A+B+C) | | 4,56 | 3,79 | 4,38 | m |
| Revetment Elevation | | 4,60 | 3,80 | 4,40 | m |

Based on the data from calculation results in **Table 13**, the elevation values of the building are obtained according to the Irri barren number calculation, where the graph illustrates the magnitude of run-up due to wave propagation according to the type of protective layer used. It can be seen that the highest elevation is obtained with the boulder stone protective layer, with a building height of 4.60 meters. Meanwhile, the tetrapod elevation is only 3.80 meters. This is due to the wave propagation on the building with the tetrapod protective layer being smaller compared to the wave propagation on the building with the boulder stone or dolos protective layer.

### Revetment Structure Dimension

Calculating the weight of tetrapod protective layer grains. The data needed to calculate the dimensions of the revetment building with the tetrapod protective layer are as follows:
Density of the protective layer = 2.40 t/m³
Density of seawater = 1.03 t/m³
Calculating the ratio between the density of the protective layer and the density of seawater:

$$S_r = \frac{\gamma_r}{\gamma_a}$$
$$= \frac{2,40}{1,03} = 2,33$$

The value of wave deformation height is:

$H'_0$ = 2,19 m
θ = 0,67 (1:1,5)
cot θ = 1,27
$K_D$ = 7,0

Therefore, the weight of the tetrapod can be determined by the following equation:

$$W = \frac{\gamma_r \times H^3}{K_D \times (S_r - 1)^3 \cot\theta}$$
$$= \frac{2,40 \times 2,19^3}{7,0 \times (2,33 - 1)^3 1,27}$$
$$= 1,20 \text{ ton}$$
$$= 1200 \text{ kg}$$
$$= 2,00 \text{ ton}$$

Based on the calculation of the weight of the protective layer, a protective layer with a weight of 1.20 tons is required. The tetrapod protective layer type armor with a weight of 2.0 tons from Marine Concrete Product PT. Wika, according to SNI 2847-2013, has a weight of 2.00 tons and a width of 1.42 meters, as shown in **Table 14.**


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**Table 14.** Marine concrete product tetrapod PT. Wika

| Armor Type | Weight (ton) | Width (mm) | Concrete Compresive Strength |
|---|---|---|---|
| Tetrapod 0.5t | 0,5 | 900 | fc' = 28 Mpa (Cube 350 kg/cm2) |
| Tetrapod 1.0t | 1,0 | 1130 | |
| Tetrapod 2.0t | 2,0 | 1420 | |
| Tetrapod 4.5t | 4,5 | 1870 | |
| Tetrapod 6.0t | 6,0 | 2050 | |

**Table 15.** Weight of boulder, tetrapod and dolos protective layer

| Description | Symbol | Value | | | Unit |
|---|---|---|---|---|---|
| | | Boulder | Tetrapod | Dolos | |
| Density of the protective layer | $\gamma_r$ | 2,65 | 2,40 | 2,65 | t/m³ |
| Density of seawater | $\gamma_a$ | 1,03 | 1,03 | 1,03 | t/m³ |
| Ratio of γr to γa | $S_r$ | 2,57 | 2,33 | 2,57 | |
| Wave transformation height | $H'_0$ | 2,19 | 2,19 | 2,19 | m |
| Building slope | θ | 0,67 | 0,67 | 0,67 | |
| cot θ (cotangent of the slope angle) | | 1,27 | 1,27 | 1,27 | |
| Coefficient of the protective layer | $K_D$ | 1,20 | 7,00 | 15,80 | |
| Number of protective layer grains | n | 2 | 2 | 2 | |
| Weight of each grain of the protective layer type | W | 4,68 | 2,00 | 0,38 | t |

**Table 16.** Width of tetrapod protective layer revetment

| Description | Symbol | Value | | | Unit |
|---|---|---|---|---|---|
| | | Boulder | Tetrapod | Dolos | |
| Number of protective layer grains | n | 3 | 3 | 3 | |
| Coefficient value of the protective layer | $k_\Delta$ | 1,02 | 1,04 | 1 | |
| Weight of each grain of the protective layer type | W | 4,68 | 2 | 0,38 | t |
| Density of the protective layer | $\gamma_r$ | 2,65 | 2,40 | 2,65 | t/m³ |
| Width of the revetment building | B | 3,70 | 2,94 | 1,57 | m |
| Effective width of the revetment building | | | 3,00 | 1,60 | m |

Calculating the width of the top of the tetrapod protective layer.

$$B = n\,k_\Delta \left[\frac{W}{\gamma_r}\right]^{1/3}$$

$$= 3 \times 1{,}04 \left[\frac{2{,}00}{2{,}40}\right]^{1/3}$$

$$= 2{,}94 \text{ m} \approx 3{,}00 \text{ m}$$

Number of tetrapod protective layer rows.

$$N = A\,n\,k\Delta \left[1 - \frac{P}{100}\right] \left[\frac{\gamma_r}{W}\right]^{2/3}$$

$$= 10 \times 2 \times 1{,}04 \times \left[1 - \frac{50}{100}\right] \left[\frac{2{,}40}{2{,}00}\right]^{2/3}$$

$$= 11{,}47 \approx 12{,}00 \text{ grains}$$

The following is an illustration and a summary of the calculation of the dimensions and elevations of the revetment structure.

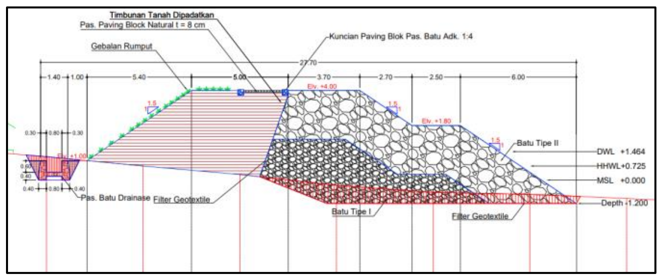


**Figure 5.** Cross Section Revetment Boulder P.1

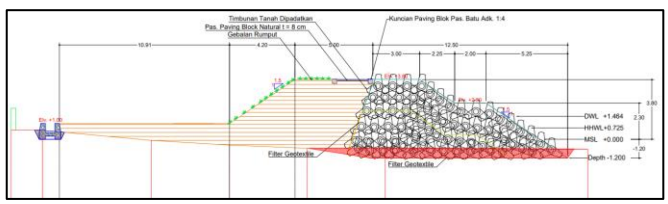


**Figure 6.** Cross Section Revetment Tetrapod P.14

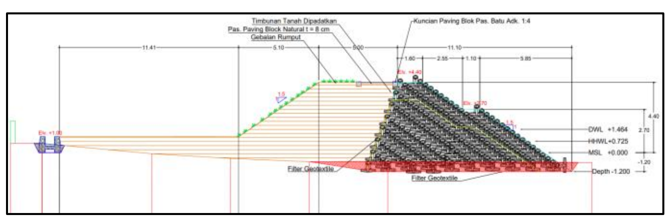


**Figure 7.** Cross Section Revetment Dolos P.14

**Table 17.** Summary of elevation and dimensions of boulder, tetrapod and dolos of revetment

| Description | Value | | | Unit |
|---|---|---|---|---|
| | Boulder | Tetrapod | Dolos | |
| Elevation 1 | 4,60 | 3,80 | 4,40 | m |
| Elevation 2 | 2,80 | 2,30 | 2,70 | m |
| Top Width | 3,70 | 3,00 | 1,60 | m |
| Thickness | 2,50 | 2,00 | 1,10 | m |
| Building Slope 1:1.5 | 33,70 | 33,70 | 33,70 | *degree* |
| HHWL | 0,73 | 0,73 | 0,73 | m |
| DWL | 1,46 | 1,46 | 1,46 | m |
| Building Foot Depth | -1,20 | -1,20 | -1,20 | m |
| Wave Height | 2,19 | 2,19 | 2,19 | m |

Based on the data from the elevation and dimension calculations for various protective layers in **Table 17**, different building elevation heights are obtained for each type of protective layer used. For the boulder stone protective layer, the peak elevation is 4.60 meters, for the tetrapod protective layer is 3.80 meters, and for the dolos protective layer is 4.40 meters. This is due to the wave run up for the three different types of protective layers, according to the characteristics of each protective layer in damping the energy from the impacting waves.

Adjusting for density, planned wave transformation height, and the coefficient of each protective layer type. For the boulder stone protective layer, the top width is 3.70 meters with the thickness of the first layer being 2.50 meters. For the tetrapod protective layer, the top width of the building is 3.00 meters with the thickness of the first layer being 2.00 meters. Meanwhile, for the dolos protective layer, the top width of the building is 1.60 meters with the thickness of the first layer being 1.10 meters.

Based on the calculation results is influenced by the different coefficients of each protective layer type, reflecting the building's ability to absorb energy from the same waves while impacting the structure.

**Table 18.** Volume of the protective layer of revetment P.14

| Type of Layer | Section Length (m) | Protective Layer Area ($m^2$) | | Total Area ($m^2$) | Volume ($m^3$) |
|---|---|---|---|---|---|
| | | Layer 1 | Layer 2 | | |
| *Boulder* | 25 | 35,96 | 24,81 | 60,77 | 1519,31 |
| *Tetrapod* | | 24,39 | 20,37 | 44,76 | 1119,07 |
| Dolos | | 12,94 | 29,16 | 42,10 | 1052,46 |

The cross-section under consideration is at point P.14, as shown in the attached image. In the calculation results for the revetment volume filled with boulder, tetrapod, and dolos protective layers, the volume for boulder stone is 1519.31 m³, tetrapod volume is 1119.07 m³, and dolos volume is 1052.46 m³. The filled volume is influenced by the peak height of the building according to the protective layer, the width of the building, and the planned depth, which is at a depth of 1.20 meters.

The revetment structure as a whole consists of 65 section divisions with a spacing of 25 meters between sections. In the volume calculation that is fulfilled according to the type of protective layer, the dimensions for P.14 are shown, representing the volume comparison conditions for other sections.

Therefore, the peak elevation, thickness of the protective layer, and width of the protective layer for the three types of materials (boulder, tetrapod, and dolos) yield different results based on the characteristics of the protective layer in dampening waves, resulting in efficient differences according to their types [11].

**Table 19.** Comparison of the results of the revetment reanalysis

| Description | | Existing | Redesign | Unit |
|---|---|---|---|---|
| Wave period in deep sea Tr | | 10,00 | 14,67 | s |
| Deformation wave height $H'_0$ | | 2,00 | 2,22 | m |
| Wave breaking height $H_b$ | | 3,338 | 3,434 | m |
| Higher High Water Level | | 0,51 | 0,73 | m |
| Breaking wave depth $d_b$ | | 2,69 | 3,51 | m |
| Revetment Elevation | Boulder | 4,00 | 4,60 | m |
| | Tetrapod | - | 3,80 | m |
| | Dolos | - | 4,40 | m |



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**Table 20.** Comparison of protective layer types

| Description | Boulder | Tetrapod | Dolos |
|---|---|---|---|
| Material | Stone | Concrete | Concrete |
| Elevation (m) | 4,60 | 3,80 | 4,40 |
| Run Up (m) | 2,84 | 2,08 | 2,67 |
| Location | On Site | Out Site | Out Site |
| Material Mobility | On Site | Pre-Cast | Pre-Cast |
| Cost | Affordable | Expensive | Expensive |
| Area (m²) | 60,77 | 44,76 | 42,10 |
| Volume (m³) | 1519,31 | 1119,07 | 1052,46 |

The wave period in the existing design is 10 seconds, while based on the calculation, the wave period in deep sea is 14.67 seconds with a 50-year recurrence interval. The deformation wave height is 2.5 meters in the existing project and 2.22 meters in the reanalysis. The breaking wave height in the existing project is 3.338 meters at a depth of 2.69 meters, while in the reanalysis, it is 3.434 meters at a depth of 3.51 meters.

The selection of the protective layer type on the revetment is based on several factors, including efficiency in dampening wave impacts, considering the magnitude of wave propagation, the cost incurred, and the material mobility to and from the project site. Based on the efficiency of the material in dampening waves, determined by the magnitude of wave propagation, the values for boulder stone, tetrapod, and dolos are 2.84 meters, 2.08 meters, and 2.67 meters, respectively. Therefore, tetrapod has better efficiency in dampening the impact of breaking waves when the propagation value is smaller compared to the other two types of protective layers. However, considering the cost and material mobility for the procurement of tetrapod, it is relatively high. There needs to be a more in-depth study on the expenditure when compared to boulder stone, which is used as the main material for the existing revetment, taking into account the location of material extraction located at the construction site, specifically at the foot of Mount Rajabasa, where direct stone mining is conducted.

In conclusion, tetrapod is more efficient in terms of wave propagation, but boulder stone is chosen based on location and lower cost. Meanwhile, dolos can be an option because it is artificial stone with better shape, coefficient, and wave propagation compared to boulder stone, but it has a more cost-efficient aspect compared to tetrapod. Based on the calculation results of the revetment building dimensions with various types of protective layers for comparison, the width of the top influences the depth of the building's foot, where with a top width of 5 meters for a soil embankment for road access in the form of paving blocks along the building, the placement of the building's foot differs for each type of protective layer [11].

## Conclusions

1. The significant wave height and period obtained account for 33% of the total highest wave height each year for 15 years. Using the Fisher Trippet Type I probability distribution method, the planned wave height in deep sea for a 5-year recurrence interval is 2.22 meters with a period of 14.67 seconds. Waves propagating toward the shoreline will undergo changes due to refraction and shoaling, with a refraction coefficient of 0.730 and a shoaling coefficient of 1.435. The resulting wave transformation height is 2.19 meters at a contour of 5 meters with a slope of 2. The breaking wave height can be determined at a 50-year recurrence interval as 3.43 meters before breaking and reaching the designed revetment structure.
2. Similar to the first scenario, the second scenario describes the wave characteristics and transformations with the same statistical approach and parameters.
3. Based on the type of protective layer used, the peak elevation of the revetment building for a 50-year recurrence interval is determined. For boulder stone protective layer, the wave propagation value is 2.84 meters, resulting in a peak elevation of 4.60 meters, with a top width of 3.70 meters, thickness of 2.50 meters, and 9 stones per 10 m². For the tetrapod protective layer, the wave propagation value is 2.08 meters, resulting in a peak elevation of 3.80 meters, with a top width of 3.00 meters, thickness of 2.00 meters, and 12 stones per 10 m². For the dolos protective layer, the wave propagation value is 2.67 meters, resulting in a peak elevation of 4.40 meters, with a top width of 1.60 meters, thickness of 1.10 meters, and 28 stones per 10 m². In a specific review along 25 meters at point P.14, the volume of boulder stone is 1519.31 m³, the volume of tetrapod is 1119.07 m³, and the volume of dolos is 1052.46 m³. The filled volume is influenced by the peak height of the building according to the protective layer, the

width of the building, and the planned depth, which is at a depth of 1.20 meters.

## Conflicts of interest

There are no conflicts to declare.

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