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Original research article

Wave Transformation Pattern in Submerged Breakwater Planning with 2D Wave Model at Mengening Beach, Badung Regency, Bali, Indonesia

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ABSTRACT

Mengening Beach is located in Badung Regency, Bali, Indonesia. The average erosion rate in Badung Regency is 1.96 m/year, so the right plan is a submerged breakwater to reduce wave energy coming to the beach, which causes erosion. This building artistically does not lessen the beauty of the beach and sea because it's below the sea mean sea water level (MSL). Because the beach is a tourist area, it is essential to maintain the beauty of the beach. Two-dimensional wave modeling uses the CMS Wave model on SMS software version 10.1 with two modeling scenarios: before and after there is a submerged breakwater. The two-dimensional wave results show that the submerged breakwater plan can dampen waves in the building placement area, which was initially 1.3 m-1.4 m high to 0.9 m-1.3 m, so this submerged breakwater plan can reduce waves by 10%-40%. From this research, readers can learn how to plan a submerged breakwater and know the performance of the planned breakwater function at Mengening Beach.

1. Introduction

As a maritime country, Indonesia consists of various archipelagic countries, so it has a very long coastline [1]. Maintaining the beach's condition in Indonesia is difficult, particularly because of erosion [2]. As time goes by, several will approblems will appearccur in coastal areas include pollution, changes in function and environmental order, and erosion [3]. One of Indonesia's provinces, Bali, is renowned for its natural beauty and 633.35 km of coastline [4]. Mengening Beach is located in Banjar Mengening, Cemagi Village, Mengwi District, Badung Regency, Bali Province, with a coastline length of 2.26 km in 2015. The average coastline change in Badung Regency is 13.75 m, and the erosion rate is an average of 1.96 m/year [5]. Ocean wave energy along the southern part of the Island Java to Nusa Tenggara with the highest power obtained around the waters of Bali [6]. Ocean wave energy can be destructivdensely populated coastal areas slated and vulnerable to coastal erosion [7].

Coastal area Mengening Beach has yet maximized for constructing coastal buildings. Because this beach has not long been known as a tourism area because of the beauty of its unspoiled beaches, this caused erosion which has impacted several coastal protection structures, namely the destruction of seawalls shown in **Figure 1** and cliffs, which became landslides in 2020 shown in **Figure 2**.

The artistic selection of the type of submerged breakwater does not reduce the beauty of the beach and sea because it is invisible and also looks like underwater coral because it is based on the Regional Regulation of the Province of Bali No. 3, 2020 regarding Amendments of Regional Regulation No. 16, 2009 concerning Regional Spatial Plans for the Province of Bali for 2009-2029 where Mengening Beach is a tourist area [8].

Figure 1. Breakdown of the seawall in 2023

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Figure 2. Bulkheads that avalanche in 2020

A breakwater is an infrastructure built to solve waves by absorbing some energy generated by waves [9] so that it can protect the area beach against waves [10]. The main objective of developing a breakwater is to reduce the height of sea waves, so coastal areas can be protected from waves that damage coastal areas [11]. The submerged breakwater structure will use tetrapod stone material because natural stone material of the same size tends to be challenging to obtain. In addition, tetrapod stone materials can be made to meet weight requirements and be designed constructively to bind more tightly together and withstand wave energy [12].

Modeling is one way to obtain characteristic waves [13]. Waves that propagate from deep waters to shallow waters (beaches) will experience changes in wave behavior (transformation) from wave properties and parameters such as refraction, shoaling, reflection, and diffraction due to the influence of the characteristics and shape of the beach [14]. Therefore, in this study, a two-dimensional wave modeling with two scenarios was carried out to determine the wave change pattern before and after a submerged breakwater plan.

The purpose of this research is to plan the construction of a submerged breakwater and to do a two-dimensional wave modeling of the breakwater plan to see whether it can reduce waves according to the breakwater function to reduce the impact of erosion on this beach.

2. Method

2.1. *Research Location*

The research location is at Mengening Beach, which is located in Banjar Mengening, Cemagi Village, Mengwi District, Badung Regency, Bali, Indonesia (Figure 3).

2.2. *Data and Equipment*

The data used in this study include (1) Study location conditions; (2) research location coordinates easting is 290660.00 and northing is 9045136.00; (3) satellite imagery on Mengening Beach; (4) design wave height, design wave period, and the direction of the waves; (5) tidal data for one year on Mengening Beach; (6) topographical and bathymetric maps of Mengening Beach. Location condition data were obtained from direct surveys at the research location on 17 August 2022 and 8 January 2023 to determine the problems that occur so that appropriate handling can be planned. Research location coordinates, and satellite imagery on Mengening Beach were obtained from Google Earth with a resolution of 1024x768, which is used in the CMS Wave modeling input. The design wave height, design wave period, and the direction of the waves obtained from the previous analysis results from engineering consultant PT. Parama Krida Pratama analyses are used in the CMS Wave modelling input. Tidal data, topographical and bathymetric maps of Mengening Beach were obtained from engineering consultant PT. Parama Krida Pratama analyses the dimensions of the submerged breakwater. The measurement of tides and topography and bathymetry will be measured in 2021 with a bathymetric map scale of 1:10000.

Figure 3. Location of the study research

2.3. *Data Analysis Methods*

This research begins with problem analysis, and then data collection is carried out with primary and secondary data. The several methods of analysis carried out are as follows.

2.3.1. *Dimensional Analysis Breakwater*

In this dimensional analysis, several parameters play an important role, namely geomorphological parameters and coastal hydro-oceanography. These parameters are the data used in this analysis from engineering consultant PT. Parama Krida Pratama analyses: the design wave height, which is 1.4 m with a wave period of 5.21 seconds, and the direction of arrival of the waves, namely from the southwest or 215°. In addition, sea level elevation based on tide data is HWL = +1.44 m, MSL = ±0.00 m, and LWL = -1.30 m.

For submerged breakwater planning, it is necessary to determine the submerged breakwater specifications as a reference and for further planning. These specifications are:

- The type of breakwater planned is a submerged offshore breakwater with a building length of 100 m consisting of 2 breakwater segments separated by a gap with a gap width of 100 m. This dimension is planned because it can provide maximum protection from threats of damage to the study area optimally and efficiently.
- Tetrapod is a concrete material with a simple, strong, and sturdy shape [15]. The submerged breakwater protection layer uses an alternative construction: artificial stone (tetrapod) on the primary layer and berm. In contrast, andesite natural stone on the second layer and core with the slope of the building is determined by $\cot\theta = 2$. Selection of the same material was also carried out in other studies [16].
- Tetrapods are developed by randomly or uniformly stacking systems with two layers of material [15].
- The peak elevation is designed to parallel sea conditions at low water level (LWL), namely at -1.30 m or 1.30 m below mean sea level (MSL), so that it is not visible at low tide according to the definition of submerged breakwater [17].
- The placement of the submerged breakwater is determined at a depth of 4 m so that the top of the building is not visible at low tide.
- Submerged breakwater comprises of several segments, including head and trunk parts [11].

The following is a dimensional calculation of the submerged breakwater structure:

a. Calculation of the peak elevation of the submerged breakwater following Eq (1) [18].

$$El_{breakwater} = LWL \tag{1}$$

Where: $El_{breakwater}$ = breakwater elevation; LWL = low water level.

b. Calculation of the height of the submerged breakwater following Eq (2) [19].

$$H_{breakwater} = El_{breakwater} - El_{seabed} \tag{2}$$

Where: $H_{breakwater}$ = breakwater height; $El_{breakwater}$ = breakwater elevation; El_{seabed} = seabed elevation.

c. Calculate the stability of the armor unit following Eq (3) and Eq (4) [20].

$$W = \frac{\gamma_r . H^3}{K_D\,(Sr\text{-}1)^3 \cot\theta} \tag{3}$$

$$S_r = \frac{\gamma_r}{\gamma_a} \tag{4}$$

Where: W = the weight of armor stone (kg); γ_r = the volumetric weight the stone (t/m³); γ_a = the volumetric weight of seawater (t/m³); H = the design wave height (m); W = breakwater height; K_D = a dimensionless stability coefficient; θ = the angle of the breakwater with the horizontal.

d. Calculation of the width of the submerged breakwater crest following Eq (5) [21].

$$B = n\, k_\Delta \left(\frac{W}{\gamma_r}\right)^{\frac{1}{3}} \tag{5}$$

Where: B = width of the breakwater crest; n = number of stonelayers; k_Δ = layer coefficient; W = the weight of the armor stone (kg); γ_r = the volumetric weight of the stone (t/m³).

e. Calculation of submerged breakwater layer thickness following Eq (6) [22].

$$t = n\, k_\Delta \left(\frac{W}{\gamma_r}\right)^{\frac{1}{3}} \tag{6}$$

Where: t = thickness of the protective layer; n = number of stonelayers; k_Δ = layer coefficient; W = the weight of the armor stone (kg); γ_r = the volumetric weight of the stone (t/m³).

f. Calculation of the number of protected layers per unit area of the submerged breakwater (10 m²) following Eq (7) [23].

$$N = A\, n\, k_\Delta \left(1-\frac{P}{100}\right)\left(\frac{\gamma r}{w}\right)^{\frac{2}{3}} \tag{7}$$

Where: N = number of stones per unit area (10 m²); A = area (10 m²); n = number of stonelayers; P = porosity coefficient; k_Δ = layer coefficient; W = the weight of the armor stone (kg); γ_r = the volumetric weight of the stone (t/m³).

g. Berms using rock piles are an extension of the primary layer of layered rock. Therefore, for the stability of the protective layer, the width, thickness, and number of stones in the berm use a calculation of Eq (3) to Eq (7) [19].

h. Calculating design stability figures [19] to control rock stability for foundations against submerged breakwater structures [24] using Eq (8) and Eq (9) and the graphs of rock $N_S{}^3$stability figures for foundations in the **Figure 4**.

$$\frac{d_1}{d_s} = \frac{H_{breakwater} - t_{berm}}{H_{breakwater}} \tag{3}$$

$$N_S{}^3 \le 24 \tag{4}$$

Where: d_s = breakwater height; $d_1 = H_{breakwater} - t_{berm}$; $N_S{}^3$= minimum design stability score.

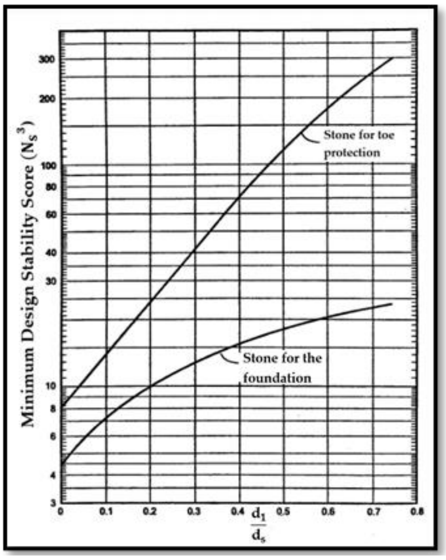

Figure 4. Graph of rock $N_S{}^3$ stability figures for foundations

2.3.2. *Wave Transformation Modelling*

Surface-Water Modeling System (SMS) is software that has capabilities as initial and final processors (pre-processor and post-processor) for modeling the water table [25]. Wave transformation analysis was completed using a two-dimensional CMS-WAVE model approach in surface-water modeling system (SMS) software version 10.1. Changes in water depth or the presence of coastal structures considerably influence wave height [26]. When the waves approach the coast, refraction occurs due to changes in water depth [27]. Input data in this model is the result of wave forecasting from previous studies that have been carried out, namely data on significant wave height, wave period, and direction of arrival of waves from the deep sea (H_s, T, θ) [28].

3. Result and Discussion

3.1. *Result of Submerged Breakwater*

In this study, the results obtained differed from other studies due to the conditions of the research location. From the differences in study locations, many things influence the differences in analysis results due to different beach characteristics, such as the amount of wind, wave height, and contour at the study location. Therefore, the dimensions of the buildings to be planned are also different at each study location. The choice of building type is adjusted to the protection needs of the study area by their respective functions, but from a planning perspective, the basic theory used is the same as that used by other researchers [10], [17]-[24].

The dimensions of the breakwater are calculated using calculations 1 to 10. Namely, the elevation of the top of the building from the submerged breakwater is determined at a low water level (LWL) which is -1.3 m. Therefore, the height of the submerged breakwater is 2.7 m.

Result of calculating using Eq (3) and Eq (4) is shown in Table 1, using Eq (5) shown in Table 2, using Eq (6) shown in Table 3 and using Eq (7) shown in Table 4.

Table 1. Calculation results of the stability of the submerged breakwater-protected layer unit

Segment	Armor Type	γ_r (ton/m^3)	W (kg)	Material
Head Part	Primary Layer	2.40	500	Tetrapod
	Secondary Layer	2.65	33	Andesite Stone
	Core Layer	2.65	2	Andesite Stone
	Berm	2.40	500	Tetrapod
Trunk Part	Primary Layer	2.40	500	Tetrapod
	Secondary Layer	2.65	23	Andesite Stone
	Core Layer	2.65	2	Andesite Stone
	Berm	2.40	500	Tetrapod

Table 2. The result of calculating the crest width of the submerged breakwater

Segment	Armor Type	γ_r (ton/m^3)	n	k_Δ	B (m)	Material
Head Part	Primary Layer	2.40	3	1.04	1.85	Tetrapod
	Secondary Layer	2.65	3	1.15	Adjust	Andesite Stone
	Core Layer	2.65	3	1.15	Adjust	Andesite Stone
	Berm	2.40	3	1.04	1.85	Tetrapod
Trunk Part	Primary Layer	2.40	3	1.04	1.85	Tetrapod
	Secondary Layer	2.65	3	1.15	Adjust	Andesite Stone
	Core Layer	2.65	3	1.15	Adjust	Andesite Stone
	Berm	2.40	3	1.04	1.85	Tetrapod

Table 3. The results of the calculation of the thickness of the submerged breakwater protection layer

Segment	Armor Type	γ_r (ton/m^3)	n	k_Δ	t (m)	Material
Head Part	Primary Layer	2.40	2	1.04	1.23	Tetrapod
	Secondary Layer	2.65	2	1.15	0.53	Andesite Stone
	Core Layer	2.65	2	1.15	0.94	Andesite Stone
	Berm	2.40	2	1.04	1.23	Tetrapod
Trunk Part	Primary Layer	2.40	2	1.04	1.23	Tetrapod
	Secondary Layer	2.65	2	1.15	0.47	Andesite Stone
	Core Layer	2.65	2	1.15	1.00	Andesite Stone
	Berm	2.40	2	1.04	1.23	Tetrapod

Table 4. Calculation results of the number of layers of submerged breakwater protection

Segment	Armor Type	γ_r (ton/m^3)	n	k_Δ	P	N (Pcs)	Material
Head Part	Primary Layer	2.40	2	1.04	50	30	Tetrapod
	Secondary Layer	2.65	2	1.15	37	274	Andesite Stone
	Core Layer	2.65	2	1.15	37	1354	Andesite Stone
	Berm	2.40	2	1.04	50	30	Tetrapod
Trunk Part	Primary Layer	2.40	2	1.04	50	30	Tetrapod
	Secondary Layer	2.65	2	1.15	37	347	Andesite Stone
	Core Layer	2.65	2	1.15	37	2555	Andesite Stone
	Berm	2.40	2	1.04	50	30	Tetrapod

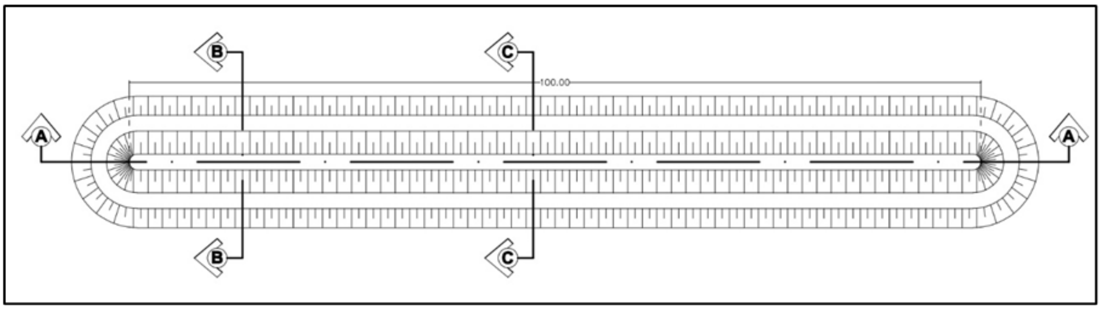

Figure 5. Layout breakwater

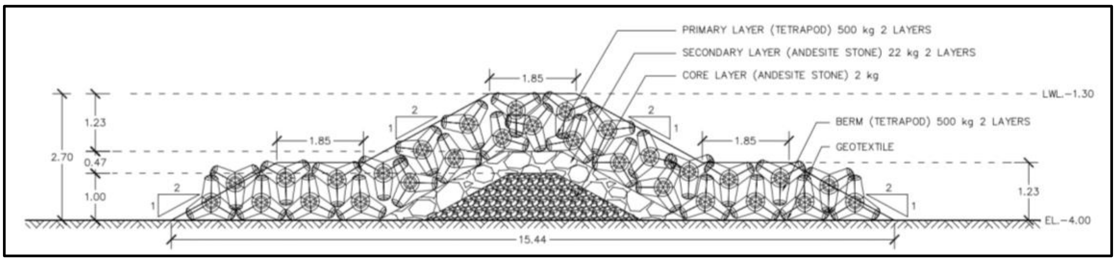

Figure 6. Cross section head part C-C

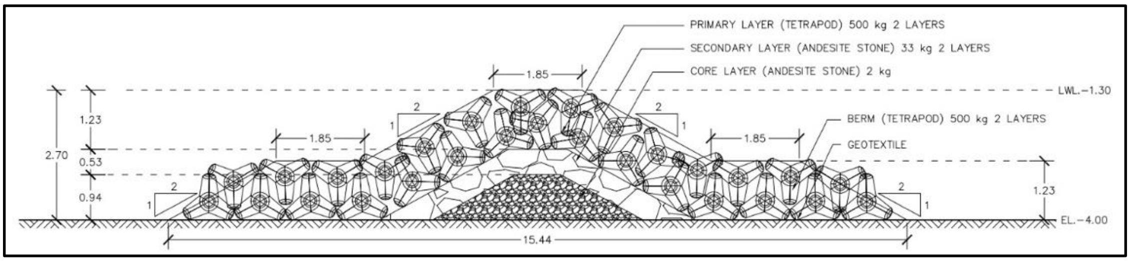

Figure 7. Cross section trunk part B-B

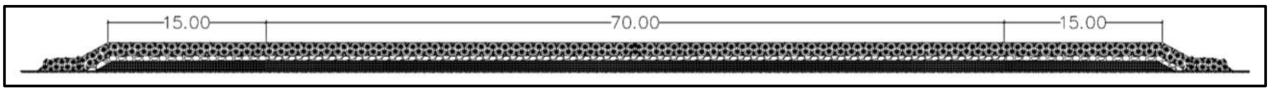

Figure 8. Long section A-A

Figure 5 results from a submerged breakwater layout plan drawing with a submerged breakwater length of 100 m. Figure 6 is the result of a submerged breakwater cross section head part C-C with details of stability of the submerged breakwater-protected layer unit in Table 1. Figure 7 is the result of a submerged breakwater cross section head part B-B with details of stability of the submerged breakwater-protected layer unit in the Table 1. Figure 8 is the result of a submerged breakwater long section A-A

The plan drawings' results in Figure 5 to Figure 8 are used as input data during modeling to determine changes in wave height due to a planned breakwater. The result of stability control for the foundation against submerged breakwater structures follow Figure 9. The foundation's stability number of N_S^3 is 18. It can be concluded that the stability of the stone for the foundation of the building is safe because of the value of $N_S^3 \leq 24$.

3.2. *Simulation Result*

In the process of planning coastal buildings, numerical analysis is used to assist the process of calculating phenomena that occur on a beach. This study used the CMS-Wave model to model the wave transformation.

The results of two-dimensional wave modeling using CMS-Wave were developed from two contour scenarios: scenario one with no submerged breakwater and scenario two with submerged breakwater.

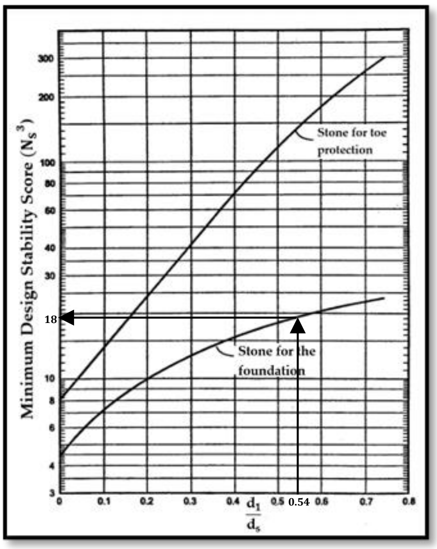

Figure 9. Graph of rock $N_S{}^3$ stability figures foundations

Figure 10 is the result of running the CMS-Wave program with scenario one. While Figure 11 is the result of running the CMS-Wave program with scenario two.

Figure 12 shows the wave profile in scenario one based on Figure 10. The wave height in the breakwater placement area reached 1.3 m-1.4 m before the breakwater. Meanwhile, Figure 13 shows the wave profile in scenario two based on Figure 11. The wave height in the breakwater placement area after the breakwater reaches 0.9 m-1.4 m. Figure 14 compares wave height profiles using scenarios one and two on breakwater one. Meanwhile, Figure 15 compares wave height profiles using scenarios one and two on breakwater two.

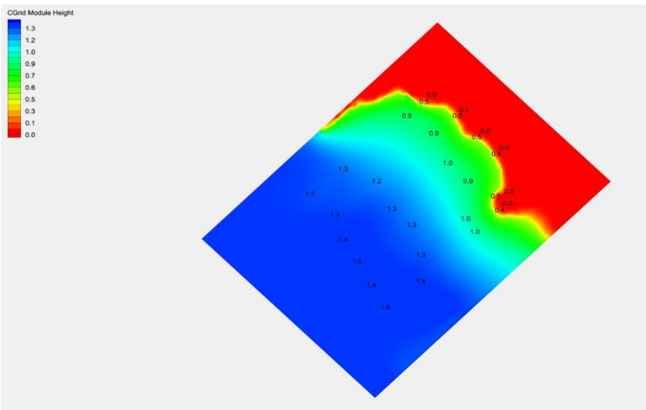

Figure 10. Wave height before there was a breakwater

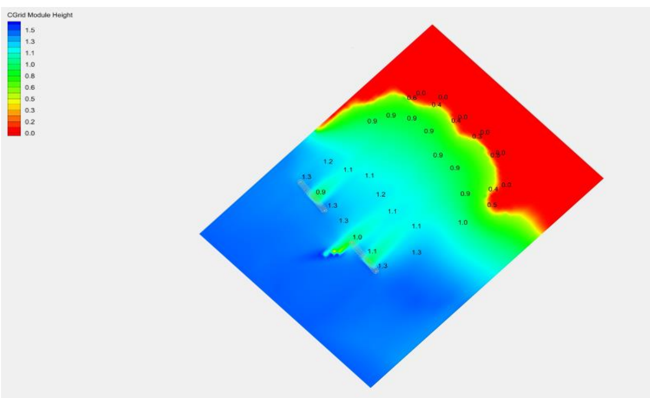

Figure 11. Wave height after there was a breakwater

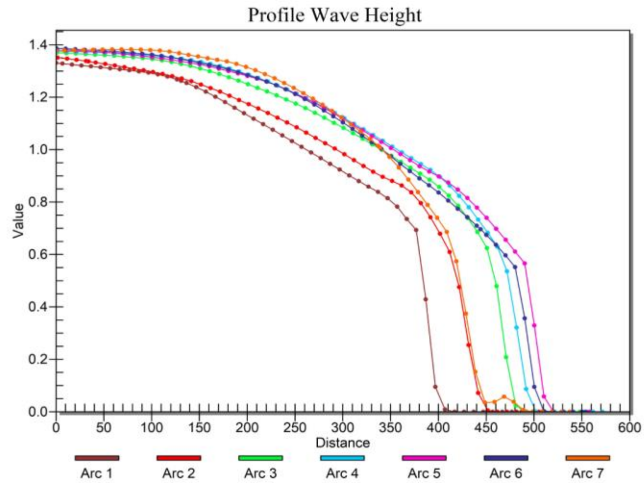

Figure 12. Profile wave height chart before there was a breakwater

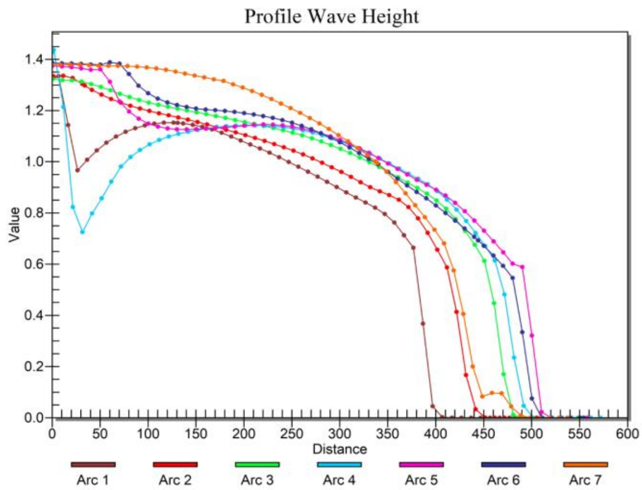

Figure 13. Profile wave height chart after there was a breakwater

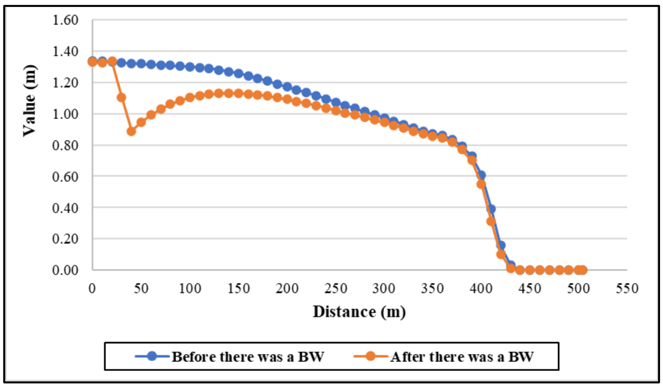

Figure 14. Profile wave height chart at breakwater 1

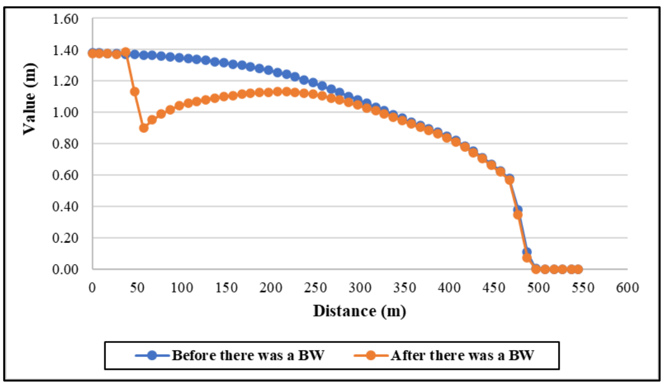

Figure 15. Profile wave height chart at breakwater 2

4. Conclusion

This research shows that apart from planning a breakwater, planners must also know whether the planned breakwater can work with its functions. Therefore, a modeling experiment must be carried out to determine the performance of the planned breakwater so that an evaluation study can be carried out if the building does not function to reduce waves.

The two-dimensional wave model simulation results show that the planned submerged breakwater can dampen waves in the building placement area, which was initially 1.3 m-1.4 m high to 0.9 m-1.3 m. This breakwater plan can reduce waves by 10%-40% so that wave energy reaching the beach and erosion can be reduced or prevented.

In addition to conducting a modeling study on the planned breakwater, it is also important to analyze other components such as materials, building layout, building slope, and environmental impact studies that affect the existence of a breakwater building.

Author Declaration

Authors' contributions and responsibilities

The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation and discussion of results. The authors read and approved the final manuscript.

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Competing interests

The authors declare no competing interest.

Additional information

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