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The Coastal Protection in Ampenan Diesel Power Plant, Mataram City, West Nusa Tenggara : Layout Design Phase

(Pelindung Pantai PLTD Ampenan, Kota Mataram, Nusa Tenggara Barat : Tahap Perencanaan Layout)

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Abstract

High waves and beach erosion are a problem in the Ampenan Diesel Power Plant facility at the Tanjung Karang Beach, Mataram City, West Nusa Tenggara Province, every year. The coastal protection structures are needed in that facility, considering the facility's importance as the electricity power supplier in Mataram City and its surroundings. This article presents the planning of coastal protection structures, especially the best layout to reduce beach erosion in that location. Firstly, the wind measurement data is analyzed, followed by the analysis of wave prediction from that wind data. The coastal process is analyzed based on available evidence to determine the cause of beach erosion in that location. Three structure alternatives were proposed and analyzed using the One-Line Model to obtain the best layout. The third alternative layout gives the best protection, which consists of a 75 m T-shape and a 75 m parallel breakwater. The construction cost estimation and method analysis also give the best result for the third alternative. The third alternative makes significant shoreline advancement in the location and gives minor adverse effects (shoreline retreat) for the surrounding area. The third alternative is still easy to build despite its significant construction cost.

Keywords— *beach erosion, coastal protection, One-Line Model, Mataram City*

I. INTRODUCTION

Mataram City is the capital of West Nusa Tenggara Province. It is located on Lombok Island, east of Bali Island. Mataram City faces the Lombok Strait with about 8 km of sandy beach. Erosion due to high waves often happens along the beach, usually from December until March every year. Moreover, the beach along Mataram City suffers slow erosion in the long term (Hutasuhut, 2019; Junaidi, 2019; Putra & Pasra, 2025; Radar Lombok, 2017; Subianto & Yuwono, 2006). However, many public facilities, like the Ampenan Diesel Power Plant (ADPP), are located along the coastline.

The ADPP belongs to the Government Electrical Company Lombok Generation Managing Unit. Its generation power capacity is 40 megawatts (MW), making it one of the big power plants in Lombok (Putra & Pasra, 2025). Therefore, the ADPP plays an important role in Mataram City's electricity supply. The ADPP is located near the shoreline because it receives marine fuel oil (MFO) for diesel machine fuel from the tanker ship. It is located on Tanjung Karang Beach, about 250m north of the Unus River, as seen in Figure 1. The west facility boundary wall of ADPP is only about 15 m from the waterline during high tide. So, the facility is threatened by erosion during high waves.

In 2008, Mataram City experienced heavy rain and strong winds for three days, developing high waves along the beach (Kompas, 2009). The Tanjung Karang Beach was eroded, and the west boundary wall of ADPP tumbled due to erosion on its wall base, as seen in Figure 2. The shallow foundation of the boundary wall also contributed to that failure. In the reconstruction phase, the boundary wall was built with a deeper foundation (about three meters deep). However, the waves can still reach the boundary wall when high waves occur again, and the alert situation will emerge again. So, comprehensive measures such as a breakwater structure are needed to protect the ADPP facility.

Figure 1. The location of Ampenan Diesel Power Plant (ADPP).

In Indonesia, much effort has been put into overcoming coastal erosion. Some locations use hard protection methods such as breakwaters, groins, jetties, or sea walls. For example, in Sanur Beach, Bali, a parallel breakwater and groin is applied (Efendi, 2016; Suhaemi & Riandini, 2013). The low crest breakwater was constructed in Tanjung Kait Beach, Tangerang, West Java (Sulaiman, 2012). A big sea wall or coastal dike was designed in Jakarta City to protect against sea floods or sea inundation (Suprayogi et al., 2017).

This article describes the design process for the beach protection structure on the ADPP, particularly the layout design. It first explains natural data, such as bathymetry, tides, and winds. Then, the alternative designs are analyzed using a numerical model.

Figure 2. The beach erosion on the west boundary wall of ADPP.

II. RESEARCH METHOD

The method of managing coastal problems has been relatively established after much experience and research, especially in the US, Europe, and Japan. The main principles for coastal problem management are as follows (Council, 2000; Management, 1990; Ministry of Public Work, 2021):

1. Identify, confirm, and quantify the coastal problem.

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2. Analyze and understand the coastal process and the cause of the problem.
3. Determine and implement the measure options with careful evaluation of the effect on the adjacent shore.
4. Consider the balance of the option’s cost and its benefits.

This article only describes the management process of the ADPP beach problem from phases 1 to 3.

Without wave measurement, the wave data can be collected from wave prediction using wind data. The Sverdrup–Munk – Bretschneider (SMB) Method is one model to predict deep-water waves (Bretschneider, 1952). The wind wave is influenced by wind speed (UA), the time the wind blows (t), and the length of the wind blow area (fetch length). The SMB Method may be applied to simple sea geometry, where fetch (F) or duration (t) is limited. The prediction of significant wave height (Hs), significant wave period (Ts), and time duration of wind blows (t) are as follows:

$$\frac{\mathrm{gHs}}{\mathrm{U_A}^2} = 1.6 \times 10^{-3} \left(\frac{\mathrm{gF}}{\mathrm{U_A}^2}\right)^{1/2} \tag{1}$$

$$\frac{\mathrm{gTs}}{\mathrm{U_A}} = 2.86 \times 10^{-1} \left(\frac{\mathrm{gF}}{\mathrm{U_A}^2}\right)^{1/3} \tag{2}$$

$$\frac{\mathrm{gt}}{\mathrm{U_A}^2} = 6.88 \times 10 \left(\frac{\mathrm{gF}}{\mathrm{U_A}^2}\right)^{2/3} \tag{3}$$

The shoreline change analysis is performed by calculating volume change using the equation of the One-Line Model (Eq. 4), which was presented first by Pelnard-Considere (Pelnard-Considere, 1957). A definition sketch of the shoreline change model is shown in Figure 3 The term y is in the cross-shore direction, and the term x is in the long-shore direction. According to the principle of sediment balance, the time variation of shoreline position can be expressed as:

$$\frac{dy}{dt} = -\frac{1}{Dc}\left(\frac{dQ}{dx} + q\right) \tag{4}$$

where dy/dt is the shoreline change rate, Dc is the closure depth, dQ/dx is the variation of sediment transport rate in the alongshore direction, and q is the on/offshore transport rate.

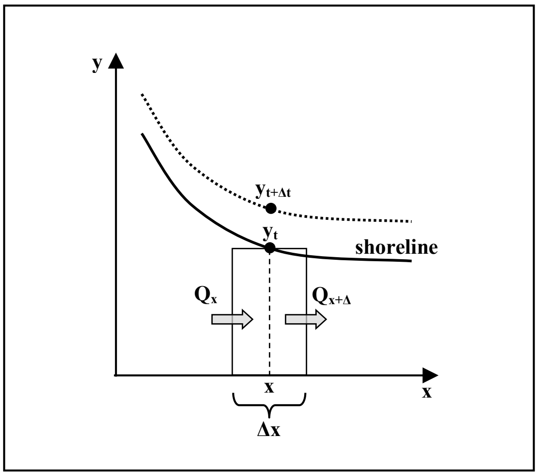

Figure 3. The sketch of the shoreline change model

Then, the new shoreline can be calculated as:

$$y_{t+\Delta t} = y_t + dy \tag{4}$$

This model can be implemented in various methods of coastal protection structures, such as breakwaters, groins, or jetties.

III. RESULTS AND DISCUSSION

A. *Bathymetry*

Figure 4 shows the bathymetry of a location 1,000 m from the Unus River to the north. The negative number of contours is sea depth, and the positive number is land height, measured from the tide's Lowest Low Water Level (LLWL). The beach slope from elevation +4.0 m LLWL until 0.0 m LLWL (red line) is relatively steep with 1 : 7 ratio. Whereas the beach slope from elevation 0.0 m LLWL until -10.0 m LLWL is relatively gentle with 1 : 44 ratio. The beach slope is relatively uniform along the shoreline

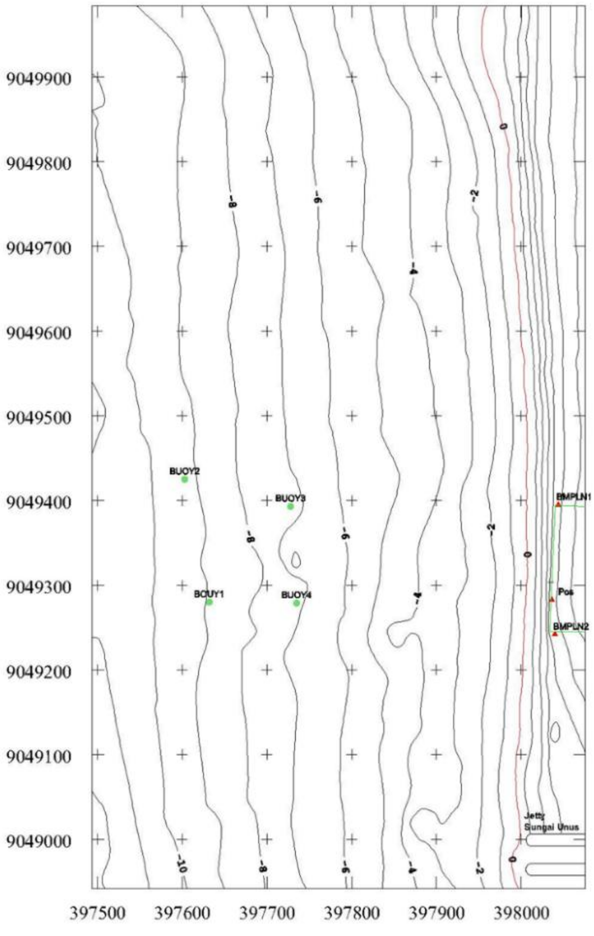

Figure 4. The bathymetry of Tanjung Karang Beach.

B. *Tide Condition*

Figure 5 shows the tide condition in Mataram Beach. It was measured in Ampenan Waters Mataram City for 25 days from May 7th, 2017, until June 1st, 2017 (Bappeda Kota Mataram et al., 2019). The measurement shows that the highest elevation is 2.17 m and the lowest is 0.01 m, so the maximum tide difference is 2.16 m. The data measurement also shows that the tidal type of Ampenan Waters is mixed mainly diurnal.

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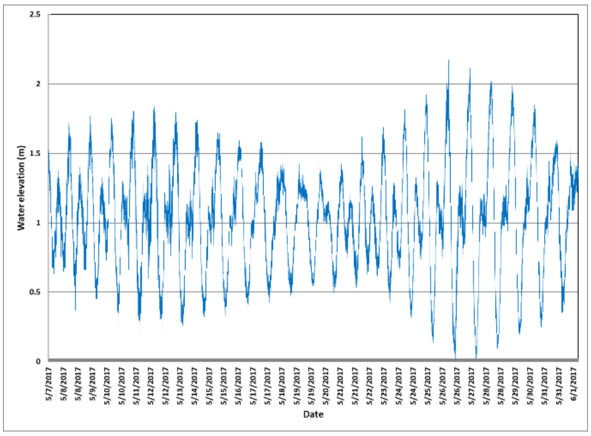

Figure 5. The tide of Ampenan Waters.

C. *Wind Condition*

Using an anemometer, the wind was measured on location for almost one year, i.e., from 24 January until 31 December 2016. The measurement is every 15 minutes, and the results are processed into hourly averages, as seen in Figure 6.

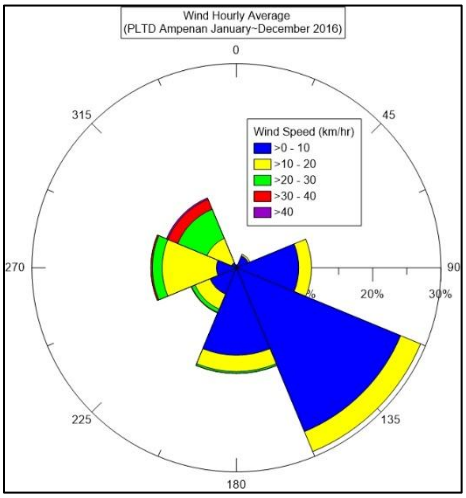

Figure 6. The wind conditions of Ampenan Waters.

D. *Wave Condition*

The condition of the waves was predicted from wind data by using the SMB Method, and the results can be seen in Figures 7. According to Figure 6, 32% of wind comes from seaward. However, only 25% of that wind generates significant wave height. The wave height can reach 1 ~ 1.5 m. Most of them have periods of 1 ~ 5 seconds. A few percent have periods of 6 ~ 10 seconds. The waves from the northwest have the most significant height and number of occurrences, i.e., 10%. The occurrence of waves from the west direction is 9%, and the southwest is 6%.

Sometimes the Mataram Beach got the swell propagated from the Indian Ocean. The swell has a 1 ~ 2 m height and a period of more than 10 seconds.

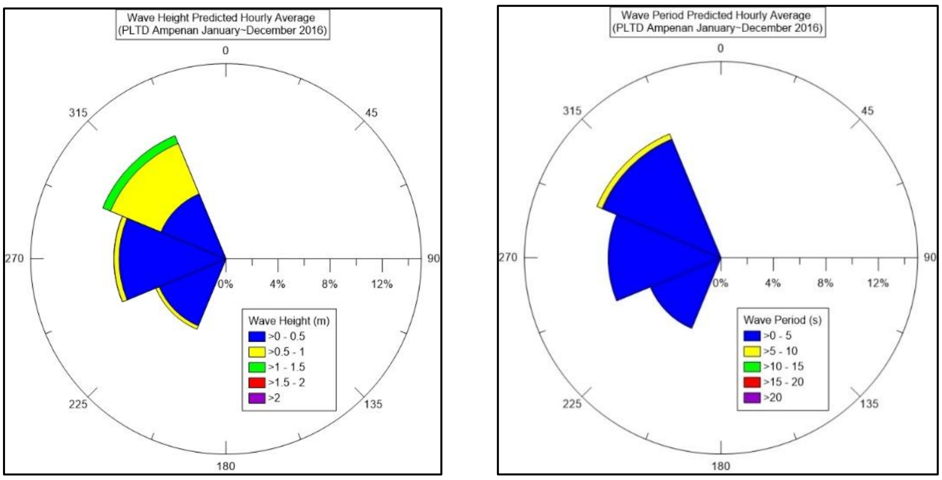

Figure 7. The wave height and wave period prediction of Ampenan Waters.

E. *Coastal Process*

The beach erosion definition is the shoreline retreat because the volume of sediment leaving the beach is more extensive than the incoming sediment volume in the particular beach area, as seen in Figure 8. The leaving–incoming sediment is caused by the sediment transport pattern, i.e., long-shore and cross-shore sediment transport. In long-term coastal processes, long-shore sediment transport has an important role. Long-shore sediment transport is caused by oblique wave activity that moves towards shoreline orientation. The incoming sediment is sourced mainly from the estuary in the surrounding coastal area. The existence of a weir or dam and increasing land use along the watershed may decrease sediment transport along the river. The incoming sediment will be less than the leaving sediment, and the shoreline will retreat gradually.

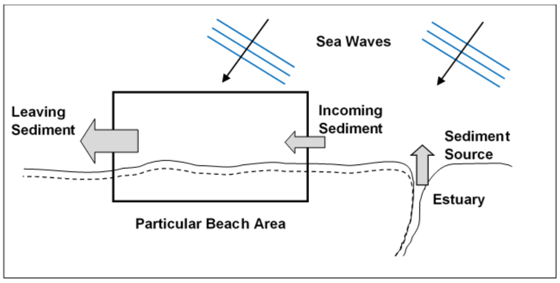

Figure 8. The long-term coastal process.

Figure 9 shows pictures of Ampenan Beach in Mataram City from a long time ago and in 2006. The old picture shows the shoreline at the boundary between the causeway and the jetty structure, while the 2006 picture shows the shoreline at the back of that boundary. It is evidence that the shoreline of Mataram City is retreating in the long term.

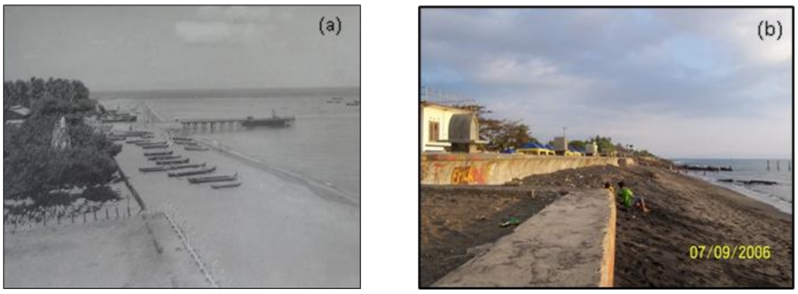

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Figure 9. The picture of Ampenan Beach in Mataram City

a) Dutch colonialization era (source: West Nusa Tenggara Museum), b) Year 2006.

On the contrary, cross-shore sediment transport has an important role in the short-term coastal processes. The high waves in a perpendicular direction will erode the sediment on the beach, bring it seaward, and place it on the nearshore area (Figure 10). The high waves event takes place only a short time (three days to one week). During the low waves event, the sediment will move back to the beach area. However, it needs a longer time.

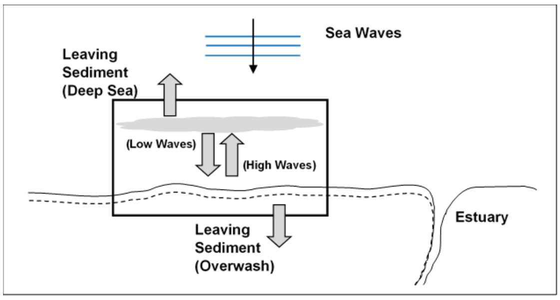

Figure 10. The short-term coastal process

As explained in the Introduction and depicted in Figure 2, the shoreline along Mataram City suffers massive erosion during high tide and high waves in a perpendicular direction. The erosion occurs quickly. The beach sediment moves seaward and settles in the nearshore area. However, the low waves can not return all the settled sediment to the beach area. Some of the settled sediment moves alongshore when the waves become oblique.

F. *Layout Design of Coastal Protection*

Based on the coastal process analysis, there are two conditions on Tanjung Karang Beach i.e. :

1. The beach suffers erosion gradually (year by year) due to long-shore sediment transport.
2. The beach also suffers significant erosion shortly due to cross-shore sediment transport.

Three design alternatives for protection structures have been proposed to overcome the erosion problem on Tanjung Karang Beach.

The first alternative is a jetty (perpendicular structure) built on the left corner of the ADPP complex as depicted in Figure 11. The jetty structure is 50 m long and 1 m high from ground level. The jetty structure has 50% permeability. The second alternative is a two-unit parallel breakwater (Figure 12). The breakwaters are 60 m long each, 1.5 m high from ground level, and placed 50 m from the ADPP complex seaward. The breakwaters are non-permeable. There is a 30 m gap between breakwater units. The gap facilitates space for an underwater fuel pipeline between the floating port and the ADPP complex. The third alternative is jetty–breakwater (Figure 13). This is a combination of both early alternatives with some modifications. The left unit is a T-shape breakwater, which consists of a 75 m parallel breakwater with a 1.5 m height and a 50 m jetty with a 1.5 m height from ground level. The breakwater is separated by 50 m on the left and 25 m on the right of the jetty structure. The right unit consists of a 75 m parallel breakwater with 1.5 m height and a 35 m jetty with 0.5 m height from ground level.

The design of coastal protection should be functional for a long time, i.e., 20 or 30 years. Therefore, the design alternatives are examined using the One–Line Model. As a model parameter, the December 2015 measured shoreline is used as the initial shoreline. The shoreline data is 1,620 m long from the Unus River mouth on the south (left side) until the Ancar River mouth on the north (right side). The wave data used the 2016 wave prediction. The sediment characteristic is sand with a diameter of D_{50} = 0.45 mm. The calibration coefficient is 0.22 on average, based on Sinarjan's work (Sinarjan, 2020).The model is run for 5 years of simulation. Figures 11, 12, and 13 also show the result of the shoreline simulation, but only along 600 m from the Unus River. Figure 14 shows the shoreline change of the simulation result in front of the ADPP and 100 m to its left.

The first alternative (Figure 11) shows a few shoreline advancements in front of the ADPP complex. The advancement is a maximum of 2.29 m and an average of 1.11 m. On average, the 100 m shoreline on the left of the jetty retreats -0.46 m. It shows a small advancement in the ADPP complex shoreline and less retreat on the left. However, the jetty structure can not overcome the cross-shore waves.

The second alternative (Figure 12) shows an advancement shoreline of 9.78 maximum and 1.15 m average on the ADPP complex. The opening section captures incoming wave energy and holds the shoreline advance at the front of the ADPP complex. On the left complex, the shoreline retreat is -7.49 m maximum and -6.21 m average. The retreat effect of the downstream structure is severe because the breakwater structure is only placed on the front of the ADPP complex. The second alternative (breakwater) may reduce the energy of cross-shore waves but gives considerable erosion on the left shoreline.

The third alternative (Figure 13) shows a more advanced shoreline on the front of the ADPP complex. The shoreline advances 9.65 m maximum and 5.18 m average. The T-shape breakwater prevents the sediment from moving to the left, and the shoreline in front of the ADPP complex moves significantly. The T-shape breakwater also reduces the retreat effect on the downstream structure. The left shoreline of the ADPP complex only retreats -4.89 m maximum and -2.55 m average.

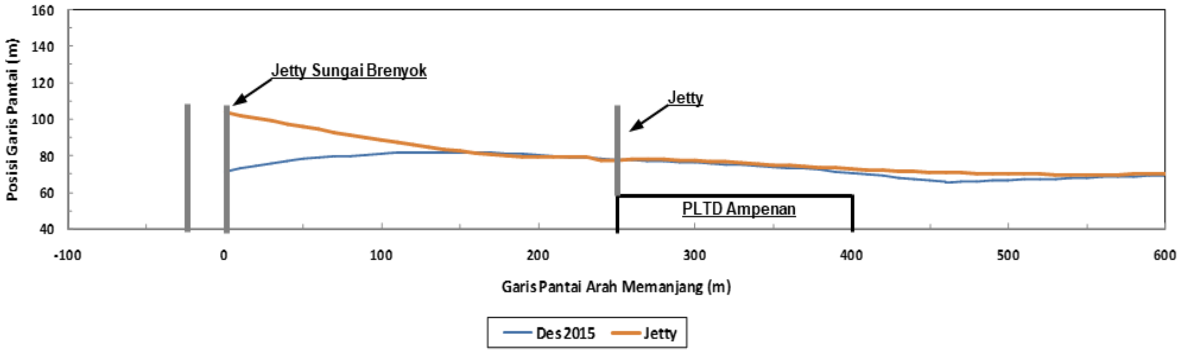

Figure 11. Jetty layout design (1st alternative)

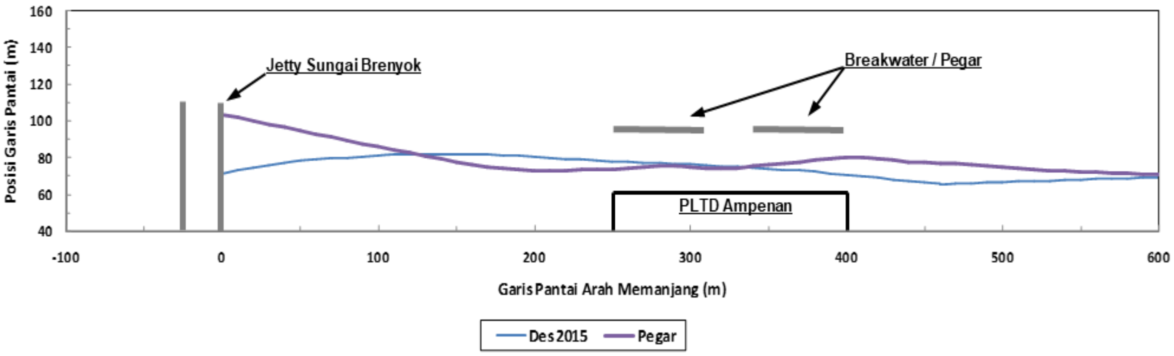

Figure 12. Breakwater layout design (2nd alternative)

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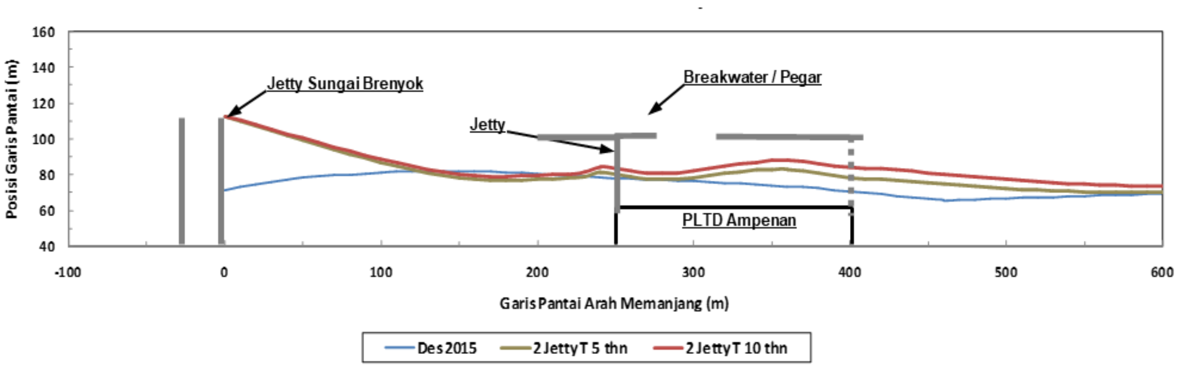

Figure 13. T-shape breakwater layout design (3rd alternative)

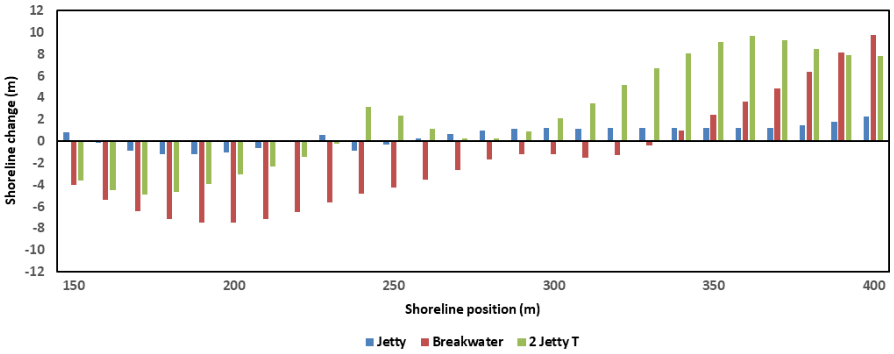

Figure 14. Shoreline change of layout simulation results

In addition to the analysis of simulation results, the design alternatives are assessed based on cost and construction method. The analysis is summarized in Table 1. The resumes show that the third alternative has more advantages than the other alternatives. The T-shaped breakwater combination provides greater shoreline advancement on the front of the ADPP complex and reduces the shoreline retreatment effect downstream of the structure. Even though the construction volume and cost are higher, the construction remains easy. The construction can be started from the inland. Therefore, the T-shaped breakwater is the best design alternative.

Table 1. Layout design evaluation

Layout Design	Advantage	Disadvantage
Jetty	Due to the oblique wave action, the perpendicular structure can block the long-shore sediment transport.	The perpendicular structure can not block the cross-shore sediment transport (or reduce the perpendicular wave action), even worsening the condition.
	The construction method is simple because it can be worked from the land side.	The perpendicular structure may have an erosion impact on the downstream side.
Breakwater	The parallel structure can block even cross-shore and long-shore sediment transport.	The parallel structure may have an erosion impact on the downstream side.
		The construction method is complex and costly
T-shape breakwater	The combination structure can block even cross-shore and long-shore sediment transport.	The construction is still costly because of the longer and larger volume.

	The T-shape layout may reduce the impact of erosion on the downstream side.	
	The construction method is simple because it can be worked from the land side.	

IV CONCLUSION

Some conclusions from the discussion are as follows:

- The maximum wind and wave conditions are dominant from the north-west. It generates the long-shore sediment transport from the north to the south.
- The Mataram Beach suffers from long-term and short-term erosion. The long-term erosion may be caused by the decreasing sediment source from the river. The short-term erosion is due to high waves in the shoreline's perpendicular direction.
- The T-shaped breakwater (third alternative) is the best design to overcome the erosion problem on the ADPP complex. The structure gives significant shoreline advancement in the ADPP complex and less erosion on the left shoreline (downstream side). The structure is also still easy to construct, even though it requires a high cost.

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