Cost analysis of repairing damage to coastal protection structures in Pariaman City, West Sumatra

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Abstract. Pariaman City is in West Sumatra Province, with a land area of 73.36 km² and a coastline length of 12.7 km. The local government has constructed coastal protection structures such as groins, jetties, and revetments to safeguard the shoreline and preserve the coastal ecosystem from damage caused by waves, abrasion, accretion, and erosion. Over time, several components of the groin, jetty, and revetment structures have experienced deterioration, necessitating repair. This study aims to identify the damage to each structure, propose appropriate repair solutions, and estimate the repair cost budget. The assessment of damage, repair guidelines, and prioritization of interventions are carried out based on the Regulation of the Minister of Public Works No. 09/PRT/M/2010 and the Circular Letter of the Minister of Public Works No. 01/SE/M/2011. This study found that the primary cause of damage was the disintegration of the rubble arrangements in several sections. The recommended repair solution involves adding new rocks and rearranging existing ones to interlock securely. The estimated cost of repairs is IDR 662,014,140.00.

1 Introduction

Pariaman City is one of the cities located in West Sumatra Province. This city lies at an elevation ranging from 2 meters to 35 meters above sea level, covering a land area of 73.36 km² and a coastline length of approximately 12.7 km [1]. Coastline changes are natural phenomena that occur continuously. These changes can manifest as coastline erosion (abrasion) or accretion (sedimentation). While sedimentation is not yet considered a threat, coastal abrasion accompanied by high waves poses a disaster risk that can result in material losses and casualties [2-5].

In efforts to protect the coastline, coastal defense structures were constructed to reduce wave energy impacting the shore, prevent abrasion, alter the rate of sediment transporting along the coast, reinforce coastal cliffs, and stabilize river mouths [6]. Between 2004 and 2011, the Pariaman City government built coastal protection structures to safeguard the shore from abrasion, accretion, and erosion by constructing groins, revetments, and jetties.

The principles of coastal protection structures are [7]:

a. a balance between supply and demand, those could be achieved by the groin structure construction.
b. Reducing the energy of waves hitting the coastal cliff, could be implemented by constructing breakwaters or the groin parallel to the coast.
c. Strengthening the coastal cliffs in order to resistant the wave, was constructed by making sea walls or revetments.
d. Adding sediment supply to the beach. This method was carried out on sandy beaches, but this activity should be a continuous activity.

Coastal abrasion refers to the erosion or reduction of land (beach) caused by wave activity, currents, and tides, which can cause shoreline retreat of approximately 6 meters per year [4, 5, 8].

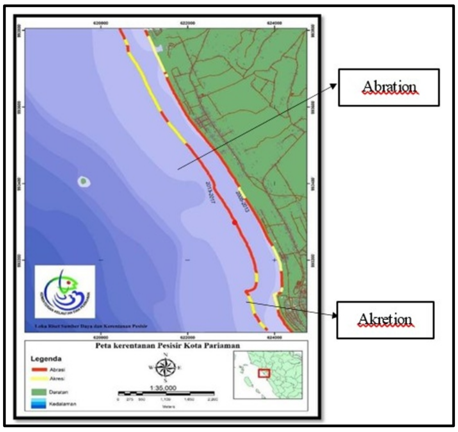

Fig. 1. Map of coastal erosion and accretion in Pariaman City (Data from the operational division, Sumatra River Basin Agency V, 2024)

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Coastal accretion is a change in the shoreline seaward due to sedimentation processes from the land or rivers, resulting in gradual shallowing toward the sea that eventually forms a delta or land protrusion [4, 5]. The occurrences of abrasion and accretion along the Pariaman coastline as shown in Fig. 1.

Coastal erosion is the process of wearing away the beach materials by waves, with the eroded materials transported elsewhere by currents. Coastal erosion occurs because the forces originating from the sea are stronger than those from the land [1]. The elevation conditions of the seabed during and after erosion at Pariaman's beach as shown in Fig. 2 and Fig. 3.

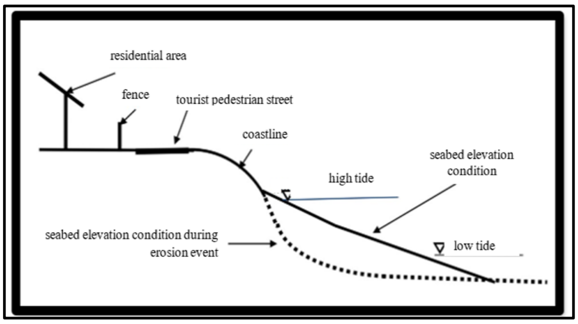

Fig. 2. Seabed elevation condition during erosion events in Pariaman City (Sumatra River Basin Agency V, 2024)

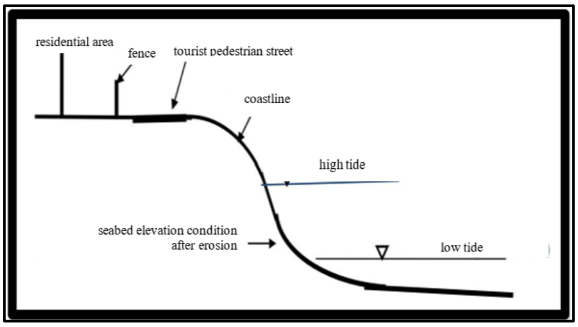

Fig. 3. Seabed elevation condition after erosion at the coastal area of Pariaman City (Sumatra River Basin Agency V, 2024).

A groin is a linear coastal structure that typically extends seaward and is oriented perpendicular to the shoreline. Its primary function is to protect the coast from erosion by partially blocking the littoral drift (the alongshore sediment transport), thereby balancing sediment input and output. This results in an increased sediment transport rate on the updrift side and a reduced rate on the downdrift side. Groins are generally applied on sandy beaches, as their primary purpose is to reduce the rate of alongshore sediment transport. Physically, groins could be classified into several types, including Type I, T-type, and L-type structures.

The coastal protection construction of groins results in reduced erosion, where the average coastline retreat for dominant waves from the southeast is 2,831 meters/year, reduced to 1,791 m/year. Whereas for dominant waves from the south, it is 1,733 m/year, reduced to 1,170 m/year [9].

A jetty is a coastal structure intended to direct water flow and protect river mouths from silting caused by sedimentation. Jetties were constructed extending sufficiently far from the river mouth, typically just beyond the breaker zone. Breaking zone was constructed, so that sediment from the upstream river still be mixed by the turbulence of breaking waves and does not settle around the river mouth.

Prevent abrasion at Bahagia Beach, Batam, is planned to build a coastal protection structure, namely a jetty, with a thickness of 3.845 m of armor stone, a thickness of 1.785 m of secondary stone, a height of 1.69 m of toe protection, and a width of 5 m of toe protection [10].

Revetment is a coastal protection structure made of rubble mound fill that functions to protects the shoreline behind it from erosion and abrasion caused by wave forces. The revetment protects the beach profile by reducing the energy of waves directly through the voids between the armor units of the protective layer. The outermost protective layer can consist of natural stones or artificial stones (concrete blocks) [11].

In Camplong Madura beach, erosion due to the coastal protection being less able to withstand large waves, considering the contour of the beach and the distribution of sedimentation which had been not well distributed, a revetment was built with a slope of 1:3 along 100 m with a peak width of 1.76 m, a height of 4.66 m, a protective layer weight of 823.40 kg [12].

Based on site observations in September 2024, several component damages had been found on the groin, jetty, and revetment structures in Pariaman.

Figure 4 shown the disintegration of rubble arrangement at the tip and body of groin one.

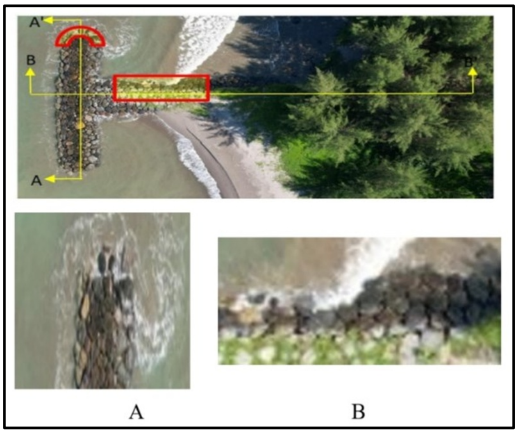

Fig. 4. Damage to the groin 1

The disintegration of rubble arrangement at the tip and body of groin two shown in Fig. 5.

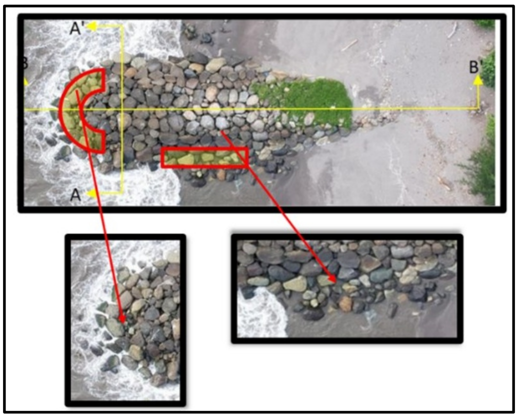

Fig. 5. Damage to the groin 2

The disintegration of rubble arrangement at the tip and body of groin three as shown in Fig. 6.

Fig. 6. Damage to the groin 3

The disintegration of rubble arrangement at the tip and body of groin four as shown in Fig. 7.

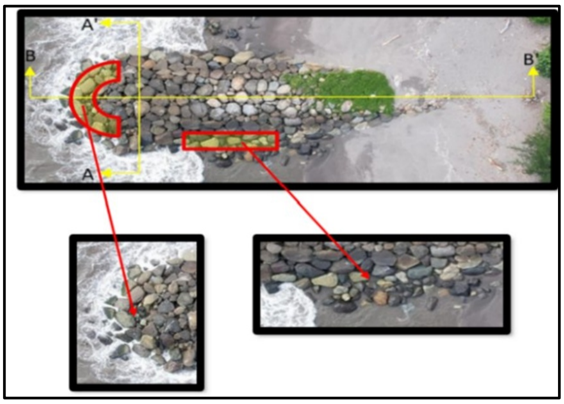

Fig. 7. Damage to the groin 4

Figure 8 shows damage to the disintegrating rubble arrangement on the outer body of the revetment structure.

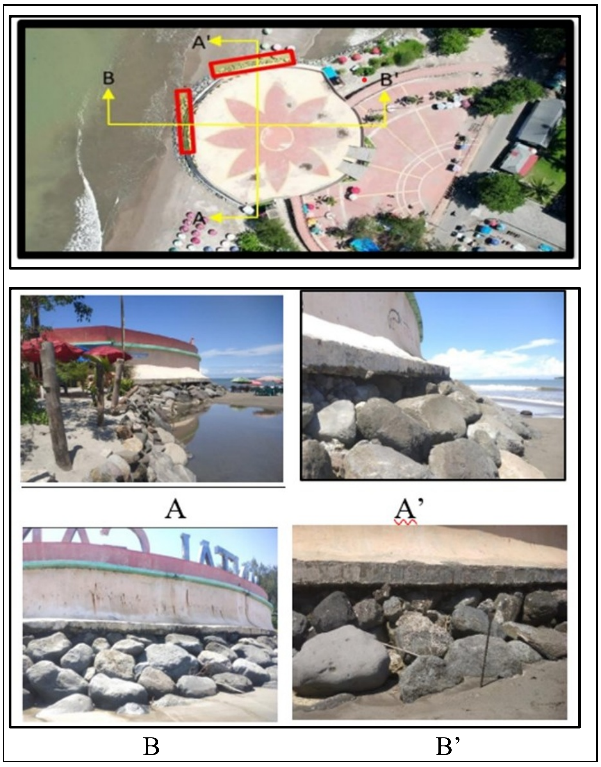

Fig. 8. Damage the revetment

Damage to the disintegrating rubble arrangement at the tip and inner body of the jetty structure as shown in Fig. 9.

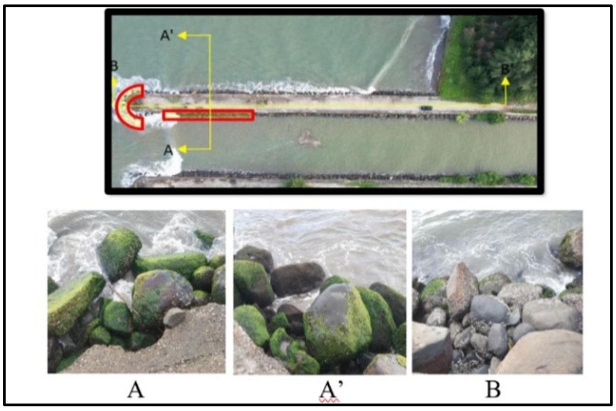

Fig. 9. Damage the jetty

Due to the significant damage observed in coastal protection structures in Pariaman, this study aims to identify the damage to each structure, propose appropriate repair solutions, and estimate the repair cost budget. The assessment of damage, repair guidelines, and prioritization of interventions are carried out based on the Regulation of the Minister of Public Works No. 09/PRT/M/2010 and the Circular Letter of the Minister of Public Works No. 01/SE/M/2011.

2 Research methodology

2.1 Data collection

Primary data had been obtained through interviews with some parties who responsible for the operational aspects of coastal protection structure maintenance and repair, and also through on-site observations (conducting direct observations and measurements of damage components found on groins, jetties, and revetments). The results of the direct measurements had been recorded using the coastal structure monitoring form in accordance with the Circular Letter of the Minister No. 01 of 2011 concerning the assessment of coastal function performance, and in accordance with the guidelines from the Sumatra V River Basin Agency 2024, West Sumatra Province.

2.2 Data processing

After conducting observations and measurements of damage to components of coastal protection structures (groins, jetties, and revetments), the next step is to assess the condition of these structures. The condition assessment system for coastal protection structure components follows the guidelines of the Sumatra V River Basin Agency 2024, with the following stages:

1. Physical Condition Evaluation
    a. Assessed based on monitoring results
    b. Condition scores had been obtained by multiplying each component's condition rating by weight.
    c. Component weights vary depending on the type of

structure
   d. The result is a structural condition index score on a scale of 1 to 4 (good to severely damaged).
2. Structural Functional Performance
   a. Functional performance determines whether the structure is still effective.
   b. Evaluation based on monitoring information.
   c. The information is analyzed by observing symptoms and impacts on the beach and protected objects (e.g., outermost islands, roads, settlements, tourism sites, public and social facilities, navigation channels)
   d. Functional performance was rated either functional or non-functional.
3. Decision Making, A decision is made on whether the structure requires repair.
   a. Repair the physical condition of the building and its function.
   b. Function performance has a significant role.
   c. Good function performance (decide on action).
   d. Poor function performance (repair the building).
   e. Poor function because the building is damaged when looking for information on the performance of the building.
4. Analyze the efficiency and effectiveness of the operational cost for repair.

3 Results and discussion

3.1 Evaluation of physical condition, functional performance, and decision-making

The evaluation of the physical conditions, functional performance, and decision-making for coastal protection structures as shown in Table 1.

3.2 Types of damage and repair actions

Table 1 shows that all coastal protection structures in Pariaman are in good condition; however, they require repairs. Table 2 shows the on-site observation on the damage primarily consists of the dislodgement of the rubble layers in several sections of the coastal protection structures and the types of damage and corresponding repair actions. The recommended corrective action by repositioning the stones to ensure interlocking and stability, and filling the voids with new rock material.

Table 1. Evaluation of physical condition, functional performance, and recommended actions for coastal protection structures in Pariaman City

Type of Structure	Physical Condition		Performance Function	Action
	Index	Condition		
Groin				
Groin 1	2,00	Quite good	Good	Repair
Groin 2	2,20	Quite good	Good	Repair
Groin 3	1,60	Quite good	Good	Repair
Groin 4	2,40	Quite good	Good	Repair
Revetment	2,5	Quite good	Good	Repair
Jetty	2	Quite good	Good	Repair

Table 2. Types of damage and repair actions

Type of Structure	Type of Damage	Repair Actions
Groin 1	The rubble arrangement has collapsed at the groin tip.	Add new stones to the vacant areas, and reposition the existing stones to ensure proper interlocking and stability.
	Rubble arrangement has collapsed on the inner section of the structure.	
Groin 2	The rubble arrangement has collapsed at the groin tip.	
	The rubble arrangement has collapsed on the outer section of the structure.	
Groin 3	The rubble arrangement has collapsed at the groin tip.	
	The rubble arrangement has collapsed on the inner section of the structure.	
Groin 4	The rubble arrangement has collapsed at the groin tip.	
	The rubble arrangement has collapsed on the outer section of the structure.	
Revetment	The rubble arrangement has collapsed on the outer side section of the structure.	Rearrange the stone layers to ensure proper interlocking, and add new stones to fill the voids at the toe section.
	The rubble arrangement has collapsed on the outer front section of the structure.	
Jetty	The rubble arrangement has collapsed at the jetty tip	Replace the stones with similar size, rearrange their positions according to the construction plan, and maintain their structural function to prevent further displacement.

3.3 Repair cost

To count the repair costs, analyze the damage that occurs to each coastal protection structure. The damage to coastal protection structures in Pariaman City is as follows:

3.3.1 Damage to the groin one

a. The rubble arrangement has collapsed at the groin one tip, as shown in Fig. 10.

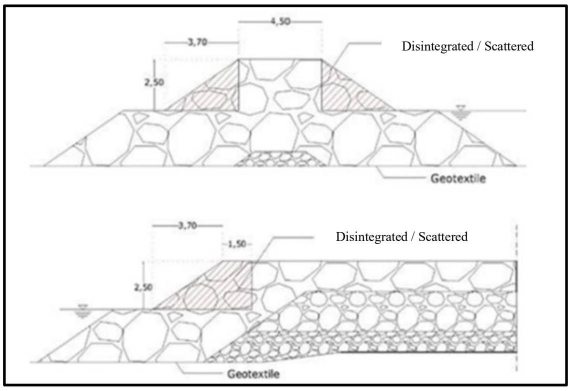

Fig. 10. The **r**ubble arrangement has collapsed at the groin one tip

b. The rubble arrangement has collapsed at the inner groin one section of the structure, as shown in Fig. 11.

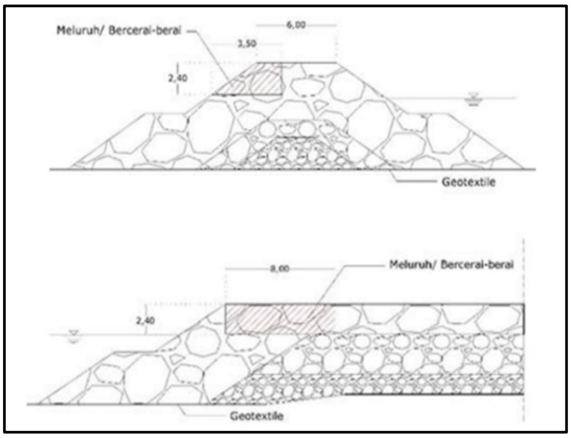

Fig. 11. The rubble arrangement has collapsed on the inner groin one section of the structure

Total volume of damage to the groin one as shown in Table 3.

Table 3. Total volume of damage to the groin one

No	Damage to the groin one	Dimension					
		Length	Wide upper	Wide sub	High	Volume	Unit
1	The rubble arrangement has collapsed in the groin tip.		1,50	5,20	2,50	39,73	m³
2	The rubble arrangement has collapsed in the inner section of the structure	8,00	2,00	3,50	2,40	52,80	m³
						Total 92,53	m³

3.3.2 Damage to the groin two

a. The rubble arrangement has collapsed at the groin two tip, as shown in Fig. 12.

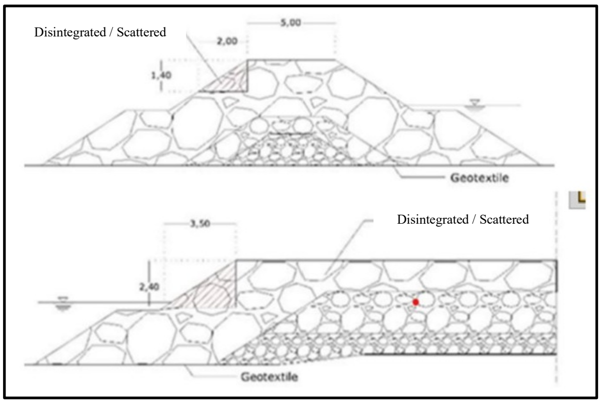

Fig. 12. The rubble arrangement has collapsed at the groin two tip

b. The rubble arrangement has collapsed at the inner groin two section of the structure, as shown in Fig. 13.

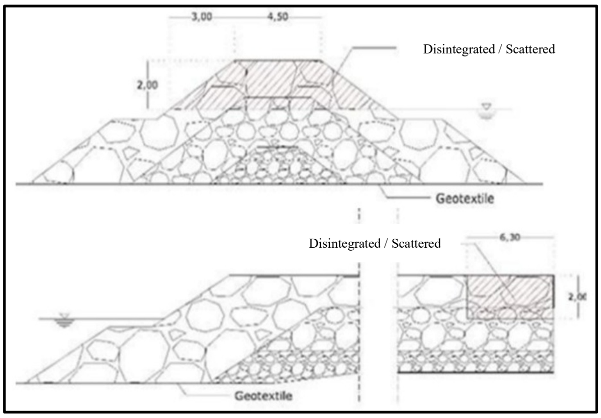

Fig. 13. The rubble arrangement has collapsed on the inner groin two section of the structure

Total volume of damage to the groin two as shown in Table 4.

Table 4. Total volume of damage to the groin two

No	Damage to the groin two	Dimension					
		Length	Wide Upper	Wide Sub	High	Volume	Unit
1	The rubble arrangement has collapsed in the groin tip.		2,50	6,00	2,40	48,40	m³
2	The rubble arrangement has collapsed in the inner section of the structure.	6,30	4,50	10,50	2,00	94,50	m³
					Total	142,90	m³

3.3.3 Damage to the groin three

a. The rubble arrangement has collapsed at the groin three tip, as shown in Fig. 14.

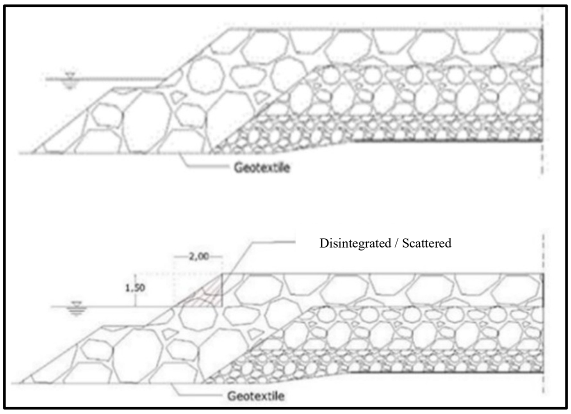

Fig. 14. The rubble arrangement has collapsed at the groin three tip

b. The rubble arrangement has collapsed at the inner groin three section of the structure, as shown in Fig. 15.

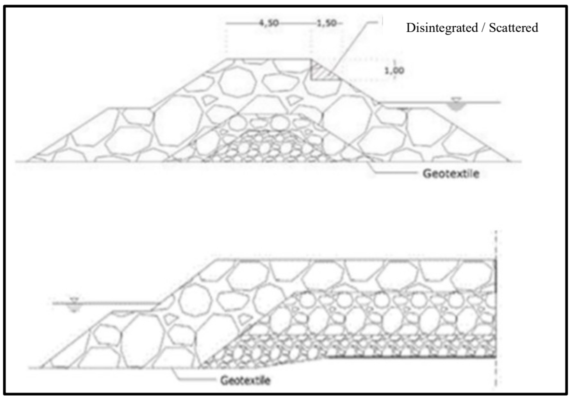

Fig. 15. The rubble arrangement has collapsed on the inner groin three section of the structure

Total volume of damage to the groin three as shown in Table 5.

Table 5. Total volume of damage to the groin three

No	Damage to the groin three	Dimension					
		Length	Wide		High	Volume	Unit
			Upper	Sub			
1	The rubble arrangement has collapsed in the groin tip.		2,00	4,00	1,50	12,57	m³
2	The rubble arrangement has collapsed in the inner section of the structure.	7,00		1,50	1,00	5,25	m³
					Total	17,82	m³

3.3.4 Damage to the groin four

a. The rubble arrangement has collapsed in the groin four tip, as shown in Fig. 16.

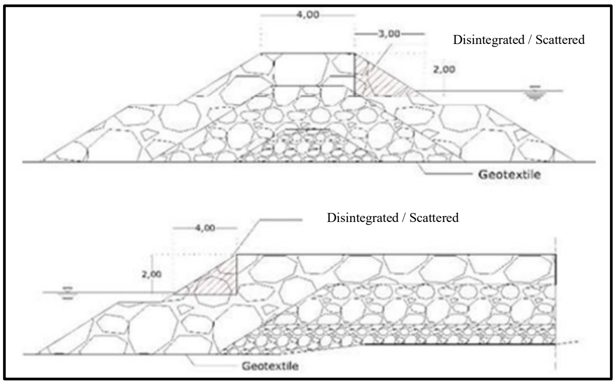

Fig. 16. The rubble arrangement has collapsed at the groin four tip

b. The rubble arrangement has collapsed at the inner groin four section of the structure, as shown in Fig. 17.

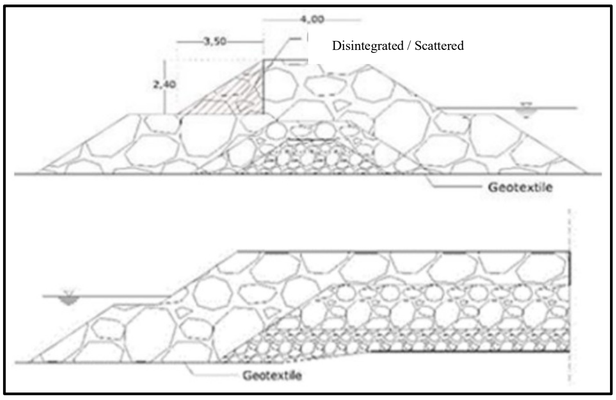

Fig. 17. The rubble arrangement has collapsed on the inner groin four section of the structure

Total volume of damage to the groin four as shown in Table 6.

Table 6. Total volume of damage to the groin four

No	Damage to the groin four	Dimension					
		Length	Wide		High	Volume	Unit
			Upper	Sub			
1	The rubble arrangement has collapsed in the groin tip.		2,00	5,00	2,00	18,84	m³
2	The rubble arrangement has collapsed in the inner section of the structure.	7,00		3,50	2,40	29,40	m³
					Total	48,24	m³

3.3.5 Damage to the revetment

The rubble arrangement has collapsed at the outer side section of the structure and rubble arrangement has collapsed at the outer front section of the structure, as shown in Fig. 18 and Fig 19.

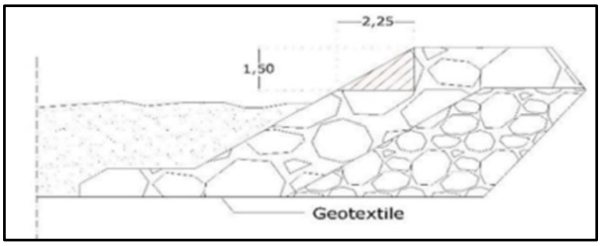

Fig. 18. The rubble arrangement has collapsed on the outer side section of the structure

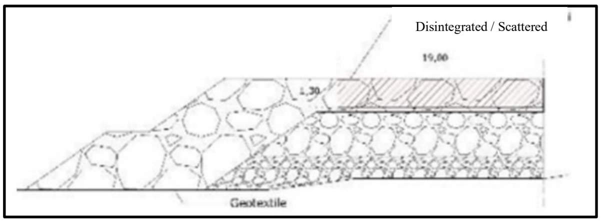

Fig. 19. The rubble arrangement has collapsed on the outer front section of the structure

Total volume of damage to the revetment as shown in Table 7.

Table 7. Total volume of damage to the revetment

No	Damage to the revetment	Dimension					
		Length	Wide Upper	Wide Sub	High	Volume	Unit
1	The rubble arrangement has collapsed in the outer side section of the structure.	19,00		1,50	1,50	15,75	m³
2	The rubble arrangement has collapsed in the outer front section of the structure.	15,00		1,50	1,50	16,88	m³
					Total	32,63	m³

3.3.6 Damage to the jetty

a. The rubble arrangement has collapsed at the jetty tip, as shown in Fig. 20.

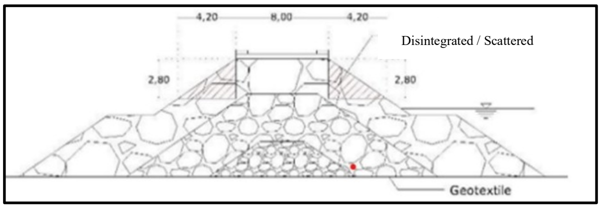

Fig. 20. The rubble arrangement has collapsed at the jetty tip

b. The rubble arrangement has collapsed at the section of the structure jetty, as shown in Fig. 21.

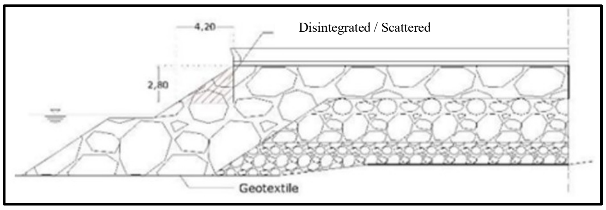

Fig. 21. Rubble arrangement has collapsed at the section of the structure's jetty

Total volume of damage to the jetty as shown in Table 8.

Table 8. Total volume of damage to the jetty

No	Damage to the jetty	Dimension					
		Length	Wide Upper	Wide Sub	High	Volume	Unit
1	The rubble arrangement has collapsed inthe jetty tip.		4,00	8,20	2,80	99,79	m³
2	The rubble arrangement has collapsed in the section of the structure's jetty.	22,00		4,20	2,80	129,36	m³
					Total	229,15	m³

The estimated repair costs for the damaged structures shown in Table 9.

Table 9. Recapitulation of repair costs for coastal protection structures in Pariaman

No	Description	Volume	Unit	Unit Price (IDR)	Total Price (IDR)
1	Preparatory works				
	1.1. Re-surveying	1	Ls	2,500,000.00	2,500,000.00
	1.2. Mobilization and demobilization of heavy equipment	1	Ls	25,000,000.00	25,000,000.00
2	Transport of armor stones (650 kg – 800 kg) to the site	583.07	m^3	254,536.69	148,413,157.60
3	Groin works				
	3.1. Groin 1	112.33	m^3	717,165.30	80,561,568.70
	3.2. Groin 2	142.90	m^3	717,165.30	102,482,921.37
	3.3. Groin 3	17.82	m^3	717,165.30	12,780,910.17
	3.4. Groin 4	48.24	m^3	717,165.30	34,596,054.07
4	Revetment works	32.63	m^3	717,165.30	23,397,517.91
5	Jetty works	229.15	m^3	717,165.30	164,339,862.83
6	Warning signs to be careful when engaging in activities at the beach building (for tourist beaches)	3	unit	779,047.38	2,337,142.13
				Subtotal	596,409,135.00
				VAT (Value Added Tax)	11%
				Grand Total	662,014,140.00

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Based on Table 9, the total estimated cost for the repair of the coastal protection structures is IDR 662,014,140.00.

4 Conclusion

The damages identified in the coastal protection structures in Pariaman require immediate repair. The primary cause of damage was the disintegration of the rubble arrangements in several sections. The recommended repair solution involves adding new rocks and rearranging existing ones to interlock securely. The estimated cost of repairs is IDR 662,014,140.00.

References

1. Wikipedia, Kota Pariaman. Available at: https://id.wikipedia.org/wiki/Kota_Pariaman
2. M.K. Aziz, A. Muslim, et al. Penanganan abrasi pantai Desa Sei Raja Kabupaten. J. Karya Teknik Sipil **5**, 63–74 (2016).
3. N. Retraubun, M. Telussa, W. Halawane. Penentuan bangunan pelindung pantai yang tepat di Desa Hatu, Kecamatan Leihitu Barat Maluku Tengah. J. Manumata **8**(1), 11–19 (2022).
4. A.Z.P.U. Richi Aldian, E. Zuryani. Perubahan garis pantai sebagai akibat dari abrasi dan akresi di kawasan pesisir Pantai Barat Sumatera Barat. In: Seminar Nasional Geoliterasi dan Pembangunan Berkelanjutan 2022 & Seminar Nasional Manajemen Bencana PSB *(SMBPSB 2022)*, 152–161 (2022).
5. N.S. Haryani, A. Irianto. Kajian perubahan garis pantai Provinsi Sumatera Barat periode 2003–2016. Tata Loka **21**(2), 293–304 (2019).
6. N. Hidayat. Konstruksi bangunan laut dan pantai sebagai alternatif perlindungan daerah pantai. J. Smartek **4**(1), 10–16 (2006).
7. C.P. Sangari, et al. Perencanaan bangunan pengaman pantai di Pantai Kalinaung Kabupaten Minahasa Utara. J. Sipil Statik **7**(8), 975–984 (2019).
8. F. Cahyati. Analisis tingkat kerusakan pantai akibat bencana abrasi di Kabupaten Bengkalis. Undergraduate thesis, 2020.
9. P. Utara, T. Baguala. Estimasi efektivitas penggunaan groin untuk mengatasi erosi pada kawasan pesisir Pantai Utara Teluk Baguala Ambon. J. Teknologi **6**(2), 703–707 (2009).
10. A. Savitri, T. Studi, T. Sipil, U.I. Batam. Perencanaan jetty di Pantai Bahagia Batam sebagai upaya pencegahan abrasi pantai. J. Komposit **7**(2), 265–274 (2023).
11. A.I. Maharani, E. Utomo. Studi bangunan pelindung pantai tipe revetment sebagai alternatif penanganan abrasi di Pantai Amal Baru Kota Tarakan. Civil Engineering Scientific Journal **3**(3), 138–149 (2024).
12. Y. Nurita, L. Disi, A. Ronie. Studi perencanaan revetment dan groin sebagai upaya penanganan erosi Pantai Camplong di Kabupaten Sampang Madura. J. Teknik Transportasi **1**(1), 70–85 (2020).