Current condition of coastal protection structures of Meulaboh, Westcoast of Sumatra Island, Indonesia

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Abstract. Meulaboh is coastal city that has tourism potential. The city has been facing coastal erosion hazard since a long time from high energy wave activity coming from Indian Ocean. To protect the coast from the erosion hazard, a coastal defence structures were built along the city's coast overlooking the Indian Ocean. Before the 2004 tsunami, hard structures built on the coast that open to waves from the Indian Ocean were damaged by daily wave activity. This study assess effectiveness of the current coastal protection structures protect coastline in the three coastal segments of the city, namely the Padang Seurahet, Ujung Karang and Kampung Pasir, in order to find out if the construction of the structures is the right choice. Related to the tourism potential of Meulaboh City also studied the possibility to expand the function of the structures. The coastal protection structures data for this study were mainly obtained from field observations in June 2021. Effectiveness of the structures protecting coastline were analysed based on technical criteria. Meanwhile, possibility to expand the function of the structures were analysed according to environmental condition of the coastal segments and types of tourism activity. The results of this study show that the hard structure that now exists on Meulaboh coast can protect the city's coast from the hazard of erosion without negatively impacting the surrounding coastline. In addition, the structure is considered to be expandable to support the development of tourism potential of Meulaboh City. Thus it can be conclude that the choice of hard structure for coastal protection in most of Meulaboh coastline is appropriate.

1. Introduction

Coastal areas are areas that are preferred to be inhabited by humans because in coastal areas there are many facilities to carry out various productive activities; and the result is that many large cities are developing in coastal areas [1, 2]. Along with the increasing number of people living in coastal areas, the problem of coastal erosion becomes important to be solved properly [3, 4].

Coastal erosion can occur due to wave activity arising from wind and or due to a reduction in the supply of sediment loads that occur naturally or due to human activities [4, 5], and coastal erosion is a coastal hazard faced by many countries with coastal areas. This situation raises various strategies to overcome the erosion hazard, either by installing engineering buildings (hard engineering structures) or by using an ecosystem-based approach (soft method), because each country or region has different environmental conditions and or objects of protection [4, 6]. In addition, the principle of action-reaction
and cost-benefit calculations are often the basis for making decisions or choosing a coastal defense strategy because the cost to build a coastal protection structure is very expensive [1, 3-5].

There are now at least five coastal erosion hazard management strategies: protection, accommodation, planned retreat, using ecosystem, and sacrifice or do nothing [3-6]. There are various choices of coastal protection methods or techniques, each of which has a different character or function from one another. Coastal protection structures that are widely chosen for coastal protection are revetments, groins, breakwaters, seawalls. A description of the character, advantages and disadvantages of these various coastal protection structures has been given, among others, by [5, 7-8].

Sometimes, the construction of coastal protection structures is not carried out properly so that the objectives of the construction of the structure are not achieved and cause new problems. Examples of these types of faults are as follows: (1) incomplete coastal protection resulting in erosion of the unprotected part of the coast; (2) placing the structure in an inappropriate location so that the structure being built is damaged; (3) improper construction calculations resulting in damage to the coastal protection structure being built (4) the selection of a structure that is not in accordance with environmental conditions so that the structure is built in vain [1].

Meulaboh City is a coastal city located on the coastal plain in the western part of Sumatra Island facing the Indian Ocean (Figure 1). This city has developed since the Dutch colonial period as a port city, and now this city is the capital of West Aceh Regency, and this city has the potential to be developed as a tourism destination [9]. To protect the coastline of Meulaboh City, coastal protection structures were built along the city's coast for a long time.

Prior to the 2004 tsunami, coastal protection structures were built but the construction was inadequate so they were damaged by daily wave activity, as happened in Padang Seurahet [10]. The condition of the Coastal protection structure after the tsunami until 2016 was as follows: in Kampung Pasir the structure was damaged due to wave activity and currents along the coast; at Ujung Karang the structure is under construction; in Padang Seurahet the structure is functioning well although there are leaks in some parts [11].

Objective of this paper is to assess appropriateness of current coastal protection structures in protecting Meulaboh coastline and possibility to expand function of the coastal structure as tourism facility. The results presented in this paper can be useful for central and local governments and planners.
in making management decisions about strategies to deal with coastal erosion hazards based on clear facts.

2. Methodology

Data on coastal protection structures were obtained from field observations carried out in June 2021, and complemented by the results of visual analysis of satellite images obtained from Google Earth dated 2021, and photographs published in various media. Field observations were specifically carried out in three coastal segments of Meulaboh City, namely the Padang Seurahet, Ujung Karang and Kampung Pasir coastal segments (Figure 1). The object of field observation is the geomorphological conditions of the coastal zones and coastal processes, and the existing coastal protection structures. Padang Seurahet segment is sandy beach part of Meulaboh bay and has curved plan shape and bounded by Ujung Karang headland and called headland-bay beach [12, 13]; Ujung Karang segment is part of Ujung Karang headland that composed of uplifted reef limestone [14]; Kampung Pasir segment is a sandy beach which is a west coast of Meulaboh tombolo [15].

Satellite images from Google Earth were used for: (1) analysis of sediment transport along the coast with a visual analysis approach of: (a) wave propagation patterns, (b) spit direction, and (c) depositional patterns that occur along the coast [16-22]; (2) measuring the length of the beach segment and coastal protection structures were done using the distance measurement facility available in Google Earth.

Identification of coastal protection structure types was carried out with reference to [5, 7, 23], and effectiveness of the coastal protection structures was assessed based on the achievement of their development goals [1] and technical criteria [24]. It also evaluates the opportunity to expand its function as a tourist attraction because Meulaboh has the potential to be developed as a beach tourism destination. The evaluation conducted based on possibility of tourism activities and environmental condition.

3. Result and Discussion

3.1. Physical Background of Study Area

The coastal plain where Meulaboh City develops is coastal lowland which is a tombolo [15]. Physically, in a flat shape, the area looks like a peninsula that juts out to the south, into the Indian Ocean. The tip of the cape is composed of carbonate reef limestone, known as the Ujung Karang area. The coastline in the coastal area of Meulaboh City is predominantly influenced by swell, which is influenced by monsoon, coming from the Indian Ocean [25,26,27], while waves generated by local winds are only 6% and dominant coming from the west according to the dominant wind direction [27]. The weak East Monsoon lasts from November – April, and the stronger West Monsoon lasts from May – October [13]. The swell approaches the coast from south to southwest, and the dominant direction is from the southwest [26, 27]. Swell height ranges from 1-3 meters with an average of 2.1 meters; dominant wave period 9-15 seconds [27].

![Figure 2. Sediment transport around Meulaboh. Image dated 24 February 2020. Image axis: 4° 07’ 33.99” N; 96° 07’ 54.48” E. Long arrows normal to coastline: dominant swell direction approaching Meulaboh coastal zone; Short arrows parallel to coastline: sediment transport direction.](image-url)
pattern around coastal structure at Suak Ujong Kalak and east coast of Ujung Karang, and spit direction at mouth of Kr Meurebo. The results of this longshore transport reconstruction are in accordance with the results of [11].

3.2. Coastal Erosion Problems

Coastal erosion hazard has long been a problem for the City of Meulaboh. The hazard that threatens the city is the hazard of erosion by wave activity coming from the Indian Ocean. The hazard of coastal erosion can also occur due to tsunami waves such as the one that occurred in 2004 [28], but the erosion hazard due to the tsunami is not included in the scope of this paper because the character of a tsunami wave is different from the nature of waves caused by wind.

Coastal erosion occurs in all parts of Meulaboh City, both on coast composed of carbonate rocks such as in the Ujung Karang area and on other parts of the coast composed of sand deposits in Kampung Pasir and Padang Seurahet. The study by [11] noted that the coastline shift landward in Kampung Pasir was around 20-50 m, in Padang Seurahet about 30-60 m, while in Ujung Karang there was no significant change. There is no explanation about the time period of the change.

In Padang Seurahet, the coastal erosion hazard threatens the coastal land which is now undeveloped land after being damaged by the 2004 tsunami. Meanwhile, in Ujung Karang, the coastal erosion hazard threatens the port area, housing and offices and the military area; while in Kampung Pasir the hazard of coastal erosion threatens residential areas.

3.3. Meulaboh Coastal Protection

The structure of the coastal protection of Meulaboh City in the three observation areas is as follows:

1) Padang Seurahet segment: this segment has been protected by a seawall of about 590 meters long. The seawall has been reinforced with irregularly installed concrete blocks, to protect the seawall (Figure 3). The coastal protection structure has been built on the same site as the one built before the 2004 tsunami. The structure effectively protect coastline.

2) Ujung Karang segment: along about 1450 meters of coastline in this segment has been protected by a revetment made of a combination of tetrapods and concrete blocks arranged neatly (Figure 4). The structure was built in 2014-2015 [11]. The structure effectively protect coastline.

3) Kampung Pasir segment: this segment extends for about 2500 meters. Most of the coastline of this segment is natural sandy beach. The seawalls have been built on two separate sections of the beach (Figure 5). At the southern end of this segment the seawall is about 220 meters long, and in the middle the seawall is about 140 meters long. In the southern part of this segment, efforts to build a seawall have been carried out repeatedly as the structure being constructed is repeatedly damaged (Figure 6).
3.4. Coastal Protection at Padang Seurahet
The coastal protection structure in this segment has been built to protect the coastal land of Padang Seurahet from the hazard of coastal erosion. Prior to the 2004 tsunami, this coastal land area was a densely populated residential area. Now, 18 years after the tsunami, the area is undeveloped land overgrown with shrubs. Technically, the current existing coastal protection structure is better than the one built before the 2004 tsunami which was a seawall without reinforcement in front so that the seawall was damaged due to the erosion of its foot [10].

The current coastal protection structure, the seawall reinforced with concrete blocks, seems to be effective in protecting the coastline from the dangers of erosion and overtopping. However, because the concrete block is not properly arranged it does not provide a beautiful view of the coastline. In addition, these coastal protection structures also block people's access from the coastal plains to the sea or sandy beaches. Now this situation is not perceived as a problem because the coastal land of Padang Seurahet is now an uninhabited area.

Taking into account local environmental conditions, to support the development of the potential of Padang Seurahet as a tourist destination in Meulaboh, it is recommended to create a sand beach by building a groin field in front of the seawall, and also equipped it with a pedestrian path for activities along the coast and enjoy the sea view.

3.5. Coastal Protection at Ujung Karang
The coastal protection structure in this segment has been built to protect the Ujung Karang area from the hazard of coastal erosion by waves coming from the Indian Ocean. The structure is effective in
protecting the Ujung Karang area from the dangers of waves in the form of coastal erosion and overtopping. Visually, the coastal protection structure looks beautiful (Figure 4).

The existence of a coastal protection structure that is higher than the protected coastal plain makes the view towards the open sea, the Indian Ocean, blocked (Figure 4). It is therefore recommended that the top of the structure be levelled so that it functions as a coastal front pedestrian path or platform that can be used as a place for recreational walking and enjoying sea views.

3.6. Coastal Protection at Kampung Pasir
Seawalls in this segment have been built locally (Figure 5). There is no information on why this has been done. However, if the location is examined, it is very possible that this was done selectively only to protect the residential areas closest to the coastline and was considered very vulnerable to the danger of coastal erosion. It can be assumed that this selective effort was made because of the enormous cost to protect the entire coastline in this segment.

In the southern part of this segment, efforts to build a seawall have been carried out repeatedly as the structure being constructed is repeatedly damaged (Figure 6). The current coastal defence structure was the last to be built. Meanwhile, in the middle of this segment, the physical structure of the coastal protection has also been seen to be damaged (Figure 5).

At his segment, there is no change in the selection of the type of coastal protection structures, namely seawalls. Thus, it can be estimated that the fate of the structure which is still in good condition will suffer damage with the same pattern of damage as the one that was built and damaged before. To prevent the same pattern of damage from happening again, it is recommended to build a coastal protection structure that can catch sediment transported along the coast and dampen waves swell coming from the Indian Ocean. The coastal protection structure in question is a groin field with a “T” shaped groin or variations thereof. When required, the groin field can be combined with a seawall or revetment. For coastal protection structures that currently exist and are still in good condition, it is recommended that they be equipped with groin or groin field to form sand deposits in front of them so that the structure is protected from the hazard of erosion that may occur.

4. Conclusion
The choice to protect the coastline with a hard structure in Meulaboh City, which is located in a high-energy coastal environment, is the right choice because it has been proven to protect the coastline from erosion. This can be seen in the Padang Seurahet and Ujung Karang beach segments. Furthermore, in addition to protecting the coastline, the coastal protection structures in the two coastal segments have the potential to be expanded into coastal tourism facilities. In the Kampung Pasir segment, which is a sandy beach, the coastal protection structure has been built only on certain parts of the coast whose coastline is close to residential areas. The seawall has been rebuilt many times and has been repeatedly damaged by wave and current activity along the coast. Therefore, in this segment it is recommended to build a coastal protection structure that can dampen waves, and inhibit and capture sediment that is transported along the coast.

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References
[1] Rangel-Buitrago N, Williams A and Anfuso G 2017 Ocean Coast Manage 116 101-10, https://doi.org/10.1016/j.ocecoaman.2017.04.006
[2] Barragen J M and Andres M 2015 Ocean. Coast. Manage. 114 11-20, http://dx.doi.org/10.1016/j.ocecoaman.2015.06.004
[3] Rangel-Buitrag N, Neal W J and de Jonge V N 2020 Ocean Coast Manage 186 105099 https://doi.org/j.ocecoaman.2020.105099
[4] Gracia A, Rangel-Buitrago N, Oakley J A and Williams A T 2018 *Ocean Coast Manage* **156** 277-289 https://dx.doi.org/10.1016/j.ocecoaman.2017.07.009
[5] Williams A, Rangel-Buitrago N G, Pranzini E and Anfuso G 2017 *Ocean Coast Manage* http://dx.doi.org/10.1016/j.ocecoaman.2017.03.022
[6] Hedge A V 2010 *Indian J. Geo-Mar. Sci.* **39** 521-530.
[7] O’Neill C R Jr (n.d.) *Structural Methods for Controlling Coastal Erosion* (Information Bulletin 200) (NY: A Cornell Cooperative Extension Program, NYS Sea Grant Extension Program, SUNY College) p 28 Retrieved from https://seagrant.sunysb.edu/glcoastal/pdfs/StructuralMethodstoControlErosion.pdf Last accessed 12 July 2021
[8] Beaver R L, Babson A L and Schupp C A (Eds) 2016 *Coastal Adaptation Strategies Handbook* (NPS 999/134090) (Washington D C: National Park Service) p 140 Retrieved 02 August 2021 from https://www.nps.gov/subjects/climatechange/coastalhandbook.htm
[9] Setyawan W B and Wulandari E 2021 Potensi Padang Seurahet, Meulaboh, sebagai tempat tujuan wisata pantai: Suatu studi pendahuluan (In Indonesian) *Prosiding Seminar Nasional Asosiasi Sekolah Perencana Indonesia* (ASPI) 2020 96-105 Retrieved from https://drive.google.com/file/d/1n6Z70VjcBM0YqXyp0nRdqSNJpDDK913C/view Last accessed 10 July 2021.
[10] Setyawan W B 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **674** 012095 https://doi.org/10.1088/1755-1315/674/1/012095
[11] Hidayat A, Syamsidik and Masimin 2016 Post-tsunami coastal structure performances around Meulaboh City, Indonesia The 3rd Int. Conf. on Sustainable Civil Engineering Structures and Construction Material, Denpasar Bali Indonesia
[12] Hsu J R – C, Yu M – J, Lee F – C and Benedet L 2010 *Coastal Engineering* **57** 76-91
[13] Klein A H F, Ferreira O, Dias J M A, Tessler M G, Silveira L F, Benedet L, De Menezes J T and De Abreu J G N 2010 *Coastal Engineer* **57** 98-111
[14] Cameron N R, Bennett J D, Bridge D McC, Clarke M C G, Djunudin A, Ghazali S A, Harahap H, Jeffery D H, Keats W, Ngabito H, Rocks N M S and Thompson S J 1983 *Geologi Lembah Takengon, Sumatera* (in Indonesian and English) (Bandung: Pusat Penelitian dan Pengembangan Geologi) p 26 + Peta Geologi skala 1:250,000
[15] Setyawan W B 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **750** 012019 https://doi.org/10.1088/1755-1315/750/1/012019
[16] Komar P D 1976 *Beach processes and sedimentation* (New Jersey: Prentice-Hall, Inc) p 429
[17] Allen J R 1982 Spits. In: *Beaches and Coastal Geology Encyclopedia of Earths Science Series* (New York: Springer) https://doi.org/10.1007/0-387-30843-1_432
[18] Dyer K R 1986 *Coastal and Estuarine Sediment Dynamic* (Chichester: John Wiley & Sons) p 342
[19] Adams P N, Inman D L and Lovering J I 2011 *Climate Change* **109** S211-S228 doi:10.1007/s10584-011-0317-0
[20] Ashton A D, Nienhuis J and Ells K 2016 *Earth Surface Dynamics* **4** 193-210 doi:10.5194/esurf-4-193-2016
[21] Klein A H F, Viera da Silva G, Taborda R, da Silva A P and Short A D 2020 Headland bypassing and overpassing: form, processes and application *Sandy Beach Morphodynamic* 557-591 doi:10.1016/b978-0-08-102927-5.00023-0
[22] Oh J – E, Chang Y S, Jeong W M, Kim K H and Ryu K R 2020 *J. Mar. Sci. Enginee.* **8** 572 doi:10.3390/jmse8080572
[23] US Army Corps of Engineers 1995 *Design of Coastal Revetments, Seawalls, and Bulkheads* (EM 1110-2-1614) (Washington, DC: Depart. of The Army, US Army Corps of Engineers) Retrieved from https://www.delmar.ca.us/DocumentCenter/View/1899/Design-of-Coastal-Revetments-Seawalls-and-Bulkheads_Army-Corps-of-Engineers-1995 Last accessed 12 July 2021
[24] Karleusa B, Krvavica N and Ruzic I 2020 *Environ Sci Proc* **2** 4 doi:
10.3390/environsci.proc2020002004

[25] Rizal A M and Ningsih N S 2020 J. Ocean Enginee. Mar. Energy https://doi.org/10.1007/s40722-020-00164-w

[26] Monecke K, Meilanda E, Walstra D–J, Hill E M, McAdoo B, Qiu Q, Storms J, Maspuptri A S, Mayasari C D, Nasir M, Riandi I, Setiawan A and Templeton C 2017 Postseismic coastal development in Aceh, Indonesia – Field observation and numerical modeling Mar. Geol. http://dx.doi.org/10.1016/j.margeo.2017.07.012

[27] Soberon A M M (n.d.) Masterplan for the Port of Meulaboh Expansion Project (Magister Thesis) (TU Delft, Faculty of Civil Engineering and Geoscience) p 161

[28] Fagherazzi S and Du X 2008 Geomorphology 99 120-9 http://dx.doi.org/10.1016/j.geomorph.2007.10.015

[29] Sondak K 2015 Menikmati suasana pantai ujong kareung di sore hari (in Indonesian) (Pasang Mata, Wisata) Retrieved from https://pasangmata.detik.com/contribution/125234 Last accessed 11 July 2021

[30] Fachrulrozi Efr 2021 Tour Andalas 2018 (@Tugu tsunami meulaboh) Gampong Pasie (in Indonesia Video 0:09) Youtube Retrieved from https://www.youtube.com/watch?v=WS7UTBKFWcKc&lc=z22rejlaypa0ibjp04t1aokgt0tyavtqzsepuf0vjsbk0h00410 Last accessed 13 July 2021

[31] Serambi TV 2016 Tanggul ambruk digerus ombak (in Indonesia Video 0:05) Youtube Retrieved from https://www.youtube.com/watch?v=is5A8X9zXIw Last accessed 12 July 2021