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Natural Coastal Protection System Preliminary Design

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ABSTRACT

Erosion is one of main problem in coastal area. Currently, natural coastal protection using vegetation such as mangrove is preferable in many places in the world (Othman, 1994; Gedan et al., 2010). However there are challenges in development of this natural coastal protection, e.g. mangrove-trees have been damaged by the waves or current, before they are growth strongly. This study focused on a combination of main natural protection and temporary manmade structures. The main protection consists of mangrove plant vegetation, expected to serve long-term protection. While temporary structure is designed to protect the growth of young mangrove from the waves and erosion, it is designed as a non-conventional rubble mound structure made of geobag with a design life is determined by growth period of mangrove seeds. The concept design criteria is considered suitable for the remote area 1) low cost; 2) manually constructed; and 3) mangrove as the main protection.

KEY WORDS: *coastal protection, erosion, mangrove, natural protection, green structure*

NOMENCLATURE

API	American Petroleum Institute
MHWS	Mean High Water Spring
H_s	Significant Wave Height
T_s	Significant Wave Period
$\cot\theta$	Seabed Slope
S_{om}	Deep Water Wave Steepness
ξ_m	Surf Similarity Parameter
ξ_{mc}	Critical Surf Similarity Parameter
$L0$	Deep Water Wave Length
g	Gravity
$\tan\theta$	Slope of the Beach
w_{stone}	Stone Mass Density
w_{water}	Water Mass Density
Δ	Relative Mass Density
N	Number of Waves during Storm Tide
S	Damage
P	Permeability Coefficient
V	Armor Volume
W_r	Sand Density
W_{50}	Armor Weight
D_{n50}	Armor Diameter
T_{wa}	Toe Protection Width
T_d	Toe Protection Height

1.0 INTRODUCTION

1.1 Background

Coastal area is susceptible from natural hazards such as storm surges, erosion and sea level rise. These may cause significant casualties and serious damage on property, infrastructures, livestock and crops. Damage to shore infrastructure is often considered to be socially and economically unacceptable. Coastal protection structure is proposed as a solution to prevent the coastal problems. There are several types of coastal protection i.e. revetment, seawall, groin, breakwater, etc. This study is focused on coastal protection due to the erosion.

The design of coastal protection should be developed with objective in providing protection to managing coastline in spatial scales that considers interactive nature of the physical processes that may be occurred as well as over longer temporal scales.

Development of coastal protection structures requires high capital cost for material, worker and heavy equipment. In some cases, e.g. in Indonesia, because the erosion is occurred in the small village at a remote, coastal protection structures are not possible to be constructed due to limitation access for material

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and heavy equipment.

In this study concept of coastal protection system that is suitable for remote area in Indonesia is proposed, with the design criteria as follow: i) low cost protection system; ii) manually constructed due to heavy equipment is out of option in most of remote areas; and iii) consists of natural vegetation as main protection because of availability mangrove trees in most coastal area in Indonesia.

Currently, natural coastal protection using vegetation such as mangrove is preferable in many places in the world (Othman, 1994; Gedan et al., 2010). There have been found in several cases that this natural coastal protection cannot work well. It is because it has been damaged by the sea forces (e.g. wave and current) before they are growth strongly.

Hence the concept of coastal protection system that is proposed in this study is a combination of natural protection and manmade structures, that consists of main and temporary protections.

This concept design described in this paper is part of the preliminary design. Further studies, including physical modeling experiment in laboratory and in the field, are considered to be carried out.

1.2 Outline of This Paper

This paper discusses conceptual design analysis of natural coastal protection system based a study case application in small fishermen village on Berau Bay. Calculation method is discussed based on several references. Design analysis consists of two parts i.e. the natural main protection and temporary structure. Conceptual design is presented in protection layout and cross section.

1.3 Methodology

In general, the following methodology is applied in this conceptual design analysis.

1. Literature study on various types of coastal erosion protection, research on natural coastal protection i.e. using mangrove and vegetation, lesson learned from existing mangrove plantation for coastal protection, various types of temporary structure, and construction method of coastal structure.
2. Preliminary design development, consists of parameter definition and assumption, determination of configuration of natural coastal erosion protection system and selection of related formula for cross section design analysis.
3. Secondary data collection of study case location. Collection of necessary available additional data from previous studies, consists of data related to design (bathymetry, river geometry, coastal and river vegetation characteristics and alternatives, etc.) and data related to construction (logistics, materials, equipment, local labor, unit cost, etc.).
4. Design of main protection i.e. determination of mangrove type and density, based on study case condition.
5. Cross section of temporary structure design shows calculation of dimension of the structure components for the study case condition.

2.0 CONCEPTUAL DESIGN ANALYSIS

In general, configuration of coastal erosion protection system that is proposed consists of two parts, i.e. main protection and temporary protection structure. The main protection is a natural protection made of mangrove plant vegetation, which is expected to be the long-term protection for eroded location. On the other hand, the temporary protection is designed to protect the growth of young mangrove in eroded area from the sea forces (e.g. waves and current) and further erosion. Typical cross section of coastal erosion protection system is illustrated in Figure 1.

2.1 Main Part of Natural Protection

The main part of natural coastal erosion protection system consists of mangrove trees that have been proved and implemented in many places as a solid structure that can shield beach profile from erosion.

Generally, mangroves are plant formations that is found growing in alluvial soil in coastal and estuaries area which is flooded by ocean tides. One of important aspect to be considered when designing the mangrove rehabilitation is the suitable habitat and planting technique. Design of type of mangrove is determined by considering the existing mangrove type existed at nearby area and its seed availability. For example, *Rhizophora* mangrove tree is shown in Figure 2. This study discusses 2 (two) types of *Rhizophora* mangrove i.e. *Rhizophora apiculata* and *Rhizophora mucronata*.

For *Rhizophora apiculata* mangrove, seedlings are ready to be plant in beach if the height is at least 30cm and consist of 4 pieces of leaves. Whereas *Rhizophora mucronata* seedlings are ready to be planted if the minimum height of 55cm and number of leaves at least 4-6 strands. Mangrove trees should be placed in the area where both wet and dry condition is occurred daily, as mangrove will not grow neither at only the wet or dry area.

In order to have daily wet and dry condition, the proposed mangrove protection should be planted at the coastline (0.0 m MSL) up to the mean low water zone. Other important consideration is the mangrove planting density, hence maximum density should be applied. Based on Khazali (1999), the required space for mangrove seedling is 1 seed per m2 or 10,000 mangrove seeds per hectare. For total required mangrove, additional 30% for replanting backup is needed to be considered.

For easy transportation between seedling area (nursery) and planting location, the mangrove seedling is prepared at a simple nursery near the location of mangrove rehabilitation, The required materials that is needed to build nursery center consists of bamboo pile and paranet or rumbia leaves as roof covers, as illustrated in Figure 3. The ideal capacity of the mangrove seedling nursery area is 3283 seeds per area of 10m x 10m (Khazali, 1999). Mangrove seedling nursery is located nearby waterfront which exposed tidal and close enough to the resident which makes it easy to be supervised.

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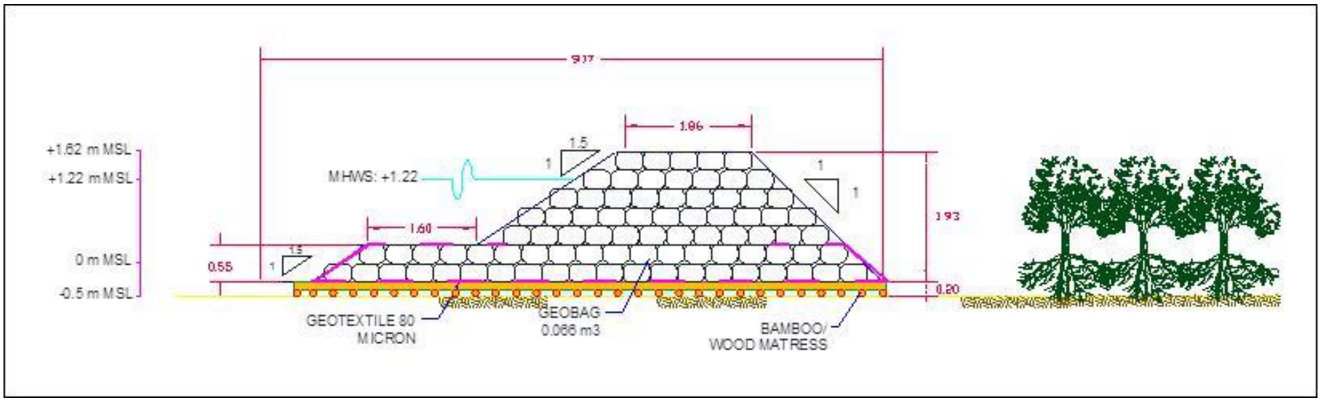

Figure 1: Cross-section of natural coastal erosion protection system.

Figure 2: Illustration of *Rhizopora* type of mangrove trees.

Figure 3: Seedling mangrove nursery area for mangrove trees.

Figure 4: Example of geobag structure in other project site in Indonesia.

2.2 Temporary Structure

Temporary structure is designed as a dyke-type structure consists of geobag. The design life is determined by the growth period of mangrove seeds, that is minimum of 2 (two) years to

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accommodate the time of planting mangrove seed and the mangrove growing until they are strong enough to serve as the erosion protection.

As it is required daily dry and wet condition, the temporary structure is designed to allow the inflow of water at high tide to supply sea water to the mangrove to help mangrove grows. Since the design location is in the remote area where access is limited, temporary structure design should consider manual construction method.

Any heavy equipment is out of option because it is very difficult to be mobilized in such area. In order to satisfy the construction method requirement, temporary structure comprises of geobag units that is possible to be lifted and arranged without any heavy equipment. It is a bag made of special material and filled with sand. Geobag material is made from a porous material that allows water to pass through without sand can get out of the bag. The illustration of geobag can be seen in Figure 4. Geobag textile material is possible to be transported to remote area by using boat, then it is be manually filled by local sand at the site.

2.3 Temporary Structure Dimension Calculation

This section discusses the calculation of temporary structure. The calculation of temporary protection structures dimension is based on Van Deer Meer (1988). Cross section of temporary structures is presented in Figure 1. Design parameters are as follow: i) The wave height and wave period are the design values for the 5 years return period (H_s = 1.1m, T_s = 5.1s); ii) Sea water density is 1.03tonnes/m^3; iii) Soil density is 1.80tonnes/m^3; iv) Seabed Slope $\cot\theta$ =1.5; and v) The Mean High Water Spring (MHWS) is +1.22m from MSL.

2.3.1 Crest Dimension

The crest width is determined based on the activity requirements on the structure surface that is 1.8m. The crest elevation of the structure is selected based on the water level at MHWS, i.e. +1.22m from MSL. Additional elevation has been taken into account is the settlement value to the MHWS water level which is assume to be 0.4m. Finally, it is obtained that the crest elevation is +1.62m from MSL.

2.3.2 Surf Similarity Parameter

In the determination of dimension of the temporary structure material, two equations of Van der Meer (1988) and Reeve (2011) are used. The first equation is for the plunging waves (breaking waves) and the second equation is for surging waves (non-breaking waves). Minimum stability is found at the transition between these two wave states. This transition can be determined by the comparison of the surf similarity parameter, ξ_m, which is shown in Equation (3).

S_{om} is the deep water wave steepness corresponding to the mean wave period and $\tan\theta$ is the slope of the beach. To calculate the S_{om}, it is necessary to calculate the deep water wave length ($L0$) by using Equation (1). The calculation result should be compared to a critical value written in Equation (4). P is permeability coefficient. In the design, the P value of 0.1 is applicable.

$$L0 = \frac{gT^2}{2\pi} \quad (1)$$

$$S_{om} = \frac{L0}{H_s} \quad (2)$$

$$\xi_m = S_{om}{}^{-0.5} \tan\theta$$

$$\xi_{mc} = \left(6.2P^{0.31}(\tan\theta)^{0.5}\right)^{\frac{1}{P+0.5}} \quad (4)$$

The formula for surging waves is shown in Equation (5). This condition is achieved when $\xi_m > \xi_{mc}$.

$$\frac{H_s}{\Delta D_{n50}} = 1.0P^{-0.13}S^{0.2}N^{0.1}\sqrt{\cot\theta}\ \xi_m{}^{P} \quad (5)$$

The formula for plunging waves is shown by Equation (6). This condition is achieved if $\xi_m < \xi_{mc}$. The value of S can be seen in Table 1, while the value of P is 0.1 for the revetment. The recommendation number of waves during storm tide is 1000<N< 3000) and the formula of relative mass density, Δ, can be seen in Equation (7).

$$\frac{H_s}{\Delta D_{n50}} = 6.2P^{0.18}S^{0.2}N^{0.1}\xi_m{}^{-0.5} \quad (6)$$

$$\Delta = \frac{w_{stone}}{w_{water}} - 1 \quad (7)$$

Table 1: Design Values for S_d for two-layer armoring (Van der Meer, 1990)

Slope	Initial Damage	Intermediate Damage	Failure
1:1.5	2	3-5	8
1:2	2	4-6	8
1:3	2	6-9	12
1:4	3	8-12	17
1:6	3	8-12	17

The calculation results is the value of critical surf similarity parameter ($\xi_{mc} = 4.52$) is greater than surf similarity parameter ($\xi_m = 4.10$). Therefore, it can be concluded that the wave characteristics is plunging. Then the calculation can be processed by using Equation (6).

2.3.3 Geobag Calculation

In order to determine geobag unit dimension, formula of armor weight calculation is used as shown by Equation (8). From the calculation, the required a Geobag unit Weight (W_{50}) is minimum of 0.025ton.

$$D_{n50} = \left(\frac{W_{50}}{W_{water}}\right)^{1/3} \quad (8)$$

The minimum required volume for one piece of armor geobag can be calculated by Equation (9).

$$V = \left(\frac{W_{50}}{W_r}\right)^{1/3} \quad (9)$$

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Based on the minimum value of geobag volume, it is chosen the geobag with the size of 0.6m length, 0.4m width and 0.275m height. Volume of the selected geobag is 0.066m^3. This volume is greater than the minimum volume (i.e. 0.014m^3), therefore it can be applicated. The dimension is also determined by considering the production ability of the geobag supplier and geobag weight so that it can be lifted by humans manually. The selected geobag weight is 119kg. As all the construction work will be handling manually, the selected geobag load is considered possible to be lifted by 1 or 2 people. The specification of material of geobag sand container is non-woven geotextile which made of double stich interlocking sewing mechanism with a polyester non-woven material, through the fabrication process.

2.3.4 Toe Protection Design

Based on Reeve (2011), the width of toe protection for structure that consisted from stone armor is 4 times the geobag diameter, while the toe protection thickness is 2 times the geobag diameter. Therefore, toe protection width (T_{wa}) is 1.6m and the toe protection height (T_d) is 0.55m.

3.0 CONCLUSION

This study successfully proposes the conceptual design of natural coastal erosion protection system which is performed to satisfy design criteria for solution of erosion problem located in remote area with limited resources. The design criteria consist of natural main protection, low cost structures and manual construction handling. Erosion protection system consists of two parts, i.e. natural main protection from mangrove and temporary protection structure that is arranged from geobag.

Main protection consists of mangrove trees which its species is determined by available existing mangrove nearby study case location. In order to allow mangroves to grow, temporary structure crest should allow overflow so that there will be daily sufficient water to maintain the requirement of dry and wet cycle. Temporary structure consists of geobag sand container which its filling material uses local sand material. This type of structure is selected because it is more flexible to the chance of deformation and reduces any heavy mobilization activities such as mobilization of rock or concrete material. Further study on design analysis such as physical modelling in laboratory is recommended to examine the durability of the system.

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