ARMOR MATERIAL SELECTION OF COASTAL PROTECTION STRUCTURE AT BINTUNI BAY, EST PAPUA INDONESIA

[1]NITA YUANITA, [2]FRIANDHAINSANFIRDHAUZ, [3]MUSLIM MUIN [4]EKOCHARNIUSILMAN

[1,2,3,4] Bandung Institute Of Technology – Indonesia
E-mail: [1]nita@ocean.itb.ac.id, [2]frianda_insanfirdaus@yahoo.com, [3]m_muin@ocean.itb.ac.id, [4]eko@ocean.itb.ac.id

Abstract- Bintuni Bay is located off Bird's Head Peninsula of New Guinea, administratively it is part of West Papua province, Indonesia. The bay is 12 miles (19.3 km) wide at its entrance and the land on both sides of northern and southern coasts are marsh. West Papua province lies in the eastern border of Indonesian Archipelago, it located about 6000 km eastern of Jakarta, capital city of Indonesia. There is a gas plant compound that had been built and operated inBintuni Bay southern coast. Due to existence of several coastal infrastructures, e.g jetties, breakwater, seawall and wharf, coastal erosion is occurred and threat the safety of the plant. In order to protect and to strengthen eroded coast, a coastal protection structure will be build alongshore of eroded coast. Coastal protection type is a rubble mound revetment structure that commonly consists of three layers i.e core layer, under layer and armor layer. Considering construction area is a remote area where most of construction equipment and material is not available nearby, suitable equipment and material need to transported from other island. Material selection especially armor material is determined based on construction method, schedule and cost. Construction method takes into account environmental condition (water depth, type of soil, current, wave and tidal), activity restriction near gas plant area, and permitted equipment. From the analysis, it is preferred to use angular stone than artificial armor (concrete unit) which it is required less construction cost and time period.

Keywords-coastal protection, armor layer, tetrapod, construction cost

I. INTRODUCTION

Coastal locations are susceptible to range of natural hazards such as storm surges, erosion and sea level change that can cause loss of life and property and damage to infrastructures, livestock and crops. Damage to shore infrastructure is often considered to be socially and economically unacceptable. The design of coastal protection should be developed with the emphasis shifting from the provision of protection to managing coastline in spatial scales that recognize the interactive nature of the processes that take place as well as over longer temporal scales. Construction project begin with the need to solve human problems, in this case is solution for coastal erosion. Cross section design of coastal protection determined by environmental condition (wave, current, soil type, water depth) and construction period of time and cost. Construction period and cost is depend on structure design (material specification and volume) and construction method at site. Construction method is procedures how the constructor will build the structure, started from material and equipment procurement, transportation and installation in project site. Construction method in coastal area is mainly affected by its environmental condition that is influenced by sea water. It is also affected by project location and special consideration that could constraint construction procedures. This paper discuss how the construction period of time and cost will determined coastal structure design, especially in considering material for armor layer.

Bintuni Bay is located off Bird's Head Peninsula of New Guinea, administratively it is part of West Papua province, Indonesia as presented in Figure 1. The bay is 12 miles (19.3 km) wide at its entrance and the land on both sides of northern and southern coasts are marsh. West Papua province lies in the eastern border of Indonesian Archipelago, it located about 6,000 km eastern of Jakarta, capital city of Indonesia. There is a gas plant compound that had been built and operated in Bintuni Bay southern coast. Due to existence of several coastal infrastructures, e.g jetties, breakwater, seawall and wharf, coastal erosion is occurred and threat the safety of the plant. In order to protect and to strengthen eroded coast, a coastal protection structure will be build alongshore of eroded coast.



Figure 1. Bintuni Bay in West Papua province in Indonesia Archipelago

Coastal protection type is a rubble mound revetment structure that consists of two layers i.e core/under layer, and armor layer. Considering construction area is a remote area where most of construction equipment and material is not available nearby, suitable equipment and material need to transported from other island. Material selection especially armor material is based on construction method, schedule and cost.

Construction method takes into account environmental condition (water depth, type of soil, current, wave and tidal), activity restriction near gas plant area, and permitted equipment. Objectives of this study is to determine coastal armor material between quarry stone and artificial unit from concrete by analyzing each alternative's construction period of time and cost. In which time period and cost is significantly depend on construction method.

II. ENVIRONMENTAL CONDITION

Tidal condition in Bintuni Bay is very dominant, with the tidal range is about 3.5 m.

Wave condition in working area is affected by monsoon, high wave season is occurred when the wave come from west. In general, wave dominantly come from east.

Longshore sediment is carried by longshore current that generated by wave. Main directions of the litoral transport in working location are East to West (E-W) direction and West to East (W-E) direction with longshore transport volume rate:

1. Q_{E-W}= 0.064 m3/s = 2,011,033 m3/year
2. Q_{W-E}= -0.051 m3/s = 1,617,139 m3/year

Thus the nettlonghore transport can be calculated i.e. 393,893.61 m3/year (East to West Direction)

Sediment transport process in project location that lead to erosion could be explained as follow: sand that carried by wave from east, trapped at the eastern part of project location due to the presence of jetty protection. This process interrupted sediment balance at the western part of jetty and caused erosion at cliff toe. Erosion rate at the eastern part of jetty was decreasing, due to sand sedimentation in that area.

III. METHODOLOGY

A. Scope of works

To obtain objectives of study, scope of works consists of:

1. Data collection: wave, tidal, bathymetry map, current, price list for certain material and equipment rent, equipment specification.
2. Cross section analysis to obtain dimension of two alternatives armor unit (quarry stone and concrete tetrapod) of coastal protection.
3. Determine construction method for coastal protection structure using each of armor alternative.
4. Scheduling analysis to obtain time period of construction for coastal protection structures using quarry stone and concrete tetrapod.
5. Cost estimation for coastal protection structures with quarry stone and concrete tetrapod armor based on construction method and scheduling analysis that had been performed.
6. Based on scheduling and cost estimation analysis, select recommended armor layer for coastal protection structure.

B. Theoretical Consideration

Typical of cross section of coastal protection structure type revetment rubble mound is presented in Figure 2.

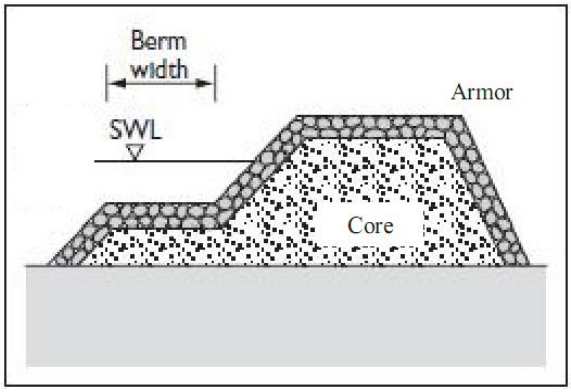


Figure 2, cross section of revetment rubble structure

The two most common methods to determine dimension of armor layer are the Hudson formula, as used by CERC (1984) in the Shore Protection Manual (SPM, 1984) or the method of van der Meer (1988).

Hudson developed a simple expression for the minimum armor weight to resist a regular wave height which may now be written in terms of the median armor unit mass, M50, relevant mass densities, and wave height, H,

$$W = \frac{w_r H_s^{\,3}}{K_D \cot\alpha \Delta^3} \quad (1)$$

Where:

W= weight of an individual armor unit in the primary cover layer (N or kN)

w_r= unit weight of armor unit (N/m^3 or kN/m^3)

H_s= design wave height at the structure site (meter)

α = slope angle of the structure

K_D = stability coefficient to take account of other variables

• = buoyant density of unit armor

$$w_r = g \cdot \rho_r \quad (2)$$

$$\Delta = \left(\frac{\rho_r}{\rho_w}\right) - 1 \quad (3)$$

Where:

ρ_r = density of armor unit (kg/m^3)

ρ_w= density of sea water (kg/m^3)

g = gravitational acceleration (m/s^2)

For concrete armor type tetrapod, van der Meer (1988) proposed formula below:

$$N_s = \frac{H_s}{\Delta D_n} = \left(3.75\, N_{od}^{0.5}/N_z^{0.25} + 0.85\right) s_{om}^{-0.2} \quad (4)$$

Where:

ρ_s= mass density of concrete (kg/m3)

D_n= Equivalent cube length, i.e., length of cube with

the same volume as tetrapod

N_{od} = Number of units displaced out of the armor layer within a strip width of one cube length

N_z = Number of waves

s_{om}= wave steepness, $s_{om}=Hs/L_{om}$

Many different concrete shapes have been developed as armor units for rubble structures. The major advantages concrete armor units is that they usually have a higher stability coefficient and thus permit the use of steeper structure side slopes or a lighter weight of armor unit than the use of quarrystone. This advantage has particular value when quarrystone of the required size is not available.

One of the earlier non-block concrete armor units was the tetrapod, developed and patented in 1950 by Neyrpic, Inc, of France (CERC, 1984). The tetrapod is an unreinforced concrete shape with four truncated conical legs projecting radially from a center point (see Figure 3)

Various other shapes such asquadripod, tribar, modified cube and hexapod (see Figure 3), have been tested by the US Corps of Engineers.It is noted that the tetrapod, quadripod and tribar are patented, but the U.S patents in these units have expired. Patents on these units may still be in force in other countries, however; payment of royalties to the holder of the patent for the use of such a unit is required. Since other units may be patented, the status of patents should be reviewed before they are used.

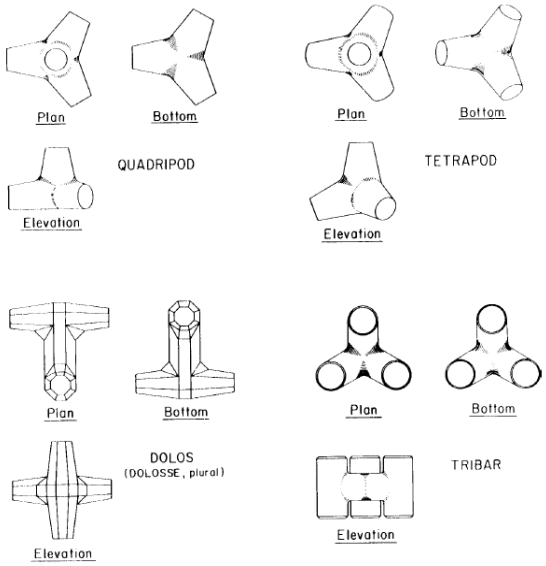


Figure 3.Various concrete armor unit: Quadripod, Tetrapod, Dolos and Tribar (CERC, 1984)

C. Design Parameters

In order to protect eroded coast, a coastal protection structure i.e. revetment is designed at the coastline below cliff. Design method followed Shore Protection Manual (1984) with design criteria is presented in Table 1.

IV. RESULTS AND DISCUSSIONS

Considering that stone quarry is not available on the island, there are two types of materials that is considered to be appliedi.e angular stone and concrete armor unit. Calculation results of dimension of alternatives armor unit is presented in Tables 2 and 3. Hs is wave height for operational condition; H1 is wave height for extreme wave 1 year return period; H10 is wave height for extreme wave 10 year return period; H25 is wave height for extreme wave 25 year return period.

Typical cross section for quarry stone armor and concrete tetrapod armor for two alternatives coastal protection is presented in Figure 4 and 5.As presented in Figures 4 and 5, coastal protection consists of geotextile as based of the structure, stone toe protection, stone under layer/core, upper geotextile that separated under layer/core and toe protection with armor layer, and armor material i.e. quarry stone and concrete tetrapod armor.

Table 1. Design Parameters

No	Parameters	Magnitude	Unit
1	Design wave height		
	Hs	0.6	meter
	H1	1.4	meter
	H10	2.3	meter
	H25	2.6	meter
2	Density of rock - ρ_r	2,650	(kg/m^3)
3	Density of concrete - ρ_c	2,400	(kg/m^3)
4	Density of sea water - ρ_w	1,025	(kg/m^3)

Table 2. Dimension of quarrystone armor unit for different wave height design

No	INPUT DATA						OUTPUT		
	H_0 (m)		Kd	Cot □	□w (kg/m3)	□r (kg/m3)	W (N)	W (ton)	Dia (m)
1	Hs	0.6	1.6	2	1025	2700	809	0.08	0.39
2	H1	1.4	1.6	2	1025	2700	12,443	1.27	0.96
3	H10	2.3	1.6	2	1025	2700	50,043	5.11	1.53
4	H25	2.61	1.6	2	1025	2700	74,090	7.56	1.75

Table 3. Dimension of tetrapod armor unit for different wave height design

No	INPUT DATA						OUTPUT		
	H_0 (m)		Kd	Cot □	□w (kg/m3)	□r (kg/m3)	W (N)	W (ton)	Dia (m)
1	Hs	0.58	7	2	1025	2400	297	0.03	0.4
2	H1	1.44	7	2	1025	2400	4,570	0.5	0.8
3	H10	2.29	7	2	1025	2400	18,380	1.9	1.4
4	H25	2.61	7	2	1025	2400	27,212	2.8	1.6

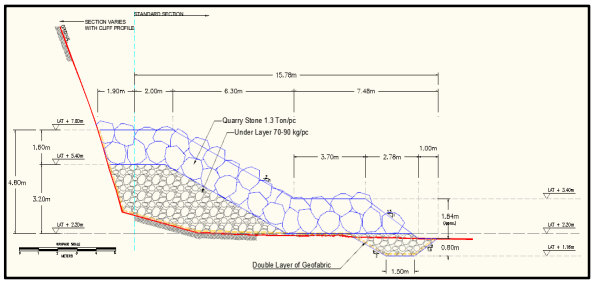


Figure 4. Typical cross section of quarry stone armor coastal protection

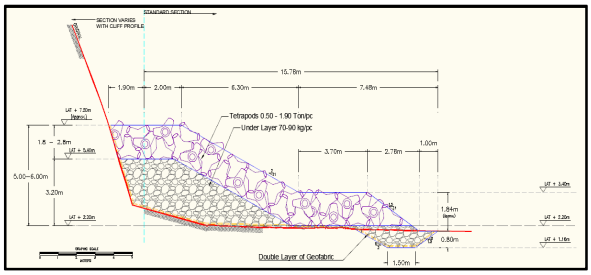


Figure 5. Typical cross section of tetrapod armor coastal protection

A. Construction Method

Construction method of coastal structure will effecteditscost and total time. In analysis of construction method of coastal protection, several aspects is considered as follow:

1) Environmental Condition.

- Tidal, is a slow water surface movement due to interaction between the earth, the moon and the sun gravitation. Tidal condition in project location is relatively high with tidal range (distance from lowest to highest water level) is about 3.5 m. Construction activity is constrained by tidal condition i.e. only in low water condition, construction activity in high water is very dangerous. Tidal will also affected transportation barge or vessel is not possible to approaching to temporary construction jetty.
- Current velocity in coastal area, magnitude of current velocity in project area is generated by tidal and wave, majorly effected by tidal current that relatively strong. Strong current threats construction activities and material/equipment offloading from barge/vessel to jetty. Thus construction activities performs only in low water condition, which mean there are no water current that disturb construction activities.
- Soil type in project location where the protection structure will be built is mixed between sand and soft clay. It is very difficult to do construction activities on soft clay.
- Coastal Profile, or slope of coastal profile in project area is very flat with slope about 1:1000, thus when the water level is increasing it will covered most of the coastal area, but in the contrary when the low water is occurred a wide dry area is appeared.

2) Safety Regulation

Due to its location in gas plant area there are several regulation that must be obeyed. Construction method and equipment selection must consider this regulation e.g.construction activities inside water is prohibited;

3) Permitted Equipment

Only permitted equipment is used in work location. Construction equipment that causing vibration such as Dozer, Vibro compactor, Dump truck and pile piling, is forbidden to work near gas plant (work area).

In general construction method assumption is as follow:

a) Construction jetty is using old construction jetty
b) Transportation of stone is from Sulawesi to site by using 1000ton material barge with draft no more than 2 m in full load. Material are directly offloading at construction jetty.
c) The excavator is able to go down to shore during low tide.
d) Material are stocked near old construction jetty
e) The excavator can reach all places required

Coastal protection area is divided into 20 sections as illustrated in Figure 6, construction of coastal structure is move from one section to another after activities in one section is finished. Procedure that is implemented in each section is illustrated in Figure 7.

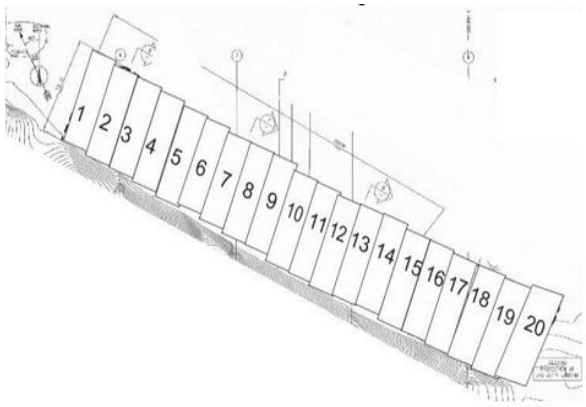


Figure 6. 20 Sections of coastal protection construction

Work activities is breakdown as presented below.

I. Preparation Work
1.1 Field Office construction
1.2 Measurement of project area
1.3 Material procurement
1.4 Material mobilization
1.5 Equipment mobilization

II. Main Construction Work (Section 1 – Section 20)
Activities in each section is illustrated in Figure 7.
2.1 Dredging of toe protection
2.2 Bottom geotextile installation
2.3 Installation of toe protection material
2.4 Installation of core material
2.5 Upper geotextile installation
2.6 Armor layer installation

III. Final Work
3.1 Equipment Demobilization
3.2 Field office discharging

Equipment that required for coastal protection structures for both quarry stone and concrete tetrapod armor consist of lifting equipment (crane), excavator, loader, boat, cart, GPS, and waterpass. The difference between those two alternatives is lifting equipment such as crane, tetrapod need crane with hook holder and stones are required a crawler type crane. Other equipment considered similar between two alternatives.

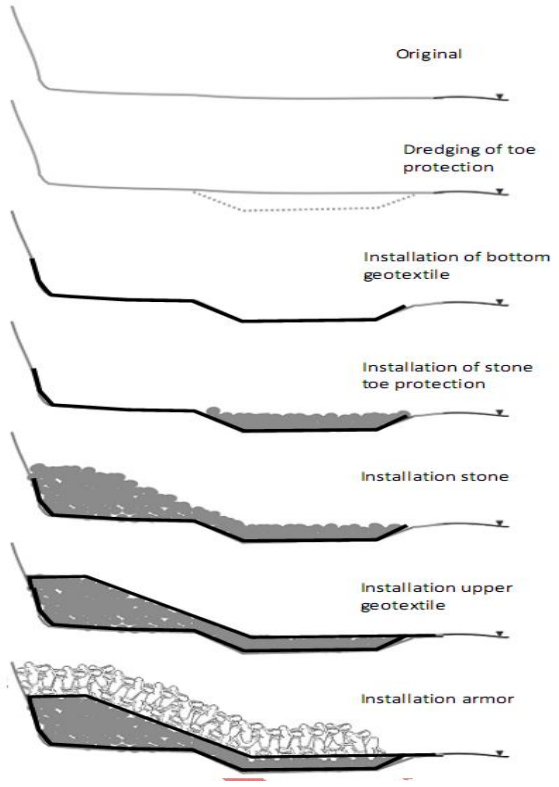


Figure 7. Illustration of typical procedure in each section

B. Construction Time Period

Based on construction method that been determined, construction schedule analysis is performed in order to get total required time for construction of coastal structure. Construction time period analysis is applied for each activities that had mentioned earlier, in general consists of:

I. Preparation work
II. Main construction (Section 1 – Section 20)
III. Final Work

Steps in construction time period analysis are:
- Calculation of volume for each activity. Volume is determined from technical drawing.
- Productivity analysis for each activity with take into account specific equipment that have been selected.
- Duration calculation, by dividing work/activity volume with each productivity.
- Analysis of activities relationship, there are 4 relations i.e. start-to-finish, start-to-start, finish-to-start and finish-to-finish.
- Bar chart development, after work/activities duration and relationship are obtained.
- Total period of time is obtained from bar chart.

Table 4 shows total time period that is required for the two alternatives, it is shown that tetrapod armor structure required longer period than quarry stone armor, because tetrapod armor need to be produced before installation while stone could be directly transported from its quarry.

Table 4. Total Period of Time for quarry stone and tetrapod armor coastal protection

No	Item	Time Period (weeks)	
		Quarry Stone Armor	Tetrapod Armor
1	Preparation	17	30
2	Main construction	36	41
3	Finishing	11	11
Total Time		**64**	**82**

C. Cost Estimation

Based on construction method and period that have been analyzed, cost estimation is performed. There are three construction aspects i.e human resources, equipment and material costs. Cost estimation for coastal protection structure with quarry stone and tetrapod concrete material as armor layer is presented in Table 5 and 6. From those tables it is shown that tetrapod armor structure required higher cost than quarry stone armor structure, due to longer period of construction time.

Table 5. Cost Estimation of Quarry Stone Armor Revetment

No	Item	Quarry Stone Armor Layer			
		Labor (USD)	Equipment (USD)	Material (USD)	Total (USD)
1	Preparation	10,547	103,270	1,526,257	1,640,074
2	Main construction	11,220	853,912	499,379	1,364,511
3	Finishing	70	55,377	-	55,447
		21,836	1,012,559	2,025,637	**3,060,032**

Table 6. Cost Estimation of Tetrapod Armor Revetment

No	Item	Tetrapod Armor Layer			
		Labor (USD)	Equipment (USD)	Material (USD)	Total (USD)
1	Preparation	5,692	73,070	2,277,677	2,356,440
2	Main construction	10,697	355,447	162,308	528,452
3	Finishing	70	55,377	-	55,447
		16,460	483,895	2,439,984	**2,940,339**

CONCLUSION

BASED ON COMPARISON OF CONSTRUCTION METHOD, CONSTRUCTION PERIOD OF TIME AND CONSTRUCTION COST ESTIMATION OF TWO MATERIAL ALTERNATIVES OF ARMOR LAYER, IT IS RECOMMENDED TO USE ANGULAR QUARRY STONE AS ARMOR LAYER OF COASTAL PROTECTION IN BINTUNI BAY WHICH CONSTRUCTION METHOD IS CONSTRAINED BY ITS REMOTE AREA, ENVIRONMENTAL CONDITION IN COASTAL AREA, AND LIMITED CONSTRUCTION ACTIVITIES NEAR SENSITIVE GAS PLANT AREA. THE MOST IMPORTANT ASPECT IS DUE TO CONSTRUCTION AREA CONSTRAINT AND CONCRETE PRICE.

REFERENCES

[1] CERC, “Shore Protection Manual”, Department of the Army US. Army Corps of Engineers, Washington DC, 1984.
[2] Oberlender, Garold D., “Project Management for Engineering and Construction”, Mc Graw-Hill Book Co. Singapore., 2000.
[3] Kim, Young C., “Handbook of Coastal and Ocean Engineering”, California State University, Los Angeles, USA.
[4] Van der Meer. J.W., “Stability of breakwater armour layers - Design formula”, Coastal Engineering, 11, 219 – 239, 1988.

★★★