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Numerical Analysis on Countermeasures of Bank Erosion, Case Study Sesayap River, East Kalimantan Indonesia

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Abstract. Bank protection structureis applied generally as acountermeasureof the bank erosion problem.The structures, such as groynes, revetments and so on, will success to protectthe riverbank locally.However, usuallythe structureswill change the cross-sectional geometry, which lead to change the flow pattern or others hydraulics parameters.Furthermore, the structure will produce another bank erosion problem in another place, especially in case that the flow is a dominant factor in riverbank erosion problem.The horizontal two dimensional bed deformation analysis of the Sesayap River is performed. The advantage of the dredging method is discussed. The dredging of bars is the appropriate choice for the countermeasures of bank erosion of the Sesayap River at Malinau, when we considered the financial efficiency and bed degradation along both banks.

Keywords:*bed deformation, bank erosion, countermeasures, numerical analysis.*

1 Introduction

Sesayap River in East Kalimantan is chosen in order to examine the interaction of channel geometry, water flow, and bed. The watershed area is around 17,432 square kilometers. The headwaters are located in the mountain forest on the national boundary between Indonesia and Malaysia. This river is one of the largest rivers in East Kalimantan. The main function of the river is a navigation channel. The channel stream passes through in three regencies, Nunukan. Malinau and Bulungan regencies (seeFigure 1). The average temperature in East Kalimantan is 26°C, which has fluctuation 5°C-7°C. The rainfall intensity is 2000-4000 mm/year and the amount of rain days are 130-150 days/year. This general description of the climate indicates that the rivers in East Kalimantan have large discharge within a half year.

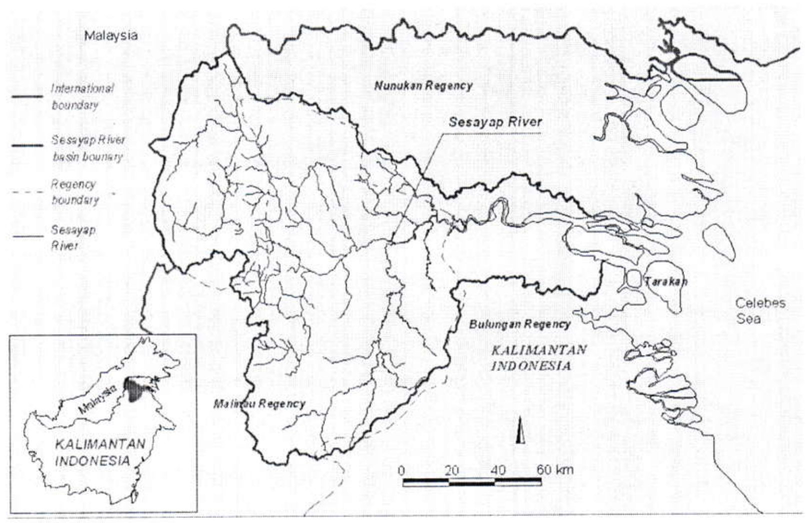

Figure 1 Location of study site in Sesayap River basin. (Source:SatuanKerjaBinaPengelolaan SDA, DirektoratBinaPenatagunaan SDA, Public Work Ministry of Indonesia)

(a)inundated water on the bank (b) bank erosion

Figure 2 Inundated water and bank erosion in Sesayap River at Malinau reach

During the last ten years, the flood and bank erosion occur intensively in Sesayap River, especially at Malinau reach. Figure 2(a) shows the floodwater from Sesayap River on November 2008 and many villages have been inundated during this time. Bank erosions were occurred at some reaches of the river as shown in Figure 2(b). The bank erosion gives damages on the road structure. The main structure of the road around 2 meters width and 40 m long was collapsed. This is the main road for transportation in Malinau Regency. Due to this hazard, the bank erosion in Malinau reach becomes main issue in this regency.

Understanding the processes and mechanisms of bank failure, their causes, and spatial extent is crucial for the identification of stabilization measures and management of bank erosion problems. Prediction of stable bank geometry as a function of material properties and river stage should represent a fundamental part of projects involving the riverbank stabilization and mitigation measures [1]. Accordingly, to accomplish the bank erosion problems, it is important to understand and consider the geology, geomorphology and hydraulic aspects of the river. Hence, in this study, field investigations were conducted to obtain: (1) the geological characteristics of the bank, (2) flow characteristics of the river, and (3) geometry and morphology characteristics of riverbed.

2 Governing Equations

Numerical simulations are performed using the horizontal two-dimensional flow model which the equations are written in general coordinate system. The model usesthe finite difference method to solve the different equations. Computation of surface flow is carried out using the governing equation of the horizontal two-dimensional flow averaged with depth. The conservation of mass, i.e., inflow and outflow of mass by seepage flow, is taken into consideration as shown in the following equation [2].

$$\Lambda\frac{\partial}{\partial t}\left(\frac{z}{J}\right)+\frac{\partial}{\partial \xi}\left(\left(\frac{\partial \xi}{\partial t}+U\right)\frac{h}{J}\right)+\frac{\partial}{\partial \eta}\left(\left(\frac{\partial \eta}{\partial t}+V\right)\frac{h}{J}\right)+\frac{\partial}{\partial \xi}\left(\left(\frac{\partial \xi}{\partial t}+U_g\right)\frac{h_g}{J}\right)+\frac{\partial}{\partial \eta}\left(\left(\frac{\partial \eta}{\partial t}+V_g\right)\frac{h_g}{J}\right)=0 \tag{1}$$

Where, t is the time, z is the water surface level. Surface flow depth is represented as h, seepage flow depth is h_g. U and V represent the contravariant depth averaged flow velocity on bed along ξ and η coordinates, respectively. Grain size distribution is evaluated using the sediment transport multilayer model as follows [3]:

$$\frac{\partial}{\partial t}\left(\frac{c_b E_b f_{bk}}{J}\right)+(1-\lambda)F_{bk}\frac{\partial}{\partial t}\left(\frac{z_b}{J}\right)$$
$$+\left(\frac{\partial}{\partial \xi}\left(\frac{\partial \xi}{\partial t}\frac{c_b E_b f_{bk} r_b}{J}+\frac{q_{b\xi k}}{J}\right)+\frac{\partial}{\partial \eta}\left(\frac{\partial \eta}{\partial t}\frac{c_b E_b f_{bk} r_b}{J}+\frac{q_{b\eta k}}{J}\right)\right)=0 \tag{2}$$

In the formulae above, f_{bk} is the concentration of bed load of size class k in the bed load layer, f_{dmk} is the sediment concentration of size class k in the mth bed layer, c_b is the depth-averaged concentration of bed load. $E_{be}$is the equilibrium bed load layer thickness [4]. The volution of bed elevation is estimated by means of the following formulae.

$$\frac{\partial}{\partial t}\left(\frac{c_b E_b}{J}\right)+(1-\lambda)\frac{\partial}{\partial t}\left(\frac{z_b}{J}\right)+\left(\frac{\partial}{\partial \xi}\left(\frac{\partial \xi}{\partial t}\frac{c_b E_b}{J}+\sum_{k=1}^{n}\frac{q_{b\xi k}}{J}\right)+\frac{\partial}{\partial \eta}\left(\frac{\partial \eta}{\partial t}\frac{c_b E_b}{J}+\sum_{k=1}^{n}\frac{q_{b\eta k}}{J}\right)\right)=0 \tag{3}$$

In them, $n$represents the number of the size class of sediment.

3 Simulation Conditions

The field analyses of bank erosion in Sesayap River at Malinau reach were discussed. The results show that the flow pattern was changed due to the presence of mid-channel bar. The flowpatternandthe bed deformationnearthebanktoebecome importantparametersontriggering theinitialbankerosionprocess. This agreed with investigations that have been done by Simon*et al.*[5].

Theflowpatternandthe bed deformationnearthebank toe,especiallyduringlowest low water (LLW) in Malinau reach arediscussed in this chapter. During this time, the flow condition mayproducehighenergydue tothedifferentwaterlevelbetweenupstreamanddownstream. The results from this simulation will be used for discussion on the countermeasure of bank erosion problem in Sesayap River.

The horizontal two-dimensional bed deformation analysis model is used in the numerical analysis. Two main cases were conducted in these simulations and described as follow: (1) Controlling the height of mid-channel bar by dredging or removal a part of volume that higher than a certain level. The dredging area is between Sta. 1650 km and Sta. 2700 km as shown inFigure 3. (2) Installing a general structure of bank protection (seeFigure 4). In this case, the revetment is chosen as a structure for the bank protection. This structure is a common structure to prevent bank erosion in Malinau. The domain in Figure 3model is indicated with a black dashed line. The topography of the calculation domain and the detailed map contour of the mid-channel bar are located between Sta. 1650 km and Sta. 2700 km. Four simulations are performed as shown in Table 1.

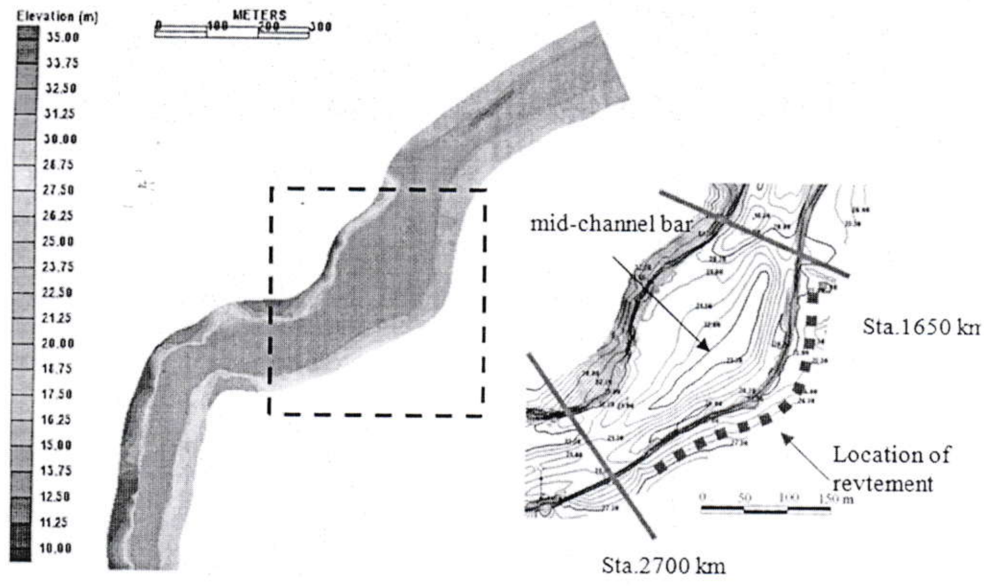

Figure 3 Topography of riverbed, floodplain and detailed contour of mid-channel bar

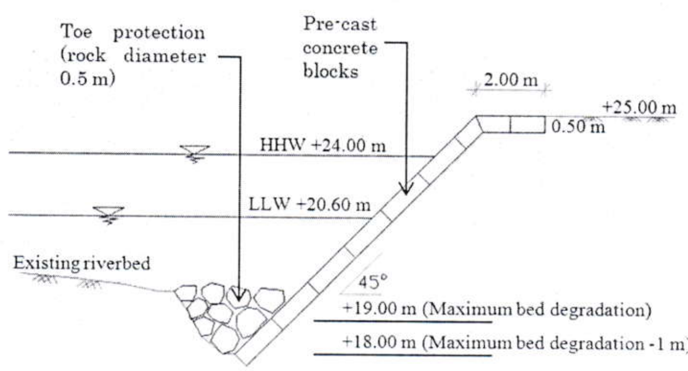

Figure 4 The type of revetment structure for bank protection in Sesayap River

Bed material is also observed in this research. There are three pointlocations for sampling data. Two samples data are collected from each location. The volume of each sample is around 2 liter. These data were collected from mid-channel bar near the location of bank erosion. The size distribution is analyzed by sieving method in laboratory. Figure 5shows the grain size distributions. Gravel and sand are the dominant in the bed material. The presence of the gravel material on the bed indicates that the bed shear stress is high values.

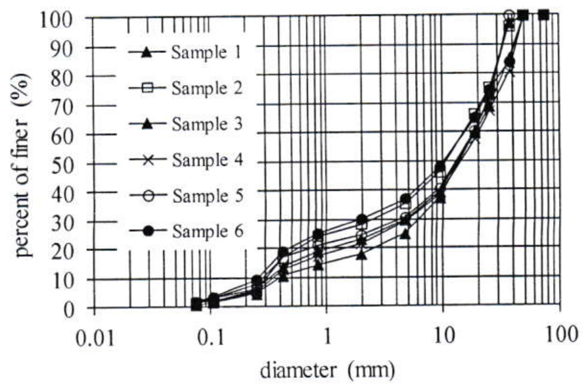

Figure 5 Grain size of riverbed material in Sesayap River

Tabel 1 Case of simulations

Case	Countermeasure	Bank material	Upstream discharge (m^3/s)	Downstream stages (m)
1a	No countermeasure	Cohesive+Non-cohesive	434.64	Unsteady
1e	The bed material higher that +20.50 m removed	Cohesive+Non-cohesive	434.64	Unsteady
2a	Install a revetment	Cohesive+Non-cohesive	434.64	Unsteady
2e	The bed material higher that +20.50 m removed and install a revetment	Cohesive+Non-cohesive	434.64	Unsteady

4 Results and Duscussions

4.1. Flow Characteristics

Figure 6 and Figure 7are showthehorizontaldistributionsofvelocityvectorunderthelowestlow water (LLW) conditionatthedownstreamarea before the bank erosion.The small size of the vector indicates the low velocity and the big size indicates the high velocity. The effect of the revetment is analyzed.

InCase1a,theflowdividedintotwopartsbythepresenceofthemidchannelbarandproducehighand convergence velocityatlee area (the downstream ofthebar which is indicated by the blue circle).Thismaybecomeastrongreasonthatbankerosionoccurredthere.The bank erosion in Sesayap River is located in this area. However, after the mid channel bar was dredged (seeFigure 6b), the flow velocity in this area decreases significantly. This means that the dredging method can control the flow velocity near the bank.

In case a countermeasure only installing a revetment as shown inFigure 7a, the flow velocity around the downstream of the bar still has high magnitude. And also tend to increase the velocity at opposite side as indicated by red circle. In this area, the flow velocity will decrease significantly after the dredging of the mid channel bar (see Figure 7b). These results show that the horizontal distribution of velocity on Case 1e and Case 2e are similar. According to the horizontal distribution of flow velocity, the revetment seems unnecessary for a countermeasure of the bank erosion problem in this river each.

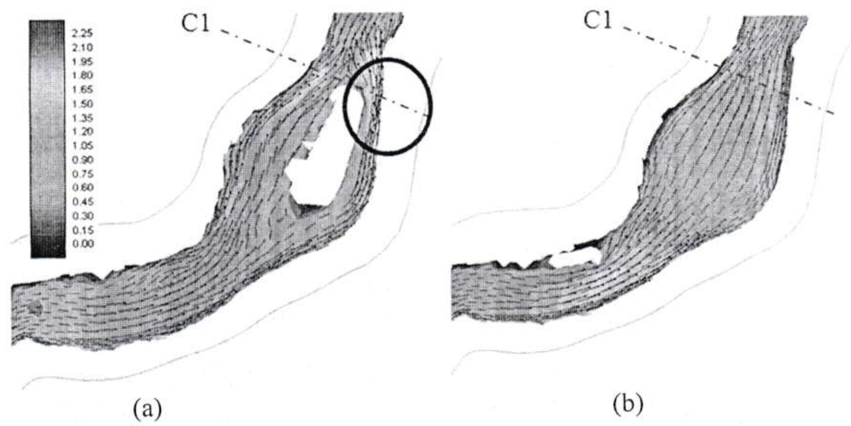

Figure 6 Horizontal distribution of velocity vector and detailed velocity contour around the downstream of the bar in Case 1a dan Case 1e

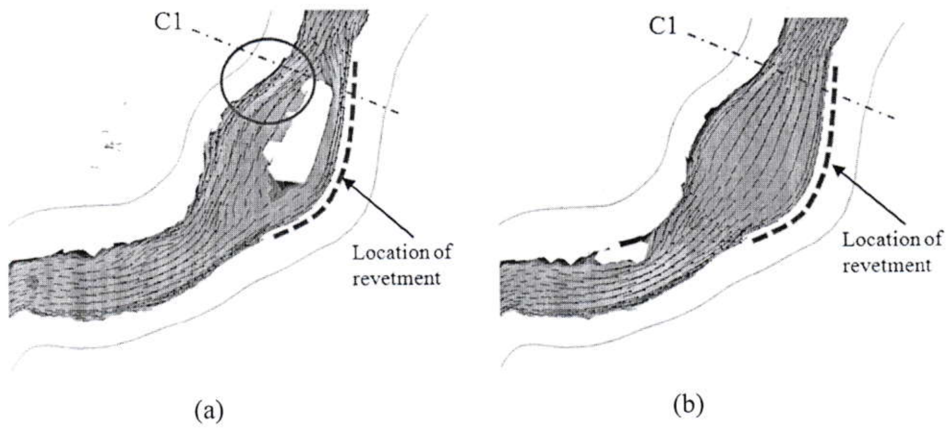

Figure 7 Horizontal distribution of velocity vector in Case 1e and Case 2e

4.2. Channel Geometry

The effect of the cohesive characteristics of bank material on the channel geometry is discussed here. Furthermore, the effects of the dredging and installing revetment will be discussed considering on the erosion rate at the bank toe. Figure 8 to Figure 11 are show the channel geometry at 48hour in Case 1aCase 1e, Case 2a, and Case 2e.

In Case 1a, the bed near the bank toe (at right bank) was eroded well. The erosion depth in Case 1a is deeper than that in Case 1e. As shown in the results of Case 1e, the bed degradation is reduced significantly by the dredging of the mid channel bar. The dredging of the bar reduces the concentration of the flow along the right bank and suppress the bed degradation and the bank erosion along the right bank.

The bed degradations occur very much in Case 2a in spite of the installation of revetment. Its means that after installing the revetment, the bed degradations near the bank toe still occurs, and will affect on the stability of the structure. This condition is similar with Case 1a. By considering the cost of the structure of revetment, it seems that this structure is not necessary.

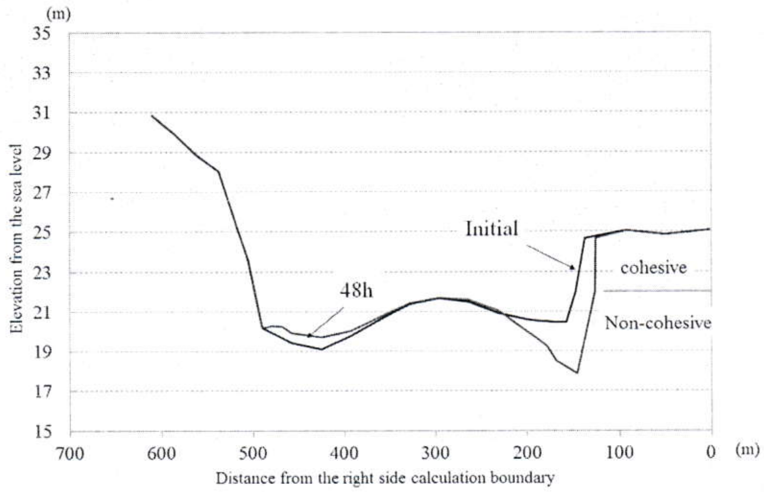

Figure 8 The temporal cross sectional change at the downstream of the bar (cross section C1) in Case 1a

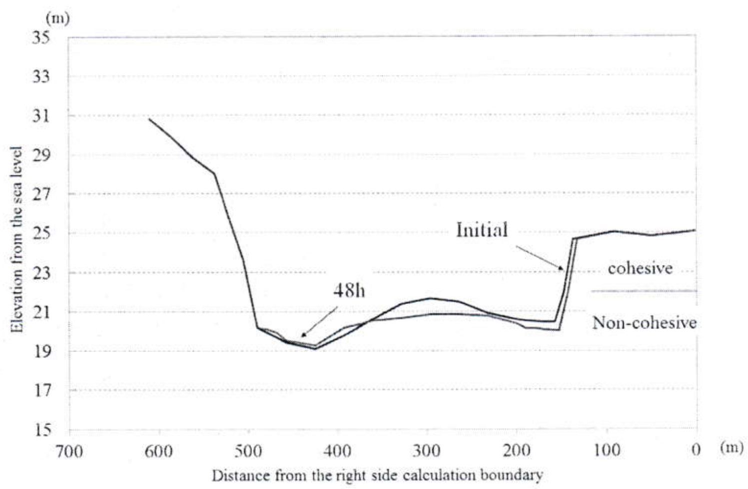

Figure 9 The temporal cross sectional change at the downstream of the bar (cross section C1) in Case 1a

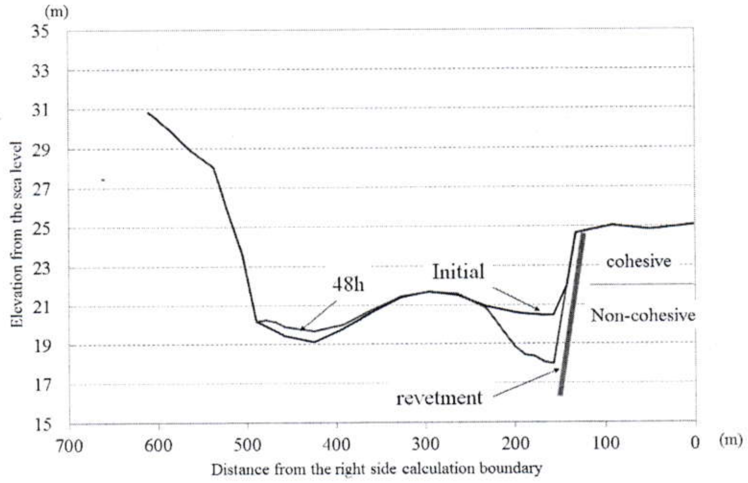

Figure 10 The temporal cross sectional change at the downstream of the bar (cross section C1) in Case 2a

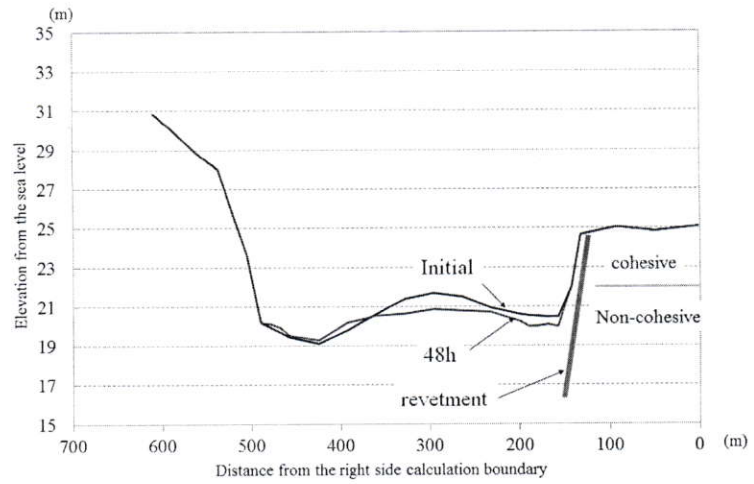

Figure 11 The temporal cross sectional change at the downstream of the bar (cross section C1) in Case 2e

5 Conclusions

Thehorizontaltwo-dimensionalbeddeformationanalysisoftheSesayapRiverat Malinau reach isperformed. Two main methods are applied to counteract of bank erosion problem this river reach. First, the dredging method to reduce a volume of mid-channel bar is applied. This method is addressed to increase the capacity of river flow.Second, the installing a general construction of riverbank protection is applied. The revetment is chosen as riverbank protection.

The result of numerical analysis in case of original condition shows that the presence of the mid-channel bar produces high velocity at the downstream bar, especially during low tide. This is the reason why in this location have an intensive activity of bank erosion. The results of dredging method show that, this method can reduces the erosion at the bed near the bank toe, significantly. As a parameter on triggering bank failure process, reducing of the bed degradation near the bank toe is an important treatment to prevent the bank erosion. The installing a construction such as revetment may protect the bank erosion successfully. However, this method cannot improve the flow pattern and bed deformation near the bank toe.

The dredging of mid-channel bar is the first action to prevent the bank erosion in Sesayap River at Malinau reach. The bank protection using a construction, which installed along the bank, should consider the financial aspect. The construction only prevents the failure process due to the gravitational force, which comes from the bank itself. In fact, the bank is composed of cohesive material, which has a good stability.

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