# ANALYZING RIVER MORPHOLOGICAL CHANGES AND FORMULATING NO REGRET STRUCTURAL MEASURES IN CHINDWIN RIVER

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**ABSTRACT**

This study focused on navigation improvement in Chindwin River between Alon and Monywa, Myanmar. Numerical analysis of two-dimensional depth-integrated flow and bed deformation was carried out to support decision-making for river improvement works. Using a flood hydrograph, computations equivalent to 103 d were conducted with different allocations of spur dikes to define the desired flow velocity, flow direction, sandbar movement, and discharge proportion. The results showed that while blocking the smaller channel can divert 50 to 80% of the flow to the main channel, the velocity in the latter increases from 1 to 1.3 m/s. On the other hand, constructing a series of dikes in the main channel can improve the navigable depth and protect the bank from erosion, but doing so will raise the water surface elevation. Efficient navigation improvement works can be implemented to maintain bank stability and avoid other impacts after gaining an understanding of sandbar movements and the effects of different countermeasures.

**Key words:** river navigation channel, numerical simulation, bed deformation, sandbar

## INTRODUCTION

Chindwin River has a 730 km-long navigable route that plays an important role in passenger and cargo transportation in Myanmar. This study focuses on navigation improvement in Chindwin River between the Alon and Monywa stretch. The study area contains two bottlenecks at which the flow bifurcates into two channels. Thus, the resulting navigable depth becomes insufficient and sandbar movement may block the route in the future. This study attempted to solve this problem using two principal simulation approaches. The first approach involved simulating the termination of the smaller channel. The second approach concerned simulating the effects of constructing a series of dikes along the main channel to deepen the navigable depth and push the flow back to the center. In this regard, computations equivalent to 103 d were conducted with flood hydrographs for a total of 7 cases. In Case 0, the flow was computed without any dikes, the goal being to understand the natural tendency of the flow in the future. The other 6 cases assumed the installation of dikes on either the right or the left bank. The results from these 6 cases were evaluated by comparing the respective depths, velocities, extents of erosion, depositions, and discharge proportions with Case 0 (i.e., without the dikes).

## THEORY AND METHODOLOGY

In this study, the two-dimensional depth-integrated mass and momentum conservation equation was used to analyze the flow, while the mass conservation equation was applied to estimate the bed sediment and suspended sediment. The simulation was conducted with the depth-integrated flow simulation model iRIC-Nays2DH (Shimizu et al., 2014) with the following modifications.

Bed load discharge in the direction of bed load $q_{b^*}$ was calculated following a previously described formula (Egashira, et al., 1997)

$$q_{b^*} = \frac{4}{15}\frac{\mathrm{K_1 K\_2}}{\sqrt{f_d + f_f}}\tau_*^{\frac{5}{2}} \tag{1}$$

The +vector of bed load transport was computed as described below (Watanabe, et al., 2001)

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$$q_{bx} = q_b \left[\frac{\bar{u}_{bx}}{V_b} - \gamma\left(\frac{\partial_{zb}}{\partial x} + cos\theta\frac{\partial_{zb}}{\partial y}\right)\right] \text{ and } q_{by} = q_b \left[\frac{\bar{u}_{by}}{V_b} - \gamma\left(\frac{\partial_{zb}}{\partial y} + cos\theta\frac{\partial_{zb}}{\partial x}\right)\right] \quad (2)$$

where $\bar{u}_{bx}$ *and* $\bar{u}_{by}$ are the flow velocities near the bed, $V_b$ is the composite velocity near the bed, $\theta$ is the inclination angle, and $\gamma$ is the correlation coefficient for the bed slope effect.

The mass conservation equation of suspended sediment is

$$\frac{\partial \bar{c}h}{\partial t} + \frac{\partial r_1 \bar{u}\bar{c}h}{\partial x} + \frac{\partial r_1 \bar{v}\bar{c}h}{\partial y} = \frac{\partial}{\partial x}\left[h \in_x \frac{\partial \bar{c}}{\partial x}\right] + \frac{\partial}{\partial y}\left[h \in_y \frac{\partial \bar{c}}{\partial y}\right] + E - D \quad (3)$$

The depositing rate $D$ was calculated using

$$D = r\, w_0\, \bar{c} \quad (4)$$

where $w_0$ is the fall velocity of a sediment particle, $c_b$ is the sediment concentration at the reference level in the vicinity of the bed surface, and coefficient $c_b$ equals $r\bar{c}$ $(r = \frac{c_b}{\bar{c}} \geq 1)$.

The suspended sediment concentration was calculated as follows (Harada, et al., 2019):

$$\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial x} = \frac{1}{h}\frac{\partial}{\partial x}\left(\varepsilon h\frac{\partial c}{\partial x}\right) + \frac{1}{h}\,(1 - \frac{c}{c_s})\,(W_e c_s - w_0 c) \quad (5)$$

where

$$c_e = \frac{W_e}{w_0}c_s \quad (6)$$

The entrainment coefficient was calculated as seen below (Ashira & Egashira, 1980)

$$\frac{W_e}{u}(= e) = \frac{K}{R_{i^*}} \quad (R_{i^*} = \frac{\Delta\rho}{\rho}\, gh/u^2) \quad (7)$$

where

$$\mathrm{K} = 1.5 \times 10^{-3} \quad (8)$$

The flow body and sediment supply were calculated using the governing equation. The deposition and erosion trends were checked against the results of the 103-d simulation. After understanding the flow regime and sandbar movement, the dikes were assumed to be installed at the proper locations to define the desired river width, flow pattern, and deposition. The 6 cases were formulated for different perspectives and characteristics. The outputs of these 6 cases were evaluated from the view point of river management.

## DATA AND MODEL VALIDATION

A detailed bathymetry survey chart created by the Directorate of Water Resources and Improvement of River Systems (DWIR, 2019) was used as the initial topography map for the model simulation. The topography raster file was created via transformation of the AutoCAD survey chart into the geodatabase format and interpolation in ArcGIS. This raster map for 2019 was extended artificially to an extent of 1 km upstream to stabilize the upstream boundary conditions. Non-uniform sediment ($D_{50}$ = 0.6 mm and $D_{84}$ = 3 mm) was employed as the river bed material in the simulation (Fig. 1). These grain size distribution data were developed based on field survey data of the Ayeyarwady Integrated River Basin Management Project (AIRBM, 2017) which was conducted 60 km downstream of the study area in the same river.

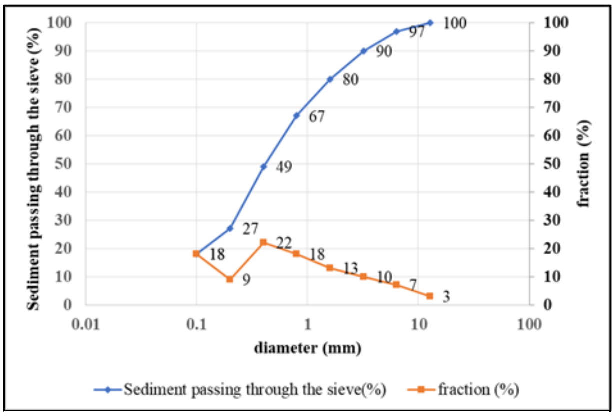


*Figure 1Sediment size distribution*

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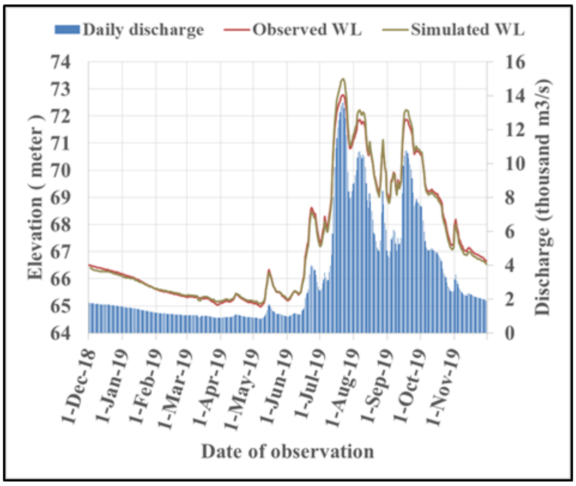


*Figure 2Comparison of observed water level and computed water level*

After setting the key parameters and creating the grid, one-year computation of the flow with bed deformation is computed. For that computation, discharge from 1st December 2018 to 30th November 2019 is employed. The computed water surface elevation is compared with field observed data to check whether the topography map, parameters and flow computation equations are fit with this simulation. The comparison revealed that the water surface elevation results are in good agreement with the field observation, as shown in Fig 2. This means that the computation results are promising.

After validation, daily discharge data from July $10^{th}$ to October $20^{th}$, 2019 for the upstream boundary condition was used to forecast the future channel changes and dike effects

## RESULTS AND DISCUSSION

An analysis of the results shows that the channel changed from an alternate sandbar to a multiple row bar system during 2015 and 2019. To understand the natural flow pattern, the simulation starts with Case 0 (without the dike). The sandbar at Bottleneck 1 migrated 110 m downstream, restricting the navigable width of the channel. At Bottleneck 2, the left channel became more dominant than before, and the water flowed into two different channels. Thus, the water depth became insufficient for safe navigation. To solve these problems and change the navigation channel to the desired parameters, a total of 6 cases with dikes were simulated.

Three approaches were applied **to mitigate the issues caused by Bottleneck 1.** The first approach involved closing the secondary (right) channel and diverting the flow to the left channel. In the second approach, the flow was concentrated along the left channel so as to obtain a sufficient depth. Simultaneously, this approach was intended to erode the middle sandbar and protect the left bank from erosion. The third approach combined the first two approaches.

Cases 2 and 3 involve closing the secondary (right) channel. Dikes are installed on the right bank. The results showed that approximately 80% of total discharge can be diverted to the left channel, thereby increasing the navigable depth by 2 m compared to that in Case 0. As the flow becomes concentrated in the left channel, its velocity rises from 1 m/s to 1.2 and 1.3 m/s in Case 2 and Case 3, respectively. Although these cases involve blocking the secondary channel with huge sediment deposition and improving navigation in the left channel, the potential for bank erosion exists.

In Cases 1, 4, and 5, the river width of the left channel is decreased to obtain a deeper channel. The results show that the channel becomes deeper by approximately 0.8 to 1.5 m compared to that in Case 0. As the discharge remains unchanged (i.e., the same as that of Case 0), the velocity remains stable between 0.9 and 1 m/s. The potential for bank erosion is reduced due to this lower velocity. These dikes can also divert the flow field to the center. Therefore, the downstream part of the sandbar is eroded. Sandbar migration is stopped by these dikes, and the elevation of the sandbar is 0.5 m lower than that in Case 0. Installing 3 dikes at Bottleneck 1 raises the elevation of water surface by 0.4 and 0.7 m compared

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to that in Case 0. This result may affect the upstream deposition pattern. In the third approach, one dike is installed on the right bank and another on the left bank. The dike on the right bank cannot divert much of the flow to the left channel and thus does not block the right channel. The result shows that the discharge proportion does not change considerably. Moreover, huge sediment deposition does not occur. The dike on the left bank functions well and erodes the downstream part of the sandbar. The elevation of the sandbar is 0.8 m lower than that in Case 0.

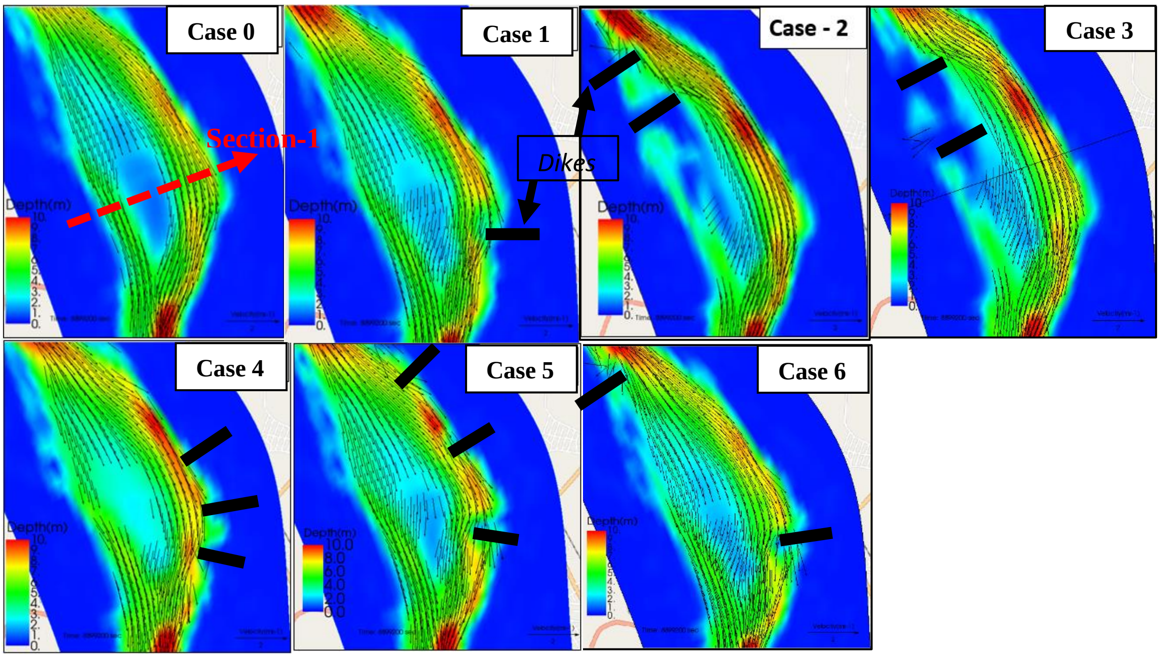


*Figure 3Locations of Dikes and Flow Regime Changes (Bottleneck 1)*

To conclude, Cases 2 and 3 can solve the problem associated with navigable depth, but the bank erosion potential is higher than that in the other cases. Cases 1 and 6 can erode the sandbar, but the discharge in the channel does not increase as desired. Cases 4 and 5 improve the navigation and protect the bank from erosion, but these interventions are costly, and the water surface elevation is raised.

Two approaches are tested for **Bottleneck 2.** The first involves diverting the flow into the left channel, and the second concerns blocking the left channel. In Cases 2 and 6, dikes are placed on the right bank to divert the flow to the left channel. In Case 2, 80% of the flow is diverted by two dikes, and huge sediment deposition takes place downstream of these dikes. On the contrary, Case 6 does not show a change in the discharge proportion because only one dike is used.

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In the second approach, dikes are installed on the right bank to block the right channel. In Case 1, two dikes are placed upstream of Bottleneck 2. In Case 3, the dikes are placed downstream of Bottleneck 2. The discharge proportion does not change considerably. In Case 4, the two dikes from both cases are combined in the simulation. Although considerably higher flow is diverted in Case 4 than Cases 1 and 3, the water flows through the dike root because of poor alignment. The poor alignment of the dikes in Case 4 is adjusted in Case 5. Over 70% of the discharge is found to flow in the desired channel, and the navigable depth increases by more than 1 m. Thus, Case 5 offers more promise for navigation.

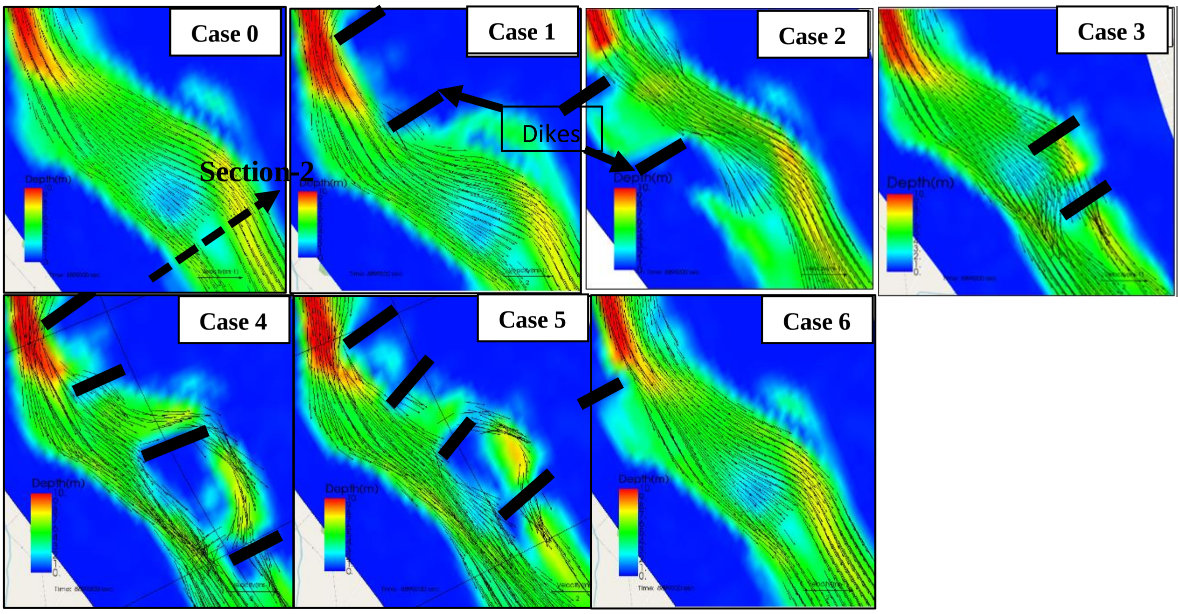


*Figure 4Locations of Dikes and Flow Regime Changes (Bottleneck 2)*

To conclude, Case 2 can divert the flow to the desired channel, but the navigable route becomes longer, which is inconvenient. Case 5 can divert the flow to the desired channel, and the navigable depth increases. However, this intervention is economically infeasible. All of the other cases are ineffective compared to Cases 2 and 5.

The discharge proportion for each channel is shown in Fig. 5. We can see that Case 2 diverts 80% of the flow to the desired channel at each bottleneck. Thus, Case 2 is the best solution to improve the navigation. The cross-sections and discharge proportions in each of the areas of concern were analyzed after simulating the 6 cases with 12 combinations in total. The results were evaluated based on criteria such as navigable depth, potential for bank erosion, economic feasibility, changes to water surface elevation, sandbar erosion, and proportion of discharge diversion.

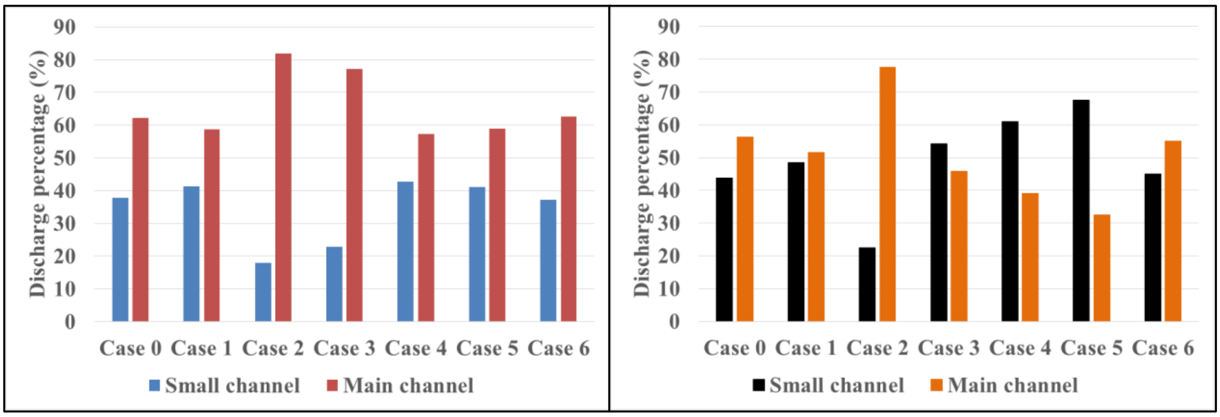


*Figure 5Discharge comparison*

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## CONCLUSION

The simulation results show that blocking the smaller channel can divert more flow to the main channel. However, doing so can also raise the potential for bank erosion. Moreover, constructing many dikes is not the perfect solution because although doing so can improve the navigable depth, the dikes can raise the water surface elevation and are economically infeasible. The results of this study can help decision-makers review and compare the advantages and disadvantages of different countermeasures. Thus, these results can help them arrive at the best solution to solve local and regional river management issues.


## ACKNOWLEDGMENTS

I express my sincere thanks to my supervisors, Dr. Daisuke Harada (Research Specialist, ICHARM), Professor Shinji. Egashira (Research and Training Advisor, ICHARM, PWRI), Dr. A. Yorozura (Senior Researcher, ICHARM, PWRI), Dr. Robin Kumar Biswas, and Associate Professor Hibino Naohiko for providing valuable ideas and guidance to my research work. I learned much about river hydraulics and sediment behavior from them. I am deeply grateful to them for their kindness, patience, and superior teaching.


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