Finding the optimum groin layout for the Konaweha river banks protection via 2D numerical modeling

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Abstract. River bank erosion has become a critical issue, especially for river bends with an alluvial soil type. Mostly, river bank erosions have caused structural failures because many national roads in Indonesia are placed near the river bend areas. Groins can reduce flow velocity, thereby increasing riverbank stability. However, most groins were installed in the river without impacting the river flow due to the improper design. This paper analyzes the use of groins placed at the river bend of the Konaweha River to protect the river bank with a length of 250 m from erosion. The evaluation employs 2D numerical modeling using MIKE21 FM to observe the influence of the groin on the river velocity, flow distribution pattern, and water level. Sixteen model scenarios with four groin configurations were tested for 25-year discharge, 2-year discharge, normal discharge 600 m³/s, and low discharge 197 m³/s to achieve the most effective plan. Based on the simulation results, Scenarios with five groins are recommended to reduce the flow velocity along the outer river bank from 2 to 0.3 m/s, thus minimizing the erosion. In addition, the spacing of groins being twice the groin length is recommended.

Keywords: numerical modeling, protection, river banks, stability

1. Introduction
For many decades, the river has been utilized for water supply, recreation, navigation, and tourism. However, land-use change, excessive use of rivers, and the lack of river maintenance cause several problems, such as flood, erosion, and sedimentation. These issues have affected the Konaweha River, located in Kendari, Indonesia, where the outer river banks were eroded [1]. The river experiences frequent bank erosion, especially at the outer river bend near the national road, see figure 1. The bank erosion has caused the disruption of public services, e.g., highway blockage and traffic diversion. Therefore, it is of utmost importance to solve the erosion problem by implementing a concept of river training, thus protecting the eroded area. River training is a standard method for river protection with special structures specifically intended to stabilize the river bank. There are several types of river protection methods: direct and indirect methods. The groin is one of the popular structures to protect the outer river banks from erosion [2]. Usually, groins are constructed in a long series transverse from the river bank to narrow the river channel. A different design in shapes, length and spacing is a critical parameter of groin effectiveness. Several studies were carried out to investigate the groin configuration;
see [3]-[6]. Using the MIKE 21C model, several numerical studies were also conducted to study the flow pattern, and velocity around groins at the outer river bends in Indonesia, see [7]-[8]. Furthermore, the physical modeling at the hydraulic laboratory was conducted to justify the effectiveness of the groins by measuring different groin configuration scenarios in [9]-[10]. In this paper, the numerical model MIKE21 FM is employed to analyze the effects of groin placement to prevent and overcome the river bank erosions at the Konaweha River.

![Erosion at the Konaweha river bank](source: [1])

**Figure 1.** Erosion at the Konaweha river bank (source: [1])

2. Methodology

2.1 Flow modeling

MIKE21 FM is used as a tool for numerical flow modeling. The software contains several modules such as hydrodynamics, waves, water quality, sediment transport, and morphological changes in the river. The modeling approach using the implicit finite element to solve the governing equations that are expressed as follows

\[
\frac{\partial \eta}{\partial t} + \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = \frac{\partial h}{\partial t}
\]

\[
\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} = -g \frac{\partial \eta}{\partial x} + \frac{1}{\rho h} \left( \frac{\partial S_{xx}}{\partial x} + \frac{\partial S_{xy}}{\partial y} \right) + \frac{g u \sqrt{u^2 + v^2}}{C_h} + A_H \left( \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right)
\]

\[
\frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} = -g \frac{\partial \eta}{\partial y} + \frac{1}{\rho h} \left( \frac{\partial S_{yx}}{\partial x} + \frac{\partial S_{yy}}{\partial y} \right) + \frac{g v \sqrt{u^2 + v^2}}{C_h} + A_H \left( \frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} \right)
\]

where:

- \( \eta \): surface elevation (m)
- \( h \): total depth (m)
- \( u, v \): current velocity, in x-axis and y-axis (m/s)
- \( g \): gravitational acceleration (9.81 m/s\(^2\))
- \( \rho \): water density (kg/m\(^3\))
\( S_{xx}, S_{xy}, S_{yy}, S_{yy} \) : component stress radiation (kg/ms\(^2\))

\( C \) : chezy coefficient (m\(^{1/2}\)/s)

\( A_H \) : eddy viscosity (m\(^2\)/s)

The numerical method is not discussed in detail in this work. Therefore, interested readers may refer to [11].

2.2 Study area

The case study in this paper is the Konaweha River, located in Kendari, Southeast Sulawesi Province, Indonesia, see figure 2. The outer river bend is already eroded approximately 10 m toward the right direction of the bend. The average river width is 120 m with 197 m\(^3\)/s, 600 m\(^3\)/s, 2,645 m\(^3\)/s, and 3,927 m\(^3\)/s for the low discharge (\(Q_{low}\)), normal discharge (\(Q_{normal}\)), 2-year discharge (\(Q_{2\text{years}}\)), and 25-year discharge (\(Q_{25\text{years}}\)), respectively. \(Q_{low}\) is the on-site measured discharge during calibration activity, while \(Q_{normal}\) is the full bank discharge in the river. The length of the modeled river and the length of the eroded river bank are 1,500 m and 250 m, respectively. The data collections were conducted by measuring the river's bathymetry, velocity, and discharge, later used as the inputs for the numerical model. A visualization of the topographic map of the river showing the river bed variation is given in figure 3.

![Figure 2. Study area](image)

![Figure 3. Konaweha River bathymetry](image)
First, the drawings in a CAD format were extracted and processed to generate the meshes, as seen in figure 4. Unstructured meshes create the computational cells within the area of interest, particularly at the river bend area. Approximately 18,241 cells were generated in this model for the hydrodynamic simulation.

![Mesh setup](image)

2.3 Model Calibration

The calibration process is necessary to confirm how reliable the model is. In this study, the velocity and surface water level parameters are selected to calibrate the model. Two locations (Location 1 and Location 2) are used as the reference points for calibrating the model and six locations for the observation point (T1 – T6) in the simulation (see figure 5). The water level and velocities measured on-site at Location 1 and Location 2 in the Konaweha river were 8.08 m, 7.76 m, 0.44 m/s, and 0.37 m/s, respectively. The calibration results show a good agreement between the observed (measured) and the numerical results after using the Manning coefficient 0.025 s/m$^{1/3}$, which gives an error below 5% (see table 1). These calibration results confirmed that the model setup and parameter are reliable for the next simulation with various groin configurations.

| Location | Discharge (m$^3$/s) | Water level (m) | Velocity (m/s) |
|----------|---------------------|----------------|---------------|
|          | measured | simulated | measured | simulated |
| 1        | 197       | 8.08 | 8.20 | 0.44 | 0.49 |
| 2        | 165       | 7.76 | 7.95 | 0.37 | 0.42 |
2.4 Simulation scenarios

The simulation was conducted until the numerical convergence was achieved for the discharge of 3.927 m$^3$/s. There are sixteen scenarios with four groin configurations used in the simulation, i.e., (1) existing river banks without groins, (2) river banks with two groins, (3) river banks with three groins, and (4) river banks with five groins as shown in figure 6. The scenarios were chosen based on the stakeholder agreement on the space optimization and material availability on the site. Based on the standard code widely used in Indonesia [11], the length of groins and spacing between groins should be less than 10% of river width and 1.5 times the length, respectively. The groin characteristics used in this work are of impermeable material with a perpendicular angle to the flow. The detailed parameters of the groins are shown in table 2.
### Table 2. Scenario for model simulation

| Scenarios | Discharge (m³/s) | Number of groins | Spacing between groins (m) | The average length of the groin (m) |
|-----------|-----------------|------------------|---------------------------|-----------------------------------|
| 1         | 0               | -                | -                         | -                                 |
| 2         | 3927 (Q_{25years}) | 2 (G2,G3)       | 30                        | 10                                |
| 3         | 2645 (Q_{2years})  | 3 (G1,G3,G5)    | 30                        | 10                                |
| 4         | 2645 (Q_{2years})  | 5(G1,G2,G3,G4,G5) | 20                        | 10                                |
| 5         | 0               | -                | -                         | -                                 |
| 6         | 2645 (Q_{2years})  | 3 (G1,G3,G5)    | 30                        | 10                                |
| 7         | 600 (Q_{normal})   | 5(G1,G2,G3,G4,G5) | 30                        | 10                                |
| 8         | 3 (G1,G3,G5)      | 20                        | 10                        |                                    |
| 9         | 0               | -                | -                         | -                                 |
| 10        | 600 (Q_{normal})   | 3 (G1,G3,G5)    | 30                        | 10                                |
| 11        | 5(G1,G2,G3,G4,G5) | 30                        | 10                        |                                    |
| 12        | 3 (G1,G3,G5)      | 20                        | 10                        |                                    |
| 13        | 0               | -                | -                         | -                                 |
| 14        | 197 (Q_{low})     | 3 (G1,G3,G5)    | 30                        | 10                                |
| 15        | 5(G1,G2,G3,G4,G5) | 30                        | 10                        |                                    |
| 16        | 3 (G1,G3,G5)      | 20                        | 10                        |                                    |

### 3. Results

3.1 Simulation of existing condition without groins

The simulation results from Scenario 1 with the existing river banks condition are given in figure 7. An indication of a centrifugal current can be seen at the outer bend that causes the right banks to be eroded as the river banks are not well protected. The flow velocities near the right banks (outer bend) vary from 1.2 to 1.6 m/s. The inner bend experiences a higher flow rate during the 25-year discharge. This event can occur due to the thalweg and river morphological changes that alter the velocity and flow distribution, causing the right banks vulnerable to erosion.

**Figure 7.** Flow pattern and velocity distribution for scenario 1
3.2 Simulation with series of groins

The simulation results for all other scenarios are shown in figure 8 and figure 9. The trends show velocity reduction by adding the groins compared to the initial condition (without the groins), as shown in figure 7. For $Q_{\text{low}}$, the highest velocity reduction is 0.56 m/s at the T6 section with five groins. The same patterns occur for $Q_{\text{normal}}$, $Q_{2\text{years}}$, and $Q_{25\text{years}}$ conditions, where the maximum velocity reduction is 1.28 m/s, 1.94 m/s, and 1.59 m/s, respectively. All scenarios using groins can effectively reduce and alter the flow velocity from the initial condition. However, adding five groins show better results for the velocity reduction near the river banks. Another parameter observed is the water level near the river banks. According to the simulation results shown in figure 9, the water level trends vary due to the river hydrodynamic flow. For the high discharges ($Q_{2\text{years}}$ and $Q_{25\text{years}}$), the water level gradually increases at the observation point T1 until T4 since T1 until T4 area is located at the upstream river banks in between the groin structures. While in T5 and T6, the water level decreases. It occurs because the observation points at T5 and T6 are already at the downstream segment, where the groins no longer affect increasing water levels.

Figure 8. Velocity at observation point for a) $Q_{\text{low}}$, b) $Q_{\text{normal}}$, c) $Q_{2\text{years}}$, and d) $Q_{25\text{years}}$

Figure 9. Water level at observation point for a) $Q_{\text{low}}$, b) $Q_{\text{normal}}$, c) $Q_{2\text{years}}$, and d) $Q_{25\text{years}}$
Figure 10 shows the simulation results of the velocity distribution for $Q_{25\text{years}}$ and $Q_{\text{normal}}$, where the velocity reduction in the river banks with five groins continues from the last groin toward the downstream part. These effects will help prevent more erosions in the river banks. In contrast, the results of the velocity reduction for $Q_{\text{low}}$ and $Q_{\text{normal}}$ stop at the edge of the river bend.

The results from all scenarios with the groins show that the flow velocity near the right river bank can be reduced, thus helping protect the river bank. The eddy patterns occur between the groins compartments and prevent the main current flow from penetrating the river banks. However, there is a variation of the velocity rate due to the configuration, length, and spacing of groins. Figure 11a shows the flow pattern of the river bend for $Q_{25\text{years}}$ and two groins, where the main flow is deflected outside the groin fields. However, as shown in figure 10b, it can be observed that the velocity in the right bank is relatively high, with a range of 0.6–1 m/s. Therefore, the groin configuration with two groins is not able to significantly reduce the flow velocity. One of the reasons is the large spacing of the groins (three times the length of the groins). Figure 11b shows the flow pattern of the river bend with $Q_{25\text{years}}$ and three groins. According to figure 10c, the velocity can be moderately reduced to 0.3–0.6 m/s. Figure 11c shows the flow pattern in the river bend with $Q_{25\text{years}}$ and five groins, with a denser spacing being 1.5 times the length of groins. In correlation with figure 10d, the flow velocity is significantly reduced to 0–0.3 m/s.

Figure 10. Velocity distribution for $Q_{25\text{years}}$ and $Q_{\text{normal}}$

Figure 11. The flow pattern of a) 2 groins; b) 3 groins; and c) 5 groins
4. Conclusion

The presence of groins in the Konaweha River helps protect the river bank from erosion. Sixteen model scenarios were simulated using MIKE21 FM, consisting of $Q_{5\text{year}}$, $Q_{2\text{year}}$, $Q_{\text{mean}}$, and $Q_{\text{low}}$ with four groin configurations (0 groin, two groins, three groins, and five groins). According to the simulation results, it is observed that using two groins with 30 meters spacing could only reduce the flow velocity up to 0.4 m/s. On the other hand, the flow velocity could be reduced up to 0.8 m/s using three groins with 30 meters spacing. Interestingly, using five groins with 20 m spacing, the flow velocity can be reduced significantly up to 1.2 m/s. The scenario with five groins (G1,G2,G3,G4,G5) is the best option based on the flow velocity magnitude. It is also found that water levels at T1 until T4 tend to increase, in contrast with the ones at T5 and T6. Regarding the 16 model scenarios simulated in this study, the spacing of groins with twice the length of the groins is the most effective option to reduce the flow velocity at the outer river bend. Another essential aspect not included in this paper due to time and resources limitations is the influence of groins on the sediment transport in the river. It needs to be investigated in a future study to verify the groin’s effectiveness.

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