Modeling of 2D Hec-Ras Simulation on Debris Flow Analysis on Morphological Changes of the Omu River, Sigi Regency, Central Sulawesi

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Abstract. Landslide is a natural disaster that shows if the soil structure in the area is unstable, where landslides occurred was in the upper part of the Omu River. When there is heavy rain, landslide material in the form of debris is carried into the river flow increasing the concentration of sediment in the river which causes debris flow. Debris flow has a destructive power that can cause damage to buildings, utilities and can threaten the lives of people in the area. This study aims to Non-Newtonian method analysis models in the HEC-RAS (2D) 6.4 software. The findings reveal that debris flow has a significant impact on the morphological stability of the Omu River, stability of the riverbed and bank erosion, which can disrupt the overall river system stability. One effective strategy for mitigating the potential risks of debris flow is the construction of the Sabo Dam on the Omu River. This dam is designed to capture and retain debris sediment, preventing it from being carried downstream. By doing so, it helps to maintain the morphological stability of the Omu River, riverbed, and reduce the impact of destructive debris flow forces.

1 Introduction

A seismic disaster of 7.4 Richter Scale magnitude struck the Central Sulawesi Province on September 28, 2018, at 18:02 local time, affecting the region with a subsequent tsunami, liquefaction, and landslides in various locations in Central Sulawesi. The earthquake had a depth of 10 km and was centered 27 km east of Donggala, Central Sulawesi. The Omu River, a tributary of the Miu River, was one of the areas where landslides occurred [1].

The landslides resulted in the entry and transport of landslide materials, including fine and coarse aggregates, into the river flow, causing sedimentation in the Omu River. Subsequently, during heavy rainfall, the river's water discharge capacity decreased due to the sedimentation. The mixture of water with the fine and coarse aggregates from the landslide debris led to high-impact debris floods.

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The flood incident report states that, due to heavy rainfall, flash floods occurred in Omu Village, Gumbasa Subdistrict, Sigi Regency on April 26, 2020 (Fig. 1). The flash flood, which occurred in the Omu River, was a result of the overflow of the river carrying sediment materials, including fine sand and coarse aggregates such as rocks. Omu Village is located near the confluence of the downstream flow of the Omu River and the Miu River [1].

In addressing the flood and sedimentation disasters in the Omu River, the Ministry of Public Works and Public Housing, through the Balai Wilayah Sungai Sulawesi III, implemented the construction of sediment control structures. This includes the construction of two consolidation dams, one sabo dam, and the river normalization to control floods and sedimentation downstream of the Omu River, where residential areas and other public facilities are situated.

Fig. 1. Map of Post-Disaster Conditions

The Omu River has a catchment area of 11.99 km² with an average slope of 0.135 within this catchment area with the longest flowpath of Omu River 12.76 km. In this research, the Omu basin was divided into three sub-basin.

2 Method

This research was conducted in the Omu River using HEC-RAS 2D software to simulate hydraulic models and evaluate river stability in relation to changes in river morphology caused by debris flow in the Omu River. The data used include hydrological analysis, riverbed gradation, and river geometry from DEMNAS, topographic survey 2020 and 2023 (Fig. 2).

Fig. 2. Research Methodology

2.1 Hydrological analysis

Planned flood discharge is determined through flood simulations utilizing rainfall and topographic data. The Omu watershed, characterized by a small to medium size, allows for the application of flood discharge distribution using the Soil Conservation Services (SCS) hydrograph unit method [2]. The bankfull discharge is subsequently used as a calibration
parameter for distributing the planned flood discharge, assuming a return period of 1.5-5 years [7].

For the design of debris flow river control, Japan International Cooperation Agency [3] utilizes the projected flood discharge magnitude (Qs), which is computed considering the 100-year return period flood discharge, incorporating sediment influence determined by sediment concentration (Cd). The correlation between sediment concentration (Cd) and riverbed slope (tan θ) can be determined using the Takahashi Formula (1991) [4].

\[ Q_s = Q_w \cdot (1 + C_d) \]

\[ C_d = \frac{\rho_w \cdot \tan \theta}{(\sigma - \rho_w)(\tan \phi - \tan \theta)} \]

where:

- \( Q_s \) = planned flood discharge with sediment influence (m³/s)
- \( Q_w \) = planned flood discharge from Synthetic Unit Hydrograph (m³/s)
- \( C_d \) = Sediment concentration
- \( \rho_w \) = water mass density (kg/m³)
- \( \sigma \) = sediment mass density (kg/m³)
- \( \rho \) = average riverbed slope (°)
- \( \phi \) = shear angle within sediment (°)

2.2 Hydraulic analysis

The sediment transport is an important factor in river stability analysis because it can affect the river geometry, where degradation or degradation can occur in river at the same time. In sediment transport simulation in HEC-RAS simulation using unsteady flow model, important parameters in the analysis are flow velocity and gradation size of the Omu riverbed which is the input in sediment transport analysis. The sediment transport function used in the model is the Wilcock and Crowe equation [5]. This is based on characteristic of flow sediment in Omu River, which is a surface-based bed-load transport equation for graded beds with sand and gravel [6].

\[ q_{0k}^* = \frac{U^2 \cdot W_k^*}{R_k g} \]

\[ q_{0k}^* = \text{Fractional bed-load sediment transport potential} \]
\[ U_* = \text{Bed shear velocity} \]
\[ W_k^* = \text{Transport function} \]
\[ R_k = \rho_{sk}/\rho_w - 1 = \text{Submerged specific gravity of grain class} \]

\[ W_k^* = \begin{cases} 0.002 \phi^{3.5} & \text{for } \phi < 1.35 \\ 14(1 - 0.324 \phi^{-3.5})^{1.5} & \text{for } \phi \geq 1.35 \end{cases} \]

where:

- \( \phi \) = \( \tau_b/\tau_{r,k} \) = sediment mobility
- \( \tau_b \) = Bed shear stress
- \( \tau_{r,k} \) = Reference shear stress

3 Result and discussion

3.1 Hydraulic simulation

In this research, scenarios were simulated for existing conditions (Fig. 3) and design conditions (Fig. 4) with the assumption of debris flow occurs. For debris flow control design, a planned flood discharge with a 100-year return period (JICA) was used, with a discharge
of 61 m$^3$/sec for the 100-year return period from 21 years rainfall data (2002-2022) from Tuva rainfall station, using the SCS method as the boundary condition in the upstream section, which served as input in the HEC-RAS 2D simulation. In the existing scenario, the velocity of the 100-year return period discharge in existing conditions upstream of the planned Sabo placement point is 4.64 m/s, and downstream of the Sabo planned placement point 16.07 m/s. Meanwhile, the velocity at the 100-year return period discharge in conditions where there is handling upstream of the planned sabo placement point is 4.48 m/s and downstream of the sabo planned placement point is 7.3 m/s. So, the construction can reduce the velocity to make it slower and reduce the energy line.

Fig. 3. Result hydraulics velocity of planned 100-year return period discharge with sediment influence of existing river scenario

Fig. 4. Result hydraulics velocity of planned 100-year return period discharge with sediment influence of design river scenario

3.2 Morphological riverbed change

Hydraulic analysis that has been done previously is followed by sediment transport analysis. The planned discharge of the 100-year return period as a result of rainfall analysis for 21 years (2002-2022) becomes a hydraulic parameter that affects changes in the morphology of the Omu River with debris parameter simulated as boundary conditions.

Based on the results of sediment transport modelling, it can be seen in there is a decrease in the riverbed in the upstream area of the Omu River before built the sediment control, where it can retain the material don’t moving to downstream, so it is expected that the stability of the Omu riverbed will be maintained. The results indicate that in the existing river scenario (Fig. 5), the river morphology is prone to degradation and aggradation along the river channel, showing average of riverbed change rate of -0.25 m, where dominant degradation occurs. On the other hand, in the designed river scenario (Fig. 6), the river morphology tends to be more stable, exhibiting average a potential degradation rate of -0.21 m, where dominant degradation occurs but lower than existing scenario. However, in the downstream area, there is not much visible change in the riverbed.
Fig. 5. Result of potential riverbed change of planned 100-year return period discharge with sediment influence of existing river scenario

Fig. 6. Result of potential riverbed change of planned 100-year return period discharge with sediment influence of design river scenario

4 Conclusion

In general, the Omu River can accommodate flood discharge on 100-years return period, the velocity of the 100-year return period discharge in existing conditions upstream of the planned Sabo placement point is 4.64 m/s, and downstream of the Sabo planned placement point 16.07 m/s. Meanwhile, the velocity at the 100-year return period discharge in conditions where there is handling upstream of the planned sabo placement point is 4.48 m/s and downstream of the sabo planned placement point is 7.3 m/s. The river morphology is prone to degradation and aggradation along the river channel, showing average of riverbed change rate of -0.25 m, where dominant degradation occurs. On the other hand, in the designed river scenario, the river morphology tends to be more stable, exhibiting average potential degradation rate of -0.21 m. So, the construction can reduce the velocity to make it slower and reduce the energy line. The velocity at upstream is slower than the velocity downstream of the building. This is caused by changes in the cross-section which decrease due to the slope or plunge of the building so that the downstream elevation change is lower, so that the downstream speed becomes faster. The Sediment Control, can maintain the riverbed. So, the building can retain the sediment material so as not to cause sedimentation downstream.

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