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# Control of The Riverbank Erosion After Landslide in the Mahakam River Area Near Mahkota Bridge.

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***Abstract***— *The landslide of the riverbank around the Mahakam River Mahkota Bridge is the main factor in conducting research at this location. The hydrodynamic behavior and post-slide shear stress are the focus of research because they may have an impact on the bridge foundation on the right side of the embankment and the construction of the road to Kalhol. Therefore, a solution is needed to reduce the continued risk. The method is used to observe the behavior of flow and shear stress around the bridge with the Delft3d numerical modeling approach. Modeling is made for up to 4 scenarios to reduce shear stress and control flow patterns so that they do not erode in land-slide-prone locations, especially in river bends. The field observation data used in the modeling consists of upstream discharge data and downstream water level fluctuations. The observation lasted for 25 hours on 26 December 2020. Identification of the existing model under extreme conditions shows shear stress up to 1.12 N/m2 even though the flow does not show a whirlpool or vortex. Other modeling is made up to 3 scenarios which include installing 1 crib, 3 cribs in parallel, and installing a full geo-bag. The last scenario is a solution that provides maximum results in reducing the shear stress to 0.01 N/m2 around the landslide area and the bridge foundation. Although the vortex flow pattern is also formed in this scenario, the location is not right on the edge of the embankment and the resulting speed of 0.5 m/s only occurs during extreme conditions.*

***Keywords***— *Mahakam river, mahkota bridge, landslide, riverbank*

## I. INTRODUCTION

The Mahakam River is a bridge that connects the city of Samarinda to Balikpapan. In early June 2020, there was erosion on the right bank of the Mahakam River, precisely at the suspension pillar of the Mahkota 2 Bridge. The local government temporarily closed access because it was feared to endanger the security of the bridge and all other assets and infrastructure around the erosion site. The erosion not only threatened the bridge but also threatened the stability of the Kalhol intake building as a raw water source with a capacity of 0.02 million $m^3$.

The moment of the landslide, which was reported by KompasTV Live (2021), identified the danger to the foundation and abutment of the Mahkota 2 Bridge that had been eroded on the right side of the river and the access road to the Kalhol intake building. Figures 1 and 2 provide a comparison of the condition of the riverbank before and after the landslide on the construction road to Kalhol, while Figure 3 shows a photo of cracks that are still vulnerable to further landslides. Based on the data from the bathymetric measurements (site plan and bathymetry from PT Nindyakarya, 2021), the horizontal erosion occurred along a 40-meter length of the original riverbank and along approximately 150 meters from the Kalhol intake to the bridge abutment, with depths varying from 6 to 20 meters. Riverbank erosion is the result of an erosion process caused by the hydraulic behavior of the river, which can disturb the stability of the riverbank and lead to landslides. Therefore, the research problem to be investigated is the effort to control riverbank erosion.


Figure 1. Condition before landslide, at 0:08 seconds (KompasTV Live, 2021).


Figure 2. Condition after landslide, at 0:20 seconds (KompasTV Live, 2021).


Figure 3. Condition after landslide, at 0:28 seconds (KompasTV Live, 2021).



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## II. Material and Methods

This research method utilizes primary and secondary data, which include:

### *2.1. Infrastructure around the Modeling Segment*

Around the location, there is the Mahkota Bridge that connects Balikpapan City and Samarinda City. It is a suspension bridge with one of its pillars located on the right bank of the Mahakam River. Additionally, approximately 200 meters upstream from the bridge, there is an intake building. The location of the bridge and the intake building can be seen in Figure 4.

Figure 4. Infrastructure of Kalhol Bridge and Intake around the Modeling Segment.

### *2.2. River Geometry*

The modeling of the Mahakam River segment was conducted along approximately 15 kilometres. There are two sources of data used to model the river's hydraulics at the landslide location. The river's bathymetry data was obtained from the Balai Rawa measurement results in 2014, while the river's morphology data around the location was measured in 2021. To combine these two different datum data, the reference point of the bridge pillar was used as a correction value. The merged results of the 2014 bathymetry data and the 2021 GEBCO DEM data can be seen in Figure 5. The width of the river under the Mahkota 2 Bridge is around 700 meters, with an average slope of 0.00086. The river's bathymetry and typical cross-sectional profile can be seen in Figure 6.

### *2.3. Boundary Condition*

The boundary conditions consist of upstream flow data and changes in water level downstream. At the same time, data calibration measurements were also carried out. These data are secondary data obtained from the East Kalimantan Provincial Technical Wetland Office in 2020. The data was recorded during the highest tide season during a 25-hour period, from 7:00 pm WITA on March 25, 2020, to 7:00 pm WITA on March 26, 2020, during the full moon (spring tide) phase. The measurement location is located at the coordinates shown in Figure 7.

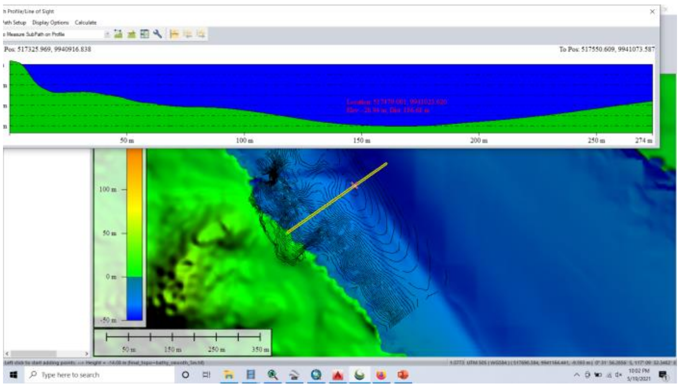

Figure 5. Bathymetry data of the river and the situation of the landslide location.

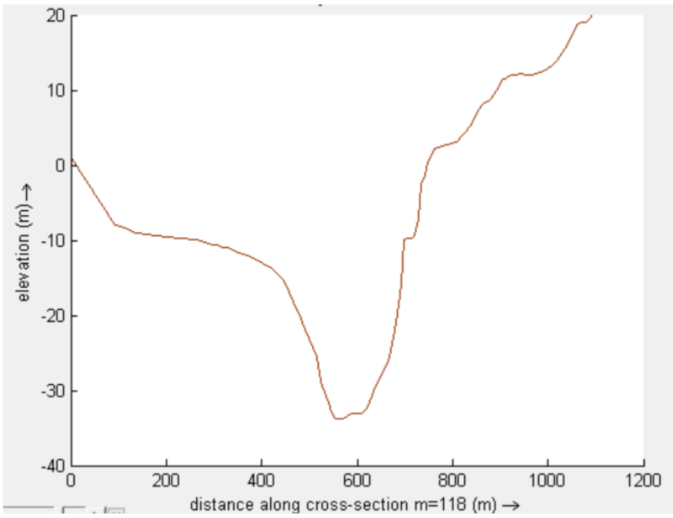


Figure 6. Typical cross section of the Mahakam River around the Mahkota 2 Bridge.

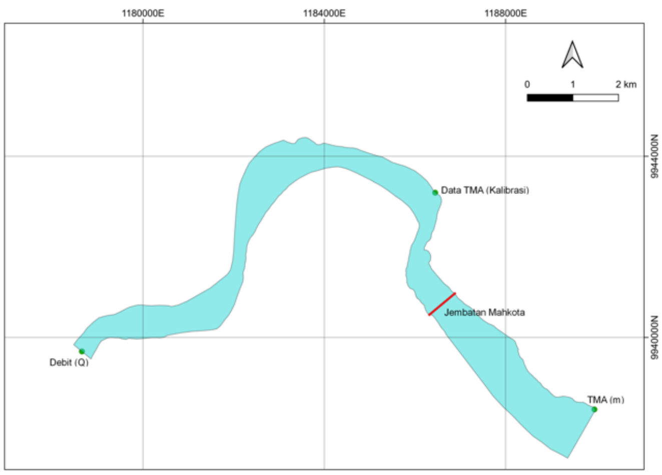


Figure 7. Domain model and boundary conditions upstream (discharge) and downstream (water level).

### *2.4. River Bed Material and Roughness*

The data on riverbed material was obtained from sediment size distribution testing conducted by PT Bumi Indonesia. The test results showed that the average $D_{50}$ diameter of the riverbed



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material was 0.007 mm, which falls within the clay criteria, as shown in Figure 8. The roughness of the river was determined using the Manning coefficient with a regular channel type, without large rocks or vegetation, and a channel roughness value of 0.025 was assigned (Chow, 1973).

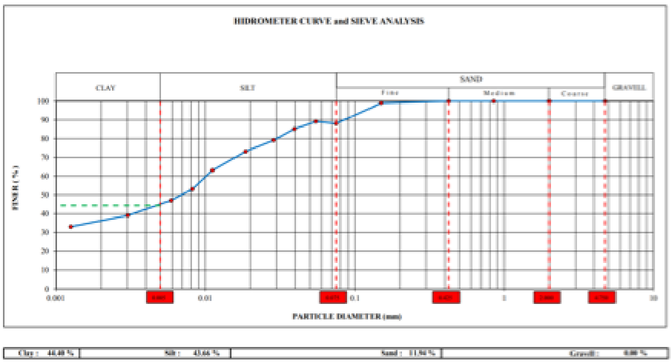



Figure 8. Particle size distribution analysis graph

## 2.5. Method of Data Analysis

The data analysis method used is to perform hydraulic analysis in the form of flow velocity parameters, flow patterns, and modeling of morphological changes in the Mahakam River. The data processing stages carried out for the analysis are as follows:

### *2.5.1. DEMNAS and Bathymetry Data*

The DEMNAS data is used to support and complete the river bathymetry data because the data obtained from the bathymetry is only along 500 m from the Kalhol intake to the abutment and 300 m wide across the river. To obtain a good model, additional river geometry is needed, for which DEMNAS data is used. The model is built along 1 km upstream and downstream from the surveyed location. The DEMNAS data used has a resolution of 8 meters and is first adjusted to the datum of the bathymetry measurements that have been carried out. The result of merging bathymetry and DEMNAS data is shown in Figure 5.

### *2.5.2. Delft3D Modeling*

In this study, hydrodynamic and sediment transport simulations were conducted using the Delft3D Flow software. The Delft3D Flow module, developed by Deltares (Delft, Netherlands), is a 3D model that can investigate flow hydrodynamics, sediment transport, and morphology. Delft3D uses the Navier-Stokes equations, including the closed k-ε turbulence model, and uses a curvilinear horizontal grid with σ layers for vertical grid resolution. The sediment transport equation used in this model is the van Rijn equation, with the settling velocity also using van Rijn's equation. The 3D river model was created using the Delft3D RGFGRID module to form a curvilinear grid model. The domain model using Delft3D shows in the Figure 9.

The hydraulic and morphological study of rivers requires sediment transport data input, which is in the form of laboratory test secondary data as shown in Figure 8. From these results, it is further analyzed to become sediment transport data that has a relationship with the magnitude of shear stress.

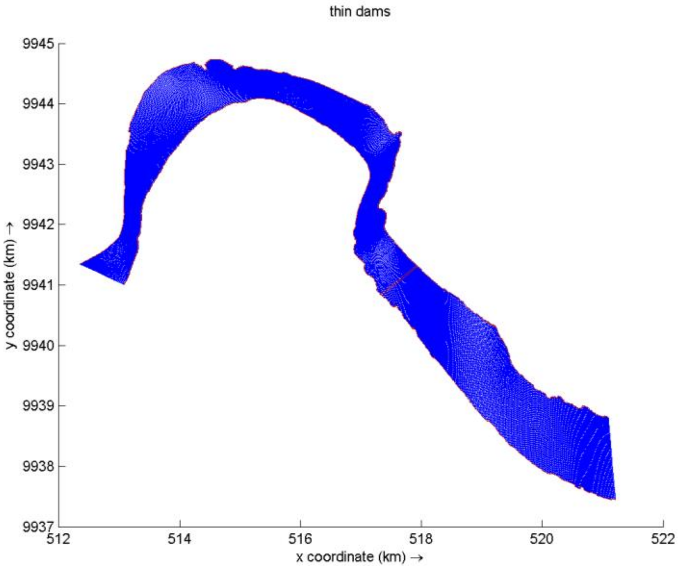



Figure 9. Domain model of the Mahakam River using Delft3D.

The relationship between bed shear stress and sediment transport can be described by the Shields criterion, which states that sediment transport will occur when the bed shear stress exceeds a critical value known as the critical shear stress. The critical shear stress depends on various factors such as sediment size, shape, density, and sorting, as well as fluid properties such as viscosity and turbulence intensity. An analytical example is as follows:

If the shear stress at the base exceeds the critical shear stress, sediment particles will be transported into the flow.

$$\tau_b = \rho \cdot u_*{}^2$$

$$u_* = \frac{U}{C}\sqrt{g}$$

Chezy C is an empirical formula for the average velocity of steady and uniform flow.

$$U = C\sqrt{RS}$$

In this case, it indicates that the Chezy and Manning formulas are equivalent, where C is;

$$C = 18\log\frac{12h}{k_s}$$

$k_s$ is the Nikuradse roughness length based on the sediment grain size distribution $D_{50}$ or approximately 0.75 times the height of the sand ripple.

### *2.5.3. Modeling Scenario*

Efforts to obtain erosion control can be carried out by conducting a modeling scenario. To determine hydraulic parameters (flow velocity, flow patterns, shear stress) modeling is done on existing river cross-sections and on conditions after erosion control measures using geobags have been implemented.

## III. RESULTS AND DISCUSSION

### *3.1. Existing Condition*

The parameters used in the existing conditions include the boundary conditions at the upstream (discharge) and downstream (variation in water level). Using the Delft3D numerical model, the input data for the Manning coefficient values are considered constant for the U and V flow components, which are 0.025. The input data for the density of sediment that is hindered from settling due to water mass balance is 1600 kg/m$^3$. These parameters are the default rules in Delft3D that must be entered for non-cohesive sediment types. Meanwhile, the initial sediment thickness conditions are assumed to have a uniform non-cohesive sediment layer depth of 5 meters from the riverbed surface. This assumption is based on the study by Patriadi et al. (2021) in the case of the downstream part of the Bengawan Solo River, which has relatively homogeneous sediment surface layers.

*3.1.1. Validation Existing Model*

Figure 10 is the result of validating the existing model, which corresponds to the location observation points in the field "TMA Data" as seen in Figure 7. The TMA Data parameter referred to is the comparison of changes in water level. The model validation was analyzed using the Root Mean Square Error (RMSE) method and resulted in a value of 0.36, which means that it is close to the observed conditions in the field, allowing the scenario modeling to continue.

*3.1.2. Flow Pattern and Velocity*

The modeling results of the existing conditions in Figure 11 describe three extreme situations that occurred during the 25-hour simulation process. These were on March 26, 2020 at 05:00 (a), 08:00 (b), and 17:00 (c). These situations were included because they were suspected of causing landslides and could potentially endanger the Kalhol construction road and bridge foundation after the landslide. The red circle area was the observation area because it was closest to the landslide location. Generally, the observation area had relatively the same flow velocity, which was 0.5 m/sec. However, the flow velocity and patterns before entering the observation area had similar behavior in Figures 11.a and 11.c.

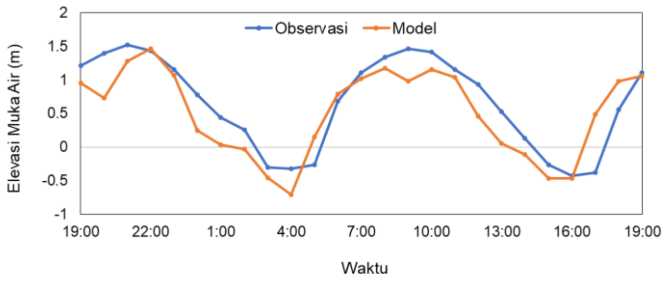
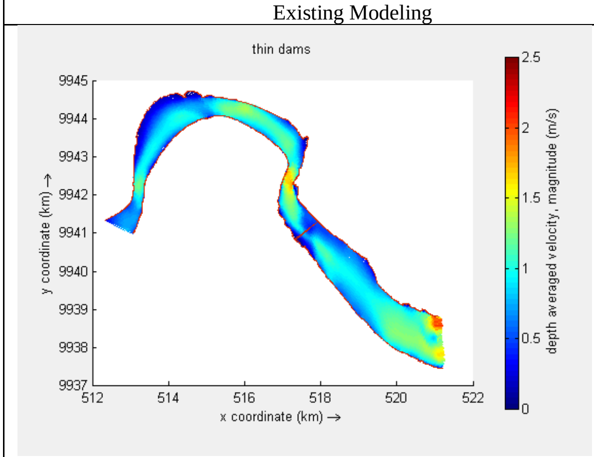
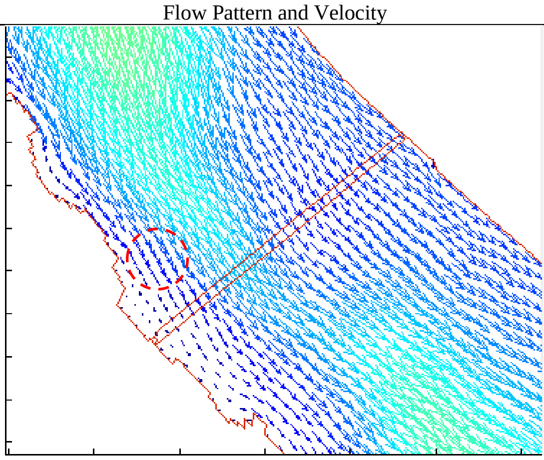
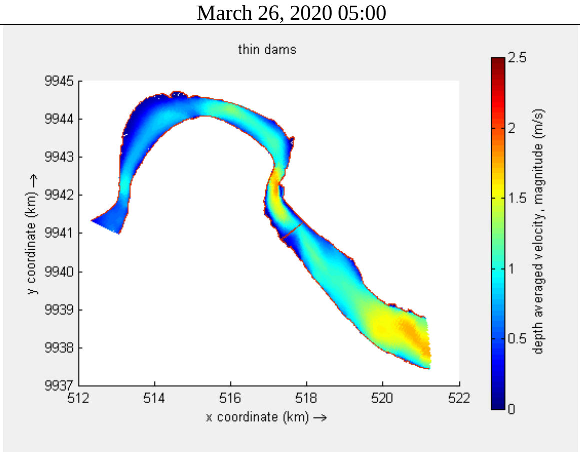
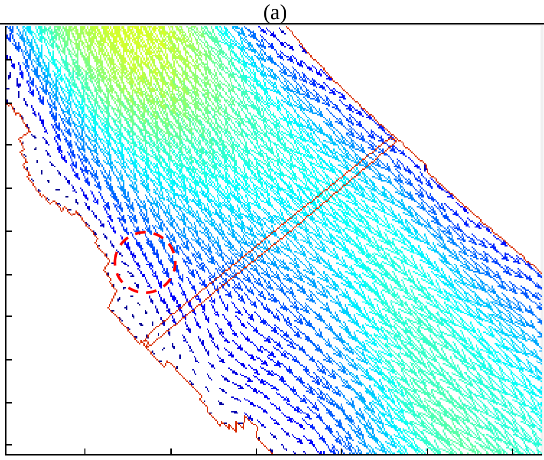



Figure 10. Validation of the model and water level observation

| Existing Modeling | Flow Pattern and Velocity |
|---|---|
|  March 26, 2020 05:00 |  (a) |
|  March 26, 2020 08:00 |  (b) |



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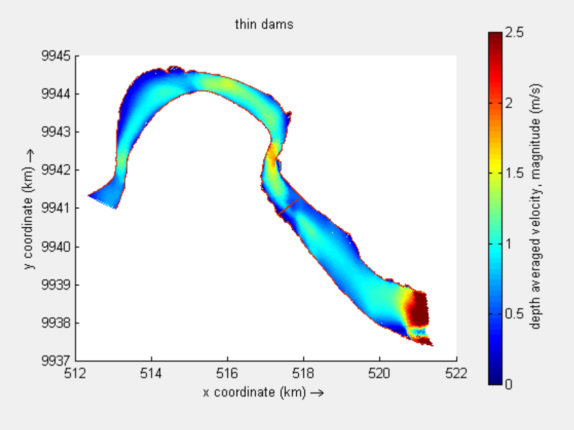
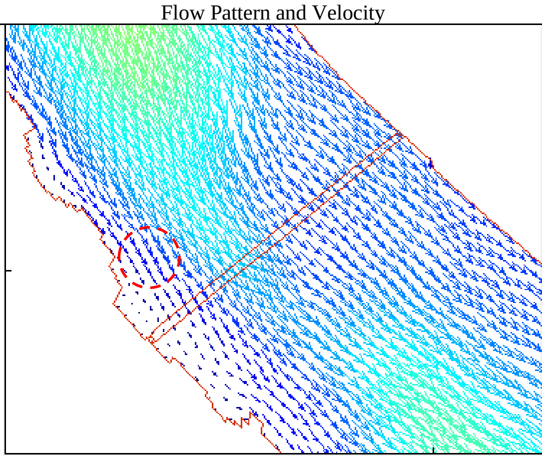
| Existing Modeling | Flow Pattern and Velocity |
| --- | --- |
|  |  |
| March 26, 2020 17:00 | (c) |

Figure 11. Flow Pattern and Velocity Output Parameters from Modeling Results of Existing Conditions

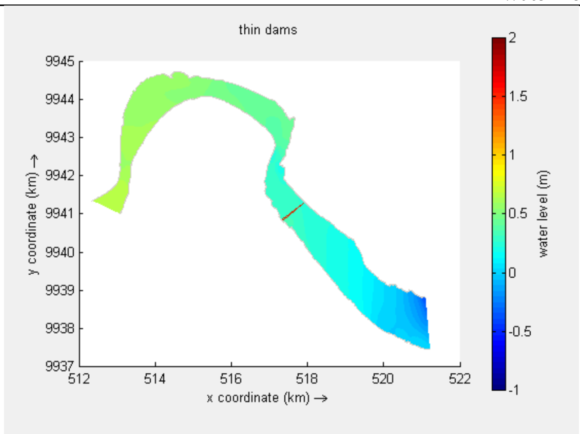
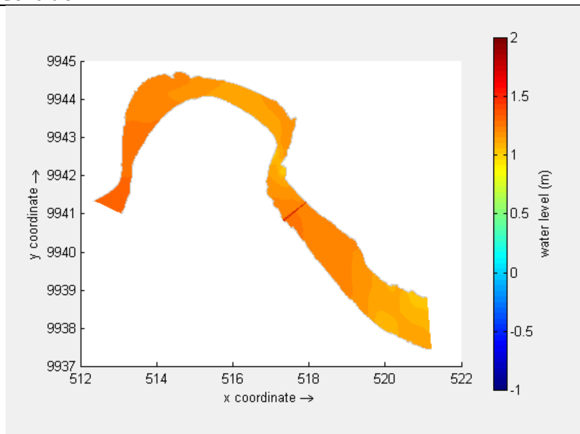
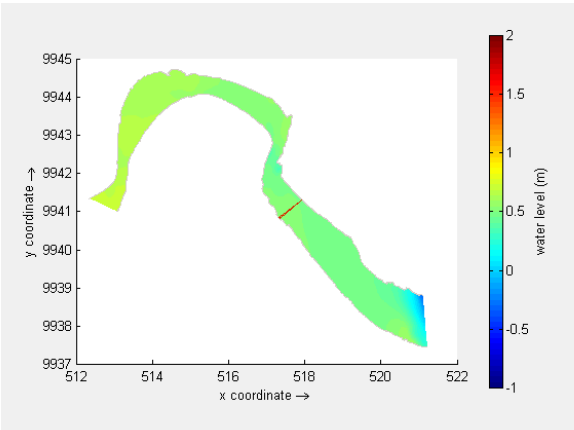
| *Water Level* Eksisting Condition | |
| --- | --- |
|  |  |
| March 26, 2020 05:00 – (a) | March 26, 2020 08:00 – (b) |
|  | |
| March 26, 2020 17:00 – (c) | |

Figure 12. Water level Output Parameters from Modeling Results of Existing Conditions



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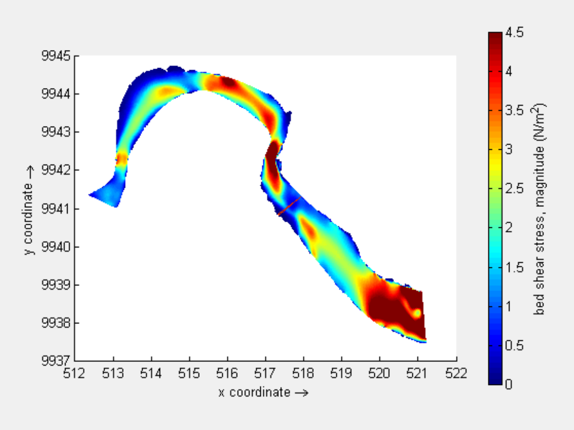
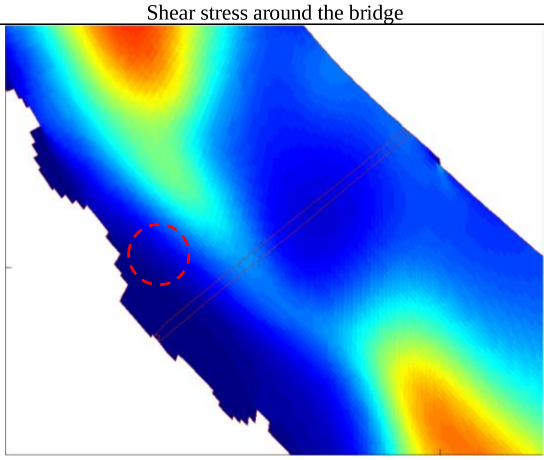
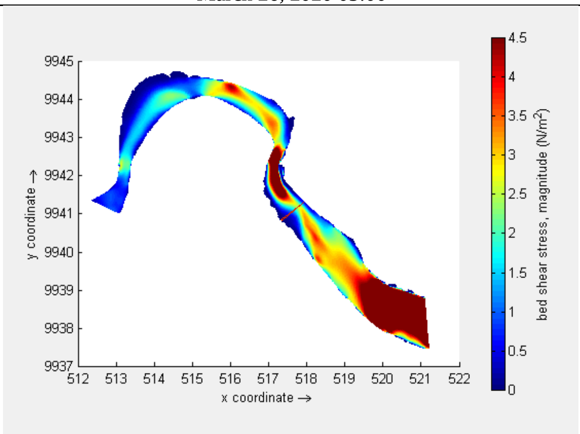
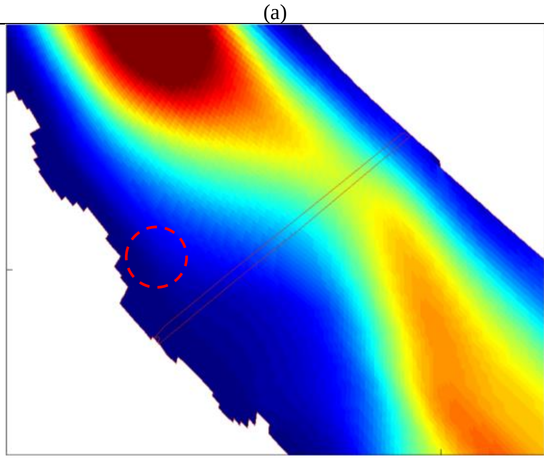
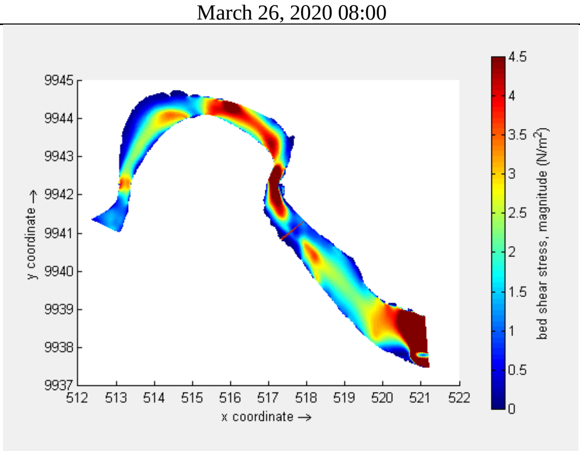
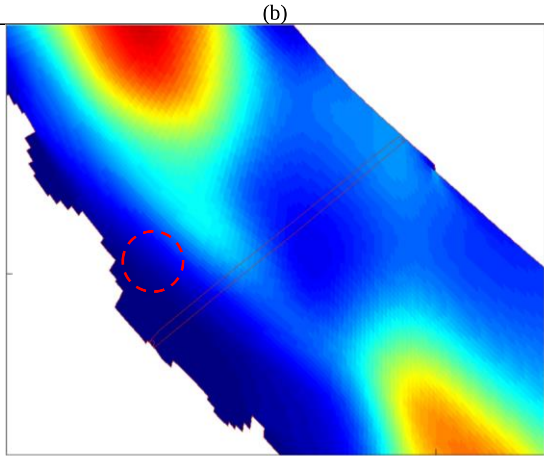
| Existing Modeling | Shear stress around the bridge |
|---|---|
|   March 26, 2020 05:00 |  (a) |
|   March 26, 2020 08:00 |  (b) |
|   March 26, 2020 17:00 |  (c) |

Figure 13. Bed shear stress Output Parameters from Modeling Results of Existing Conditions

That is, the flow velocity tended to approach the right bank of the river, reaching 0.95 m/sec. Observing Figure 11.b, the flow velocity level of 0.95 - 1.50 m/sec was in the middle of the river with flow patterns turning left after the Mahkota Bridge. This difference can be observed in the tidal conditions that occurred at 8:00 a.m. with a water level elevation of 1 m (Figure 12.b). This elevation was in a state of approaching and/or nearing the maximum tide, while at 05:00 and 17:00 it was at the beginning of the tide or had just passed the lowest ebb phase. The analysis of the tidal conditions was observed through Figure 10, which shows the relationship between time and water level elevation at the "Data TMA" point (Figure 7).

Figure 13 shows the bed shear stress condition at the maximum condition according to the domain limit. The pattern of bed shear stress depicted resembles the flow pattern in Figure 12 and ranges between 0.75 - 1.20 N/m$^2$.

### *3.2. Scenario Modeling*

In this scenario, a simulation was conducted at the eroded location. At this location, it is planned to bury the entire



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eroded area with geobags. The plan for the geobag placement can be seen in Figure 14. The installed geobags provide a uniform velocity distribution behavior under extreme conditions, ranging from 0.5 m/sec at the riverbank to 1 m/sec at the center of the river, precisely at the river bend before the Mahkota Bridge. The new problem arising in this scenario is the displacement of the vortex on the left side of the Mahkota Bridge with a flow velocity of 0.5 m/sec. Therefore, another model is possible to ensure that the flow remains in the center of the river to avoid the occurrence of water whirls that can endanger the foundation of the central part of the bridge due to potential scouring. The construction of geobags does not have a significant influence on tidal changes in the flow pattern in the Mahkota 2 Bridge area.

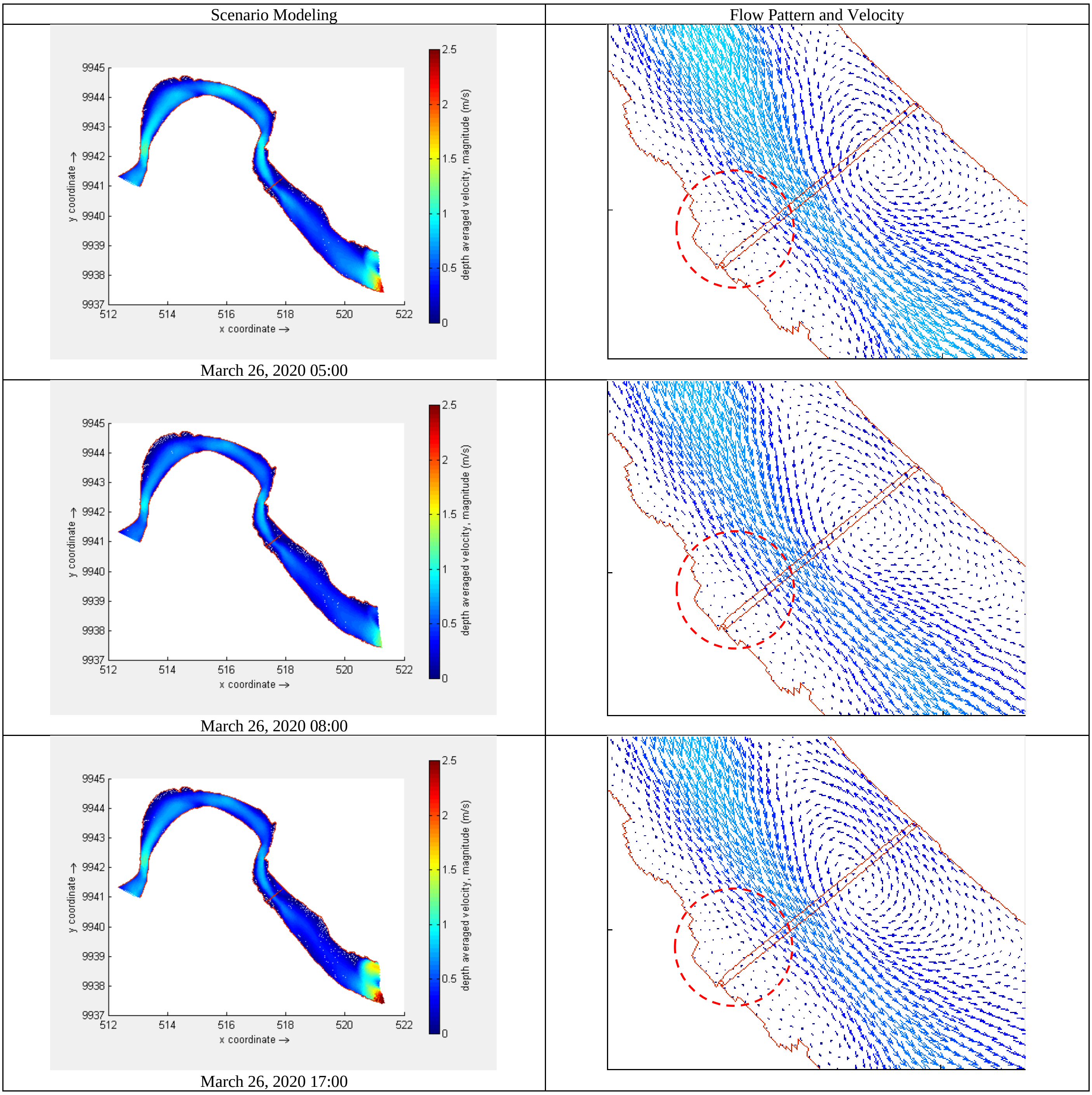

Figure 14. Flow Pattern and Velocity Output Parameters from Modeling Results of Scenario Modeling



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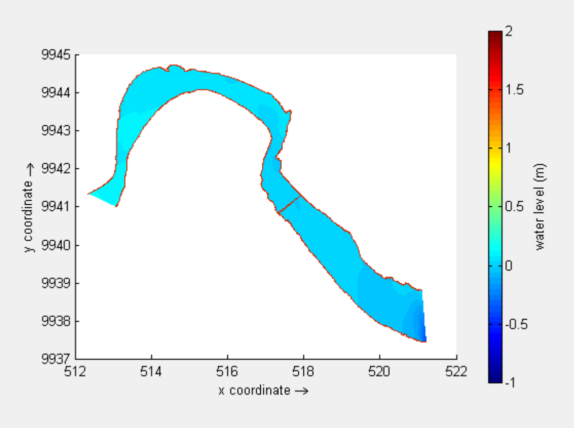
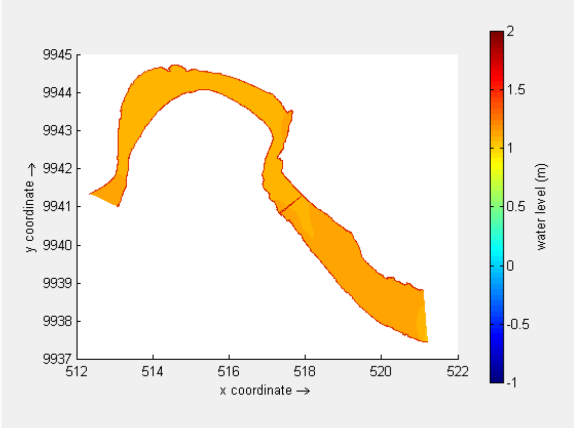
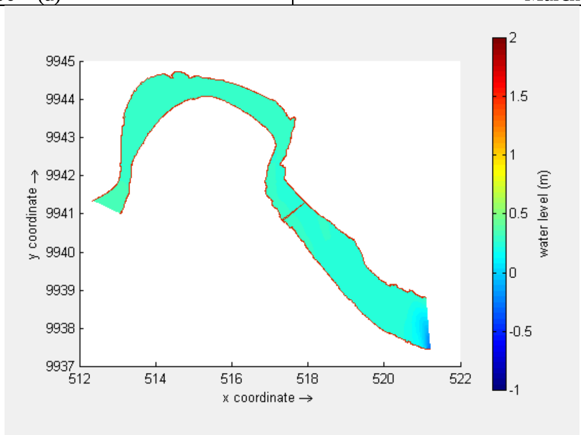
`Water Level of Scenario Modeling




March 26, 2020 05:00 – (a)



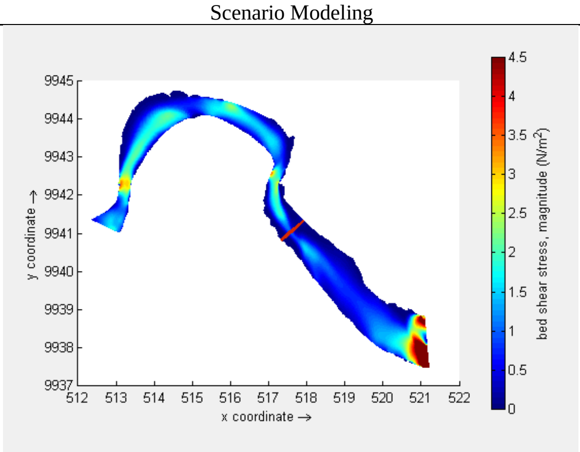

March 26, 2020 08:00 – (b)




March 26, 2020 17:00 – (c)

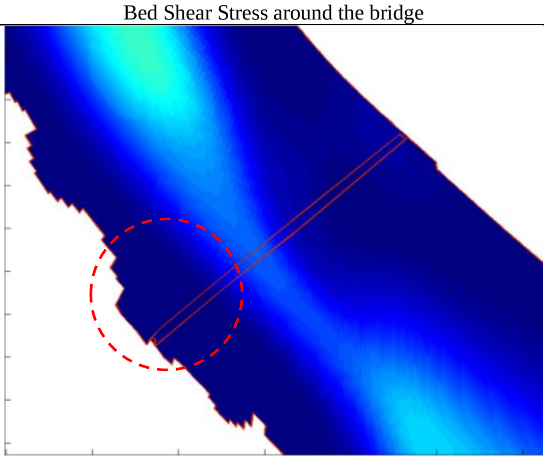
Figure 15. Water level  Output Parameters from Modeling Results of Scenario Modeling

Scenario Modeling




March 26, 2020 05:00

Bed Shear Stress around the bridge



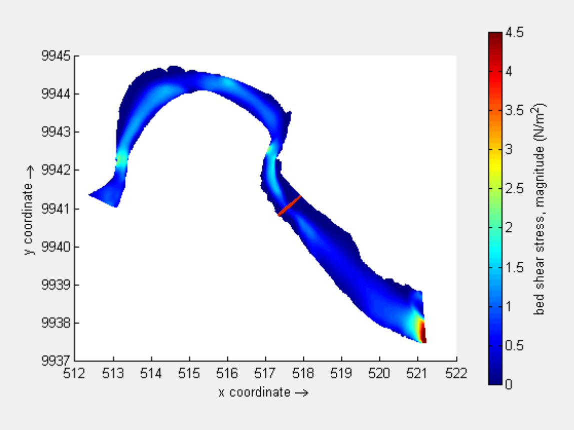
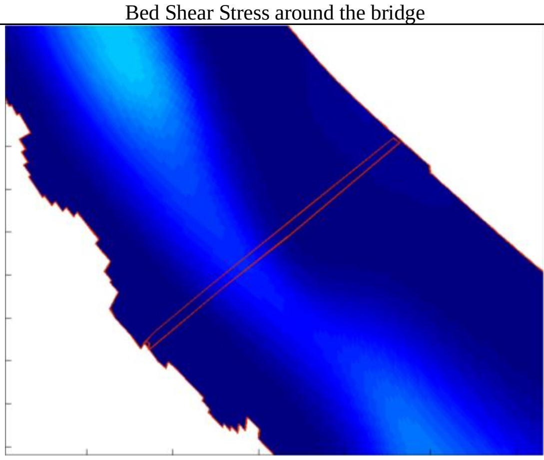
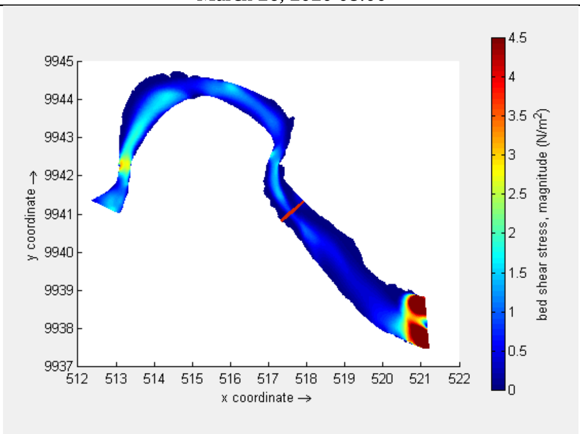
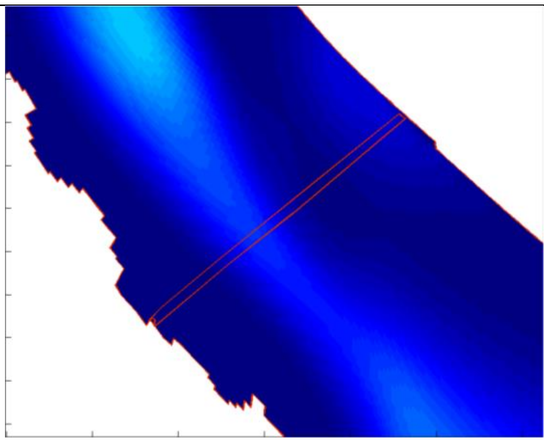
| Scenario Modeling | Bed Shear Stress around the bridge |
|---|---|
|  March 26, 2020 08:00 |  |
|  March 26, 2020 17:00 |  |



Figure 16. Bed shear stress Output Parameters from Modeling Results of Scenario Modeling

On the other hand, the bed shear stress condition in Figure 16 is different. The results of the model can be used as a reference in planning construction solutions because the resulting bed shear stress decreases to 0.01 N/m2, and the same reduction occurs in the middle of the river.

## IV. Conclusion

The hydraulic behavior of the river after the landslide has a flow velocity of 0.95 - 1.50 m/s which ranges from 150 m from the right bank. The existing condition shows that the shear stress of the riverbed ranges from 0.70 - 1.25 N/m$^2$ and the relative bed roughness in the middle of the river. The obtained comparison of the change in river bed shear stress between the full geobag modeling scenario and the existing condition at the study site is 0.01 N/m$^2$.

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