RESEARCH PAPER

RIVER BED STABILIZATION STRUCTURES PLACEMENT DETERMINATION BASED ON SATELLITE DATA

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Abstract

River bed stabilization structures placement determination is challenging in limited river morphological data availability area, especially related to post disaster budget allocation proposals. This research aims to propose a new methodology in river bed stabilization structure determination by using ASTER GDEM v.2 and CGIAR-CSI SRTM v.4.1. The study case is the post debris flood event in Bangko River, West Sumatera, Indonesia. The Bangko River was selected due to the fact that it has various morphology within a short river segment, which are steep, proliferating, and meandering. The satellite data were analyzed based on several requirement stated in the design requirement of spacing between riverbed stabilization dam in Pacific Northwest and in Indonesia, combined with rapid post disaster survey information. The analysis elaborating the initial ($\theta$), static ($\theta_s$) and dynamic ($\theta_d$) equilibrium slope theory in determining interval and required number of the stabilization dam. The riverbed change also explored based on upper side sub dam toe depth and overburden height parameter. The Bangko River bed slope alteration due the dam arrangement were resulted and summarized in this paper.

Keywords: river bed, stabilization, satellite data.

INTRODUCTION

General Background

River bed stabilization structures placement determination is challenging in limited river morphological data availability area. Moreover, during flash flooding post event, the river will create its temporal sediment transport pattern to reach a new equilibrium (Remaître & Malet, 2010). Therefore, it is necessary to propose river bed stabilization structures for budget allocation proposal.
Without sufficient topographical and land cover data, the river stabilization structure determination can be misplaced or miss reckoning in terms of structures quantity (Shikada & Yamashita, 2000). The river stabilization structures miss planning can leads to worse river degradation situation or to creating other disaster such as flood overflow in prone locations (Wisoyo, 2012).

This research aims to propose a new methodology in river bed stabilization structure determination by using a certain satellite data and compare the proposed method with the one that occupying the different data. In order to reach that goal, a study case of river bed stabilization structure placement case in Bangko River (figure 1), West Sumatera, Indonesia, is utilized. The Bangko River was selected due to the fact that it has various morphology within a short river segment, which are steep, proliferating, and meandering (figure 2).
Figure 2. Bangko River Reach and its appearance during the flood event.

Where: (a) Flat area at lower river reach, Jorong Sungai Pagu; (b) New sedimentation material at torrent, Jorong Ujung Jalan; (c) Braided river pattern at outspread point of debris flow, upstream Bangko River.

The different data compared in the analysis are the ASTER GDEM and the SRTM topographical satellite data. The data would be analyzed based on several requirement stated in the design requirement of spacing between riverbed stabilization dam in Pacific Northwest (Chatwin, Howes, Schwab, & Swanston, 1994) and in Indonesia (Sumaryono, Yunita, & Puspitosari, 2013).
Literature Study

The sediment control in a river basin became the core of Integrated Sediment Disaster Management Approach in recent changing climate condition (Lee, Lee, Sim, Kim, & Yang, 2015). The sediment is mainly generated in upstream area and moving gravitationally to the downstream that can alter the river morphology (Krapesch, Hauer, & Habersack, 2011), create disasters for human and assets in vicinity. One of the solution is to build rives stabilization structure (figure 3), which are called as sabo technology application, in the river system (Mouri et al., 2013). The sabo approach require some topographical data in a certain of detail, as mentioned in the design standard (Sabo Team, 1999). The designer usually conducting terrestrial geodetic survey to collect the topographical data of the river basin. However, in some remote area, the topographical survey data does not exist. It makes post disaster rapid countermeasure against river morphology changes difficult to be led, as Bangko River Flood Event, 8 February 2016.

![Diagram of river bed slope and stabilization structure](image)

Figure 3. River bed slope (θ) with (a) and without (b) stabilization structure. Generated from Sabo Design Practice (Osanai, Mizuno, & Mizuyama, 2010).
Figure 4. Raster image of ASTER GDEM v.2 (a) and SRTM v.4.1 (b) of Bangko River Basin.

The detailed topographical data of river morphology analysis can also result from LIDAR survey, which its detail is linear to survey resources allocation (Moretto, Delai, & Lenzi, 2013). An approach of using satellite free data was also initiated, in terms of prediction and mitigation of volcanic eruption-induced sediment disasters (Nakano, Yamakoshi, Shimizu, Tamura, & Doshida, 2010). However, the approach to use satellite data for river bed stabilization structure placement determination has not ever been evaluated. The topographical satellite data that are free available are Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model (ASTER GDEM v.2) and Shuttle Radar Topography Mission DEM (SRTM DEM v.4.1) (figure 4).

The ASTER GDEM v.2 was released in October 2011, which provided a 1 arc-second elevation grid size with vertical accuracies generally between 10 – 25 meters (m) (Tachikawa, Hato, Kaku, & Iwasaki, 2011). The SRTM DEM v.4.1 from CGIAR-CSI has filled no data grid with interpolation method (Jarvis, Reuter, Nelson, & Guevara, 2008), resulting in 3 arc-second elevation grid size DEM with ~ 4.5 m RMS error tested in Australia region (Rexer & Hirt, 2014).
Methodology of Study

In case of disaster event that alter the river morphology, which had not been predicted before, the first attempt is to conduct a site visit. This rapid post disaster survey is the best approach to collect undisturbed data of the morphological changes that happened in the location. The data collection include the location of out breached post flood sedimentation, the sediment source that potentially to be transported, the new river path, and the subsequent flood risked settlement and asset. Those locations were marked using Global Positioning System and accompanied with photograph or drone scene capture.

The location data can be used to acquire the topographical satellite data extend that need to be acquired. The ASTER GDEM V.2 data is available online from NASA Reverb, LP DAAC Global Data Explorer, and J-spacesystems ASTER GDEM Page. The SRTM DEM v.4.1 can be downloaded from CGIAR-CSI website (http://srtm.csi.cgiar.org/). In this research, CGIAR-CSI SRTM v.4.1 with 3 arc-seconds size was chosen due to the fact that it uses interpolation data to fill the no data value cells. The NASA v.3 SRTM has smaller cell size (1 arc-second) but the DEM voids were filled with ASTER GDEM data. It is recommended to use the CGIAR-CSI SRTM v.4.1 data, by the intention of having better SRTM and ASTER data comparison independency.

The downloaded DEM then processed with GIS Tools to have same coordinate system and same grid size (1 arc-second size). The next step is to impose river data (from Indonesian Geospatial Portal, http://portal.ina-sdi.or.id/) to the DEM (burning/ fencing) using AGREE method (Hellweger & Maidment, 1997). The Bangko River width as average stream buffer is ~150 m or 5 cells. After that, the raster was fix from sink holes existence that can cause error in DEM flow analysis. The DEM without sink then can be used to calculate flow direction, flow accumulation, stream definition, stream segmentation, catchment grid delineation, catchment polygon processing, drainage line processing, adjoin catchment processing. This approach can be done using hydrology analysis tools or HEC tools in GIS (Mustafa, Amin, Lee, & Shariff, 2012).
These resulted data, which are river raster, flow accumulation raster, AGREE elevation raster, raster cell coordinate to calculate river length between raster cell, and river bed slope raster, can be used to create long section of the Bangko River for sabo placement design. The selected river reach is the main Bangko River reach that evidence debris flood in 8 February 2016. An immediate post flood survey was conducted on 16-20 February 2016. In this particular location, the river stabilization dam is designed with 4-8 m height of main dam overall height and 2-4 m of sub dam overall height, which is small typical river stabilization dam (Asian Disaster Reduction Center, 2006). The static sediment transport scenario was designed to reach 2° to 6° slope in 2-10° river bed slope zone (sand mining area with training dyke), 10° slope in 10-15° river bed slope zone (avoid debris flow occurrence), 15° slope in 15-20° river bed slope zone (reduce debris force), and no river stabilization structure in more than 20° river bed slope zone (proposed natural conserve area). Dynamic slope is set as 0.5-0.9 of original slope to put minimum space between dam by the intention of avoiding over sediment accumulation at the upper sub dam during the debris event. However, these parameter can be adjusted to a certain river cases through a detail survey.

![Figure 5](image_url)  
Schematization of a series of river bed stabilization structures.
River bed stabilization structure determination based on ASTER GDEM v.2 and SRTM DEM v.4.1 were assessed based on four constrains. The confining conditions are static and dynamic equilibrium slope (equation 1 - 4) (Chatwin et al., 1994; Sumaryono et al., 2013). The outline was visualized in figure 5, to clarify the used parameters in these equations:

\[ L_1 = \frac{H_d}{\tan(\theta - \theta_s)} + \frac{h_s - td}{\tan(\theta - \theta_s)} \]  

(1)

\[ L_2 = \frac{H_d}{\tan(\theta - \theta_d)} - \frac{ob}{\tan(\theta - \theta_d)} \]  

(2)

\[ \theta_s = \frac{80.9\phi}{g\left(\frac{nQ}{0.29B\sqrt{\phi}}\right)^{6/7}} \]  

(3)

\[ \theta_d = \left(\frac{0.005q(\rho_s - \rho_w)^{2\phi}}{10g^{1/2}(nq)^{3/2}}\right)^{4/7} \]  

(4)

where

- \( L_1 \) : static type dam spacing (m)
- \( L_3 \) : dynamic type dam spacing (m)
- \( \theta \) : original river bed slope (°)
- \( \theta_s \) : static equilibrium slope (°)
- \( \theta_d \) : dynamic equilibrium slope (°)
- \( B \) : flow width (m)
- \( Q \) : flood discharge (m\(^3\)/s)
- \( q \) : unit flood discharge (m\(^3\)/s/m)
- \( g \) : gravitation (m/s\(^2\))
- \( \phi \) : sediment grain size (d\(_{50}\)) (m)
- \( n \) : Manning roughness coefficient
- \( \rho_s \) : sediment density (kg/m\(^3\))
- \( \rho_w \) : water density (kg/m\(^3\))
- \( H_d \) : effective height of riverbed stabilization main dam (m)
- \( h_s \) : height of upside adjacent sub dam (m)
- \( td \) : toe depth (m)
- \( ob \) : over burden height (m)
RESULT AND DISCUSSION

The stream paths generated from the ASTER v.2 and SRTM v.4.1 have differences in length and coverage area. The reason is that those data has different void filling and interpolation method. Moreover, the use of ASTER v.2 raster resulting more riverbed stabilization structures compared to the one proposed from SRTM v.4.1 raster (table 1). It is presumed that the stream path bred from ASTER v.2 raster is more meandering than the other one although both of them have a coinciding outlet. The limitations of the data still allow the riverbed stabilization analysis to be conducted. It can offer a dam allocation presumption, in order to maintain the riverbed stability after the disaster event.

Table 1. The results of the proposed riverbed stabilization structure analysis.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>ASTER v.2</th>
<th>SRTM v.4.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>River reach</td>
<td>11.190 m</td>
<td>13.918 m</td>
</tr>
<tr>
<td>L₁</td>
<td>2.344 m</td>
<td>2.061 m</td>
</tr>
<tr>
<td>L₂</td>
<td>17.189 m</td>
<td>15.112 m</td>
</tr>
<tr>
<td>Required dam</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Zone B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>River reach</td>
<td>9.706 m</td>
<td>6.680 m</td>
</tr>
<tr>
<td>L₁</td>
<td>206 m</td>
<td>170 m</td>
</tr>
<tr>
<td>L₂</td>
<td>955 m</td>
<td>784 m</td>
</tr>
<tr>
<td>Required dam</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>Zone C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>River reach</td>
<td>1.458 m</td>
<td>791 m</td>
</tr>
<tr>
<td>L₁</td>
<td>200 m</td>
<td>164 m</td>
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<tr>
<td>L₂</td>
<td>704 m</td>
<td>577 m</td>
</tr>
<tr>
<td>Required dam</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>
CONCLUSION AND RECOMMENDATION

The use of satellite topographical data provides a dam allocation presumption, in order to maintain the riverbed stability after the disaster event. This method can be used when detail topographical data and sediment data do not exist yet. The further calibration of the resulted river bed stabilization arrangement using field measurement evidence is necessary to be conducted. The calibration effort can sharpening this method into modules that can be used in other places that has similar watershed characteristics.

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REFERENCES


