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Modeling the Slippage of Mount Merapi Cold Lahar Flow Due to the Placement of Non-Permanent Broad-Crested Weir Structures Downstream of the Pabelan Bridge

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ABSTRACT: The flow pattern that occurs in rivers due to the descent of cold lava often causes damage in various areas. This phenomenon is inseparable from the volume of water mixed with volcanic material flowing through the open channel, which results from input water supply or water storage passed by cold lava. Hydrology researchers study the water mixed with volcanic eruption material that remains on higher ground. River flow is influenced by the riverbed surface profile and varying river widths. When given a certain volume with specific viscosity, a dense flow may form, which can be observed on the water surface, while the denser viscosity underneath the surface remains invisible to the naked eye.

If the runoff of cold lava material in these channels is not measured, it can lead to uncontrolled jumps. The structured form of such uncontrolled and dense jumps can be observed through the resulting flow patterns. To prevent undetected flow patterns, hydraulic measuring structures are needed, one of which includes a weir with a bottom opening—known as flow over a weir—along with surrounding bridge structures. This sluice gate is easy to operate, even manually. However, estimating water operation needs under excess water availability is not straightforward due to the effects of depth and jumps occurring around the bridge. Hydraulic jump patterns often overlook measurable aspects, which can be a constraint when there is an increase in cold lava supply mixed with rainwater during peak discharge flow events.

To address this, observations must be validated through model testing using an apparatus known as a weir, which produces jumps of water along with sediment material—an area that still requires in-depth research in modeled channels. The weir modeling and connecting bridge include instruments and various weir treatments, with adjustable pressurized water using a pump at specific discharges. To analyze structural damage height, flow pattern determination, and flow velocity, observations are made using valve openings on certain pumps. The researcher tests and measures the deposition positions of cold lava sediments, one by one, based on slope positions of specific river sections. The testing begins with valve openings of 0.5 and 0.75, reading instruments, moving the weir position from a 20 cm to 240 cm distance from the bridge. A graph of the weir test results is then generated based on bottom opening movements below the bridge, with three test repetitions for each pump opening, recording depth values, jump lengths, and travel time measured using test instruments.

The results of the weir and bridge test analysis are recommended as reference information for bridge construction planners. The results show that varying weir positions under certain conditions indicate a collapse value for the Glidik II bridge, correlating with jump length and cold lava flow speed. This research is a laboratory study using weir and bridge models. The target output is a journal article based on simulation results of flow pattern determination in a channel, by shifting the weir position relative to the bridge structure. The experiment uses various model material diameters, presented in tabular and graphical formats, particularly focusing on flow with sediment and cold lava materials in hydraulic laboratory models.

The findings are observed up to the point of bridge collapse at a depth of 4.5 cm with a ½-second valve opening at the 37th second (in model scale), equivalent to 45 meters (in empirical scale). The results will then be written into a journal article for publication in an international journal.

KEYWORDS: bridge alignment, flow dynamics, bottom-crested weir, viscous flow

1. INTRODUCTION

The sliding flow of cold lava accompanied by volcanic material from Mount Merapi in Magelang Regency, Central Java, in 2010 caused the collapse of a bridge located in Pabelan, Salatiga. The large volume of volcanic material from Mount Merapi disrupted the national road access in the central region of Central Java, as the collapsed bridge was the sole connection between Magelang Regency and Salatiga. The Ministry of Public Works and Housing, through the Central Java National Road Implementation Agency under the Directorate General of Highways, planned to reconstruct the Pabelan River Bridge, along with the Serayu Opak River Basin Agency, as a permanent solution to address the cold lava flood problem from Mount Merapi.

According to a survey by the Head of the Central Java River Basin Agency, Mr. Eka, the temporary bridge installation at the Pabelan site was technically infeasible. Moreover, one of the two main piers of the Pabelan River Bridge had been washed away during the 2010 flood. Given this condition, the proposed temporary handling by installing a temporary bridge was deemed unviable at the existing bridge site, as the remaining piers could not safely support a temporary structure over a non-permanent broad-crested weir.

The collapse of the Pabelan Bridge was caused by floods carrying volcanic materials from Mount Merapi. It was found that the bridge's foundation did not reach the bedrock of the riverbed due to lava deposits. Thus, when subjected to high-flow floods carrying volcanic materials, the bridge collapsed for the third time..

The Pabelan River Bridge, built in 1970, had a lifespan of 40 years. It was 40 meters long and 7.5 meters wide. The bridge's superstructure was composed of permanent steel girders and consisted of two spans. The collapse also triggered landslides along the national road embankment in Salatiga. The plan to install a Bailey Bridge to replace the Glidik II Bridge was implemented in three stages, with spans of 20 meters in stage 1 and 20 meters in stage 2. It was also planned to limit vehicle loads to a maximum of 20 tons. Currently, the Pabelan Bridge has been reconstructed using a steel structure.

The collapse of the bridge across the river, if left unmonitored, can lead to extensive damage to the surrounding land and even compromise channel structures. To prevent damage in the model area, hydraulic measurement structures are needed, one of which includes a sluice gate with a bottom opening, commonly known as a weir. This type of structure is easy to reposition manually. However, estimating operational water needs under conditions of excess water availability is complex due to influencing factors such as depth, head differences between upstream and downstream, and the variability of hydraulic jumps, all of which often disregard the measurable components. This becomes problematic during peak flow conditions of cold lava from Mount Merapi. Therefore, this needs to be verified through model testing using a wide-crested weir capable of generating turbulence and structural failure. In-depth research on this modeling is thus required.

The results of the weir placement analysis are expected to provide valuable information to water infrastructure planners. Testing weir positions under various conditions has shown differences in flow depth, jump patterns, and travel time. These findings can later be applied to the design of other hydraulic structures, helping determine the optimal distance between the weir and bridge in managing cold lava flows.

Manual observations assist researchers in data collection. Distance indicators between the weir and bridge are marked externally on the instrument, signaling potential collapse points. Instruments measure flow dynamics after passing through the weir and bridge, using centimeter units. The urgency of this research is expected to provide recommendations for managing cold lava flows in the Pabelan River, and to help field operators determine the types and sizes of volcanic materials that pose risks to residential structures along the river.

2. LITERATUR REVIEW

2.1. Cold Lava Floods

Lahar is a flow of large volcanic debris originating from the slopes of a volcano. The remarkable mobility of this flow signifies that lahar is one of the greatest hazards posed by volcanic activity. In addition to primary hazards, secondary hazards such as cold lava flows can also endanger residential areas located along river basins through which they pass (Pua et al., 2024).

Cold lava, or lahar dingin, refers to a flow of volcanic material typically consisting of a mixture of rocks, sand, and gravel, transported by water flowing down volcanic slopes (Lisa et al., 2013). Cold lava floods are a type of natural disaster caused by volcanic activity (Nasarudin, 2022). When a volcano erupts and emits lava, large rocks may also be ejected and carried along with the lava flow. cold lava—which originates from hardened lava—also carries the same large rock materials. Therefore, cold lava floods possess a high potential for destruction, especially toward human settlements (Fauzan Fadlan & Nurcholis, 2023)

2.2 Jump Length of the Weir

A broad-crested weir is the base portion of an overflow structure that functions as a flow measurement device. The cross-section of the overflow from a sharp-crested weir typically has a rectangular shape (SNI-03-6455.3-2000; SNI-03-6455.5-2000). A weir is classified as a broad-crested weir when the flow adheres to the crest, forming a straight and parallel flow line, and acts as an overflow structure where the upstream energy head is lower than the length of the crest (Soewarno, 1991).

According to hydraulic expert Ir. Bambang Triatmodjo, there is no definitive theoretical formula to determine the weir jump length (Lj). The jump length of water flow can only be obtained through laboratory experiments. To address this theoretical gap, correction factors must be derived from experimental testing on various hydraulic models.

2.3. Weir.

A weir is a discharge measurement structure that operates without a contraction section; hydraulic jumps occur downstream of the structure (Soewarno, 1991).

A weir is a device designed to shift flow patterns within a channel by converting flow energy into a hydraulic jump. This means that the faster the flow released through the weir, the higher the resulting jump, allowing water to be redirected to other locations more efficiently, with greater speed and measurable control (Hannif Chaudri, 2000).

The primary function of a weir is to convert kinetic energy into a jump. It is used to dam or elevate the water surface by transforming kinetic energy into hydrodynamic energy, where subcritical flow transitions into a supercritical jump (Subramanya, 2016).

The operation of the weir is achieved by creating a difference in elevation between the upstream and downstream sides, enabling the conversion of mechanical energy from a driving source into kinetic energy (as indicated by the Froude number). This energy is then used to overcome the water jump occurring along the channel. A weir is formed due to changes in flow conditions, particularly from

supercritical flow to critical flow. Typically, a hydraulic jump on a weir occurs when the crest elevation is lower than the critical depth of the flow, or when water flows out of an overflow structure. At the location of the weir, large water vortices are usually observed, accompanied by significant energy loss.

After the jump occurs, the flow becomes calmer as its velocity decreases drastically while its depth increases sharply. The application of this hydraulic jump phenomenon includes energy dissipation in hydraulic structures to prevent downstream erosion, increasing pressure on protective layers to reduce uplift forces on the weir structure, extending the spill distance, and releasing air pockets within sediment supply networks to prevent trapped pressure in viscous fluid flow.

2.4. Model Iteration.

Flood wave iteration in rivers after disaster events in Korea, modeled in a laboratory using the 1D routing method, produced unsteady propagation velocities in open channels (Ven Tee Chow, 2015).

A wave is a form of propagating energy generated by vibrations transmitted through a medium. Therefore, a wave can be defined as a vibration that travels through intermediary substances such as solids, gases, or liquids (Zubaidah et al., 2018).

Flood wave propagation in dam-break scenarios and calibration experiments using 1D laboratory models at the University of Mississippi, United States, demonstrated that head loss values could be simulated by applying weighted factors based on various valve opening settings (Xinya Ying, 2013).

Physical flow modeling experiments using the finite element method for wave propagation were compared with laboratory experiments. The results showed that the compressible flow method effectively simulated head loss propagation (A. Kaceniauskas, 2016).

3. RESEARCH METHODOLOGY

3.1. The research methodology is described as follows:

1. **Site Survey**
   A field survey was conducted near the upstream area of the cold lava source.
2. **River and Bridge Survey**
   A survey was also conducted near the river and the Pabelan Bridge site.
3. **Research Setup and Characteristics**
   The modeling was carried out in the Hydraulics Laboratory at the State University of Surabaya (Unesa).
4. **Research Procedure**
   The simulation phase involved running water flow through a *tilting flume* apparatus by mixing cold lava sample materials with water. The research was conducted from June to November 2024.
5. **Target Points and Research Steps**
   a) **Instruments and Equipment Used:**
   - Model sluice gate
   - Water pump
   - Tilting flume
   - Flow watch
   - Storage tank for test water
   - Height measuring ruler
   - Writing tools for data recording

   b) **Working Steps:**
   - Prepare all the tools and equipment mentioned above.
   - Prepare the model materials to be used for observation during the experiments.
   - Measure the width and height of the channel to calculate flow volume.
   - Apply the experimental setup using the existing bridge model.
   - Conduct flow control treatments with valve openings at ¾ and fully open settings.

4. RESULTS AND DISCUSSION

Table of Test Results Without Sediment

Ketinggian 4 cm , Bukaan 1			
	Hulu (dt)	Jembatan (dt)	Ket
1 cm	28	34	
2 cm	32	38	
3 cm	36	42	
4 cm		46	
5 cm		50	
6 cm			
7 cm			
8 cm			

Ketinggian 4 cm , Bukaan 1/2			
	Hulu (dt)	Jembatan (dt)	Ket
1 cm	23	28	
2 cm	25	30	
3 cm	28	34	
4 cm		36	
5 cm		40	
6 cm		44	
7 cm		47	
8 cm		50	

Table of Test Results with Sediment

Ketinggian 4 cm , Bukaan 1/2			
	Hulu (dt)	Jembatan (dt)	Ket
1 cm	23	28	
2 cm	25	30	
3 cm	28	34	
4 cm		36	
5 cm		40	
6 cm		44	
7 cm		47	
8 cm		50	

Ketinggian 4 cm , Bukaan 1			
	Hulu (dt)	Jembatan (dt)	Ket
1 cm	28	34	
2 cm	32	38	
3 cm	36	42	Jembatan Runtuh
4 cm			
5 cm			
6 cm			
7 cm			
8 cm			

Table Description

Ketinggian : Height
Bukaan : Opening
Hulu : Upstream
Jembatan : Bridge
Keterangan :Description

5. CONCLUSION

1. Prior to the construction of a permanent weir, the potential for structural failure was significantly higher, as sediment discharge through the river carried materials with undetectable particle diameters.
2. The distance between the slope of Mount Merapi and the non-permanent weir, along with the bridge's height from the riverbed, increases the likelihood of bridge collapse.
3. In the laboratory model, testing with a ½ valve opening showed no indication of bridge collapse, both with and without cold lava sediment.
4. Bridge collapse was observed when the cold lava sediment used had a larger gradation, indicating that coarse sediment increases the risk of failure.
5. In the laboratory modeling, bridge collapse occurred at a bridge height of 3 cm with a fully opened valve, with a failure time of 42 seconds.

6. RECOMMENDATIONS

1. Increasing the height of the bridge relative to the riverbed can help prevent the collapse of both the bridge and the non-permanent weir.
2. Constructing a permanent weir can ensure the stability of flow discharge beneath the bridge and along the downstream channel.

REFERENCES

Journal Articles

1. Fadlan, A. F., & Nurcholis, N. (2023). Analysis of Cold Lava Flood Disaster Impact in Sumberwuluh Village, Candipuro District. *Jurnal Sosial Teknologi*, 3(10), 825–830.
2. Kaceniauskas, A. (2005). Simulation of Physical Flow Experiment. *Journal*.
3. Lisa, O. K., Desa, M., Salam, K., & Magelang, K. (2010). The Impact of Cold Lava Disaster on Land Use Changes. *Journal*, 208–217.
4. Nasarudin, N. (2022). *Zonation Monograph and Community Preparedness in Cold Lava Flood-Prone Areas*.
5. Paguler, A. (1988). Flood Simulation of the Mississippi River. *Journal*.
6. Pua, S., Alam, B., & Barat, S. (2024). Analysis of Residential Land Damage in Affected Areas. *Journal*, 9(3), 427–433.
7. Xinya, Y. (2004). Simulation of Flood Propagation Prediction. *Journal*.
8. Darmadi, K. (2014). Steady Flow Analysis. *Journal*.

Books

1. Chow, V. T. (2005). *Open Channel Hydraulics*. New York: McGraw-Hill.
2. Irianto. (2012). *Hydraulics 2*. Surabaya: Unipress UNESA.
3. Irianto. (2012). *Water Structures*. Surabaya: JTS UNESA.
4. Irianto. (2013). *River Engineering*. Surabaya: JTS UNESA.
5. Irianto. (2018). *Hydraulic Modeling*. Surabaya: JTS UNESA.
6. Kustini, I. (2013). *Irrigation and Water Structures*. Surabaya: JTS UNESA.

7. Mawardi, I. (2012). *Permanent Weirs*. Jakarta.
8. Soedradjat. (1983). *Fluid Mechanics and Hydraulics*. Bandung: Nova.
9. Soewarno. (1991). *Hydrology: Measurement and Management of River Flow Data (Hydrometry)*. Bandung: Nova.
10. Subramanya, K. (2015). *Flow in Open Channels*. New York: McGraw-Hill.