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EXPERIMENTAL STUDY OF DAM BREAK FLOW GENERATED BY THE FLAP GATE IN HORIZONTAL CHANNEL

*Vitta Pratiwi[1,2], Muhammad Syahril Badri Kusuma[3,4] ,Hadi Kardhana[3] and Mohammad Farid[3,4]

[1]Doctoral Program of Civil Engineering Department, Institut Teknologi Bandung, Indonesia
[2] Civil Engineering Department, Universitas Komputer Indonesia, Indonesia
[3]Faculty of Civil and Environmental Engineering, Institut Teknologi Bandung, Indonesia
[4]Center for Coastal and Marine Development, Institute for Research and Community Services, Institut Teknologi Bandung, Indonesia

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ABSTRACT: The risk of dam break failure become one of the most important issues to decide the feasibility of reservoir and dam development in Indonesia. This paper presents an experimental work result of a dam break flow through a single oblique obstruction in a straight rectangular channel. The dam break flow was generated by a sudden swing of a flap gate set on the contraction join of a horizontal reservoir and a horizontal channel. The initial condition of the dam break flow is set up based on the water height in this reservoir. A spatial temporal measurement of depth and velocity of the generated dam-break flow was conducted around the obstruction. The flow depth was measured using an ultrasonic-based sensor supported by a GPRS communication system, and the flow velocity was measured using a high-speed type current meter. Less correlation between the measured depth and velocity flow in the first of three seconds after the flow generation, where the flow has a high intensity of turbulent, was observed due to the limitation of data acquisition capacity. Compared to Noel's experimental works where the dam-break mechanism is simulated using an uplift gate, the flow depth and velocity profiles of the current experimental work have a good agreement in its pattern and in less agreement in its magnitude. Meanwhile, compared to Noel's numerical model result, it has fewer agreement results. These differences might be occurred due to the influences of differences dam break mechanism and data acquisition system.

Keywords: Dam break, Flood flow, Experimental model, Flap Gate, Horizontal Channel

1. INTRODUCTION

Indonesia, the fourth most populous country in the world with a population of 269 million, needs proper infrastructure to ensure the supply of water needs throughout the year. Nowadays, the reservoir remains as a strategic option, as a green solution such as rain harvesting still requires a more in-depth and comprehensive study to find out the feasibility of its application in Indonesia [1]. At present, Indonesia has 286 dams and targets the construction of 65 new dams, which is one of the infrastructures used to fulfill clean water requirements [2]. Many of the existing reservoirs have already been operated for more than 50 years, where sedimentation and water quality problems were observed due to land-use change and human activity in its catchment area [3]. Meanwhile, previous research indicated that natural hazards such as earthquakes, extreme rainfall, and climate change had arisen the risk of failure that can lead to a disastrous flood in the downstream part. This phenomenon can increase the risk of dam-break or failure of the dam.

The importance of dam safety in Indonesia was arisen due to the failures of Situ Gintung dam in 2009 [4-6]. These events have encouraged the Indonesia Government to increase disaster preparedness and planning to minimize the potential impacts associated with dam failure. One of the research outcomes of this experimental work is to contribute to the improvement of mathematical model capacity in predicting flood map hazards in urban areas due to dam collapse. The availability of this flood hazard map is essential to the development of people's awareness that can prevent the increased risk due to the related flood hazard [7-9].

Dams with significant size in America fail on average once a year [10]. Dam Break Flow has unique flow characteristics that depend on the dam break mechanism. Dam break flow could potentially generate a high-risk flood hazard to the urban area along the downstream riverine of related reservoir/dam [11]. This kind of flood could generate high-risk disaster to the built environment where many houses, roads, bridges, and other function building were already developed [12]. Hence, understanding the dam break flow around a building is very important for the disaster risk reduction effort generated by dam-break flow. The recorded dam break event (e.g., CNN [4] and WHO

[5] and Wikipedia [6] have shown that the dam break mechanism and river/channel geometry may cause the dam break flow may cause a very complicated three-dimension turbulent flow. However, most of the previous study has been conducted with many simplifications, so this kind of flow remind as interesting research to find a more reliable result. Noel et al. [13] have conducted a study of dam-break flow around a building obstruction based on the numerical model.

Besides using physical models, analysis with numerical models have also been developed to determine the flow characteristics of the dam break phenomenon. Numerical models have now been developed to help users understand the flow profile due to dam break more easily and with more complex conditions, but it is still being studied whether the numerical model provides precise results relating experimental models or real conditions. Previous studies related to numerical modeling of 2D dam break are using Saint-Venant shallow-water equations with finite difference method solutions [11,14,15] and finite volume [16-19]. The study of dam-break numerical models applied to the real case was conducted by Valiani et al. [20] in the Malpasset Dam, Unami et al. [21] cases in the Ghanaian Valley and Yakti et al. [22] cases in Way Ela Natural Dam. The experimental work was compared to Noel et al. [13] numerical results computed with finite-volume Roe-scheme.

The dam break mechanism was commonly modeled by using a sudden opening gate system. This gate is separating the upstream reservoir, and the downstream channel is rapidly removed, as presented in [23]. As a complex unsteady turbulent flow, a dam break flow experimental model requires massive measurement of the spatial-temporal distribution of flow depth and velocity, as shown in [24-29]. Nevertheless, the current experimental set-up was developed using a sudden opening of the flap gate as a dam-break mechanism, as presented in the following paragraphs.

2. EXPERIMENTAL SETUP

The experimental work was carried out in the Civil Engineering Hydraulics Laboratory of Institut Teknologi Bandung using a dam break current experiment facility developed by Kusuma et al. [30]. It consists of a rectangular horizontal channel of 10 m length, 1 m width and 0.5 m depth, a small rectangular water pool, a flap gate, and observation supports (see Fig.1). The channel wall is made of flexible glass with a thickness of 8 mm, which visually observes the flow of water. The channel's bed is made of frictionless stainless steel. A small rectangular water pool is used as a reservoir at the upstream and as a water recirculation tank at the downstream. The upstream reservoir is made of concrete with 4 m long, 2 m wide, and a height of 0.6 m. The water recirculation tank is made from steel and is supported by a centrifugal pump and pipeline.

The flap gate made from steel is used to generate dam-break flow in Fig.2. A dam break flow is generated whenever a sudden swing up of the flap gate occurs. It is recommended to choose a flap gate rather than a vertical lift gate since the horizontal movement of the flap gate seemed to decrease the fault-related with the dam break wave as fairly low faults were detected with reasonable gate opening speeds. However, flap gates have a disadvantage when they are tested with the sediments in the canal, where they could potentially delay the movement of the gate [31].

As an initial condition, the gate was closed with a 40 cm water height in the upstream reservoir. A rectangular obstruction (with 0.11 m wide, 0.22 m long and 0.11 m height) from wood was obliquely (64˚ angle to the channel axis) placed at a distance of 3.4 m from the gate in Fig.1. This placement was defined to support the comparison study with that of Noel [13] current experiment where 5 point measurement (G1, G2, G3, G4, and G5) of flow velocity and depth around that obstruction were conducted.

The shape and size of the obstruction, the distance of the measurement point, and the depth of the water in the reservoir are based on previous research Noel [13]. Several changes of the previous experimental set-up [30] were made to adjusted the required size of the current physical dam break model where the x-axis is used on a scale of 1: 1 while the y-axis uses a scale of 1: 0.278.

The flow velocity was measured using a current meter in Fig.3 supported with a digital data logger connected to the data acquisition system. The speed measuring instrument used is a current meter with a diameter of 1.5 cm with a type of high speed that can measure flow at high speed. Speed measurement starts when the gate is opened until the speed tool cannot read the value of the flow velocity passing at that point. The current meter is placed 2 cm from the bottom of the channel to get the speed data during low and high flow depth conditions.

In this experiment, the water level was measured automatically by using a modified water level system. It consists of an ultrasonic-based sensor to measure the water level and an AVR-based microcontroller to control the measurement process, calculate the water level, and send it to the computer using serial communication (Fig.3). The brief description of the system is described in Munir [32]. The depth observation results were compared in every step of measurement.

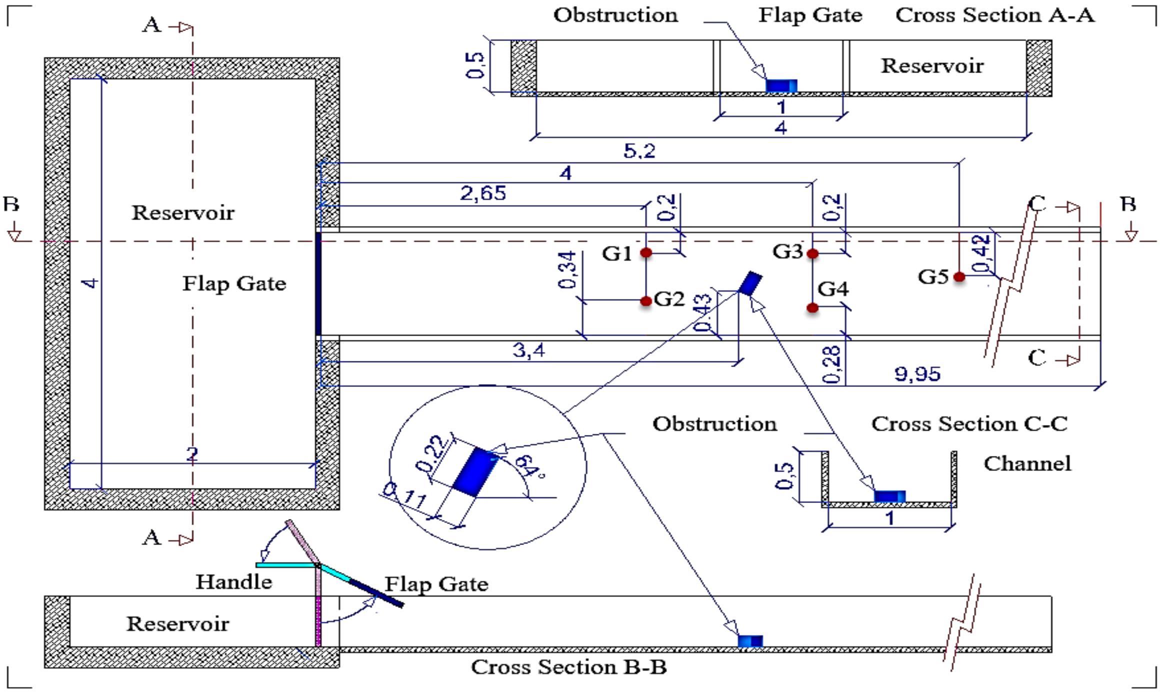


Fig.1 Sketch of experimental set-up (all dimensions in meters)

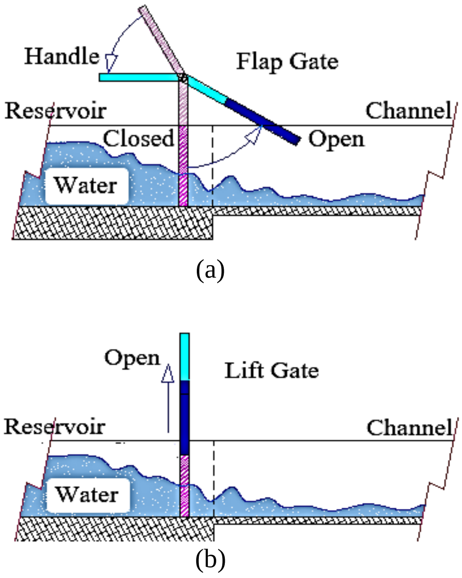


Fig.2 Scheme of Dam-Break Flow Generator System (a) Noel [13] (b) Current Experiment

The observation data discussed in this paper cover only one initial condition where the water depth of the upstream reservoir was 40 cm, the downstream channel was dry, and one oblique obstruction placed on the centerline of the channel in Fig.1.

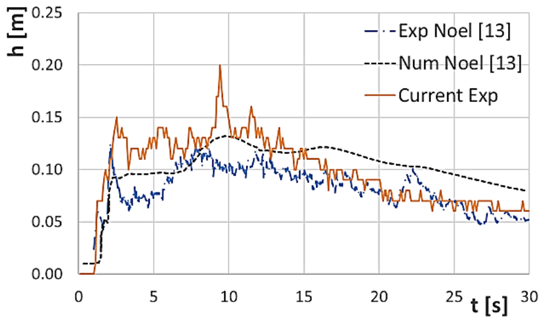
These experimental results were compared to the previous experimental and numerical study conducted by Noel [13] that conducted the same configuration of measurements but using up-lift gate instead of flap gate mechanism of dam-break flow generator system the current experimental works (Fig.2). It should also be aware that in Noel's work [13], the numerical model was developed based on depth-averaged velocities, and the experimental measurements represent the velocity field at the surface. Meanwhile, the velocity measurement of the current experimental represents the average velocity taken at the point of 2 cm from the channel bed. All those values are assumed to be sufficiently similar to allow at least a partial comparison study.

(a) (b)

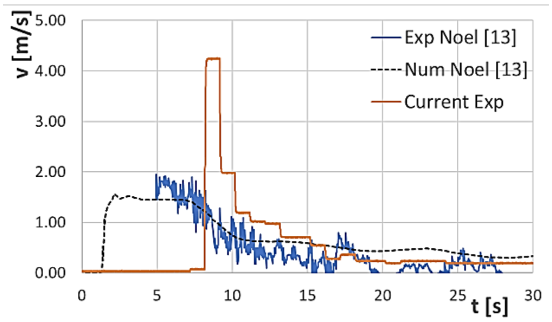
Fig.3 (a) Current meter (b) Ultrasonic Sensor

3. RESULTS AND DISCUSSION

The following paragraph discussed the comparison results of water depth measurements at points G1, G2 G3, G4, and G5 around the obstructions (see fig.1), with that of the experimental and numerical work results of Noel [13] as were presented in figs.4 to 8.



(a)



(b)

Fig.4 Comparison of water depth (a) and velocity (b) at G1

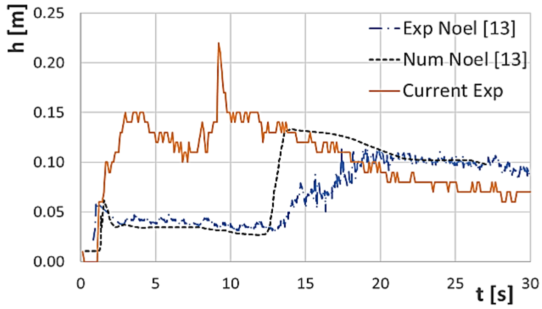
A comparison study of the dam-break flow depth at point G1 was presented in fig.4. It was found that the flow depth rising curve of both experimental results was practically in the same pattern during the first 2 seconds and then was significantly different until 17 seconds after the sudden opening gate. The peak of the flow depth rising curve of the current experimental work was much higher but reached lately compared to Noel [13] works. Meanwhile, the decreasing curve of the water depth of both experimental works was practically in the same pattern but with a difference fluctuation level for the last 22 seconds (from the 17th to the 30th second after the opening). Most of the flow depth observed in the current experimental work was practically higher than that of Noel's work [13].

Meanwhile, compared to Noel's numerical model result [13], during the first 2 seconds after the sudden opening gate, the raising depth curve of both experimental have the same pattern. However, a different magnitude of current experimental with the numerical model was bigger than that of Noel experimental works [13]. However, during the first 2 seconds to the 17 second, the numerical was comparable to the average pattern and magnitude of both experimental results, but its time peak was more closed to that of current experimental results. During the decreasing curve, Noel's numerical model results [13] has the same pattern with higher magnitude compare to both experimental works.

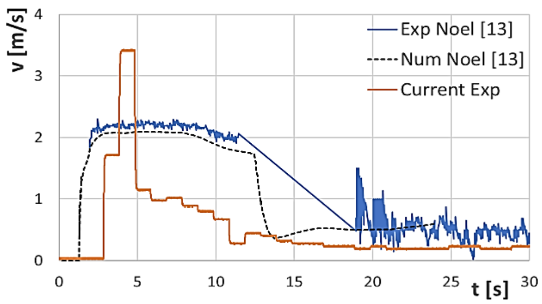
As it is shown in fig.4(b), due to the limitation of the experimental measurement system, the comparison of the current work and Noel's work could only be done from the 7th seconds. This limitation was generated by the difference capacity of data acquisition between the velocity measurement system (1000/s) with depth measurement system (10/s). This implied that during the first 7 seconds, where the flow was turbulent, the represented depth in fig.4(a) might not be the same flow event with the represented velocity in fig.4(b). The same problem is recognized in the first 5 seconds in Noel's experimental works.

Noel's work [13] numerical model was developed based on depth-averaged velocities, and the experimental measurements represent the velocity field at the surface using high-speed cameras to film tracers on the free surface. Meanwhile, the current experimental velocity measurement represents the average velocity taken at the point of 2 cm from the channel bed. The difference caused faster velocity compared to Noel's [13] because Noel's measures surface velocity, while the current meter of the current experimental starts to measure the flow velocity when the water reach 2 cm. At first, the flow is dominated by turbulent flow. When the flow hit the obstruction, the channel bed influence on the flow is more dominant, causing the average mass velocity to be measured with the current meter to be lower than surface velocity. The peak of velocity raising curve of the current experimental work was reached lately with a significantly higher magnitude compared to Noel's works. However, good agreement of velocity pattern between the current experimental work and Noel's work was observed after the 14th seconds. Based on the comparison study at point G1, it could be seen that the flow dissipation in Noel's work was stronger than that of the current experimental works. This might be occurred due to the influence of the opening gate system and the recirculation flow generated by the channel expansion at its opening gate location. Higher fluctuation is observed in Noel's experimental work velocity profile in the last 15 seconds before the end of the flow.

The comparison result at point G2 was shown in Fig.5. During the first 2 seconds after the sudden opening gate, both experimental works have a good comparable magnitude and pattern of increasing curve with that of the numerical result. From the 2nd seconds to 13th seconds, the pattern and magnitude of the increasing curve resulted from experimental and numerical works of Noel works [13] are in a good comparable. Meanwhile, the rising curve of the current experimental works was significantly different in its magnitude and its pattern with that of both of Noel's works [13]. From the 13th to 20th seconds after the sudden opening gate, the flow depth of current experimental works start to following its falling curve from its peak at the 13th second to act the peak of the numerical depth curve at the 14th second across the rising curve of Noel experimental works at the 19th seconds. The numerical falling curve starts from the 14th second following the same pattern of that of current experimental and across the peak of Noel's experimental works [13] at the 20th second, where all the falling curve start to follow the same pattern. The peak of the current experimental has a faster occurrence and a higher magnitude compared to the peak of Noel's experimental work (twice) and Noel's Numerical works (1.5 times). The first 2 seconds after the sudden opening gate, where the flow has a high intensity of turbulent, the correlation between the measured flow depth and the measured flow velocity were not good due to the difference acquisition capacity of the current meter and ultrasonic sensor.



(a)

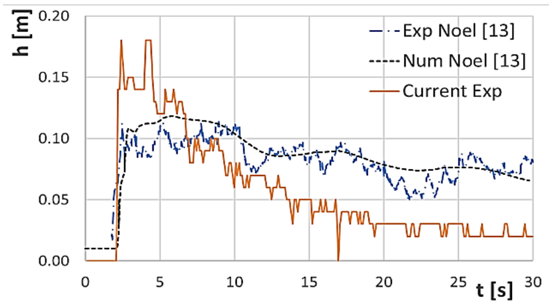


(b)

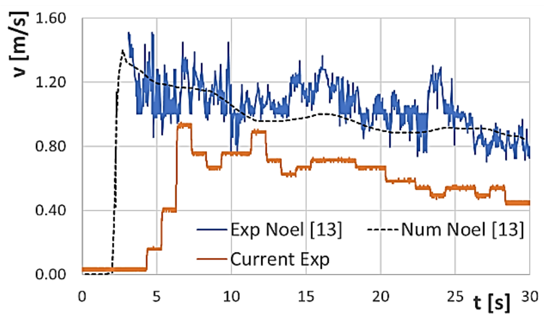
Fig.5 Comparison of water depth (a) and Velocity (b) at G2

As shown in fig.5(b), the same influence of experimental set-up generated approximately the same pattern with different magnitude of depth and velocity pattern at point G2 compared to point G1. The reliable measurement for comparison study started around the 4th seconds from the opening gate. The velocity profile of current experimental results seems to be more consistent than that of Noel's experimental work. Higher fluctuation and more comparable results to the numerical work are observed in the velocity profile of Noel's experimental work in the last 11 seconds before the end of the flow.

The comparison result at point G3 was shown in Fig.6. The influence of the same capacity problem of the measurement system to the experimental work was observed in the first 2nd seconds after the opening gate for Noel's work and 5th seconds after the opening gate for the current experimental work. The same pattern with different magnitude of the depth profile of G3 with that of G1 was observed. In this case, compared to the current work, the depth falling curve profile of Noel's experimental work is higher and more comparable to numerical work. A more comparable pattern and magnitude of velocity profile were observed between the experimental and numerical models of Noel's works compared to the current work.



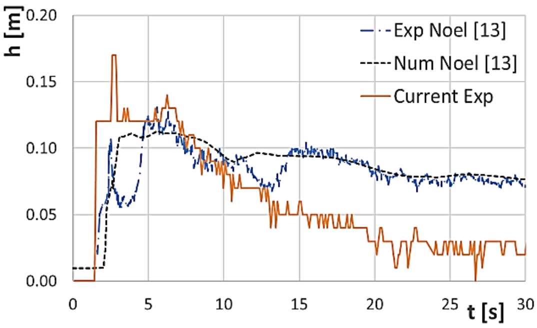
(a)



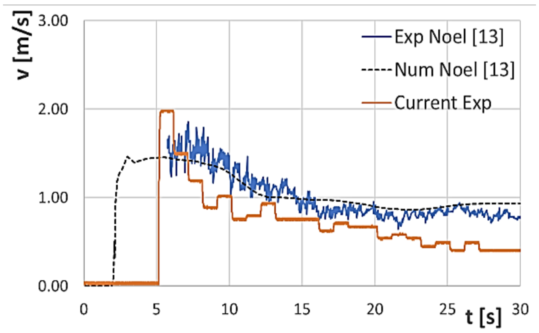
(b)

Fig.6 Comparison of water depth (a) and velocity (b) at G3

The comparison result at point G4 was shown in Fig.7 The influence of the same capacity problem of the measurement system to the experimental work was observed in the first 5th seconds after the opening gate for both experimental works. Most comparable results of the current experimental works with Noel's experimental work was found between the 5th and the 13th seconds for the depth profile and after the 6th seconds for the velocity profile. However, more comparable results of both depth and velocity profiles were found among Noel's work compared to the current experimental works.



(a)



(b)

Fig.7 Comparison of water depth (a) and Velocity (b) at G4

The comparison result at point G5 was shown in Fig.8. The influence of the same capacity problem of the measurement system to the experimental work was observed in the first 6th seconds after the opening gate for the current experimental work and 10th seconds after the sudden opening gate for Noel's experimental works. Most comparable results of the depth profile of the current experimental work with both Noel's works (experimental and numerical) were found compared to the other point of observation. However, the decreasing curve of the velocity profile of Noel's experimental work was less comparable compare to the other point of observation. The peak of the velocity rising curve of the current experimental works was much higher than that of Noel's work.

After the sudden opening gate, the strong dam break wave crash against the obstruction, the flow separates, creating surge waves crossing each other, and the development shadow zone behind the obstruction, as shown in Fig.9. This implied that at point G1 and G2 (before obstruction) during the first 5 seconds, the depth profile increase, getting stable at 10th seconds and decrease after 20th seconds. At point G3, G4, and G5 (after obstruction) during the first 5 seconds, the depth profile increase, and after 10th seconds there is no significant change in-depth profile. This happens because at points G1 and G2 are still affected by the front of obstruction while points G3 and G4 are affected by shadows zone and shock wave crossing behind the obstruction.

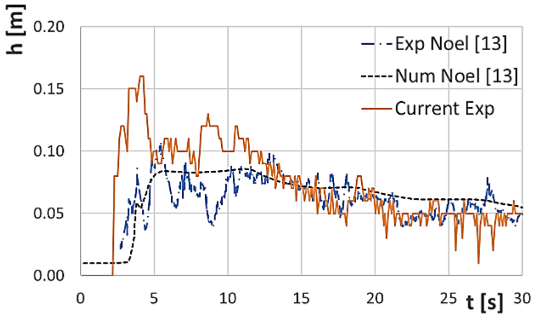


Fig 8 (a)

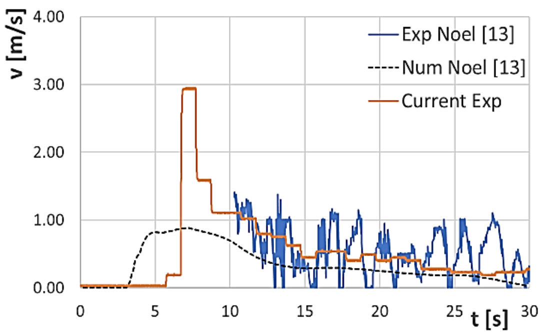


Fig 8 (b)

Fig.8 Comparison of water depth (a) and Velocity (b)at G5

The obstruction shape with almost facing the gate, the non-symmetric distribution of the flow around the obstruction is increased, and the separation effect appears. This phenomenon influence velocity profile, during the first 10 seconds the shape of the front wave is affected by the obstruction, the velocity profile increase. After 15th second propagation speed remains almost unchanged, the effect of the obstruction will decrease with the distance from the gate, thus causing differences peak in the velocity profile at points G1, G2, G3, G4, and G5. The shape and sharpness of the obstruction's angle to the direction of the flow also affect the magnitude of the velocity and depth of the flow. So that the placement of obstruction adjusted to the ability to reduce the obstruction against the flow.

4. CONCLUSION

An experimental work of the dam break flow through a single obstruction in a horizontal straight rectangular channel in the hydraulic laboratory of ITB, Indonesia. The dam break flow was generated by a sudden swing of a flap gate set on the contraction join of a horizontal reservoir and a horizontal straight channel, which was developed to simulate the well known Situ Gintung dam break event in Indonesia.

Due to the difference acquisition capacity of the current meter and ultrasonic sensor, it was found that in the first of three seconds after the sudden opening gate, where the flow has a high intensity of turbulent, the measured flow depth and the measured flow velocity were not in good correlation.

A comparison study was conducted using the results of experimental and numerical works of Noel et al., where the dam-break mechanism is simulated using an uplift gate that puts in the expansion join of a long horizontal reservoir with a straight horizontal channel. The current experimental result has a good agreement of the pattern of flow depth and flow velocity profiles but has a different magnitude compared to that of Noel's experimental model results. How ever, it is also found that the current experimental study has fewer agreement results with that of Noel's numerical model result. These differences might be occurred due to the influences of not only of the differences dam-break mechanism but also the different capacity of data acquisition and measurement system.

The current experimental study has a good contribution to improving the understanding of the dam break flood flow characteristics and the research capacity of the research team and laboratory.

5. ACKNOWLEDGEMENTS

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