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Study On Scouring and Protection of USBR-III Type Downstream of Spillway

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Abstract. In the downstream part of the spillway building, especially in the flood way, occurs phenomenon of changing flow conditions from super critical to sub critical which causes a hydraulic jump and used by energy absorbers to reduce flow energy. The hydraulic jump in the floodway causes scouring of the bottom, particularly in the unprotected downstream spillway. Using 3 different dimensional baffle block models provides three different discharge variations in four flow simulations. Based on the results of the analysis and planning of the baffle block, it is found that the effectiveness in protecting the downstream scour of the spillway, namely baffle block dimensions of 1:1, 1:3 and 1:5. The three models of baffle blocks are used to determine the change in channel cross-section, scour pattern, scour volume and flow parameters that occur in downstream of spillway. The results showed that without baffle block was 32.80%, 1:1 baffle block was 43, 24%, 1:3 baffle block was 10.01% and 1:5 baffle block was 47.77%. The results of the drainage simulation showed that the higher the water level and the velocity of the flow at the bottom of the channel, the less the flow will be and will not be able to lift the bottom material of the channel.

Keywords: Spillway, Baffle Block, Scouring Presentation

INTRODUCTION

Spillway structures are hydraulic structures to channel flood water through a dam without compromising the safety of the dam [1]. The spillway's capacity must be sufficient to dissipate the design flood, and the water flow exiting the spillway must not damage the structure of the spillway or the dam body. A spillway is a structure that drains flood discharge into a reservoir to keep it from overflowing [2].

The elevation of the water level due to damming results in a difference in energy height (head) between the upstream and downstream of the spillway building, if water from upstream crosses the spillway, it will have a high quantity of energy, causing the velocity of the passing flow to be even larger. [3].

In the spillway building, there is a difference in water level elevation between upstream and downstream, which causes a supercritical flow and a hydraulic jump [4]. As a result, the flow condition on the spillway's sloping surface is supercritical, whereas the flow condition on the downstream side is subcritical. A hydraulic jump occurs when the flow changes from supercritical to subcritical [5]. This hydraulic jump frequently creates wave rolls or vortexes, which can cause scouring at the channel's bottom, particularly in the unprotected downstream [6].

Hydraulic jump at downstream of the spillway, it can reduce flow energy. Hydraulic occurrence demands the present of stilling basin to protect the riverbed [7]. Multiple models of stilling basin have been introduced by the United States Bureau of Reclamation (USBR) which construction has been tested, making it easier for research. This USBR type consists of USBR-I type with Froude number < 2.5, USBR-II with Froude number > 3, USBR-III with Froude number > 4.5, and USBR-IV with Froude number between 2.5 - 4,5 [8].

Although the utilization of stilling basin USBR-type can reduce energy, in reality scouring still occurs at the bottom of the channel at downstream of the stilling basin [9], which may damage to the building.

Scour is defined as subsidence of the riverbed due to erosion below the natural surface elevation or an assumed datum [10], scouring is the process of deepening the riverbed due to the interaction between the flow and the riverbed material [11]. Divided scour into three types, namely [5]:

1. General scour, this scour occurs not at all related to the presence or absence of hydraulic structures. This scour is caused by the energy of the water flow.
2. Localized scour (constriction scour) in the river channel, it occurs due to narrowing of the river channel, hence the flow becomes more concentrated.
3. Local scour around the building, it occurs due to the local flow pattern around the river building.

The parameter used to determine the type of scour (clear water scour or live bed scour) is the ratio between the upstream velocity and the limiting velocity or the critical velocity of sediment required to move sediment from the bed [12]. This ratio is called the flow intensity, it may take one or two forms depending on the velocity used. For bottom sediments in flow, the shear stress is expressed by the Shield equation, which is a non-dimensional shear stress which is a function of the Reynolds number and the flow diameter provided tahat if $\tau_0 > \tau_c$ then scouring occurs and if $\tau_0 < \tau_c$ then sedimentation occurs [8].

Therefore, this equation has a direct correlation with sediment transport, because most sediment transport equations are in the form of bed shear stress [13]. Critical shear velocity can be determined in the existing sediment, but the value of u* is usually not directly readable for flow condition experiments and must be described using the velocity profile assumption [14].

Second, a more general form of flow intensity uses the depth averaged approach velocity (V) and the critical depth averaged approach velocity (Vc). The critical depth averaged approach velocity is the minimum average depth of flow for which sediment movement will occur [3] The flow intensity form (V/Vc) requires known or assumed vertical velocity data (usually logarithmic) to calculate the critical depth averaged velocity (Vc) for the sediment present [1].

The phenomenon of changing flow conditions from super critical to sub critical which causes a hydraulic jump is used by energy absorbers to reduce flow energy [9]. The stilling basin with baffle blocks is the most commonly utilized type of energy absorber. The baffle block serves to cause a hydraulic jump. After the hydraulic jump, the baffle block decreases the flow momentum, lowering the velocity. [11].

Baffle blocks have the advantage of being able to generate hydraulic jumps and limit flow velocity, preventing scouring at the river's bottom and riverbanks, which endangers the river's geometry. [11]. However, it also has the disadvantage that having a steep slope is less effective in reducing scour and the installation pattern of the baffle block with the spacing of the baffle blocks adjusted to achieve a better flow stabilizing ability [15].

This study is important to identify the hydraulic aspect as a key in preserving the spillway structure stability. The increased water flow speed is caused by the increasing number of water discharges flowing from upstream to downstream of the dam, as the rushing and uncontrollable water flow speed can produce an overflow on the spillway building, endangering the downstream part of the building's stability.

Therefore, it is necessary to have variations in water dampening structure energy when an overflow occurs around the spillway, unaffecting the water flow to the downstream of the spillway building.

In previous study, energy dissipation increases by placing the threshold in front of the energy absorber structure in an optimal position when a hydraulic jump occurs (16). When a dam is built, it protects the land from flooding and optimizes the spillway construction process to avoid a dam break that could damage the surrounding area. Changing the model or shape of the energy reducer with variations in the slope designed using the control tube through the Q_{1000} and Q_{PMF} can be used to test the effectiveness of the energy absorber building design in decreasing the water flow energy. This condition is aimed to determine the suitable type of energy absorber building for variations in flow discharge to reduce downstream scouring on the spillway building.

A research development on spillway downstream scouring should be performed continuously through more optimal and efficient energy absorber building model variations to gain a description of minimum damage occurred.

The purpose of this analysis is to study the behavior of the scour pattern on the effect of the baffle block (Buffle Block) on the flow characteristics and to get alternative solutions to local scour problems on bridge pillars. The objective is to analyze to what extent the deviations from the empirical calculation and the results of the physical model can occur, so that accurate information can be obtained in order to determine hydraulic repair efforts if one day there is another energy reducer plan with similar building configuration and conditions.

METHODOLOGY

This section contains the methods used in problem solving including the analytical methods described in detail. The study was performed by experimental method in the Laboratory of Hydraulics, Water Engineering Study Program, Department of Civil Engineering, Faculty of Engineering, University of Muhammadiyah Makassar. The type of the study was a physical modeling at 1: 100 ratios. A physical model was selected as the physical phenomena of the existing problems could be prototyped and designed on a smaller scale with sufficient similarity. This research used a USBR-III stilling basin object and baffle block modelled with a USBR-III spillway and baffle block made of wood. The tool used was an open channel (Sediment Transport Channel). Figure 3 is a flow chart of the methodology performed starting from the literature study, data analysis, to the research conclusions.

In this study, two data sources were used consisting of primary and secondary data. Primary data were taken directly from physical model simulation in the laboratory. Secondary data consisted of literatures and previous study results performed both in the laboratory and other places related to this study.

Flowing simulation was performed 63 times on various speeds (U), flowing times (t), flowing discharges (Q), and flowing heights (h). Sand materials were used with a dominant intermediate diameter of 0.47 mm according to the filter analysis results of Wentworth at 0.25 – 0.50 mm.

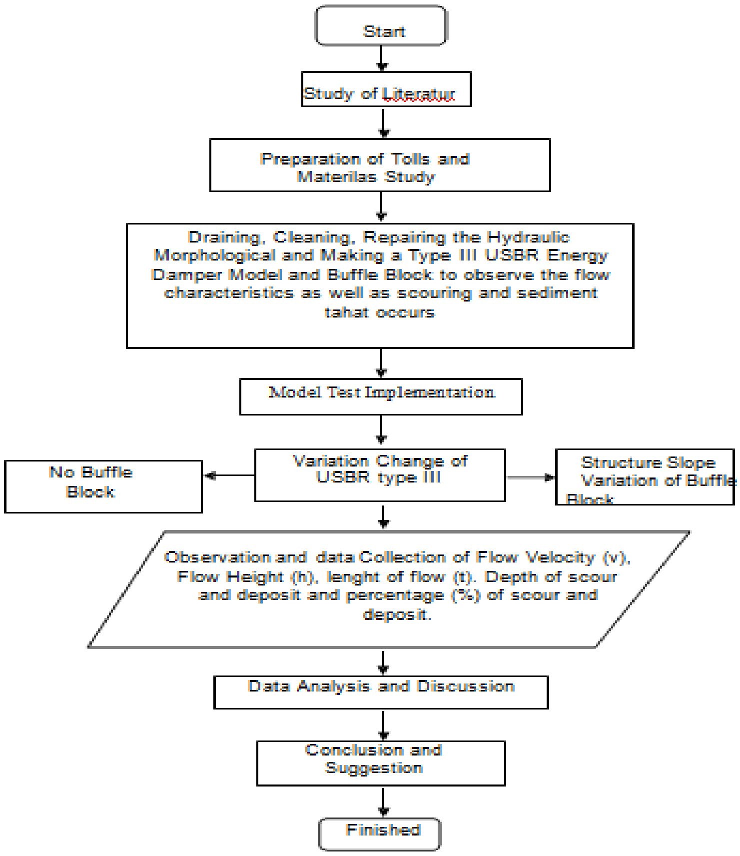

FIGURE 1. Research Flowchart

The research implementation was carried out in the Hydraulics Laboratory of the Water Engineering Study Program, Department of Civil Engineering, Faculty of Engineering, Unismuh Makssar, using an open channel device. The design of the energy reducer model was made with a distorted model scale, where the horizontal scale is the same as the vertical scale. The design of the energy reducer model made with a slope of 1:1, 1:3, and 1:5. This slope difference was used to analyze the effectiveness of scour protection from the three variations. The design form is as shown in the image below.

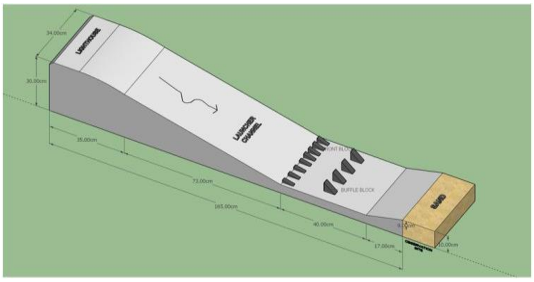

FIGURE 2. USBR Type III Swimming Pool with Distorted Scale

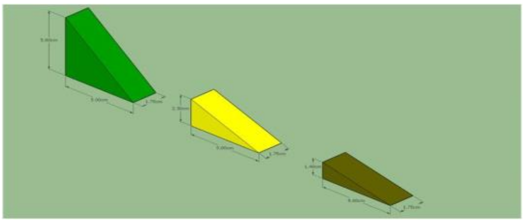

FIGURE 3. Baffle Block Models

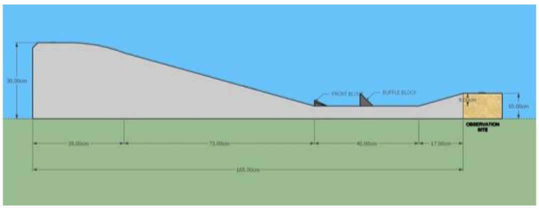

FIGURE 4. Scouring Observation Point on Flume

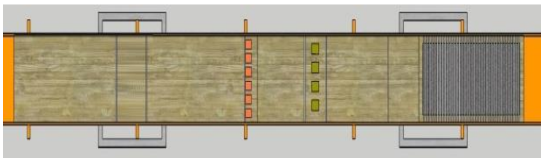

FIGURE 5. Buffle Block Variation and Physical Model in Flume from above

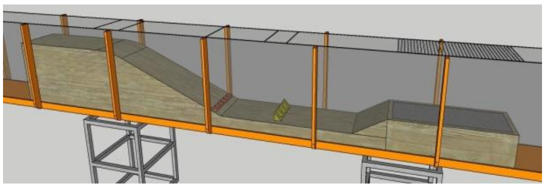

FIGURE 6. Physical Model Perspective in Flume

The Surfer software was used to change the interpolation and lattice parameters, examine the data continuity with a variogram, and determine the errors and dashes on the scouring data analysis on the USBR III spillway constructing downstream. A correlation function based on the correlation coefficient and R2 determination test was determined to confirm the influence of x and y variables with the SPSS (Statistical Package for the Social Sciences) program to identify the linear correlation of the scoured data between independent variables (x) and dependent variables (y) that had either positive or negative correlation.

RESULT AND DISCUSSION

Scouring Study at Downstream of Unprotected Stilling Basin for USBR-III Type

- **USBR-III Structure without *Buffle Block***

This research was carried out without providing protection at downstream of the spillway in the flow conditions where transport of live-bed scour sediment occurs. The scour measurement on the channel model using a ruler produces scour depth points (Z direction) for each X and Y direction coordinates above the surface of the material.

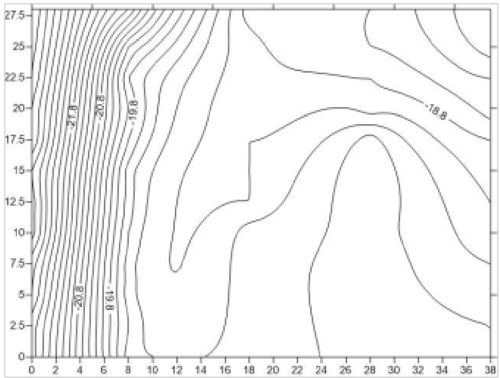

FIGURE 7. *Surfer* program simulation of scoured contour results at Q = 18.8 L/s

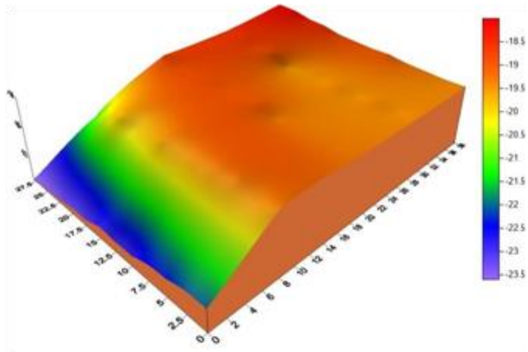

FIGURE 8. *Surfer* program simulation of scoured perspective at Q = 18.8 L/s

From Figure 9, the regression 7xxequation value is obtained:

$$\mathrm{Y} = \mathrm{a} + \mathrm{bx}$$

$$Y = 20.7 \pm 0{,}38\,x \tag{1}$$

Relationship between flow depth and maximum scour

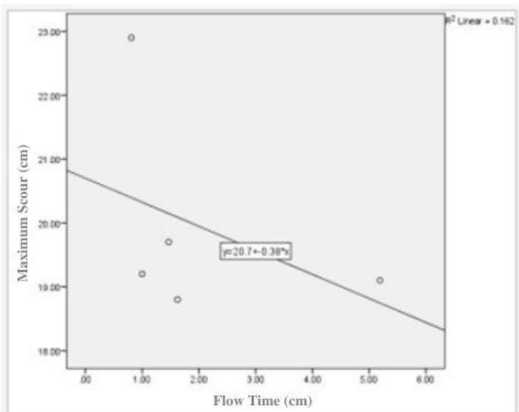

FIGURE 9. *SPSS* program simulation on the correlation of flowing time and maximum scouring

Correlation number of R^2 = 0.162 means there is relatively very low relationship between flow height and scour depth. From the graph, it can be concluded that the higher the flow, the greater the ratio between the maximum balance scour depth and the flow depth, thus the greater the scour depth.

From the results of the study, it can be observed that the higher the flow, the greater the ratio of the maximum scour depth to the flow depth.

Correlation number of $R^2 = 0.162$ indicates relatively strong relationship between the flow height and the maximum balance scour depth. From the graph, it can be stated that the higher the flow, the greater the ratio between the maximum balance scour depth and the flow depth, thus the greater the scour depth.

The relationship between flow time and the maximum scour depth.

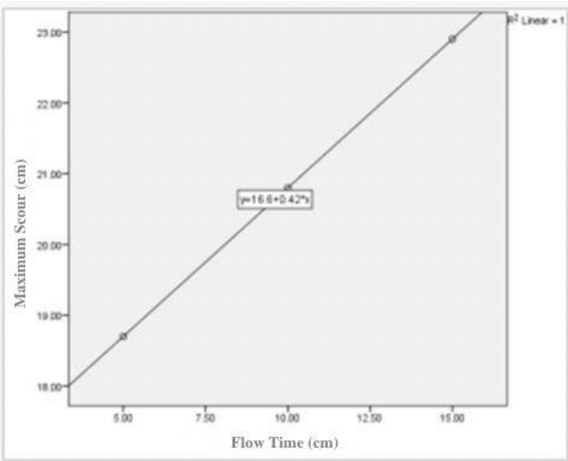

FIGURE 10. *SPSS* program simulation on the correlation of flowing time and maximum scouring

From the figure 10, the regression equation value is obtained:

$$Y = a + bx$$

$$Y = 16.6 \pm 0{,}42\ x \tag{2}$$

Correlation number of $R^2 = 1.00$ shows relatively very strong relationship between the flow time and the scour depth. The relationship between the maximum scour depth compared to the downstream water depth and the scouring time (t) versus the characteristic time (t_1) can be seen in Figure 6, scouring time is the time needed for scouring process to reach equilibrium, while the characteristic time is the time reached at depth scour is equal to the depth of downstream flow.

This shows the level of relationship between the two parameters is close. While the correlation value has a positive value indicating the relationship is unidirectional, the maximum (maximum of scour depth) downstream of the stilling basin is strongly influenced by the characteristic time and flow depth at downstream of the stilling basin.

In the study of scour holes, scour occurs starting downstream of the weir near the stilling basin and then continues along the flow until it reaches a certain length. The scouring continues until it forms a scour hole, the depth of which tends to be silted up towards the far downstream of the stilling basin. Meanwhile in the downstream part of the scour hole there is sediment deposition. This deposition continues to develop until it finally erodes back downstream, finally collects and deposits increases downstream and gets longer with time. The scour hole can be seen as shown in Figure 7 and Figure 8 above.

The scour depth occurs at downstream of the spillway is closely related to the flow velocity that occurs in the channel. The figure explains the influence of flow velocity with the length of the scour hole as stated in the regression equation. The logic of linking the flow velocity with the length of the scour is because if the flow velocity is large, the shear velocity will be greater, this causes the longer the scour that occurs. The equation has a correlation number of $R^2 = 1{,}000$ indicates a close relationship between flow velocity and the magnitude of scour and the depth of scour occurs at downstream of the spillway.

Scouring Study at Downstream of the Swimming Basin with Protection For USBR-III Type

- **Baffle Block Protection with slope of 1:1**

The scour depth without protection for discharge was 18.8 lt/sec with a maximum average scour depth of 16.1 cm. For the first scour protection study using a 1:1 buffle block, running three times with the same flow rate of 88.8 lt/sec and observed for 90 minutes because it has seen a small change in scour depth and is close to stability.

The final result of running shows that there is scour around the downstream of the baffle block, with an average scour depth of 6.5 cm and an average scour length of 12.5 cm. The shape of the scour can be seen in a three-dimensional image, as shown in Figures 11 and 12 . From the research on baffle block protection, it can be seen that there is still large scour downstream of the protection.

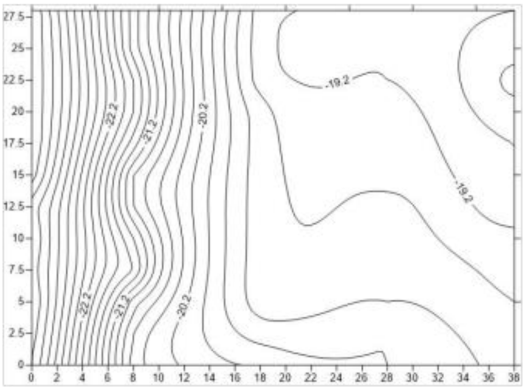

FIGURE 11. *Surfer* program simulation of scoured contour results at Q = 18.8 L/s

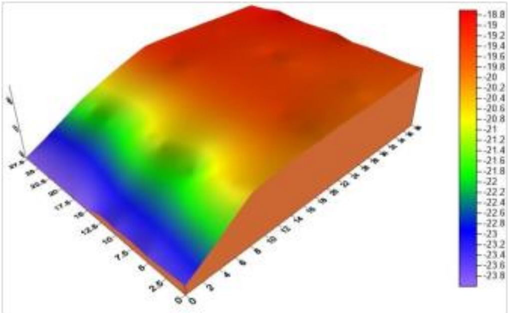

FIGURE 12. *Surfer* program simulation of scoured perspective at Q = 18.8 L/s

- **USBR-III structure with 1:3 Baffle Block**

This study used a baffle block protection with a slope of 1:3 from a discharge of 88.8 lt/sec, running three times with the same discharge of 18.8 lt/sec and observed for 90 minutes because it looks close to stability.

The final result of running shows that there is still scour around the downstream of the baffle block with an average scour depth of 2.0 cm. The shape of the scour can be seen in Figures 13 and 14. From the research, it can be seen that there is still small scouring downstream of the protection, thus it is necessary to carry out maximum protection from the maximum scour depth.

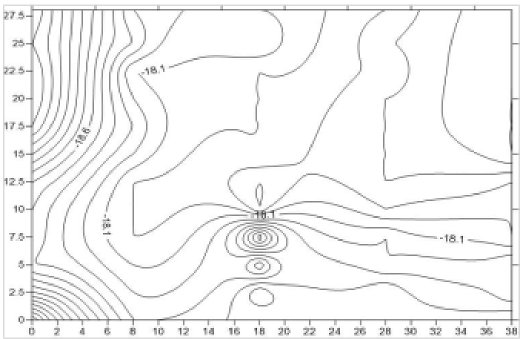

FIGURE 13. *Surfer* program simulation of scoured contour results at Q = 18.8 L/s

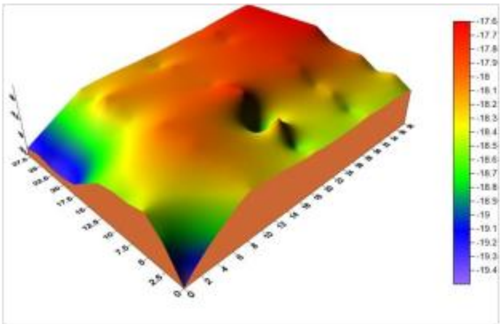

FIGURE 14. *Surfer* program simulation of scoured perspective at Q = 18.8 L/s

- **USBR-III structure with 1:5 Baffle Block**

Using baffle block protection from a discharge of 18.8 lt/sec, running three times with the same discharge of 18.8 lt/sec and observing for 90 minutes because it has seen a small change in scour depth and is close to stability.

The final result of running shows that there is still scour around the downstream of the baffle block, with an average scour depth of 6.5 cm and a scour length of 12.5 cm. The shape of the scour can be seen in the three-dimensional contour drawing as shown in Figures 15 and 16.

According to observations during the scour process at downstream of the spillway, scour begins downstream near the spillway and then continues along the flow until it reaches a certain length. The scouring continues until it forms a scour hole, the depth of which tends to be silted up towards the far downstream of the spillway. Meanwhile, in the downstream part of the scour hole, sedimentation occurs

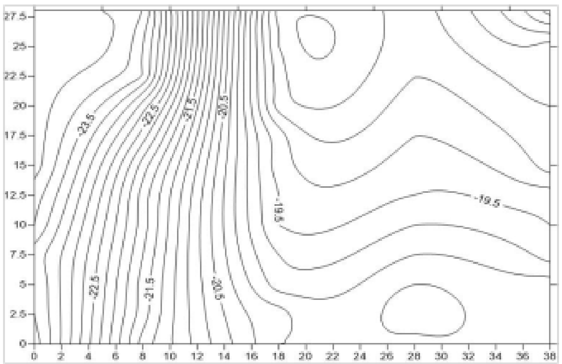

Figure 15. *Surfer* program simulation of scoured contour results at Q = 18.8 L/s

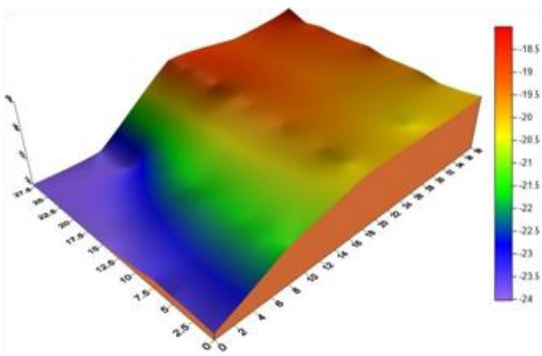

Figure 16. *Surfer* program simulation of scoured perspective at Q = 18.8 L/s

Based on observations during the scour process at the spillway, scour occurs starting downstream near the spillway and then continues along the flow until it reaches a certain length. The scouring continues until it forms a scour hole, the depth of which tends to be tilted up towards the far downstream of the spillway [2]. Meanwhile in the downstream part of the scour hole there is sediment deposition. This deposition continues to develop until it finally erodes back downstream, eventually collects and deposits increases downstream and gets longer with time [3].

• **Scour Percentage**

The percentage of scour was calculated based on the number of scours that occur in each simulation carried out with various variations of baffle blocks. To determine the amount of scour that occurs at downstream of the USBR (observation point) in each variation of the baffle block, namely without using Baffle Block, with 1: 1 Baffle Block, with 1: 3 Baffle Block and 1: 5 Baffle Block. This can provide an overview of baffle block function in protecting scour at the spillway.

TABLE 1. The scour reduction value of USBR-III

Number	Variation of Buffle Block	Total Scouring Volume (cm^2)	Volume of Matereial Before Scouring (cm^2)	Presentation of Scour (%)
1.	No Buffle Block	2258,68	6916	32,80
2.	Buffle Block 1:1	2990,70	6916	43,24
3.	Buffle Block 1:3	6291,10	6916	10,01
4.	Buffle Block 1:5	3308,88	6916	47,77

From table 1. above, it can be seen that the baffle block scour with a slope of 1:3 with a scour percentage of 10.01%. Thus, it can be stated that the buffle block with a slope of 1:3 is the most effective to protect scour at downstream of USBR_III spillway.

CONCLUSION

The average scour depth that occurs at baffle blocks of 1: 1 and 1: 5 is the highest at 6.5 cm, while the most effective in reducing scour is 1: 3 baffle block with an average scour depth of 2, 0 cm.

The scour protection by regression determination test on flow parameters shows that the higher the water level and the flow velocity at the bottom of the channel, decrease and less able to lift the channel bottom material[1].

The scour reduction in the baffle block variation with a slope of 1:3 with a scour percentage of 10.01%, this indicates that the baffle block with a slope of 1:3 is the mostef fective in protecting scour at downstream of the USBR_III spillway.

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