Effectiveness of sediment flushing by using under sluice flush canal

A Safanpo¹, Suripin² and I K Hadihardaja³

¹ Civil Engineering Department, Cenderawasih University, Makassar, Indonesia
² Civil Engineering Department, Diponegoro University, Semarang, Indonesia
³ Civil Engineering Department, Bandung Institute of Technology, Bandung, Indonesia

E-mail: safanpo2000@yahoo.com

Abstract. The objective of this study was to analyse the effectiveness of sediment flushing system of under sluice channel at a floodway. An empirical model of under sluice flushing were built to determine its effectiveness. The object model of this study was the Sedayulawas floodway, located in Lamongan, East Java, Indonesia. This study used Hydraulic Physical Model Test. The model conducted in the Laboratory of Surakarta River Center. The variables of this study were sediment weight of flush sediment, upstream water level, sediment mass density, sediment diameter, current velocity, and water discharge. The result of this research discovers that the upstream water level, sediment mass density, sediment diameter, current velocity, and the water discharge, directly proportional towards the weight of the flush sediment.

1. Introduction

A floodway was built in Babat, Lamongan, East Java to reduce flooding in Bengawan Solo River (figure 1). The floodway was built in 2000 with 12.3 km length, 100 m width, 0.0002433 slopes, and 640 m³/s rates of flow. This floodway has a stop lock door on its inlet (figure 2). In the downstream, there is a rubber dam, which has 4 x 25 mm width, 3 m height and a pillar prism that has thickness 5 mm on bottom and 1.67 m on top (figure 3).

Figure 1. Map for floodway of Sedayulawas.
Since 2010, in every rainy season, the Sedayulawas floodway is less able to function as it should be. In the upstream area, the water level is high. However, the water in the downstream still floods. The ineffective function of the floodway is caused by several factors, one of which is due to the high sedimentation along the floodway. The sedimentation in floodway can be reduced by building a flushing construction. The under sluice flush canal was chosen instead of other types of canals. The laboratory analysis is needed.

This research uses a hydraulic-physical model test method and held in Laboratory of Surakarta River Center. The physical model of Sedayulawas floodway was built using scale 1:66.667. Due to the capacity of the pump and the field area in laboratory (figure 4 and figure 5), the physical model is made 2,200 m length; 1,700 m from rubber dam into upstream area and 500 m from rubber dam into downstream area.

The characteristic of the drainage is surface water-free, the acceleration of Earth's gravity is the dominant parameter, so the requirement that should be fulfilled is the unvarying dynamic characteristic between the models and the prototypes. In this case, the Froude number (Fr) in the model must be the same as the prototype and the gravity in the prototype is the same with the model, so that the hydraulic physical model test parameters scale as shown in table 1.

Movable bed with the coal powder material was made an order to know the pattern of the sediment movement in the upstream of rubber dam. The physical model was created to examine the effect of changes in flow rate, and the width of the flushing door towards the flush sediment.
Figure 5. The model of flush canal.

Table 1. Hydraulic-physical model test parameter.

| Parameter     | Notation | Scale            |
|---------------|----------|------------------|
| Height        | H        | \( H = 66.667 \) |
| Length        | L        | \( L = 66.667 \) |
| Velocity      | V        | \( V = \left( \frac{H}{2} \right)^{1/2} = (66.667)^{1/2} = 8.165 \) |
| Time          | T        | \( T = \left( \frac{H}{2} \right)^{1/2} = (66.667)^{1/2} = 8.165 \) |
| Debit         | Q        | \( Q = \left( \frac{H}{2} \right)^{5/2} = (66.667)^{5/2} = 36289 \) |
| Manning value | N        | \( N = \left( \frac{H}{2} \right)^{1/6} = (66.667)^{1/6} = 2.014 \) |

2. Literature review

The research related to sediment flushing in the floodway and motion weir located at the mouth of the river or close to the waterfront has been widely reported. By using numerical models, Ji et al. The analyses the sediment flushing in the rubber dam at the mouth of the Nakdong River, South Korea, when the seawater at low tide conditions [1]. In the research, the study did not use the flush canal. The research simulated the opening door of the flood control in Dombo floodway, Sayung, Central Java, on the four conditions [2]. The research concluded that the door of the flood control on the floodway is ineffective. In the research, the study did not use the flush canal and did not take into account the influence of the tide. By using hydraulic model, the study analyses sediment flushing in Bojonegoro rubber dam, East Java. In this research, the study did not also use the flush canal and did not take into account the influence of the tide [3].

There are three types of hydraulic flushes, namely sluicing operation, venting of density current and flushing operation. Flushing operation is aimed to erode the settles sediment in the upstream, and it typically has larger granules (coarse material), so that the eroded sediment load will be carried to the downstream by the flow of water and flush out through the door of the flushing operation. Flushing sediment technique is applied by increasing the speed of water flow on the disposal door, so that the speed of water flow becomes greater and enough to grind or erode the sediment that has been accumulated through the door system, for example in the bottom outlet system [4-5].

Generally, flushing can be classified into two categories, Empty or Free-flow Flushing and Flushing with Partial Drawdown [6-7]. Empty or free-flow flushing is a flushing technique implemented by making the water reservoir empty, while the river water flow is maintained into the reservoir, then used the water as the sediment flush out through the bottom outlet.

3. Research methods

To identify the variables that should be investigated, this research uses non-dimensional numerical analysis by applied method of Buckingham \( \pi \) [8]. The influencing parameters are the height of water...
level in Sta. FW16 ($H$, in m), gravitation ($g$, in m/s$^2$), mass density of sediment ($\rho_s$, in kg/m$^3$), Current velocity ($Q$, in m$^3$/s), velocity ($v$, in m/s), weight of sediment ($W_s$, in g), diameter of sediment ($d_s$, in m). Each of these parameters has been chosen based on the dimensions of $M$ (mass), $L$ (length), and $T$ (time), as described in table 2 below.

Table 2. Parameter dimension.

| Variable dimension | $H$ | $g$ | $\rho_s$ | $Q$ | $v$ | $W_s$ | $d_s$ |
|--------------------|-----|-----|----------|-----|-----|-------|-------|
| $M$                | 0   | 0   | 1        | 0   | 0   | 1     | 0     |
| $L$                | 1   | 1   | -3       | 3   | 1   | 0     | 1     |
| $T$                | 0   | -2  | 0        | -1  | -1  | 0     | 0     |

The repeat parameters are $H$, $g$, dan $\rho_s$.

\[
\pi_1 = H^0 \cdot g^1 \cdot \rho_s^1 \cdot Q \quad (1)
\]

\[
\pi_1 = H^{-2.5} \cdot g^{-0.5} \cdot \rho_s^0 \cdot Q \quad (2)
\]

\[
\pi_1 = \frac{Q}{H^2 \sqrt{gH}} \quad (3)
\]

\[
\pi_2 = Hx \cdot gy \cdot \rho sz \cdot v \quad (4)
\]

\[
\pi_2 = H^{-0.5} \cdot g^{-0.5} \cdot \rho_s^0 \cdot v \quad (5)
\]

\[
\pi_2 = \frac{v}{\sqrt{gh}} \quad (6)
\]

\[
\pi_3 = Hx \cdot gy \cdot \rho sz \cdot Ws \quad (7)
\]

\[
\pi_3 = H^{-3} \cdot g^0 \cdot \rho s-1 \cdot Ws \quad (8)
\]

\[
\pi_3 = \frac{W_s}{H^2 \rho_s} \quad (9)
\]

\[
\pi_4 = Hx \cdot gy \cdot \rho sz \cdot ds \quad (10)
\]

\[
\pi_4 = H^{-1} \cdot g^0 \cdot \rho s0 \cdot ds \quad (11)
\]

\[
\pi_4 = \frac{d_s}{H} \quad (12)
\]
\[
f(\pi_1, \pi_2, \pi_3, \pi_4) = f \left( \frac{Q}{H^2 \sqrt{gH}}, \frac{v}{\sqrt{gH}}, \frac{W_s}{H^3 \rho_s}, \frac{d_s}{H} \right) = 0
\]  

(13)

It is simplified by operating multiplication or division between non-dimensional between variables, then eliminating the constant value so that the formula becomes simpler.

\[
\pi_5 = \frac{\pi_2}{\pi_4} = \frac{W_s}{H^2 \rho_s d_s} \cdot \frac{H}{d_s} = \frac{W_s}{H^2 \rho_s d_s}
\]  

(14)

\[
\pi_6 = \pi_1 \cdot \pi_2 = \frac{Q}{H^2 \sqrt{gH}} \cdot \frac{v}{\sqrt{gH}} = \frac{Qv}{H^3 g} = \frac{v Q}{H^3 g}
\]  

(15)

\[
f(\pi_5, \pi_6) = f \left( \frac{W_s}{H^2 \rho_s d_s}, \frac{v Q}{H^3 g} \right) = 0
\]  

(16)

\[
\frac{W_s}{H^2 \rho_s d_s} = f \left( \frac{v Q}{H^3 g} \right)
\]  

(17)

\[
W_s = H^2 \rho_s d_s \cdot f \left( \frac{v Q}{H^3 g} \right)
\]  

(18)

Based on the analysis of the non-dimensional number, the variables that should be investigated are \( H, \rho_s, d_s, Q, B, \Delta H, \) and \( W. \)

4. Results and discussions

The results were presented in Table 3, along with two non-dimensional numbers. A graph was made to show the relationship between the two non-dimensional numbers and its trendline (figure 6).

As shown in figure 6, the trendline is \( y = 21649 \cdot x^{0.948} \), since \( y = \frac{W_s}{H^2 \rho_s d_s} \) and \( x = \frac{V Q}{H^3 g} \) then

\[
\frac{W_s}{H^2 \rho_s d_s} = 21649 \left( \frac{v Q}{H^3 g} \right)^{0.948}
\]

Figure 6. The correlation of two non-dimensional number and its trendline.

The result of this research discovers that the upstream water level, sediment mass density, sediment diameter, current velocity, and the water discharge, directly proportional towards the weight of the flush sediment. The same reports were also reported by Atmojo and Suripin [9] and Guo et al. [10].
### Table 3. Experimental data.

| No | \( H_{FW16} \) (cm) | \( \nu \) (cm/s) | \( Q \) (cm³/s) | \( W_s \) (g) | \( vQ/(H_s^2 \rho_d) \) | \( W_s / (H_s^2 \rho_d) \) |
|----|-------------------|-----------------|----------------|-------------|-------------------------|-------------------------|
| 1  | 1.65              | 13.34           | 2,783.20       | 27,250      | 7.1603                  | 142,764                 |
| 2  | 1.60              | 12.05           | 2,783.20       | 29,250      | 8.3465                  | 162,969                 |
| 3  | 1.58              | 12.24           | 2,783.20       | 30,250      | 8.8041                  | 172,835                 |
| 4  | 1.55              | 12.45           | 2,783.20       | 31,250      | 9.4853                  | 185,527                 |
| 5  | 1.50              | 13.13           | 2,783.20       | 33,250      | 11.0391                 | 210,780                 |
| 6  | 1.35              | 11.63           | 3,031.21       | 31,500      | 14.6107                 | 245,526                 |
| 7  | 1.25              | 12.36           | 3,031.21       | 34,500      | 19.5540                 | 314,934                 |
| 8  | 1.18              | 12.56           | 3,031.21       | 36,500      | 23.6206                 | 373,894                 |
| 9  | 1.15              | 12.76           | 3,031.21       | 38,500      | 25.9241                 | 415,227                 |
| 10 | 1.10              | 13.48           | 3,031.21       | 41,500      | 31.2839                 | 489,196                 |
| 11 | 1.20              | 11.80           | 3,141.43       | 35,800      | 21.8605                 | 354,601                 |
| 12 | 1.10              | 12.35           | 3,141.43       | 39,800      | 29.7131                 | 469,156                 |
| 13 | 1.05              | 12.73           | 3,141.43       | 42,800      | 35.2143                 | 553,714                 |
| 14 | 1.00              | 13.10           | 3,141.43       | 45,800      | 41.9498                 | 653,259                 |
| 15 | 0.95              | 13.66           | 3,141.43       | 49,800      | 51.0340                 | 787,050                 |
| 16 | 1.64              | 11.67           | 2,783.20       | 26,240      | 7.5081                  | 139,154                 |
| 17 | 1.59              | 12.36           | 2,783.20       | 29,240      | 8.7237                  | 164,969                 |
| 18 | 1.57              | 12.60           | 2,783.20       | 31,240      | 9.2373                  | 180,772                 |
| 19 | 1.54              | 12.84           | 2,783.20       | 33,240      | 9.9742                  | 199,912                 |
| 20 | 1.45              | 13.52           | 2,783.20       | 36,240      | 12.5831                 | 245,851                 |
| 21 | 1.30              | 11.81           | 3,031.21       | 35,080      | 16.6059                 | 296,069                 |
| 22 | 1.24              | 12.40           | 3,031.21       | 39,080      | 20.0957                 | 362,519                 |
| 23 | 1.17              | 12.75           | 3,031.21       | 42,080      | 24.5980                 | 438,454                 |
| 24 | 1.14              | 13.10           | 3,031.21       | 45,080      | 27.3214                 | 494,760                 |
| 25 | 1.09              | 13.68           | 3,031.21       | 49,080      | 32.6317                 | 589,212                 |
| 26 | 1.10              | 12.05           | 3,141.43       | 40,050      | 28.9828                 | 472,103                 |
| 27 | 1.00              | 12.70           | 3,141.43       | 45,050      | 40.6689                 | 642,562                 |
| 28 | 1.04              | 13.00           | 3,141.43       | 49,050      | 37.0085                 | 646,833                 |
| 29 | 0.99              | 13.30           | 3,141.43       | 53,050      | 43.8939                 | 772,032                 |
| 30 | 0.94              | 13.95           | 3,141.43       | 58,050      | 53.7975                 | 937,058                 |
| 31 | 1.63              | 11.77           | 2,783.20       | 28,700      | 7.7124                  | 154,073                 |
| 32 | 1.58              | 12.52           | 2,783.20       | 31,700      | 9.0055                  | 181,119                 |
| 33 | 1.56              | 12.71           | 2,783.20       | 32,700      | 9.4983                  | 191,654                 |
| 34 | 1.53              | 12.90           | 2,783.20       | 33,700      | 10.2186                 | 205,337                 |
| 35 | 1.44              | 13.64           | 2,783.20       | 36,700      | 12.9567                 | 252,442                 |
| 36 | 1.29              | 11.96           | 3,031.21       | 41,820      | 17.2217                 | 358,447                 |
| 37 | 1.23              | 12.66           | 3,031.21       | 46,820      | 21.0216                 | 441,409                 |
| 38 | 1.16              | 12.92           | 3,031.21       | 49,820      | 25.5761                 | 528,090                 |
| 39 | 1.13              | 13.18           | 3,031.21       | 52,820      | 28.2245                 | 590,013                 |
| 40 | 1.08              | 13.86           | 3,031.21       | 57,820      | 33.9938                 | 707,051                 |
| 41 | 1.09              | 12.14           | 3,141.43       | 51,300      | 30.0191                 | 615,863                 |
| 42 | 0.99              | 12.87           | 3,141.43       | 57,300      | 42.4901                 | 833,881                 |
| 43 | 1.03              | 13.07           | 3,141.43       | 62,300      | 38.3021                 | 837,594                 |
| 44 | 0.98              | 13.38           | 3,141.43       | 67,300      | 45.5214                 | 999,500                 |
| 45 | 0.93              | 13.96           | 3,141.43       | 73,300      | 55.5770                 | 1,208,810               |
5. Conclusion
The results could be used as one starting point for the design of sediment flushing in Sedayulawas floodway, and others. This research does not consider the sediment flow patterns, so it is suggested that the next research will take it into account to determine the position of the under sluice flush door.

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