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The influence of sandy clay bed material to local scour behaviour

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Abstract

As a type of gate that is used to control the water level upstream, sluice gate is the gate with simple shape and outstanding ability to flush the sediment. The operation of the gate is considered an important process. The up and down movement of the gate would affect the velocity and cause local scour as the result of fluctuating rate. This research aims to assess the effects of discharge and gate-opening height variations, as well as the type of bed-channel material, on the change of depth of scour (d_s). The research was conducted of open channel flow model with a sluice gate able to up and down movement. The discharges used in the research were 9 types ranging from 1.0 to 5.0 dm^3·s^{-1}. There were 5 variations in the height of gate-opening ranging from 0.5 to 2.5 cm at intervals of 0.5 and types of channel-bed material. The results of the research showed that the depth of scour can be analysed as a function of discharge, height of gate-opening, height of water level upstream and downstream, and the type of bed material used. The scour depth equation is $d_s = 1.7822(\frac{Q}{a})^{1.1347} a$. Calculated coefficient of determination of the relationship between two types of channel-bed material and the depth of scour was R^2 = 0.946. Consequently, it can be concluded that the equation can be applied on both types of bed-channel material.

Key words: *sandy clay bed material, scour depth, sluice gate*

INTRODUCTION

Flow underneath gate has a tremendous amount of potential energy. This energy should be dissipated to prevent the possibility of scour the downstream of river and to minimize erosion and the undermining of the structure which endanger the structure safety [ALI *et al.* 2014]. Because of the flow condition around the gate structure are complex, the design and planning of an apron are typically based on experimental results, modelling and measurement from similar projects. An additional complexity is the composition of sediment which is usually a mixture of sand, clay and rock [BREUSERS, RAUDKIVI 1991]. The scour depths are used to predict expected prototype of scour. In order to use model data for predicting scour depths associated with a stilling basin, the model bed material type and size must be chosen carefully to allow scaling [WHITTAKER, SCHLEISS 1984].

The knowledge about erosion behaviour of cohesive sediment is necessary for solving various problem like soil erosion in catchments, reservoir sedimentation, river morphological prediction etc. [FARHOUDI, SHAYAN 2014]. The sediments like clay normally behave as cohesive material. When sand and gravel are mixed with clay and silt, the mixture also exhibits certain amount of cohesion. The condition of incipient motion of cohesive sediments and their mixture are affected by large number of independent variable [KOTHYARI, JAIN 2008]. The characteristics of principal sediments also play an important role such processes along with the flow and fluid characteristics as in the case of cohesion-less sediment. For cohesion-less sediments the critical shear stress can be reliably determined by using any one of the versions of Shields's function from knowledge of grain density, size and gradation and fluid properties.

The role of sediment detachment and its transport on the evolution of river morphology is well known. Some aspect of cohesive sediment detachment are also significant for engineering project such as embankment stabilization, scour around the bridge pier etc. [KOTHYARI, JAIN 2008]. The condition of initiation of motion and process of detachment and transport of sediment by stream flow in the form of bed load and suspended load for uniform and non-uniform cohesionless sediment are reasonably well understood. Scour phenomena at the downstream of sluice gate have absorbed wide attentions by various researcher. MARUZEK [2001] investigate of scour in one type of soil composed. She examines the characteristics of scour in clay by submerged plane turbulent wall jets. The scour of clay created by a plane turbulent wall jet was not two dimensional, but varied across the width of the sample. This irregularity may be due to the flume wall and the disturbances along the downstream of sluice. And the type of scour hole profile that will form under given flow conditions cannot as yet be predicted.

SARAÇOĞLU and AĞAÇCIOĞLU [2015] observed the effect of side weir to flow-scour characteristics and scour depth on clay-sand mixed beds. The result of observation showed that the depth of scour increases rapidly with time at the beginning, and then asymptotically approaches stable value in all experiments as in non-cohesive material. That means the scour depth reaches an equilibrium condition. Time to equilibrium depends on the approach flow intensity and the dimensions of side weirs.

DEBNATH and CHAUDURI [2012] investigated of local scour around circular piers embedded in clay sand mixed cohesive sediment beds. The results of investigation showed that the effect of clay-content, water content and bed shear strength on scouring process, the scour geometry and time variation of scour. The data suggested that clay and clay-sand mixtures, are not constant values similar to the non-cohesive sediment.

CHAUDURI and DEBNATH [2013] also observed the initiation of pier scouring and scour hole profile in cohesive sediments. The cohesive material was mixed with fine sand in different proportions. From the observation results that for clayey and clay-sand mixed cohesive sediments, the time variation of scour was much different from that of sand beds. In cohesive sediment, scouring in the form of chunks creates a rough surface. It was also observed that with increase in clay content, the maximum scour depth and its peripheral expansion decreased up to 0.5 clay fraction and there after increased.

Many researcher has been investigate scour created downstream of the apron at non-cohesive bed material too. Investigation of the scour characteristics without any apron below a vertical gate under different tail water depth [GOEL 2010]. The experimental data was collected with the various discharge and sluice opening were kept equal to 2 cm under the gate as constant at all discharge. The result of experiment laboratory showed that the scour behind the sluice gate depends on discharge, tail water depth, flow condition and gate opening. The scour depth and length are sensitive to discharge, tail water depth and flow condition especially at higher discharge and lower tail water on the vertical gate.

The next experimental of local scour of non cohesive was done at horizontal rigid apron [HAMIDIFAR, NASRABADI 2011]. Two types of non uniform sediments with median diameters of 0.73 mm and 1.85 mm were used in the experiment. The results of the experiments showed that the scour hole does not reach the equilibrium state even after 48 hours. Although the scour profiles seems to be three dimensional in nature, some result of observation showed that there is a geometrical similarity between the scour hole in all of the experiment [ABDEL-RAHIM 2016]. Another experimental that relation with scour characteristics was investigate to find out the length of rigid apron behind the gate corresponding to scour hole formed at downstream. Another purposes of this study is to find the minimum length of rigid apron to prevent erosion downstream it. The results of the experimental showed that scour length is found to be function of head difference (H), the downstream normal flow depth (y_n) and flow condition under the gate. The depth of scouring is depends on the bed shear stress of flow motion and head difference (H).

The initiation of movement of a particle due to action of flow fluid is defined as the instant when the applied forces due to fluid drag and lift, causing the particle to move, exceed the stabilizing force due to gravity [GRAF 1984]. For uniform sediments unidirectional flow this condition is best defined by the Shields curve (Fig. 1), which defines the threshold in terms of the entrainment function [BREUSERS, RAUDKIVI 1991]. The Figure 1 showed the relationship between the critical velocity (u_*), sediment density (ρ_s), diameter size of sediment (d) and kinematics viscosity (v). Various sediment particles moving at any time may have different sizes, shapes, specific gravity and fall velocities. When a channel's sediment transport capability exceed the rate sediment supply from upstream, the balance of sediment load has to come from the channels itself. In this chase, the channel start to degrade. Because of the no uniformity of the bed material size, finer material will be transported at a faster rather than the coarser material and remaining bed material become coarser [YANG 1996].

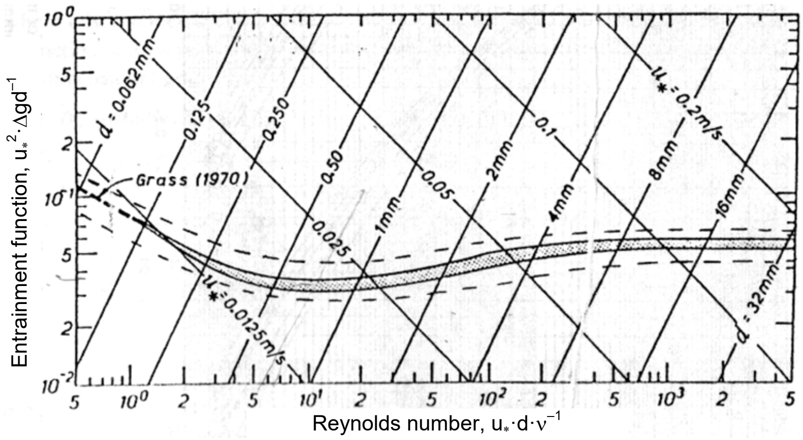

Fig. 1. Shields's curve: u_* = critical velocity, ρ_s = sediment density, d = diameter size of sediment, v = kinematics viscosity; source: BREUSERS, RAUDKIVI [1991]

In this paper the scour phenomena at the downstream of sluice gate was investigated. The experiments of this present study have been carried out the scour characteristics under sluice gate without apron of two kind non-cohesive bed in the clay-sand mixture (sandy loam and loamy sand). The aims of the study is to knowing the differences the scour characteristics between two type of the non-cohesive bed. The scour holes characteristics can be observed and calculated from the discharge, the differences of water level upstream and downstream of the sluice gate as shown in Figure 2.

MATERIAL AND METHODS

DIMENSIONAL ANALYSIS

From dimensional analysis, the effective parameters on the scour phenomenon can be expressed as (see Fig. 2):

$$d_s = F(a, Q, D_m, L_s, h_d, y_0, y_1, y_2, y_{tw}, Gs, g, \rho) \qquad (1)$$

where: d_s = depth of scour, cm, a = gate opening height, cm, Q = discharge, dm^3·s^{-1}, D_m = diameter size of sediment, L_s = the scour lenght, h_d = height of sedimentation, cm, y_0 = upstream water level, y_1 = water level front of the gate, y_2 = water level the end of scouring, y_{tw} = tail water level, Gs = specific gravity, g = acceleration due to gravity, ρ = mass density of water.

The independent variable are a, Q and type of material. The dependent variable are d_s, L_s, h_d, y_0, y_1, y_2, y_{tw}. And using the Langhaar methode, we can conclude:

$$\frac{d_s}{a}; \frac{Q}{g^{0.5}a^{1.5}}; \frac{y_{tw}}{a}; \frac{y_0}{a}; \frac{\Delta H}{a} \qquad (2)$$

where: ΔH = head difference between upstream water level and downstream water level, cm; other symbols as under the Eq. (1).

The dimensionless number will analysis the data of the result experimental model test. The result of initial analysis showed that the graph of relationship between the dimensionless number will form the closest equation to the empirical result of hydraulics physical test. From the result of dimensional analysis then determine the relationship which the best contribution to scour characteristics.

EXPERIMENTAL

The experimental were conducted in an acrylic side flume with recirculating water at Applied Hydraulics Laboratory in Water Resources Engineering Faculty, Brawijaya University, Malang, Indonesia. The length of flume is 9.0 m and width 0.50 m and high 0.60 m. The uniform water flow depth could be adapted by means of a tailgate installed at the channel end. The water pumped continuously from the downstream tank into the upstream head tank with the maximum capacity is 10.0 dm^3·s^{-1}. A Rehbock devices mounted on the upstream end of the channel to measuring and calculating the flow into the channel. A Rehbock was calibrated to measure the discharge. The mixture sand and clay laying over the bed of the flume with 0.20 m depth and the density of the mixture is 2.735. The water depths and bed levels were measured by point gauges. The velocity was measured by a calibrated Pitot tube. The sluice gate was installed in the flume and can be lifted and lowered to desired under-gated opening height that permits to form submerged hydraulic jump condition on the movable bed. Schematic of experimental apparatus is shown in Figure 3. Water was pumped from reservoir to upstream tank and flow to the Rehbock measurement and water entered the channel through stilling tank. Two kind of non-cohesive bed material were used in this experiment.

CALIBRATION OF WEIR FORMULA

Calibration is needed to know the eligible of model against the sample of experiment, so the sample can be declared for use in an experiment. If the test is different from the measured model, some constanta number is required to adjust the test result to the measured model. The calibration process as a comparison of measured data and calculated data can only be done during the calibration process. For velocity measurement, calibration is done by comparing the velocity data measured from the velocity device meter (Current meter/Pitot tube/Thomson/Rehbock, etc.) at a calculated velocity.

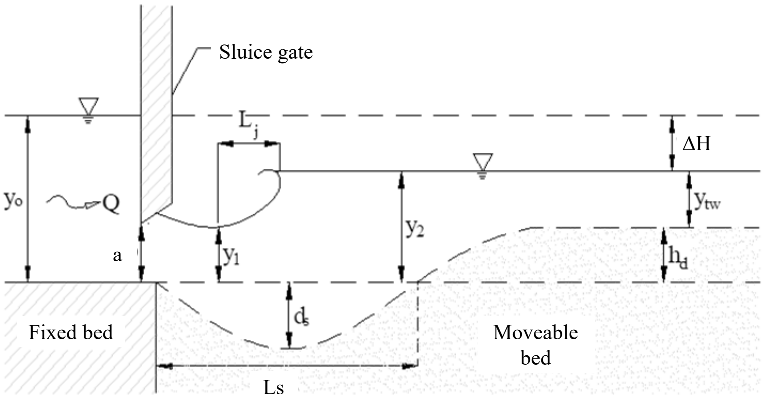

Fig. 2. Parameters of the calculation of scour characteristics; L_j = hydraulic jump, L_s = length of scour, y_0, y_1, y_2, y_{tw}, h_d, d_s, Q, a as under the Eq. (1); source: own elaboration

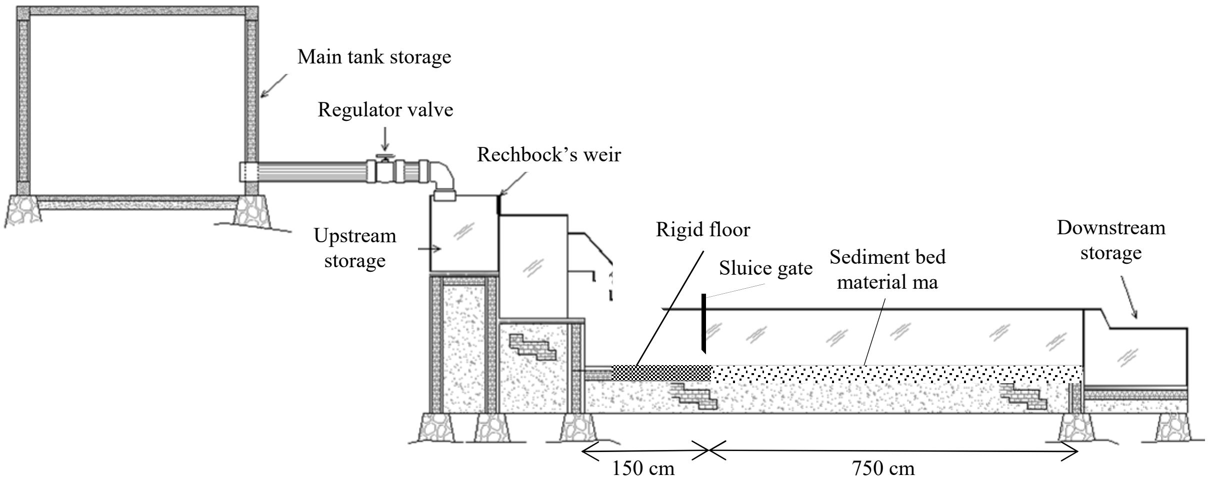

Fig. 3. Experimental setup for scour hole at open channel flume; source: own elaboration

Measured discharge measurements are calibrated with measurable discharges. The measured speed data of the speed measuring instrument is calculated to obtain the calculated debit data. The calculated discharge data is calibrated with measured debit (discharge quantity). Finally the combination having the results nearest to measured data was chosen [BERGHOUT, MEDDI 2016].

This paper using the Rehbock weir to measure discharge which is mounted and arranged in a way that the flow is not drowned. The Table 1 showed some equations used to calculate the discharge on the Rehbock weir. Further details on the experimental configurations are listed in Table 2. This picture 4 below showed the soil fraction classification under USDA system.

METHODS

A sieve analysis was carried out to determine the grain size distribution for each type of bed material and the median grain size (d_{50}). Downstream of the sediment box was equipped with a sand trap to prevent any incidental transport of the fine sand into the flow system. The draft of treatment was intended to get an overview of the flow behaviour due to variations in opening gate to the hydraulic and scour characteristics on the sandy-clay bed channel. For the channel bed material, treatment variations were directed to obtain data that illustrate the effect of submerged flow to change the velocity and scouring. With the variation of the discharge start = 0.5 dm^3·s^{-1} to 5.0 dm^3·s^{-1} with water depth measurements upstream and downstream of the gate, while openings gate (a) ranging from 0.5 cm to 2.5 cm.

Preliminary study goes to know the boundary condition of the research. The flume was initially filled with water to avoid the undesirable erosion of the sediment bed. The first running with the amount of discharge of 0.5 dm^3·s^{-1}. The water flows through the channels and the appropriate discharge began the measurement. The data obtained was the height of at the upper gate (y_o), the depth of the flow in front of the vena contractâ (y_{0b}), the depth in the area of turbulence (y_1) and the depth in the downstream flow (tail water (y_2). Meanwhile, the scour process was recorded with handy-cam and camera. Each experiment was run for one hour to knowing the scouring process. At the end of the run time the flow was stopped and the characteristics of the scour hole and sediment such as the maximum depth of scour, the length of scour were measure.

Table 1. Discharge equation at crest weir

Parameter	REHBOCK [1929] $Q = C_d \frac{2}{3}\sqrt{2g}by$	BOS [1978] $Q = C_e \frac{2}{3}\sqrt{2g}b_e y_e^{1.5}$	Recent study $Q = K\,b\,y^{1.5}$
B	–	–	0.702 m
D	$0.10 \text{ m} \le D \le 1.00$ m	≥0.30 m	0.50 m
b		≥0.30 m	0.37 m
y	$0.025 \text{ m} \le y \le 0.60$ m	$0.07 \text{ m} \le y \le 0.60$ m	0.029–0.148 m
y/D	<1.00 m	≤0.50 m	0.058–0.296 m
y/B		≤0.50 m	0.042–0.211 m

Explanations: B = width of bed channel, D = height channel from bed, b = width of crest, y = depth of water level at crest.
Source: own elaboration.

Table 2. Design of experimental model

Discharge symbol	Discharge value	$a_1 = 0.5$ cm	$a_2 = 1.0$ cm	$a_3 = 1.5$ cm	$a_4 = 2.0$ cm	$a_5 = 2.5$ cm
Sandy loam material M1						
Q_1	1.0 $dm^3 \cdot s^{-1}$	M1Q_1a_1	M1Q_1a_2	M1Q_1a_3	M1Q_1a_4	M1Q_1a_5
Q_2	1.5 $dm^3 \cdot s^{-1}$	M1Q_2a_1	M1Q_2a_2	M1Q_2a_3	M1Q_2a_4	M1Q_2a_5
Q_3	2.0 $dm^3 \cdot s^{-1}$	M1Q_3a_1	M1Q_3a_2	M1Q_3a_3	M1Q_3a_4	M1Q_3a_5
Q_4	2.5 $dm^3 \cdot s^{-1}$	M1Q_4a_1	M1Q_4a_2	M1Q_4a_3	M1Q_4a_4	M1Q_4a_5
Q_5	3.0 $dm^3 \cdot s^{-1}$	M1Q_5a_1	M1Q_5a_2	M1Q_5a_3	M1Q_5a_4	M1Q_5a_5
Q_6	3.5 $dm^3 \cdot s^{-1}$	M1Q_6a_1	M1Q_6a_2	M1Q_6a_3	M1Q_6a_4	M1Q_6a_5
Q_7	4.0 $dm^3 \cdot s^{-1}$	M1Q_7a_1	M1Q_7a_2	M1Q_7a_3	M1Q_7a_4	M1Q_7a_5
Q_8	4.5 $dm^3 \cdot s^{-1}$	M1Q_8a_1	M1Q_8a_2	M1Q_8a_3	M1Q_8a_4	M1Q_8a_5
Q_9	5.0 $dm^3 \cdot s^{-1}$	M1Q_9a_1	M1Q_9a_2	M1Q_9a_3	M1Q_9a_4	M1Q_9a_5
Loamy sand material M2						
Q_1	1.0 $dm^3 \cdot s^{-1}$	M2Q_1a_1	M2Q_1a_2	M2Q_1a_3	M2Q_1a_4	M2Q_1a_5
Q_2	1.5 $dm^3 \cdot s^{-1}$	M2Q_2a_1	M2Q_2a_2	M2Q_2a_3	M2Q_2a_4	M2Q_2a_5
Q_3	2.0 $dm^3 \cdot s^{-1}$	M2Q_3a_1	M2Q_3a_2	M2Q_3a_3	M2Q_3a_4	M2Q_3a_5
Q_4	2.5 $dm^3 \cdot s^{-1}$	M2Q_4a_1	M2Q_4a_2	M2Q_4a_3	M2Q_4a_4	M2Q_4a_5
Q_5	3.0 $dm^3 \cdot s^{-1}$	M2Q_5a_1	M2Q_5a_2	M2Q_5a_3	M2Q_5a_4	M2Q_5a_5
Q_6	3.5 $dm^3 \cdot s^{-1}$	M2Q_6a_1	M2Q_6a_2	M2Q_6a_3	M2Q_6a_4	M2Q_6a_5
Q_7	4.0 $dm^3 \cdot s^{-1}$	M2Q_7a_1	M2Q_7a_2	M2Q_7a_3	M2Q_7a_4	M2Q_7a_5
Q_8	4.5 $dm^3 \cdot s^{-1}$	M2Q_8a_1	M2Q_8a_2	M2Q_8a_3	M2Q_8a_4	M2Q_8a_5
Q_9	5.0 $dm^3 \cdot s^{-1}$	M2Q_9a_1	M2Q_9a_2	M2Q_9a_3	M2Q_9a_4	M2$Q_{9a}a_5$

Explanations: a = gate opening height.
Source: own elaboration.

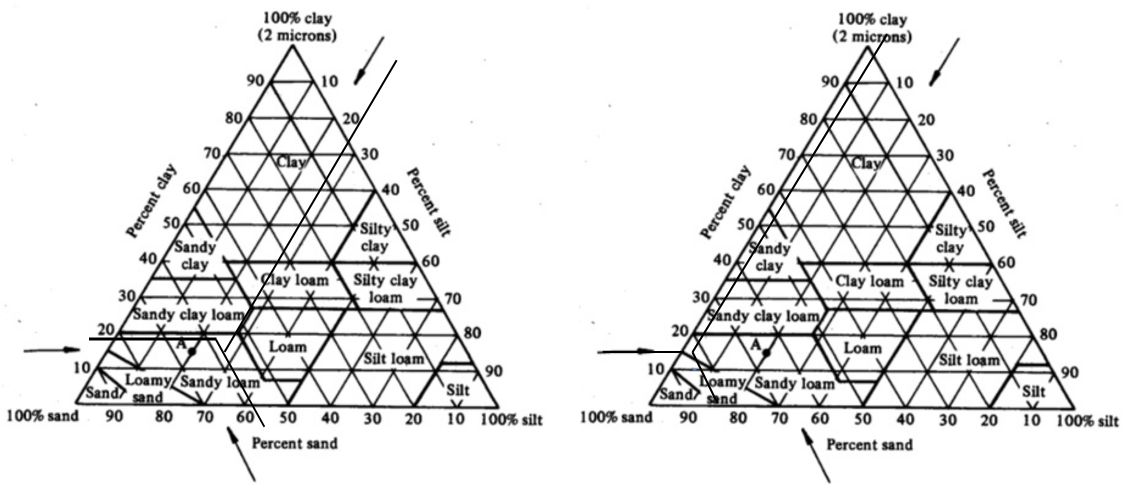

Fig. 4. Classification of sand clay material: a) sandy loam, b) loamy sand; source: FOTH [1984]

MATERIAL

Two types of bed material were tested in the study, that is, sandy loam and loamy sand (Tab. 3). The selecting type of the material considering the type of soil around the experimental study. The purpose of this selection is to know how the effect of the type of material to scour characteristics. Each type of material was run in 60 minutes to know the process of scouring. Characteristic of flow observation are shown in Table 4. To investigate the effect of cohesive material to scour characteristics are shown in Table 5. The depth

Table 3. Characteristics of bed material

Material	d_{10}	d_{50}	d_{60}	d_{90}	Gs
	mm				(–)
M1	0.065	0.42	0.56	2.0	2.735
M2	0.070	0.40	1.28	1.38	2.253

Explanations: M1 = sandy loam, M2 = loamy sand, d_{10} = 10% finer sediment size, d_{50} = 50% finer sediment size, d_{60} = 60% finer sediment size, d_{90} = 90% finer sediment size.
Source: own elaboration.

across the channel width were measured by a point gauge. The velocity were measured by two methods, first by a Pitot-tube and second by calculating discharge flow on the Rehbock measurement. To measure the water level at a Rehbock weir is used a hosepipe connected out with stilling tank. So that the water level at Rehbock weir can be read by a water pipe placed at the same height from the bottom of the tank (Fig. 3). The Pitot tube was also used by WHITTAKEs and

Table 4. Characteristics of flow observation

Depth calculated acc. to Rehbock's formula		Discharge Q	
cm	m	$m^3 \cdot s^{-1}$	$dm^3 \cdot s^{-1}$
1.25	0.0125	0.0010	1.0
1.65	0.0165	0.0015	1.5
2.00	0.0200	0.0020	2.0
2.35	0.0235	0.0025	2.5
2.70	0.0270	0.0030	3.0
3.00	0.0300	0.0035	3.5
3.30	0.0330	0.0040	4.0
3.55	0.0355	0.0045	4.5
3.85	0.0386	0.0050	5.0

Source: own study.

SCHLEISS [1984] as an indirect method to measure the flow depth along the channel flume. The measured critical depth was compared with analysis from calculation of Rehbock's formula.

Table 5. Experimental results data for scour depth and scour length

Discharge Q $dm^3 \cdot s^{-1}$	Sandy loam					Loamy sand					Discharge Q $dm^3 \cdot s^{-1}$	Sandy loam					Loamy sand				
	a1	a2	a3	a4	a5	a1	a2	a3	a4	a5		a1	a2	a3	a4	a5	a1	a2	a3	a4	a5
	cm											cm									
	0.5	1.0	1.5	2.0	2.5	0.5	1.0	1.5	2.0	2.5		0.5	1.0	1.5	2.0	2.5	0.5	1.0	1.5	2.0	2.5
1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	9.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.5	4.8	3.4	0.0	0.0	0.0	4.3	0.0	0.0	0.0	0.0	1.5	15.0	11.5	0.0	0.0	0.0	14.0	0.0	0.0	0.0	0.0
2.0	7.0	5.0	3.7	0.0	0.0	6.3	3.1	0.0	0.0	0.0	2.0	22.5	17.0	18.0	0.0	0.0	20.0	0.0	0.0	0.0	0.0
2.5	9.3	7.5	5.4	2.5	0.0	8.2	5.4	0.0	0.0	0.0	2.5	26.5	26.0	20.0	15.0	0.0	23.0	16.6	0.0	0.0	0.0
3.0	10.3	8.4	6.4	7.1	0.0	11.0	6.9	5.0	0.0	0.0	3.0	33.0	29.0	25.0	25.5	0.0	28.0	22.0	20.0	0.0	0.0
3.5	13.3	11.0	8.3	8.0	0.0	12.4	6.4	6.4	0.0	0.0	3.5	42.0	37.5	36.0	35.0	32.0	33.0	23.0	23.0	0.0	0.0
4.0	0.0	11.9	8.5	8.2	3.9	13.4	11.2	8.4	1.1	0.0	4.0	45.0	43.0	39.0	57.0	27.5	39.0	34.0	28.0	11.0	0.0
4.5	0.0	13.2	11.1	9.3	8.3	15.1	11.5	9.7	7.4	0.0	4.5	54.0	50.0	45.0	45.0	35.0	45.0	35.0	38.0	32.0	29.0
5.0	0.0	14.5	12.0	10.5	10.1	16.2	14.0	11.0	9.0	4.7	5.0	65.0	60.0	48.0	40.0	41.5	47.0	39.0	35.0	32.0	21.0

Explanations: a1, a2, a3, a4, a5 as in Table 2.
Source: own study.

RESULTS AND DISCUSSION

Scour phenomena downstream of sluice gate constitute an important field of research of its frequent occurrence in engineering applications. To knowing more clear, Figure 5 showed that occur at discharge 3.5 $dm^3 \cdot s^{-1}$ and opening gate 1.5 cm for sandy loam material type. Figure 5a show the plane condition before running process. Figure 5b show the condition of bed material after 10 minutes running process. In order to investigate the relationship between the bed material type and scour characteristics in downstream of the sluice gate, the values of scour depth (ds) were plotted against the opening gate (a), at desire discharge as shown in Figure 6. The result showed that at the same discharge, the scour depth decrease for increasing opening gate. The same trend for two kind of materials. The differences between two type of material is a scour depth of loamy sand deeper than another. It because of clay content for loamy sand is less than sandy loam. The soil ability of loamy sand to resist the high velocity that occur the scouring depends on the composition of the material (sand, fine sand, clay and silt). More sand content in that material could be more easier to scour because of it soil durability smaller. The ability to hold the soil and sand bonding is lower. So that scouring is greater. The same result occurred by FARHOUDi and SHAYAN [2014]. They demonstrate an increasing the scour depth with reducing the of grain size. Clearly, this would be attributed to impossed resistance of larger size particle during the phenomenon. Consequently, as the grain size decreases the maximum scour depth, would move toward downstream of the reach resulting a larger length of scour hole. Scour characteristics is not only influenced of type of bed material but also affected by the gate opening height. In the Figure 6 the higher of opening gate the scour depth is deeper. It conducting with the velocity occur under the sluice gate and the discharge. For the same discharge condition, the higher of the opening gate that increasing the scour depth. It's associated with the flow rate that occurred. For the same discharge condition, the higher opening gate that flow rate decreases. As a result, the depth of scouring decreases. For the decreasing velocity, the bed material will be influence by the fall vea)

b)

Fig. 5. The bed material condition at discharge $Q = 3.5$ dm^3·s^{-1} with gate opening height $a = 1.5$ cm; a) before running, b) after running; source: own elaboration

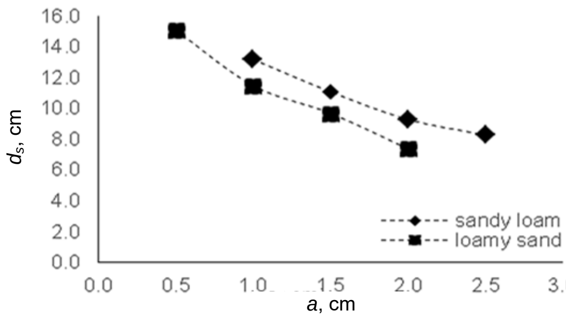

Fig. 6. Scour depth (d_s) and height of opening gate (a) for both bed material; source: own study

locity condition. That is condition in which the ability of the bed material to settle is greater than the flow velocity. For the lower height opening gate position, the flow rate increasing.

Enhancement the flow velocity will move the bed material so as to shear, moving and even jumping that cause develop the hole of scour. It because of the ability of the bed material to settle is smaller than the flow velocity. As shown at Figure 7. The same trend condition applies for both types of bed material. For the smaller discharge, the opening gate variation not to much compare with greater discharge. Its affect the collected data for the smaller discharge is less than anther. So that the discussion for the smaller discharge is not raise.

As shown on Figure 8a, by increasing the opening gate at the same discharge for the both type of material that there is a significant relationship between opening gate to scour depth. It shown as a coefficient determination $R^2 = 0.9774$ for sandy loam material and 0.9778 for loamy sand. This indicates that the opening gate is very affect changes in the depth of scours.

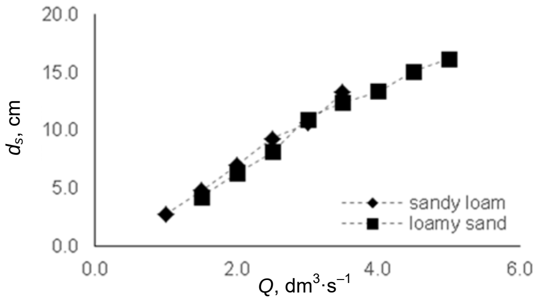

Fig. 7. Scour depth (d_s) and discharge (Q) for both material in 0.5 cm opening height; source: own study

The same condition as shown on Figure 8b, by increasing the discharge at the same opening gate the depth of scouring increasing. This is shown as coefficient determination $R^2 = 0.9965$ for sandy loam and 0.9818 for loamy sand. This is also shown that the discharge has a significant affect to scour depth. The discharge and opening gate as a independent variable that affect the another variable such as velocity along the open channel, water level in upstream and downstream of sluice gate, water depth upstream and downstream of the channel. The same condition n for the both of the bed material. This indicates that the type of soil also affect the scour depths. The basic equation that represent of scouring depth based on the influence of the opening gate and discharge is shown as below:

$$\frac{d_s}{a} = 1.7822\left(\frac{Q}{a}\right)^{1.1347} \quad \text{for sandy loam} \tag{3}$$

$$\frac{d_s}{a} = 1.801 Fr^{1.290} \quad \text{for loamy sand} \tag{4}$$

Where as Fr is the Froude number that a function of discharge, gravity acceleration and velocity. The above equation could be predict the scour depth based on opening gate and the discharge. The comparison showed that the result of the experiment have a good precision with earlier researcher.

The scour length for the both type of bed material could be seen at Figure 9. As the same condition to the scour depth, that increasing the height of opening gate for the desire discharge the length of scour decreasing. It because when the opening gate at the same discharge, the turbulence velocity occur under the gate. With the high velocity the grain of sediment material start to moves, rolling and even jumping. The movement of sediment occur the scour hole. Material sediment around the hole will bring the smaller grain material away from the downstream flow. So the length of scour occur. Increasing velocity under the gate occur the scour hole deeper and length of scour longer towards downstream. Otherwise, the decreasing of velocity under the gate occur is shallower of scour hole and decreasing the length of scour. The same condition for the both of the type of material. The loamy sand has a deeper scour hole and length. As illustrated in the Figure 10 and 11, the loamy sand has a clay composition less than the sandy loam type. The strength among the grain sediment material is

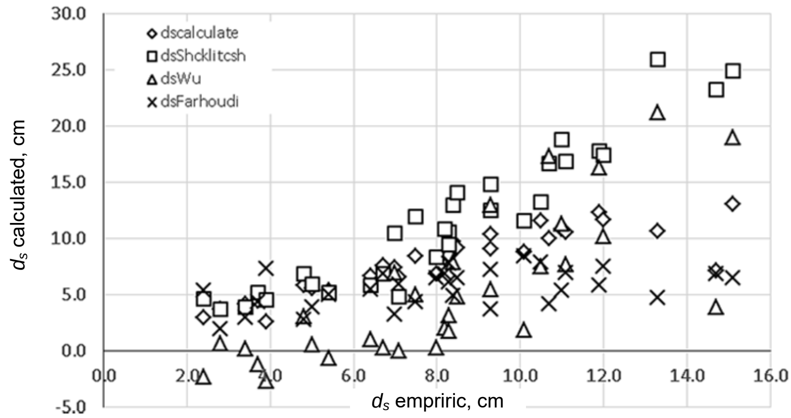

Fig. 8. Comparison between calculated depth of scour (d_s) and experimental given by earlier researcher; source: own study

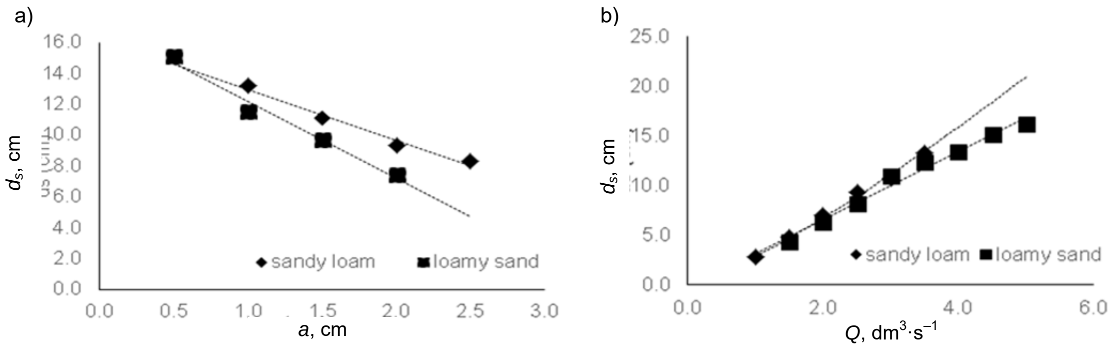

Fig. 9. The coefficients correlation *a* (a) and Q (b) to scour depth (d_s); source: own study

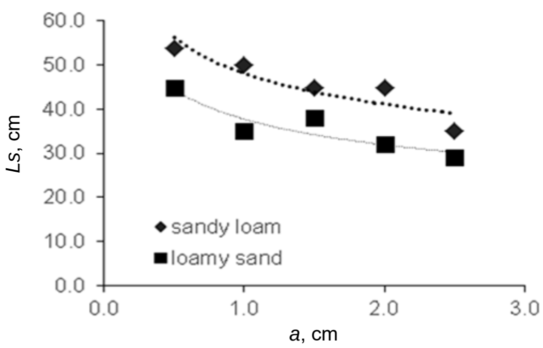

Fig. 10. Length of scour depth and height of opening gate for both bed material; source: own study

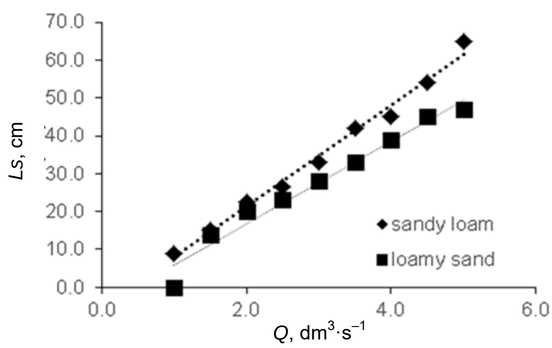

Fig. 11. Length of scour depth and discharge for both bed material; source: own study

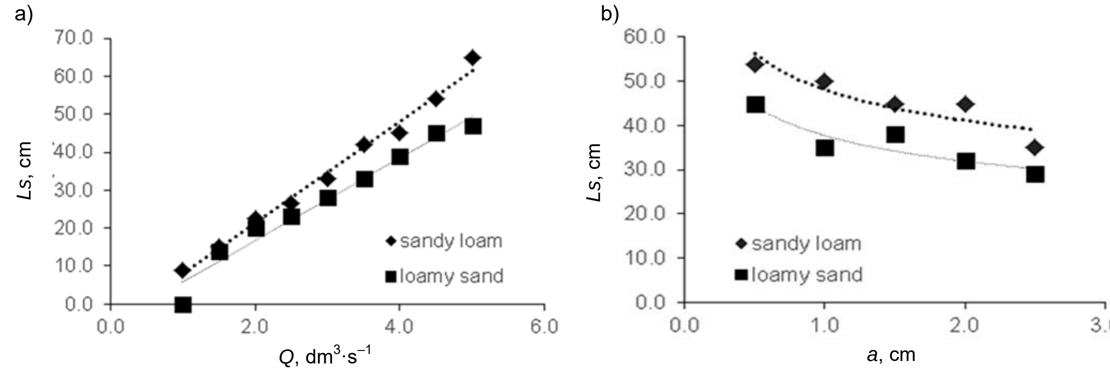

Fig. 12. Coefficients correlation discharge Q (a) and *a* (b) to scour length (*Ls*); source: own study

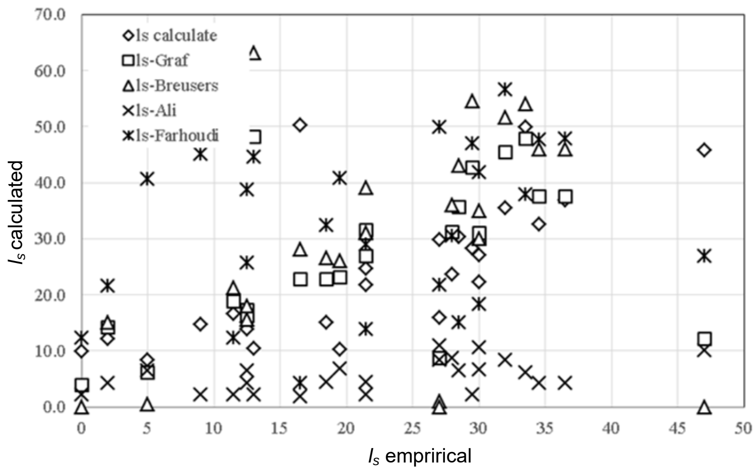

Fig. 13. Comparison between calculated depth of scour (d_s) and experimental given by earlier researcher; source: own study

lower thus the resistance of flow fluctuation is lower too. This resulted the grain of sediment material more easily transported and develop the scour hole deeper and longer and vice versa.

As shown at Figure 12a, by increasing discharge at the same opening gate for the both type of material that there is a significant relationship between discharge to scour depth. It shown as a coefficient determination R^2 = 0.9887 for sandy loam material and 0.9678 for loamy sand. This indicates that the discharge is very affect changes in the depth of scours. The same condition as shown on Figure 12b, by increasing the opening gate at the same discharge the depth of scouring increasing. This is shown as coefficient determination R^2 = 0.7744 for sandy loam and 0.8357 for loamy sand. This is also shown that the discharge has a significant effect to scour depth. The discharge and opening gate as a independent variable that affect the another variable such as velocity along the open channel, water level in upstream and downstream of sluice gate, water depth upstream and downstream of the channel. The same condition for the both of the bed material. This indicates that the type of soil also affect the scour depths. The basic equation that represent of scouring depth based on the influence of the discharge is shown as below:

$$\frac{l_s}{a} = 8.7036\left(\frac{y_3}{a}\right)^{1.0785} \quad \text{for sandy loam} \quad (5)$$

$$\frac{l_s}{a} = 12.2133\frac{y_3}{a} - 9.4682 \quad \text{for loamy sand} \quad (6)$$

This result of experimental was compared to results of another researcher (Fig. 13).

This relationship applies for both type of sediment bed material. The loamy sand has a scour length shorter than the sandy loam material. The sediment material more porous when sand composition dominated. The more dominant sand fraction the smaller resistance of soil strength, and vice versa. Others researcher reported the influence of materials [MINATTI *et al.* 2010]. Fine, coarse sand and gravel could be easily be extended to cohesive soils provided id related to the erosion resistance parameters. The main disadvantage with using non cohesive materials is that while the scour depth may be correct, the extend of the scour hole is much greater than would occur in rock [WHITTAKES, SCHLEISS 1984].

Land ease penetrated depends on the porous space is formed among the soil particles. Density of particle porosity determine the simplicity of circulating water and air [FOTH 1984]. The result of the experimental investigation showed that the loamy sand bed material is more resistant to flow fluctuation turbulence. The scour characteristics of loamy sand bed material is more deeper and shorter than the sandy loam bed material. Beside the affect of the discharge and height of opening gate.

CONCLUSIONS

This research analysis the scour geometry at the downstream of sluice gate under two kind of bed materials. The test were conducted at clear water conditions. Ninety running process were tested under different discharge and height of opening gate. Based on the experimental result, some regression relationships were suggested to estimate the temporal characteristics dimensions of scour hole.

Result obtained from this experiments show that in the case of the height of opening gate at the same discharge increases, the scour depth is decreased. This is due to the fact that opening gate as a device that decrease velocity and then changes flow condition from subcritical flow to super critical flow. So fluctuating velocity would be change the bed material to moving, rolling and jumping. Second, the changes of flow condition will decrease with increasing the height of opening gate. Similarly, the increase in the discharge at the same height of opening gate will increasing the scour characteristics even the depth or length. The high velocity will be form the scour hole first and then the particle of sediment bed material moving to downstream of the channel. The increasing movement occur the length of the scour along the open channel. Third, the two type of sediment bed material has a differences degree of scour characteristics. It because the differences of percentage content of each type. The loamy sand bed material more porous when sand composition dominated. The more dominant sand fraction the smaller resistance of soil strength.

For the further research, it should add some type of sandy clay bed material to obtain more complete and comprehenship the scouring characteristics. And also in addition the shorter interval of gate opening high with the higher gate opening range. So as increasing the ratio of gate opening and discharge more variated.

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Wpływ piaszczysto-gliniastego materiału podłoża na lokalne rozmycie koryta

STRESZCZENIE

Wrota śluzy o prostym kształcie i wyjątkowej zdolności do przemywania osadu są urządzeniem do kontrolowania poziomu wody powyżej śluzy. Ważnym procesem jest sposób operowania wrotami. Ruch wrót w górę i w dół wpływa na szybkość przepływu i powoduje lokalne rozmycie dna. W badaniach prezentowanych w niniejszej pracy oceniano efekt odpływu i zmiennej wysokości otwarcia wrót oraz typu materiału podłoża na głębokość rozmycia (d_s). Badania prowadzono na modelowym, otwartym kanale przepływowym z wrotami śluzy o ruchu pionowym. Zastosowano 9 prędkości przepływu – od 1,0 do 5,0 $dm^3 \cdot s^{-1}$ i 5 wysokości otwarcia śluzy – od 0,5 do 2,5 cm w przedziałach co 0,5 cm oraz różne typy materiału podłoża. Wyniki badań dowiodły, że głębokość rozmycia można analizować jako funkcję odpływu, wysokości otwarcia śluzy, wysokości poziomu wody powyżej i poniżej śluzy oraz typu użytego podłoża. Otrzymane równanie głębokości rozmycia ma postać $d_s = 1{,}7822(\frac{Q}{a})^{1{,}1347} a$. Obliczony współczynnik determinacji dla zależności głębokości rozmycia od dwóch typów materiału podłoża wynosił $R^2 = 0{,}946$. Można zatem wnioskować, że równanie może być stosowane do obydwu typów podłoża.

Słowa kluczowe: *głębokość rozmycia, piaszczysto-gliniasty materiał podłoża, wrota śluzy*