Aerator Performance Effectiveness to.pdf

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Aerator Performance Effectiveness to Prevent Cavitation in Steep Channel

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***Abstract*—The incoming air from the atmosphere into the water flow which reaches the bed of the flow > 7% can prevent the cavitation at the bed of the chute spillway channel. At the time of the concentration of air bubbles in the bed flow cannot naturally reach 7 %, then aerator is required at the bottom of the channel, so that the concentration is increased to > 7%.The purpose of this study was to test the aerator effectiveness in increasing the concentration of air bubbles at the bottom of a steep channel. This study used steep channel whose length is 10 m, width 0.2 m, and height 0.4 m, while slope of steep channel is 20º and25º.The discharge is 20.9 l/s.A set of video cameras was used to take a picture of the movement of air bubbles. A Sony ED210 CCTV whose specifications are: indoor, 1/3 "color CCD, 540 TVL resolution, 0.1 lux was used for documentation purpose. The analysis of air bubbles was conducted using aUlead Video Studio 11 equipped with a ImageJ software version 1.43. The results of this study was on the slope of steep channel bed α = 25°, and Q = 20.9 l/s, at a point 7.2 m from the inlet flume on the condition of artificial air entrainment in the downstream flow region after the first aerator was installed, new aerator unit is not required.**

Keyword-Aerator performance, Cavitation prevention, Steep channel, The concentration of air bubbles, ImageJ software version 1.43

I. INTRODUCTION

A. *Self AirEntrainment*

The hydraulic conditions in the spillway construction involve four flow regimes, namely (a) the subcritical flow, which is when the flow approaches the spillway construction; (b) the critical flow, which is when the flow passes through the crest; (c) the supercritical flow, which is when the flow is in the downstream of slope channel; and (d) the critical flow, which is when the flow is at the tip end of the slope channel [1].

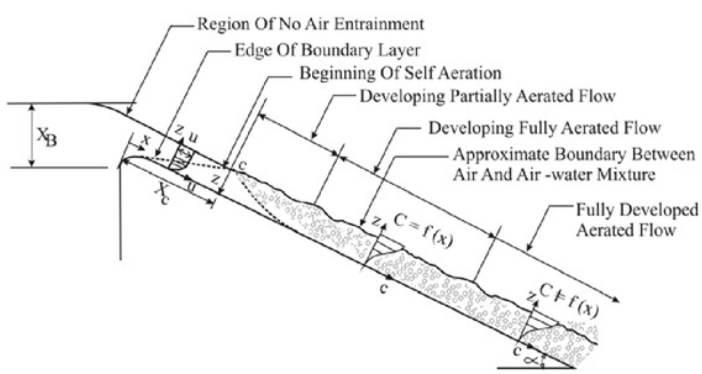

Fig. 1. The aeration along the spillway (Falvey, 1990)

Nomenclature:

X_B	:	is The height of pressure over the spillway
A	:	Is The slope of chute spillway channel
d_{ab}	:	Is the absolute error
u'	:	Is the diameter of air bubbles
ρ_w	:	Is the density of water
u_r	:	Is the velocity of air bubbles
C_m	:	Air between surface waves flow
C_t	:	Air concentrations at the bottom of the mixing zone
Z	:	Depth measured from and perpendicular to the surface of the bed flow of streams
C	:	Air concentration
C_e	:	The average air concentration (vertical)
P_g	:	Normal distribution function
K', D'	:	The function of average air concentration C_e
z_t		Depth of transition

According to Borman as quoted by [2], the self air entrainment in spillway construction involves three areas, namely (a) no air entrainment; (b) developing; and (c) fullydeveloped. Supercritical flow that occurs in the slope channel as well as the air entrainment area of no air entrainment and developing is suspected to lead to erosion and cavitation.

B. Equation of Self Air Entrainment

The concentration distribution of air bubbles in the selfair entrainment according to [3] is presented in the following equation. The equation is only valid if the concentration of air bubbles on the surface of a minimum flow of 90%.

$$C = 1 - \tanh^2\left(K' - \frac{z/z90}{2D'}\right) \tag{1}$$

At a concentration of air bubbles on the surface of the flow <90% then other equations, (2) and (3), are used. The equation (2) is used for the underlying zone; while the equation (3) is used for mixing zone. Equation (2) and (3)are presented below.

$$C = C_1\left(\frac{z}{z_t - z}\right)^m \tag{2}$$

$$\frac{1 - C_m}{1 - C_t} = 2\left(1 - P_g\right) \tag{3}$$

C. Artificial Air Entrainment

The erosion in the slope channel can be reduced or eliminated by (a) increasing the high of pressure; (b) increasing the fineness of the bed and walls of slope channel; (c) installing aerationslots; and (d) installing aerators[4]. The effort to improve the fineness of the bed and the channel wall by using a specific material is an expensive step. Chanson [4] suggests that cavitation erosion is reduced or eliminated by installing aeration slots or aerator. The principle of slots aeration or aerator installation is entering the air to the bed of a steep channel, so that the pressure at the base of the channel can be improved.

Chanson [5] has conducted experiments on the spillway model construction made of concrete which showed that the air concentration of 1% to 2% can reduce erosion due to cavitation, while with the air concentration between 5% and 7%, erosion can be stopped totally. Chanson [5] goes on to argue that the air entrainment from the atmosphere into the body flow so as to achieve the basic flow of> 7% can prevent the base of the spillway construction from cavitation.

The types of aerator are deflector or ramp,grooves, and offsets as well as the combination among the three [6].The groove construction is often combined with airduct, so that the air supply to the bed of the flow can be fulfilled. The purpose of installing a deflector is to elevate the flow of boundary layer so that air can enter the bottom or body flow. Aeration grooves, slots or air ducts are used to distribute air across the width of the aerator. Offsets are used in hydraulic structure that has a ramp slope to prevent the reversal of flow towards upstream.

D. Equation of Artificial Air Entrainment

Especially on the flow over the deflector and in aeration zone, there is a flow of upper,lower, and between the two or the point is completely water or C=0. Based on the small control volume, the equation of the air-water flow continuity is as follows.In the condition of upper free surface, the equation isexpressed as follows [5]:

$$\frac{D}{D_t}C = -div\, \vec{q}_{air} \tag{4}$$

It refers to the assumption of fixed flow and $\frac{\partial C}{\partial x} << \frac{\partial C}{\partial z}$, then in the free upper surface is:

$$u\frac{\partial C}{\partial x} + u_r \cos\alpha \frac{\partial C}{\partial z} = D^U + \frac{\partial^2 C}{\partial z^2} \tag{5}$$

The completion of the equation (4) is a Gaussian distribution, as shown below [5].

$$C = \text{erf}\, \frac{z}{\sqrt{2\frac{D^{up}}{u}X\,(1+\frac{u_r}{u}\cos\alpha\,\frac{z}{x})}} \tag{6}$$

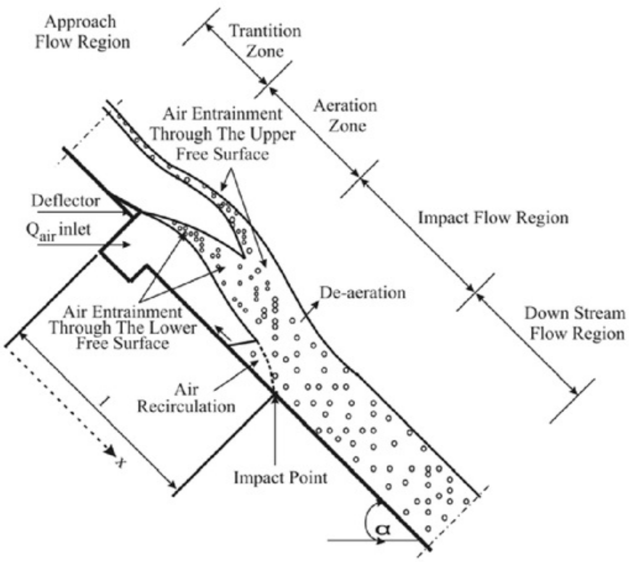

Fig.2. The flow over the deflector and in aeration zone

At the lower free surface conditions, the continuity equation becomes as follows [5].

$$u\frac{\partial C}{\partial x} + C\frac{\partial u}{\partial X} = \frac{\partial}{\partial z}(D\frac{\partial C}{\partial z}) \tag{7}$$

Equation (7) can be written as follows [5].

$$u\frac{\partial C}{\partial x} = \frac{\partial}{\partial z}\{(D+D_0)\frac{\partial C}{\partial z}) \tag{8}$$

The completion of the equation (8) is a Gaussian distribution, as shown below [5].

$$C = 1 - \text{erf}\, \frac{z}{\sqrt{2\frac{D+D^{lo}}{u}x}} \tag{9}$$

Nomenclature:

C	:	is the distribution of airconcentration
C_{tr}	:	Is the theory of distribution airconcentration
E_{abs}	:	Is the absolute error
z_{90}	:	Is the depth of flow where the air concentration is C=90%
l	:	Is measured from the downstream end of the deflector to the impactpoint
x	:	Is measured from the downstream end of the deflector up to the point of the review
g	:	Is the gravitational constant
D^{up}	:	Is the coefficient of turbulent diffusivity in the upperinterface
D^{lo}	:	is the the coefficient of turbulent diffusivity in the lowerinterface
ρ_w	:	is the density of water

The purposes of this study were: (a) to describe the distribution of air bubbles concentration on the condition of artificial water entrainment, (b) to test the aerator effectiveness in increasing the concentration of air bubbles at the bottom of a steep channel; and (c) to explain the need for the number of units aerator which should be installed in steep channels.

II. EXPERIMENTAL METHODS

In this study, a steep channel whose length 10 m, width 0.2 m, height 0.4 m with the slope 25° was used, it was fused with the wall of a water tub. The width of the flume used was 0.2 m. The selection of the basic flume slope of α=25° is based on the following considerations: (a) according to [5], that the definition of a steep channel refers to the scale of $\alpha \geq 20°$, so that α=25° and α=25° was selected; (b) the selection of α=25° is based on the Chow's opinion [7] that a channel is considered to be steep if $\alpha > 6°$. The distribution of water into a tub is carried out with tanks controlled by valves. The dischargeis 20.9 l/s. The instrument such as Thompson(V Notch) is used to calibrate the flow rate. A set of video cameras was used to take a picture of the movement of air bubbles. A Sony ED210 CCTV whose specifications are: indoor, 1/3 "color CCD, 540 TVL resolution, 0.1 lux was used for documentation purpose. The analysis of air bubbles was conducted using aUlead Video Studio 11 equipped with a ImageJ software version 1.43.

Air bubbles were measured at 0,03m from the flume's side wall toward asflume (cross sectional). In the longitudinal direction, air bubbles were measured at X=3.530 m, X=4.530 m, X=6.203 m; as well as X=7.203 m, and 8.703 m. The location of measurement was along the "developing" zone. In the vertical or perpendicular direction, the flows (normal depth) were measured up to 25 categories of class depths, depending on the depth of normal flow.

Flow pressure was measured in the "developing" zone, at four points in the longitudinal direction, i.e. at X=3.530 m in the downstream of the inletflume; X=4.530 m in the downstream of the inletflume; X=6.203 m in the downstream of the inletflume; X=7.203 m in the downstream of the inletflume, all is located at the bed of the flow. The position of the pressure measurement point is in the middle of a cross sectional flow.

The layout of the bottom of the water tank, top of water tank, pumps, guttering, and the hole to measure the pressure are presented in Figure 3.

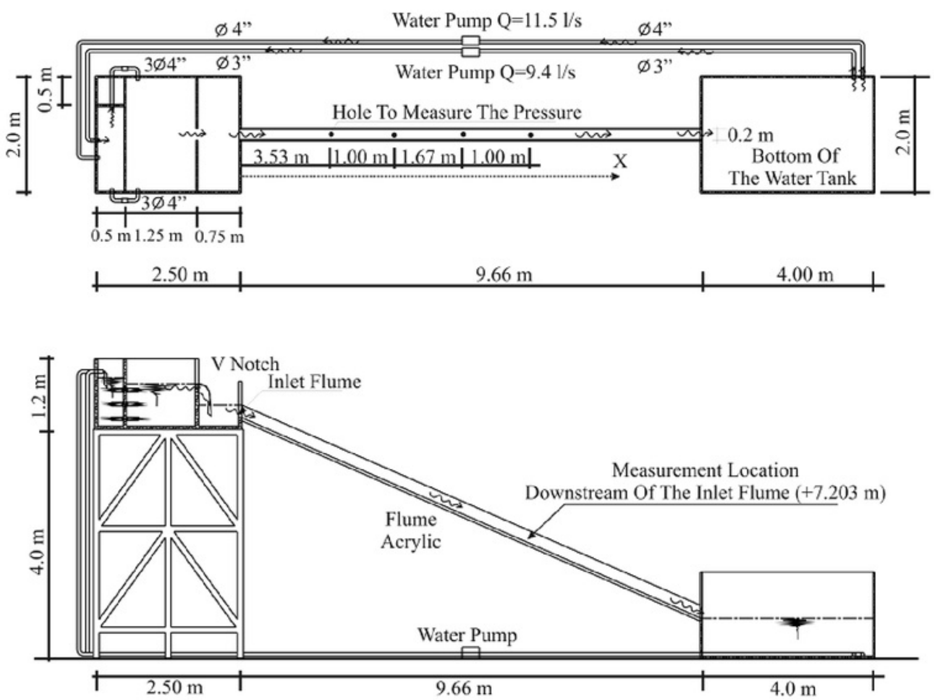

Fig.3. The layout of research tools and instruments

III. RESULTS AND DISCUSSION

A. The Profile of ConcentrationDistribution of AirBubbles on Self Air Entrainment inSteepChannels

1) The Distribution Profile of Air Bubbles Concentration on α = 20Q = 20.9 l/s at a Point 7.2 m from The InletFlume

Based on Figure 4 below, it can be seen that the air bubbles have not reached the bed of the stream. The bubble has reached the bed stream whose concentration is 0.6%. The concentration of air bubbles that spread has not been homogeneous. Furthermore, the concentration of the air bubble has not reached 10% on the bottom, so the occurrence of low pressure or the low cavitation index is still possible. Such conditions could inflict damage for the structure of the steep channel of chute spillway of the dam. Hence, aerator is required [8].

Air bubbles is distributed from 0 mm depth (measured from the bottom and perpendicular to the bottom flow z) up to 31.99 mm. Falvey[2] argues that in conditions such as Figure 4.12, the bottom area is still included in the developing area because the concentration distribution of air bubbles has not spread homogeneously, so it cannot be categorized into a fully developed region. The distribution of air bubbles concentration on the condition of self air entrainment at α = 20°, Q = 20.9 l/s, at a point 7.203 m from the inlet flume, the distribution shape of air bubbles concentration during experiment was close to the [3] than that of [5].

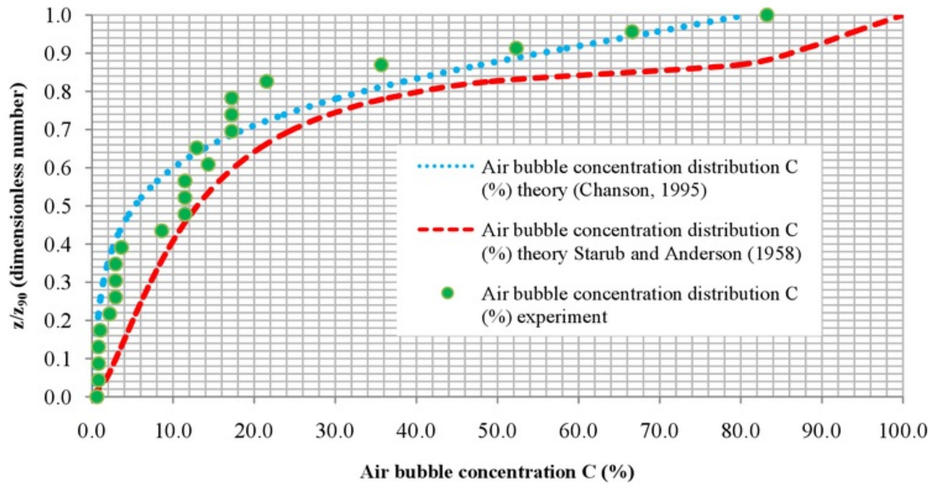

Fig.4.Air bubble concentration on α=20°, Q=20.9 l/s, at the point of7.2 m frominlet flume

2) The Distribution Profile of Air Bubbles Concentration on α = 20Q = 20.9 l / s at a Point 7.2 m from The InletFlume

Based on Figure 5 below, it can be seen that an air bubble has reached the bottom of the flow. The concentration of air bubbles in the depth of the flow (measured from the bottom and perpendicular to the bottom flow z) z = 0 mm is 2.92%. The concentration of air bubbles that spread has not been homogeneous. Furthermore, at the bottom of the depth (measured from the bottom and perpendicular to the base flow z), the concentration of the air bubbles has not reached 10%, so the occurrence of low pressure or the low cavitation index is still possible. Such conditions could inflict damage for the structure of the steep channel of chute spillway of the dam. Hence, aerator is required [8].

Air bubbles are distributed from 0 mm depth (measured from the bottom and perpendicular to the bottom flow z) up to 29.4 mm. Falvey[2] argues that the condition as seen in Figure 5 is still categorized into developing area because the concentration distribution of air bubbles has not spread homogeneously, so it cannot be categorized into a fully developed region. The distribution of air bubbles concentration on the condition of the natural air intake (self air entrainment) at α = 25 °, Q = 20.9 l / s, at a point 7.2 m from the inlet flume, the distribution shape of air bubbles concentration during experiment was close to theory of [5] than that of [3].

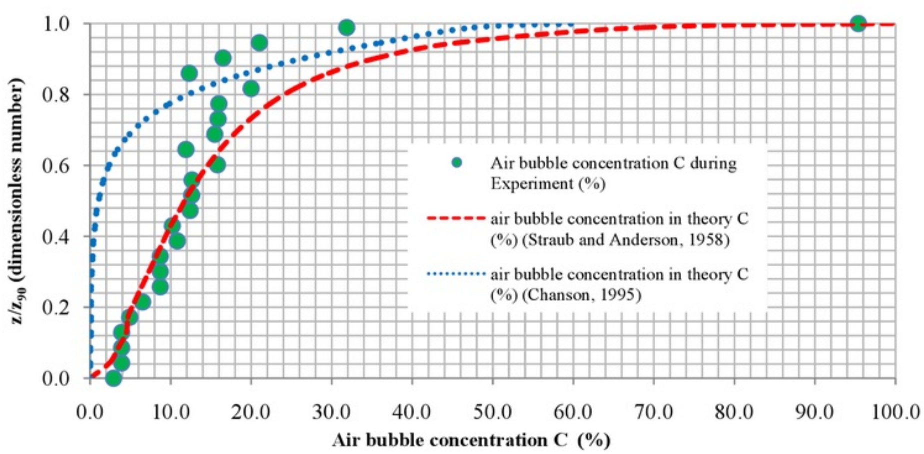

Fig.5.Air bubble concentration on α=25°, Q=20.9 l/s, at the point of 7.2 m frominlet flume

3) The Pressureon Self Air Entrainment Conditions inThe Point 3.5 m, 4.5 m, 6.2 m and 7.2 m in The Downstream of Inlet Flume

Falvey [2] argues that the air entrainment in the no air entrainment and developing area may cause cavitation. This assumption is supported by [8] that cavitation occurs in areas where the pressure is low as well as in areas where air bubbles have not touched the bottom of streams or in the *developing* area. According to [5] the minimum Froude number which is taken into consideration in the installation of the first aerator is 7.0. According to [9] the minimum Froude number which is taken into consideration in the installation of the first aerator is 6.0.Pressure in four point of downstream inlet flume Q= 20.9 l/s and α= 25°presented in Table I.

TABLEI. The pressures at four points in the downstream of the inlet flume Q=20.9 l/s and α=25°

Measurement Position	**ρ_w(kg/m^3)**	**g (m/s^2)**	**h *pressure head* (m)**	**p(Pressure in the bed of the channel N/m^2)**	**u (the flow velocity) m/s; and Froude number)**
7.2 m in the downstream of inlet flume	998.228	9.81	0.0262	256.5	3.63/6.8
6.2 m in the downstream of inlet flume	998.228	9.81	0.0265	259.2	3.59/6.7
4.5 m in the downstream of inlet flume	998.228	9.81	0.0271	265.4	3.56/6.6
3.5 m in the downstream of inlet flume	998.228	9.81	0.0279	273.4	3.52/6.5

B. Aerator Draft (a combination betweendeflector,duct, andairduct) to Prevent the Damage of Cavitation

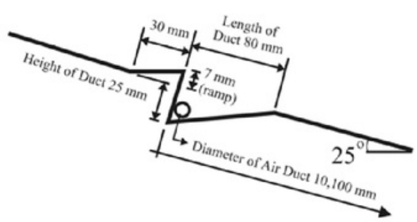

Fig.6.Aerator dimension (combination between deflectors, duct and air duct) the result of research design

The ramp height measured from the flume bed is 7 mm. The slope of ramp to the bottom slope of the flume is 10°. Thus the ramp length is 30 mm. This groove aerator shape is a triangle, while its size is, the length=80 mm, and the inside=25 mm. The air duct shape is a circle, while the size of its diameter is 10 mm. The aerator which is the result of this research design is presented in Figure 6.

C. The Profile of ConcentrationDistribution of AirBubbles on ArtificialAirEntrainment in SteepChannels

Based on the study results as presented in Table I above, and by considering experts' opinion regarding the minimum Froude number above, the aerator can be installed on the point of 7.2 m in the downstream of the inlet flume with bottom slope of the flume of 25°, and Q=20.9 l/s due to Froude number of 6.8. On the other point and other slope of the flume, installation of aerator is not required. Therefore, the aerator draft is based on the above parameters, namely point 7.2 m in the downstream of the inlet flume on the bottom slope of flume of 25°, Q=20.9 l/s and u=3.63 m/s. Thus the data analysis and discussion of the results of research on the condition of artificial air entrainment will only choose the slope channel of 25° only.

1) The profile of concentration distribution of air bubbles at α=25°, Q=20.9 l/s at point 7.2 m from theinlet flumeinfree surface aerationexactly in x/l=0.50

The profile of distribution of air bubbles in the area of free surface aeration is in form like a tongue of water (C=0%) between the air bubble+water (C>0%). In this area it was divided into four sections, namely (a) the depth of between 0 mm to 10 mm is air; (b) the depth of between 10.5 mm to 20.9 mm are air bubbles+water

(C>0%); (c) The depth of between 21 mm to 27.2 mm is actually water (C=0%) which is called as "tongue of water"; but in this case because of the leap of bubbles then it still contains air bubbles; and (d) the depth of between 28.14 mm to 42.21 mm is air+water (C>0%). x is the point review of air concentration distribution. x is measured from the downstream end of the deflector up to the point of the review. l is the end point of leap of stream which is commonly called impactpoint. l is measured from the downstream end of the deflector to the impactpoint. x/l is the ratio between x and l which is within the range of free surface aeration. In this case x=0.06 m and l=0.12 m so that the x/l=0.50, the distribution profile appears as "the tongue of water" and is analysed is located in the middle of a long leap of "tongue of water" [10].

Based on Figure 7, it appears that the value of the mean of absolute error($\bar{E}_{abs}$)of the concentration of air bubbles of C experiments on the concentration of air bubble according to Chanson's theory [3] is 24%. The Standard Deviationofabsolute error(E_{abs}) ofair bubble concentration of C experiments on the concentration of air bubble according Chanson's theory [3] is 19.57%.

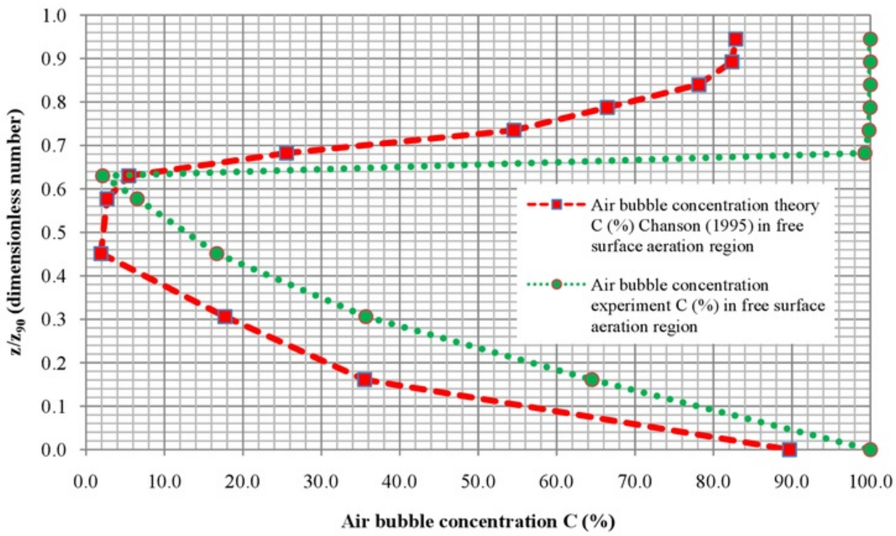

Fig.7. The distribution of concentration of air bubbles at α=25°, Q=20.9 l/s at point 7.2 m from the inlet flume in free surface aeration exactly in the x/l=0.50

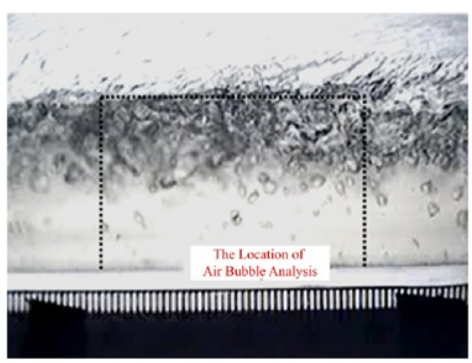

Fig.8. Profile of concentration distribution of air bubbles before aerator is installed

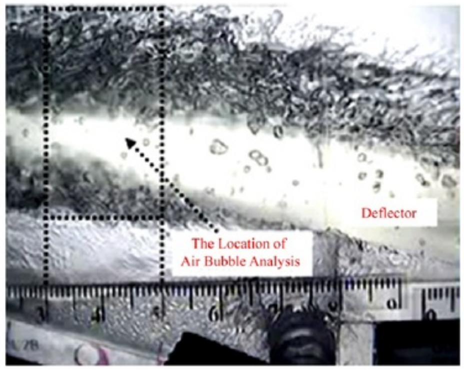

Fig.9. Profile of concentration distribution of air bubbles after aerator is installed

2) The Profiles of Concentration Distribution of Air Bubbles at α=25°, Q=20.9 l/sat Point 8.7 mfrom TheInlet FlumeinDownstream Flow Region

Based on Figure 10, below is the cross section whose distance is 8.7 m from the downstream of the inlet flume, it appears that the distribution of air bubbles concentration begins at the depth (measured from and perpendicular to the base flow) 0 mm to 71.4 mm. The lowest value of concentration is 59.21% and the highest value is 96.45%. The range of concentration value is 37.25%. The value of the average concentration of air bubbles is 87.82%, the standard deviation value is 9%, and the value of the variance is 81%. Referring to the values $(\bar{X})$ of the above statistics, it can be concluded that the distribution of air bubbles concentration in the region, the form of the distribution is not rectangular [10]. According to [5], the downstream region of the aerator is divided into four categories namely the aeration zone, impact point zone, downstream flow region, and equilibrium flow region. Referring to the above description, the distribution of air bubbles concentration is not in the form of rectangular or also known as inhomogeneous, so that it can be concluded that this region is included into downstream flow region.

According to [8], the installation of the new aerator after the first aerator is installed, if the concentration of air bubbles C (%) in the bottom of the downstream flow aerator in the region is at least 10%. In addition to [8], Falvey [6] argues that if the concentration of the air bubbles at the bed of chute spillway is greater than 0.10, or 10%, then the additional aerator is unnecessary. Therefore, at the slope of the steep channel α=25°, and Q=20.9 l/s, new and additional aerator iis unnecessary after the first aerator is installed. According [11], the slope of flume bottom ≥20°, the average value of the air bubbles concentration typically has reached 30%, and the concentration of air bubbles near the bed of the stream has already reached more than 8%, then the bed surface and side of the stream has been protected from damage due to cavitation. In such conditions mentioned above, then at the remaining length of the chute spillways on the side of downstream aerator, an additional aerator is not needed [11]. The results of this study are in accordance with the facts on the field, namely (a) on the Laiban dam in Philippines that the first installation of aerator is 180 m from spillway crest, whose basic inclination is (α) of 20.3°; (b) in the Cholbun dam in Chile, the first installation of aerator is 165 m from spillway crest, whose basic inclination(α) of 27.1°; and (c) in the San Roque Dam in the Philippines, the first installation of aerator is 165 m from the spillway crest, whose basic inclination is (α) of 14° [11]. The installation of aerator in a location 7.2 m downstream of the inlet flume is helpful to prevent the occurrence of cavitation, because the concentration of air bubbles in the base stream reaches 59.41%. This finding is consistent with the opinion of Peterka which states that air bubbles have reached the bottom of the channel to prevent damage due to cavitation, and according to Chanson, 5-7% air bubble concentration which has reached the bottom of a steep channel can prevent damage due to cavitation [9]. Based on these results, the installation of aerators in the chute spillway channel at the dam in Wadaslintang in Wonosobo regency are too many. The number of Aerator installed in the dams in Wadaslintang in Wonosobo should be one unit only, because the estimated concentration of air bubbles at the base and at the end of downstream of the chute channel remains at > 10% [12].

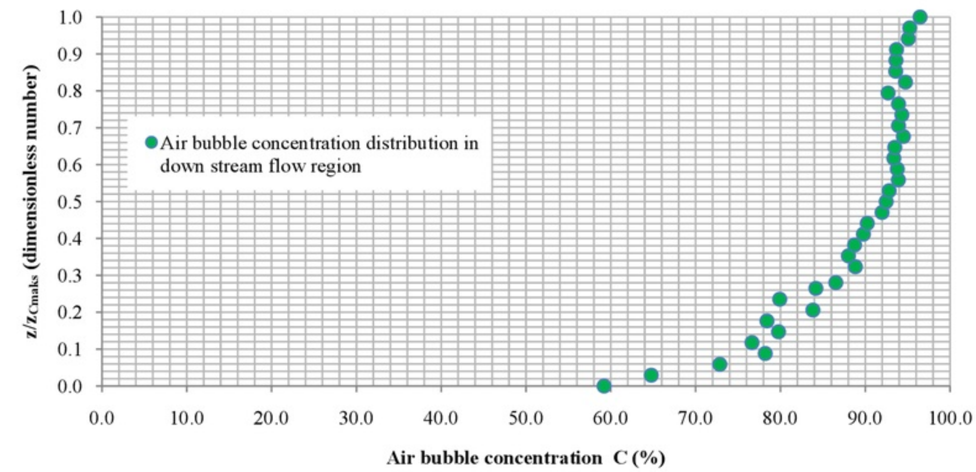

Fig.10. Distribution of air bubble concentration C (%) experiment in the downstream flow region at α=25°, Q=20.9 l/s

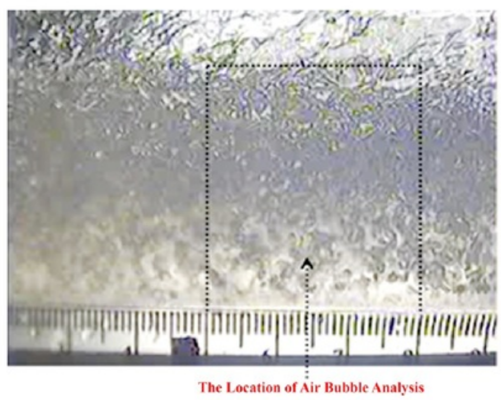

Fig.11. Profile of concentration distribution after the air bubble aerator installed in the downstream flow region at α=25°, Q=20.9 l/s

IV. Conclusion and Suggestion

A. Conclusions

First, at Q=20.9 l/s and the slope of the bed flow α=25°, the aerator can be installed in cross section of 7.2 m in the downstream of the inlet flume research, because (a) the parameter of air bubbles concentration in the bottom of the channel is 3% and is still less than 7% or the possibility of cavitations is still very great; (b) the Froude number has already reached the minimum threshold requirement of aerator installation which is 6.8 and is already in the range of (6-7); and (c) the cross section of 7.2 m has a pressure lower than in the cross section of 6.2 m which is (256.5 N/m^2<259.2 N/m^2);

Second, the equation proposed by Chanson which states that the distribution of air bubbles concentration C (%) in the area of free surface aeration downstream aerator is normal or Gaussian supported by the results of research, so that this equation does not need to be modified;

Third, the distribution shape of air bubbles concentration C (%) at cross section of +8.7 m from downstream aerator is not homogeneous. On the base of the flow, the concentration of the air bubbles is smaller than in the central part and the surface of the stream. Air bubble concentration distribution C (%) in this region tends to be trapezoid. Thus, this area can be referred to as the downstream flow region;

Fourth, at the slope of the bed of steep channel basis α=25°, and Q=20.9 l/s, at a point 7.2 m from the inlet flume on the condition artificial air entrainment in the downstream flow after first aerator is installed, a new aerator is not necessary. In addition, the installation of aerator in a location 7.2 m from the downstream of the inlet flume is helpful to prevent the occurrence of cavitation, because the concentration of air bubbles in the bottom stream reaches 59.4% greater than 10%.

B. Suggestion

Based on these results and conclusions, the number of aerators in the chute spillway channel at the dam in Wadaslintang in Wonosobo regency is redundant. The number of Aerator installed in the dams in Wadaslintang in Wonosobo should be one unit only, because the estimated concentrations of air bubbles at the base and at the end of downstream of the chute channel remains at > 10%.

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