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Self and artificial air entrainment in steep channel

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Abstract

High flow velocity causes a low pressure even negative, especially in steep channel bed. Force caused by negative pressure will lift the bed surface and side walls of the building hydraulic structures, which can lead to flaking on the bed surface and side walls of the building. In supercritical flow, air from the atmosphere enters into the body even reach the bed flow. Air entrainment enters into the body and bed flow can prevent or reduce the phenomenon of cavitation in channels bed. The purposes of this study were: (a) describe concentration distribution of air bubbles in the developing regions of the self air entrainment; (b) describe concentration distribution of air bubbles in the artificial air entrainment; and (c) aerator effectiveness test in increasing air bubble concentration in the steep channel bed. Three purposes of research were achieved using experimental methods implemented in the Hydraulics Laboratory of the Department of Civil and Environmental Engineering (JTSL), Faculty of Engineering, Gadjah Mada University (UGM). In this study, the steep channel having a length of 10 m, width 0.2 m, height 0.4 m with slope varies from 20°, and 25°, which was fused with the wall of the water tank. Discharge was 20.9 l/s. The conclusion of this research were: (a) the concentration distribution of air bubbles on the condition of self-air entrainment in slope channel bed 25° and discharge=20.9 l/s can be predicted using the results of the calculation equation Straub and Anderson (1958) modification; (b) the concentration distribution of artificial air entrainment on the slope of the channel bed=25° at a point 7.2 m from the inlet flume and in the free surface aeration, was the Gaussian or normal, and (c) on the slope of the channel bed=25°, 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 installed a new aerator is not required anymore.

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Keywords: self and artificial air entrainment; Concentration distribution of air bubbles; steep channel.

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1. Introduction

The hydraulic conditions in the spillway involves four flow regimes, namely (a) the subcritical flow, when the flow is approaching the spillway; (b) the flow of critic at the time of passing the peak (crest); (c) the supercritical flow of downstream slope channel (crest); and (d) the critical flow at the tip end of the slope channel [1]. According to Borman as quoted by [2], regime air entrainment in spillway naturally involves three areas, namely (a) no air entrainment; (b) developing; and (c) fully developed. Supercritical flow that occurs in the slope channel as well as the no air entrainment and developing air entrainment area are supposed to lead to erosion and cavitation. This supposition is supported by [3] that erosion occurs in areas where the low pressure as well as in areas where air bubbles have not touched the bottom of the channel or in the developing area.

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

The purposes of this study were: (a) describe concentration distribution of air bubbles in the developing regions of the self-air entrainment; (b) describe concentration distribution of air bubbles in the artificial air entrainment; and (c) aerator effectiveness test in increasing air bubble concentration in the steep channel bed.

1.1. Self air entrainment

According to [4] the air entrainment processes occur due to fluctuations in the turbulent flow velocity of u is fast enough to overcome the surface tension. In addition, the fluctuations in the turbulent flow velocity of u have been greater than the velocity of air bubbles components. The process of *self-aeration* is presented in Fig. 1 below.

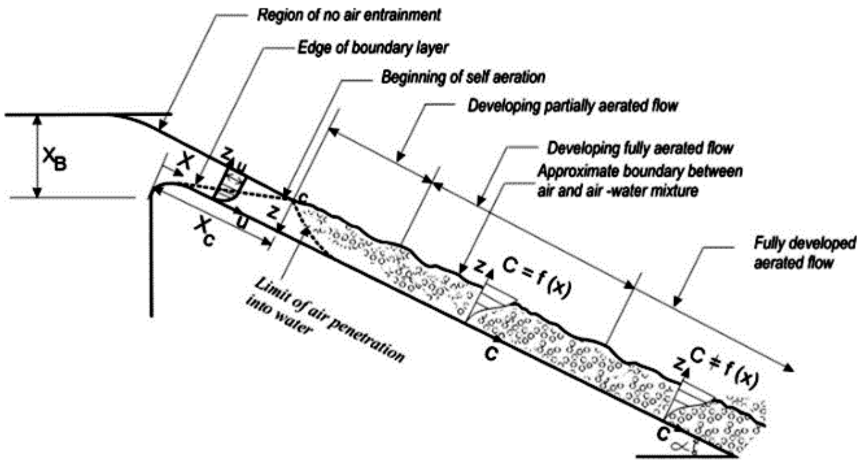

Fig. 1. The aeration along the spillway [5].

The concentration distribution of air bubbles in the self air entrainment according to [6] as presented below. The equation is only valid if the concentration of air bubbles on the surface of a minimum flow of 90%.

$$C = 1 - \tanh^2\left(K' - \frac{z/z_{90}}{2D'}\right) \quad (1)$$

At a concentration of air bubbles on the surface of the flow <90% then another equation are used which are (2) and (3). 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.

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

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

Where:

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
z_t	Depth of transition
C	Air Concentration
K', D'	The function of average air concentration C_e
C_e	The average air concentration (vertical
P_g	Normal distribution function

1.2. Artificial air entrainment

The flows above the deflector and in the aeration zone consist of a flow of upper, lower, and between the two or the point is completely water or C=0. At the upper free surface conditions, the continuity equation becomes as follows:

$$C = \mathrm{erf} \frac{z}{\sqrt{2 \frac{D^{up}}{u} X (1 + \frac{u_r}{u} \cos\alpha \frac{z}{x})}} \tag{4}$$

At the lower free surface conditions, the continuity equation becomes as follows:

$$C = 1 - \mathrm{erf} \frac{z}{\sqrt{2 \frac{D + D^{lo}}{u} x}} \tag{5}$$

Where:

D	The coefficient of turbulent diffusivity
D^{up}	The coefficient of turbulent diffusivity in the upper interface
x	The distance measured from the beginning of the boundary layer to the downstream channel
D^{lo}	The coefficient of turbulent diffusivity in the lower interface

2. Method

In this experiment, steep channel which is used has 10 m long, 0.2 m wide, 0.4 m high with a basic slope channel of 20° and 25°. The steep channel is joined into the wall in a water tub. The distribution of water into the tub carried from the tank which is controlled by the valve. The flow rate is 20.9 l/s. A set of video camera is used to take the picture the air bubbles movement. The air bubble was analyzed using a software program called Ulead Video Studio 11 which is equipped with the ImageJ software.

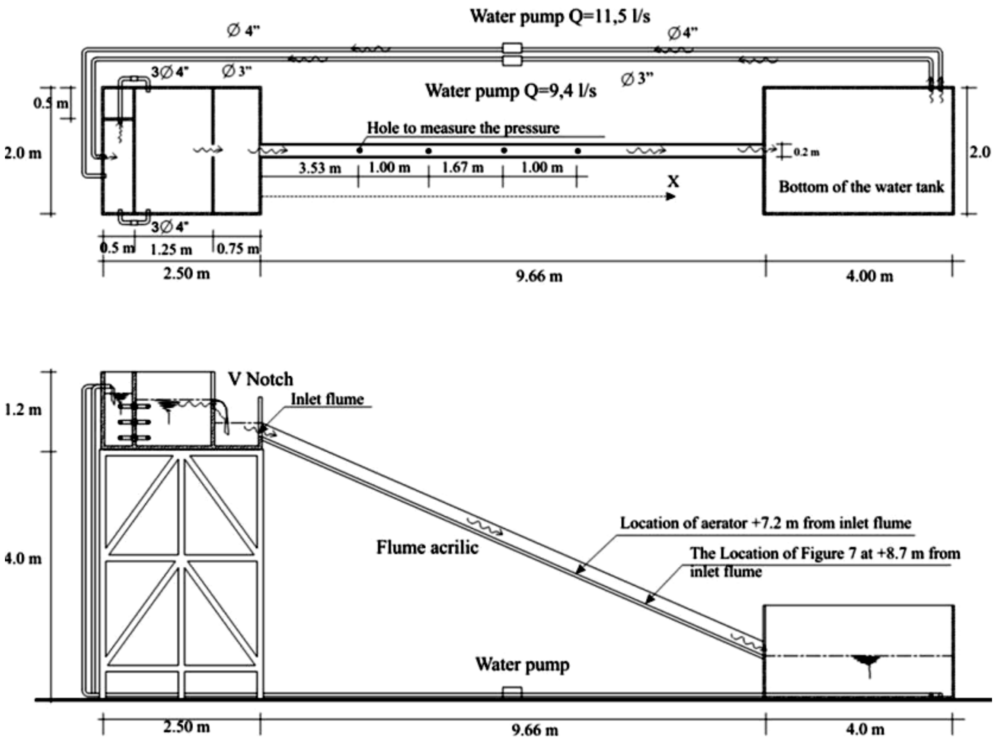

Fig. 2. The layout of the tools and instruments of research.

The air bubbles were measured at 3 cm from the side wall toward the flume as guttering (cross-sectional). In the longitudinal direction, air bubbles are measured on a piece of x=93 cm; 248 cm; 298 cm; 366 cm; 418 cm from the inlet flume; and x=572.1 cm; 608.1 cm; 620.3 cm; 720.3 cm; and 870.3 cm from the inlet flume. The location of measurement is along the developing zone. In the vertical direction or perpendicular to the flow (normal depth) it was measured up to 25 categories or classes of depth, it depends on the depth of the normal flow.

The flow pressure is measured in the developing zone, at four points in the longitudinal direction, i.e. at x=3.530 m in the downstream of the inlet flume; x=4.530 m in the downstream of the inlet flume; x=6.203 m in the downstream of the inlet flume; x=7.203 m in the downstream of the inlet flume, all is located at the bed of the flow. The location of the pressure measurement point is in the middle of the flow (as of flume). The layout of the bottom of the water tank, top of the water tank, pumps, flume, as well as holes for measuring the pressure at the bottom of the flow is presented in Fig. 2.

3. The results and discussion

3.1. Profiles of concentration distribution of air bubbles in α=20°, Q=20.9 l/s at the point of 7.2 m of the inlet flume, the Froude number=5.8, on condition of self air water entrainment

Based on Fig. 3, it can be said that the air bubbles have not reached the bottom of the flow. The bubble has reached a bed flow of a concentration of 0.6%. The air bubbles were distributed from the depth of 0 mm (measured from the base and perpendicular to the base flow of z) to 31.99 mm. Falvey [2] states that the condition as in Fig. 3 below is still included in the developing zone because of the concentration distribution of the air bubbles have not spread in homogenously, so that it cannot be categorized into a fully developed zone.

The concentration of air bubbles on the surface of the flow of 97.29%. This value has reached 90%, so it can be made a dimensionless curve which requires z_{90} or the concentration at normal depth one has a value of 90%. Therefore, in this case it can be compared with the proposed equation (1) at the same time can also be compared with the equation (2) and (3), as presented in Fig. 3.

The concentration of air bubbles that spread is not homogeneous yet, in addition, in the bottom of the normal depth, the air bubbles concentration have not reached 10%, so it is still possible the case of low pressure or the occurrence of cavitation index lower. Such conditions are still very harmful to the structure of the channel or steep channels of the dam. Hence, aerator remains necessary [9].

The concentration distribution of air bubbles on the condition of the self air entrainment at α=20°, Q=20.9 l/s, in the point of 7.203 m from the inlet flume, the concentration distribution of air bubbles form more experimental approach theory [6] than the theory [7].

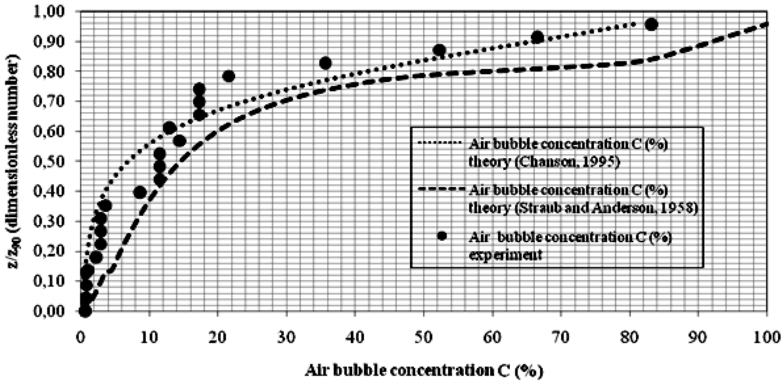

Fig. 3. The concentration of air bubbles at α=20°, Q=20.9 l/s, at the point of 7, 2 m of the inlet flume.

3.2. Profile of the concentration distribution of air bubbles at α=25°, Q=20.9 l/s at the point of 7.2 m from the inlet flume, the Froude number=7.1, on condition of self-air entrainment

Based on Fig. 4, it can be said that the air bubble has reached the basic flow. The concentration of air bubbles in depth (measured from the base and perpendicular to the base flow of z) z flow=0 mm is 2.92%. The air bubbles were distributed from 0 mm depth (measured from the base and perpendicular to the base flow of z) up to 29.4 mm. Falvey [2] states that the condition as in Fig. 4 is still included in the developing zone because of the concentration distribution of the air bubbles have not spread homogenously, so that it cannot be categorized into a fully developed zone.

The concentration of air bubbles on the surface of the flow is of 95.39%. This value has reached 90%, so it can be made dimensionless curve which requires $z_{90.}$ Therefore, in this case it can be compared with the proposed equation [6]; it can also be compared with the equation [7], as presented in Fig. 4.

The concentration of air bubbles that spread is not homogeneous. In addition, at the bottom of the depth (measured from the base and perpendicular to the base flow of z) the air bubbles concentrations have not reached 10%, so it is still possible the case of low pressure or the occurrence of cavitation index lower. Such conditions are still very harmful to the structure of the steep channel or slope channels dam. Hence, aerator remains necessary [9].

The concentration distribution of air bubbles on the condition of self air entrainment at α=25°, Q=20.9 l/s, in point of 7.2 m from the inlet flume, the concentration distribution of air bubbles experimental form more approach theory [7] than the theory [6].

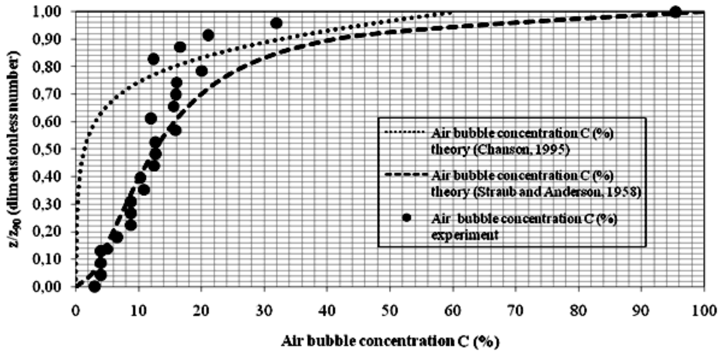

Fig. 4. The concentration of air bubbles at α=25°, Q=20.9 l/s, at the cross section of 7.2 m from the inlet flume.

3.3. Profile of distribution of concentrations of air bubbles at α=25°, Q=20.9 l/s at the point of 7.2 m from the inlet flume in free surface aeration precisely in x"/l=0.50

The form of profile of distribution of air bubbles in the area of free surface aeration is like a tongue of water (C=0%) between the air bubble and water (C>0%). This area is 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 is air bubbles and water (C>0%); (c) the depth of between 21 mm to 27.2 mm is actually water (C=0%) and is called as "the tongue of water"; but in this case because there is a leap of bubbles then it still contains air bubbles; and (d) the depth of 28.14 mm to 42.21 mm is air and water (C>0%).

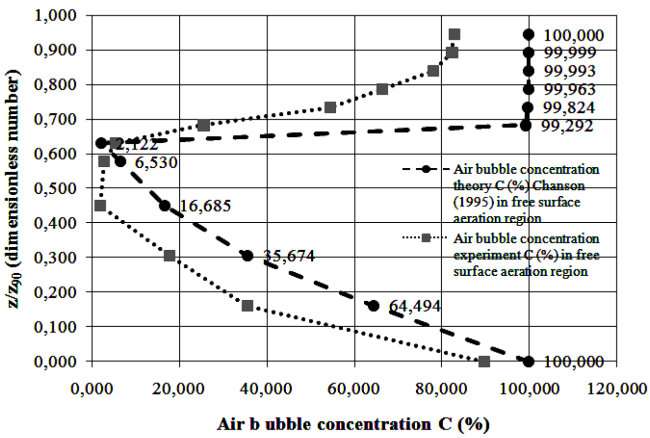

Fig. 5. Concentration distribution of air bubbles at α=25°, Q=20.9 l/s at the point 7.2 m from the *inlet flume* in *free surface aeration* precisely in x"/l=0.50.

x"/l is the ratio between the distance of the *free surface aeration* which become the consideration of the downstream end of the deflector (x") with the distance from the downstream end of the deflector or *duct* wall until the end of the leap of "the tongue of water" (l). In this case x=4 cm and l=8.0 cm so that x"/l=0.50 means that 'the tongue of water" which is analyzed is located in the middle of the length "the tongue of water" leap.

Based on Fig. 5, it appears that the value of the Absolute Error mean ($(\bar{E}_{abs})$) the concentration of air bubbles C experiments on the concentration of air bubble on theory [6] is 24%. The value of Standard Deviation of Absolute Error ($((E_{abs}))$) the concentration of air bubbles C experiments on concentration of air bubble on theory [6] is 19.57%. The value of 19.57 %<20%, so it can be said that the concentration of air bubbles experiment distribution at α=25°, Q=20.9 l/s at a point of 7.2 m from the inlet flume in free surface aeration precisely in x”/l=0.50 still follow the profile presented in [6].

3.4. Profiles concentration distribution of air bubbles in α=25°, Q=20.9 l/s at the point of 8.7 m of the inlet flume in downstream flow region

The air bubble concentration distribution in Fig. 6 is measured at the location of + 8.7 m in the downstream of the inlet flume (see Fig. 2). It appears that the concentration distribution of air bubbles is started from a depth of (measured from and perpendicular to the base flow) 0 mm to 71.4 mm. The concentration lowest value is of 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 $(\bar{X})$ is 87.82%, the standard deviation value is 9 %, and the variance value is 81%.

According to [8] in 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 that the concentration distribution of air bubbles is not homogeneous and shape of distribution is not rectangular, so it can be said that the region includes in the downstream flow region.

According to [9] that the new aerator is installed after the first aerator installed, if the concentration of air bubbles C (%) at the bottom of the aerator in *the downstream flow region* is at least 10%. In line with that, the opinion [5] says that if the concentration of the air at the base of the sliding channel is greater than 0.10 or 10%, then another aerator is not necessary. Thus, the steep slope of the channel base α=25°, and Q=20.9 l/s, after the first aerator, the new aerator is not necessary. According to [10] that in the bottom slope flume of ≥20°, the mean value of the concentration of air bubbles typically has reached 30%, and the concentration of air bubbles near the base flow has been more than 8%, then the base surface and the side flow are already protected from the damage due to cavitation. On condition as mentioned above, then the remaining length of *the chute spillways* in the *downstream* side, the new aerator is no longer needed [10].

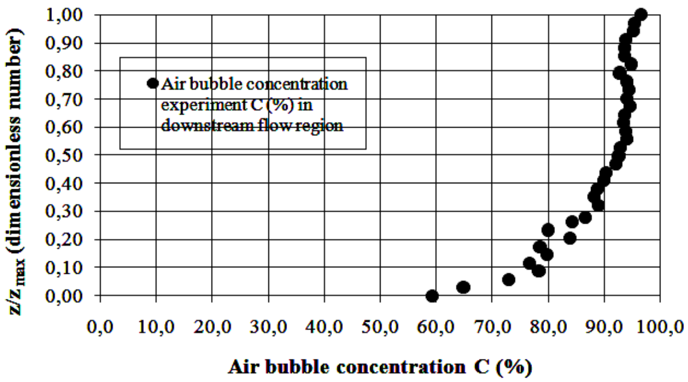

Fig. 6. The concentration distribution of air bubbles C (%) experiment in downstream flow region at α=25°, Q=20.9 l/s.

4. Conclusions

First, the equation (2) and (3) is closer to the distribution concentration air bubble C experiments mainly on α≤25°, Q=20.9 l/s in cross section 6.2 and 7.2 m from the *inlet flume* compared to the equation (1). The profiles of concentration distribution of air bubbles in the *self-air entrainment* conditions of α≤25° and at Q=20.9 l/s in the point 6.2 m and 7.2 m from the *inlet flume,* proved that the proposed equation by [6] suggested to be modified;

Second, the original equation (1) $C = 1 - \tanh^2\left(K' - \frac{z/z_{90}}{2D'}\right)$ is modified into $C = 1 - \tanh^{0.8}\left(K' - \frac{z/z_{90}}{2D'}\right)$. The parameter K' and D' contains parameters C_e in the original equation (1) C_e=0.9 sin α, whereas the equation (1) the modification scale of C_e is converted to C_e= 0.6 sin α;

Third, at Q=20.9 l/s and the slope of the bed flow α=25° aerator can be installed on the point of 7.2 m in the downstream of *the inlet flume* of the study, because (a) the parameters of the concentration of air bubbles in the base flow is 2.9 % is still less than 7% or the possibility of cavitation is still very big; and (b) the Froude number has reached the minimum threshold requirement of aerator installation of 6.8 which is already in the range of (6-7);

Fourth, the equation (4) and (5) that the concentration distribution of air bubbles C (%) in the area of free surface aeration in the downstream aerator is normal or Gaussian supported by the research results, so that this equation does not need to be modified;

Fifth, on the slope of a steep channel bed α=25°, Q=20.9 l/s, at a cross section of 7.2 m from the inlet flume on artificial air entrainment condition in the downstream flow region after the first aerator installed, new aerator is not necessary. In addition, the installation of aerators in location 7.2 m at the inlet flume downstream is useful to prevent the occurrence of cavitation.

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