Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia Engineering 37 (2012) 287 – 293

Procedia Engineering

www.elsevier.com/locate/procedia

The Second SREE Conference on Engineering Modeling and Simulation (CEMS 2012)

Calculation Method of the Length of Side Air Cavity

XIONG Yu[a,b], LIU Hao-yuan[a,b], HE Qing-yan[a,b], DONG Tuan-jie[a,b], TENG Jia-hong[a,b], ZHANG Fa-xing[a*]

[a]*State Key Laboratory of Hydraulics and Mountain River Engineering, Sichuan University, Chengdu, 610065, China;*
[b]*School of Hydraulic and Hydro-electric Engineering, Sichuan University, Chengdu ,610065, China*

Abstract

Once lateral aerator could work together with bottom aerator, the side air cavity can eliminates non-aerated flow area of the bottom aerator efficiently. Existing research results on the calculation of the length of side air cavity are insufficient. This paper studies characteristics of cavity and jet dispersion under conditions of different aerator's thicknesses and slopes of the chute through laboratory model experiments and dimensional analysis. After evaluating the influence of lateral aerator's design value and inlet flow's hydraulics parameters, we derived the formula to calculate the length of side air cavity. The calculated results correspond well with the experimental results.

Key words: hydraulics; cavitations alleviation by aeration; lateral aerator; dimensional analysis; length of side air cavity

1. Introduction

Forced aeration device is an effective method to prevent cavitation damage to water release structure in case of high speed flows. Liu Chao[1] provided that non-aerated flow area still exists if bottom aerator is used alone, indicating that cavitation damage cannot be prevented completely in this way. He also suggested that the cavitation damage can be much better prevented if lateral aerator can be used. Many hydraulic parameters can be used to describe effects of aeration, such as length of air cavity, negative pressure and ventilation. Among these parameters, the length of air cavity is the most important one.

Bottom aerator's design value and inlet flow's hydraulics parameters affect the length of bottom cavity. Researchers have shown how to calculate the length of bottom cavity[2]. For example, ① Formula of rigid body projectile, such as Pan Shui-bo[3] and P.Rutschmann[4]; ② Empirical formula, such as Shi

* Corresponding author. Tel.: 86-28-85408683.
E-mail address: zhfx@scu.edu.cn.

doi:10.1016/j.proeng.2012.04.241

Qi-sui's[5] calculation method to the length of cavity shapes by gentle slope with small deflector; ③ Numerical simulation method, like Yang Yongsen's[6] study about two-dimensional flow; ④Differential equation, Xu Yi-min[7] had obtained mathematical equations though studies about the forces of differential equation. Because the research on lateral aerator starts late, the shape of side cavity is irregular and the flow is complicated, existing research results about the calculation of the length of side air cavity are less. By combining lateral aerator with bottom aerator, Yue Chao[8] established a computing formula about outflow angle of jet flow, solving the calculation problem of the length of side cavity. The paper adopts the method of dimensional analysis and gets a calculate formula about v', which has the dimension of velocity. It also considers the influence of turbulent flow velocity and lateral aerator's design value. Then he applied the theory of rigid body projectile, and got the formula to calculate the length of side air cavity.

2. Model test

2.1. Model design

The experiments were conducted in the State Key Laboratory of Hydraulic and Mountain River Engineering, Sichuan University, Chengdu. The experimental model consisted of an upper water tank, an inlet, an open channel chute, lateral aerators, a weir and so on. The length of the chute is 9.0m and the section size is 0.18m×0.30m (W×H). A pair of lateral aerators is installed at a distance of 6.0m from the inlet (Fig.1). There are 8 shapes of lateral aerator in total, and its design value and inlet flow's hydraulics parameters are shown in Table 1. The length of the lateral aerator is 0.60m or 0.45m and the contraction angles are 0.95°, 1.91°, 2.86° or 3.81°. The maximum discharge is $0.16m^3/s$ and the flow velocity at the aerators varies from 3.84 to 6.72 m/s.

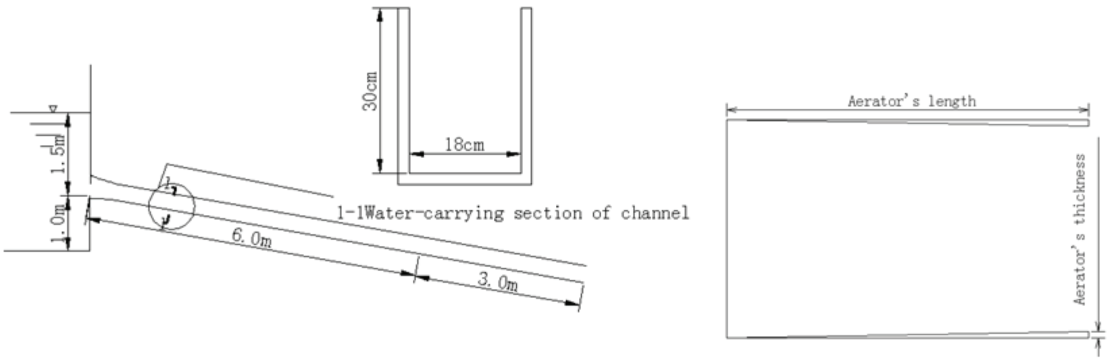

Fig. 1. Schematic diagrams of model test

Table 1. Experimental details

Series	Case	Aerator's falloff angle (°)	Aerator's thickness (m)	Discharge Q ($m^3 \cdot s^{-1}$)	Contraction velocity ($m \cdot s^{-1}$)	Hydraulic radius (m)	Reynolds number ($\times 10^5$)	Froude number
1	1	0.95	0.01	0.04	4.03	0.03	1.20	5.17
	2	0.95	0.01	0.11	5.22	0.05	2.23	4.56
	3	0.95	0.01	0.16	6.10	0.05	2.78	4.84
2	4	1.91	0.02	0.03	4.16	0.03	1.09	5.66
	5	1.91	0.02	0.11	5.45	0.05	2.20	4.53
	6	1.91	0.02	0.16	6.72	0.05	2.82	5.24
3	7	2.86	0.03	0.03	4.32	0.03	1.06	5.83
	8	2.86	0.03	0.08	5.19	0.04	1.83	4.51
	9	2.86	0.03	0.11	5.67	0.04	2.11	4.49
4	10	3.81	0.04	0.03	4.10	0.03	1.09	4.54
5	11	0.95	0.01	0.04	4.28	0.03	1.15	6.05
	12	0.95	0.01	0.11	5.47	0.05	2.31	4.97
	13	0.95	0.01	0.16	6.38	0.05	2.90	5.23
6	14	1.91	0.02	0.04	3.84	0.04	1.21	4.53
	15	1.91	0.02	0.11	5.41	0.05	2.24	4.65
	16	1.91	0.02	0.16	6.54	0.05	2.86	5.18
7	17	2.86	0.02	0.04	4.86	0.03	1.36	6.14
	18	2.86	0.02	0.11	5.16	0.05	2.07	4.14
8	19	3.81	0.03	0.03	4.89	0.03	1.23	6.48
	20	3.81	0.03	0.09	5.58	0.04	1.93	5.00

2.2. Experimental results

When water flows through the aerators, the jet, side cavity, and water wing appear (Fig.2). The dip angle of the chute, α, is 9.56°. L_t stands for the length of side cavity. Test results show that if the length of the aerator remains invariant, the length of side cavity increase as the falloff angle becomes larger (Table 2).

Fig. 2. Flow pattern

Table 2. Relationship between falloff angle and the length of side air cavity

Case	Aerator's falloff angle (°)	Length of side air cavity (m)
1	0.96	0.186
4	1.91	0.274
7	2.86	0.352
10	3.82	0.473
2	0.96	0.338
5	1.91	0.677
8	2.86	0.822
3	0.96	0.477
6	1.91	0.647
9	2.86	0.773

3. Calculation method of side cavity's length

3.1. Calculation of v'

The chute flow was affected by gravity as well as contraction velocity and fluctuating velocity. The jet flow exerted impact on the side walls, and then the side air cavity formed. Influenced by vertical fluctuating velocity, diffusing flow's lower edge gradually spread. Zhang Fa-xing[2] proved that emergence angle of jet flow is unequal to angle of flip bucket because of the influence of water depth and turbulent diffusion. Pan Shui-bo[3] indicated that self-aeration capacity of the jets is mainly caused by turbulent intensity. Turbulent jet sucks air into water from diffusing flow's lower edge. When water falls to the slab of the chute, vortex roll is produced by diffluence. Vortex roll is highly related to the thickness of aerator and its deflect angel. So it can be concluded that the factors which influence the degree of turbulent diffusion are relatively complex. To simplify the calculation method, the factor v' was used to describe the degree of turbulent diffusion. v' is perpendicular to the contraction velocity(Fig.3).

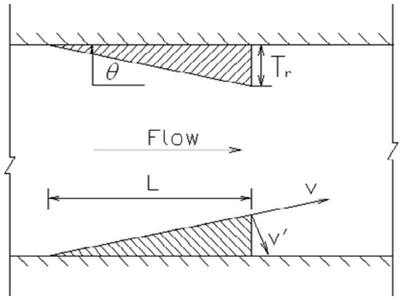

Fig. 3. Analysis of v' and v

The impact factors of v' are the design value of the lateral aerator, discharge chute's design value, inertia force, viscous force and the pressure in cavities, namely, aerator's thickness T_r, aerator's length L, width of the chute B, inlet flow's height h, contraction velocity v, as well as liquid's movement viscosity coefficient υ. Suppose that the aeration of the chute flow is fully, the pressure in cavities equals to zero. Thus, the relation of v' is:

$$v' = f(T_r, L, B, h, v, \upsilon) \quad (1)$$

Based on Buckingham π theorem in scale analysis, following characteristic formula is gotten:

$$\varphi\left(\frac{v'}{v}, \frac{T_r}{L}, \frac{T_r}{B}, R_e\right) = 0 \quad (2)$$

$R_e = \dfrac{vR}{\upsilon} = 1.06\times10^5 \sim 2.90\times10^5$, R represents hydraulic radius. Analyzing the data and fitting relationships among $\dfrac{v'}{v}$, $\dfrac{T_r}{L}$, $\dfrac{T_r}{B}$ and R_e, following result is gotten:

$$\frac{v'}{v} = 0.5\times\frac{T_r}{L} + A\frac{T_r}{B} + 6800\times\frac{1}{R_e} - 0.01 \quad (3)$$

Factor A is dimensionless. Relationship between A and B is shown as table 3.

Table 3. Relationship between factor A and B

B/m	A
0.18	0.27
0.20	0.28
0.43	0.45

3.2. Force analysis

Analyzing the force of jet flow, considering gravity contraction velocity v and turbulent diffusion degree v', ignoring the effect of resistance and wind velocity, using formula of rigid body projectile, we established the formula of jet flow's central length, L_t:

$$\begin{cases} L_t = (v\cos\theta + v'\sin\theta)t + \dfrac{1}{2}g\sin\alpha t^2 \\ t = \dfrac{T_r}{v'\cos\theta - v\sin\theta} \end{cases} \quad (4)$$

t stands for the time that the diffusing flow spent hitting side walls, g stands for gravitational acceleration, g=9.8m/s^2. Simultaneous equation 3 and 4, L_t can be described as follows:

$$\begin{cases} L_t = (v\cos\theta + v'\sin\theta)\dfrac{T_r}{v'\cos\theta - v\sin\theta} + \dfrac{1}{2}g\sin\alpha \left(\dfrac{T_r}{v'\cos\theta - v\sin\theta}\right)^2 \\ v' = \left(0.5\times\dfrac{T_r}{L} + A\dfrac{T_r}{B} + 6800\times\dfrac{1}{R_e} - 0.01\right)v \end{cases} \quad (5)$$

4. Result certification

The calculation method was confirmed by the experimental data of Yue Chao[8] and Liu Chao[9]. The movement viscous coefficient of water, υ, is 1.176×10^{-6}m^2/s. The chute width, B, in this paper is 0.18m. Dip angle α=9.56°, while in Yue's test, B=0.20m, α=25°. In Liu's test, B=0.43m, α=4.51°. Yue Chao's and Liu Chao's tests both take the form which combines lateral aerator with bottom aerator. Liu Chao[10] proved that the length of side air cavity is considerably affected by the size of aerator, therefore the error is relatively large. Comparison chart of calculated and tests data of the length of side air cavity is shown in Fig.4. It can be seen that the calculation results were consistent with the experimental data.

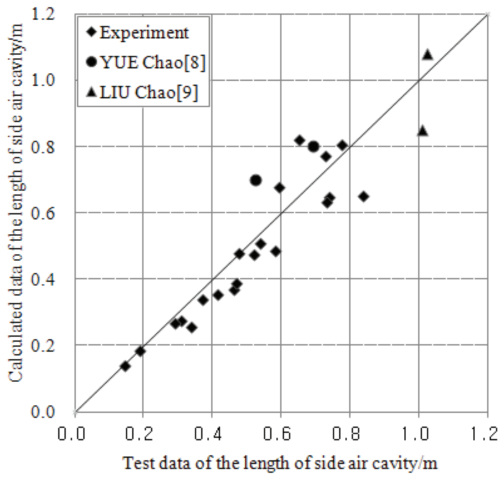

Fig. 4. Comparison between calculated and test data of the length of side air cavity

5. Conclusion

The length of side air cavity varies with the change of lateral aerator's design value. When the length of lateral aerator stays invariant, the length of side air cavity increases as the falloff angle increases.

The paper adopts method of dimensional analysis to get the calculation formula of v'. v' is a factor to describe the degree of turbulent diffusion. Based on this formula, calculation method of length of side air cavity is also established. The method can indicate the length of side air cavity with high accuracy. Thus it can provide theoretical basis for practical engineering.

Acknowledgements

This project is primarily founded by the National Natural Science Foundation of China (Grant No. 51109150) and Sichuan University's Scientific Research Action Plan (Grant No.295). The authors also appreciate the great support and help from the State Key Laboratory of Hydraulic and Mountain River Engineering, Sichuan University, Chengdu.

References

[1] LIU Chao, YANG Yong-quan, DENG Jun, et al. Experimental study on air entrainment to alleviate cavitations for downstream sidewalls of ogee-section in spillway tunnel. *Journal of Hydrodynamics,* Ser.A, Vol.21, No.4, pp: 465-472, 2006. (In Chinese)

[2] ZHANG Fa-xing, XU Jian-qiang, XU Jian-jun. Correction method for emergence angle of jet flow over aerator. *Yangtze River*, Vol.41, No.2, pp: 87-90, 2010. (In Chinese)

[3] PAN Shui-bo, SHAO Ying-ying, SHI Qi-sui, et al. The self-aeration capacity of the water jet over the aeration ramp. *Journal of Hydraulic Engineering*, No.5, pp: 13-22, 1980. (In Chinese)

[4] P Rutschmann, W H Hager. Design and performance of spillway chute aerator. *Water Power & Dam Construction*, Vol.42, No.1, pp: 36-42, 1990.

[5] SHI Qi-sui, PAN Shui-bo, SHAO Ying-ying, et al. Experimental investigation of flow aeration to prevent cavitation erosion by a deflector. *Journal of Hydraulic Engineering*, Vol.14, No.3, pp: 1-13, 1983. (In Chinese)

[6] YANG Yong-sen, YANG Yong-quan. Numerical calculation for two dimensional cavity flow downstream of an aerator. *Journal of Hydraulic Engineering*, Vol.31, No.6, pp: 54-60, 2000. (In Chinese)

[7] XU Yi-min, WANG Wei, XU Wei-lin, et al. Calculation of the cavity length of jet flow from chute aerators. *Water conservancy and hydropower technology*, Vol.35, No.10, pp: 7-9, 2004. (In Chinese)

[8] YUE Chao, NIU Zhi-pan, LI Jin. Calculation of the lateral cavity length. *Science Technology and Engineering*, Vol.9, No.6, pp: 1443-1445, 2009. (In Chinese)

[9] LIU Chao. Study on Air Entrainment to Alleviate Cavitations for Downstream Sidewalls of Ogee Section in Spillway Tunnel. *Doctoral Dissertation of Sichuan University*, 2006. (In Chinese)

[10] LIU Chao, ZHANG Guang-ke, LI Nai-wen, et al. The effect of base aerator on the length of lateral cavity. *Journal of Sichuan University(Engineering Science Edition)*, Vol.40, No.1, pp: 1-4, 2008. (In Chinese)