# Energy Dissipation of Water Flow over a Drop

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Abstract

Recently derived energy dissipation equation by Chamani(2008) and the profile function of the free overfall by Marchi(1993) were verified with present experiment data. The experiment was conducted in hydraulic laboratory, Hanyang University where the flume is 7m long and 0.44m wide, and the height of the drop structure is 0.205m. Water depth and free overfall profile data were collected using an ultra sonic distance sensor and photographic images. The time-averaged water depth data and the free overfall profile were analyzed to examine the energy dissipation pattern over the drop structure

Keywords : Drop structure, Energy dissipation

## 1. Introduction

A vertical drop is a commonly used hydraulic structure which conveys water from a higher elevation to a lower elevation, dissipating the energy through the pool at the base of the drop. Due to the energy loss over the drop, the slope of the river bed does not vary rapidly so that the shape of the river bed can be conserved. However a degree of the effect by the vertical drop depends on the dimensions of the structure and design considering the effect of the drop in the downstream inappropriately can cause severe structural failure. Therefore numerous researchers have focused on investigating the relationship between the dimensions of the drop and the energy dissipation to design it more safely.

The first attempt to predict the energy dissipation over the drop was carried out by Moore(1943). Moore conducted an experiment with two vertical drops having different height and showed the relative height of the drop $\left(\frac{H}{Y_c}\right)$ plays an important roles in energy loss at a drop. Afterward White(1943) criticized Moore's work and suggested an analytic solution to estimate the energy loss with several assumptions. Rand(1955) introduced the dimensionless parameter ,called drop number $\left(\frac{Y_c}{H}\right)^3$ and presented the relationships between drop characteristics and drop number with experimental results. Gill(1979) and Rajartnam(1995) modified the assumptions which had been made by previous researchers and derived new analytic solution to predict the energy dissipation over a drop as well as verified the methods by comparing the analytic results with the experiment data. Chamani(2008) employed a different approach to calculate the relative

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energy loss $\left(\frac{\Delta E}{E_0}\right)$. The flow pattern is divided into two region (shear layer and surface jet) depending on the thickness of the jet plunging into the pool and the length of the nappe sliding over the pool. Chamani also carried out an experiment to demonstrate the applicability of the model.

Herein the energy dissipation equation suggested by Chamani and the free overfall function derived by Marchi(1993) were compared with the present experiment data. Experiment data collected by ultra sensor distance sensor and photographic images were employed to support the validation of the models.

## 2. Experimental Setup

Experiments were conducted in hydraulic laboratory, Hanyang University. The flume is 10.2m long, 0.44m wide, and consisted of tempered glass for side walls and polyvinyl chloride for a bed. The drop was fabricated with acrylic and ventilated with six holes having diameter of 0.01m. The locations of the holes are 0.02m away from the top of the drop in vertical and aligned parallel to the bed. The length and height of the drop is 2m and 0.205m respectively. An inclined structure was attached to the end of the drop in upstream to prevent the abrupt pressure change which can induce unstable inflow condition. Also discharge varies from 0.00847 $m^3/s$ to 0.0476 $m^3/s$, controlled by electromagnetic flowmeter which has the accuracy of ± 0.5%. The schematic view of the flume is illustrated in Fig 1.

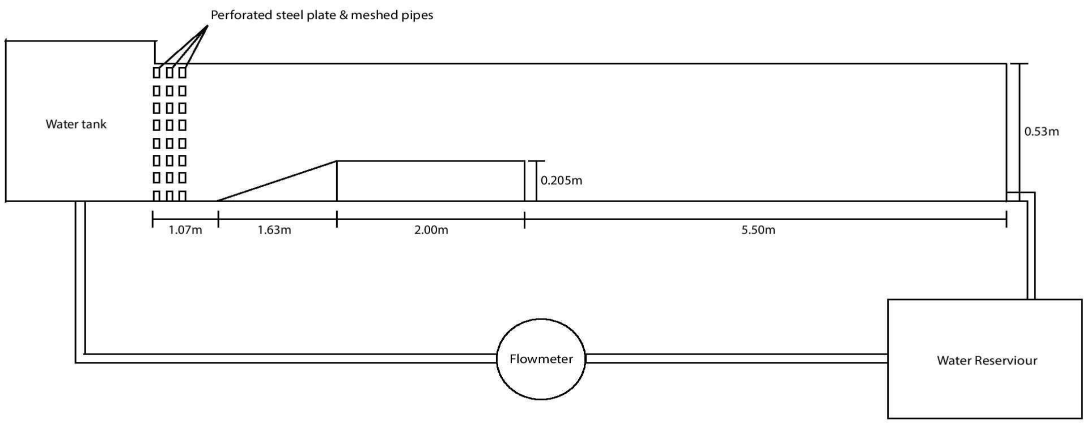



Figure 1. Schematic view of the flume

## 3. The Literature Review

### 3.1 Water Surface Profile

Marchi(1993) derived free overfall function from stream function in inviscid, irrotational, and two-dimensional flow by combining functions of velocity components, pressure, total head, and total momentum. The free overfall function in the case of upstream subcritical flow is expressed as below with the origin at the edge of the drop.

(a) Boundary conditions

$$x \to -\infty = h \to Y_c \ ; \ H_t^* = \frac{3}{2} \ ; \ M_t^* = \frac{3}{2} \ ; \ h^{*\prime} = z^{*\prime} \ ; \ h^{*\prime\prime} = z^{*\prime\prime};$$

($H_t^*$=total head, $M_t^*$=total momentum)

(b) The brink depth

$$Y_0^* = 0.706 \, (x^* = 0)$$

(c) The upstream water surface profile

$$h^*(x^*) = 1 - \frac{1}{(1.844 - 0.866x^*)^2} \ (-\infty < x^* < 0) \quad (1)$$

(d) The nappe lower profile

$$z^*(x^*) = -0.222x^{*2} - 0.192x^* \ (x^* > 0, z(x^*) > -H^*) \quad (2)$$

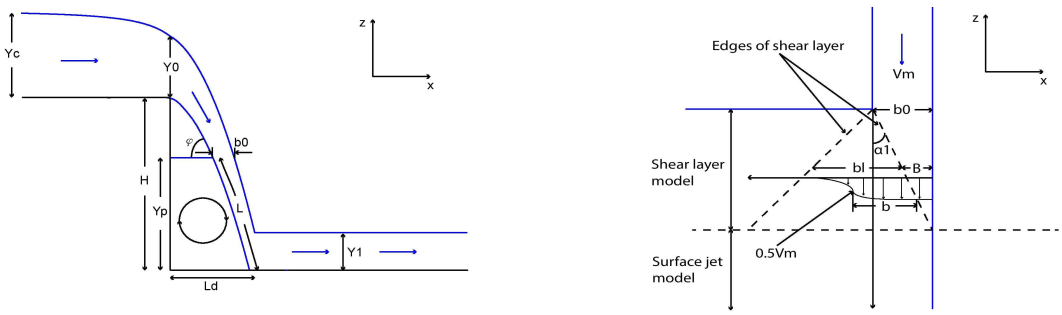
(e) The nappe upper profile

$$h^*(x^*) = -0.222x^{*2} - 0.192x^* + Y_0 \ (x^* > 0, h(x^*) > -H^* + Y_1^*) \quad (3)$$

where parameters with a star are the normalized variables divided by $Y_c$, $\sqrt{gY_c}$, $\rho g Y_c$ in case of length, velocities, and pressure respectively. The analytic solution accurately predicts the water surface profile in upstream while there are discrepancies in the nappe profile. This is because Marchi assumed total head is conserved, which means the energy is not dissipated over the drop. However it was proved that turbulent mixing over the pool reduce the amount of the energy(Rajartnam, 1995)

### 3.2 Energy Dissipation

Chamani(2008) introduced new approach to calculate the relative energy loss at a drop. Chamani applied two analytic solutions, shear layer model and surface jet model, depending on the thickness of the jet impinging into the pool and the length of the nappe sliding over the pool. Fig 2 describes the definition of the important variables in the drop structure and shear layer in turbulent jet.




(a) (b)

Figure 2. Definition of variables in (a) a drop (b) a turbulent jet shear layer

where $Y_c$=critical depth, $Y_0$=brink depth, $H$=drop height, $Y_p$=pool depth, $b_0$=jet width, $L$

=energy dissipation length, $L_d$=pool length, $Y_1$=downstream depth, $V_m$=impact velocity, bl=the distance between two edges of shear layer, b=the distance from the edge of shear layer to the point where the velocity is $0.5V_m$, and $\alpha_1$=empirical coefficient of shear edge angle, 4.8° (Rajartnam, 1976). Furthermore the empirical equations for b and bl were derived by Rajartnam(1976).

$$b = c_1|z|\begin{cases} c_1 = 0.115\,, \; shear\,layer\,\mathrm{model} \\ c_1 = 0.065\,, \; surface\,jet\,\mathrm{model} \end{cases} \tag{4}$$

$$bl = c_2|z| \; (c_2 = 0.263\,, \; shear\,layer\,\mathrm{model}) \tag{5}$$

where $c_1$ and $c_2$ are the empirical coefficient.

The relative energy loss equation by Chamani is calculated as following steps.

(a) Pool depth (Chamani, 2000)

$$\frac{Y_p}{Y_c} = \sqrt{\frac{4}{(A+1.6)^2} + A - 1.4} \;\; ; \; A = \sqrt{2(\frac{H}{Yc} + 1.695)} \tag{6}$$

(b) Pool length (Rand, 1955)

$$\frac{L_d}{H} = \frac{1.98(1+0.358\frac{Y_c}{H})\sqrt{\frac{Y_c}{H}}}{\sqrt{1+0.358\frac{Yc}{H} - \frac{Yp}{H}}} \tag{7}$$

(c) Energy equation (Chamani, 2008)

$$\frac{x}{b_0} = \frac{LV_m}{q} = \frac{L_d}{Y_c}\sqrt{2(\frac{H}{Y_c} - \frac{Y_p}{Y_c} + 1.5)} \tag{8}$$

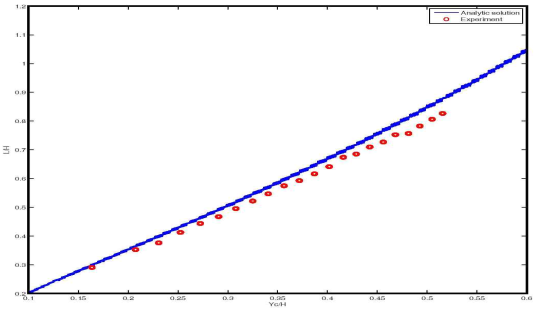
(d) Energy dissipation (Chamani, 2008)

$$\frac{\triangle E}{E_0} = 0.0133\frac{x}{b_0} \;\; \text{(shear layer model)} \tag{9}$$

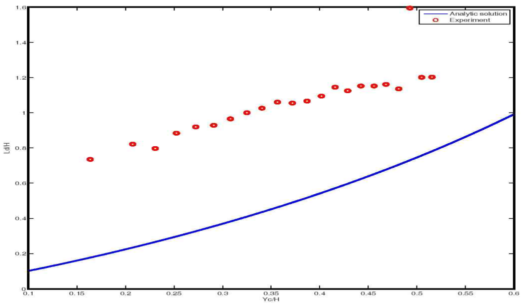
$$\frac{\triangle E}{E_0} = 1 - \frac{2.96}{\sqrt{\frac{x}{b_0}}} \;\; \text{(surface jet model)} \tag{10}$$

## 4. Results and Discussion

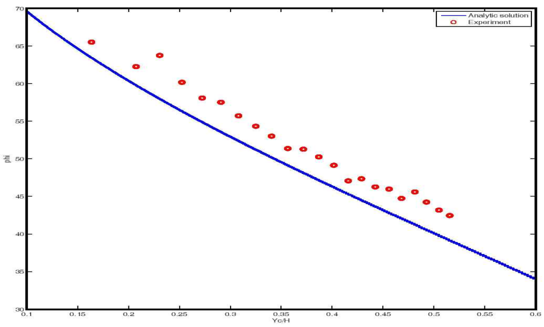
Table 1 shows the results of the experiment. As displayed in the table 1, the relative energy loss decreases as the discharge increases, which is explained by the measured free overfall profile data in the nappe. Marchi derived the water surface profile with the assumption of the no energy dissipation. However the energy is dissipated in the pool, which decelerates the velocity of the nappe and drags the water surface profile toward the drop wall in reality. This is demonstrated by the fact that the measured angle is greater than the predicted value about three degree. Also there were huge gap between the measured values and predicted values of $L_d$ and the little discrepancies also existed between the measured values and the predicted values of $L_d$ in the work by Chamani.



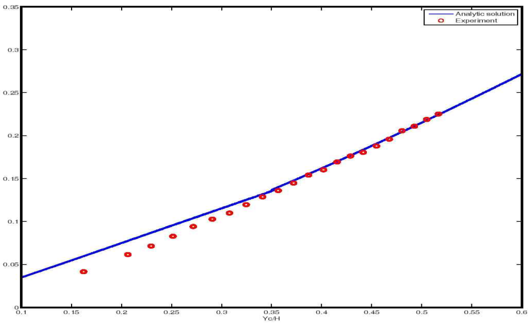

(a) L/H – Yc/H




(b) Ld/H – Yc/H




(c) ϕ – Yc/H




(d) Y1/H – Yc/H

Fig 3. Comparison between predicted values and measured vales

## Conclusion

The previous works by Marchi and Chamani were verified with the present experiment data. The predicted values derived from these analytic solutions showed good agreement with the experiment data in general. However there were some discrepancies between the predicted values and the measured values because of the defective assumptions by the previous researchers. Therefore further investigations should be conducted in estimating the energy dissipation over a drop to obtain more reliable predictability.

## References

1. Chamani, M. R., Rajaratnam, N., &Beirami, M. K. (2008). Turbulent jet energy dissipation at vertical drops. *Journal of hydraulic engineering*, *134*(10), 1532-1535.

2. Lin, C., Hwung, W. Y., Hsieh, S. C., &Chang, K. A. (2007). Experimental study on mean velocity characteristics of flow over vertical drop. *Journal of Hydraulic Research*, *45*(1), 33-42.

3. Marchi, E. (1993). On the free overfall. *Journal of Hydraulic Research*, *31*(6), 777-790.

4. Akram Gill, M. (1979). Hydraulics of rectangular vertical drop structures.*Journal of Hydraulic Research*, *17*(4), 289-302.

5. Rajaratnam, N., &Chamani, M. R. (1995). Energy loss at drops. *Journal of Hydraulic Research*, *33*(3), 373-384.