Numerical Investigation of Hydraulic Characteristics of Vertical Drops with Screens and Gradually Wall Expanding

Behnam Nayebzadeh[1*], Mohammad Ali Lotfollahi-Yaghin[2], Rasoul Daneshfaraz[3]

[1]Ph.D. Student of Civil Engineering-Hydraulic structures, University of Tabriz, Iran
[2]Civil Engineering Faculty, University of Tabriz, Tabriz, Iran
[3]Department of Civil Engineering, Faculty of Engineering, University of Maragheh, Maragheh, Iran

ABSTRACT

In the present study, the hydraulic characteristics of vertical drops with screens and the gradually wall expanding in downstream using FLOW-3D software were investigated. For this purpose, two porosity ratios of the screens of 40 and 50%, 5 gradually expanding with 3 vertical drop heights in the specified discharge range were used. It was found that the numerical results are closer to the experimental results with the RNG turbulence model than k-ε. By increasing the drop height, the $\Delta E/E_0$ due to the jet floor impact intensity increases and decreases of y_p/P. The maximum $\Delta E/E_0$ for 25 cm height was 51.60% and the lowest for 15 cm was 44.25%. For a constant drop height with increasing discharge, the $\Delta E/E_0$ decreased and increased of y_p/P. The gradually wall expanding causes turbulence on the edges and a non-uniform distribution of y_d/P and by increasing y_p/P and y_d/P, it causes a 25% increase in $\Delta E/E_0$. The presence of screens, increases of y_p/P, y_d/P and $\Delta E/E_0$ by 44%. The simultaneous use of gradually wall expanding and screens cause a 46% increase in $\Delta E/E_0$ and a decrease in y_p/P and y_d/P. It has been shown that the contribution of screens is greater than the gradually wall expanding, with their simultaneous application increasing $\Delta E/E_0$ up to 33.5%.

KEYWORDS

Vertical drop, Porosity ratio, Turbulence models, Gradually wall expanding, FLOW-3D.

---

[*] Corresponding Author: Email: bnayebzadeh@yahoo.com

1. Introduction

Vertical drops reduce the natural slope of the earth to the design slope. Thus sudden transfer and falling of flow over drops case decrease the energy flow [1-3].

In the present study, the energy dissipation with gradually expanding wall and different porosity ratios of vertical screens downstream of the vertical drops under different hydraulic and geometrical conditions is investigated using FLOW-3D software.

2. Dimensional analysis

Figure 1 shows the important parameters of the present study.

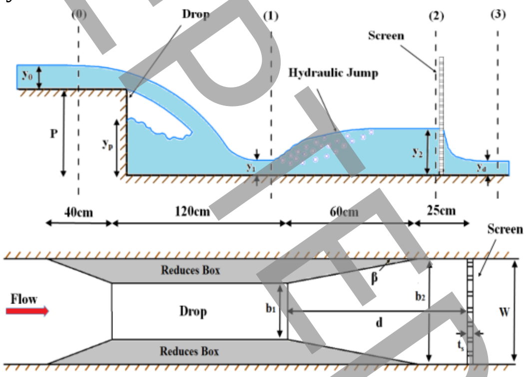

Figure 1. Vertical drop with vertical screen and gradually expanding

Important parameters on energy dissipation can be written as:

$$\Delta E = f_1(\rho, \mu, g, Q, W, P, N, t, d, y_c, y_0, B, y_d, y_p) \qquad (1)$$

where, ΔE energy dissipation, ρ Mass density, μ Dynamic viscosity, g Gravitational acceleration, Q flow rate, W channel width, P drop height, N porosity ratio, t screen thickness, d Distance between screen and drop, y_c critical depth, y_0 upstream depth, B = b_1/b_2; gradual divergence ratio, y_d downstream depth, and y_p pool depth. Finally, according to the Buckingham-π theorem, the relative energy dissipation can be defined as:

$$\frac{\Delta E}{E_0} = f_4(N, B, \frac{y_c}{P}) \qquad (2)$$

Also the relative depth of the pool and the relative depth downstream the screen are expressed defined as:

$$\frac{y_p}{P} = f_5(N, B, \frac{y_c}{P}) \qquad (3)$$

3. Methods and materials

3.1. Governing equations

The FLOW-3D® software uses the Finite Volume Method to solve the three-dimensional Reynolds Averaged Navier–Stokes equations of fluid motion. These equations can be written in a Cartesian coordinate system (x, y, z) and are referenced to Ghaderi and Abbasi (2019) [4]. In this study, RNG and k-ε turbulence models were used to simulate flow characteristics under turbulent flow conditions. The turbulence models equations are referenced to [5-6].

3.2. Computational mesh and applying boundary Conditions

The numerical models simulation was performed according to the specifications of the laboratory model [7]. Table 1 lists the geometric and hydraulic conditions of the numerical solution.

Table 1. Dimensional and hydraulic numerical parameters

$B=b_1/b_2$	N(%)	P(m)	y_0(m)	y_c(m)	Fr_0	Q(L/min)
1, 0.8, 0.68, 0.5	40, 50	0.15-0.2	0.021-0.068	0.092-0.058	0.68-0.92	150-800

Based on this mesh-refinement study, a computational mesh with 1620785 elements was selected for further calculations, with the selected appropriate mesh results in a relative error and RMSE of 3.40%, 0.18 cm.

4. Results and Discussion

4.1. Data Verification

In order to select the appropriate turbulence model, compared the free surface profiles at 600 L/min in numerical solution and the experimental results with RNG and k-ε turbulence models (see Figure 3).

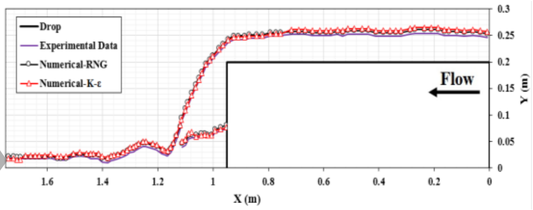

Figure 3. Comparison of free surface profiles from numerical results and laboratory [7]

The results of the numerical solution with the RNG turbulence model provide closer data to the experimental results. The highest percentage of relative error and RMSE were 3.99% and 0.01 m, respectively. Model validation was performed by comparing pool depths obtained from FLOW-3D results with laboratory results.

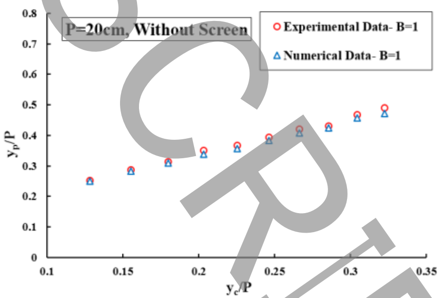

Figure 4. Comparison of pool depth of numerical and laboratory values

The maximum relative error of the pool depth from numerical solution and RMSE error were 3.78% and 0.018, respectively. Therefore, there is a good agreement between the numerical and laboratory values.

4.2. Effect of gradually wall expanding and vertical screens on flow over of vertical drop

It is observed that by increasing the drop height, the depth of the pool decreases and the amount of energy dissipation increases. Increasing the drop height from 15 to 25 cm reduces the depth of the pool by 7.5% and increases energy dissipation by 4.5%.

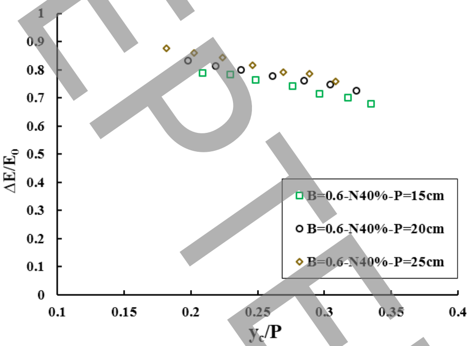

Figure 6. Energy dissipation at three different drop heights

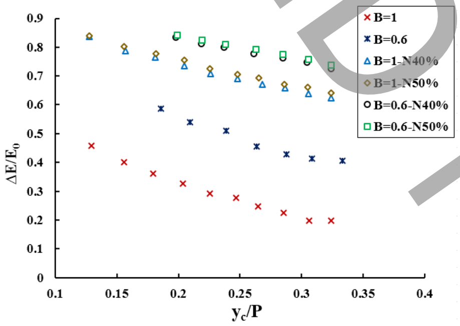

Figure 7. The effect of the presence of gradually wall expanding and vertical screens on energy dissipation

The simultaneous use of the gradually expanding wall and screen plates due to hydraulic jump and flow turbulence increases the energy dissipation to 46%.

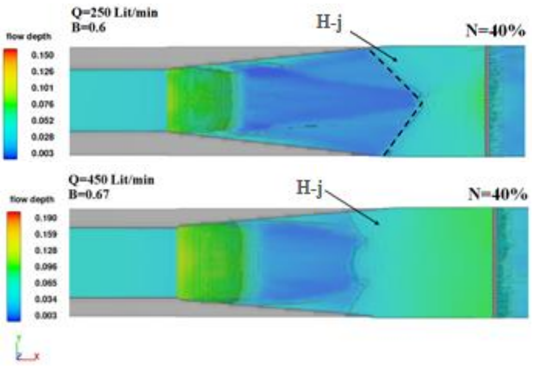

Figure 8. V-shaped and classic hydraulic jump in low discharge

It can be seen that, with constant gradually expanding wall, the hydraulic jump tends to upward in the screen 40%, while in the screen with the 50% porosity ratio, the hydraulic jump moves downward. The jump formed after the drop is V-shaped despite the screen plates.

4. Conclusions

1- Numerical results with the RNG turbulence model provide closer data to the experimental results than the k-ε turbulence model. The highest relative error percentage and RMSE value were 3.99% and 0.01 m, respectively.

2- The gradually expanding wall created downstream of the vertical drop causes turbulence on the jet sides as well as the uneven distribution of depth below it and increases the depth of the pool and the downstream depth on drop below 25% of energy dissipation efficiency flows.

3- Applying gradually expanding wall and screen plates, on average, increases 46% the efficiency of the current energy dissipation downstream of the vertical drop.

5. References

[1] Moore, W. L., *Energy loss at the base of a free overfall*. Transactions of the American Society of Civil Engineers, 1943. 108(1), p. 1343-1360.

[2] Rajaratnam, N. and M. R. Chamani, *Energy Loss at Drops*. Journal of Hydraulic Research, 1995. 33(3), p. 373-384.

[3] Ghaderi, A., M. Dasineh, S. Abbasi, *Impact of Vertically Constricted Entrance on Hydraulic Characteristics of Vertical Drop (Numerical Investigation)*. Journal of Hydraulics, 2019. 13(4), p. 121-131.

[4] Ghaderi, A., Abbasi, S. *CFD simulation of local scouring around airfoil-shaped bridge piers with and without collar*. Sādhanā, 44(10), 216, 2019.

[5] Daneshfaraz, R., S. Sadeghfam, and A. Ghahramanzadeh, *Three-dimensional numerical investigation of flow through screens as energy dissipators*. Canadian Journal of Civil Engineering, 2017. 44(10), p. 850-859.

[6] Daneshfaraz, R., O. Minaei, J. Abraham, S. Dadashi, A. Ghaderi, *3-D Numerical simulation of water flow over a broad-crested weir with openings*. ISH Journal of Hydraulic Engineering, 2019. 1-9.

[7] Nayebzadeh, B., M.A. Lotfolahi-Yaghin, and R. Daneshfaraz, *Experimental study of Energy Dissipation at a Vertical Drop Equipped with Vertical Screen with Gradually Expanding at the Downstream. AUT Journal of civil engineering*, 2019. (in Persian). DOI:1022060/CEEJ.2019.16493.6265.