International Journal of Current Science Research and Review

ISSN: 2581-8341

Volume 06 Issue 11 November 2023

DOI: 10.47191/ijcsrr/V6-i11-40, Impact Factor: 6.789

IJCSRR @ 2023

Comparison of Energy Dissipation in Ogee and Stepped Spillway Using the Fluent Software

Xiao Xin Qian[1], Lu Liu[2], Xiaohu Zhu[3]

[1] Hydraulic Scientific Research Institute, Wenzhou, China

[2] College of Hydropower & Information Engineering, Wuhan, China

[3] Department of Civil Engineering, Hangzhou, Zhejiang, China

ABSTRACT: One of the essential components of any dam is the spillway, which stands as one of the oldest man-made hydraulic structures. It serves as a device designed for the measurement and regulation of water flow, facilitating the controlled passage of excess water and sediment from the upstream to the downstream. This structure finds extensive application in dam construction. Given the critical nature of its function, a stepped spillway demands robust and reliable instruments to ensure high efficiency, ready for use at any moment. Providing crucial information about the behaviour of this significant structure, including flow characteristics such as the flow curve, water level profile, pressure, and velocity pattern at different points of the flow, is essential for its design, monitoring, and safety program. In this research, the Fluent software was employed, utilizing the RSM turbulence mode for simulating the flow on both Ogee and stepped spillways. The comparison of energy loss in these spillways was conducted, employing the VOF model to trace the free flow surface. The obtained results were validated using previous researchers' studies.

KEYWORDS: Energy Dissipation, Fluent, RSM Turbulence Model, Stepped Spillway.

INTRODUCTION

To dissipate kinetic energy, a stilling basin is typically constructed at the base of dams. Maximizing the transfer of kinetic energy downstream necessitates that the relaxation basin be designed with larger dimensions or additional arrangements for effective energy dissipation (1,2). Consequently, the implementation and maintenance costs, as well as stability, are impacted for the dam. Step spillways represent structures employed to enhance the hydraulic conditions of flowing water and facilitate energy dissipation. Constructing such spillways results in reduced dimensions of the relaxation basin, thereby lowering costs. In certain situations, it even leads to the elimination of the stilling basin. Ogee spillways, characterized by numerous hydraulic advantages, have undergone extensive study. Properly designed, these structures can achieve exceptionally high efficiency. The commendable performance of Ogee spillways in accommodating flow, coupled with their effective flow measurement capabilities, empowers engineers to employ this spillway type in diverse locations and scenarios (3,4). Chatila et al. used the finite element computational fluid dynamics software, ADINA, to predict the free surface over an ogee spillway and thus model the flow field. Since the actual flow is turbulent the k–ε flow model was used. Their results were in close agreement with measured free-surface profiles over the entire length of the spillway (5). Tabbara et al. also used the finite element computational fluid dynamics module of the ADINA software to predict the main characteristics of the flow. This was included the determination of the water surface, the development of skimming flow over corner vortices, and the determination of energy dissipation. Since the actual flow was turbulent, the k–ε flow model was used (6).

In emergency action planning and dam safety risk assessment, dam breaches are considered for a range of flood conditions that may include dam crest floods (DCF) and design floods, such as the Probable Maximum Flood (7). Due to the significance of this structure, numerous studies have been conducted on these spillways by various researchers. However, at present, the studies on stepped spillways predominantly rely on models, with only a few experimental equations available for calculating the dispersion rate. These models have shown physical stability. Yet, owing to the intricate nature of the flow and the boundary conditions in these structures, the extent of numerical studies in this field has been restricted. In free-surface turbulent flows, large amount of air may be entrapped and advected in the water current. The resulting air-water flows are frequently observed in natural water systems, where they are also relevant to water quality, ecological sustainability and integrated assessment within such systems (8,9). Reeve et al performed an intensive set of tests with varying slope, stone size, and porosity were undertaken. The location of the inception points and the water

International Journal of Current Science Research and Review
ISSN: 2581-8341
Volume 06 Issue 11 November 2023
DOI: 10.47191/ijcsrr/V6-i11-40, Impact Factor: 6.789
IJCSRR @ 2023

depth at this point obtained from their investigation were compared with those from existing formulae. Two new empirical equations have been derived, on the basis of a regression analysis, to provide improved results for gabion stepped spillways (10,11).

MATERIALS AND METHODS

To validate the precision of the research findings, the stepped spillway's physical model at Wuhan River Scientific Research Institute was employed. The computational domain for numerical simulation on the stepped spillway is described below. The crest of the spillway is positioned at a height of 78.9 meters from the claw, and the design head of the spillway is 7.9 cm. The spillway stepped area features a slope of 0.7H, 1V, connected to the claw by an arch to beam ratio of 28. The height-to-width ratio of the first 5 steps has been adjusted so that the tips of the steps are tangent to the standard profile. The heights of the first 5 steps are 4, 2.2, 3, 4, and 5, respectively. From the 5th step onwards, the dimensions of the steps have been kept uniform and equal to 6*4.5cm. The downward slope of the claw is considered to be zero. The spillway has a width of 30 cm, and the flow rate passing through the spillway is approximately 0.02. In an experimental investigation by Kamyab Moghaddam et al., they examined a stepped spillway. In their research, inclined steps with varying slopes were utilized, equipped with a liminimeter and pitot tube to measure water depth, and velocities were recorded for calculating relative energy losses through the application of the Bernoulli equation. Their findings indicated the reliability of this method for energy loss calculations. Elaborating on their methodology, a similar approach was applied in the recent study to assess flow characteristics. The experimental results were subsequently compared with those obtained by Kamyab Moghaddam et al., with the aim of evaluating the model's accuracy (12). To simulate the Ogee spillway, the required geometry and parameters were similar to the aforementioned spillway, with the removal of steps while maintaining the slope of the spillway body.

MESHING AND NETWORK PRODUCTION

In both simulations, considering the flow conditions and employing different networks to address the problem, the solution field was appropriately divided by suitable networks. Crucial areas were covered with finer grids, and the model meshing was performed using Gambit software. A paver pattern was utilized in the meshing process. The dimensions of the elements at the inlet and outlet boundaries of the flow were set to 0.005 and 0.002 meters, respectively. For the other boundaries of the solution domain (air boundaries), larger elements with dimensions ranging from 0.006 to 0.012 meters were used. Initially, greater mesh density was assigned to the crown and the sloping part, and during the solution process, it was increased around the free surface to enhance the accuracy of the calculations.

MODEL SETUP

After entering the generated network into the numerical model environment, the following settings were made:

- Two-dimensional model with second degree accuracy
- steady - solution method
- VOF - free surface tracking method
- Velocity-pressure coupling by SIMPLE method
- Separation of the pressure equation with the PRESTO model!
- Separation of equations with the second-order upwind model

RESULTS OF NUMERICAL ANALYSIS

The results of the numerical analysis are presented in the form of velocity vectors and the profile of the free surface of the flow in Figures (3) and (4). Different colors are utilized to depict the water level. Figure (5) displays the velocity vectors on the crest of the Ogee spillway, while Figure (6) illustrates the velocity vectors on step number 5 of the stepped spillway.

International Journal of Current Science Research and Review
ISSN: 2581-8341
Volume 06 Issue 11 November 2023
DOI: 10.47191/ijcsrr/V6-i11-40, Impact Factor: 6.789
IJCSRR @ 2023

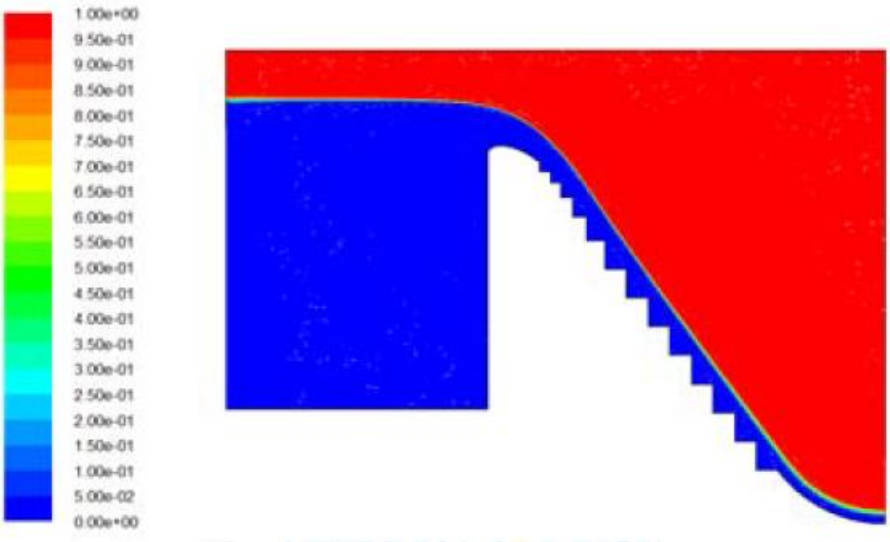

Figure 1. The profile of the free water surface on the stepped spillway

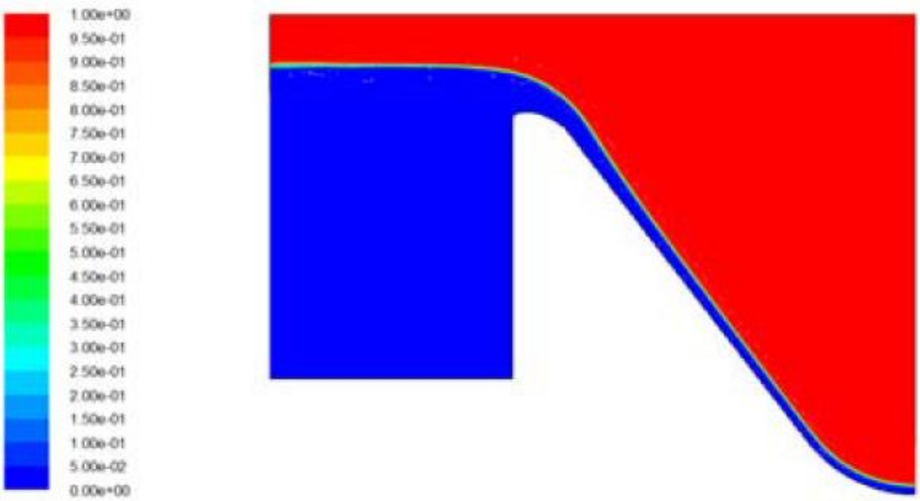

Figure 2. The profile of the free water surface on the Ogee spillways

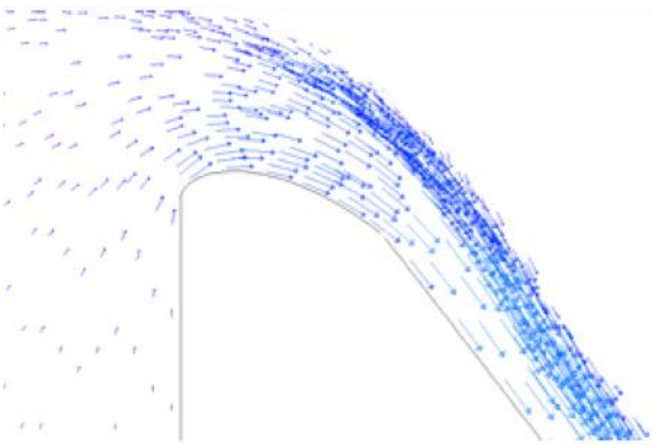

Figure 3. Velocity vectors on the spillway crest

International Journal of Current Science Research and Review
ISSN: 2581-8341
Volume 06 Issue 11 November 2023
DOI: 10.47191/ijcsrr/V6-i11-40, Impact Factor: 6.789
IJCSRR @ 2023

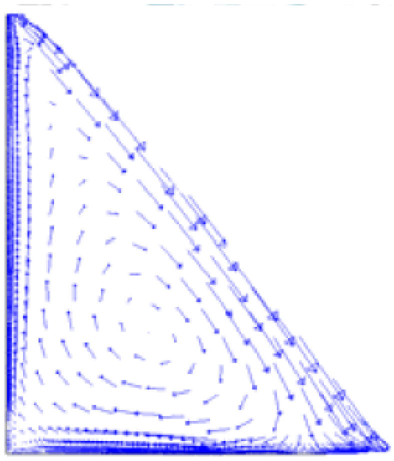

Figure 4. Velocity vectors on step number 5

CALCULATION OF ENERGY LOSS

The calculation of the energy upstream of the spillway crown (H1) is as follows:

$$H_1 = y_1 + \frac{v_1^2}{2g} \quad (1)$$

Where y1 represents the water depth upstream of the spillway, v1 is the velocity approaching the spillway, and g denotes the acceleration due to gravity.

To calculate the energy downstream of the spillway H2 the following relationship is used:

$$H_2 = y_2 + \frac{v_2^2}{2g} = y_2 + \frac{q^2}{2gy_2^2} \quad (2)$$

In the above relationship, y2 is the depth of water at the bottom of the spillway and q is the discharge per unit width. The amount of relative energy loss is defined as follows:

$$\frac{\Delta H}{H2} = \frac{H2 - H1}{H1} \qquad (3)$$

The energy dissipation in stepped and Ogee spillways has been compared by the fluid volume method and it has been shown that the relative energy dissipation in stepped spillways has increased by 80.9% compared to Ogee spillways. The results of the simulation of the flow on stepped and Ogee spillways in the present study are shown in Table (1). As it is evident in this table, the relative amount of energy dissipation in stepped spillway has increased by 75.95% from Saturday to Ogee spillway (13,14).

Table 1. Energy dissipation values using the parameters obtained from the numerical model

Spillway	*Y1*	*Y2*	*H1*	*H2*	$\frac{\Delta H}{H1}$ (%)
Stepped Spillway	0.8270	0.0223	0.8277	0.4762	42.4600
Ogee	0.8270	0.0200	0.8277	0.5863	24.1340

Another method for comparing the amount of energy loss in stepped and Ogee spillways is described as follows:

$$\frac{\Delta H}{H1y} = \frac{H2S - H2}{H2y} \qquad (4)$$

where H2S is the amount of energy downstream of the Ogee spillway and H2 is the amount of energy loss downstream of the stepped spillway, using formula (4), the relative energy dissipation is equal to 18.7755 (15,16).

CONCLUSION

The RSM turbulence model combined with the VOF method was used to simulate the flow over the corresbasining step and Ogee spillways. The numerical results obtained from the implementation of the Fluent software and their comparison with the research results of previous researchers can be seen. The software is suitable for numerical modeling of flow on spillways. Also, according to the obtained results, using a numerical model to simulate the flow on a stepped spillway and a Ogee because of saving a lot of time and money. Its bottom is recommended compared to the physical (laboratory) model.

REFERENCES

1. Xiong K, Weng Y hong, He Y long. Seismic failure modes and seismic safety of Hardfill dam. Water Science and Engineering. 2013 Apr 1;6(2):199–214.
2. Jin F, Hu W, Pan J, Yang J, Wang J, Zhang C. Chapter 19 - Comparative Study Procedure for the Safety Evaluation of High Arch Dams1. In: Zhang C, Jin F, Wang J, Xu Y, editors. Seismic Safety Evaluation of Concrete Dams [Internet]. Butterworth-Heinemann; 2013 [cited 2023 Nov 21]. p. 429–58. Available from: https://www.sciencedirect.com/science/article/pii/B9780124080836000192
3. Stefanovski JD, Dimirovski GM. Automated Open-Canal Water-Supply Systems. IFAC Proceedings Volumes. 2001 May 1;34(3):189–94.
4. Ahmad M ud D, Stein A, Bastiaanssen WGM. Estimation of disaggregated canal water deliveries in Pakistan using geomatics. International Journal of Applied Earth Observation and Geoinformation. 2004 Nov 1;6(1):63–75.
5. Chatila J, Tabbara M. Computational modeling of flow over an ogee spillway. Computers & Structures. 2004 Sep 1;82(22):1805–12.
6. Tabbara M, Chatila J, Awwad R. Computational simulation of flow over stepped spillways. Computers & Structures. 2005 Oct 1;83(27):2215–24.
7. Wang Z, Bowles DS. Dam breach simulations with multiple breach locations under wind and wave actions. Advances in Water Resources. 2006 Aug 1;29(8):1222–37.
8. Gualtieri C, Chanson H. Physical and numerical modelling of air-water flows: An Introductory Overview. Environmental Modelling & Software. 2021 Sep 1;143:105109.
9. Yu S, Yue F, Zhang Q, Chen Z, Yin P, Hao J, et al. Geobag stepped spillway for check dams: A pilot study. International Journal of Sediment Research. 2023 Feb 1;38(1):115–27.
10. Reeve DE, Zuhaira AA, Karunarathna H. Computational investigation of hydraulic performance variation with geometry in gabion stepped spillways. Water Science and Engineering. 2019 Mar 1;12(1):62–72.
11. Coker AK. CHAPTER 1 - Numerical Computation. In: Coker AK, editor. Fortran Programs for Chemical Process Design, Analysis, and Simulation [Internet]. Houston: Gulf Professional Publishing; 1995 [cited 2023 May 29]. p. 1–102. Available from: https://www.sciencedirect.com/science/article/pii/B9780884152804500029
12. Kamyab Moghaddam A, Hamedi A, Amirahmadian S. Experimental Study of Energy Loss in a Stepped Spillway Equipped with Inclined Steps in the Nappe and Skimming Flow Regimes. International Journal of Science and Engineering Applications. 2022;11(12):346–50.
13. Chanson H, Aoki S ichi, Maruyama M. Unsteady air bubble entrainment and detrainment at a plunging breaker: dominant time scales and similarity of water level variations. Coastal Engineering. 2002 Jul 1;46(2):139–57.

International Journal of Current Science Research and Review
ISSN: 2581-8341
Volume 06 Issue 11 November 2023
DOI: 10.47191/ijcsrr/V6-i11-40, Impact Factor: 6.789
IJCSRR @ 2023

14. Takahashi M, Gonzalez CA, Chanson H. Self-aeration and turbulence in a stepped channel: Influence of cavity surface roughness. International Journal of Multiphase Flow. 2006 Dec 1;32(12):1370–85.
15. Narayanan V, Seyed-Yagoobi J, Page RH. An experimental study of fluid mechanics and heat transfer in an impinging slot jet flow. International Journal of Heat and Mass Transfer. 2004 Apr 1;47(8):1827–45.
16. Rao SS. 17 - Basic Equations of Fluid Mechanics. In: Rao SS, editor. The Finite Element Method in Engineering (Fourth Edition) [Internet]. Burlington: Butterworth-Heinemann; 2005 [cited 2023 Nov 21]. p. 557–74. Available from: https://www.sciencedirect.com/science/article/pii/B9780750678285500184