Transitional Steps Zone in Steeply Sloping Stepped Spillways

Jalal Attari[1] and Mohammad Sarfaraz [2]

1- Assistant Professor, Power and Water University of Technology, Iran
2- Graduate Student, Department of Civil Engineering, Sharif University of Technology, Iran

attari@pwut.ac.ir

Abstract

Construction of large dams, using roller compacted concrete (RCC) technique, allows for steeply stepped spillways to form part of the dam body which leads into cost and time saving. If the ogee spillway crest and stepped chute profile are joined without a transitional stepped zone, the flow behavior would be unfavorable for low discharges. The flow falls on the bottom of first steps, springs out like a jet and impinges on some steps further downstream. This process of flow separation from the stepped bottom and successive impingement may cause significant damage on the steps. This paper presents the importance and need for the transition steps to join the ogee crest profile and the stepped chute. For this purpose, physical as well as numerical modeling was employed on a case study. The original design was modified by introducing a transitional stepped zone, in accordance with the CEDEX profile, and results showed a favorable flow pattern. Furthermore, the good agreement of the numerical results with physical modeling observations highlights the advantage of hybrid modeling for hydraulic structures.

Keywords: Stepped Spillways, RCC dams, Transitional Steps Zone, Physical modeling, Numerical Modeling

1. INTRODUCTION

Stepped spillways are playing a new role following developments in the field of construction technology and in view of the need to improve the visual impact of hydraulic structures used for dissipating energy of flood release from dams, effectively reducing the size of the energy dissipation basin required downstream and, hence cut costs [1]. Construction of large dams using roller compacted concrete (RCC) technique, allows for the stepped spillways to form part of the dam body, which leads into cost and time saving. This procedure results a steeply sloping stepped spillway with the slope of more than 50 degrees [2, 3].

A typical stepped spillway is divided into two distinct regions: the more or less conventional crest profile and the stepped chute. Until now, standard design procedures in the literature do not involve how to join these two regions [2]. So the designers attach the stepped chute directly to the point of tangency in the crest profile (see figure1).

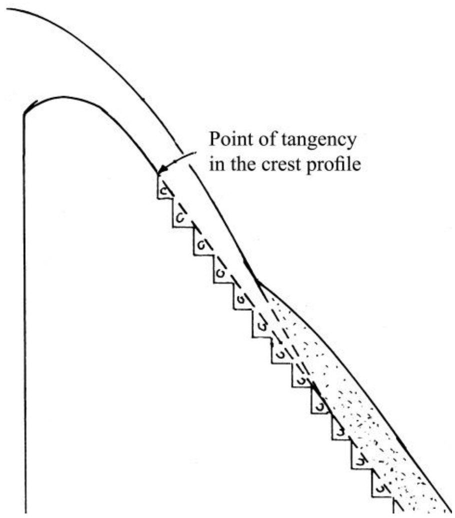

Figure1. Configuration of conventional design of stepped spillways [2]

In the small discharges, the flow falls like a jet onto the first step, the full impact hitting the tread of the step, and thus leaves horizontally, thereby missing the intermediate steps and so causing greater problems with successive impacts [2, 4]. If the first step is relatively large by comparison with the surface flow and the latter is swift, a springboard effect tales place and the surface flow tends to jump [2, 4]. When the discharge increases, the jump disappears. The solution of this problem is suggested by CEDEX hydraulic laboratory, throgh using a transitional stepped zone, joining the crest profile to the stepped chute [4, 5]. The step height of this region is followed by the design head (H_d) as illustrated in the figure2. The first small step is located with the horizontal distance of $H_d/3$ to the crest and the other steps follow the figure procedure until the last reaches the point of tangency [4, 5]. From this point to the end of the chute, a fixed stepped chute with the design height (h) and length (l) is positioned.

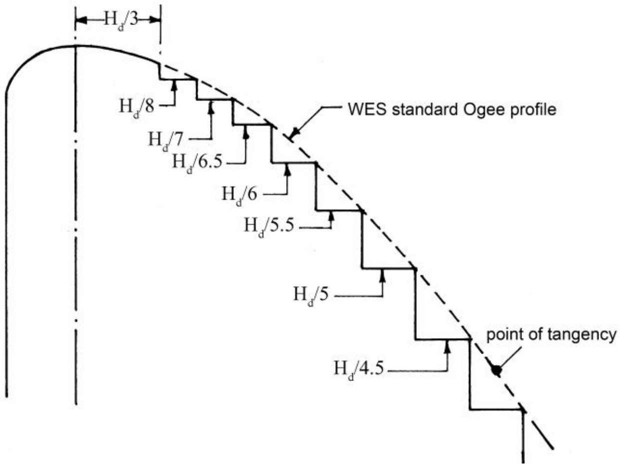

Figure 2. Proposed transitional steps zone by CEDEX [4, 5]

This paper concerns this problem in two physical models of a steeply sloping stepped spillway and presents a solution to it, both by physical and numerical models.

2. PHYSICAL MODELS EXPLANATION

In order to investigate the flow behavior adjacent to the tangency point in the stepped chute, two physical models of stepped spillway were constructed in the Water Research Institute (WRI) in Iran, having same design parameters, i.e. step height and its length, unit discharge and slope of the chute.

In the first option (figure 3), the crest profile was joined to the stepped chute, having no transition zone, i.e. using conventional design as demonstrated in the figure1.

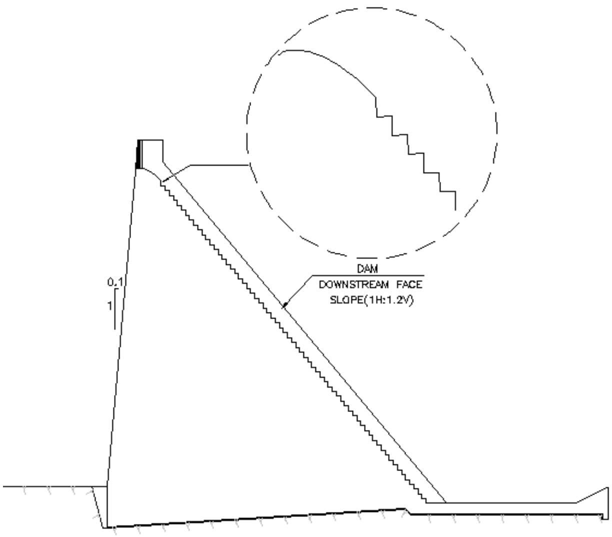

Figure 3. Schematic diagram of the first physical model, conventional design [2]

In the second model, figure 4, the crest profile and the stepped chute was joined by a transitional smaller steppes, as indicated by CEDEX (Figure 2).

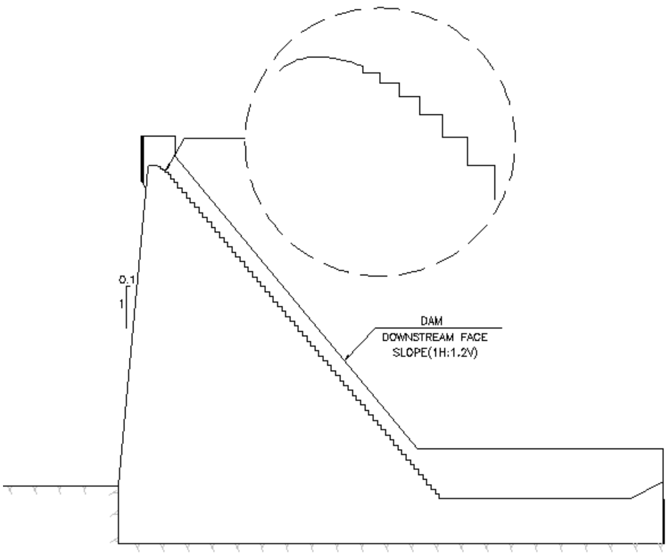

Figure 4. Schematic diagram of the second physical model, having the transitional stepped zone [2]

3. Numerical Model

The commercially available Computational Fluid Dynamics program (Flow-3D) was used for solving the Reynolds-averaged Navier-Stokes equations in combination with the RNG k-ε eddy-viscosity closure model. The software solves the fully three dimensional transient Navier-Stokes equations using the FAVOR[1] and VOF method [6]. The solver uses finite volume approximation to discretize the computational domain. The pressure and velocity are coupled implicitly by using the time-advanced pressures in the momentum equations and time-advanced velocities in the continuity equations. It solves these semi-implicit equations iteratively using relaxation techniques. FAVOR defines solid boundaries and determines fractions of areas and volumes (open to flow) in partially blocked volume to compute flows correspondent to those boundaries. In this way, boundaries and obstacles are defined independently of grid generation, avoiding saw tooth representation of the use of body-fitted grids. The RNG model was selected for the current simulation based on the recommendations of [6].

4. Results and Analysis

As mentioned before, this paper focuses on the inflow condition of the stepped spillway. So the presented results are given for this region.

4.1. Conventional Design (No Transitional Steps)

Figure 5 shows the inflow condition of the first model, with the low discharge equal to $50 m^3/s$. As it is shown the flow hits the first step, then leaves it horizontally and passes nine steps, hitting the thirteenth steps and this spring board effect continues to the end of the chute.

[1] Fractional Area/Volume Obstacle Representation

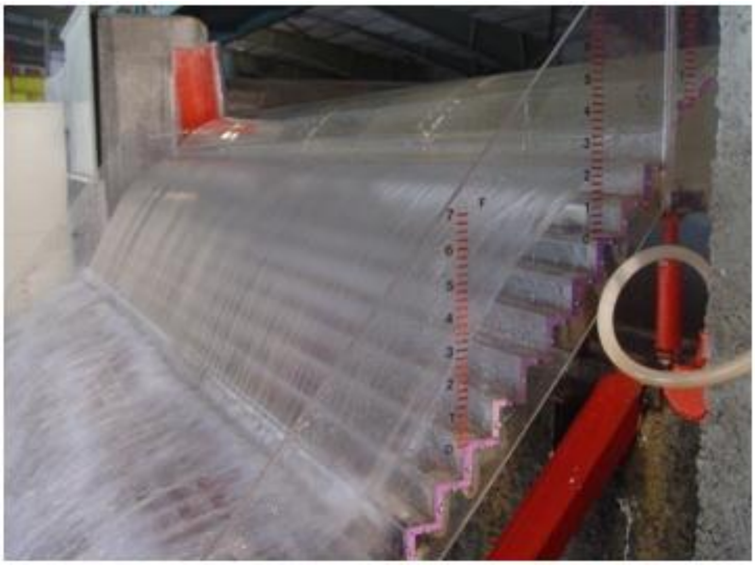

Figure 5. Spring board effect in the conventional design of physical model, passing low discharge

Figure 6 presents the result of the numerical model in the same discharge. This also indicates that numerical modeling is capable enough to capture the free surface of flow and showing the spring board effect in the low discharge.

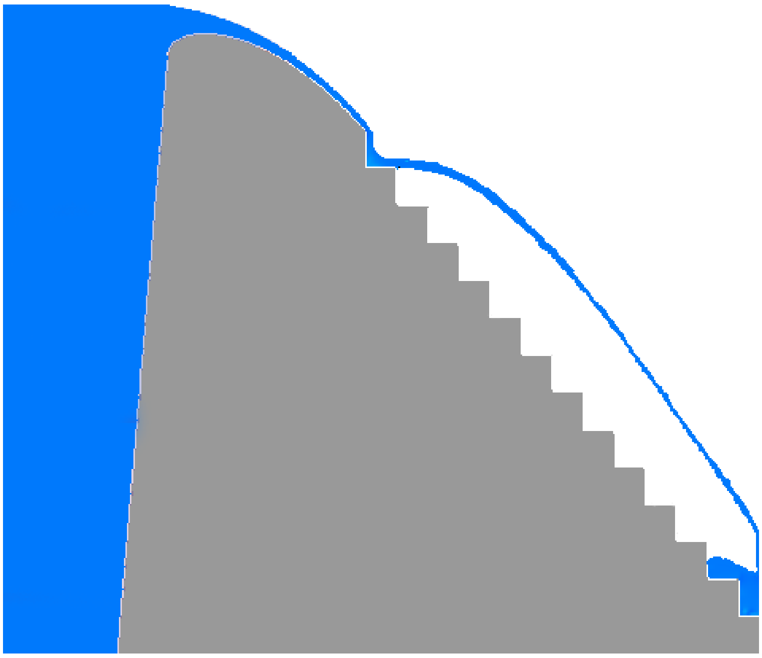

Figure 6. Spring board effect in the conventional design of numerical model, passing low discharge

4.2. Importing Transitional Steps

Figure 7 illustrates inflow condition of low discharge equal to $50m^3/s$ in the physical model having transitional steps. It is clear that the spring board effect is eliminated by using the transitional steps zone.

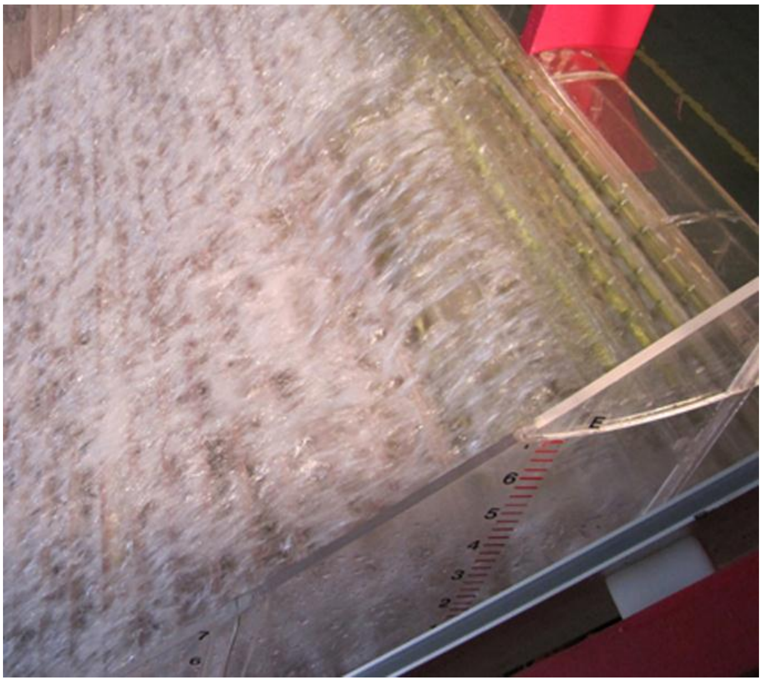

Figure 7. Regulated flow in the proposed design of physical model, passing low discharge

Figure 8 illustrates result of the numerical model for the same discharge. It also indicates that numerical modeling is capable enough to capture the free surface of flow and showing the regulated flow in the low discharge.

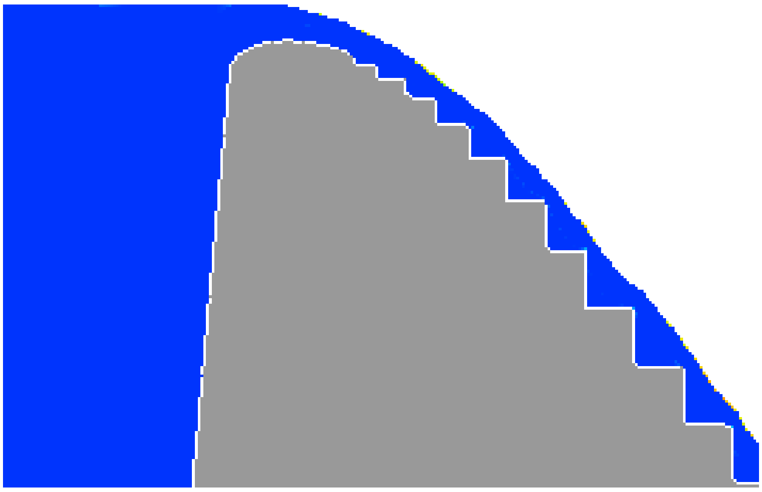

Figure 8. Regulated flow in the proposed design of numerical model, passing low discharge

5. CONCLUSIONS

This paper indicates that the ogee spillway crest and the stepped chute profile must be joined by the appropriate transition zone, in accordance with the CEDEX profile, to regulate the flow after leaving the crest and before reaching the stepped chute. This zone eliminates the flow jump in the low discharges, if the conventional design is used. Also flow patterns predicted by numerical simulations were in a good agreement with the physical modeling observations. This points out that a proper numerical modeling of the proposed design before construction the physical model, will result in cost and time saving of the project.

6. ACKNOWLEDGMENT

The physical model tests were carried out in the Water Research Institute in Tehran, Iran as a part of assignment by the Iran Water and Power Development Company. The authors are grateful to them for their sincere co-operation.

7. REFERENCES

1. Chanson, H. (2001). *"The Hydraulics of Stepped Chutes and Spillways"*, A. A.Balkema, Lisse, pp. 375.

2. Sarfaraz, M. (2010). *"Hydraulic Design and Modeling of Stepped Spillways Located on RCC Dams, Case Study: Javeh RCC Dam"*, BSc. thesis, Power and Water University of Technology, Tehran, Iran, (in Farsi).

3. Minor, H.E., and Hager, W.H. (2000). *"Hydraulics of Stepped Spillways"*, A. A.Balkema, Rotterdam, pp. 201.

4. Matos, H. and Elviro V. (2000), *"Stepped Spillways. Design for the Transition between the Spillway Crest and the Steps"*, Hydraulic Laboratory of CEDEX, Spain, HYDRA, pp. 260-265.

5. Khatsuria, R.M., (2005), *"Hydraulics of Spillways and Energy Dissipators"*, Marcel Dekker, New York, U.S.A., pp. 95-127.

6. Sarfaraz, M. and Attari, J. (2011), *"Numerical Simulation of Uniform Flow Region over a Steeply Sloping Stepped Spillway"*, 6th National Congress on Civil Engineering, Semnan University, Semnan, Iran.