Three-Dimensional Numerical Simulation of Two-Phase Flow overThree-Side ChannelSpillway ofShahr-Chay Dam

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Abstract

Three-side channel spillways in certain topographical conditions as a dam drainage channel, despite hydraulic constraints, are supposed to be the best option. High energy fatalities, stream turbulence and extensive oscillating blows on the floor and lateral channel walls are considered as an outstanding hydraulic condition that should be scrutinized. In this study, the flow over the crest of the three-side channel spillway of shahr-chay dam and the side channel to its endsill is modeled numerically and in three dimensions in real dimensions using FLUENT software. Comparison of the numerical results with the experimental data shows that this model is capable of predicting the three-dimensional flow pattern.

Investigation of the flow pattern of the spillway crest and side channel,indicates the asymmetric turbulence of the flow surface relative to the central longitudinal axis of the spillway due to the asymmetric geometry of the spillway crest. The lateral channel is not capable of sufficiently damping the water surface turbulence and vortex streams continue to sill. Also this spillway has the ability to pass the design flood flow despite the occurrence of submergence in spillway crest and its effect on spillway drainage.

Keywords: Three-side channel spillway, FLUENT software, Flow pattern, Turbulence

1. Introduction

Three-side channel spillways are one of the types of dam's drainage channel which, despite the hydraulic constraints, are the best option under certain topographical conditions. Three side spillways are a special type of side spillways in which the flow enters the side channel from the front and sides of the spillway [1].In areas where limiting the height of the dam by increasing the length of the spillway crest should be considered and On the other hand, the sides of the dam supports have a steep slope, so that the spillway crest cannot be located along the axis of the dam,using these spillways would be the most appropriate option[2]. Advantages of this type of spillway include increasing the effective length of the spillway crest in a limited width, a significant increase in the flow rate with slight changes in the upstream water flow head, and no spillway crest submergence to very large heads [3].

Turbulence and severe oscillations of water on the floor and side channel walls and the possibility of spillover disturbances downstream of the spillway and the structure of the spillway terminal are among the adverse hydraulic conditions in these spillways that need to be carefully investigated [2]. The turbulence and pressure fluctuations in the lateral channel of these overflows are high so that no specific dynamic equation can be presented for the water surface profile [4].

As can be seen in Figure 1, In three-side spillways , the inlet flow to the lateral channel from the baseline of the spillways crest(Along the channel), Helps to flow water into the channel.This flow transmits waves and surface perturbations of flow within the lateral channel to the chute. If necessary, lateral channel disturbances (adjustment basin) are eliminated and deprecated flow enter the chute.

The flow coming from the sides of the weir crest collides in the middle of the basin,As a result, the flow energy decreases and the water level rises and As a result, the flow energy decreases and the water level rises and becomes a bulge [5].

Figure 1. Three side spillway plan and profile

Limited studies have been performed on the hydraulic performance of three side spillways and so far, there has not been a complete and accurate method for designing spillways.Often, by trying to build a hydraulic model and modify the parameters affecting the hydraulic performance of these spillways, the model has achieved optimal geometrical and hydraulic conditions of the model and generalized the results to the original sample [4].Because of the cost and time consuming studies of hydraulic models and on the other hand, the complexity of the geometry and hydraulic phenomena occurring within the three-sided spillway channelcompared to other types of spillways, the optimal hydraulic performance of the three side spillways even after construction is questioned.

There have been many studies so far to understand the relationship between effective parameters and how they affect the flow over one-sided spillways,Included in these studies are the works of Hinds(1926), Farney and Markus(1962), Yen and Wenzel(1970), Bremen and Hager(1989) and Kouchakzadeh et. Al (2002).But there are few studies on the hydraulic performance of three-side spillways and most work has focused on improving and improving the hydraulic performance of the flow over these spillways.Examples include the Farney (1962), Knight (1989) and water Research Center studies.Studies by the Water Research Center have been carried out on hydraulic models of three dams in Iran, namely ShahidYaaghoobi, Jareh and Sivand.These studies focused on determining optimized values for three design parameters: side channel bed slope, the appropriate elevation and shape of the end sill for the spillways.Farney and KnightStudies on the discharge coefficient and the rate of drainage of hydraulic models of these spillways [2].

Montazar and Salehi (2006), studied a number of parameters affecting the hydraulic performance of these spillways. In this studyby defining pressure fluctuations as the objective function and parameters such as sill height, sill location and lateral channel slopeas effective parameters, more detailed studies were performed on these spillways.They conclude that increasing the sill height has a significant effect on decreasing the flow turbulence and pressure fluctuations in these spillways and changing the sill location has little effect on turbulence [4].

Mina et. al. (2016), analyzed numerically the discharge capacity and the possibility of cavitation phenomenon occurring in the divergent three side spillway.The results showed that by increasing the flow head on the spillway,gradually, the amount of spillway discharge coefficient tends to be constant. Also, the use of lateral arms of spillway crest has a positive effect on the rate of discharge coefficient [5].

Bagherzadeh and Manafpour (2017), numerically simulated a three-dimensional flow field over a three-sided U-shaped spillway and into the lateral channel using the MPS semi-implicit Lagrangian method.Comparison of numerical results with experimental data showed that this model is capable of predicting the three-dimensional model of the current. Also the comparison of the results of Lagrangian numerical model with Eulerian numerical model shows that Lagrangian method is more accurate than Eulerian method [3].

In this study, the flow through the spillway crest of the three sides of the UrmiaShahrchay Dam and the side channel to its end sill is modeled numerically and in three dimensions in real dimensions using FLUENT software and the spillway capability in evacuation of design flowrate with sufficient safety and the possibility of depreciation of flow turbulence in the side channel is investigated.

2. Introducing Three Side spillway of Shahr-chay Dam

1, 2. Spillway

The present study was carried out on three side spillway of Shahr-chay dam.This dam is an earth dam located 15 kilometers from the city of Urmia on the river shahr-chay.The spillway with a crest length of 147.22 m was constructed on the left bank of the dam and It is generally composed of two crest of 1580 (50 m) and 1581.5 (97.22 m) levels.Hydraulic properties of the three-side spillway flow including depth, velocity and pressure for a maximumdischarge of 1900 m^3 / s were investigated and the results of numerical model were compared with physical model.Figure 2 shows the plan and longitudinal profile of the three side spillway of the Shahr-chayDam [6].

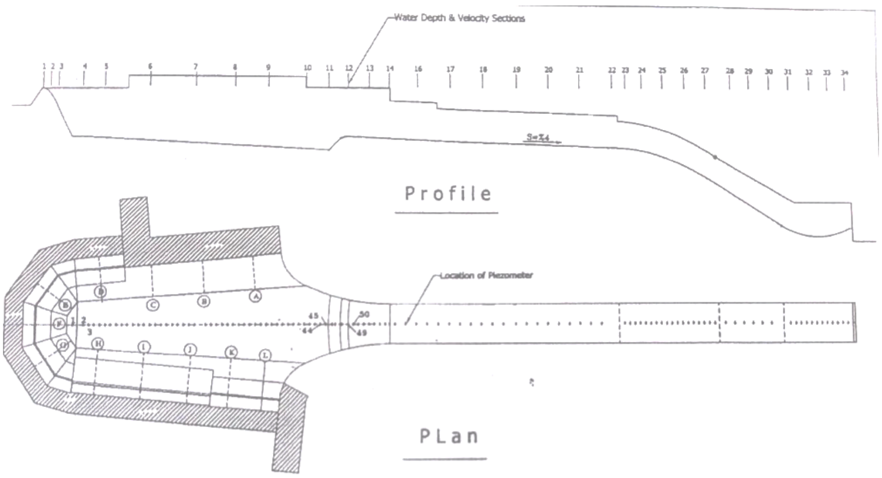

Figure 2. The plan and longitudinal profile of the three side spillway of the Shahr-chay Dam.

1, 2. Physical model of spillway

To calibrate and test the numerical model, the experimental data of the 1:40 scale hydraulic model of the Shahr-chay Dam spillway at the Water Research Institute were used. The major hydraulic variables measured are: Water level profiles, flow velocity and piezometric pressureon spillway sureface,the floor of chute and bucket.The equipment used to measure the above variables are:Piezometer,Pitot tube and Pressure transducer [6].

3. Simulate the flow through the three-side spillway crest

1, 3. The governing equations

In this study, by examining the possibilities and limitations of the available software, FLUENT software was used to simulate the flow field in a three-sided spillway.The laws that govern the process are the law of continuity and momentum that in turbulent flow mode, the averaged Reynolds-Navier-Stokes equations are derived from the form of relations 1 and 2.

$$\frac{\partial u_i}{\partial x_i} = 0 \qquad (1)$$

$$\rho\left[\frac{\partial \overline{u_i}}{\partial t} + \overline{u_j}\frac{\partial \overline{u_i}}{\partial x_j}\right] = B_i - \frac{\partial \overline{p}}{\partial x_i} + \frac{\partial}{\partial x_i}\left[\mu\frac{\partial \overline{u_i}}{\partial x_j} - \rho\overline{u_i^{'}u_j^{'}}\right] \qquad (2)$$

Where, u_i is the velocity component in the x_i direction, p Pressure, ρ density, μ Dynamic viscosity and The $-\rho \overline{u_i^{'} u_j^{'}}$ sentences are known as Reynolds stressesWhich must be calculated using the appropriate turbulence model.

k-ƐRNGturbulence model, includes two transmission equations for turbulence kinetic energy (k) and turbulence kinetic energy dissipation rate (ε)to obtain Reynolds stresses and eddy viscosity.

Turbulence kinetic energy equation (k):

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_i}(\rho k u_i)=\frac{\partial}{\partial x_j}[\alpha_k \mu_{eff} \frac{\partial k}{\partial x_j}]+G_k+G_b-\rho\varepsilon-Y_M+S_k \quad (3)$$

Turbulence kinetic energy dissipation rate equation (ε):

$$\frac{\partial}{\partial t}(\rho \varepsilon)+\frac{\partial}{\partial x_i}(\rho \varepsilon u_i)=\frac{\partial}{\partial x_j}[\alpha_\varepsilon \mu_{eff} \frac{\partial \varepsilon}{\partial x_j}]+C_{1\varepsilon}\frac{\varepsilon}{k}(G_k+C_{3\varepsilon}G_b)-C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}+S_\varepsilon \quad (4)$$

In these equations G_k, represents the turbulent kinetic energy production due to the changes in the mean velocity gradient.G_b is the generation of turbulent kinetic energy due to buoyancy.Y_M shows the contribution of density changes in compressible bubbling currents to the total energy dissipation rate.. The values of α_ε and α_k are also the negative effects of the Prandtl number for the values of ε and k, respectively. S_εAnd$S_k$are also user-defined terms [7].

2, 3. Numerical spillway modeling

Numerical modeling of the three side spillway of Shahr-Chay dam including reservoir, three side spillwaycrest and lateral channel to its end sill using the k-Ɛ RNG turbulence model and the VOF finite volume method, with FLUENT19 software has been implemented in the actual dimensionsfor the discharge design of the 1900 m^3/s .AUTOCAD software was used to create the overflow geometry and ICEM software was used to generate the mesh and boundary conditions.After many attempts and errors, the computational cell dimensions between 0.8 and 1.3 m were detected for spillway and used as mesh dimensions so that in areas with high gradient and spillway floor, finer elements and in areas far from the flow, larger mesh was chosen to reduce mesh size and computation time.

The spillway model and boundary conditions are presented in Figure 3.In upstream two inputs with an inlet velocity and inlet pressure boundary condition are used to bring the water and air into the stream.For the downstream model the outlet pressure boundary condition means that the current enters the atmosphere and for the free flow surface the inlet pressure boundary condition that is in contact with the atmospheric pressure is also used as the boundary condition of the wall for the other numerical models.

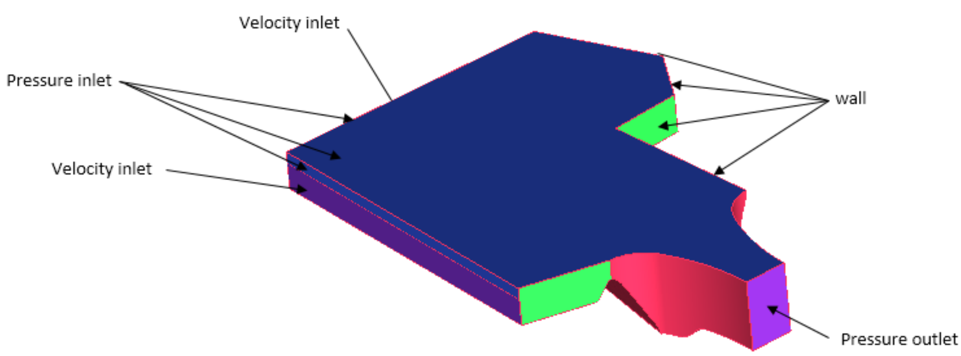

Figure 3. Spillway model and boundary conditions

4. Results and Discussion

For the numerical model validation, the experimental data of the three-side spillway physical model of the Shahr-chay Dam is used.For this purpose, profiles of depth and mean velocity of flow on the central axis of the channel were drawn for experimental and numerical values.Then, the flow pattern and water level changes in the transverse sections were studied.

1, 4. Longitudinal flow profile at the central axis

Fig. 4 shows the longitudinal profile of the flow at the central axis in the numerical model with experimental values for the flow rate of 1900 m^3 / s.value of R2 = 0.96 between the numerical and experimental data indicates that there is a good correlation between the experimental results and the numerical model.According to the figure, the flow profile enters the lateral channel after crossing the spillway crest and the bulge is formed in this area due to interference with the lateral streams.

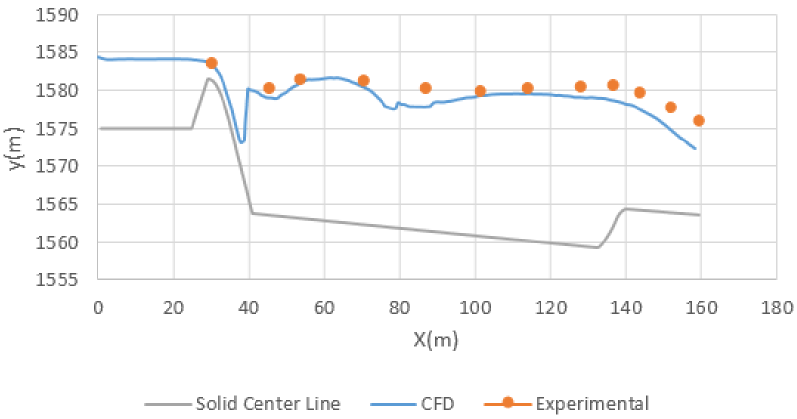

Figure 4. Longitudinal profile of flow in the central axis of the spillway for the flow rate of 1900 m^3 / s

2, 4. Flow velocity profiles around the end sill

Figure 5 shows the results of the average velocity obtained from the numerical and experimental models.The results show that within the lateral channel the average flow velocity is almost constant, and eventually the flow velocity gradually increases as the flow passes over the sill and changes from sub-critical to supercritical flow conditions.

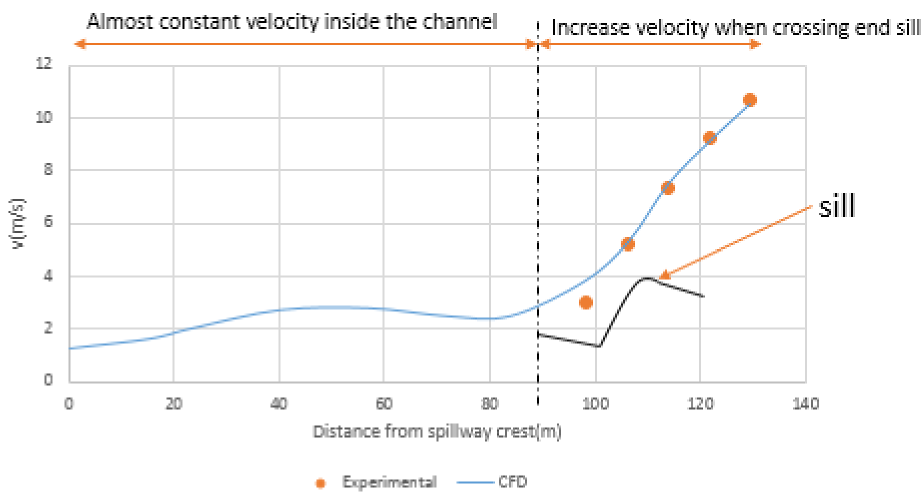

Figure 5. Longitudinal profile of the mean flow velocity along the lateral channel of the spillway

3, 4. Passing flow pattern

Figure 6 shows the flow inside the side channel.Due to the asymmetric shape of the three-side spillway at the beginning of the channel, the flow enters the lateral channel after crossing the spillway crest and hydraulic jump occurs.Then the bulge is formed in this area due to interference with lateral flows.In the following due to the wall on the left side of the spillway channel, the downward flow from the right, drives the water into the channel to the left and Increases the height of water near the wall. According to the figurethis spillway has the ability to pass the design flood flow despite the occurrence of submergence in spillway crest and its effect on spillway drainage.

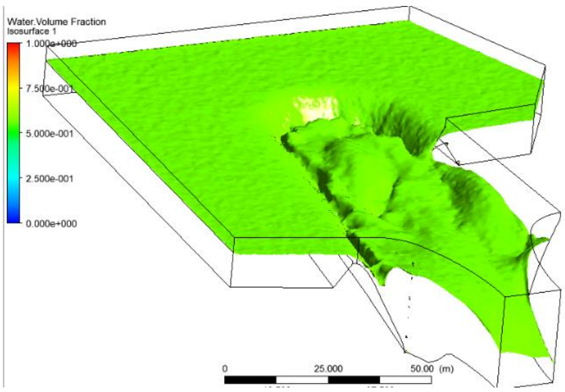

Figure 6. Flow inside the spillway side channel

4, 4. Transverse flow profile

In the present study, the transverse flow profile at sections H to O (Fig. 7) is derived.In this paper, four sections of H, I, N and O (Fig. 8) are reviewed.At the H-section, the flow enters the channel in all three directions, creating a bulge in the water surface.Next, near the end of the lateral channel, there is a difference in height and sharp transverse oscillations in the sections.These oscillations are due to the asymmetric geometry of the spillway crest.The lateral channel was not capable of sufficiently damping the water surface turbulence so that these oscillations entered the downstream chute as they crossed the end sill and it can significantly affect the hydraulic performance of the flow in the chute andspillway terminal structure.

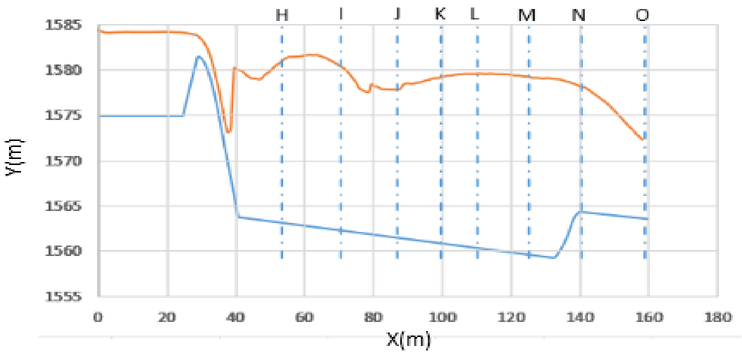

Figure 7. Position of the cross sections

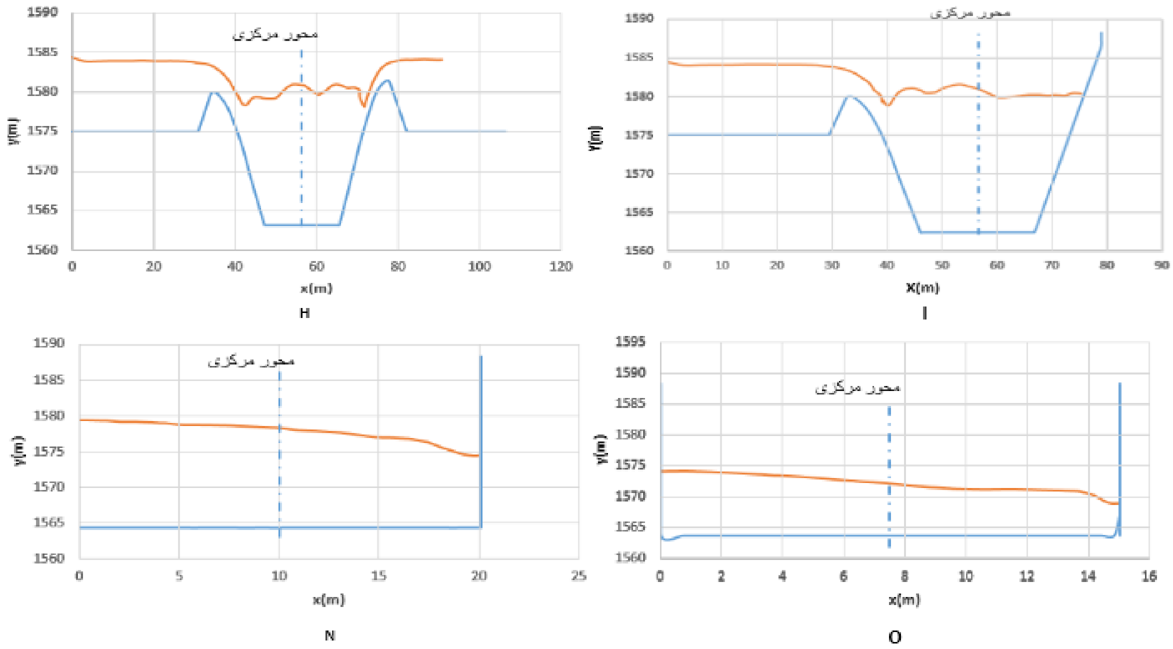

Figure 8. Transverse profile of water surface

5, 4. Investigate velocity field changes

Figure 9 shows the velocity vectors in four transverse sections (The position of the sections is shown in Figure 7).According to the figure, it can be seen that after the fall of the flow from the spillway crest, at the sides of the lateral channel, two rotational currents form after the collision of the downstream currents into the lateral channel and decreases the rotational power of these currents along the lateral channel.

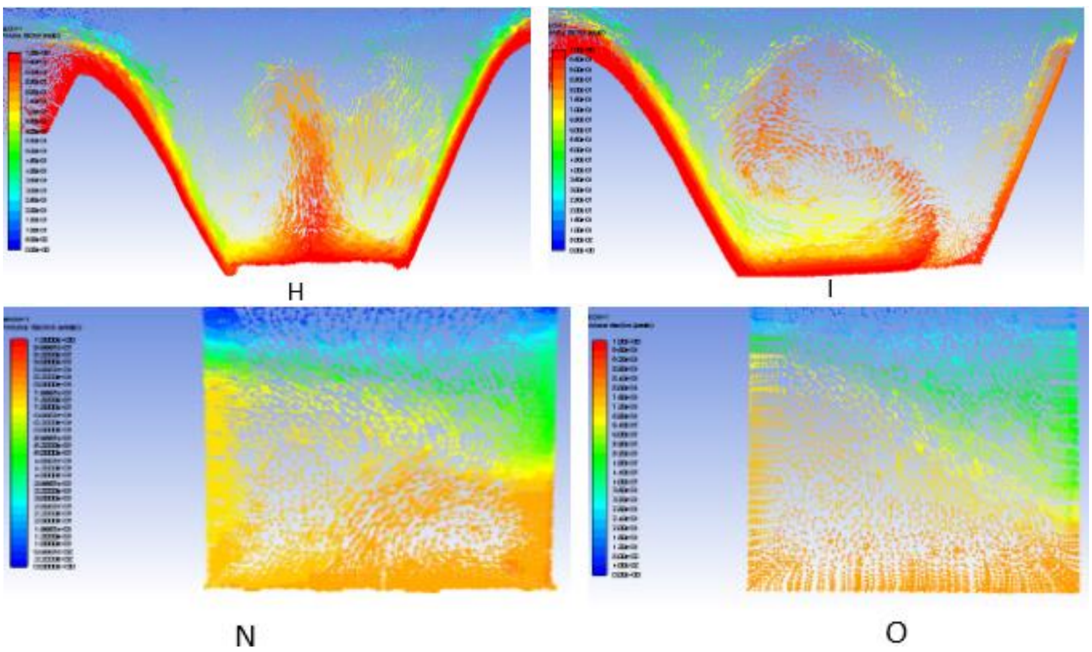

Figure 9. Display of velocity vectors

5. Conclusion

- ✓ Thek-ε RNG turbulence model has sufficient capability to solve the flow field crossing the three-side spillwayover the Shahr-chay Dam.
- ✓ Changes in flow velocity in the longitudinal section indicate thatwithin the lateral channel, the average flow velocity is almost constant and eventually increases as the flow passes over the end sill and changes the flow conditions from sub-critical to sub-critical.
- ✓ The phenomenon of local submergence occurred at the bottom of the spillwaycrest and the drainage coefficient decreased.
- ✓ As a result of collision flows from the overflow sides into the lateral channel, bulge are formed.
- ✓ Due to the non-uniformity of the transverse flow profiles, water surface oscillations entered the downstream chute as they crossed the end sill and it can significantly affect the hydraulic performance of the flow in the chute andspillway terminal structure.

6. References

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