# LABORATORY INVESTIGATION OF DOWNSTREAM SUBMERGENCE OF SHAFT SPILLWAY ON DISCHARGE EFFICIENCY

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***ABSTRACT:*** *Shaft spillway is one of the spillway types used to pass additional waters and floods from the upstream to the downstream of dams. In addition to providing adequate capacity, the spillway design should be sufficient hydraulically and structurally. The flow pattern, typical hydraulic conditions and the flow characteristics at shaft spillways would vary depending on the relative size of their various components. In this study, through the construction of a physical - hydraulic model of a shaft spillway, the impact of the spillway geometry on the hydraulic conditions of the stream was evaluated with performing 108 different experiments in the submerged conditions of this type of spillway. Then, in a part of the study, the relationship between* $C_d$ *and H/D was extracted with the help of regression, and the results were presented as graphs. The obtained results showed that at shaft spillways, the H/D submergence is inversely proportional to the discharge coefficient of the Cd flow rate.*

**Keywords:** Shaft spillway, Discharge coefficient, Submergence, flow pattern

## INTRODUCTION

Shaft spillway is a spillway composed of a circular crest that directs the flow to an inclined or vertical axis, which is connected to a low gradient tunnel. The axis connection to the tunnel is done by a bend with a proper radius that eventually transports the water to the dam downstream. There is a good reason to emphasize on the importance of a reliable spillway with appropriate conditions while constructing the dams, since the failure and destruction of different dams could have been the result of improper design of the spillways or using the spillways with insufficient capacity. It is preferred in embankment dams not to build a concrete spillway on the dam body, as the use of a spillway inside the dam reservoir and apart from the dam body will reduce the risk of scouring and saturation of the dam downstream shell. Also in the narrow valleys, while the technical requirements to implement other spillovers meet limitations, the use of shaft spillways would be a good choice [1]. In this type of spillways, if the flow passage is completely free, when the flow passage functions as half-full, the spillway control would be aperture control, and while it operates fully submerged, it would be flow control in the water pipe. In general, when the ratio of $\frac{H_0}{R_0}$ ($R_0$ is the radius of the shaft spillway crest) is smaller than 0.45, the control is at the spillway, and with increased value of this ratio, the submergence becomes more. When this value becomes greater than 1, the spillway will be completely submerged, and the discharge coefficient will strongly reduce [2]. For the energy load on the spillway crest, the spillway crest would be the controller. When the control is at the crest, in the turning vertical section after the crest, the flow would be half filled and inclined towards the wall. As the flow rate increases, the thickness of the jet stream will increase and suddenly turns into the full vertical fountain. Following the formation of water jet, the jetting mode will occupy the area above the split. For greater energy load, the jetting point occurs at a higher height and small vortices appear on the stream surface. After forming the branching and jetting points, the spillway submergence begins. From this stage then, control would be at the aperture [3]. In this case, the equation of the shaft spillways discharge is as follows:

$$Q = C_d \left(\frac{r}{0.275}\right)^2 H_a^{0.5} \qquad (1)$$

Where Q: Flow rate passing through the shaft spillway r: Conduit radius at the beginning of bottleneck, Ha: Height difference between the water level in the reservoir and the intended point. Figure 1 shows the details of the above relation. At the beginning, most of cylindrical spillways in the world were constructed in the United States, Portugal and Italy. As the input hopper is similar to the flowers bloomed in the morning, in English-speaking countries, such spillways are known to shaft spillways. The first type of this spillway was built in 1896 for the Blackton reservoir in England [4]. One of the main problems faced by these spillovers is creation of strong spiral vortices at their inlets. Quick proposed the Froude number for vortex modeling. He also suggested the use of Reynolds number for modeling vortex on some cases [5]. Vermin recommended the practical designing for shaft spillways [6]. He revealed that the tunnel channel should not be more than 75% full. This measure protects the channel against the raging currents or states of flows with negative pressure. Fatoor and Beschiga concluded that if the spillway is submerged in the shaft spillways, the value of flow rate would be 1.34 times of the flow rate in the free form (design) [7]. Also, in case of non-aeration to the water tunnel over the spillway, there will be a turbulent current there. Wagner noted that if the depth of water over the spillways' crest is more than 50 mm in the model, the effect of surface tension on the discharge coefficient would be insignificant and minor [8]. Bagheri and Nohani have examined impact of making the crest of weir multifaceted on discharge coefficient of shaft spillway [9]. Laboratory data analysis showed that spillway crest multifaceted increases the flow through and increases the discharge coefficient of shaft spillway and the most increase is obtained when the spillway crest is made three dimensionally.

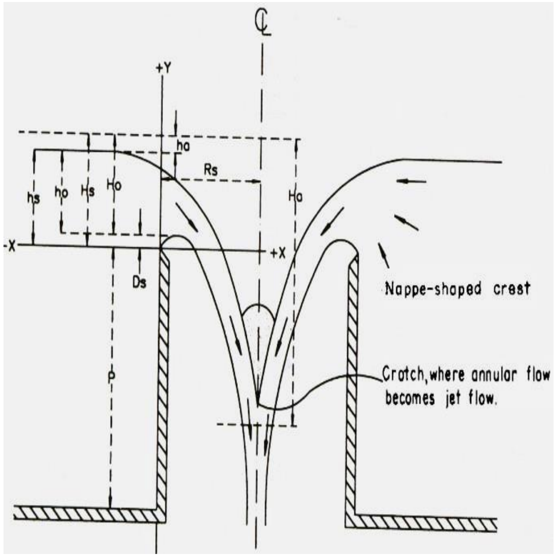


**Figure 1: Cross-section of a shaft spillway in aperture control condition**

## MATERIALS & METHODS

To do the necessary studies and achieve the research objectives, a physical model of the shaft spillway was made and tested in the hydraulic laboratory. The tank water was transferred and entered by 4 pumps with different flow rates and bypasses into the main flume. The flume with vertical tilt has the dimensions as: Width: 90 cm; Height: 30 cm; Length: 250 cm. The laboratory model of the shaft spillway was placed at the end of the flume at a distance of 45 cm from each side. Passing through the spillway and exit through the water tunnel, the water enters a flume (length: 90 cm, width: 60 cm and height: 30 cm). The outflow rate of the flume enters into another tank by a trapezoidal spillway where the flow rate is measured volumetrically. Then, the water is returned to the first tank by 4 pumps with the maximum flow rate of 660 liters per minute. Three different models of shaft spillways were built: First model with a crest diameter of 14 cm, the second model with crest diameter of 17 cm, the third model with crest diameter of 20 cm and the water tunnel with a length of 100 cm. The bodies of all models are identical and made of fiberglass. A number of 108 different experiments were performed on the spillway model. After preparation of the model, the water was pumped by the pumps from the main tank into the flume. Then, using a digital sounder (depth finder), the water height above the spillway crest was measured about 40 cm above the spillway entrance. After a while the situation was remained stable, the outlet flow entered the water flume through the shaft spillway tunnel, then entering the end tank, and was measured volumetrically. After reading the required data, the volume of the inflow was increased and previous steps were repeated. During each test, the values of flow rates and surface water over the spillway were controlled for several times to avoid any mistakes. The above procedure was done and repeated for different models of shaft spillways. The physical model constructed to be used in experiments carried out in the laboratory is shown in Figure 2.

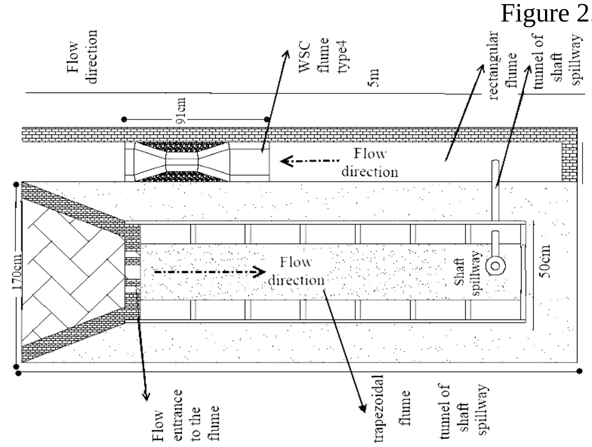


**Figure 2: General view of the physical hydraulic model used in the laboratory**

## RESULTS AND DISCUSSIONS

A general summarization of tests performed is listed in Table 1. Then, having the tables for each test, the discharge - height curves were drawn and the calculations of discharge coefficient of shaft spillway were done for the $H_0/R_s > 1$ mode using equation (1). After performing the tests, the discharge coefficient of the shaft spillway was calculated as follows: The value of flow rate passing through the spillway was divided by the computing flow rate, and the discharge coefficient was obtained. A summary of the results is shown in Table 2 and also as graph in Figure 3. The aim of this paper was to examine the impact of two parameters of spillway diameter (D) and the height of the water over the spillway (H) as two parameters affecting the discharge coefficient of the flow rate ($C_d$). Thus, after analyzing the laboratory results, the classical regression analysis was done to obtain an applied formula at laboratory scale to calculate the discharge coefficient of the flow rates of the shaft spillways according to Figure (4). The analysis was done between Cd as the output variable and the submergence ratio (H/D) as the input variable, and the equation (2) was defined and extracted.

$$C_d = 0.18(\frac{H}{D})^{-1.3} \qquad (2)$$

The data obtained can be used to achieve an overall and clear result. The observations show that in shaft spillways, by raising the water level over the spillway in case of submergence, the $C_d$ coefficient reduces. Also comparing the use of spillway with different diameters, by increasing the diameter of the spillway, the discharge coefficient ($C_d$) will increase. This indicates the effect of submergence ratio H/D on the discharge coefficient of the flow in the submerged state.

**.Table 1: Details of tests and physical models**

| Number of | Spillway crest | Bend curvature radius | Bend diameter (d) cm | Number of tests |
|---|---|---|---|---|
| 1 | 14 | 8 | 5.6 | 36 |
| 2 | 17 | 8.3 | 6.2 | 36 |
| 3 | 20 | 9 | 7.6 | 36 |

**Table 2: Results of the Cd calculations than to the submergence depth**

| $H$ | $D$ | $Q(m^3/s)$ | $Q_t$ | $C_d$ | $H/D$ |
|---|---|---|---|---|---|
| 0.12 | 0.14 | 0.0041 | 0.018 | 0.224 | 0.857 |
| 0.15 | 0.14 | 0.0043 | 0.025 | 0.168 | 1.071 |
| 0.17 | 0.14 | 0.0044 | 0.031 | 0.142 | 1.21 |
| 0.18 | 0.14 | 0.0046 | 0.036 | 0.126 | 1.28 |
| 0.12 | 0.17 | 0.0055 | 0.022 | 0.257 | 0.705 |
| 0.15 | 0.17 | 0.0056 | 0.029 | 0.195 | 0.882 |
| 0.17 | 0.17 | 0.0058 | 0.035 | 0.165 | 1 |
| 0.18 | 0.17 | 0.0059 | 0.038 | 0.155 | 1.058 |
| 0.12 | 0.2 | 0.0092 | 0.026 | 0.352 | 0.6 |
| 0.15 | 0.2 | 0.0098 | 0.036 | 0.268 | 0.75 |
| 0.17 | 0.2 | 0.0102 | 0.044 | 0.231 | 0.85 |
| 0.18 | 0.2 | 0.0104 | 0.048 | 0.217 | 0.9 |

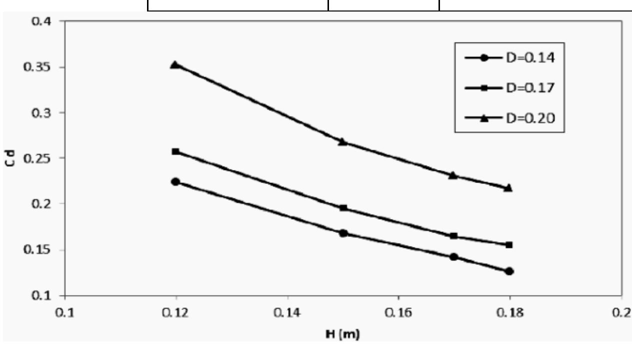


**Figure 3: Changes in discharge coefficient than to the submergence depth in shaft spillways with different crest diameters**

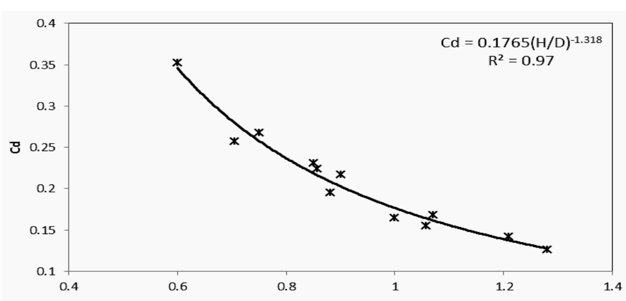


**Figure 4: Regression proportion of discharge coefficient changes than to the depth of submergence in shaft spillways**

## CONCLUSIONS

Spillway is one of the discharging structures of additional floods in dams. If the technical terms do not allow the implementation of other types of spillovers, using the shaft spillway would be a convenient and economical option. The present study analyzed the submergence ratio (H/D) to the discharge coefficient of $C_d$ flow. After repeated testing and making changes in the geometry of the intake structure, the following results are briefly obtained. In general, the results showed that in the shaft spillway, in submergence conditions, the discharge coefficient of the flow reduces by the rising in water level on the spillway; while, with increased diameter of the spillway, the discharge coefficient of the flow would increase. The derived regression equation indicates that in shaft spillways, the submergence H/D ratio is reversely related to the discharge coefficient of the flow $C_d$.

## REFERENCES


1. Nohani, E. and Musavi Jahromi, H. 2010. Effect of Number and Thickness of Vortex breaker on the coefficient of discharge in shaft spillway, National Conference of Water, Soil, Plant Science & Agricultural Machinery in IAU Dezful Branch.
2. Khatsuria, R. M. 2004. Hydraulics of Spillways and Energy Dissipators, Civil and Environmental Engineering, Aseries of Reference Books and Text Books, P. 151-195.
3. Mohamad Vali Samani, H. 1997. Design of Hydraulic Structures. Dez Ab Consulting Engineers Company, Ahwaz, Iran. PP: 424.
4. Thandaveswarra, B. S. 2006. Hydraulics: Siphon – Shaft spillways. Indian Institute of Technology Madras.
5. Quick, M. C. 1970, Efficiency of air – entraining vortex at water intakes, J. Hyd. Div., ASCE.
6. Vermeyen, T. 1991, Shaft spillway model:Beaver Dam Pennsylvania, United State Bureau of Reclamation(U.S.B.R.).Denver,P.12.
7. Fattor, C. A. and Bacchiega, J. D., 2003. Analysis of Instabilities in the change of regime in morning-glory spillways, Journal of Hydraulic Research., 40 (4): 114-123.
8. Wagner, W. E. 1956. Morning glory shaft spillways:Determination of pressure – controlled profiles, Transaction,ASCE (121) 345-349.
9. Bagheri, A., Nohani, E. 2014. Impact of making the crest of weir multifaceted on discharge coefficient of shaft spillway. indian journal of fundamental and applied life sciences, 4 (s4): 3633-3639.