Hydraulics of Morning Glory Spillway—An Overview

Prajakta Gadge and M. R. Bhajantri

Abstract Morning glory spillway is one of the water conveyance structures from the reservoir to downstream and is named due to its horny shape. In this type of spillway, water passes through a vertical shaft, horizontal or nearly horizontal tunnel, and joins the downstream river channel. They are used advantageously at dam sites in narrow canyons with steep abutments. The cost of construction of the morning glory spillway is low due to the use of a diversion tunnel constructed at the time of dam construction as a horizontal tunnel. This paper gives an overview of the morning glory spillway in respect of its hydraulic design considerations and different hydraulic aspects that need to be studied in evolving the efficient design of the spillway. The paper presents the desk study of the tunnel spillway of Lakya Tailing Dam, Kudremukh, Karnataka, studied at CWPRS, Pune, along with the discussion of the behavior of the spillway at the project site. This dam plays a vital role in running the Kudremukh Iron Ore Plant. At the project site, vibrations were experienced while passing the discharge over the morning glory spillway inlet. CWPRS carried out the detailed desk studies considering theoretical design considerations and recommended to provide aeration pipe on the spillway crest and suggested strengthening of morning glory inlet shaft. The study is discussed in detail in the present paper.

Keywords Morning glory spillway · Vertical shaft · Diversion tunnel · Energy dissipator

1 Introduction

The morning glory spillway is attractive which can often be constructed at less cost than other types and it is readily adapted to dams in narrow, steep canyons. The vertical shaft spillway of large capacity generally has a morning glory crest, so the spillway is called a morning glory spillway. Figure 1 shows the view of morning glory intake. The crest profile of a morning glory intake conforms to the lower surface of a

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nappe flowing over an aerated sharp-crested circular weir for various combinations of P/Rs and Hs/Rs as shown in Fig. 2.

In contrast to the crest profiles of straight spillways, where the profiles become flatter with increasing heads, the crest profiles for circular weirs become steeper as the head increases. USBR [3] has defined the crest profile in terms of upstream and downstream quadrants for selected conditions of P/Rs = 0.15, 0.30 and 2.0, and Hs/Rs = 0.2 to 2, similar to the crest profiles for straight ogee spillways.

Structures with vertical shafts are designed to operate either with free flow, submerged flow, or both. Generally, a free weir flow prevails over the crest for Ho/Rs up to about 0.45, partly submerged weir flow for Ho/Rs values between 0.45 and 1.0, and above this value, the weir is completely submerged and the coefficient of discharge sharply falls. However, morning glory spillways are typically designed to only operate in the crest control range (free flow) as larger discharges could result in adverse flow conditions in the downstream conduit or tunnel (slug and/or pressure flow). The circular crest should converge to the shaft; the diameter of the shaft would

Fig. 1 Typical view of morning glory intake

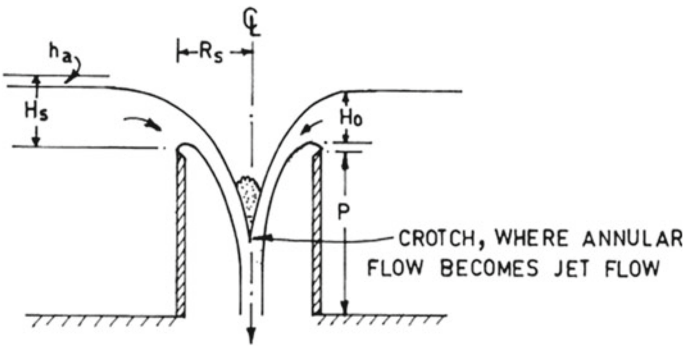

Fig. 2 Crest profile for morning glory spillway intake

generally be the same as the diameter of the downstream leg or tunnel. Generally, the tunnel section is selected, so that it will not flow more than 75–80% full at the downstream end for the maximum discharge.

Aeration and de-aeration are very important features of this type of spillway as the entrapped air may become explosive leading to the catastrophic condition. The air entrainment mechanism is closely related to the type of flow conditions in the shaft and has been schematically illustrated in Fig. 3. Khatsuria [2] has reported the general consideration for the morning glory spillway. At the beginning of overflow with low water levels, the discharge characteristics are similar to a weir control and the flow in the shaft clings to the walls as a relatively thin sheet. The volume flow rate of air is determined by the shear action of the air–water interface and by entrainment into the mass of water. This type of flow has been designated as Region I. The quantity of air entrained increases with discharge, and with the increase in discharge, a point is reached when the sheet of water is sufficiently thick to completely seal the air passage at the lower end of the shaft. This water discharge separates Region I from Region II. This type of flow is characterized by an annular hydraulic jump. Further increase in the discharge merely causes the location of the jump to move upward in the vertical shaft. The quantity of air entrained then decreases with discharge. When the jump reaches a point near the top of the shaft, the flow is said to become submerged.

The paper presents the desk study of tunnel spillway of Lakya Tailing Dam, Kudremukh, Karnataka studied at CWPRS [1].

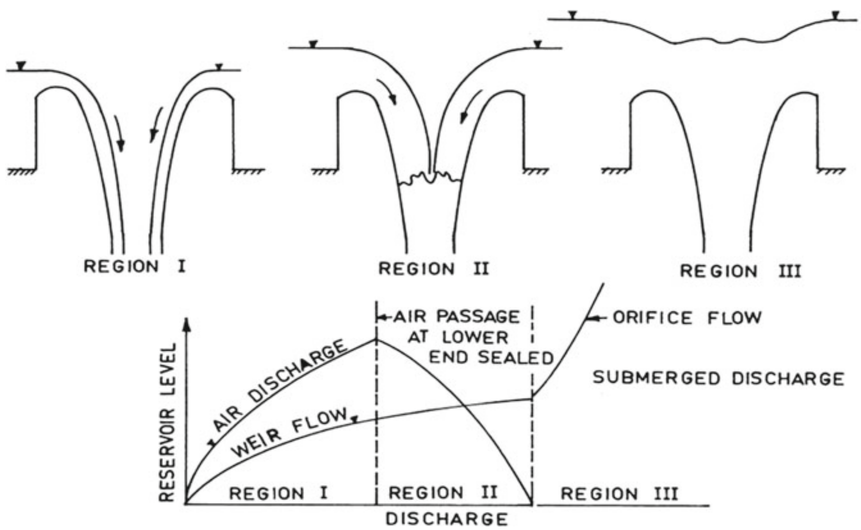

Fig. 3 Flow conditions in the shaft

2 Case Study

2.1 The Project

The Lakya Dam is located at Kudremukh in Chickmaglur District of Karnataka state about 110 km from the coastal city of Mangalore. Figure 4 shows the index map of the project. The iron ore taken from the mines contains 38% useful material, and the remaining 62% contains residual iron content of 22% is tailing which is required to be stored. For storage of tailings, a 100 m high earth dam is constructed on Lakya holey, a tributary of Bhadra River. Construction of the tailing dam took place in two stages. The construction of the 65 m high Lakya Dam was completed in 1980 in the first stage, and in the second stage in 1994, the dam was raised from 65 to 100 m. The Lakya Dam with the top at El. 890 m and a total capacity of 245 million cum was designed for a PMF discharge of 854 m^3/s inflow. Flood routing studies were carried out, and maximum water level El. 874.4 m and routed discharge of 33 m^3/s were worked out corresponding to a morning glory spillway inlet crest at El. 875 m. The Lakya holey stream is at an elevation of El. 1427 m and travels 7.9 km before meeting Bhadra River near Kudremukh. It drains an area of 18.7 km^2 up to Lakya Dam site. The catchment area of Lakya holey is moderately wide fan shaped and receives an annual rainfall of about 7000 mm. The purpose of the reservoir is to store tailings and meet the plant process water requirement. Figure 5 shows the view of the tailing deposits from the intake tunnel leading to the KIOCL plant.

There were no regulatory devices provided for spillage of flood except tunnel spillway. In the first stage, a 17.5 m wide and 160 m long chute spillway was provided on the right bank to take care of the design flood of 611 m^3/s at FRL El. 850 m. While

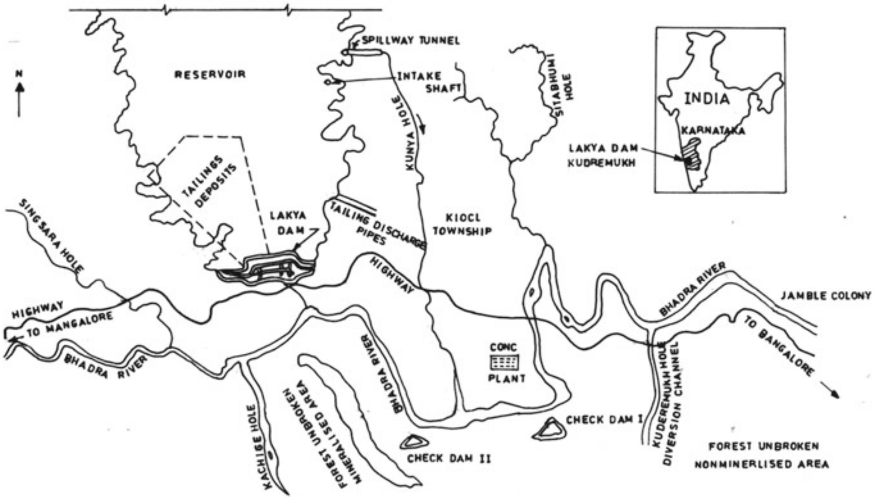

Fig. 4 Index map of the project

Fig. 5 View of tailing deposit from intake tunnel leading to plant

raising the dam, the chute spillway provided on the right bank of the earth dam got buried in the body of the dam and a 3.75 m(H) × 4 m (W) D-shaped tunnel spillway with control structures at different elevations was provided as a flood surplussing arrangement. Two inlets at El. 875 m and El. 885 m were provided for surplussing the water. Both the morning glory inlet at El. 875 m and the overflow inlet at El. 885 m which are connected to the same tunnel spillway are located at about 200 m from the Lakya Dam along the left flank of the reservoir. The inner diameter of the shaft at the morning glory crest is 3.5 m which reduces gradually to 2.1 m at El. 872.293 m. From El. 866 m, a 900 bend begins which joins the existing D-shaped tunnel. An overflow spillway inlet in the form of an inclined shaft with the crest at El. 885 m connecting to the tunnel spillway was constructed to surplus the flood at a later stage when the use of the morning glory spillway inlet will be stopped by plugging the upstream face of the intersection of an inclined shaft with a horizontal tunnel. Figure 6 shows the cross section of the tunnel spillway. Figure 7 shows the details of the morning glory intake. Figure 8 shows a view of the morning glory intake.

At the tunnel spillway exit, a stilling basin was provided for energy dissipation. The downstream channel was protected by providing gabions along the banks. A secondary weir was constructed at about 100 m downstream to boost up the tail water levels to ensure jump formation in the stilling basin. The tunnel spillway discharges in Kunya holey stream which joins river Bhadra after traversing about a kilometer.

A morning glory inlet at El. 875 m connected with the tunnel spillway is in use since 2001. At the project site, vibrations were experienced while passing the discharge of the order of 16–27 m^3/s over the morning glory spillway inlet and the

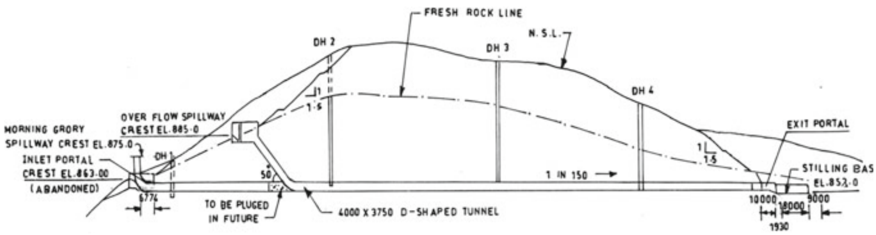

Fig. 6 Cross section of tunnel spillway

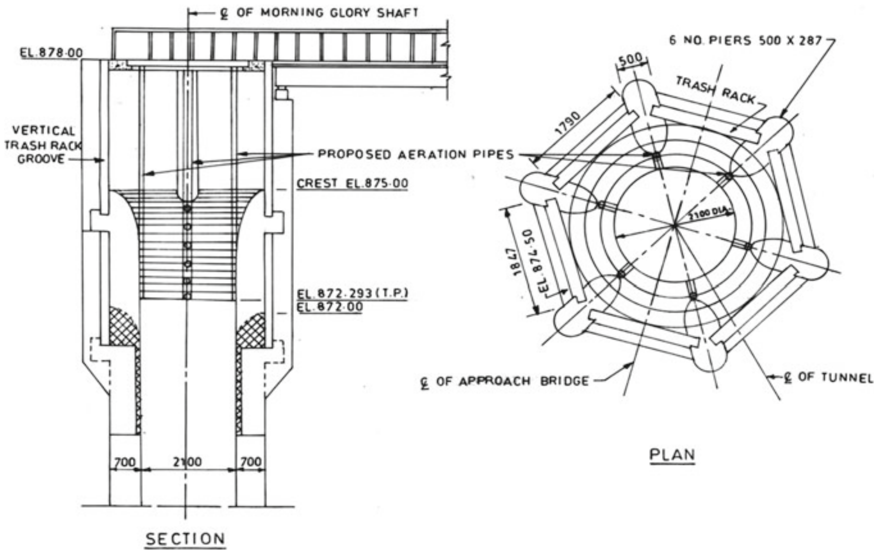

Fig. 7 Details of morning glory spillway intake

noise was heard during the operation of the spillway. Therefore, the desk studies were referred to CWPRS for assessing the hydraulic adequacy of the tunnel spillway to pass the design discharge and performance of the spillway.

2.2 Desk Study

The design for the morning glory spillway was worked out based on the procedure given in "Design of Small Dams—USBR Publication" and found to be in order. The discharging capacity curve based on the above calculations is depicted in Fig. 9. The design maximum outflow of 33 m^3/s could be passed with a maximum reservoir water level of 877.32 m as against the top of pier El. 878 m. Therefore, the discharging capacity of the morning glory spillway inlet was found to be adequate.

Fig. 8 View of morning glory intake

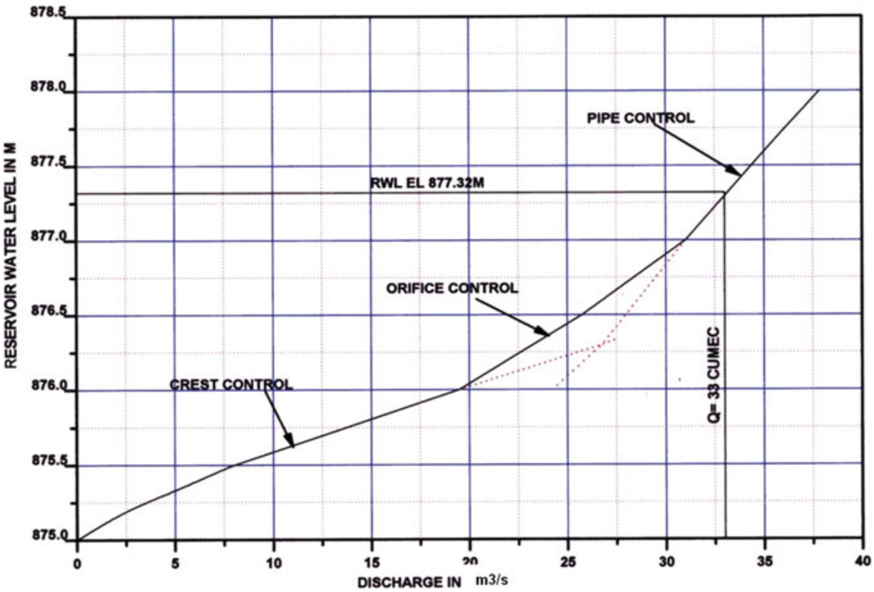

Fig. 9 Discharging capacity curve of morning glory spillway inlet

At the project site, vibrations were experienced while passing the discharge of the order of 16–27 m^3/s over the morning glory spillway inlet. The flow approaching the spillway was calm and quiet without any formation of vortices. The crotch in the morning glory was moving up and down approximately by 2 m. The noise was heard during the operation of the spillway. Accordingly, vibrations were measured using a vibration meter at the site. Table 1 gives the reservoir levels, discharge passed, and maximum vibrations recorded in microns quiet.

It was observed that the head over the crest was in the range of 0.86–1.6 m. The intensity of vibrations increased as the depth of overflow increased. This phenomenon was correlated with the discharging capacity curve with respect to head over crest (h). The region between $h = 0$ to 1 m was in the crest control zone; $h = 1$–2 m was the orifice control zone which is between the crest and pipe control zone; $h =$ 2 to 3 m was in the zone of pipe control. The vibrations were experienced when the discharge of the order of 16–27 m^3/s was passed over the morning glory spillway inlet. This range of discharges falls in the transition zone.

For the circular weir, the water profiles for the higher heads fall inside those for the lower heads closer to the spillway profiles. Therefore, if the morning glory inlet is designed for the maximum water head, sub-atmospheric pressures along the lower part of the nappe will occur for water heads less than maximum. In such case, aeration is required to ventilate the nappe from downstream of the crest, so as to introduce air in between the vertical face and lower water surface profile to avoid make and break action and consequent vibrations of the shaft. Therefore, it was suggested to provide aeration pipes along the periphery of the morning glory crest. Initially, two pipes of 5 cm (2 inch) diameter each were installed inside the crest in two opposite spans with the view to release the air trapped in the flow. However, it was observed that air was being sucked through the pipe and the intensity of vibrations was reduced. Subsequently, these pipes were replaced by three bigger size pipes of 10 cm (4 inch) diameter. Figure 10 shows the view of these pipes.

It was observed at the site that vibrations were again experienced where the reservoir was at El. 876.44 m and the morning glory spillway inlet was passing a discharge of approximately 25 m^3/s. During the site visit, it was observed that the pipes were not along the periphery of the crest and the cross bracings to keep the pipe in position were obstructing the flow. Hence, it was recommended to install a 10 cm (4 inch) diameter pipe each along the inner side of the pier to improve the

Table 1 Vibrations measured in the morning glory inlet structure by using vibration meter

Date	Rainfall (mm)	Reservoir level m	Discharge m^3/s	Maximum vibrations in microns
10–7–2001	86.00	876.60	27.16	400
11–7–2001	32.00	876.42	25.053	150
12–7–2001	5.00	876.20	22.78	60
13–7–2001	24.00	876.00	19.49	25
14–7–2001	10.00	875.86	16.07	11

Fig. 10 Aeration pipes in morning glory spillway inlet

aeration of flow and reduce the vibrations as shown in Fig. 7. It was also suggested to strengthen the morning glory inlet shaft to reduce/withstand vibrations.

3 Conclusion

Morning glory spillways are commonly used in large dam projects due to their lower construction costs by using an existing diversion tunnel as a horizontal tunnel. This paper highlighted the desk study for Lakya Dam at Kudremukh, Karnataka, carried out at CWPRS, Pune. This dam plays a vital role in running the Kudremukh Iron Ore Plant. At the project site, vibrations were experienced while passing the discharge over the morning glory spillway inlet. Based on the desk studies, recommendations were provided to install aeration pipes to improve the aeration of flow and to strengthen the morning glory inlet shaft to reduce/withstand vibrations. Accordingly, the aeration pipes were installed at the site which resulted in reducing the intensity of vibrations.

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B. Deolalikar, Former Joint Director, and Mrs. M.I. Sridevi, Former Research Officer, are gratefully acknowledged for the studies.

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