Assessment of Pressures on Spillways Using Aerators and Air Vent Pipes

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Abstract: The large quantity of water running in the rivers is to be harness and use it most efficiently for various purposes. The running water can be stored by creating reservoirs. In the science of hydraulics, many basic flow equations are available to predict the behavior of the flow of fluids but while deriving them many assumptions are made, making it an ideal situation, which limits their application to only for certain simple situations. The present study area is on Nagarjuna Sagar Dam, the giant among the masonry dams across River Krishna in Telangana State. A hydraulic model study was conducted to evaluate the cavitation damage due to negative pressures in terms of their magnitudes and locations on the spillway of the dam due to the floods in 2009 using the model studies on it. The experiment was carried out by providing a step (Aerator) with a tread of 0.025 M and riser corresponding to glacis slope at El. +300.00ft (+91.441m). For various discharge conditions and also by providing two air vent pipes of 0.015m dia in a bay on either side to supply the air so that the niche will have two locations to supply the air along its width. The experiments were carried out for free flow and gated operations for various discharge conditions. The maximum negative pressures observed at pressure tube points in vent no 2 duly providing an aerator and air vent pipes of 0.015m dia is 0.01 at P3 for gated condition at maximum flood discharge conditions, there are no negative pressures observed at pressure tube points in vent no.1.

Keywords: Hydraulics, Cavitation, Aerator, Air vent pipes, Negative pressures, Discharge conditions.

Introduction: A spillway is a waterway provided to dispose of surplus flood waters from a reservoir after it has been filled to its maximum capacity. The irregularities on spillway surfaces will be in a high speed flow causes small areas of flow separation. If the velocities are high enough the pressure may fall to below the local vapor pressure of the water. Vapor bubbles will form and when they are carried away downstream into high pressure region the bubbles collapse and possible cavitation damage may occur (Hubert 1990). In hydraulic structures, water contains air bubbles and various types of impurities of many different sizes. Microscopic air bubbles or impurities in water are necessary to initiate cavitation. Vaporization is the most important factor in the cavitation bubble growth. The principal causes of cavitation damage on spillway surface can be classified in structural or geometrical features such as inadequate design, misalignment of boundary, and surface roughness on the boundary. Cavitation phenomenon is a common and a complex process on spillways that threatens the stability of spillway structure and it may cause damage to the structure. Cavitation phenomenon in hydraulic structures can be a function of flow velocity, flow pressure, duration of operation (Henry and Falvey T). Cavitation intensity is largely a function of pressure and velocity so the variation in damage is attributable to very low localized pressures downstream from the gates due to air starvation (K. Warren Frizell). Aeration process is the most effective and cheapest control method of cavitation. The best, economical and most practicable remedial measures to the cavitation damage occurred on any spillway is the continuous supply of air. This can be done by providing aerators such as deflectors, transverse grooves etc. In order to design the aerator and its location it is required to know the magnitude of negative pressures and their points of occurrence (Jalal Attari). The objective of present study is to determine the pressures at different elevations on the spillway under free flow conditions and also under gated conditions for the vents which were damaged severely and to the negative pressures by providing a step [Aerator] with a tread of 2.0m and riser corresponding to glacis for various discharge conditions and also by providing two Air Vent Pipes of 1.2 m dia in a bay on either side to supply the air so that the niche will have two locations to supply the air along its width.

Review of Literature: Cavitation damage to spillway surfaces may be prevented with the use of aeration devices. These serves to introduce air into the layers close to the channel bottom in order to reduce cavitation erosion. Under some circumstances, the aerator can be drowned out, will cease to protect the spillway surface, and act prominently as a cavitation generator. The flow over the stepped spillway is classified in to two regimes, napped flow and skimming flow (Ravinder.B and Giridhar M V S S). The cost of cavitation resistant material to protect surfaces is prohibitive. For these reasons, the spillway surface is protected from cavitation erosion by introducing air next to the spillway surface. Air is introduced artificially by aeration devices located on the spillway floor and sometimes on the sidewalls (Chanson. H).

The spillway of Nagarjuna Sagar Dam across Krishna River was eroded several times during the floods in 2009 due to cavitation which was resulted from the negative pressures developed over the spillway. On further investigation of the problem, it was found that there was a large deviation of the existed profile of the spillway from the design profile, which actually led to the development of negative pressures in such a magnitude that could create the problem (Giridhar M V S S *et. al*).

Methodology: Experiments were conducted to measure the pressure points at all the points of observation in Vent No 2 duly providing a step [Aerator] with a tread of 0.025 m and riser corresponding to glacis slope at elevation +91.441m for various discharges also by providing two air vent pipes of 0.015 m dia. in a bay on either side to supply the air so that the niche will have two locations to supply the air along its width. And also check whether they are positive or negative. Only vent no 2 is selected because the technical information provided by the authorities is the negative pressures are expected more in vent no. 2. The experiments were carried out by keeping all the vents of the dam fully open i.e., Free Flow Condition and Gated condition for various discharge conditions. Figure 1 shows the photograph representing the air vents and aerator.

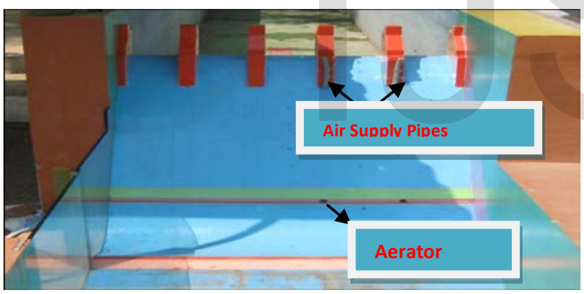

Fig.1: Photograph of air vents and aerator

Free Flow condition (FFC): In the first instance, the experiments were carried out by keeping all the vents of the dam fully open i.e., Free flow condition for various discharge conditions like Maximum Flood Discharge, 3/4th of Maximum Flood Discharge,1/2 of Maximum Flood Discharge & ¼ th of Maximum Flood Discharge. Each discharge condition is explained with the main focus of the studies on the measuring of the pressures at all the points of observation on vent no 2.

***Discharge Condition 1: Maximum Flood discharge**:* Initially a discharge corresponding to Maximum Flood discharge (Q_m= 1.0286 Cusecs) was allowed into the model. After stabilization of flow throughout the model, the pressure points at all the points of observations in Vent No 2 were noted. In this discharge condition, negative pressures were observed on vent no 2 at 1 location i.e., P3= -0.006. Table 1 represents the pressures on vent no 2 for maximum flood discharge.

***Discharge Condition 2: Three fourth of maximum flood discharge**:* In this condition, three fourth of maximum flood discharge (Q_p =11, 48,250 Cusecs, Q_m= 0.7715 Cusecs) was allowed into the model. After stabilization of flow throughout the model, the pressure points at all the points of observations in Vent No 2 were noted. In this discharge condition, negative pressures were observed on vent no 2 at 1 location i.e., P2= -0.003. Table 1 represents the pressures on vent no 2 corresponding to the three fourth of maximum flood discharge.

***Discharge Condition 3**: **Half of maximum flood discharge**:* In this condition, half of maximum flood discharge (Q_p=7, 65,000 Cusecs, Qm= 1.0286 Cusecs) was allowed into the model. After stabilization of flow throughout the model, the pressure points at all the points of observations in Vent No 2 were noted. In this discharge condition, negative pressures were observed on vent no 2 at 1 location i.e., P2= -0.002. Table 1 represents the pressures on vent no 2 corresponding to half of maximum flood discharge.

***Discharge Condition 4**: **One fourth of maximum flood discharge**:* In this condition, one fourth of maximum flood discharge (Q_p =3, 82,750 Cusecs, Q_m= 0.2571 Cusecs) was allowed into the model. After stabilization of flow throughout the model, the pressure points at all the points of observations in Vent No, 2 were noted. In this discharge condition, negative pressures were observed on vent no 2 at 1 locations i.e. P2 = -0.002. Table 1 represents the pressures on vent no 2 corresponding to one fourth of maximum flood discharge.

Gated Condition (GC): In this condition, discharge is varied and gates are operated by maintaining Full Reservoir Level (FRL).Firstly one fourth of Maximum Flood Discharge is allowed through the model and the pressures on the Vent no 2 of the spillway were observed and noted. Similarly, experiments were carried out to measure the pressures on the vent no 2 of the spillway for 1/2 of Maximum Flood Discharge, 3/4th of Maximum Flood Discharge and Maximum Flood Discharge. Each discharge condition is explained with the main focus of the studies on the measuring of the pressures at all the points of observation on vent no 2.

***Discharge Condition 1**: **One fourth of maximum flood discharge**:* In this condition, one fourth of maximum flood discharge (Q_p=3,82,750 Cusecs, Q_m= 0.2571 Cusecs) was allowed into the model. After maintaining the Full reservoir

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level in the model, the pressure points at all the points of observations in Vent No 2 were noted. In this discharge condition, negative pressures were observed on vent no 2 at 1 location i.e. P3= -0.003. Table 2 represents the pressures on vent no 2 corresponding to one fourth of maximum flood discharge.

Discharge Condition 2: Half of maximum flood discharge: In this condition, half of maximum flood discharge (Q_P=7, 65,000 Cusecs, Qm= 1.0286 Cusecs) was allowed into the model. After maintaining the full reservoir level in the model, the pressure points at all the points of observations in Vent No 2 were noted. In this discharge condition, negative pressures were observed on vent no 2 at 1 locations i.e. P3= -0.007. Table 2 represents the pressures on vent no 2 corresponding to half of maximum flood discharge

Discharge Condition 3: Three fourth of maximum flood discharge: In this condition, three fourth of maximum flood discharge (Q_P=11, 48,250 Cusecs, Q_m= 0.7715 Cusecs) was allowed into the model. After maintaining the full reservoir level in the model, the pressure points at all the points of observations in Vent No 2 were noted. In this discharge condition, negative pressures were observed on vent no 2 at 1 location P3= -0.01. Table 2 represents the pressures on vent no 2 corresponding to the three fourth of maximum flood discharge.

Discharge Condition 4: Maximum Flood Discharge: In this condition, discharge corresponding to Maximum Flood discharge (Q_P =15, 31,000 Cusecs, Q_m= 1.0286 Cusecs) was allowed into the model. After maintaining the full reservoir level in the model, the pressure points at all the points of observations in Vent No 2 were noted. In this discharge condition, no negative pressures were observed on vent no. 2. Table 2 represents the pressures on vent no 2 corresponding to the maximum flood discharge.

Results: By providing a step (Aerator) with a tread of 0.025 m and riser corresponding to glacis slope at El. +300.00ft (+91.441m). for various discharges and providing two Air Vent Pipes of 0.015 m dia in a bay on either side to supply the air so that the niche will have two locations to supply the air along its width.

Free Flow Condition: Under free flow condition, following results were obtained:

- Under maximum flood discharge, negative pressures were observed at pressure tube points P3 in vent no 2.
- Negative pressures under three fourth of maximum flood discharge condition, were observed at P2 in vent no 2
- From the experiments, it was found that under half of maximum flood discharge condition, negative pressures was occurring at P2 in vent no 2.
- Under one fourth of maximum flood discharge condition, negative pressures were observed at pressure tube points at P2 in vent no 2.

Gated Condition: Under gated condition following results were obtained:

- Under maximum flood discharge, no negative pressures were observed at pressure tube points in vent no. 2.
- Negative pressures under three fourth of maximum flood discharge condition, were observed at P3 in vent no 2
- From the experiments, it was found that under half of maximum flood discharge conditions, negative pressures were occurring at P3 in vent no 2

- Under one fourth of maximum flood discharge condition, negative pressures were observed at pressure tube points at P3 in vent no 2.

Discussions:

From the results obtained from the experiments, maximum negative pressures observed at pressure tube points in vent no 2 duly providing an aerator and air vent pipes of 0.015m diameter is 0.01 at P3 for gated condition at maximum flood discharge conditions. Fig.2 shows that there are no negative pressures observed at pressure tube points in vent no.1.

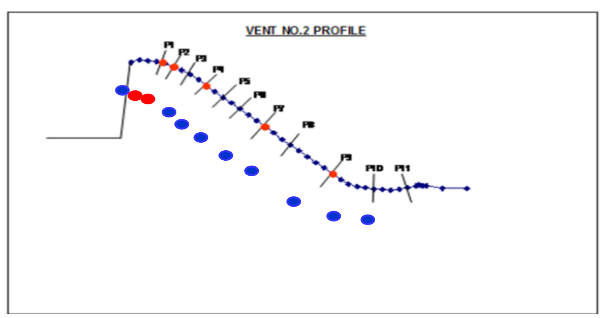

Fig 2.Negative Pressure points on the spillway profile of Vent No 2(Aerator and air vent pipes of 0.015m dia)

Table 1: Pressures on vent 2 for Free Flow Condition (Aerator & 0.015 m ϕ air vents)

Pressure Points	Pressures observed on Vent No.2 in Mts			
	Maximum Flood discharge Condition	*Three fourth of maximum flood discharge Condition*	*Half of maximum flood discharge Condition*	*One fourth of maximum flood discharge Condition*
P_{1}	+0.03	+0.02	+0.02	+0.001
P_{2}	+0.01	**-0.003**	**-0.002**	**-0.002**
P_{3}	**-0.006**	+0.01	+0.01	+0.01
P_{4}	+0.01	+0.01	+0.01	+0.01
P_{5}	+0.06	+0.05	+0.05	+0.03
P_{6}	+0.06	+0.06	+0.06	+0.03
P_{7}	+0.02	+0.02	+0.02	+0.007
P_{8}	+0.17	+0.07	+0.07	+0.04
P_{9}	--	--	--	--
P_{10}	+0.33	+0.28	+0.28	+0.08
P_{11}	+0.41	+0.32	+0.32	+0.15

Table 2: Pressures on vent 2 for Gated Condition (Aerator & 0.015 m ϕ air vents)

Pressure Points	Pressures observed on Vent No.2 in Mts			
	One fourth of maximum flood discharge Condition	*Half of maximum flood discharge Condition*	*Three fourth of maximum flood discharge Condition*	*Maximum Flood discharge Condition*
P_{1}	+0.008	+0.001	+0.03	+0.02
P_{2}	+0.005	+0.006	+0.003	+0.03
P_{3}	**-0.003**	**-0.007**	**-0.01**	+0.01
P_{4}	+0.007	+0.01	+0.01	+0.02
P_{5}	+0.04	+0.05	+0.06	+0.05
P_{6}	+0.03	+0.05	+0.06	+0.04
P_{7}	+0.006	+0.001	+0.01	+0.07
P_{8}	+0.05	+0.006	+0.06	+0.08
P_{9}	--	--	--	+0.15
P_{10}	+0.09	+0.15	+0.26	+0.21
P_{11}	+0.17	+0.27	+0.36	+0.26

Table.3: Negative pressures in vent no 2 for Free flow condition (Aerator and air vents)

Discharge Condition	Discharge in cusecs	Negative pressures observed at pressure tube points along the Vent No 2 of the spillway in mts
MFD	1.0286	P3= -0.006
3/4th of MFD	0.7715	P2= -0.003
½ of MFD	0.5143	P2= -0.002
1/4th of MFD	0.2571	P2= -0.002

Table.4: Negative pressures in vent no 2 for Gated condition (Aerator and air vents)

Discharge Condition	Discharge in cusecs	Negative pressures observed at pressure tube points along the Vent No 2 of the spillway in mts
3/4th of MFD	0.7715	P3=-0.01
½ of MFD	0.5143	P3=-0.007
1/4th of MFD	0.2571	P3=-0.003

Conclusions: The spillway of Nagarjuna Sagar dam across River Krishna was severely eroded during the floods of 2009 due to cavitation which was resulted from negative pressures developed over the spillway. On further investigation of the problem, it was found that there was a large deviation of the existed profile of the spillway from the design profile, which actually led to the development of negative pressures in such a magnitude that could create a problem. In order to provide a remedial measure to the damage occurred on Nagarjuna Sagar Spillway due to cavitation it is required to find the magnitude of negative pressures occurring at different elevations on the spillway. For this purpose, a two dimensional physical model was constructed at a scale of 1:80 producing first five vents in the model. Based on the difference in elevations between the design profile and existing profile, pressure tubes were installed at points where maximum difference was observed. The model was run under gated conditions as well as under free flow conditions allowing one-fourth of MFD, half of MFD, three-fourth of MFD and full discharges. Maximum negative pressures observed at pressure tube points in vent no 2 duly providing an aerator and air vent pipes of 0.015m dia is 0.01 at P3 for gated condition at maximum flood discharge conditions, that there are no negative pressures observed at pressure tube points in vent no.1.

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