Hydraulic Model Studies for Evaluating the Performance of Energy Dissipater's In the Form of Curved Stilling Basin to Protect the Right Bank of River near Dam – A Case Study.

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Abstract - *A spillway is a crucial component of any dam project. The improper dam design is to blame for the failure of several dams. The planning and construction of the spillway should be done properly. The Himalayan region has recently developed orifice spillways. Since the efficacy of a gated overflow spillway depends on the depth of flow between the FRL and overflow crest elevation, only the widest practical gates are suitable. The incorporation of a breast wall enables orifice spillways, which combine the benefits of deeper flows over the crest with modestly sized gates. The dissipation of kinetic energy generated at the toe of the spillway is essential for bringing the flow velocity of the river back to normal in shortest distance. The energy dissipation arrangement is the most vital part and needs to be done carefully. However hydraulic jump type stilling basin found to be suitable for this project. In the present case an entire design of a spillway suitable to suit the typical site conditions has administered. Spillway has designed for maximum flood discharge of 15,800 m^3/s.*

Key Words: **Energy Dissipator curved stilling Basin, Orifice spillway, Discharging Capacity, Water surface and Pressure Profile, PMF (Probable Maximum Flood).**

1. INTRODUCTION

Physical hydraulic models are commonly used and proved to be indispensable tool during design stages to optimize a hydraulic structure and to make secure operation of the structure. Hydraulic design of Himalayan terrain is characterized for its high mountains, deep narrow valleys, fragile geology, and complex geological condition which involves many problems which includes Site specification problem due to topography, availability of foundation, nature of soil and rock strata etc. And problems are associated with complex flow phenomena viz. non uniform flow in the approach portion, rapidly varied flow because of complex geometry, high velocities due to high heads leading to cavitation damages, etc. Presently problems cannot be deal analytically and therefore they must be tackled by conducting studies on physical models of these structures. Dissipation of kinetic energy at the base of the spillway is essential for bringing the flow in d/s River to normal condition in as short of distance as possible. In India stilling basin & ski jumped bucket are commonly used as energy Dissipators. Many safety precautions in the forms of riverbank protection works, extended training wall, etc. are provided to protect the riverbanks on either side of spillway which may prove to uneconomical in certain cases and necessitates deep excavation for providing the foundation for the extended training wall that may induce hill slope destabilisation and undermining, resulting in landslide and property loss. Present study is based on run of river scheme in Himalayan region which is located on Punatsangchuu River in western Bhutan. The orifice spillway has been provided to pass a flood discharge (PMF) of 11500m3/s along with Glacial Lake outburst flood (GLOF) 4300 m3/s through 5 orifice openings of size 9.6m width × 17.4 m high with crest level 1166 m. The MWL/FRL is at El.1202 m and the Minimum draw down level (MDDL) is at El.1195. Hydraulic jump type stilling basin has been provided as energy Dissipator to dissipate energy for main spillway.

2. STATEMENT OF PROBLEM/OBJECTIVE

Main objective of the study is to investigate hydraulic parameters such as discharging capacity of spillway, water surface profile, pressure distribution over spillway surface and to finalization of energy dissipator in the form of curved stilling basin for a dam project by means of physical model studies.

3. LITERATURE REVIEW

(Ninad Doke, et al. March 2019) They had experimented that, When the water is dispatched through the spillway the static energy gets converted in kinetic energy. This energy is in high magnitude due to the force which destroys the nearby area by flooding. Thus, the kinetic energy is reducing to acceptable limits. They used Ski-jump energy dissipator to reduce the kinetic energy of Khadakwasla dam. (Dr. M.R. Bhajantri et al. 2018) They had experimented that, Dissipation of K.E. generated at the toe of spillway is important for bringing the flow velocity of the river back to normal in shortest possible distance. Great deal of sediments entering the reservoir may be a significant issue in

Himalayan region which reduces the capacity of the reservoir and damages the hydropower plants. Although no design procedures were readily available for designing the energy dissipators for orifice spillways, experience from the hydraulic model studies and prototype provides useful guidelines. (Dhaktode Asaram et al. June 2016) They studied to investigate the consequences of various slope of ogee spillway surface on energy dissipation. With slope of 1:1, 0.85:1, and 0.75:1 three ogee spillway models were prepared. 18 test runs were applied to analyze the energy dissipation downstream the three spillway models. (Sokchhay Heng et al. May 2012) They had studied that; Spillway is a major concern for stabilization of hydraulic structures and their downstream channel. The objective of this study was to select an appropriate movable riverbed material for reproducing scour hole in the physical model and to analyze the characteristics of its formation using the selected material. (Saiful Bahri Hamzah et al. June 2016) They had experimented that, Physical model was utilized to create an assessment of Batu Dam spillway, yet on make informed recommendations of its hydraulic performance and proposed alterations optimum configuration was obtained from a model scale of 1:25. Simulations with reference to various reservoir levels and discharges to analyze effects of the various flow conditions were performed. Physical hydraulic models are commonly used during design stages to optimize a structure and to make sure a secure operation of the structure. (IS Code 10132: 1982) This code has guideline on selection of spillways and energy dissipators. (IS Code 7365: 2010) This code has guideline on Criteria for hydraulic design of bucket type energy dissipators.

4. METHODOLOGY

For conducting model experiment, it is necessary to obtain correct information from the prototype. The entire operation of the model depends on the equality of the prototype data. The data would help in establishing the model prototype conformity pattern and to enhance the predictability of the model. Generally, the following prototype data would be required for planning, construction of spillway model and conducting model studies.

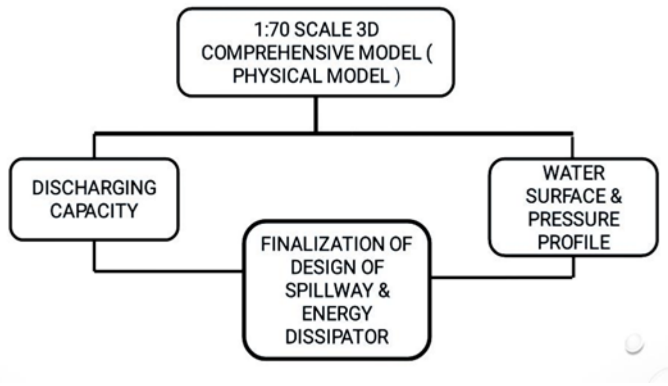


Chart -1: Methodology flow chart

4.1 MODEL CONSTRUCTION:

A model need not be made of the same materials as the prototype. If surface over which water flows are reproduced in shape and the roughness of the surface is approximately to scale (in fact smoother in the model than corresponding to prototype roughness), the model will usually be satisfactory. Generally, the riverbed is made up of smooth cement plaster, spillway, non-overflow section of the dam etc. in masonry with neat plaster, spillway piers in teakwood, radial gates in sheet metal and outlets are fabricated in transparent Perspex. Close tolerances, particularly in critical areas such as spillway crests, tangent points, energy dissipating appurtenances, model dimensions etc. are essential. Greatest accuracy should be maintained where there will be rapid changes in direction of flow and very high velocities occur. The profiles of spillway and their allied structures are finished to their final shape with the help of metallic templates fixed in alignment and elevation. Piezometers are generally welded to the templates so that their alignments are secured. The finishing of piezometers in model should be done meticulously to prevent measurement errors that would result from improper installation. Complicated curves for bell mouths of sluice spillway, breast walls, bends and transitions can be made from Perspex which has been heated in oven and reshaped by pressing between the male and female concrete molds. It is not possible to reproduce the entire reservoir upstream of spillway nor is it necessary to do so. For the spillway located in the main river gorge with practically straight river course, reproduction of about 600 to 800 m reach is usually adequate. Where the river has appreciable curvature immediately upstream of dam, or where the spillway is located on a flank, so that obliquity of flow approaching the spillway is likely to occur, special care must be taken to incorporate these features. On the downstream, the river reaches to be incorporated would be slightly beyond the section of stage-discharge measurement in the prototype. Existing geometrically similar 1:70 scale 3-D comprehensive model was modified incorporating proposed design of energy dissipator arrangement (stillingbasin) with reduced No. of span for spillway (5 No.) and river cross sections downstream of dam axis. The spillway was reproduced in masonry, finished with smooth cement plaster, and painted with enamel paint. Piers, breast wall and radial gates were in PVC foam sheets. The power intake was fabricated in Perspex. The model was equipped with suitable inlet and outlet arrangements including discharge measurements. Arrangements were made for measurement of water level, and velocities. Photos 4.1.1 and 4.1.2 show the view of dry model from upstream and downstream respectively. The accepted relationships of hydraulic similitude, based on Froudian criteria were used to express the mathematical relations between the dimensions and hydraulic quantities of the model and the prototype. The general relations expressed in terms of model scale are as given below:

Parameter	Scale Relation
Length	1:70
Area	1:4900
Velocity	1:8.367
Discharge	1:40996.34
Time	1:8.367
Pressure in m of water head	1:70
Manning's `n'	1:2.03

Table-1 Model Scale Relations for Various Dimensions

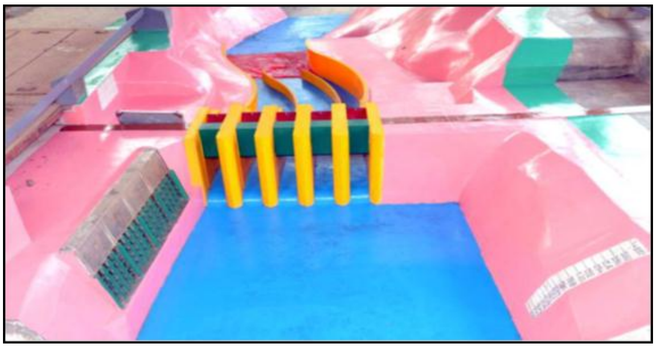


Photo 4.1.1 View of Dry Model from Upstream

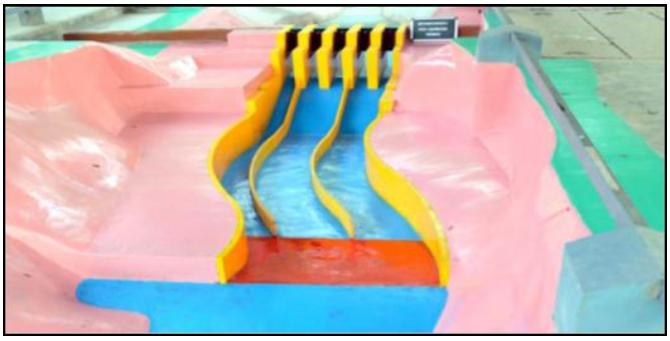


Photo 4.1.2 View of Dry Model from Downstream

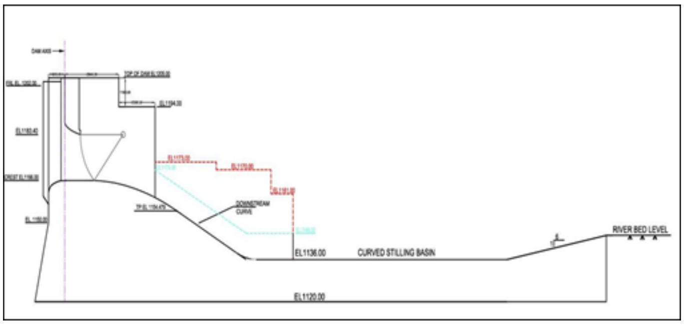


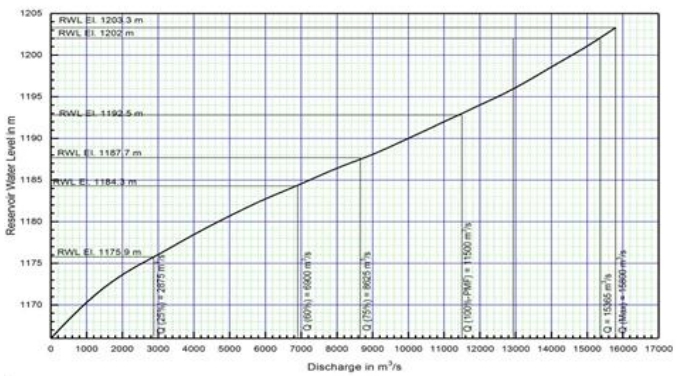
Chart 2: Cross Section of Spillway

5. EXPERIMENTATION

While experimentation, necessary arrangements were made like measurement of discharge, reservoir water levels, tail water level, etc.

5.1 DISCHARGING CAPACITY OF SPILLWAY:

Hydraulic model studies were conducted for assessing discharging capacity of the spillway for entire range of discharges for the ungated operation of spillway. The studies indicated that maximum discharge of 15,365 m^3/s could be passed at FRL El. 1202 m. It was observed that design maximum discharge of 15,800 m^3/s (PMF+GLOF) could be passed through 5 spans fully open with upstream RWL El. 1203.3 m whereas PMF of 11,500 m^3/s could be passed at RWL El. 1192.8 m. The water surface follows the breast wall bottom profile for the entire width for the orifice flow regime, thus making the entire height of orifice fully effective. Free flow was observed for discharges up to 10,500 m^3/s and thereafter there was a transition to orifice flow. Graph 1 shows the discharging capacity curve for ungated operation of the spillway.



Graph 1: Discharging Capacity Curve

5.2 WATER SURFACE PROFILES:

Water surface profiles were observed along the center line of spillway along with stilling basin and downstream for entire range of discharges. Figures 5.2.1 to 5.2.4 show the water surface profiles with ungated and gated operation of spillway.

It was observed that trunnion of radial gates is well above upper nappe of the jet arising from the orifice opening for all the operating conditions of the spillway. Water surface elevation is below the top of the training wall till the end of stilling basin for lower discharges (6,900 m3/s and below) However, water surface elevation overtopping the training wall for higher discharges (discharges higher than 6,900 m3/s). Water surface elevation in the stilling basin for design maximum discharge of 15,800 m3/s is 1173 m. So, the height of the training wall may be decided considering the water surface profiles, free board requirement and bulking effect in the prototype.

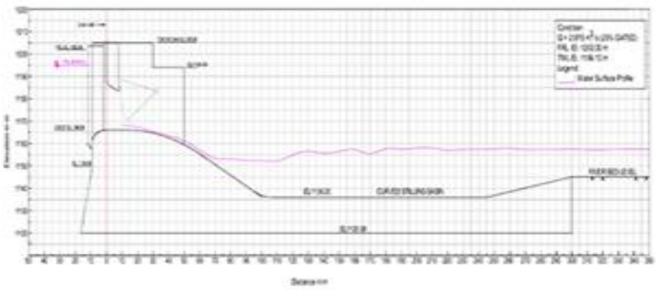


Figure 5.2.1 Water Surface Profile Q=2875 m3/s (Gated operation of spillway)

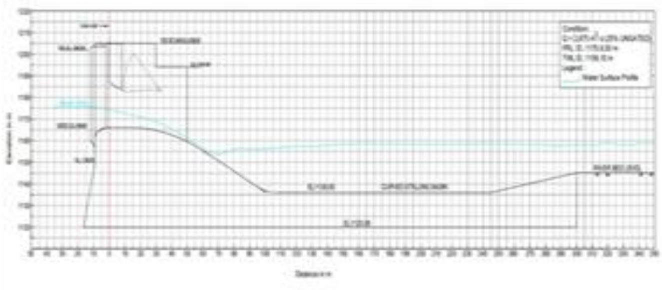


Figure 5.2.2Water Surface Profile Q=2875 m3/s (Ungated operation of spillway)

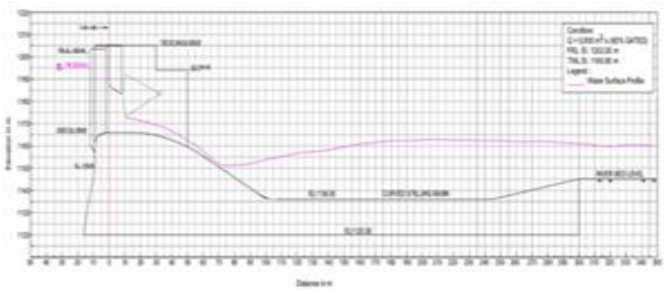


Figure 5.2.3 Water Surface Profile Q=6900 m^3/s (Ungated operation of spillway)

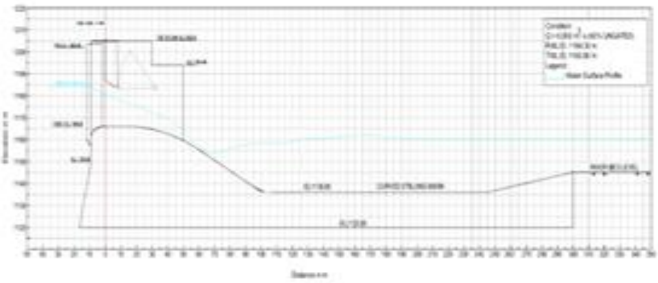


Figure 5.2.4 Water Surface Profile Q=6900 m^3/s (Ungated operation of spillway)

5.3 PRESSURE PROFILES

Studies were conducted for observing piezometric pressures for various conditions at locations on the bottom profile of spillway along Centre line of spillway up to end of stilling basin and along the side of intermediate pier for ungated as well as gated operation of the spillway maintaining reservoir at FRL El. 1202 m. The piezometric pressures in meter of water columns on the spillway profile are shown in Figures 5.3.1 to 5.3.4. The studies indicated that the pressures drop steadily as the flow accelerates over the spillway crest. There is a rise in pressure as the flow passes over the stilling basin. Positive pressures were observed for the entire range of discharges; also corresponding cavitation indices observed to be more than critical cavitation index of 0.2 for the entire length of spillway. Hence, the spillway profile is not susceptible to cavitation damage.

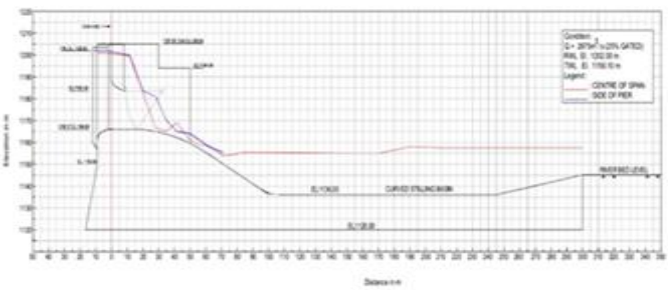


Figure 5.3.1 Pressure Profile Q=2875 m^3/s (Gated operation of spillway)

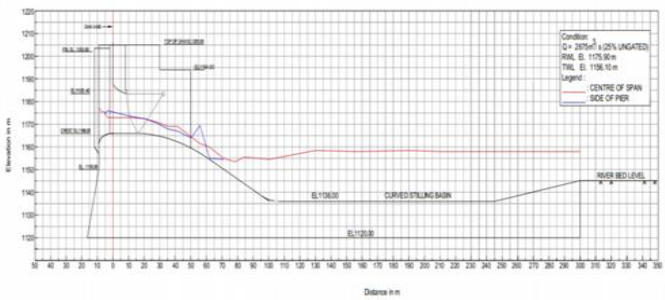


Figure 5.3.2 Pressure Profile Q=2875 m^3/s (Ungated operation of spillway)

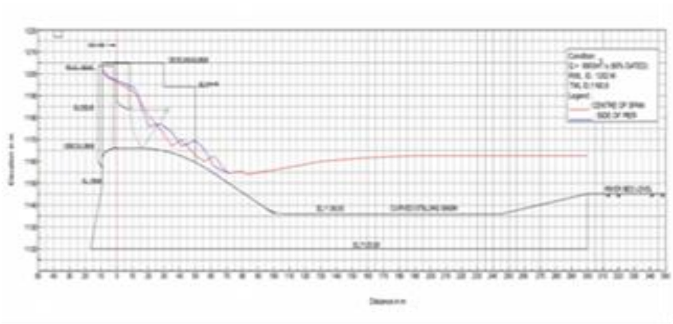


Figure 5.3.4 Pressure Profile Q=6900 m³/s (Gated operation of spillway)

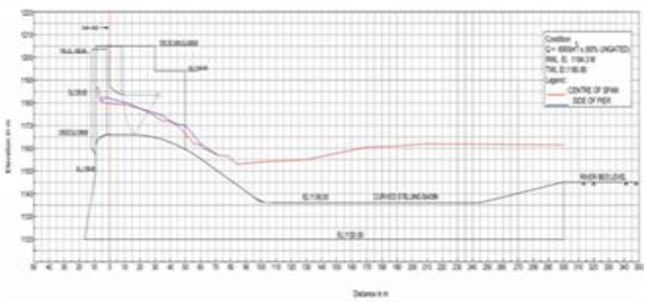
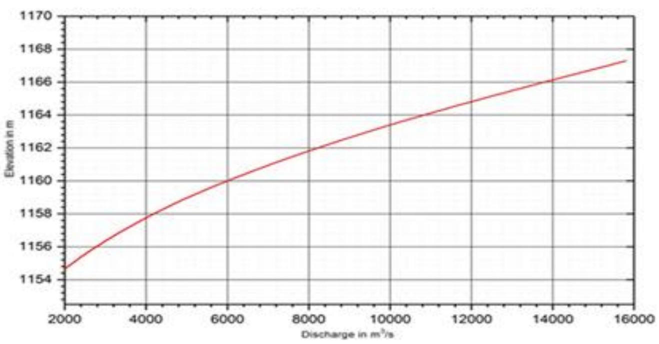


Figure 5.3.4 Pressure Profile Q=6900 m³/s (Ungated operation of spillway)

5.4 PERFORMANCE OF ENERGY DISSIPATOR (CURVED STILLING BASIN):

Performance of spillway with stilling basin was studied for the entire range of discharges up to the design maximum discharge of 15,800 m³/s gated and ungated operation of spillway. The tail water levels at 300 m downstream of dam axis were maintained as per the tail water rating curve shown in Graph 2.



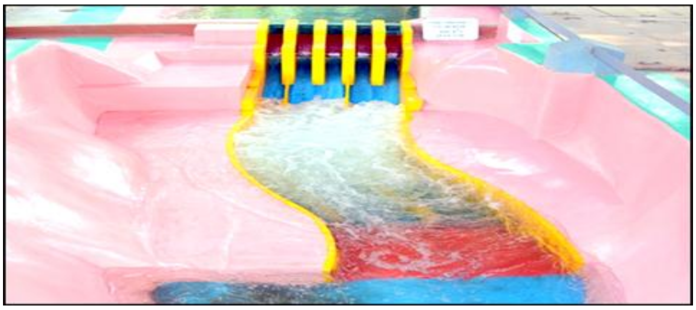
Graph 2: Tail water rating curve at 300 m downstream of dam axis

For gated operation of spillway at FRL El. 1202 m, the flow conditions were observed for the entire range of discharges. From model studies it was found that the hydraulic jump forms over the glacis of the spillway (near the toe of the basin) and front of the jump fluctuates (oscillates) between chainage 60 to 70 m and 70 to 80 m (from dam axis) over the spillway glacis for 2,875 m³/s up to 15800 m³/s respectively. Water surface elevation is below the top of the training wall for 2,875 m³/s in the basin and the same overtops the training wall in the basin for 6,900 m3/s and above. Highly turbulent and volatile flow conditions were observed in the stilling basin for the discharges in the range of 6,900 m³/s up to 15,800 m³/s with water surface overtopping the training wall substantially in the stilling basin area causing flow returning into the stilling basin from the downstream area.

For ungated operation of spillway, the flow conditions were observed for the entire range of discharges (up to 15,800 m³/s). From model studies it was found that the hydraulic jump forms over the glacis of the spillway (upstream of the toe) and front of the jump fluctuates (oscillates) around chainage 60 and 70 m (from dam axis) over the spillway glacis for 2,875 m³/s and up to 15800 m³/s respectively. Water surface elevation is below the top of the training wall for 2,875 m³/s in the basin and the same overtops the training wall in the basin for 6,900 m³/s and above. Highly turbulent and volatile flow conditions were observed in the stilling basin for the discharges in the range of 6,900 m³/s up to 15,800 m³/s.

Flow conditions downstream of spillway for Q = 2,875 m³/s (Gated flow)

Flow conditions downstream of spillway for Q = 2,875 m³/s (Ungated flow)



Flow conditions downstream of spillway for Q = 6,900m^3/s (Gated flow)

Flow conditions downstream of spillway for Q = 6,900m3/s (Ungated flow)

6. RESULT & CONCLUSION

1. Tranquil flow conditions were prevailing upstream of spillway for entire range of discharges with mild vortices in the vicinity of breast wall. Intensity of vortices in the wake of the pier was slightly more for higher discharges. Tranquil flow conditions with no air entrainment vortex formation in front of the intakes were observed for all the flow conditions.

2. Discharges of 15,800 m 3 /s (PMF+GLOF), 15,365 m3/s and 11,500 m3/s could be passed through all six spans at RWL El. 1203.3 m, FRL El. 1202 m and RWL El. 1192.8 m respectively. Considering the free board above FRL, discharging capacity of the spillway is adequate.

3. Positive pressures were observed for the entire range of discharges hence, the spillway profile is not susceptible to cavitation damage. Therefore, the pressures along the profile of spillway are found to be satisfactory.

4. Studies conducted on 3-D comprehensive model indicate that performance of stilling basin is satisfactory for lower discharges (for 60% of PMF and below discharges). Trunnion of radial gates is well above upper nappe of the jet arising from the orifice opening for all the operating conditions of the spillway. Hence, location of trunnion is found to be acceptable. Water surface elevation is below the top of the training wall till the end of stilling basin for lower discharges (for 60% of PMF and below discharges). However, water surface elevation overtopping the training wall substantially in the stilling basin area (for higher range of discharges, 6,900 m 3/s and above) causing the flow returning into the stilling basin from the downstream area. Thus, existing top elevation of training wall in the stilling basin area looks inadequate. So, the height of the training wall may be decided considering the water surface profiles, free board requirement and bulking effect in the prototype. Velocities at downstream of stilling basin are found to be within acceptable limit for various discharges. Severe return flows observed downstream of stilling basin especially at right bank of river for higher discharges may destabilize the right bank area at the end of stilling basin. Strengthening of right-side riverbanks at the end of stilling basin is highly.

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