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Technical Memorandum No.

95 -RR (H2 -02)

Hydraulic Model Studies for Jamrani Drinking Water Multipurpose Project, Nainital (Uttarakhand)

IRRIGATION RESEARCH INSTITUTE
ROORKEE – 247667 (UTTARAKHAND)
INDIA

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Roorkee **August, 2024**

IRRIGATION RESEARCH INSTITUTE
ROORKEE - 247 667 (UTTARAKHAND)
visit us at: *www.iriroorkee.res.in*; email:
info@iriroorkee.res.in; roh2.iri@gmail.com

Technical Memorandum
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CHIEF ENGINEER & DIRECTOR : Sudheer Kumar
☎ 01332-257501 (O)
Fax : 01332-262487

SUPERINTENDING ENGINEER : R. C. Gupta
☎ 01332-257505 (O)
Fax : 01332-262487

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PROJECT SPONSORING AUTHORITY:
The Project Manager,
Uttarakhand Project Development and construction Corporation Ltd.,
Damuadhunga, Kathgodam (Nainital)

RESEARCH PERSONNEL:

R.P.Kuriyal	: Executive Engineer
Sumit Malwal	: Assistant Engineer
Ani Tyagi	: Assistant Engineer
Abhishek Sinha	: Research Supervisor
Govind Ram	: Scientific Assistant

SYNOPSIS

The Multipurpose Jamrani Dam Project envisages construction of 150.6 m high concrete gravity dam on Gola River, upstream of existing Gola barrage, located about 10 Km upstream of Kathgodam. The dam proposes a live storage of about 144.30 MCM out of which about 42.70 MCM will be utilized for meeting the drinking water requirements and the remaining for irrigation in Uttarakhand. The dam with its top at EL 765.6 m has five sluice spillways (crest level= EL. 706.0 m) of 8.0 m width each separated by 10.0 m thick piers. Radial gates of size 8.0 m (L) x 10.0 m (H) have been provided to regulate the flow over spillway. A surface spillway of (4.0 m x 4.0 m) with its crest at EL 758.0 m has also been provided between the sluice spillway 3 & 4 to pass the floating debris. The dam is designed for a spillway probable flood of 7590 cumec with its top EL 765.6 m.

The hydraulic model studies were conducted at IRI, Bhadrabad to find out the discharging capacity of spillway, to assess the performance of flow conditions upstream and downstream of the spillway for the entire range of discharges for ungated and gated operation of spillway, behaviour of jet trajectory and plunge pool, pressure profiles and velocities downstream of plunge pool. It was observed that the discharge of 7590 m^3/s could be passed at RWL El. 747.1 m with left end gate of spillway in closed condition, and the maximum discharge of 9000 m^3/s could be passed at HFL El. 763.6 m keeping 2.0 m freeboard as the dam top is 765.6 m. A discharge coefficient of 0.845 and 0.8912 was calculated at design discharge of 7950 m^3/s at all 5 gates open and only 4 gates open (free flow) respectively. The

maximum trajectory length observed was 295 m at 8 m opening under gated condition. Positive pressures were observed on the spillway surface for the entire range of discharges upto 7590 m^3/s in free flow conditions and on breast wall under gated condition. While, negative pressures were observed at 705.5 m & 703.0 m level under all gated conditions. A standard design of aerator as per IS code is recommended to convert negative pressures into atmospheric pressure at proposed location. A maximum velocity of 8.95 m/s was observed at 350 m downstream of dam axis at center of river at 7590 m^3/s discharge while only 4 bays were fully opened. The studies conducted for assessing the performance of plunge pool indicated that the performance of energy dissipation was satisfactory upto 5700 m^3/s as jump was confined within the plunge pool. However, for high discharges with gated and ungated operation of the spillway at the end of plunge pool, rapidly varied super critical flows were noticed. The left bank along plunge pool shall be cut down and will be protected to withstand high thrust of jet.

KEY WORDS	**-**	Spillway, plunge pool, coefficient of discharge, energy dissipation, sub-atmospheric pressure, velocity etc.
SUBJECT	**-**	Comprehensive 3D physical hydraulic model studies
PROJECT	**-**	Jamrani Drinking Water Multipurpose Project, Nainital (UK)

Approved by	**Recommended by**	**Submitted by**
(R.C. Gupta) **Superintending Engineer**	**(R.P. Kuriyal)** **Executive Engineer**	**(Sumit Malwal)** **Assistant Engineer**

Hydraulic Model Studies for Jamrani Drinking Water Multipurpose Project, Nainital (Uttarakhand); 1:55 Scale, 3-D Comprehensive

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1.0 INTRODUCTION

1.1 The Project

The Multipurpose Jamrani Dam Project is proposed to be Constructed in District Nanital of Uttarakhand State on Gola River. The Project envisages construction of 150.6 m high concrete gravity dam on Gola River, upstream of existing Gola barrage, located about 10 Km upstream of Kathgodam. The dam proposes a live storage of about 144.30 MCM out of which about 42.70 MCM will be utilized for meeting the drinking water requirements and the remaining for irrigation in Uttarakhand and for power generation through 14MW installed capacity power house.

The dam with its top at EL 765.6 m has five sluice spillways (crest level= EL. 706.0 m) of 8.0 m width each separated by 10.0 m thick piers. Radial gates of size 8.0 m (L) x 10.0 m (H) have been provided to regulate the flow over spillway.

A surface spillway of (4.0 m x 4.0 m) with its crest at EL 758.0 m has also been provided between the sluice spillway 3 & 4 to pass the floating debris. Width of surface spillway piers is 5.0 m.

The ski-jump bucket with bucket radius of 50 m with lip angle of 30^0 has provided at the toe of spillway to deflect the discharges from dam and adjoining structures. A plunge pool for energy dissipation of water jet deflected through flip bucket has also provided in down-stream at a distance of 96.847 m from flip bucket.

The intake of the power house is located on right side of dam spillways. The power house has an installed capacity of 14 MW (2X7 MW).

The stretch of reservoir is 10.0 kilometers. The dam is designed for a spillway probable flood of 7590 cumec with its top EL 765.6 m. The High Flood Level (HFL), Full Reservoir Level (FRL), and Mean Draw Down Level (MDDL) have been fixed at EL 763.6 m, 762.0 and 717.47 m respectively.

2.0 TERMS OF REFERENCE FOR THE PRESENT STUDIES

Initially the Project Manager, Uttarakhand Project Development and construction Corporation Ltd., Damuadhunga, Kathgodam (Nainital) vide his letter no.16/PM-2/PIUJ/Model Study Dated 08/08/2021 referred hydraulic model studies for Jamrani Drinking Water Multipurpose Project, Nainital to Hydraulic Research Station, Bahadrabad with scope of studies as below:

a) Discharging capacity of sluice spillway with full and partial operation of gates.
b) Water surface profiles for entire range of discharges.
c) Pressure profile for entire range of discharges.
d) Velocity profile for entire range of discharges.
e) Performance of energy dissipation arrangement.
f) Observation of approach flow conditions.
g) Minor modification if any, needed during the course of study based on preliminary results.

Further the Project Manager, Uttarakhand Project Development and construction Corporation Ltd., Damuadhunga, Kathgodam (Nainital) vide his letter no.33/PM-2/PIUJ/Model Study Dated 13/07/2022 provides a revised scope of studies as below:

a) Adequacy of spillway structures for the passage of flood corresponding to MWL (EL 763.60m) with all five sluice spillways and one surface spillway.
b) Adequacy of spillway structures for the passage of flood corresponding to MWL (EL 763.60m) / FRL (EL 762.0m) with four sluice spillways and one surface spillway.
c) Spillway discharge rating curve for spillway discharge 25%, 50%, 75% and 100% of PMF.
d) Optimization of spillway crest with respect to static pressure for spillway discharge 25%, 50%, 75% and 100% of PMF.
e) Requirement of the aeration arrangement for the spillway vis-à-vis cavitation problem. If yes, select size and location of aeration device along the spillway glacies.
f) Water surface profile over the spillway profile for different range of discharges.
g) Pressure profiles along the centre line of spillway and side of training wall for spillway discharge 25%, 50%, 75% and 100% of PMF.
h) Velocity of water over the spillway glacies at different locations.
i) Water jet through and height from the bucket lip for spillway discharge 25%, 50%,

75% and 100% of PMF.

j) Performance of the bucket in energy dissipation for spillway discharge 25%, 50%, 75% and 100% of PMF.

k) Flow profile water around plunge pool.

l) Scour depth near plunge pool for spillway discharge 25%, 50%, 75% and 100% of PMF.

In addition to above the alignment of dam axis has been revised (1st revision) by slight rotation of 3 degree from existing dam axis keeping the abutment on right bank of river as fixed. It has been observed that the trajectory from the spillway is still falling on the left bank and away from the centre of plunge pool. So, it was decided to further rotate the dam axis.

Further, the Project Manager, vide his Letter No.35/PM-2/PIUJ/Model Study Dated 13/07/2022, has informed IRI that after consultation with higher officials and dam design consultant Ehyte India Pvt. Ltd., the dam axis has again been revised to 8 degrees (clockwise) making a total of 11 degrees rotation (Final revision) from existing dam axis keeping the abutment on right bank of river as fixed.

The present report describes the results of the model studies including all above mentioned scope of works.

3.0 THE DATA

The Project Manager, Uttarakhand Project Development and construction Corporation Ltd., Damuadhunga, Kathgodam (Nainital) vide her mail dated 22.07.2021 & 22.10.2021 has provided the following initial data and drawings for model studies which were further revised on date 10.10.2022 after various discussion with experts and visiting HRS, Bahadrabad. The following drawings for aforesaid model were studied: -

- Contour Map of the river from 1000 m u/s to 500 m d/s
- Cross section of the river at an interval of 50 m each
- Project Layout Plan
- Upstream view of dam section
- Upstream Consolidation Grouting details
- Dam section through Spillway
- Dam section through under-sluice
- Dam Non-Overflow Block cross section through lift shaft
- Dam section through maximum non overflow block

- NOF section through Power Intake
- Intake structure Plan and details
- Intake Structure section and details
- Trash Rack Details

Other data/ details provided by the sponsor are as follows:

- Salient features of proposed Jamrani Dam
- Manning's n value for Gola River
- Rating Curves for year 2020-21 and 2021-22
- Alignment of Dam axis by 11 degrees
- Details of aerator

4.0 THE MODEL

A geometrically similar comprehensive model was constructed to the scale of 1:55 as per the data & drawings made available by Sponsors. About 1000 m upstream and 500 m downstream river reach from Dam axis of the river Gola has been represented in the model. The model datum has been constructed in brick masonry while contours were finished with rough cement concrete plastered to simulate the Manning's coefficient 'n' of the river. The slope as per contour plan and river cross sections as per actual has been maintained in the upstream reach of the river bed. The key plan of the comprehensive model is shown in **Figure 01**.

The discharge fed into the river model was measured over sharp crested weir provided on upstream of the model. Honey comb walls have also been provided at the upstream end of model to ensure the smooth entry of water into the model. The water levels and velocities were observed with the help of pointer gauge/model scale and current meter respectively.

Proving of River: After the construction of the river model (without dam and other appurtenant structures), the model was run with different discharges varying from 500 cumec to 8427 cumec and water levels were recorded at different specific cross sections of the river. The sponsor had not supplied the GD curve for the full range of discharge. Therefore, during the proving of the model, the tail water levels at about 400 m downstream of dam axis were maintained as per theoretical stage discharge curve. The water levels were observed at different river sections for discharge run in the model and are tabulated in **Table 01**. The observed water levels at different sections were compared

with the theoretical water levels and plotted in **Figure 06.** As the observed and theoretical GD curves are almost identical at different sections, the model was assumed to be proved from 600 m upstream to 400 m downstream of dam axis.

Implementation of Structure in model: After proving of the river, complete dam structure along with the energy dissipation arrangement and the power intake structures on the right bank was represented in the comprehensive model as per drawings provided by sponsor. The channel bed at downstream has been kept erodible to observe scour development. Loose stones of sizes (10-20 mm dia) have been placed in the plunge pool and its downstream in the river bed. Piezo-points have been installed at key points to observe hydrostatic pressure along the dam spillways profile, surface-spillway profile and piers etc. The discharge through intakes has controlled by gate-valves installed in intake tunnels and measured over V-notch provided in downstream. The **Figure 02 to 05** shows the General Arrangement Drawings of the project provided by the sponsors. Also, **Photos 1 and 2** show the upstream and downstream views of the dry model with dressed river banks.

The accepted equations for similitude, based on Froudian criteria were used to express the mathematical relationship between the dimensions and hydraulic parameters of the model and the prototype. The general relationships of hydraulic quantities are expressed in terms of model scale as given Table A below:

Table A: Model Scale Relation for Various Dimensions

Variable	Froude Scale Ratio
Length	1:55
Area	1:3025
Velocity	1:7.416
Discharge	1:22434
Time	1:7.416
Pressure in (m) of water head	1:55
Manning's 'n'	1:1.9501

5.0 MODEL STUDIES

After incorporating the various structures and dressing of river bed downstream of plunge pool, the model was run at various discharges to check the behaviour of flow and different structures in the vicinity of dam structure. As per sponsors request, the initial

study was conducted at 8427 m^3/s and it was found that the design discharge was passing well below the MWL even at one gate closed condition. Hence, during model visit, the sponsors desired to verify the discharge feed in model through Sharp crested weir. Also, it was decided that the spillway parameters shall be optimized for 7590 m^3/s discharge which is routed peak outflow in place of 8427 m^3/s discharge (peak inflow). Therefore, initially to verify sharp crested weir, *area-velocity method was recommended by IRI to save time and cost* in the approach channel of model.

The observations and calculations from area-velocity method are given in **Table No. 02.** The table indicates that there is a negligible difference in discharge measured by sharp crested weir and area-velocity method. Hence, the discharge feed in model through the sharp crested weir is reliable.

Further, it was instructed by the sponsor vide MoM No. 64/PM-2/PIUJ/Model Study dated 08.06.2023 to calibrate the sharp crested weir volumetrically again by using large tank or by using another weir downstream of present weir in the form of a Parshall Flume as per ISO-9826 & IS-14371 at Hydraulic Research Station, Bahadrabad. The Parshall flume was constructed at HRS with the rigid walls and bed as per IS standards due to limitation of space at downstream of present weir at HRS, Bahadrabad and is shown in **Photo 03**. The various results noted from Parshall Flume are compiled in **Table 03** which indicated that at higher discharges, the variation is almost negligible and within permissible limits. Hence, the sharp crest weir discharge values are considered as final.

The present hydraulic model studies were conducted for assessing the performance of spillway in respect of approach flow conditions, discharging capacity, pressure profiles on spillway surface and chute spillway & water surface profiles, performance of plunge pool for the entire range of discharges with gated and ungated operation of spillway. The model was run for different discharges viz. 1900 m^3/s, 3800 m^3/s, 5700 m^3/s and 7590 m^3/s and water levels at different cross sections were recorded along with observations of flow behaviour at upstream and downstream of dam axis. The revised tail water levels were maintained d/s of dam axis at chainage 450 m as per the tail water rating curve supplied by project authorities and is shown in **Figure A** as below:

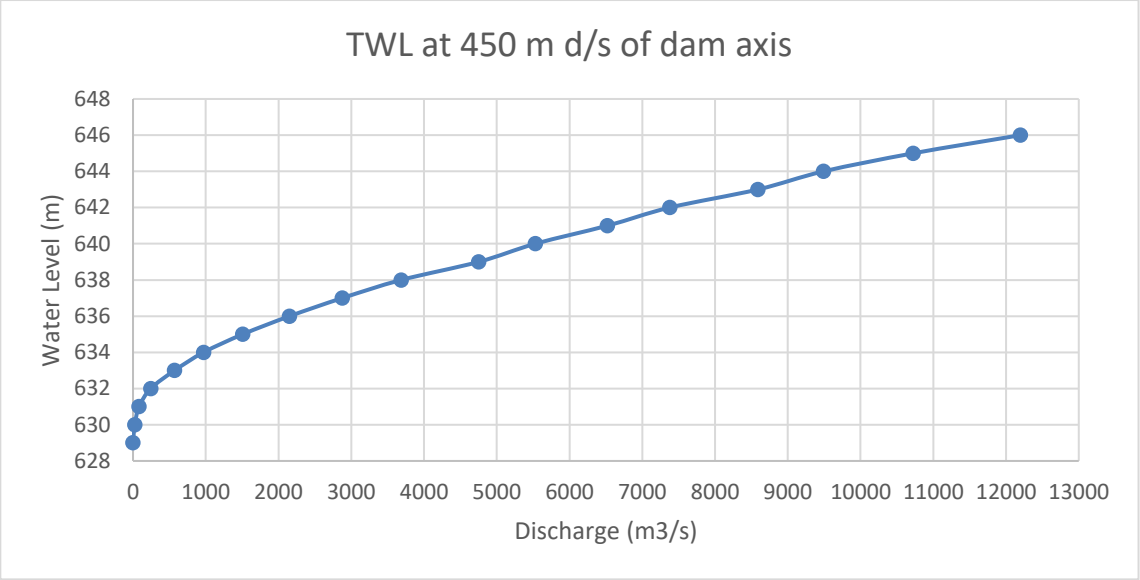

Figure A: Tail Water Level to be maintained at 450 m downstream of dam axis

5.1 Flow Conditions Upstream of Dam Axis

Studies were conducted for observing the flow conditions upstream of the spillway for the entire range of discharges for ungated and gated operation of spillway. The approach flow conditions upstream of spillway were less turbulent or laminar in all gated and ungated conditions. Due to slight obliquity of approach flow conditions, the intensity of flow was relatively towards right end spans during ungated operation of the spillway (free flow condition); whereas air entraining vortices were seen forming intermittently in front of each spillway span during ungated operation.

Photos 5 to 8 show the flow conditions upstream of spillway for ungated operation (free flow) while passing 5700 m^3/s at all 5 bays opened and 7590 m^3/s at only 4 bays opened and for 4 m and 9 m gated operation respectively.

5.2 Discharging Capacity of the Spillway

Hydraulic model studies were conducted for assessing the discharging capacity of the spillway for entire range of discharges for the ungated operation of spillway. The studies indicated that the design discharge of 7590 m^3/s (routed discharge of 8427 m^3/s peak flow) could be passed at El. 736.7 m with all 5 gates fully open. Maximum discharge of 11000 m^3/s could be passed at HFL El. 763.6 m keeping 2.00 m freeboard as the dam top is 765.6 m.

As per IS 11223: 1985, “Guidelines for fixing spillway capacity”, in the clause related to gated spillway under mechanical and human failures, assuming 10% gates inoperative,

discharging capacity of spillway for remaining spans needs to be assessed. The left most gate was kept closed and rest 4 gates were kept opened. With left end gate of spillway in closed condition, the discharge of 7590 m^3/s could be passed at RWL El. 747.1 m and maximum discharge of 9000 m^3/s could be passed at HFL El. 763.6 m keeping freeboard of 2.0 m as the dam top is 765.6 m. **Figure B** below shows the discharging capacity curves for ungated operation of spillway with all five spans and 4 spans operating respectively.

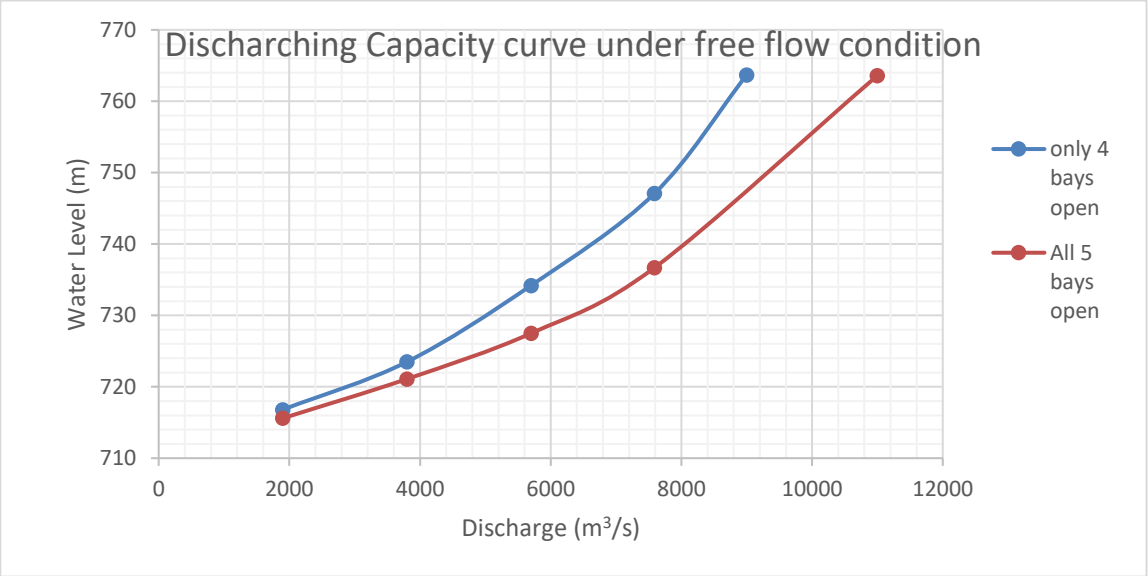

Figure B: Discharging Capacity curve under free flow conditions

Refer **Table 04 & 05** for discharging capacity of spillway at different discharges.

Coefficient of Discharge: The coefficient of discharge was calculated for both the conditions i.e. all 5 bays open and only 4 bays open condition (free flow).

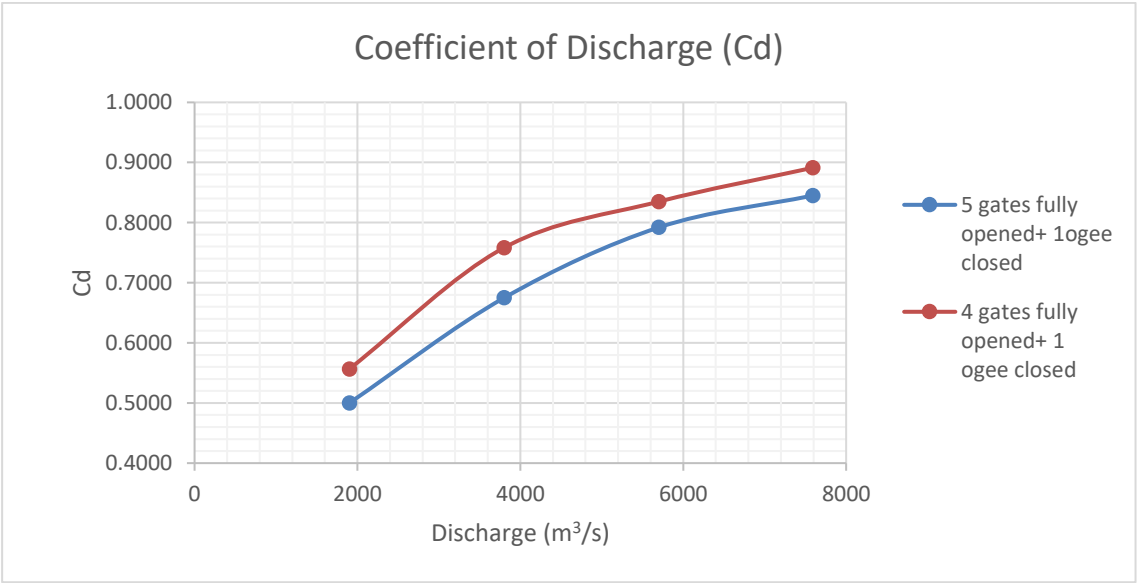

Figure C-1: Coefficient of Discharge under free flow conditions

A discharge coefficient of 0.845 was observed at design discharge of 7950 m^3/s at all 5 gates open. However, a discharge coefficient of 0.8912 was observed at a design

discharge of 7950 m^3/s at only 4 gates open condition.

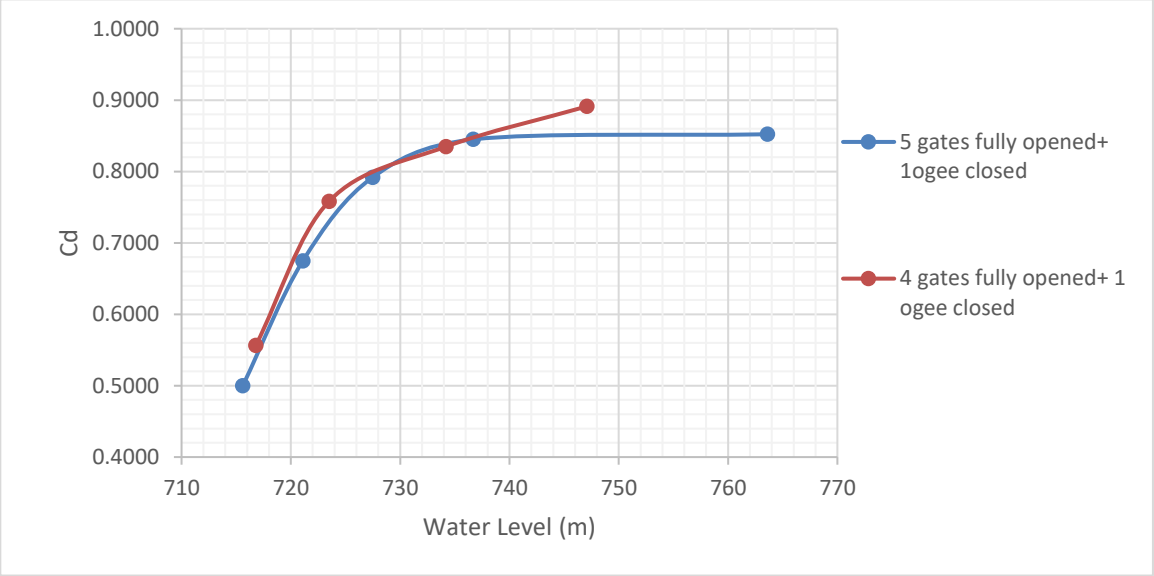

Figure C-2: Coefficient of Discharge under free flow conditions

The variation of discharge coefficient of the proposed crest with head over the crest and reservoir level is tabulated in **Table 06A & 06B** and shown in **Figure C-1 & C-2** above.

5.3 Water Surface Profiles and Performance of Plunge Pool

Studies were conducted for observing water surface profiles from Chainage 50 m upstream to 450 m downstream of the dam axis at spillway glacis, plunging jet, within plunge pool and downstream of plunge pool for different discharges of 1900 m^3/s, 3800 m^3/s, 5700 m^3/s and 7590 m^3/s at various conditions mentioned in **Table 4 & 5**. Results are shown in **Figures 7 to 11** for all 5 bays fully opened and in **Figures 12 to 16** for only 4 bays fully opened. The revised TWL has been maintained at 450 m cross section downstream of dam axis.

All 5 bays fully opened (free flow): The jet trajectory top of 699.1 m was observed at 7590 m^3/s (PMF) while at HFL maintained condition, the maximum trajectory top recorded was 705.6 m. The various trajectory levels at different cross sections are shown in **Table 4** and plotted in **Figure 7 to 11**. The jet for discharges upto 7590 m^3/s are falling within the plunge pool. The maximum trajectory length of 255.0 m and 296.0 m was recorded at 7590 m^3/s and 11000 m^3/s respectively. For discharge, 7590 m^3/s and above a humplike structure appears within the plunge pool area, which is creating secondary jump at the end of plunge pool. At 11000 m^3/s discharge, the disturbed or turbulent flow was observed due to falling of jet at the end slope of plunge pool. The performance of jet and plunge pool can be seen in **Photo 9 to 13.**

Only 4 bays fully opened (free flow): The jet trajectory top of 701.7 m was observed at 7590 m^3/s (PMF) while at HFL maintained condition, the maximum trajectory top recorded was 704.4 m. The various trajectory levels at different cross sections are shown in **Table 5** and plotted in **Figure 12 to 16**. The maximum trajectory length of 270.0 m and 310.0 m was recorded at 7590 m^3/s and 9000 m^3/s respectively. The jet for discharges 7590 m^3/s and above is creating secondary jump at the end of plunge pool which is creating disturbed or turbulent flow and also a humplike structure appears within the plunge pool area. The performance of jet and plunge pool can be seen in **Photo 14 to 18.**

Partial Gate opened: The gate rating was done at 2 m, 4 m, 6 m, 8 m, 9 m and 10 m gate openings. All the gates were kept equally opened. It was found that at HFL maintained condition, the maximum trajectory length observed was 295.0 m at 8 m gate opening and the maximum trajectory top of 706.5 m was observed at 6 m gate opening. The details are shown in **Table 07** and the gate rating at different level-maintained condition viz. 717.47 m (MDDL), 762.00 m (FRL) & 763.60 m (HFL) are shown in **Figure D** below:

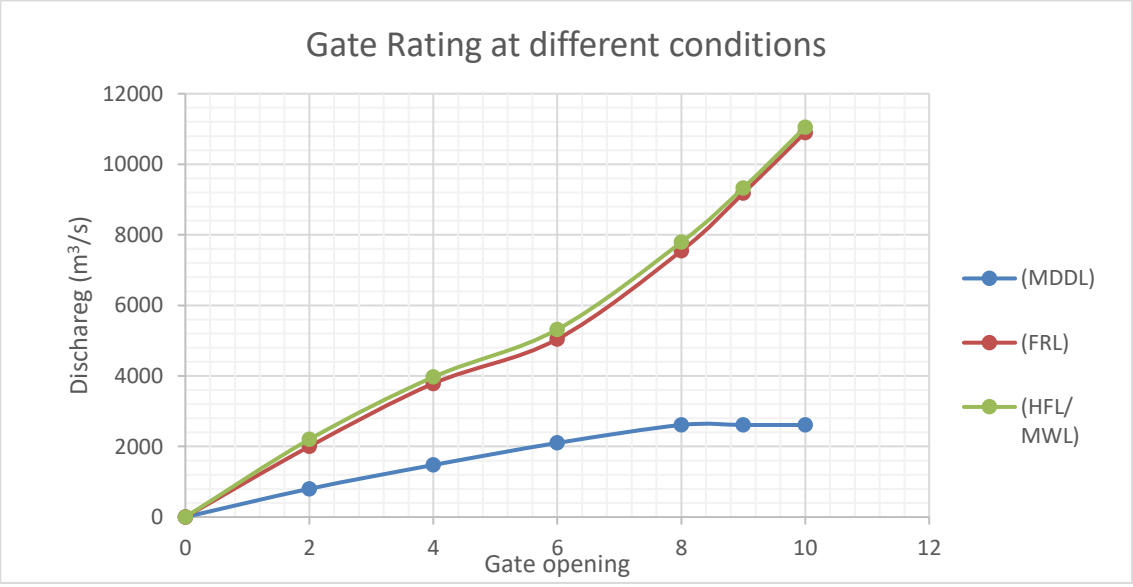

Figure D: Gate Rating Curve

The performance of trajectory under gated condition can be seen in **Photo 19 to 22**.

5.4 Pressures

Cavitation is the most complex hydrodynamic phenomenon and can cause serious damage to the spillway surface and is influenced by pressures, velocities and duration of spillway operation. The inception of cavitation damage can be assessed by the cavitation index. Pressures are measured on spillway surface to assess cavitation index for the minimum pressures and if it is less than the critical cavitation index of 0.2, necessary remedial measures are suggested to mitigate cavitation damages.

Initial pressure studies indicated the negative pressures on the spillway surface, which was conveyed to the sponsor in the form of a note. The sponsor vide mail dated 08.06.2023 provided the provision of aerator with two 600 mm dia pipe on the inner face of divide wall. Further, sponsor vide mail dated 28.08.2024 provided the figure for location and size of aerator to be installed in the model as shown below. Hence, at the level of 702.0 m an aerator was installed on spillway surface in the model as shown in **Figure E** below:

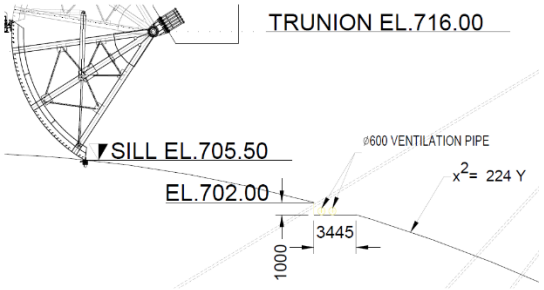

Figure E: Location of Aerator

Piezometric pressures were measured for various conditions as mentioned in **Table 08, 09 & 10** at different ungated and gated conditions. The location of piezo points on the surface profile of spillway along centre line in central bay and along the breast profile are shown in **Figures 17**.

The pressures on the spillway profile in bay No. 3 are shown in **Figures 23 to 27** while all 5 bays were fully opened. The piezometric pressures at various locations along the spillway surface and breast wall are given in **Table 8 & 9**. Positive pressures were observed on the spillway surface for the entire range of discharges upto 7590 m^3/s in both free flow conditions but negative pressures were observed at 705.5 m & 703.0 m level under all gated condition as shown in **Table 10**. The maximum negative pressure of -4.29 m was observed at 6 m gate opening.

Also, the negative pressures were observed along breast wall in free flow condition. The maximum negative pressure of order of -7.7 m has been observed at point no 1 at 7590

m^3/s. However positive pressures were observed in gated condition. The installation of air ducts at breast wall shall reduce the negative pressures and formation of intermittent vortex. A typical section of aerator on spillway surface is shown in Figure F below:

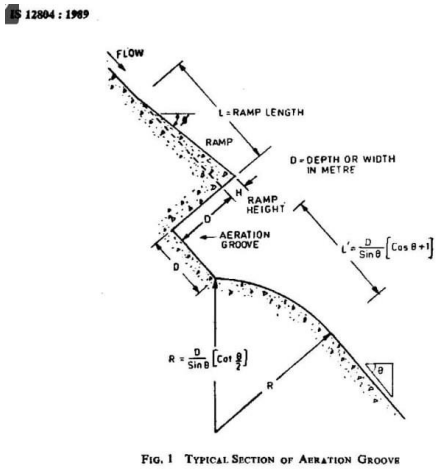

FIG. 1 TYPICAL SECTION OF AERATION GROOVE

Figure F: Typical section of Aerator Groove as per Indian Standards

5.5 Velocity

Velocities were measured at 0.6D depth (where D is the depth of flow in a given location) at the downstream of plunge pool at various cross-sections (350 m, 400 m, 450 m downstream of dam axis). The velocities were recorded under different conditions viz all 5 bays fully opened (free flow), only 4 gates fully opened (free flow) & under gated condition and the result are shown in **Tables 11A, 11B & 11C**. Downstream of plunge pool, the flow gets accelerated at higher discharges due to formation of secondary jump at end sill. At the end of plunge pool, rapidly varied super critical flows were noticed for high discharges with gated and ungated operation of the spillway. Necessary bank protection measures are needed to strengthen the left bank adjacent to plunge pool and downstream of plunge pool as high velocities of 6 to 9 m/s were observed at different conditions. The protection measures are essential to avoid uncontrolled erosion of the river banks and downstream of plunge pool.

a) Velocity Measurement under Free Flow Condition

Velocities were measured by using current meter under free flow conditions along the right, center and left of the river. The velocity observations were taken for the discharges of 1900 m^3/s, 3800 m^3/s, 5700 m^3/s and 7590 m^3/s at different locations. A maximum velocity of 8.16 m/s was observed at 450 m downstream of dam axis at center of river at 7590 m^3/s discharge while all 5 bays were fully opened. Also, a

maximum velocity of 8.95 m/s was observed at 350 m downstream of dam axis at center of river at 7590 m^3/s discharge while only 4 bays were fully opened. The recorded velocities under free flow condition are shown in **Table 11A & 11B**. The maximum velocities are concentrated at the centre line of river.

b) Velocity Measurement under Gated Conditions

Velocities were also measured along the right, center and left of the river under Gated condition at FRL El. 763.6 m (all the five gates equally opened) for gate opening of 2.0 m, 4.0 m, 6.0 m, 8.0 m, 9.0 m & 10.0 m at different locations by using current meter. A maximum velocity of 7.0 m/s was observed at 9.0 m gate opening at HFL maintained condition. The recorded velocities under gated condition are shown in **Table 11C**. The velocity profile along left, centre and right bank of river are shown in **Figure G** below:

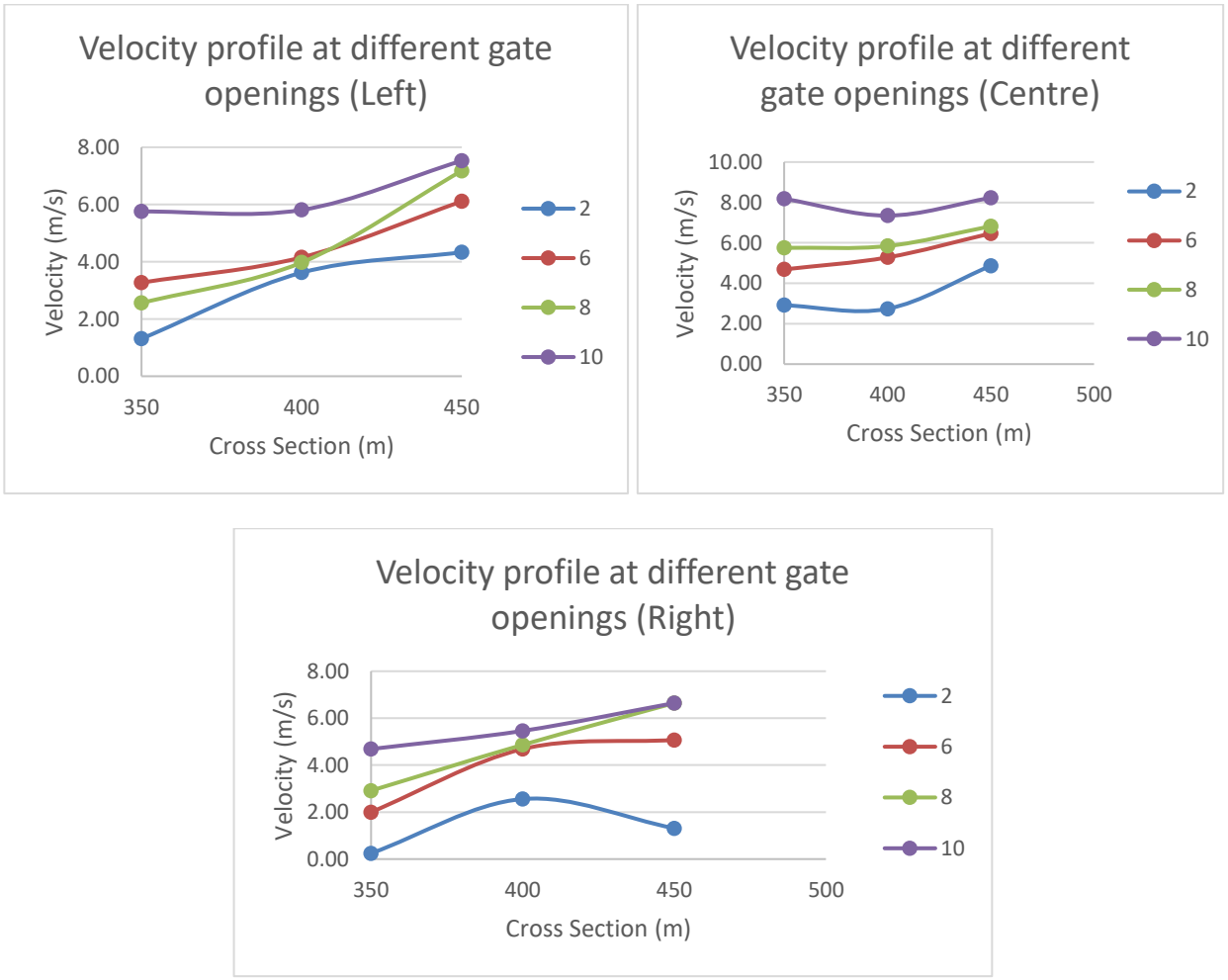

Figure G: Velocity Profiles at different gate openings at downstream of plunge pool

It is suggested that all the spans of the spillway be operated equally and partially for passing various discharges. Any uneven operation would create return eddies within the plunge pool area.

6.0 CONCLUSIONS & SUGGESTIONS

Based on the observations on the model and discussions with the project/ design engineers following conclusions are drawn:

1. Due to slight obliquity of approach flow conditions, flows were seen concentrating towards left end spans during ungated operation of the spillway (free flow condition); whereas air entraining vortices were seen forming intermittently in front of left bays of spillway.

2. The studies for spillway discharging capacity indicated that the design routed discharge of 7590 m^3/s could be passed at RWL El. 736.7 m with all gates fully open. But the maximum discharge of 11000 m^3/s could be passed at HFL El. 763.6 m keeping 2.0 m freeboard as the dam top is 765.6 m.

3. As per IS 11223: 1985, "Guidelines for fixing spillway capacity", in the clause related to gated spillway under mechanical and human failures, assuming 10% gates inoperative, discharging capacity of spillway for remaining spans needs to be assessed. With left end gate of spillway in closed condition, the discharge of 7590 m^3/s could be passed at RWL El. 747.1 m and the maximum discharge of 9000 m^3/s could be passed at HFL El. 763.6 m keeping 2.0 m freeboard as the dam top is 765.6 m.

4. A discharge coefficient of 0.845 was calculated at design discharge of 7950 m^3/s at all 5 gates open (free flow). However, a discharge coefficient of 0.8912 was observed at a design discharge of 7950 m^3/s when only 4 gates were open (free flow). The variation of discharge coefficient of the proposed crest with head over the crest is tabulated in **Table No. 06**.

5. It was observed that the trunnion of the radial gate was well above the water surface profiles for the discharges up to design discharge of 7590 m^3/s under all free flow and gated conditions. However, it was observed that the flow entering from the central bay was touching the trunnion of the radial gate intermittently while passing maximum discharge of 11000 m^3/s at HFL El. 763.6 m during ungated operation.

6. Positive pressures were observed on the spillway surface for the entire range of discharges upto 7590 m^3/s in both free flow conditions but negative pressures of the order of -2.7 m to -4.3 m were observed at 705.5 m & 703.0 m level under all gated condition. However, with increase in increase in gate opening the pressures are decreasing. The designed aerator as per IS code 12804 with connecting air duct shall reduce the negative pressures within permissible range. Further, positive pressures were found on breast wall under all gated condition. The location and number of provided aerator is adequate.

7. The maximum and minimum trajectory length observed at free flow condition while only 4 bays fully opened were 270 m and 150 m from dam axis at design discharge 7590 m^3/s and 190 m^3/s. Also, while all 5 bays were fully operating, the observed maximum and minimum trajectory length was 255 m and 150 m at corresponding discharge of 7590 m^3/s and 450 m^3/s. Also under gated condition, the maximum trajectory length observed was 295 m at 8 m opening. The observed trajectory lengths are shown in **Table 04, 05 & 07** under different conditions.

8. The water surface profile indicates that the maximum water level observed at end sill under only 4 bays open condition was 692.0 m. However, the top EL of divide wall is 708.7 m. So, the divide wall may be curtailed upto 695.0 m, which shall not impart any change in hydraulic behaviour of jet trajectory. The tentative curtailment details of divide wall are shown in **Figure 16**.

9. A maximum velocity of 8.16 m/s was observed at 450 m downstream of dam axis at center of river at 7590 m^3/s discharge while all 5 bays were fully opened and a maximum velocity of 8.95 m/s was observed at 350 m downstream of dam axis at center of river at 7590 m^3/s discharge while only 4 bays were fully opened. Also, A maximum velocity of 7.0 m/s was observed at 9.0 m gate opening at 350 m cross section while HFL condition was maintained.

10. Downstream of plunge pool, the flow gets accelerated at higher discharges due to formation of secondary jump at end sill. At the end of plunge pool, rapidly varied super critical flows were noticed for high discharges with gated and ungated operation of the spillway. Necessary bank protection measures are needed to strengthen the left bank adjacent to plunge pool and downstream of plunge pool as

high velocities of 6 to 9 m/s were observed at different conditions. The protection measures are essential to avoid uncontrolled erosion of the river banks and downstream of plunge pool.

11. The impact of jet was also found reaching upto the bottom of plunge pool as shown in **Figure 16**. And the jet was found hitting within the plunge pool area upto 7590 m^3/s discharge while at HFL maintained condition under 4 bays fully opened the jet was hitting at the top of front slope. The scouring within Plunge pool can also be seen in **Photo 24**. The maximum scoured level of 595 m was observed within the plunge pool area with the use of well graded boulders at design discharge. The scouring studies are qualitative in nature and scour depth value is tentative and completely depends on the strata available at site.

12. The left bank along plunge pool shall be cut down and will be protected to withstand high thrust of jet. The probable cutting on left bank is shown in **Figure 28**.

7.0 ACKNOWLEDGEMENT

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The assistance extended by the technical staff of IRI, Bahadrabad in construction and experimentation on model is gratefully acknowledged.

Annexure- 01

Salient Feature of Jamrani Dam Multipurpouse Project

I. General

1. Latitude	29^0 16' 12.50" N
2. Longitude	79^0 36' 43.92" E
3. Topo-map	65 E / 12
4. Location	10 Km upstream of Kathgodam in Nainital District, Uttarakhand,
5. Village	Jamrani
6. Tehsil	Haldwani
7. District	Nainital
8. State	Uttarakhand
9. Name of the river	Gola
10. Name of Basin	Ganga
11. Catchment Area of dam site	450 Km^2

II. Hydrology

1. Average Annual Rainfall	2016 mm
2. Average Annual yield at dam site	
a. 50% Dependable year	393.31MCM
b. 75% Dependable year	283.06 MCM
3. Flood	
a. Probable Maximum Flood	8427Cumec
b. Diversion Flood	1500 Cumec (for hydrology Design)

III. Dam and Spillway Arrangements

1. Type	Concrete Gravity Dam
2. Length at Crest	405 m
3. Max height above deepest Foundation level (EIev. - 615m)	150.60 m
4. Crest of Spillway	706.00 m
5. Width at top	8 m
6. Top of Dam	765.60 m
7. Type of gate	Radial type
8. No. and size of gate spillway and	5 No. 8 m (W) x 10 m (H) for breast type 1 no. 4 m (W) x 4 m (H) for surface spillway.
9. Discharge passing	7590 Cumec for (n-1) condition
10. Free board	2 m above MWL

IV. Energy Dissipation Arrangement

1.	Type	Trajectory Bucket type with plunge pool
2.	Invert Level of bucket	675.63 m
3.	End sill elevation of lip	682.33 m

V. Diversion Arrangement

1.	Type	Horse shoe shaped
2.	Diameter	2 No. 8.1 m dia.
3.	Length	650 m & 750 m respectively on right bank of Gola river
4.	Lining	Concrete (M20 grade)
5.	Upstream coffer dam	22 m high (concrete type with concrete lined upstream face)
a.	Top width	5 m
6.	Downstream coffer dam	9 m high (rock fill type with concrete lined downstream face M15 grade)
a.	Top width	5 m
7.	Diversion design flood	1890 Cumec

VI. Reservoir

1.	Top dam level	765.60 m
2.	Max water level	763.60 m
3.	Full reservoir level	762.00 m
4.	M.D.D.L	717.47 m
5.	River bed level	635.00 m
6.	Gross Storage ¼at El. 762.00 m½	208.60 MCM
7.	Live Storage	142.72 MCM
8.	Dead Storage	65.88 MCM
9.	Submergence Area ¼at El. 762.00 m½	428.57 Ha

VII. Intake

1.	Type	Bell mouth entry type (2 Nos.)
2.	Centerline of intake	713.80 m
3.	Dia. of Intake	2.0 m
4.	Height of trash rack opening	6.18 m
5.	Crest level	712.80 m
6.	Size of intake gate	1.66 m (W) x 2 m (H)
7.	Design Discharge	7.22cumec

VIII. Penstock

1. No of penstock	2 Nos. bifurcating into 2 penstock each of 1.2 m diameter to serve vertical Francis Turbine
2. Length (upto D line of power House)	155.3 m
3. Diameter	1.7 m for 2 Nos. and 1.2 m for 4 Nos.

IX. Power House

1. Location	On right bank
2. Type	Surface
3. No of size of units	4 Nos.
4. Type of turbine	Vertical Francis turbine
5. Installed capacity	4 x 3.5 MW
6. Net design head	106.82 m
7. Design discharge for one unit	3.61 Cumec
8. Size of power house	55.30 m x 14.0 m x 23.0 m

X. Kathgodam Barrage

1. Length	81.00 m
2. Crest level of other bays	506.50 m
3. Crest level of sluice bays	506.50 m
4. Bad level of river downstream	502.00 m
5. Design discharge	3250 Cumec
6. Pond level	510.75 m

XI. Irrigation

1. CCA	150027 Ha
2. Area being irrigated at present	238317 Ha
3. Further area proposed to be irrigated	57065 Ha
4. Total irrigated Area	295382 Ha
5. Existing average intensity of irrigation	158.85 %
6. Proposed average intensity of irrigation	196.88 %
7. Total requirement of water for irrigation	416.30 MCM

XII. Demand for drinking water

@ 117 mld for 10.65 lac population projected	42.70 MCM/ yearly for the year 2051

Annexure- 02

Tables

Table 01: Theoretical & Observed Water Levels at different Cross Sections (without Dam)

Study No.-01: Proving of Model

Sl. No.	River Q (m^3/s)	Water Levels (EL in m)														
		Cross Section 600 m U/S		Cross Section 400 m U/S		Cross Section 200 m U/S		Cross Section 100 m U/S		Cross Section Dam Axis		Cross Section 100 m D/S		Cross Section 200 m D/S		Maintained at Cross Section 400 m D/S
		Theoretical	Observed	Theoretical	Observed	Theoretical	Observed	Theoretical	Observed	Theoretical	Observed	Theoretical	Observed	Theoretical	Observed	Theoretical
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
1	500	644.99	644.73	642.29	642.03	640.17	640.00	638.40	638.17	637.21	637.00	635.60	635.83	634.87	635.13	633.04
2	1000	645.75	645.57	643.20	642.93	641.11	640.67	639.28	638.63	638.23	638.20	636.86	636.87	636.06	636.17	634.24
3	2000	646.93	647.00	644.46	644.27	642.47	642.37	640.57	640.37	639.72	639.60	638.98	638.77	637.86	637.90	635.96
4	4000	648.66	648.93	646.37	646.20	644.50	644.47	642.50	642.30	641.84	641.67	641.04	641.17	640.41	640.07	638.51
5	6000	650.08	651.63	647.92	648.00	646.11	645.87	644.05	643.97	643.47	643.50	642.71	642.43	642.26	642.57	640.67
6	8427	651.56	655.60	649.51	649.57	647.75	647.50	645.63	645.90	645.13	645.30	644.65	644.50	644.18	643.47	642.74

Table 02: Sharp Crest Discharge Verification by Current meter in approach channel

Sl No.	Discharge Measured by Current Meter in Approach Channel									Discharge Measured by Sharp Crest				
	X-Section of Approach Chaneel	Width of Approach Channel (m)	Depth of Flow (d) (m)	Velocity of Flow (Model) in m/s					Q (Model) Cusec	Q (Proto) (m^3/s)	Width of Crest (m)	Height of Crest from u/s bed (m)	Head over Crest (cm)	Q (Model) Cusec	Q (Proto) (m^3/s)
				Location	at 0.2 d	at 0.6 d	at 0.8 d	Avg. Veocity (m/s)							
1	1	1.490	1.160	Left	0.153	0.207	0.201	0.196	11.96	7598	1.78	1.20	22.06	11.95	7590.1
				Center	0.195	0.225	0.231								
				Right	0.147	0.207	0.195								
				Average	0.165	0.213	0.209								
2	2	1.465	1.140	Left	0.219	0.207	0.201	0.203	11.97	7605					
				Center	0.213	0.201	0.195								
				Right	0.195	0.195	0.201								
				Average	0.209	0.201	0.199								
3	3	1.490	1.155	Left	0.153	0.189	0.189	0.197	11.97	7605					
				Center	0.195	0.249	0.255								
				Right	0.165	0.201	0.177								
				Average	0.171	0.213	0.207								

Table 03: Discharge Measurement through Parshall Flume

ISO: 9862-Free Flow condition in Parshall Flume
b=1.2 m Q= 2.904*(Ha)^1.577

Q at weir (m^3/s)	Ha (m)	Discharge Scale	(Ha)^1.577	Q_{guage} at Parshell Flume (m^3/s)	% lower than weir discharge
7590	0.253	22434	0.11	7458	1.74
7000	0.238	22434	0.10	6773	3.25
5000	0.192	22434	0.07	4827	3.46

Table No. 04: Observed Water Surface Profile and Trajectory length along spillway at different discharges

(Free Flow Conditions, all five sluice spillways and one surface spillway open)

S.No.	Distance from dam axis (m)	Location	*Water Levels (m) at different discharges (m^3/s) in Bay No. 5 & 3*									
			1900		3800		5700		7590		11000	
			Bay-5	Bay-3	Bay-5	Bay-3	Bay-5	Bay-3	Bay-5	Bay-3	Bay-5	Bay-3
1	-50	Upstream of dam axis	715.5	715.5	721.4	721.2	727.6	727.5	736.9	736.8	763.5	763.6
2	-25		715.3	715.6	721.2	721.1	727.6	727.5	736.8	736.7	763.5	763.6
3	0	Dam Axis	715.6	715.6	721.1	721.1	727.5	727.5	736.6	736.6	763.6	763.6
4	20	along spillway profile	711	711.2	715.3	715	715.2	715.2	715.7	715.1	715.7	715.6
5	40		706	706.5	709.5	709	711.1	711.1	712.2	712.1	713.7	712.5
6	60		699	699	700.3	700.3	704.2	704.2	705.2	705.1	707.4	707.5
7	80		687.6	687.2	689.7	689.3	691.2	691.3	693.6	693.1	696.2	696.3
8	100		678	678.2	680	680	682.6	681.9	683.4	683.1	685.4	686.3
9	120		679.1	679.1	681.2	681.4	682.8	682.5	685.3	685	686.7	687.1
10	130		684.3	684.2	685.4	685.3	687.8	687.7	688.9	688.5	690.2	691.2
11	150	Jet Trajectory	691.2	691.4	694	694	696.2	696.4	697.6	697.6	702.4	701.1
12	160		691.1	**691.4**	695.4	**695.7**	696.1	**696.7**	699	**699.1**	703.8	704.6
13	170		689.6	689.2	692.2	692.1	695.8	695.5	698.6	699	704.2	**705.6**
14	190		672.4	675.5	683.2	682	689.6	689.6	694.1	693	701.2	701.4
15	210		654	654	667.7	664.6	676.2	676.1	684.1	685.3	696.5	698.6
16	230		640	640	643.7	646.7	658.8	658.2	669.5	669.7	688.6	692.1

17	250		639	639	646	646	647	647	648.4	648.8	678.2	678.7
18	270		638.5	638.5	641	641	644.5	644.5	645.3	645.8	664.5	664.7
19	290		638.3	638.3	641	641	644	644	644.4	644.9	651.2	651.7
20	310		638	638	640.5	640.5	643.3	643.3	643.7	646.8	643.6	646.5
21	330		638	638	640	640	643	643	644.5	646.8	645.4	646.6
22	350	D/s of Plunge Pool	637.5	637.5	640.4	639.9	642.9	642.9	644.5	644.2	656.4	657.1
23	400		637.6	637.4	640.4	639.7	640.2	641.3	644.1	643.1	651.4	650.9
24	450		636.2	635.7	638.7	638.2	641.7	639.8	643.3	641.9	647.6	646.2
TWL to be maintained EL. (m)			635.8		638.2		640.2		642.3		645.5	
Trajectory Length (m)			217		230		245		255		296	
Trajectory Fall El. (m)			641	640	640	646.7	646.1	646.2	646.3	646.5	641.1	641.4

Table No. 05: Observed Water Surface Profile and Trajectory length along spillway at different discharges

(Free Flow Conditions, only four sluice spillways and one surface spillway open)

S.No.	**Distance from dam axis (m)**	**Location**	***Water Levels (m) at different discharges (m^3/s) in Bay No. 4 & 2***									
			1900		**3800**		**5700**		**7590**		**9000**	
			Bay-4	**Bay-2**	**Bay-4**	**Bay-2**	**Bay-4**	**Bay-2**	**Bay-4**	**Bay-2**	**Bay-4**	**Bay-2**
1	-50	Upstream of dam axis	716.8	716.8	723.6	723.6	734.4	734.2	747.3	747.2	763.6	763.7
2	-25		716.8	716.8	723.6	723.5	734.3	734.2	747.1	747.1	763.7	763.7
3	0	Dam Axis	717	716.8	723.5	723.5	734.2	734.2	747.1	747.1	763.7	763.7
4	20	along spillway profile	711.2	711.5	715.3	715.5	715.4	715.5	715.5	715.4	715	715.7
5	40		707.2	707.1	710.4	710.5	711.7	711.6	712.4	712.6	712.8	712.7

6	60		698.6	698.7	702.7	702.8	703.7	703.7	705.5	705.3	706.5	705.8
7	80		687.4	687.4	690.2	689.9	692.7	692.3	693.7	693.4	694.9	694.7
8	100		678.6	678.7	681.2	681.2	683.4	683.6	684.9	684.8	682.1	685.9
9	120		679.7	679.8	681.7	682.1	684.1	684.1	685.7	685.8	687.4	687.8
10	130		684.6	684.8	687.1	687.4	689.1	689	690.3	690.4	691.6	691.7
11	150	Jet Trajectory	692.6	692.8	695.7	695.7	697.7	697.5	698.5	698.6	701	701.5
12	160		692.4	**692.9**	695.6	**696.2**	698	**699.2**	700.2	700.5	703.4	703.6
13	170		690	690.2	693.1	694.6	697.1	698.4	700.6	**701.7**	703.4	704
14	190		678.4	679.3	682.6	685.5	694.2	694.2	672.2	698.3	701.5	**704.4**
15	210		656.3	656.1	669.9	672.1	682	682.6	689.6	690.5	697.5	698.9
16	230		640.2	640.2	650.1	650	666.4	667.6	680.1	680.1	689.4	693.6
17	250		641	641	645	645	643.3	646	664.3	666.6	679.3	680
18	270		639	639	642.2	642.2	644	644	645.2	645.4	668.6	668.9
19	290		638.5	638.5	642	642	643.5	643.5	643.6	643.9	642.3	657.4
20	310		638.4	638.4	641.3	641.3	643.4	643.4	641.2	641.4	642.7	642.5
21	330		638	638	641	641	643	643	641.9	645.6	644.6	644.5
22	350	D/s of Plunge Pool	637.8	637.4	640.6	640.9	643	643.5	642.1	644.5	644.2	653.5
23	400		637.8	637.2	640.4	638.6	643.2	642.1	644	643.6	646.2	644.6
24	450		636.2	635.8	638.9	637.7	642.2	639.7	643.3	642.3	645.6	642.4
TWL to be maintained EL. (m)			635.8		638.2		640.2		642.3		645.5	
Trajectory Length (m)			230		233		255		270		310	
Trajectory Fall El. (m)			639.9	640.2	642.5	644.5	643.9	643.7	645.2	645.4	642.6	644.5

Table 06A: Coefficient of discharge for surface spillway at different discharges under different conditions

S. No.	Discharge (m^3/s)	5 gates fully opened			4 gates fully opened		
		Reservoir level at 25 m u/s (m)	Head above centre of opening (Hc)	C_d	Reservoir level at 25 m u/s (m)	Head above centre of opening (m)	C_d
1	**1900**	715.6	4.6	**0.5000**	716.8	5.8	**0.5566**
2	**3800**	721.1	10.1	**0.7110**	723.5	12.5	**0.7583**
3	**5700**	727.5	16.5	**0.7920**	734.2	23.2	**0.8359**
4	**7590**	736.7	25.7	**0.8450**	747.1	36.1	**0.8912**

Table 06B: Coefficient of discharge at different reservoir levels

Reservoir Level (m)	Cd	Reservoir Level (m)	Cd	Reservoir Level (m)	Cd
716	0.5125	726	0.773	736	0.843
717	0.545	727	0.787	737	0.847
718	0.582	728	0.7985	738	0.848
719	0.615	729	0.81	739	0.849
720	0.645	730	0.817	740	0.85
721	0.673	731	0.823		
722	0.697	732	0.83		
723	0.719	733	0.835		
724	0.74	734	0.839		
725	0.759	735	0.841		

Table No. 07: Gate rating of Surface Spillway & Trajectory length from dam axis
(Under Gated conditions, All Gates Equally open and one surface spillway open)

S. No.	Gate Opening (m)	Reservoir Level (m)				
		717.47	762.00	763.60		
		(MDDL)	(FRL)	(HFL/ MWL)		
		Discharge (m^3/s)	Discharge (m^3/s)	Discharge (m^3/s)	Trajectory Length (m)	Max. height of Trajectory El. (m)
1	0	0	0	0	0	0
2	2	800	2000	2200	270	704
3	4	1475	3784	3969	270	705.5
4	6	2100	5042	5316	290	706.5
5	8	2609	7545	7789	295	705.9
6	9	2609	9177	9330	295	705.4
7	10	2609	10900	11050	295	705.2
8	9	2094	7348	7559	only 4 gates open & surface spillway close	
9		2094	7387	7652	4 gates+ ogee open	

Table No. 08: Observed Hydrostatic Pressures along Surface Spillway & Breast wall at different discharges (All 5 gates & ogee spillway open)

Piezo point no.	Orientation (Spillway No. 03)			Observed Hydrostatic Pressures (m)				
	Location	Horizontal Distance Along Profile from center line of Dam axis (m)	Elevation (m)	At different discharges (Free Flow- Ungated condition)				
				1900	**3800**	**5700**	**7590**	**11050**
1	Breast Wall	0.87 m U/S	718.50	_	-2.20	-3.05	-6.60	-10.50
2		3.45 m D/S	716.25	_	0.55	-1.00	-1.60	-4.40
3		11.12 m D/S	716.00	_	-2.20	-3.05	-5.00	0.83
1	Spillway Profile (Left Row)	1.12 m D/S	705.00	7.70	9.35	11.00	12.65	15.95
2		7.35 m D/S	706.00	6.60	8.80	9.63	9.90	9.90
3		17.89 m D/S	705.50	4.95	7.43	7.15	6.05	1.65
4		33.23 m D/S	703.00	30.80	30.80	4.40	2.75	-4.13
5		54.63 m D/S	696.00	0.28	1.65	1.65	0.83	-4.13
6		74.47 m D/S	686.00	2.20	6.60	4.95	4.40	4.95
7		88.17 m D/S	679.00	6.05	9.35	13.75	17.60	26.95
8		106.45 m D/S	675.63	5.50	10.45	13.20	17.05	29.15
9		121.34 m D/S	678.00	4.95	10.18	15.13	18.70	29.70
10		130.57 m D/S	682.00	3.85	6.60	8.25	10.45	16.50
1	Spillway Profile (Center Row)	1.12 m D/S	705.00	7.15	8.25	10.45	11.55	14.30
2		7.35 m D/S	706.00	6.60	8.25	7.15	5.50	0.55
3		17.89 m D/S	705.50	4.68	7.15	6.33	4.40	-1.65
4		33.23 m D/S	703.00	2.48	4.40	4.13	2.75	-3.30
5		54.63 m D/S	696.00	2.75	3.85	3.85	1.38	0.55
6		74.47 m D/S	686.00	4.95	6.60	9.08	10.45	14.85
7		88.17 m D/S	679.00	6.88	10.45	14.85	18.43	28.60
8		106.45 m D/S	675.63	-2.48	1.65	3.30	6.60	15.40
9		121.34 m D/S	678.00	1.10	5.50	9.63	12.65	19.80
10		130.57 m D/S	682.00	1.38	2.20	2.75	3.85	5.50
1	Spillway Profile (Right Row)	1.12 m D/S	705.00	6.05	7.70	6.88	5.50	_
2		7.35 m D/S	706.00	8.25	9.90	12.10	14.30	20.90
3		17.89 m D/S	705.50	4.95	7.70	6.60	4.95	_
4		33.23 m D/S	703.00	2.75	4.40	0.00	0.00	_
5		54.63 m D/S	696.00	2.48	3.85	4.95	4.95	3.30
6		74.47 m D/S	686.00	0.55	1.65	2.75	3.85	4.68
7		88.17 m D/S	679.00	1.93	6.05	9.90	13.75	22.00
8		106.45 m D/S	675.63	4.13	4.40	2.75	5.50	13.75
9		121.34 m D/S	678.00	4.13	8.25	12.65	15.95	22.28
10		130.57 m D/S	682.00	0.28	1.10	3.03	3.30	4.95

Table No. 09: Observed Hydrostatic Pressures along Surface Spillway & Breast wall at different discharges (4 gates & ogee spillway open)

Piezo point no.	Orientation (Spillway No. 03)			Observed Hydrostatic Pressures (m)				
	Location	Horizontal Distance Along Profile from center line of Dam axis (m)	Elevation (m)	At different discharges (Free Flow- Ungated condition)				
				1900	**3800**	**5700**	**7590**	**9000**
1	Breast Wall	0.87 m U/S	718.50	_	-3.33	-3.60	-7.77	-9.00
2		3.45 m D/S	716.25	_	-2.77	-2.22	0.83	-5.50
3		11.12 m D/S	716.00	_	-1.66	-2.22	2.22	1.10
1	Spillway Profile (Left Row)	1.12 m D/S	705.00	8.25	10.45	12.10	14.58	15.95
2		7.35 m D/S	706.00	7.15	9.35	9.63	10.45	10.45
3		17.89 m D/S	705.50	5.50	7.70	6.33	4.40	2.20
4		33.23 m D/S	703.00	3.85	3.85	3.58	1.10	-3.58
5		54.63 m D/S	696.00	2.48	3.30	1.10	-1.10	-3.85
6		74.47 m D/S	686.00	-0.83	4.68	2.75	4.95	4.95
7		88.17 m D/S	679.00	7.15	11.06	16.50	22.00	26.95
8		106.45 m D/S	675.63	5.78	11.06	17.88	24.20	29.70
9		121.34 m D/S	678.00	6.33	12.65	18.43	24.20	29.70
10		130.57 m D/S	682.00	4.40	7.15	10.45	13.20	17.05
1	Spillway Profile (Center Row)	1.12 m D/S	705.00	8.25	9.90	11.00	13.20	14.30
2		7.35 m D/S	706.00	7.70	7.70	6.05	3.58	0.55
3		17.89 m D/S	705.50	5.50	6.88	4.95	1.93	-1.93
4		33.23 m D/S	703.00	2.75	4.40	3.03	0.00	-3.85
5		54.63 m D/S	696.00	3.03	4.13	4.40	1.65	1.10
6		74.47 m D/S	686.00	5.23	8.25	10.45	12.38	14.85
7		88.17 m D/S	679.00	7.70	12.93	12.10	23.10	28.60
8		106.45 m D/S	675.63	-0.55	2.20	7.15	12.10	14.30
9		121.34 m D/S	678.00	2.20	7.70	12.65	15.95	19.80
10		130.57 m D/S	682.00	1.54	2.48	3.58	4.40	5.23
1	Spillway Profile (Right Row)	1.12 m D/S	705.00	6.88	7.15	5.50	2.75	0.00
2		7.35 m D/S	706.00	8.80	11.00	13.75	17.05	20.90
3		17.89 m D/S	705.50	5.50	7.15	5.50	2.75	0.00
4		33.23 m D/S	703.00	0.00	0.00	0.00	0.00	0.00
5		54.63 m D/S	696.00	3.03	4.40	4.68	4.40	3.30
6		74.47 m D/S	686.00	1.10	2.75	3.85	4.40	4.40
7		88.17 m D/S	679.00	3.30	9.35	12.65	17.60	22.00
8		106.45 m D/S	675.63	5.78	6.05	3.85	4.40	5.50
9		121.34 m D/S	678.00	5.23	10.45	15.68	20.90	25.30
10		130.57 m D/S	682.00	1.10	2.48	3.58	3.85	4.95

Table No. 10: Observed Hydrostatic Pressures along Surface Spillway & Breast wall at different gate openings (All gates equally open)

Piezo point no.	Orientation (Spillway No. 03)			Observed Hydrostatic Pressures (m)					
	Location	Horizontal Distance Along Profile from center line of Dam axis (m)	Elevation (m)	At different gate openings, m (Gated condition)					
				2	**4**	**6**	**8**	**9**	**10**
1	Breast Wall	0.87 m U/S	718.50	3.85	32.73	27.50	33.70	32.73	_
2		3.45 m D/S	716.25	14.85	37.68	34.65	36.80	38.68	_
3		11.12 m D/S	716.00	18.70	31.08	33.00	32.08	36.34	_
1	Spillway Profile (Left Row)	1.12 m D/S	705.00	O.F.	O.F.	O.F.	O.F.	28.60	12.10
2		7.35 m D/S	706.00	O.F.	O.F.	O.F.	O.F.	21.45	5.50
3		17.89 m D/S	705.50	2.75	3.85	5.50	6.88	5.50	_
4		33.23 m D/S	703.00	-2.20	-4.40	-4.68	-4.40	-3.30	-3.30
5		54.63 m D/S	696.00	-2.20	-6.05	-6.05	-5.50	-4.40	-3.85
6		74.47 m D/S	686.00	0.55	-0.55	0.00	1.65	3.58	5.50
7		88.17 m D/S	679.00	7.70	12.65	15.95	20.90	23.65	27.50
8		106.45 m D/S	675.63	4.40	11.00	15.40	20.35	7.15	10.45
9		121.34 m D/S	678.00	4.13	11.83	17.05	22.00	26.40	30.80
10		130.57 m D/S	682.00	6.33	8.80	11.00	14.30	15.95	17.05
1	Spillway Profile (Center Row)	1.12 m D/S	705.00	O.F.	O.F.	O.F.	O.F.	26.95	9.90
2		7.35 m D/S	706.00	O.F.	O.F.	O.F.	O.F.	13.75	-4.95
3		17.89 m D/S	705.50	-3.70	-1.65	1.65	10.45	33.00	_
4		33.23 m D/S	703.00	-3.85	-4.13	-4.29	-4.13	-2.75	-2.75
5		54.63 m D/S	696.00	2.20	1.60	1.65	1.65	2.20	1.65
6		74.47 m D/S	686.00	7.98	7.15	9.90	10.45	12.10	13.75
7		88.17 m D/S	679.00	9.35	12.65	17.88	22.55	13.75	24.20
8		106.45 m D/S	675.63	-6.60	-3.30	-1.10	5.50	10.73	19.25
9		121.34 m D/S	678.00	2.33	3.85	7.70	13.75	18.15	22.00
10		130.57 m D/S	682.00	0.55	1.65	2.48	3.30	1.10	3.58
1	Spillway Profile (Right Row)	1.12 m D/S	705.00	O.F.	O.F.	O.F.	O.F.	14.85	-4.40
2		7.35 m D/S	706.00	O.F.	O.F.	O.F.	O.F.	31.35	17.60
3		17.89 m D/S	705.50	1.10	2.20	3.85	4.40	3.58	-1.10
4		33.23 m D/S	703.00	_	_	_	_	_	_
5		54.63 m D/S	696.00	1.93	1.93	2.20	1.65	3.30	3.30
6		74.47 m D/S	686.00	-1.38	-1.38	-1.10	1.38	3.30	5.50
7		88.17 m D/S	679.00	0.00	4.40	8.80	15.18	18.70	24.20
8		106.45 m D/S	675.63	2.75	2.75	_	_	_	_
9		121.34 m D/S	678.00	1.10	3.30	0.00	-4.40	0.00	-4.95
10		130.57 m D/S	682.00	-2.42	-2.75	-1.38	1.38	3.85	5.50

Note: O.F.- Over Flow

_ - No reading

Table No. 11 A: Observed Velocities at downstream of plunge pool at different discharges

(Free Flow Conditions, all five sluice spillways and one surface spillway open)

S. No.	Location		1900			3800			5700			7590			11000		
			Left	Centre	Right	Left	Centre	Right	Left	Centre	Right	Left	Centre	Right	Left	Centre	Right
1	350	D/s of Plunge Pool	0.78	1.67	2.20	0.60	3.98	2.91	2.56	5.58	2.20	2.20	6.29	3.45	5.75	**7.88**	4.69
2	400		1.67	2.56	3.45	1.31	4.15	4.69	5.81	5.40	6.64	2.56	5.81	5.80	6.17	7.35	5.46
3	450		5.22	5.58	7.53	5.58	6.64	6.82	7.71	**8.06**	6.82	7.18	**8.16**	5.93	7.53	8.23	6.64

Table No. 11 B: Observed Velocities at downstream of plunge pool at different discharges

(Free Flow Conditions, only four sluice spillways and one surface spillway open)

S. No.	Location		1900			3800			5700			7590			9000		
			Left	Centre	Right	Left	Centre	Right	Left	Centre	Right	Left	Centre	Right	Left	Centre	Right
1	350	D/s of Plunge Pool	0.24	0.24	0.07	2.02	6.82	3.09	3.45	**8.60**	1.13	3.27	**8.95**	1.67	3.09	**9.13**	4.15
2	400		1.67	2.91	4.15	4.87	8.24	5.58	3.45	6.64	3.45	4.15	6.82	3.27	3.80	7.00	4.51
3	450		5.75	5.58	6.29	7.18	6.64	7.71	2.20	**8.60**	6.27	5.75	7.96	4.87	7.00	7.88	5.58

Table No. 11 C: Observed Velocities at 400 m downstream of plunge pool at different discharges

(Gated conditions, All Gates Equally open, FRL maintained)

S. No.	Gate Opening (m)	350 m d/s			400 m d/s			450 m d/s		
		Left	Centre	Right	Left	Centre	Right	Left	Centre	Right
2	2	1.31	2.91	0.24	3.62	2.74	2.56	4.33	4.87	1.31
4	4	2.38	4.69	1.85	4.15	3.80	2.74	5.58	5.75	4.87
6	6	3.27	4.69	2.00	4.15	5.28	4.69	6.11	6.47	5.07
8	8	2.56	5.75	2.91	3.98	5.84	4.87	7.18	6.82	6.64
9	9	3.98	**7.00**	3.18	4.15	6.29	4.56	6.64	5.93	5.75
10	10	5.75	**7.88**	4.69	5.81	**7.35**	5.46	**7.53**	**8.23**	6.64

Annexure- 03

Photos

Photo 01: Upstream view of dam

Photo 02: Downstream view of dam

Photo 03: Parshall Flume

Photo 04: Dressing of Plunge pool area and downstream of Plunge pool

Photo 05: Flow behaviour at upstream of dam axis at 5700 m^3/s while all 5 gates were fully opened (free flow)

Photo 06: Flow behaviour at upstream of dam axis at 7590 m^3/s while only 4 gates were fully opened (free flow)

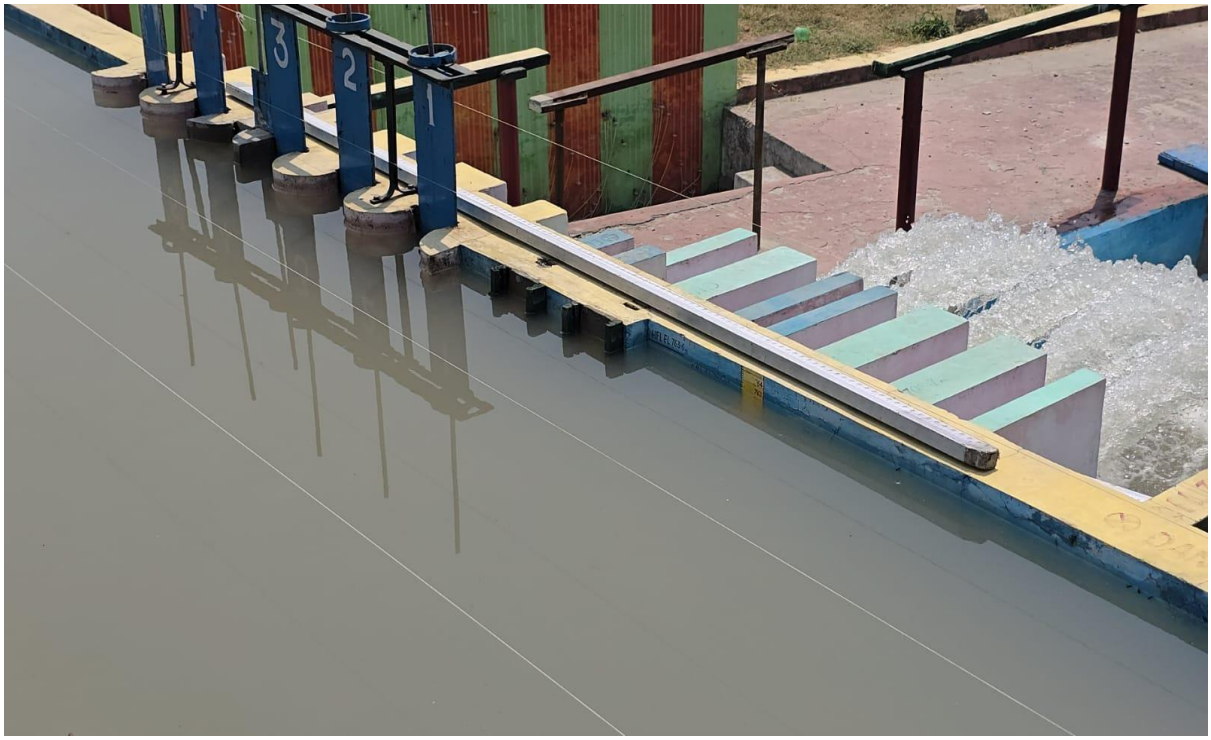

Photo 07: Flow behaviour at upstream of dam axis at 4 m equal gate opening of all 5 bays at HFL

Photo 08: Flow behaviour at upstream of dam axis at 9 m equal gate opening of all 5 bays at HFL

Photo 09: Flow behaviour of jet trajectory and plunge pool while all 5 gates open at 1900 m^3/s at free flow

Photo 10: 5 Flow behaviour of jet trajectory and plunge pool while all 5 gates open at 3800 m^3/s at free flow

Photo 11: Flow behaviour of jet trajectory and plunge pool while all 5 gates open at 5700 m^3/s at free flow

Photo 12: Flow behaviour of jet trajectory and plunge pool while all 5 gates open at 7590 m^3/s at free flow

Photo 13: Flow behaviour of jet trajectory and plunge pool while all 5 gates open at HFL at free flow

Photo 14: Flow behaviour of jet trajectory and plunge pool while 4 gates open at 1900 m^3/s at free flow

Photo 15: Flow behaviour of jet trajectory and plunge pool while 4 gates open at 3800 m^3/s at free flow

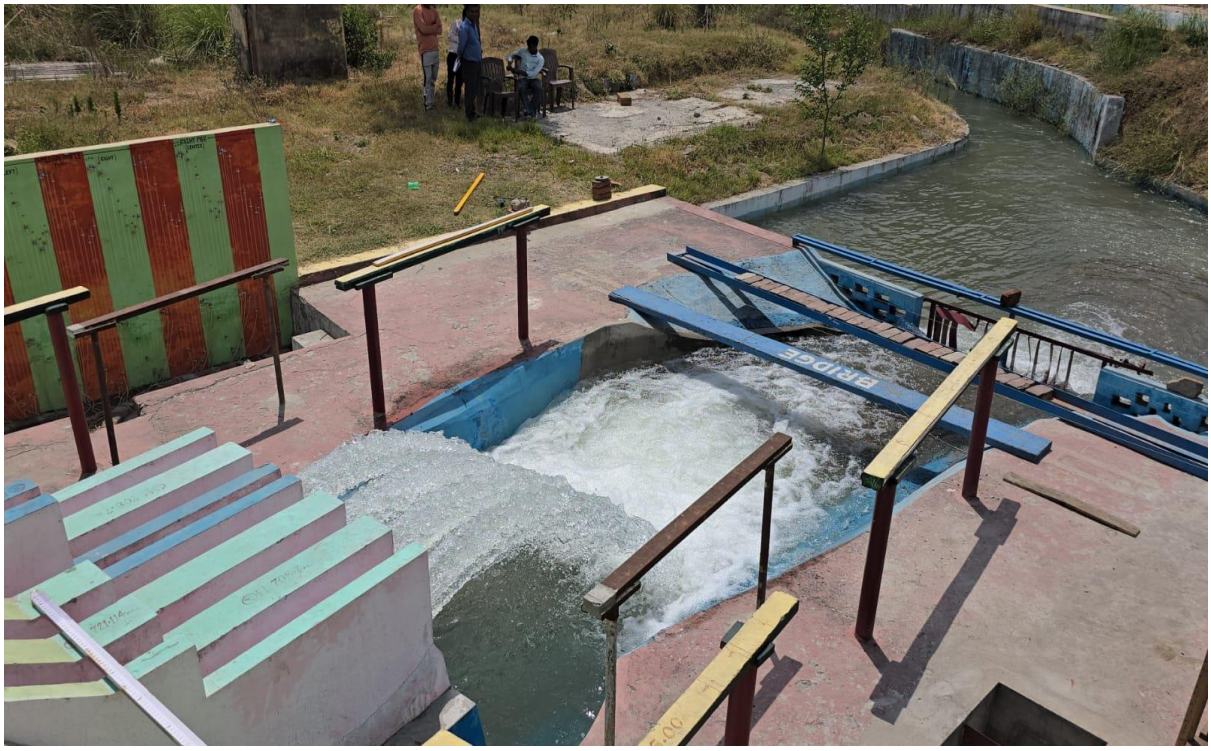

Photo 16: Flow behaviour of jet trajectory and plunge pool while all 4 gates open at 5700 m^3/s at free flow

Photo 17: Flow behaviour of jet trajectory and plunge pool while 4 gates open at 7590 m^3/s at free flow

Photo 18: Flow behaviour of jet trajectory and plunge pool while 4 gates open at HFL at free flow

Photo 19: Flow behaviour of jet trajectory and plunge pool at HFL at 2 m gated condition

Photo 20: Flow behaviour of jet trajectory and plunge pool at HFL at 6 m gated condition

Photo 21: Flow behaviour of jet trajectory and plunge pool at HFL at 8 m gated condition

Photo 22: Flow behaviour of jet trajectory and plunge pool at HFL when only 4 bays 9 m open gated condition at HFL

Photo 23: A joint inspection of Jamrani model studies by officials of UPDCC & a team of consultant-Ehytes Pvt. Ltd. Dated 05.06.2023

Photo 24: Scouring within Plunge pool and downstream of end sill in river at 7590 m^3/s while only 4 gates were open (free flow)