DISCARGE MEASUREMENT THROUGH MULTIPLE GATES OF LOW HEAD POWER PLANTS UNDER UNFAVORABLE CONDITIONS

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ABSTRACT

The irrigation canal fall based hydro power plants are very common for generation of electricity in India. The efficiency testing of two such hydropower plants, located on Upper Ganga Canal in district Haridwar of Uttarakhand state in India, has been performed by IIT Roorkee. Both the plants have semi open casing type Kaplan turbines. The plants have been constructed during 1950s and have been renovated recently by reputed turbine companies.

The feasible method for discharge measurement was mounting the propeller current meters at the stop log gate grooves of the plant. There were four stop log gate grooves, each of size 4 m (height) x 4.25 m (width) before the inlet of each turbine and a matrix of 12 current meters were fitted on each groove to measure the velocity profile. Thus a total of 48 current meters were used to measure the discharge through a turbine. Two ultrasonic level sensors (ULS) were used to measure the water level at each upstream and downstream of the plant; one ULS was mounted each abutments of upstream/downstream. A continuous flow of trash was observed due to existence of a pilgrim place *Har ki Pauri* located on canal head at about 12 km upstream of Pathri hydropower plant and 58 km upstream of Mohammadpur hydropower plant. The trash was removed continuously during the testing using electric operated trash cleaning machine. Due to trash, some of the current meters stopped rotating during the testing and a method of interpolation of velocity from other points was adopted. A high uncertainty of around 3.3% was estimated in the evaluation of unit efficiency and was agreed by the customers. The alternate method to measure discharge in such situations could not be deployed due to limited resources.

1. INTRODUCTION

Upper Ganga canal (UGC), originally constructed in 1854 for an original head discharge of 6000 ft^3/s (160 m^3/s), has been augmented gradually to the present discharge of 10,500 ft^3/s (295 m^3/s). The maximum discharge capacity of the canal in initial reaches are being further remodeled to be as 370 m^3/s (13068 cusec) which include 20% extra inflow for silt ejector. The width of canal is varying from 40 m to 80 m.

As the drops ranging from 3m to 9m meters in the canal are available at some locations, small hydro power plants of low head and high discharge were established at these drops. Though main purpose of this canal is irrigation but of late drinking water to few cities is being supplied from this canal.

Requests were made by the refurbishing contractors for conducting efficiency testing on both small hydropower plants on this canal as their part of contract with the plant owner individually. These power plants are Pathri Hydro Power Plant at Bahadrabad and Mohammadpur Hydro Power Plant at Mohammadpur. Plant parameters of these power plants are given in Table 1.

Table: 1: Details of Mohammadpur and Pathri SHPs

Parameters	**Mohammadpur SHP**	**Pathri SHP**
Capacity (MW)	3 x 3.1	3 x 6.8
Distance from canal head, (km)	58	12
Rated unit Discharge (m^3/s)	76.46	83.81
Rated head (m)	5.18	9.3
Turbine type	Vertical Kaplan	Vertical Kaplan
Generator	Synchronous Type	Synchronous Type
Intake gate type	Fixed wheel	Wheel Type Gate
Draft tube gate	Flap type	Slide Gate

2. Background

Both power house are installed on the same canal around 46 km apart and receive slightly different discharges due to reduced discharge on account of two off-taking distributaries. The head drops available to both SHPs are also different. Capacity of a power plant depends on the available head and discharge, and is therefore different for the two power plants. Both the power plants were commissioning during period of 1950-55. Subsequently, renovation and modernization were carried out by reputed equipment manufacturers on both power plants during period of 2011-2014. Manufacturer requested Indian Institute of Technology Roorkee to measure the available discharge in the intake channel and net head to evaluate the efficiency of each generating unit. Efficiency test was conducted on single unit considering all units similar and was agreed by the customer that the efficiency tested for one unit will be taken valid for other units as well. Objective of testing were:

(a) To measure the discharge in the power channel (water conductor system)
(b) To measure the efficiency of generating units at rated load

The source of water to these power stations is the canal diverted from Ganga River at Bhimgoda barrage. The design discharge of the power house of the canal at Mohammadpur SHP and Pathri SHPs are 229.38 m^3/s and 251.43 m^3/s respectively. There are float operated fish belly gates side spill system for releasing the water on the side of power house building. Main canal works as a forebay tank for both power plants. The steel trash racks are provided at the intake works. There are 4 racks per machine bay i.e. 12 nos. in all. Amount of floating debris reaching the racks varies from season to season and large amount is generally received during rains, high flow and festive seasons.

2.1 Mohammadpur Power Plant

The water from canal is fed to the 3 turbines through twelve intake gates for Mohammadpur power plant. The intake are shown in Figure 1.

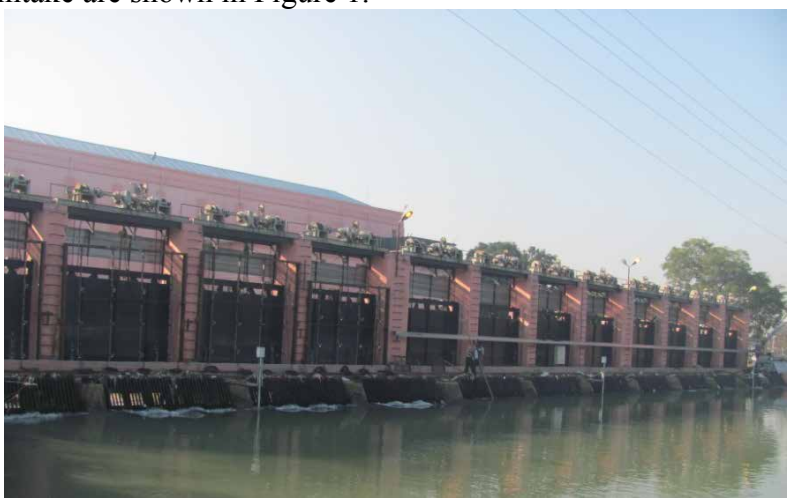


Figure 1 – Twelve intake gates for three units at Mohammadpur Power Plant

2.1.1 Pre-visit of Plants and Measurement Plan

During previsit of plant, it was observed that power plants were commissioned in period of 1950-1952 and there is not a single provision available for discharge and head measurements. Layout of Mohammadpur SHP is shown in Figure 2.

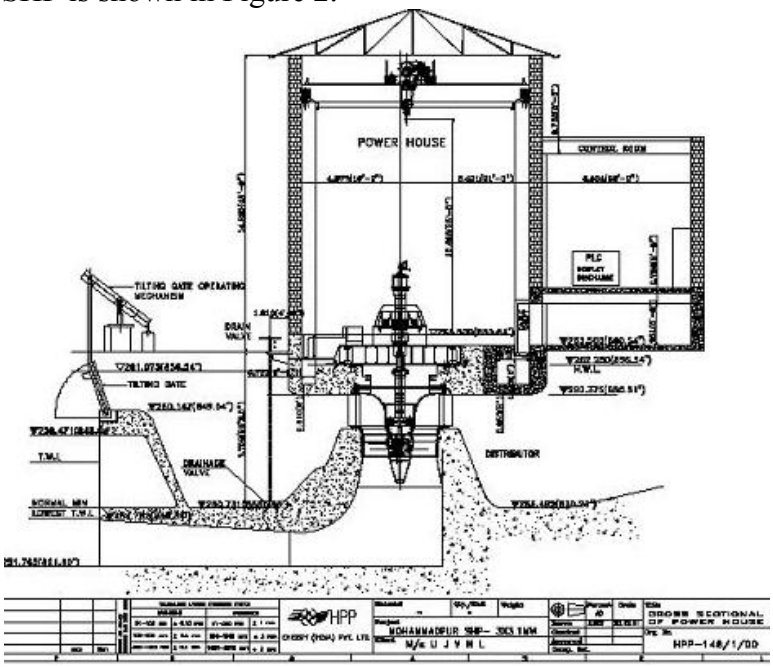


Figure 2- Section Elevation of Mohammadpur Power Plant Unit

On inspecting the flow condition and the provisions available in power plant, it was observed that the requirements of IEC-60041 and ISO-748 for flow measurement may not met either in

headrace channel or in tailrace channel. Intake gate have vertical wheel type design and thereafter channel has steep slope, therefore it was not possible to install the mounting frame of propeller current meter at intake gate for discharge measurement. Upstream of intake gate, stop log gate was installed and it was decided to fix current meters at the stop log gate position.

2.1.2 Discharge Measurement

For measurement of discharge, it was decided to install a matrix of current meters at stop log gate grooves located upstream of intake gate slot which is in agreement with the equipment manufacturer. Flow conditions at stop log gate opening appeared to have low turbulence and less eddy-formation. However it was not free from the floating trash entering through the trash rack. There were four stop log gates for one unit and dimensions of each gates are 4300 x 4000 mm. A matrix of 12 propeller current-meters was used for simultaneous measurement of flow velocity in a 3 x 4 matrix i.e. 12 points in the each stop log gate location. As there are four stop log gates for a single generating unit so 48 propeller current meters were used. Velocity data was obtained with large uncertainty due to low number of current-meters and non-working of some of them due to entering of trash through the trash rack opening.

A box type mounting frame was fabricated as per the drawing shown in Figure 3 and photographs shown in Figure 4. Four vertical pipes are selected to fix inside a C-channel frame and 3 current-meters are mounted on each vertical pipe. All vertical pipes have elliptical cross section to minimize the flow disturbances due to their insertion in the canal. Thus total 12 current-meters are available for measurement of velocity at any instant of time. One structure was installed at one stop log gate to fix current meters for measurement of velocities and four stop log gates are feeding water to one turbine. Therefore total four such structures were fabricated and installed in all four stop log gates feeding to one generating unit. It resulted in measurement of velocity at 48 points in the flow measurement section of one unit. The flow velocities were observed to vary in the range of 0.5-2.3 m/s for Mohammadpur SHP and 0.3 – 2.4 m/s for Pathri SHP.

2.1.3 Velocity Data & Velocity Profile

The flow velocity are measured through current-meter. The average rotation of propeller for 2 minutes duration was taken for velocity calculation and each data is repeated 3-4 times. The variation in data was observed within 5% for all the measurements. The average velocity at each current-meter location for Mohammadpur SHP is presented in Table 2. Velocity measured by propeller current meters was recorded in data logger and is read by the computer. Velocities were calculated from counter which counts the rotation per minute. Few abrupt velocity data were recorded in gate 2 to gate 4 and were discarded for calculation of discharge. These data were then determined by interpolation from the velocity data at nearby locations as marked in Table 2. These are due to debris and trash in water which affected the rotation of propeller current meter. Similar measurements are performed at other loads also.

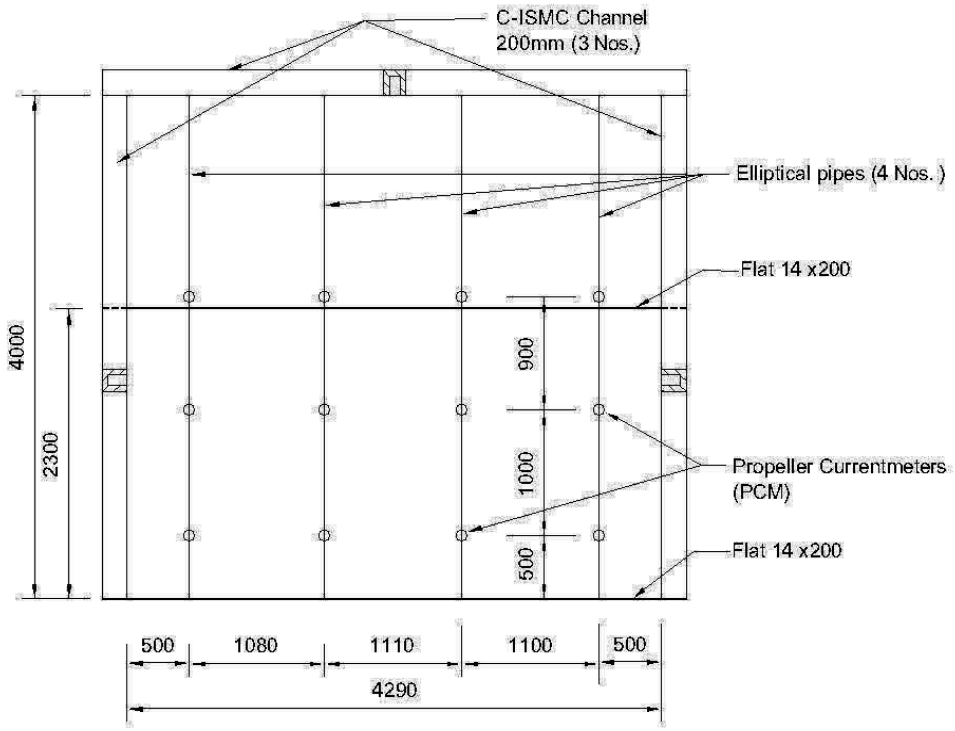


Figure 3: Structure for fixing current meters at Mohammadpur SHP

Figure 4: Mohammadpur Propeller Current Meter Structure

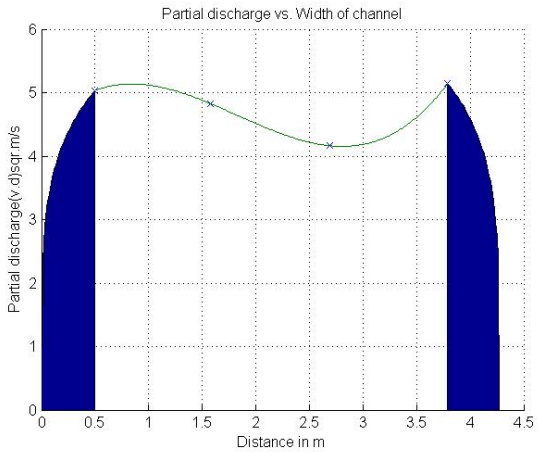
Table 2: Average velocity data at 100% rated load for Mohammadpur SHP

Height from bottom of duct	Average flow velocity along the width starting from left side, m/s			
Gate 1	0.5	1.58	2.69	3.79
0.5	2.020	2.006	1.733	2.225
1.5	2.534	2.170	1.774	2.473
2.4	0.703	0.808	0.797	0.537
Gate 2				
0.5	2.064	1.602	1.182	1.054
1.5	2.609	2.459	2.390	2.267*
2.4	0.392	0.329	0.479	0.471
Gate 3				
0.5	1.044	0.997*	0.949	1.689
1.5	0.966	0.847	2.002	1.973
2.4	0.211	0.438	0.336	0.241
Gate 4				
0.5	1.490	1.984	2.220*	2.456
1.5	3.476	2.476	2.559*	2.641
2.4	1.061	0.324	0.493	0.672

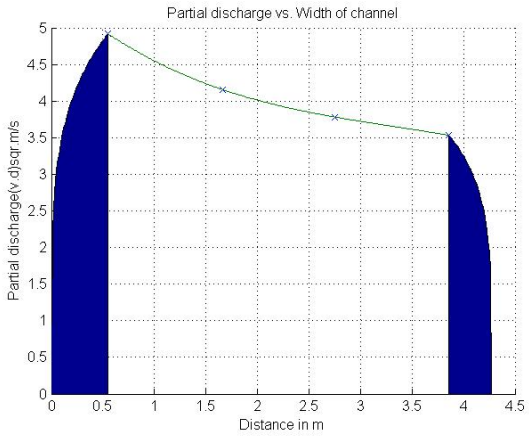
* Due to trash, PCM at these points was not working properly. Their velocity data were calculated by interpolation from the neighboring point velocities.

Velocity Profile

Velocities atat different gates of Mohammadpur SHP is measured through currentmeters and average discharge calculated at each vertical is used to determine the discharge. The variation of unit width discharge at each gate is shown in Figure 5. It is seen that the unit width discharge profiles are little unconventional at each gate which may be attributed to flow of trash and generation of vortices in the canal.



Gate-1



Gate-2

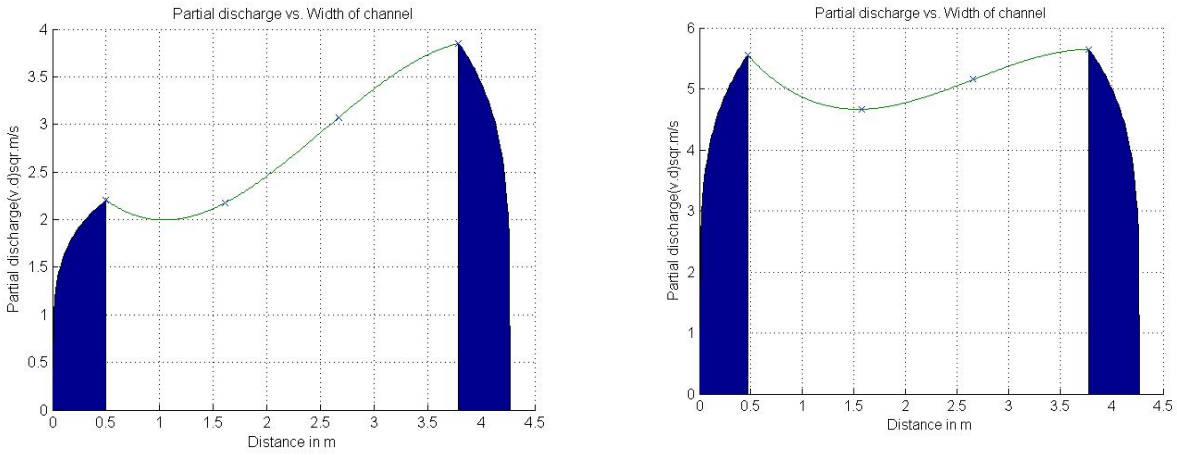


Figure 5: Unit width discharge profile at different gates of Mohammadpur Power Plant

2.1.4 Result of Velocity Measurement

At the end of the velocity measurement, the average-velocity data was downloaded from the data logger to a PC. Point velocities were obtained at all the points of four structures as shown in Table 2 and unit width discharge profile were shown in Figure 5. Based on this data, the discharge was calculated by velocity-area integration method though a sophisticated software developed at IIT Roorkee [1]. The value of discharge through the power channel was found to be only 68.928 m^3/s for Mohammadpur SHP at rated load.

2.1.5 Uncertainty in Discharge Measurement

Due to unfavorable condition for discharge measurement as large amount of trash in flow the uncertainty in discharge measurement is estimated as 3.082%.

2.1.6 Head Measurement

It was decided to install ULS on left and right side of headrace and tailrace channel for level measurement in headrace and tailrace. The levels of ULS were measured using a total station and the depth of water from the sensor level was determined during the duration of performance test.

2.1.7 Power Measurement

A precision class digital wattmeter was connected at the generator relay and metering panel in parallel to the existing digital multi-function meter for power measurement.

2.1.8 Assessment of Uncertainty in Unit Efficiency Measurement for Mohammadpur SHP

Following uncertainty was found

(a) Uncertainty in Discharge Measurement = ± 3.082%
(b) Uncertainty in Head Measurement = ± 0.855%

(c) Uncertainty in Electrical Power Measurement = ± 0.735 %
(d) Uncertainty in Efficiency Measurement

$$f_\eta = \sqrt{3.082^2 + 0.855^2 + 0.735^2}$$

$$= \mathbf{\pm 3.282\%}$$

2.1.9 Efficiency Calculation

Efficiency were calculated as per IEC 60041 and summarized in Table 3.

2.1.10 Results of Unit Efficiency Test

The measured values of major parameters and the calculated values of efficiency at different loads are summarized in Table 3.

Table 3 – Summary of measurement results for efficiency test on generating unit

Load (%)	Net head (m)	Average discharge (m^3/s)	Power output (kW)	Unit efficiency (%)
100	5.955	68.928	3200.700	86.63
80	6.450	45.033	2510.600	88.30
60	6.366	37.054	1826.260	79.09
110	6.135	65.899	3417.200	86.34

2.2 Pathri Power Plant

Since the site conditions of Pathri Power Plant were similar to Mohammadpur SHP, same method was deployed for discharge measurement in this power house also. Layout of Pathri Power House is given in Figure 6.

A box type mounting frame is also fabricated as shown in Figure 7 and photograph of installation is shown in Figure 8.

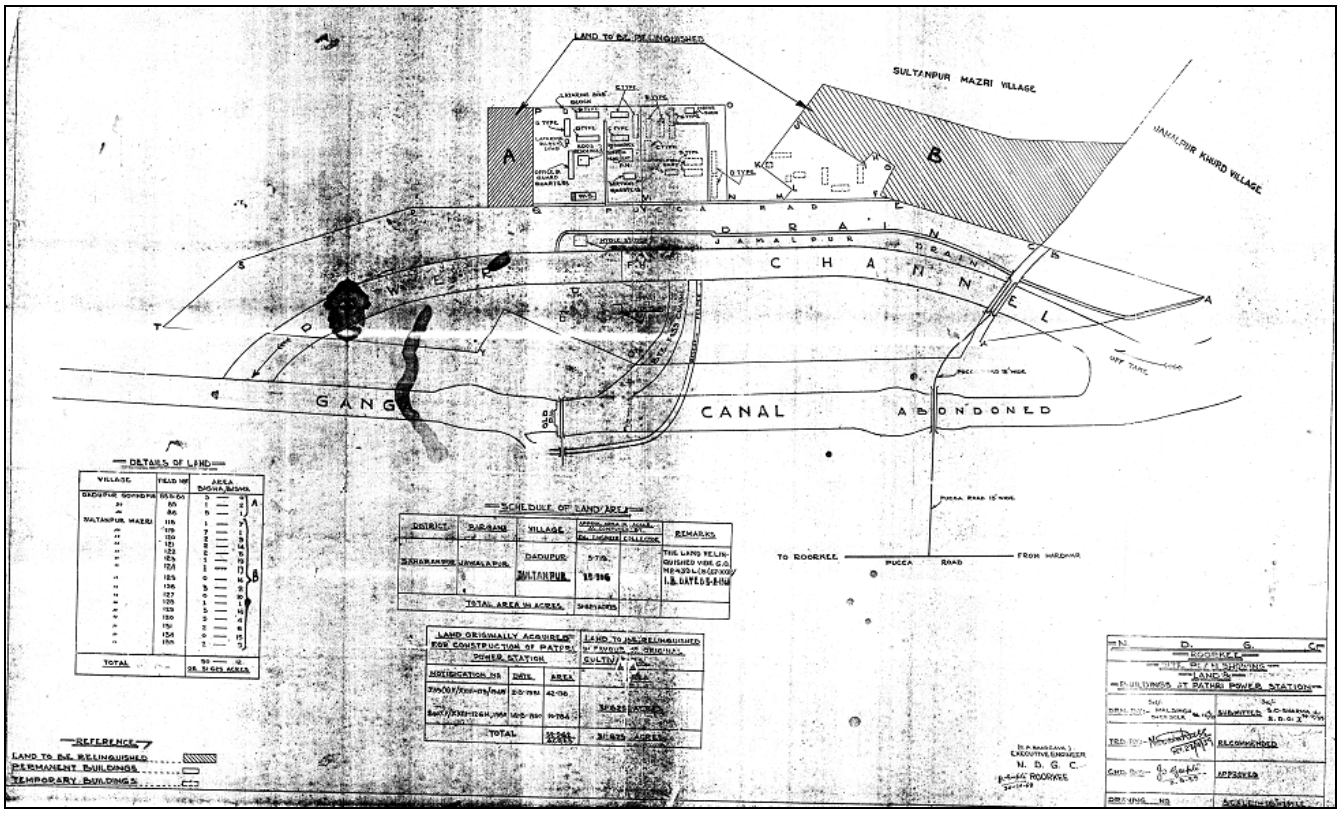


Figure 6: Layout of Pathri Power House

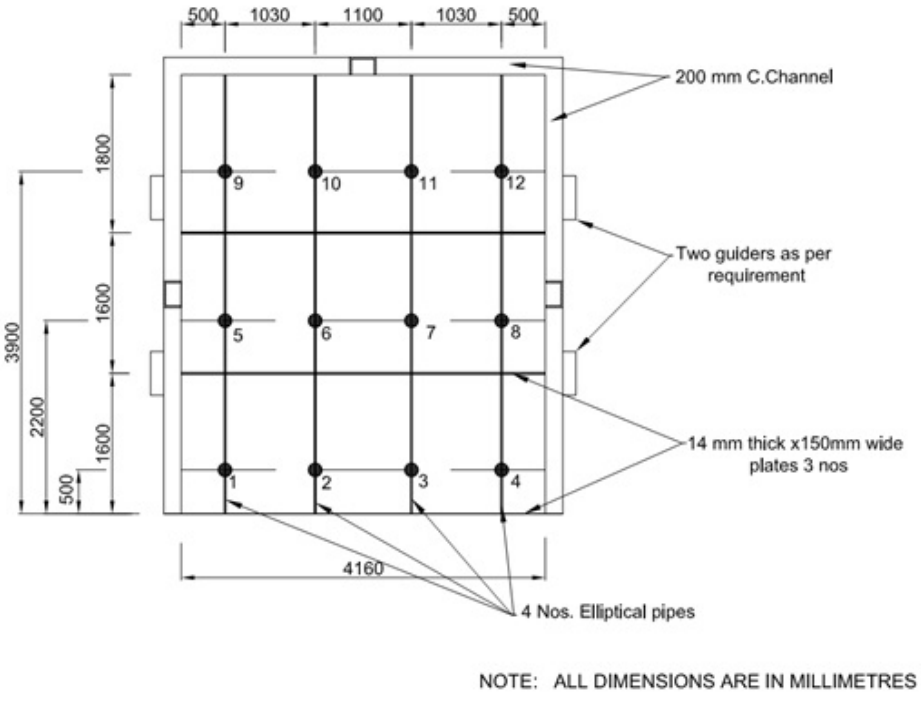


Figure 7: Propeller current meter mounting structure for Pathri SHP

Figure 8: Pathri Propeller Current Meter Structure

2.2.1 Velocity Data & Velocity Profile

The average of velocity values observed during discharge measurement of Pathri SHP is listed in Table 4.

Table 4: Average velocity at 100% rated load for Pathri SHP

Height from bottom of duct	Average flow velocity along the width starting from left side, m/s			
Gate 1	0.44	1.485	2.59	3.635
0.235	0.235*	0.162	0.253*	0.390
1.935	1.113	1.649	1.680	1.931
3.635	1.489	1.645*	1.599	1.379
Gate 2				
0.277	1.371	0.416	0.406	1.359
1.977	1.606	1.812	1.707	1.943
3.677	1.225	1.119	1.218	1.155
Gate 3				
0.19	1.131	0.197	0.258	0.358
1.89	1.707	1.643	1.685	1.682
3.59	0.952	0.412*	0.936	0.310
Gate 4				
0.29	2.017	0.035	0.194*	0.200
1.99	1.619	0.441	1.327	1.512

3.69	0.352	0.358	0.557	0.793

*Due to trash, PCM at these points was not working properly. Their velocity data were calculated by interpolation from the neighboring point velocities.

2.2.2 Result of Velocity Measurement

At the end of the velocity measurement process, the average-velocity data was downloaded from the data logger to a computer. Point velocities were obtained at all the points of four stop log gates as shown in Table 4. Based on this data, the discharge was calculated by velocity-area integration method though a sophisticated software developed at IIT Roorkee [1]. The value of discharge through the power channel was found to be 74.927 m^3/s for Pathri SHP at rated load.

2.2.3 Assessment of Uncertainty in Unit Efficiency Measurement for Pathri SHP

(a) Uncertainty in Discharge Measurement = ± 3.082%
(b) Uncertainty in Head Measurement = ± 0.394%
(c) Uncertainty in Power Measurement = ± 0.735 %
(d) Uncertainty in Efficiency Measurement = ± 3.193%

2.2.4 Result of Unit Efficiency test

Table 5 – Summary of measurement results for efficiency test on generating unit

Load (%)	Net head (m)	Average discharge (m^3/s)	Power output (kW)	Unit efficiency (%)
100	10.772	74.927	7025.300	89.06
80	10.727	57.896	5375.600	88.56
60	10.854	42.482	3968.200	88.05
110	10.384	85.033	7667.200	88.85

3. PROBLEMS ENCOUNTERED DURING MEASUREMENT

3.1 Discharge Measurement

1. As these power houses are established on UGC with canal head at Haridwar which is a holy place of India, there are lot of dumping of solid and polythene wastes in this canal including floral offering and other materials used for religious purpose. Also washing of cloths, cattle wallowing , discharge of industrial waste adversely increases the amount of trashes in canal which affect velocity measurement in canal. This resulted in frequent stoppage of PCMs.
2. Canal width is about 65-70 m near the power plants so it is not possible to install a

structure in headrace channel because lots of trashes that can affect the movement of propeller, thus giving the error in measurement.

3. Also these kind of hydropower plants having low installed capacity and plant owners/ manufacturers have less paying capacity for the testing, therefore there is lesser possibility of using instruments of better accuracy.
4. Width of tailrace channel is also about 65-75 m, thus it is also as cumbersome as the headrace to build a structure and take measurements.

3.2 Concluding Remarks

There are several power plants, installed on large capacity canals with less available head. There may be some variations in the trash conditions. Installing a structure for measurement of velocity requires a large number of current-meters and the uncertainty is generally high in such conditions. Under such condition what can be the best possible method for discharge measurement for these power plants. Also method should be cost efficient because these power plants having low capacity (up to 25 MW) and are thus less paying for testing.

4. ACKNOWLEDGEMENT

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