

COST BENCHMARKING FOR CIVIL STRUCTURES OF MICRO/MINI HYDRO ELECTRIC PROJECTS LOCATED IN UTTARANCHAL

M. K. SINGHAL

ARUN KUMAR

Alternate Hydro Energy Centre
Indian Institute of Technology, Roorkee
Roorkee

ABSTRACT

For planning and execution of Mini/Micro Hydro Power Projects, estimate of cost for various civil structures is a very important aspect. On the basis of various projects under construction in Uttaranchal, the cost curves have been developed for civil structure of these projects. These curves can be used to estimate the cost of civil structures on the basis of site parameters such as design discharge, design head, width of river at the location of diversion weir, general slope of the terrain along the alignment of penstock pipe and remoteness of site.

1.0 INTRODUCTION

Eleven Micro/Mini Hydro Projects are being executed by Uttaranchal Renewable Energy Development Agency in various districts of Uttaranchal through community participation. These sites are under various stages of construction. The site parameters of these projects are shown in Table 1.0. This includes the remoteness factor of site which has been calculated based on the altitude and distance of site from the nearest road head.

Table 1.0: - Details of Mini/Micro Hydro Power Projects under Execution in Uttaranchal

Sl. No	Project Name	Capacity (kW)	District	Gross Head (m)	Discharge (m³/s)	Remoteness factor
1.	Liti-II,	2 x 25	Bageshwar	46.5	0.182	1.2
2.	Karmi-III,	2 x 25	Bageshwar	57.82	0.154	1.0
3.	Lamabagar	2 x 100	Bageshwar	45.70	0.798	1.0
4.	Kuwanri	2 x 25	Bageshwar	48.0	0.160	1.50
5.	Jagthana	2 x 50	Bageshwar	49.0	0.400	1.2
6.	Jakhna	2 x 50	Tehri Garhwal	52.74	0.280	1.3
7.	Taluka	1 x 20	Uttarakashi	73.51	0.040	1.2
8.	Sharma	2 x 50	Chamoli	45.50	0.429	1.3
9.	Gamsali	2 x 25	Chamoli	40.0	0.195	1.2
10.	Wachham	2 x 250	Bageshwar	48.94	0.138	1.5
11.	Gogina-II	2 x 25	Bageshwar	36.45	0.232	1.0

The geographic locations of the project sites have been shown in Fig 1.0

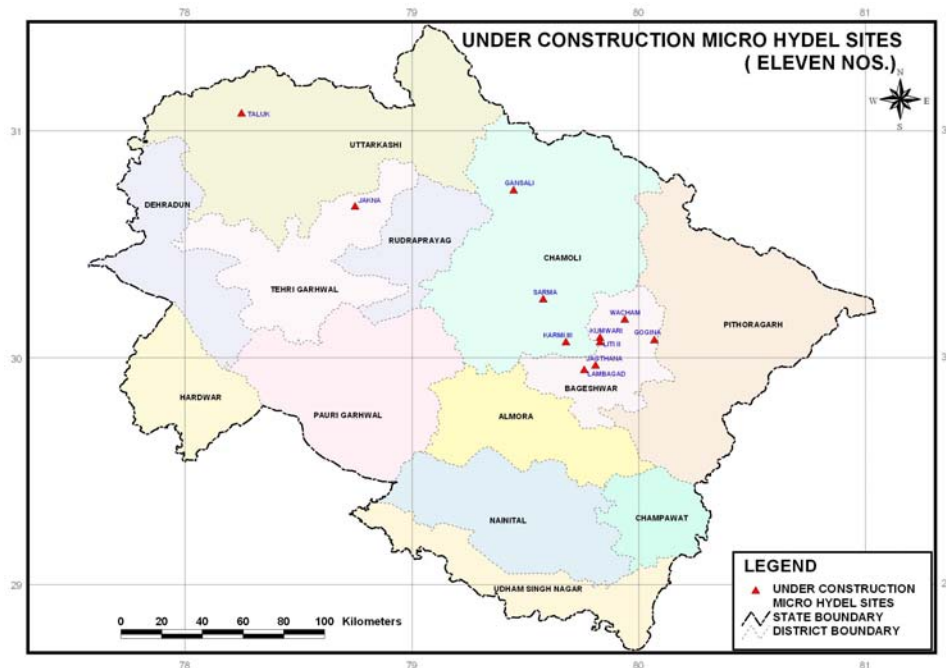


Fig.-1.0: Location of Micro/Mini Hydro Power Project in Uttarakhand

2.0 CIVIL WORKS COMPONENTS OF MICRO/MINI HYDRO POWER PROJECT

The typical layout for Micro/Mini Hydro Project has been shown in Fig. 2.0. The project comprises of diversion weir (to divert the flow from river to feeder channel), feeder channel/intake channel (to carry the water from the diversion weir to desilting tank), desilting tank (for removing the silt from the water), power channel (for carrying the water from desilting tank to forebay tank), forebay tank (for storing the water to provide sufficient water depth over intake of penstock pipe), penstock pipe (to carry the water from the forebay tank to power house) and power house (to house the power generating equipments).

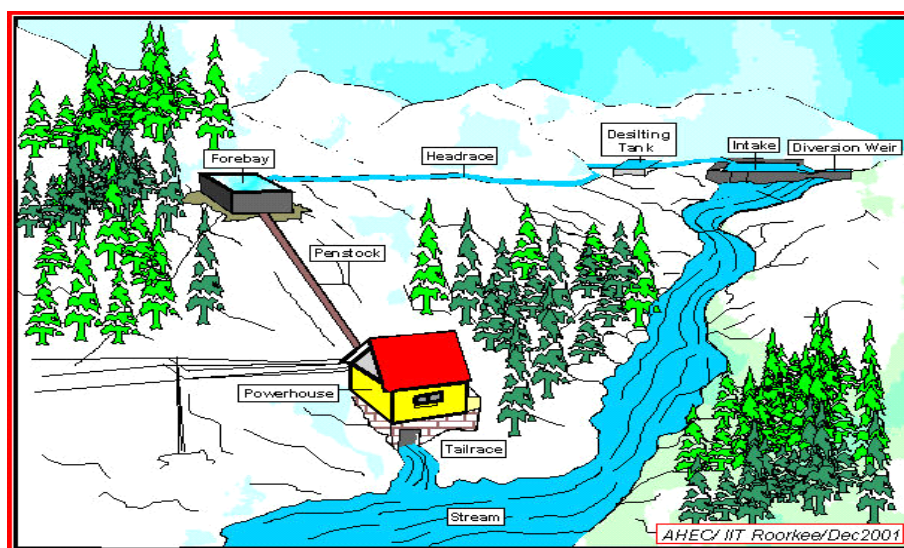


Fig.-2.0: Typical Layout of Mini Hydro Power Project

3.0 DIVERSION WEIR

The diversion weir can be provided as trench type permanent weir or bush boulder type semi permanent weir. For all the eleven projects, the bush boulder type semi permanent weirs have been provided. The cost of the diversion weir depends on the section and length of weir. The section of weir increases as the discharge diverted for power generation increases. The various parameters of diversion weir have been shown in Table 2.0. The cost of diversion weir has been rationalized by dividing with remoteness factor. The cost curve has been developed in between cost per unit of length of weir with design discharge weir and shown in Fig. 3.0.

Table – 2.0: Details of Diversion Weir

Sl No	project name	Discharge (cumec)	Length (m)	Cost (Rs.)	Rationalized cost (Rs)	Rationalized cost per m length (Rs)
1	Taluka	0.046	5	239626	200484	40097
2	Kumwari	0.17	12	470507	313671	26139
3	Karmi_III	0.194	12	369,740	369740	30812
4	Liti-II	0.225	13	385005	320838	24680
5	gamsali	0.244	10	335389	280604	28060
6	gogina_II	0.29	12	323406	323406	26951
7	jakhana	0.35	30	1016424	759335	25311
8	jagthana	0.44	12	441762	368135	30678
9	Sarma	0.487	10	389787	304295	30429
10	Lamabagad	1	25	828481	824555	32982
11	wacham	1.725	30	1400131	916830	30561

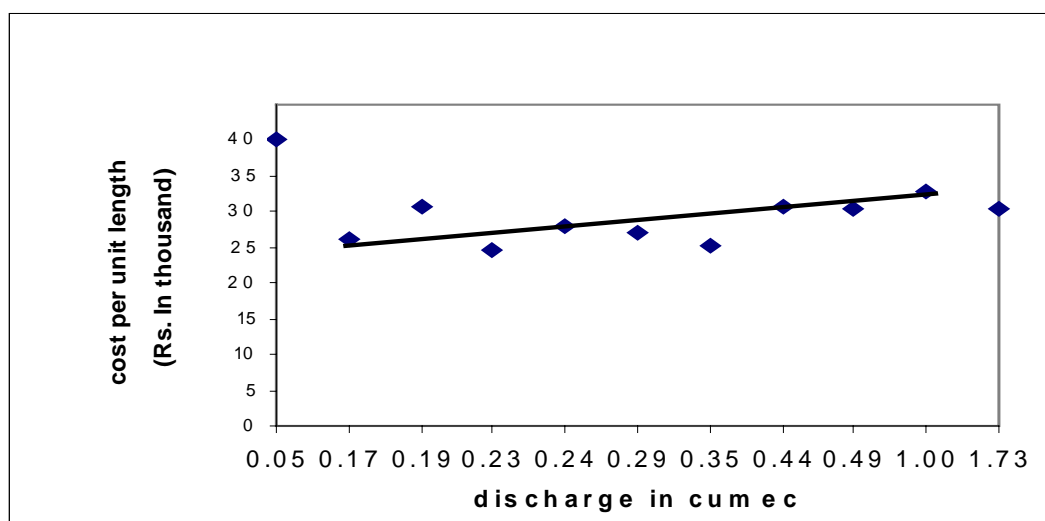


Figure-3.0: Cost curve for diversion weir

4.0 FEEDER CUM POWER CHANNEL

The cost of feeder cum power channel depends on the length and size of channel. The size of channel increases with increase in design discharge of channel. The details of feeder cum power channel have been shown in Table 3.0. The rationalized cost of the channel has been calculated by dividing the cost of channel with remoteness factor. The cost curve has been developed in between cost per unit length of channel and design discharge and shown in Fig. 4.0. The cost coefficient for feeder cum power channel has been determined by dividing the cost of power channel with the variables affecting the cost of as detailed below:

Calculation for Cost Coefficient for Feeder cum Power Channel

Cost of channel (C)	=	K ₁ x L x P x T
P	=	W + 2D + 2 x D/4 for (Free Board)
A	=	W x D
	=	Q/V
Where		
K ₁	=	Constant
W	=	Width of Power Channel
D	=	Depth of water in Power Channel
L	=	Length of power channel
T	=	Thickness of Power Channel
P	=	Perimeter of Cross Section of power channel
A	=	Cross sectional area of water in Power Channel
Q	=	Design Discharge of Power Channel
V	=	Velocity of Flow in Power Channel
For optimize section W		
P	=	2 D
	=	2 D + 2 D + D/2
	=	4.5D
A	=	2 D x D
	=	2D ²
T	=	0.75D (For designing power channel wall as retaining wall)
C	=	K ₁ x L x 4.5D x 0.75 $\left(D + \frac{D}{4} \right)$
	=	4.21 K ₁ x L x D ²
	=	4.21 x K ₁ x L x A/2
	=	2.10 x K ₁ x L x Q/V
	=	K ₂ x L x Q
Where		
K ₂	=	2.10 x K ₁ /V (Taking V as constant)
Cost coefficient for power channel	=	C/(L x Q)

Table: 3.0 Details of Feeder cum Power Channel

Ssl No	Project Name	Discharge (cumec)	Length (m)	Cost (Rs)	Rationalized cost (Rs)	Rationalized cost per unit length(Rs)	Rationalized cost per unit length & per unit discharge (Rs)
1	Taluka	0.046	16	41982	34985	2187	47534
2	Kumwari	0.17	90	409515	273010	3033	17844
3	Karmi_III	0.194	550	1614757	1614757	2936	15134
4	Gogina_II	0.29	190	479844	479844	2525	8709
5	Liti-II	0.225	700	2140068	1783390	2548	11323
6	Gamsali	0.244	370	754462	628718	1699	6964
7	Jakhana	0.35	1300	699236	537874	414	1182
8	Jagthana	0.44	900	4326463	3605386	4006	9105
9	Sarma	0.487	80	291510	224238	2803	5756
10	Lamabagad	1	1200	5515764	5515764	4596	4596
11	Wacham	1.725	1322	7248938	4832625	3656	2119

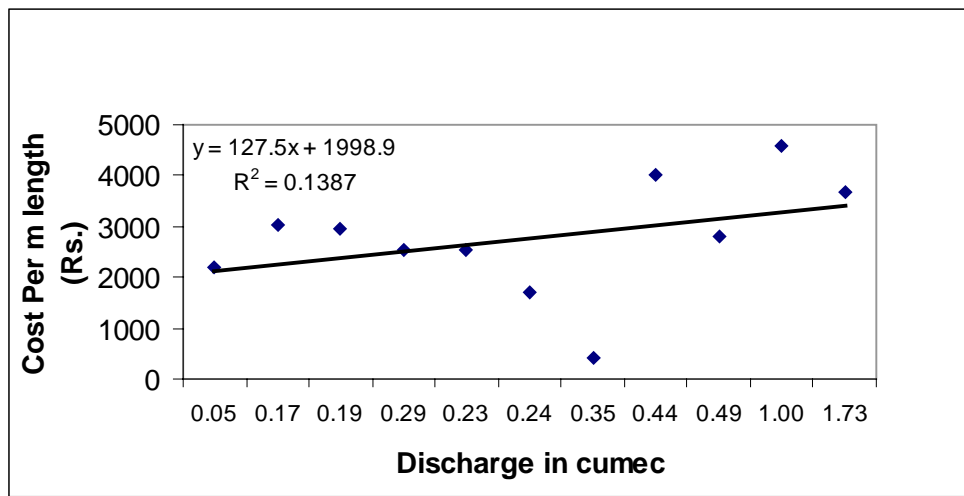


Fig. – 4.0 Cost Curve for Feeder Cum Power Channel

5.0 DESILTING CUM FOREBAY TANK

In Micro/Mini Hydro Power Project, the desilting and forebay tank may be provided separately or combined. In most of Micro/Mini Hydro Power Project under construction in Uttaranchal desilting cum forebay tank has been provided. The cost of desilting cum forebay tank increases with increase in design discharge as size of tank increases for higher discharges. The details of desilting cum forebay tank have been shown in Table 4.0. The rationalized cost of the tank has been calculated by dividing the cost of tank with remoteness factor. The cost curve has been developed in between cost of tank and design discharge and shown in Fig. 5.0. The cost

coefficient for desilting cum forebay tank has been determined by dividing the cost of tank with the variables affecting the cost that is design discharge.

Table-4.0: Details of Desilting Cum Forebay Tank

sl No	project name	Discharge (cumec)	Cost (Rs)	Rationalized cost (Rs)	Rationalized cost per unit discharge (Rs)
1	Taluka	0.046	187415	156801	3408726
2	Kumwari	0.17	524866	349911	2058298
3	Karmi_III	0.193	423955	423955	2196658
4	Gogina_II	0.29	315602	315602	1088284
5	Liti-II	0.225	385952	322908	1435147
6	Gamsali	0.244	322493	268744	1101411
7	Jagthana	0.44	484380	403650	917386
8	Jakhana	0.35	861178	662445	1892699
9	Sarma	0.492	457282	351755	714950
10	Lamabagad	1	1242227	1236340	1236340
11	Wacham	1.725	4015929	2629701	1524464

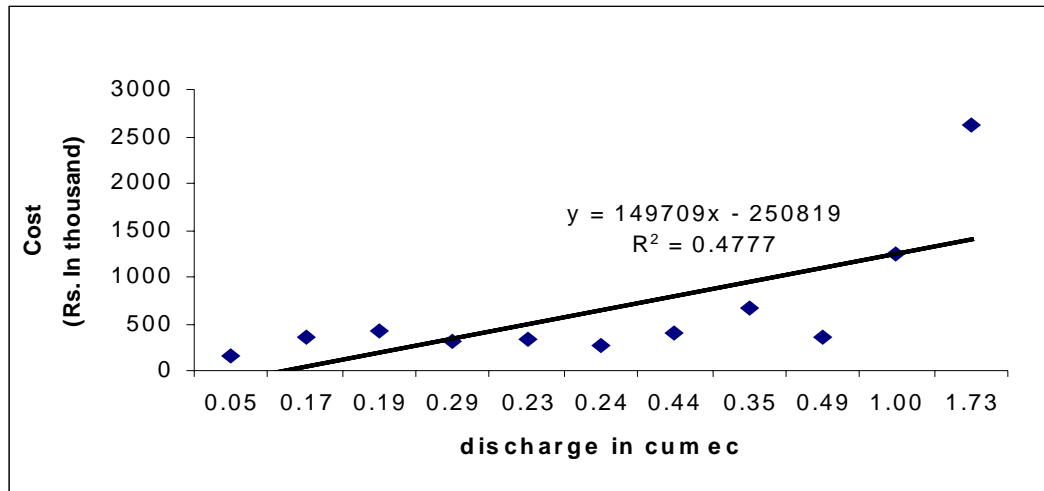


Figure – 5.0 Cost Curve of Desilting Cum Forebay Tank

6.0 PENSTOCK PIPE

The cost of penstock pipe depends on the length, diameter and thickness of pipe. The diameter of pipe increases with increase in design discharge of penstock pipe. The details of penstock pipe have been shown in Table 5.0. The rationalized cost of the pipe has been calculated by dividing the cost of pipe with remoteness factor. The cost curve has been developed in between rationalized cost per unit length of pipe and design discharge and shown in Fig. 6.0. The cost coefficient for penstock pipe has been determined by dividing the cost of pipe with the variables affecting the cost as detailed below:

Calculation for Cost Coefficient for Penstock Pipe

$$\begin{aligned} \text{Cost of Penstock (Cp)} &= k_{p1} \times L_p \times D_p \times T_p \\ D_p &= Q_p/V_p \\ T_p &= P \times D_p/2\sigma \\ &= (0.1 \times H) \times (Q_p/V_p)/2\sigma \end{aligned}$$

Where

$$\begin{aligned} k_{p1} &= \text{Constant} \\ L_p &= \text{Length of Penstock Pipe} \\ D_p &= \text{Diameter of Penstock pipe} \\ T_p &= \text{Thickness of Penstock pipe} \\ Q_p &= \text{Design Discharge of Penstock pipe} \\ V_p &= \text{Velocity of Flow in Penstock pipe} \\ P &= \text{Pressure in penstock pipe} \\ \sigma &= \text{Permissible stress in penstock pipe} \end{aligned}$$

$$\begin{aligned} C_p &= k_{p1} \times L_p \times (Q_p/V_p) \times 0.1 H \times (Q_p / V_p)/2\sigma \\ k_{p2} &= k_{p1} \times 0.1/(V_p^2 \times 2\sigma) \\ &= \text{constant for fix value of } V_p \\ C_p &= k_{p2} \times L_p \times Q_p^2 \times H \end{aligned}$$

$$\begin{aligned} \text{Cost coefficient for penstock} &= C_p/(L_p \times Q_p^2 \times H) \\ L_p &= \frac{H}{\sin \theta} \end{aligned}$$

(Where θ is slope of terrain along the alignment of penstock pipe).

$$\text{Cost coefficient for penstock} = (C_p \times \sin \theta / (H^2 \times Q_p^2))$$

Table-5.0: Details of Penstock Pipe

Sl No.	project name	Disc. (cumec)	Head (m)	Length (m)	sine of slope	cost (Rs)	Rationalized cost (Rs)	Rationalised cost per unit length (Rs)	Rationalised cost*sin of terrain angle /head^2per dis^2 (Rs)
1	Taluka	0.046	73.51	180	0.408	119311	99426	552	3549
2	Gogina_II	0.232	36.45	65	0.561	390346	390346	6005	3060
3	Liti-II	0.182	46.50	100	0.465	271535	226279	2263	1468
4	Karmi-III	0.154	57.82	190	0.304	576725	576725	3035	2212
5	Kumwari	0.160	48.00	120	0.400	366960	244640	2039	1658
6	Gamsali	0.195	40.00	430	0.093	1505258	1254382	2917	1914
7	Jagthana	0.400	49.00	100	0.490	510951	425793	4258	543
8	Jakhana	0.280	52.74	150	0.351	556232	427871	2852	689
9	Sarma	0.429	45.50	765	0.059	3674290	2826377	3695	440
10	Lamabagad	0.798	45.70	100	0.457	800671	800671	8007	275
11	Wacham	1.38	48.94	120	0.408	2358965	1572643	13105	141

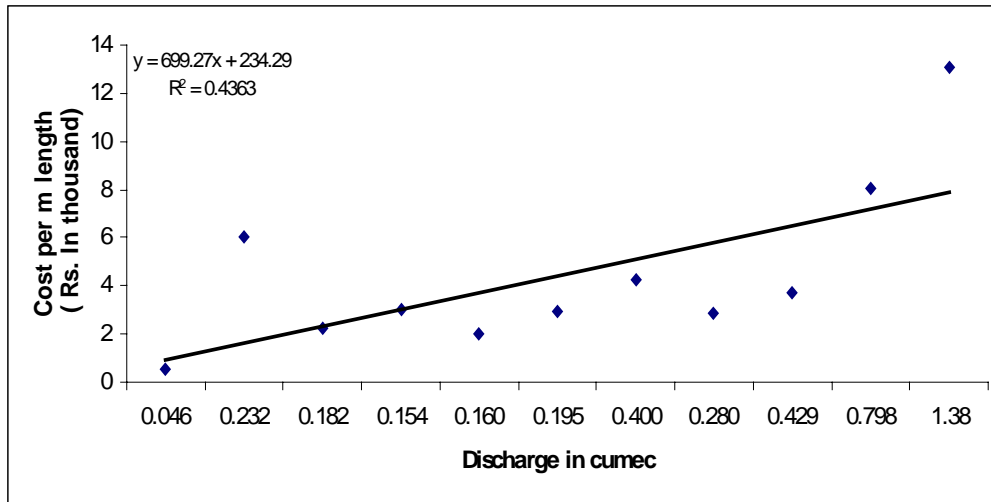


Figure – 6.0 Cost Curve for Penstock Pipe

7.0 POWER HOUSE

The cost of power house depends upon size of the machine to be installed. The size of machine increases with increase in design discharge. However, for the same discharge, the size of machine decrease with increase in head available for power generation. The details of power house for each project have been shown in Table 6.0. The rationalized cost of the power house has been calculated by dividing the cost of power house with remoteness factor. The cost curves have been developed in between rationalized cost of power house and design discharge for different head and shown in Fig. 7.0. The cost coefficient for power house has been determined by dividing the cost of power house with the variables affecting the cost as detailed below:

Calculation for Cost Coefficient for Power House

$$\begin{aligned} \text{Cost of Power House (Cp)} &= Nm \times kp_1 \times Dm \\ Dm &= \frac{84.60\phi_3 \cdot H^{1/2}}{N} \\ \phi_3 &= 0.0019 \times Ns \times Dm/d \\ Dm/d &= 1/0.0555 \text{ (for normal diameter range)} \\ Ns &= \frac{N\sqrt{P}}{H^{5/4}} \\ P &= kp_2 \times Q \times H \end{aligned}$$

Where

Nm	=	Number of units
N	=	Speed of machine in rpm
Ns	=	Specific speed of machine
kp ₁	=	Constant
Dm	=	Diameter of runner
d	=	Diameter of jet
ϕ ₃	=	Velocity ratio at discharge diameter of runner
P	=	Power Potential of one unit

$$\begin{aligned}
H &= \text{Head for power generation} \\
Q &= \text{design discharge} \\
N_s &= \frac{N\sqrt{kp_2 \times Q \times H}}{H^{5/4}} \\
\phi_3 &= 0.0019 \times \frac{N\sqrt{kp_2 \times Q \times H}}{H^{5/4}} \times 1/0.0555 \\
&= 0.03423 \times \frac{N\sqrt{kp_2 \times Q \times H}}{H^{5/4}} \\
D_m &= 84.60 \times 0.03423 \times \frac{N\sqrt{kp_2 \times Q \times H}}{H^{5/4}} \times H^{1/2}/N \\
&= 2.896 \times \frac{\sqrt{kp_2 \times Q}}{H^{1/4}} \\
kp_3 \text{ (Constant)} &= 2.896 \times \sqrt{kp_2} \\
D_m &= kp_3 \times Q^{1/2}/H^{1/4} \\
\text{Cost of Power House (Cpow)} &= Nm \times kp_1 \times D_m \\
&= Nm \times kp_1 \times kp_3 \times Q^{1/2}/H^{1/4} \\
\text{Cost coefficient for power house} &= \text{Cpow}/(Nm \times Q^{1/2}/H^{1/4})
\end{aligned}$$

Table-6.0: Details of Power House

Sl No.	project name	capacity (kW)	Head (m)	Discharge	cost (Rs)	Rationalised cost (Rs)	Rationalised cost *dis ^{1/2} /head ^{1/4} (Rs)
1	Taluka	20	73.51	0.046	383255	319379	23394
3	Karmi-III	50	57.82	0.154	598259	598259	85139
4	Kumwari	50	48.00	0.160	915288	610192	92729
2	Liti-II	50	46.50	0.182	588877	490731	80171
5	Gamsali	50	40.00	0.195	593862	494885	86897
2	Gogina_II	50	36.45	0.232	633928	633928	124268
7	Jakhana	100	52.74	0.280	857615	659704	129537
6	Jagthana	100	49.00	0.400	891880	743233	177667
8	Sarma	100	45.50	0.429	749430	576485	145383
9	Lamabagad	200	45.70	0.798	681751	681751	234233
11	Wachham	500	48.94	1.38	1660056	1106704	491536

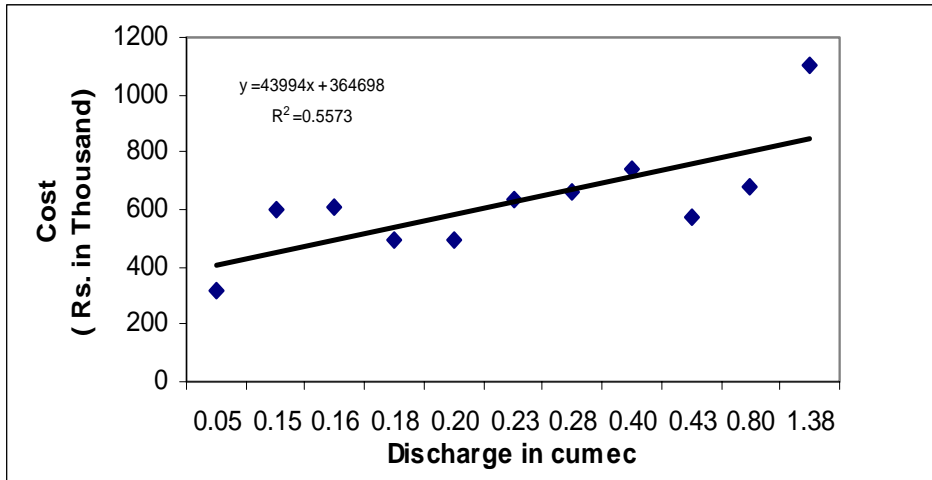


Figure – 7.0 Cost Curve for Power House

CONCLUSION

On the basis of these curves, the cost of various civil works of Small Hydro Projects located in small streams in hilly area can be estimated. These curves are applicable for the projects having installed capacity in between 20 kW to 200 kW with no. of units are two.

ACKNOWLEDGEMENT

Authors wish to express their deep gratitude to Govt. of Uttarakhand for awarding the work of Design and Drawing of online SHP Projects in Uttarakhand and Uttarakhand Renewable Energy Development Agency for executing these projects

REFERENCES

1. CBIP publication no. 175 on Small Hydro published in the year 1975
2. Handbook Nigam, P.S., “Handbook of Hydro-Electric Engineering”, Published by Nem Chand and Bross., Roorkee, 1979
3. Shrish Gupta, M. Tech thesis on “Cost Effective Design for Micro Hydro Schemes” submitted in AHEC in 2002.
4. Charli Fulzele, M. Tech thesis on “Optimization of SHP Schemes in Uttarakhand” submitted in AHEC in 2004.