Design of Water Conductor System for Ultra Low Head Hydropower Project – A Case Study

S.V. Jain[1*], S.K. Singal[2]

[1]Nirma University of Science and Technology, Ahmedabad – 382481, Gujarat, India
[2]Indian Institute of Technology, Roorkee – 247667, Uttarakhand, India
[*]Corresponding author (e-mail: svjain5@yahoo.com)

Many Indian villages suffer from poor and unreliable power supply. On the other hand, a huge amount of energy is wasted throughout the country in natural streams and flowing canals with ultra low head (less than 3 meters) because there is currently no cost-effective way to convert it into a usable form. In such areas, small hydropower schemes can be undertaken on canals flowing through nearby areas which can satisfy their energy needs up to larger extent. Along the canals there exist various falls depending on the topography of the region to cater the country slope. On such falls due to low-head relatively low specific energy is available. This requires large volumetric flow rates and consequently large and expensive machines to recover the energy. As returns on small hydro schemes are marginal, it is very crucial to lower the cost of the project by optimizing the design of water conductor system. In this paper, the cost-effective design of water conductor system of Nadiad mini hydropower project has been presented.

1. Introduction

Energy is the prime need for the growth of any country's economy. It is the measure of prosperity of the nation. Energy crisis is mainly due to two reasons; firstly that the population of the world has increased rapidly and secondly the standard of living of human beings has increased in recent years. The conventional sources of energy like coal, oil and natural gas suffer from various disadvantages like limited reserves, pollution issues, increased fuel prices etc. Hence, in recent years the focus of harnessing energy has been shifted towards non-conventional energy sources like solar, small hydro, biomass, wind etc.

In recent years, the conventional large hydropower plants became unfavourable as they suffer from problems like submergence of valuable land, long gestation period, resettlements and rehabilitation of the affected people as well as political issues associated with them. On the other hand, small hydropower (SHP) projects are free from these problems and Government of India is promoting such schemes by providing financial assistance and administrative supports. At present, SHP is the second most used renewable energy source in the world, just behind solid biomass [1].

In many Indian villages the power cut may vary from 2 to 20 hours in a day. Conversely, large amount of energy is wasted in flowing water through canals and rivers. Small/mini/micro hydropower schemes can be undertaken in these regions for the sustainable development of the villages. The head available for power generation is relatively less in canal based schemes but the discharge is generally high. Thus the size of electro-mechanical equipments, power house etc is comparatively high. Hence it is very crucial to design the water conductor system in cost effective manner.

In the present study, the design of water conductor system of Nadiad mini hydropower project is presented. It is located at a chainage of 33,800 m on the Nadiad branch canal in Kheda District of Gujarat State. The discharge data of the canal were analyzed and 800 kW capacity mini hydro project has been proposed. The design of various components of water conductor system such as cross regulator, power channel, upstream & downstream transitions and tail race channel has been presented.

2. Small hydropower

There is a general tendency all over the world to define small hydropower by the power output. Different countries follow different norms, the upper limit ranges between 5 to 50 MW. In India the project having total power capacity less than 25 MW is referred as small hydropower. The current status of SHP in India is given in Table 1 and the classification of hydropower stations is given in Table 2.

Table 1. Small hydropower scenario in India [2]

Overall potential below 25 MW	Over 15,000 MW
Identified potential	14,294 MW (5,403 sites)
Installed capacity	2141 MW (645 projects)
Under construction	1,233 MW (349 projects)
Capacity addition during 2002-2007	Over 500 MW
Target capacity addition – 11th Plan (2007-2012)	1400 MW
Policy announced for private sector development	18 states

Table 2. Classification based on head [3]

Type	Range of Head
Ultra Low Head	Below 3 m
Low Head	3 to 40 m
Medium/ High Head	Above 40 m

In Gujarat, there exists a SHP potential of around 187 MW in 287 projects in different parts of the state, of which 129 MW through 264 potential sites are from canal based schemes. At present, only 7 MW through 2 SHP projects have been tapped so far. It is very important to explore the balance potential by installing various small hydropower projects.

Small hydropower can be broadly categorized according to layout in three categories as: Run-off river type, Dam-toe based and Canal based project. Canal based small hydropower scheme is intended to generate power by utilizing the fall in the canal. These schemes may be planned in the canal itself or in the bye pass channel. These are low head and high discharge schemes. These schemes are associated with advantages such as low gestation period, simple layout, no submergence and rehabilitation problems and practically no environmental problems.

In SHP, the various components can be categorized in two parts: (i) Water conductor system (civil works components) and (ii) Electro- mechanical equipments. The purpose of water conductor system is to divert the water from the canal and convey towards power house. In canal based schemes, the water conductor system comprises of cross regulator, power channel, upstream & downstream transitions and tail race channel. The Electro-Mechanical equipments mainly include hydro turbine, generator, governor, gates, valves and other auxiliaries.

3. Design of water conductor system for ultra low head hydropower project – a case study

In Gujarat state, there exist more than 180 major and medium irrigation canals [4]. Huge amount of energy is being wasted in the flowing water of canals which can be utilized for electricity generation at the falls of the canals and thus the existing irrigation system can serve the purpose of irrigation as well as energy need of the nearby areas. Nadiad Branch Canal takes off from Mahi Main Canal at a chainage of 40,850 m near Khakhanpur village. It is around 36 km long and there exists a fall of 2.47 m near Piplag village on this canal which has been considered for the present study. The details of the Nadiad branch canal are as under:

Design discharge	:	85 cumecs
Bed width	:	21.34 m
Water Depth	:	3.35 m
Top width	:	36.58 m up to the fall, 28.35 then onwards
Depth of fall	:	2.47 m

The discharge data of Nadiad branch canal for the period of 1997 to 2007 were collected from Mahi Irrigation Circle, Nadiad. The data were analyzed, flow-duration curve was drawn, the power potential and energy generation were worked out and 800 kW capacity mini hydro project has been proposed from techno-economic considerations. The design of various components of water conductor system has been presented in this section.

3.1 Cross regulator

To regulate the water and then divert it towards the power house via power channel, gated cross regulator has been proposed. Considering the low capacity of the project, the cross regulator has been proposed on the existing fall with some modifications to take advantage of existing fall structure, *which is already having protection work of around 8 m on upstream side and around 20 m on downstream side*, and hence to achieve saving in cost.

At the cross regulator the proposed work are: (i) The bed width at the fall is to be increased from present bed width of 21.34 m to 27 m, to pass the design discharge of Nadiad branch canal i.e. 85 cumecs. For this on upstream side the bed width is to be expanded and then on downstream side again the bed width is to be contracted. (ii) 3 no.s of manually operated vertical fixed wheel steel gates of size 8 m × 2.2 m (width × height) were proposed for controlling the FSL of water supplied in power channel. (iii) 2 no.s of R.C.C. piers having width of 1.5 m and length of around 6 m were proposed. The salient features of Cross regulator are given below and the plan view of cross regulator is shown in Fig. 1.

Discharge capacity	:	85 cumecs
Total width	:	27 m
No. and size of bays	:	3×8 m
No. and size of piers	:	2×1.5 m
Size of gates	:	8×2.2 m (width × height)

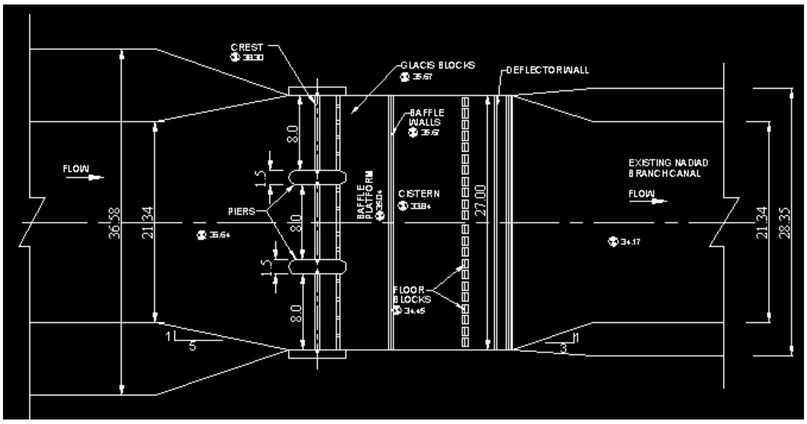

Figure 1. Plan view of cross regulator

3.2 Power channel

The rated discharge for the power generation is 45.12 cumecs. But when more water is available, the turbines can be over loaded by 10%. Hence, the capacity of the power channel was proposed to be 10% more than that of rated discharge i.e. 1.1×45.12 = 49.63 cumecs, say 50 cumecs. It was proposed that the power channel should be concrete lined to minimize the loss of seepage and also for the safety point of view as the water had to negotiate the sharp bends.

The design criteria of power channel are: (i) The design discharge is 50 m^3/s. The flow velocity and bed slope has been taken as 1.1 m/s and 1 in 6000 respectively. (ii) The radius of curve has been taken as 100 m to minimize the head losses and limit the land requirement. The off take angle of channel has been kept as 45^0. (iv) Considering the low capacity of the project, the desilting arrangement to remove the silt from the water has not been provided. The salient features of the power channel are given below and the cross sectional view of power channel is shown in Fig. 2.

Location	:	On the left bank of Nadiad branch canal
Cross section of channel	:	Trapezoidal
Type of channel	:	P.C.C. lined
Design discharge	:	50 cumecs
Bed width	:	8.6 m
Water Depth	:	3.35 m (same as Nadiad branch canal)

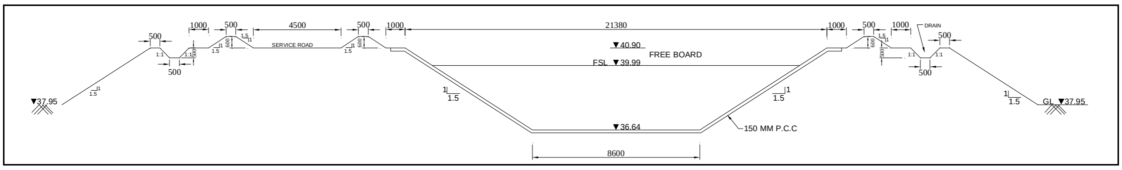

Figure 2. Cross sectional view of power channel

3.3 Upstream and downstream transitions

At the end of power channel, to lead the water into the power house, an upstream transition (forebay pool) in 23.0 m length, *having R.C.C. floor,* has been proposed. The vertical wing walls should be expanded from 8.6 m to 17.8 m in plan, with splay of 1:5 in 23.0 m length, and the bed should be depressed from 36.64 m to 34.00 m in the same length. The inner faces of the side walls of the transition should be flared from a slope of 1.5: 1 (H:V), *at upstream end of transition*, to vertical, *at the junction with intake structure*.

At the end of power house, to lead the water into the tail race channel downstream transition in 13.5 m length, *having R.C.C. floor,* has been proposed. The vertical walls should be contracted from 17.6 m to 8.6 m in plan, with splay of 1:3 in 13.5 m length, and the bed should be raised from 31.15 m to 34.17 m in the same length. The inner faces of the side walls of the transition should be flared from vertical, *at the draft tube outlet*, to a slope of 1.5: 1 (H:V), *at the junction with tail race channel*. The upstream and downstream transitions can be seen in the plan view of power house as shown in Fig. 3.

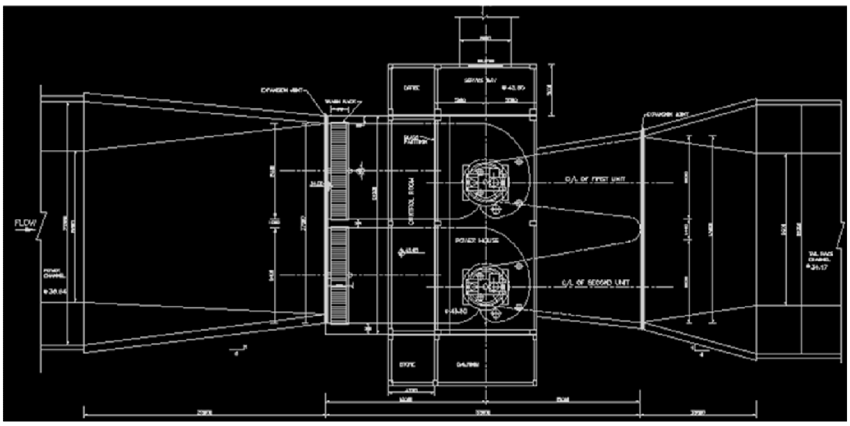
Figure 3. Plan view of power house

3.4 Tail race channel

About 172 m long tail race channel has been proposed to carry water released from the power house to back to the Nadiad branch canal at about 166 m downstream of existing fall. The section and bed slope of tail race channel were kept same as of the power channel. Bed level at the starting of tail race channel was 34.17 m and at the confluence of tail race channel with Nadiad branch canal was 34.14 m. The salient features of the tail race channel are given below and the cross sectional view of tail race channel is shown in Fig. 2.

Bed level at the starting point	:	34.17 m
Cross section of channel	:	Trapezoidal
Type of channel	:	P.C.C. lined
Design discharge	:	50 cumecs
Bed width	:	8.6 m
Water Depth	:	3.35 m
Service road	:	4.5 m wide, on the left bank
Confluence point	:	166.0 m downstream of existing fall at an angle of 45º w.r.t Nadiad branch canal
Bed level at the confluence	:	34.14 m

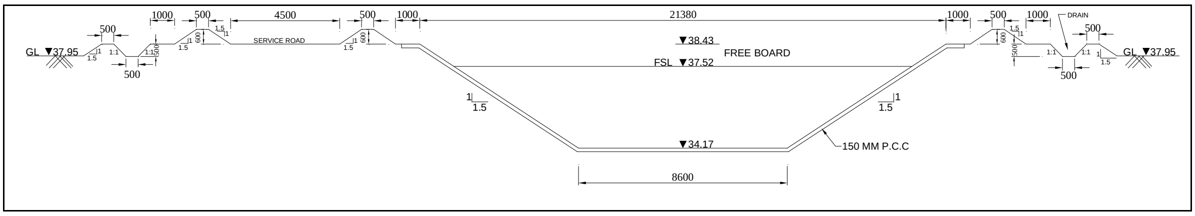

Figure 4. Tailrace channel

4. Conclusions

The canal based layouts are advantageous in terms of hydrology and geology of the site. As they are in plain regions they are easily approachable and do not suffer from problem of power evacuation. Also they have low gestation period and do not suffer from problems of submergence and rehabilitation. The design of water conductor system of Nadiad mini hydropower project has been carried out from techno-economic considerations. The cross regulator has been proposed on the existing fall to take the advantage of the existing structure. Considering the availability of discharge and cost of the project 2 units of 400 kW capacity Semi Kaplan turbine with siphon intake considered to be most appropriate as it helps in elimination of intake & draft tube gates as well as reduction in size and cost of power house. The findings of the present study may be useful for the cost-effective design of water conductor system under similar conditions.

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