Design Of Civil Components of Micro Hydro Power Plant: A Case Study

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Abstract- Northern areas of Pakistan are endowed with vast hydropower generation potential. Many micro-hydropower plants (MHPP) working in private and public sectors are without proper engineering design. The proposed project has been designed on a stream in the peochar valley, Swat, Pakistan. The stream is having enough discharge and most importantly adequate head that can be easily available to generate electricity. The flow data of the stream was collected from SRSP's office. For suitable positioning of civil components of the hydropower plant, a survey has been made to mark proper points. Such point was marked which had a large head because greater the head, the more is the capacity of the plant. A favorable point on the stream was selected where diversion works were designed to divert a part of water from stream to a canal. Canal conveys water to the settling basin and forebay. Through the penstock, water strikes the blade of turbine and generate electricity. The net head obtained at the site is 76ft. The designed discharge was determined to be 10 cusec. After determining these parameters, the design of civil components was undertaken. The approach channel dimensions were designed to be 2.5 ft × 2.24 ft. Settling basin forebay were designed according to the design discharge. This plant was designed to have a power generation capacity up to 40 kW.
Keywords- Micro-hydro power plant, Hydropower generation, Stream water flow, Green Energy

1 Introduction

There is a very rapid depletion of non-renewable resources for generating electricity and the electricity demand is increasing due to the growing population and the desire for standard living. According to an estimation, presently more than 1.5 billion people are deprived of access to electricity throughout the world [1]. Pakistan is also facing multifaceted challenges in the power sector and almost 50 million people are having no access to the electric grid [2]. Alternatively, harnessing water, tidal and solar energy can overcome the power shortages and to meet the electricity. Subsequently, MHPP is considered one of the desirable sources for power generation because of its environment-friendly nature and extensive potential available throughout the world [3]

The energy of the moving water is used for the generation of hydropower. The energy production from moving water dates back to ancient Greek times. Ancient Greek used to grind wheat into flour by rotating wheels through moving water. The water wheel is placed in a stream that picks up the moving water in buckets. The kinetic energy of the flowing water turns the wheel and is converted into mechanical energy that grinds the wheat into flour. In the late 19th century, a tremendous development had been made to generate electricity from hydropower. Many MHPP working in private and public sectors are without proper engineering design. In the present study, the work has been carried out to propose and design MHPP on a stream in the peochar valley, Swat, Pakistan. The stream is having enough discharge and most importantly, sufficient head that can be easily used to generate electricity for the local people. The flow data of the stream was collected from SRSP's office.

2 Design Methodology

Design methodology deals with the numerical background related to design of the micro hydro power plant. It involves the identification of some basic equations and relation to be used for the project. In the present work, two types of design methodology are involved: 1) Hydraulic design and 2) structure design.

2.1 Hydraulic design of civil components of MHPP

2.1.1 Weir and intake structure

A side intake is normally located at the bank of diversion works and consists of an opening called orifice through which water is entered and drawn to the downstream approach channel. The majority of small hydropower schemes are of the run-of-river kind, where water used for the power generation is brought back to the river at tail-race (downstream). Also, in run-of-river hydropower project electricity is generated from discharges larger than the minimum required to operate the turbine.

2.1.1.1 Design of orifice for side intake

The typical section through weir and section through submerged orifice is illustrated in Figure 1. The discharge through orifice of an intake when in submerged condition can be calculated as;

$$Q=A\times V= A \times C\sqrt{2g(H_r - H_h)} \qquad (1)$$

Where; Q= discharge (m^3/sec), V= velocity (m/sec), C= coefficient of discharge of the orifice

$H_r - H_h$=Difference between the river and the headrace canal water level

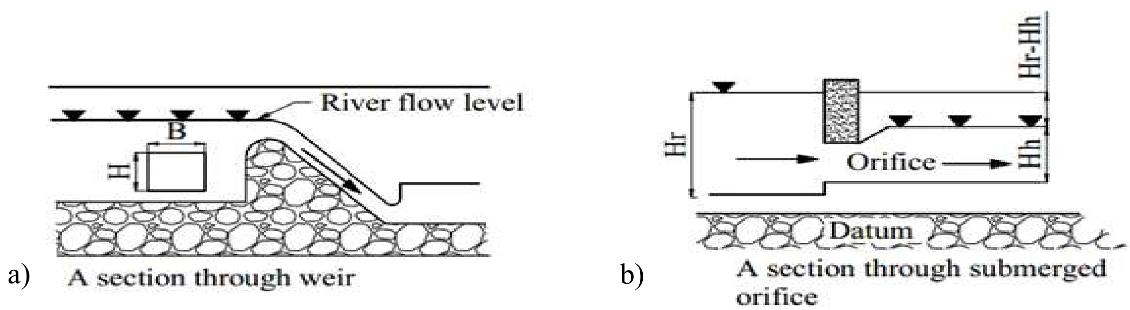

Figure 1: a. A section through weir, b. A section through submerged orifice

The size of slope and cross-section of an approach channel should be designed in such a way that the required turbine discharge (design discharge) can be economically traveled to the head tank (fore-bay). Generally, the size of cross-section and slope are interrelated. During the designing of a channel, the slope should be not higher to prevent more head loss. This gentler slope will produce low velocity and ultimately result in greater cross-section. On contrary, when the slope is steep, the velocity will be higher and resulting in smaller cross-section but the head loss, in this case, will be more. The cross-sectional shape of canal is decided according to the site conditions and stability. It may be rectangular, trapezoidal or some other possible shape. By using Manning's equation find the depth and width of the channel.

$$Q = \frac{1.49 \times A \times R^{2/3}}{n} \qquad (2)$$

Here, the channel is rectangular, so:

$$\frac{Q \times n}{1.49 \times \sqrt{S}} = \frac{A^{\frac{5}{3}}}{P^{\frac{2}{3}}} = 1.26H^{\frac{8}{3}} \qquad (3)$$

The equation (3) provided the height of approach channel. Provided with height, calculating the width and Cross-sectional area of the channel by W = 2H and A = W x H respectively.

When the flow is diverted from stream or river, there are some suspended particles. The settling basin is used to settle down these suspended particles. Settling basin has two portions: the first portion is called sand trap which settles down smaller size particles and the second portion is called gravel trap which settles down larger particles. There are different components of settling basin like, inlet zone, settling zone and outlet zone as shown in Figure 2.

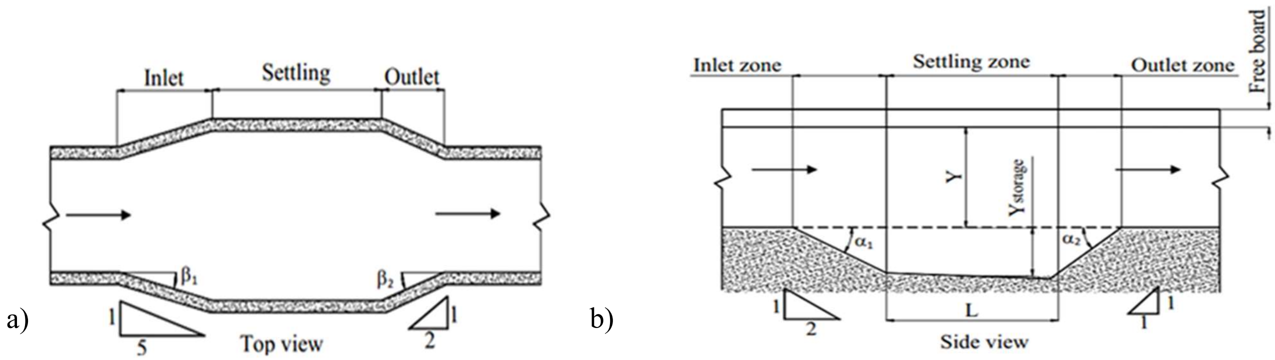

Figure 2: a. Top view of settling basin, b. Side view of settling basin

$$L_s = \frac{2 \times Q}{(W_s \times V_v)} \qquad (4)$$

Where, Q = design flow in m^3/s, Ws = Basin width

V_v= fall velocity, taken as 0.03m/s for the value for 0.3mm particles.

$$D_c = \frac{VO_s}{(L_s \times W_s)} \qquad (5)$$

Where, Dc = average collection depth, VO_s = volume of silt stored in the basin in m^3 and Ls = Basin length

2.1.4 Design of fore-bay

Structurally, the fore bay and settling basin are same but in forebay, outlet transition is replaced with a trash rack. The typical fore bay for MHPP is shown Figure 3. The recommended size for forebay should be such that a person can go inside for cleaning and at least once a year to repair.

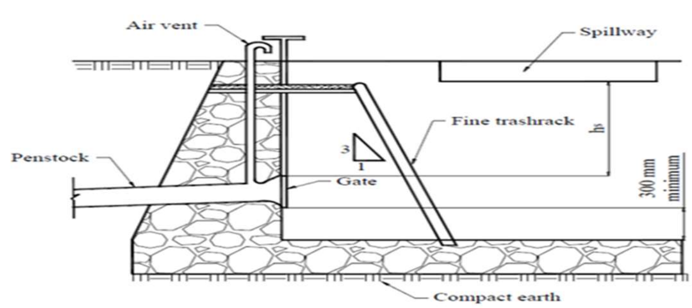

Figure 03: Typical Fore bay in MHPP

It has been recommended that the minimum submergence head for a penstock should be calculated as below:

$$h_s \geq \frac{V^2}{2g} \qquad (6)$$

For the design of the weir and approach channel, different moments are calculated and sliding and overturning stability checks are applied to check the stability. For the structural design of the settling basin, determine the dimension (length, width and height) of the tank from hydraulic design. The tank should be designed according to the situation (whether the length to width ratio is more or less than 2), so in this case it is more than 2. Thus, assuming the long wall is a cantilever and the short wall to act like a beam with both ends fixed. In the present study the shape of the tank is rectangular. The tank that is resting on ground the slab, the slab should be designed in such a way that it can safely transfer water weight and the structure self-weight to the ground. Normally, the floor slab thickness ranges from 150 mm to 250 mm with a minimum of 3% reinforcement.

3 Results and discussion

3.1 Hydraulic Design

3.1.1 Intake structure

The intake structure dimensions and flow characteristics are determined and summarized in Table 1.

Table 01: Intake structure Hydraulic Design

Intake structure					
Discharge (Q)	**Velocity of Water Through Orifice (V)**	**Area of Orifice (Q/V)**	**Height of Orifice (H)**	**Width of Orifice (W)**	**Depth of Weir (D)**
10 cusecs	4.815 ft/sec	2.068 ft²	0.75 ft	2.77 ft	2.75 ft

3.1.2 Approach channel

In the present study, the channel is a rectangular channel and the slope is found out from the site topography. Approach channel design values have been summarized in Table 02.

Table 02: Approach channel Hydraulic design

Approach Channel							
Discharge (Q)	**Slope (S)**	**Max Velocity (Vmax)**	**Height (H)**	**Width (W)**	**Area (A)**	**Actual Velocity (V)**	**Depth of Approach Channel**
10 cusecs	1/500	4.92 ft/sec	1.24 ft	2.48 ft	3.09 ft²	3.23 ft/sec	2.24 ft

3.1.3 Design of settling Basin

According to [4] the thumb rule for the width of the settling basin is 2 to 5 times the width of the approach channel. Assume the width of the settling basin will be two times the width of the channel. All others dimensions of settling basin have been calculated and summarized in Table 03.

Table 03: Hydraulic Design of settling Basin

Design of settling basin							
Discharge (Q)	**Width of Settling Basin (Ws)**	**Settling Velocity of Particles (Vv)**	**Settling Basin Length (Ls)**	**Silt Load (S_l)**	**Silt Density (S_d)**	**Volume of Silt (VO_s)**	**Collection Depth required for settling basin (D_c)**
10 cusecs	4.94 ft	0.197 ft/s	16.2 ft	12096 kg	73.68 kg/ft³	328.34 ft³	4.1ft

3.1.4 Design of Forebay

The hydraulic analysis provided the dimensions for the forebay which is shown in Table 04. The minimum submergence head required for the penstock is done in accordance with the standard [5].

Table 04: Hydraulic Design of forebay

Design of forebay									
Discharge (Q)	**Storage Capacity of Fore-bay**	**Volume (V)**	**Length (L)**	**Width (W)**	**Actual Depth**	**Velocity in Penstock**	**Min head in Fore-bay Req above crown (h_s)**	**Storage Depth (d_b)**	**Min Depth ($h_s + d_b$)**
10 cusec	60 sec	600 ft³	16.1ft	4.94 ft	7.5 ft	9.8 ft/sec	2.25 ft	1 ft	3.25 ft

3.2 Structure Design

All the structural components of MHPP have been designed in accordance with the standard.

3.2.1 Structure design of Approach channel

Multiple checks and standards applied to the check the stability of retaining the wall, designed for approaching the channel and the designed values are provided in Table 05. The retaining wall's structure dimension has been provided in Table 06.

Table 05: Approach channel structure design

Approach Channel							
Discharge (Q)	**Slope (S)**	**Max Velocity (Vmax)**	**Height (H)**	**Width (W)**	**Area (A)**	**Actual Velocity (V)**	**Depth of Approach Channel**
10 cusec	1/500	4.92 ft/sec	1.24 ft	2.48 ft	3.09 ft²	3.23 ft/sec	2.24 ft

Table 06: Retaining wall of approach channel

Structure Design Walls of approach channel				
Top Width of Retaining Wall	**Bottom Width of Retaining Wall**	**Height of Retaining Wall**	**Unit Weight of PCC (γ_c)**	**Unit of Water (γ_w)**
0.75 ft	1.5 ft.	2.24 ft.	150 lb/ft³	62.4 lb/ft³

3.2.2 Structure design of forebay and settling basin

The reinforcement details for the design of settling basin and forebay is mentioned in Table 07.

Table 07: Structure design of settling basin and forebay

Structure design of settling basin and forebay				
Design of long wall		**Design of short wall**	**Design of base slab for settling basin and forebay**	
Thickness of the Wall (d)	**Vertical & Horizontal Reinforcement**	**Vertical & Horizontal Reinforcement**	**Thickness of the Slab**	**Reinforcement in Both Directions (Mesh)**
12 inches	#4 bar @ 9in c/c	#4 bar @ 9in c/c	6 inches	#4 bar @ 9in c/c

4 Conclusion

In this study, the design of different components of Peochar MHPP is done by using standard rule and procedure. The different components include; the intake structure, approach channel, settling basin and forebay are designed. From the hydraulic design the sizes of these components are determined. The results obtained from the redesign are more economical as compared to the existing MHPP at the site. MHPP will tremendously improve the socio-economic life in northern regions of Pakistan. This will ultimately reduce the wood cutting issue which northern people are using for energy consumption, particularly in the winter season. This will result in discouraging deforestation and ultimately preserve the ecosystem.

5 Recommendations

The following recommendations have been suggested in these studies:

• The proposed project in the present studies, is economically viable and it can be attractive for private investors. Therefore, the government of KPK should invite and encourage the private sector to take up this project for implementation.

• A single turbine unit has been proposed. In future, a design scheme having two smaller turbine units equivalent in capacity to a single unit could be worked out. This would be beneficial in a way that during lower flows a single turbine unit would be operational while during full design flow both the units will be working.

• In the proposed scheme, economic analysis is done by doing an economic comparison between the proposed MHPP and an equivalent capacity thermal power plant. Another way of doing this economic analysis is through Long Run Marginal Cost Method (LRMC). An economic study based on LRMC could be done in the future.

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