Two Ideas to Regain the Power Otherwise Lost in Run-off River Schemes with Elevated Powerhouses

Introduction

For run-off schemes, floods often require powerhouses to be set back from the riverbanks. This raising of the level of the powerhouse frequently curtails much of the potential head. Two low-cost proposals for such run-off schemes are presented. One proposal is a draft tube combined with a longitudinal baffle wall in the tailrace, which regains much of the power otherwise lost in the tailrace. The second proposal described is a new way of controlling the water level inside draft tubes. Both methods increase the output power for a given head.

1. Background

The following concepts were conceived during a rehabilitation project for a Nepal run-off river plant in the village of Katunje. Nepal - like many other third world countries - has many run-off river plants and has experienced severe flooding which have swept away powerhouses.

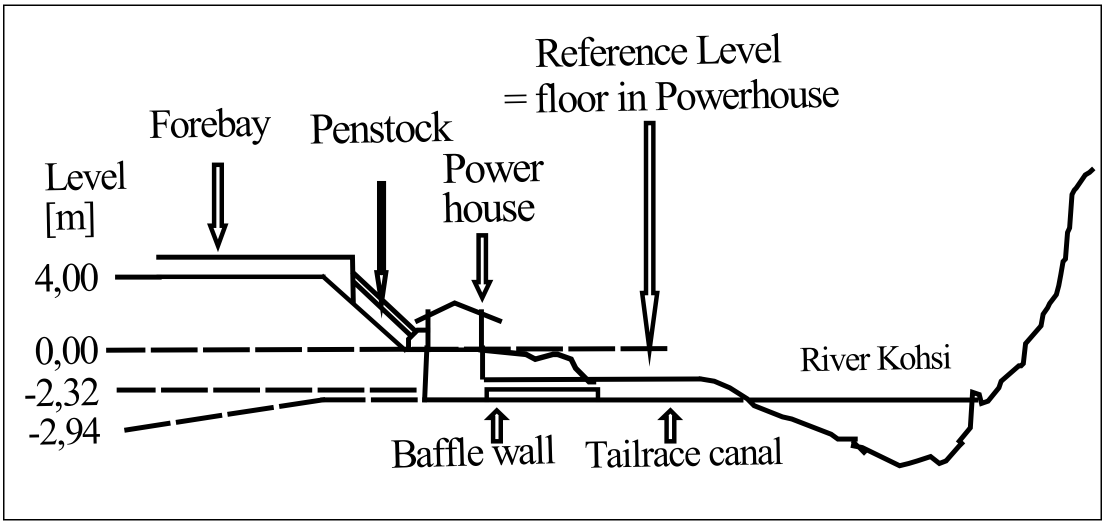

Figure 1. Cross-section of Kohla River valley in Nepal with the Katunje hydropower plant.

Powerhouses are therefore generally placed high enough to survive the highest flood known by anyone in the village. Most of these schemes use cross flow turbines.

Cross-flow turbine manufacturers in the western world (e.g. Ossberger Turbinen Fabrik) use draft-tubes, but in developing countries like Nepal draft tubes are almost never used. Placing the powerhouse at a safe level often means a loss of 2-3 metres of head.

If (as in Katunje) the total head is 6 metres, when the powerhouse is placed 2 metres above normal river level, only 4 m of usable head will be left. In this case use of a draft tube could regain most of the 2 metres otherwise lost.

1.1 Conicity of Draft Tubes

Draft tubes are also used to minimise the velocity of the water leaving the draft tube. The velocity is inversely proportional to the area of orifice of the draft tube. Hence, one will aim to maximise the cone angle of a draft tube. If, however, the cone angle of a draft tube exceeds 8°,

water will start to detach from the inner sides. Thus, no part of the draft tube, which is above tail water level, should have an inclination angle α of more than 4^0 - relative to the vertical.
Mind that in cases where the upper part of the draft tube is bolted to a rectangular cross section of a turbine – that the maximum slope of 4^0 also applies to the slope of the four corner lines where the rectangular sides of the cross section of the turbine are shaped into the joining surfaces of the upper part of the draft tube.

1.2. Clearance below Draft-Tubes

In this paper the part of the tailrace, into which the lower part of the draft tube must be immersed, is referred to as the (draft tube-) basin.

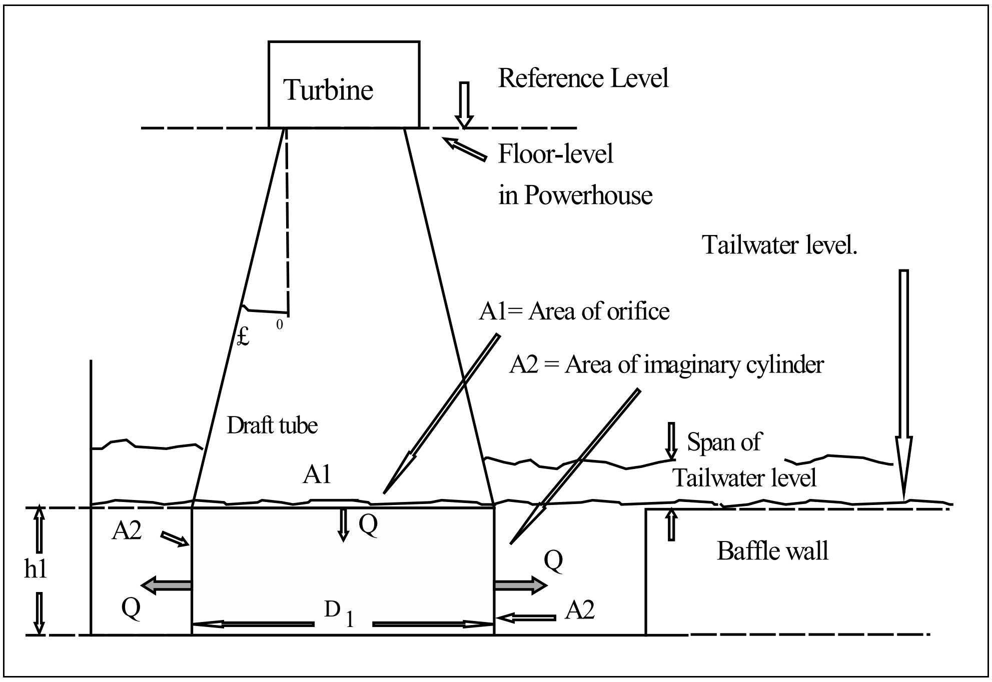

Figure 2. Required clearance (h_1) below draft-tube.

The clearance below the draft-tube and the bottom of the basin is a trade off between:

1. A long draft tube - in order to extract maximum power
2. A sufficient clearance (between the lower rim of the draft tube and the floor of the draft tube basin) so as not to obstruct the flow and to allow for a smooth gentle change of the draft tube's vertical flow to the - more or less - horizontal flow out of the basin and into the tailrace.

In order for draft tubes to minimise the output velocity, the cross section area of the orifice must be maximized.
Additionally - in order not to obstruct a free flow - the area of the flow leaving the draft tube must not be less than the orifice of the draft tube.

Hence:

a. The area (A_1) of the lower orifice (Diameter = D_1) of the draft tube

must be followed by an identical (or larger) area:

b. Area (A_2) of the vertical side of an imaginary cylinder stretching from the lower rim of the draft tube down to the bottom of the draft tube basin.

This restriction sets the requirement for the minimum clearance between the lower rim of the draft-tube and the bottom of the basin. The clearance can be calculated as follows:

The area A_1 of the orifice of the bottom of a draft tube (with a diameter of D_1) is:

$$A_1 = \pi * (D_1/2)^2.$$

The area (A_2) of the side of the vertical imaginary cylinder is $A_2 = \pi * D_1 * h_1$

- where h_1 is the clearance between the lower orifice of the draft tube and the bottom of the tailrace,
- yielding: $h_1 \geq D_1 / 4$

1.3. Use of Rounded Edge Draft Tubes

Often (to avoid turbulence around the edge of the draft tube) a circular steel tube around - and welded to - the lower edge of the draft tube is used to give a minimum rounding radius (r_3). Such a ring provides a cheap and practical means to smooth the transition from the almost vertical flow in the draft tube into the horizontal flow in the basin.

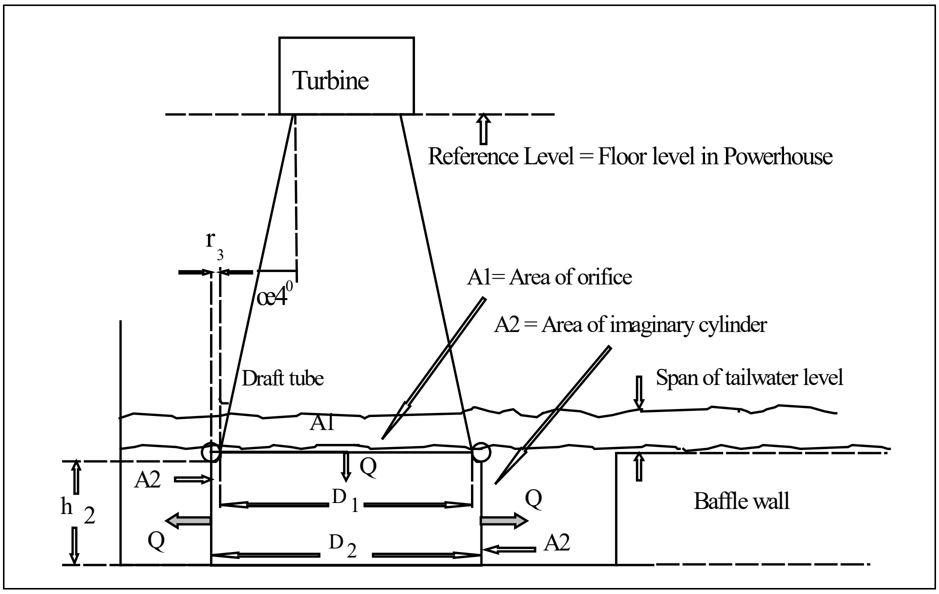

Figure 3. Impact on the required clearance h_2 of a circular tube welded to the bottom of the draft tube.

As for the sides of the draft tube, no surface above the tailwater level should have an inclination angle of more than 4°. Hence, if a circular steel tube around the lower edge of the draft tube is used together with a baffle wall (see Fig 3), the centre of the steel tube should be levelled with the top of the baffle wall to keep the bottom of the draft tube submerged. The new clearance h_2 required between the bottom of the draft tube and the bottom of the basin will increase when using the circular tube. The new clearance (h_2) can be approximately calculated using the horizontal diameter between the two centres of the ring formed tube

$$(\text{i.e. } D_2 = D_1 + 2 * R_3) \quad => \quad h2 \geq D_1 + 2 * R_3$$

Thus, when trading the ratio of the clearance h_2, and the rounding radius (r_3) of the horizontal tube, two conflicting aspects have to be considered:

1. Maximum head should be gained from the draft-tube, calling for a minimum clearance.

2. Sharp corners (low curving radius e.g. around the lower edge of draft tube) in the flow should be avoided. This calls for maximum clearance to allow for a smooth change of the direction of the flow from the draft tube into the tailrace.

The optimum ratio between the rounding-radius of the tube and the clearance (i.e. r_3 to h_2) – is to be calculated by a competent hydrologist.

2. Stabilizing Water Level in the Tailrace

For a draft tube to work, its bottom rim must always be submerged. Yet, the more the water level increases above the lower rim of the draft tube, - the more head is lost. Thus, for run-off river schemes a changing tailrace water level will conflict with the wish to stabilize the water level to just above to the lower rim of the draft-tube.

To minimise the impact of flow variations on the water level around the draft tube, the idea was conceived to create a basin below the draft tube by placing a baffle wall (i.e. a weir) across the tailrace.

According to ‘Micro Hydropower Source-book’ (ref 1) the discharge (Q [m^3/s]) (through a weir with a rectangular opening, with a width (w [m]), and with a rise (h [m]) in water level above the rectangular opening of the weir) - is linked as: **$Q = 1.8 (w - 0,2 h) * h^{3/2}$.**

Thus, if the width (w) of the rectangular notch in a weir is sufficiently large, h will become very small. Hence, if - instead of placing the weir perpendicular to the tailrace - it is placed longitudinally (i.e. diagonally) in the tailrace, “w” can be increased / extended as shown in figure 4.

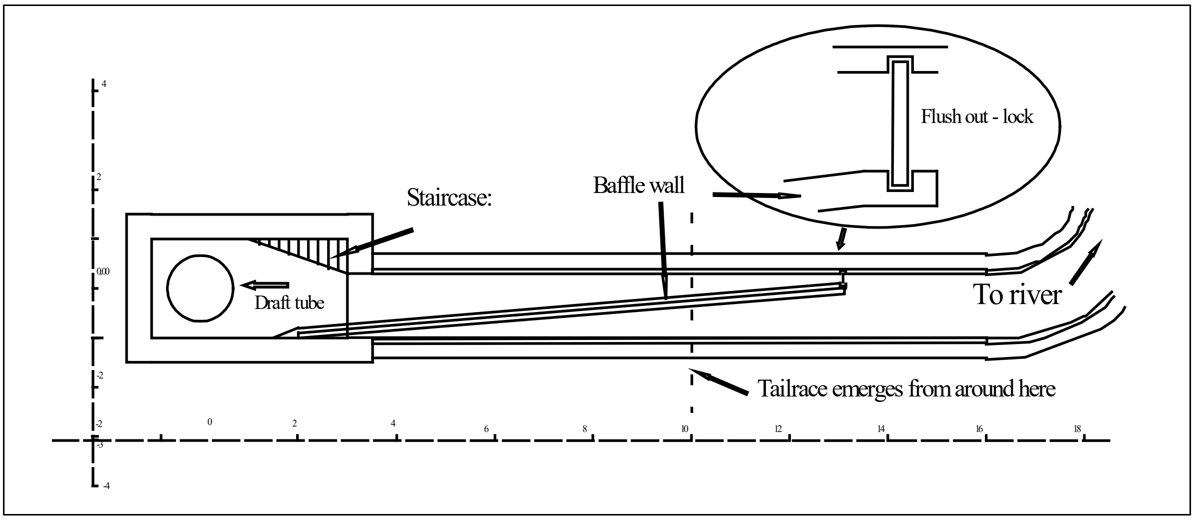

Figure 4. Draft tube basin, baffle wall, and tailrace.

For the Katunje site the width of the tailrace was designed to be 1,25 m and the length of the weir / baffle wall to be 11 m = 8,8 times the width of the tailrace (see fig 4). Using the equation for Q, w, and h with the data for the Katunje site yields the following correlation between rise in water flow and water level:

10 l/s	0,64 cm	200 l/s	4,68 cm	600 l/s	9,73 cm
50 l/s	1,85 cm	300 l/s	6,13 cm	800 l/s	11,79 cm
100 l/s	2,94 cm	400 l/s	7,42 cm	1000 l/s	13,68 cm

2.1. Joining the Tailrace to the River Further Downstream

As water passes over the baffle wall, the water level on the riverside of the tailrace will build up until the flow stabilizes. Therefore, neither the basin nor the tailrace, need any slope, (apart from what might be required to drain the tailrace and the basin for maintenance).

If the level of the river drops significantly from the power house and further down stream - and if the geological conditions allow for it – the head can be further increased by taking the trace of the tailrace further downstream before it is joined to the river as shown as bird's eye view on figure 5.

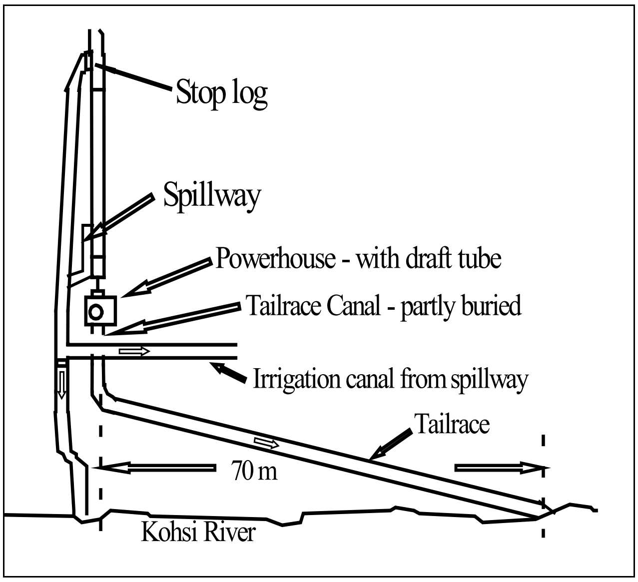

Figure 5. Joining the tailrace to the river further downstream.

As the slope of the tailrace can be kept low (almost zero), the level of the tailrace can be kept at the level, where the tailrace is joined to the river. This allows for a further increase in the height of the draft tube, and a corresponding power increase.

2.2. Flooding

The concept will work for floods submerging the tailrace up to just below the floor of the powerhouse. The foundations and the civil works must be designed to survive such floods. Only for water levels exceeding the water level in the draft tube basin, will the power generation be curtailed.

2.3. Settling of debris below draft tube

If the baffle wall would extend from side to side of the tailrace, the draft tube basin could never be emptied. Hence, a lock is placed in one side of the baffle wall (at the down stream end) to allow for debris and gravel to be swept out.

3. Stabilizing the Water Level in the Draft Tube Using Cross-flow Turbines

If a cross flow turbines have their runners immersed in the draft tube water the water leaving the runner will drop down into the draft tube and cause splashing. Thus, if the water column in the draft tube rises too high, the splashing will hit the runner and brake its rotation. If - on the other hand - the water column in the draft tube is too low, precious head will be lost.

Hence, a system is required to control the distance between the runner and the water level in the draft tube. Ossberger Maschinen Fabrik in Germany (which manufactures cross-flow turbines with draft tubes) uses a spring to pre-tension a valve in the upper part of the draft tube to control the water level in the draft tube. The present system, however, is controlled by the pressure difference between the ambient pressure and the pressure at the top of the draft tube and, thus, depends on the level of the tail water.

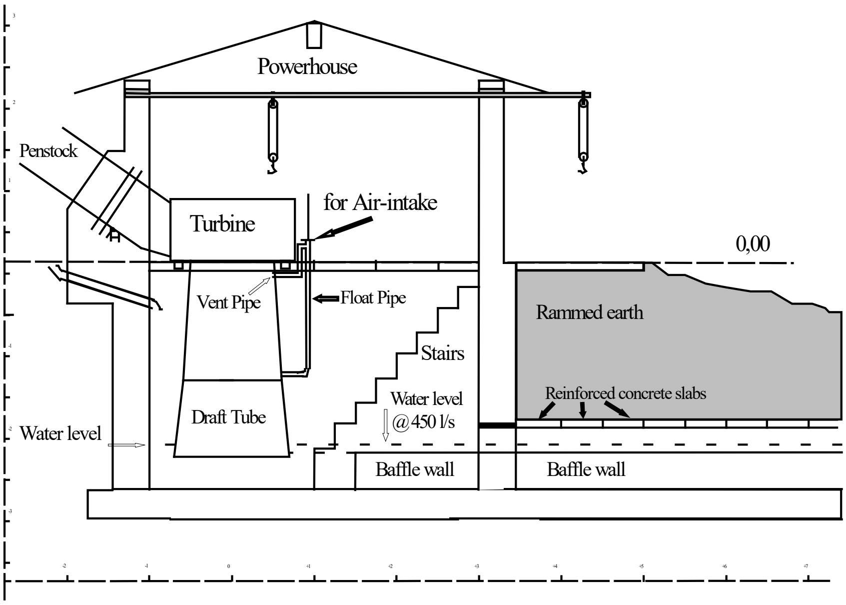

Figure 6. Draft tube with float based water level control system.

3.1. An Alternative Float Based Control System

To minimise the influence of the variations in the tailwater level an alternative control system has been devised. The system is shown in figure 6 & 7 and comprises of a float, which detects the water level and lets in air to the draft tube, if / when the water level raises above a certain set point. Hence, this control is insensitive to variations in the tailwater level, and it allows the operator to monitor and to adjust the draft tube water level for maximum output power.

The system is simple to manufacture. Two pipe stubs - one near the bottom and one near the top (placed above each other) - are welded onto the end of the draft- tube.

The tube system as shown on figure 6 & 7 can be made out of standard plumbing components using 3/4" water pipes and associated fittings. Inside the longest of the vertical pipes is inserted a float (made of a 20 mm Ø standard plastic pipe with airtight plugs at both ends). An M6 steel rod (0,4 m long) is fastened to the top end plug of the plastic pipe / float. On the M6 rod is mounted a brass cone with an internal thread, allowing its position on the rod to be adjusted. The brass cone rests on the edge of a 7,0 mm hole at the top fitting and forms the air valve.

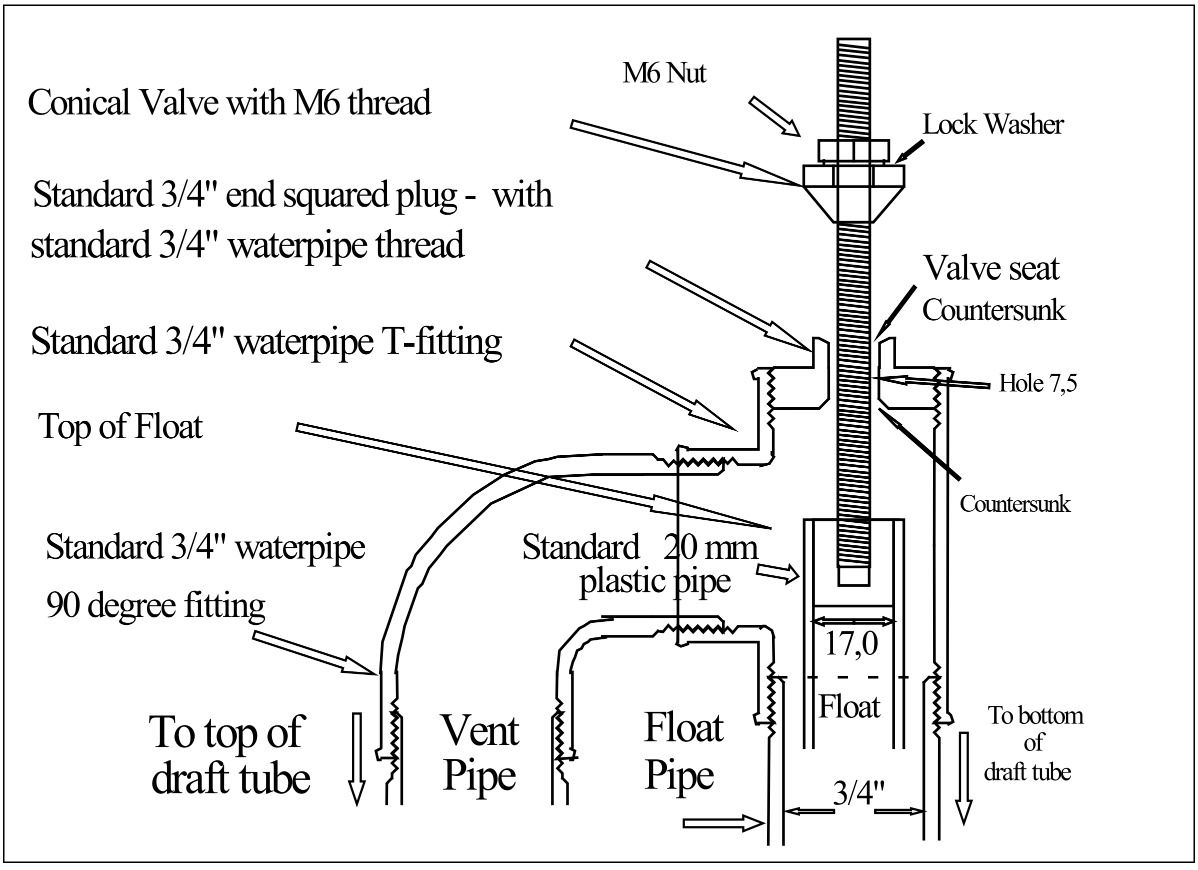

Figure 7. Detailed view of float and valve seat.

4. Conclusion

A proposal for a run-off river schemes is presented, which, at low cost allows regaining much of the head, which can otherwise be lost at sites, where the difference of the level of the powerhouse and the level of the river takes a significant toll of the available head. A combination of a draft tube and a longitudinal baffle wall in the tailrace has been devised, which regains a part of the power otherwise lost in the tailrace.

Also an alternative method to stabilize and optimise the water level in a draft tubes below a cross flow turbine has been presented. It is my hope that these ideas could come be used, not least in third world stand-alone hydropower sites. Comments will be received with much gratitude. Contacts can be obtained at the address given below.

References:

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