Effect of the Entrance Zone on the Trapping Efficiency of Desilting Tanks in Run-of-River Hydropower Plants

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Back

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ABSTRACT

Run-of-river mini hydropower plants are generally installed in mountainous streams where the catchments are generally steep and vulnerable to high soil erosion. Seasonal heavy rains, especially in tropics and monsoon regions produce large sediment yield from these catchments and the streams experience high sediment concentrations during seasonal floods. Therefore, removal of sand entering into headrace canal in run-of-river mini hydropower plants is an important issue in the run-f-river mini hydropower schemes to reduce the erosion of turbines and other components in contact with water. The desilting tanks constructed in series with the headrace canal play an important role here. The shape and the size of the desilting tank are major factors on the sand trapping efficiency of it. This paper presents a series of laboratory experiments carried out to investigate the effect of the entrance zone on the sand trapping efficiency of the desilting tanks using a scale model of a desilting tank with varying entrance expansion angles. The sand trapping efficiency is found to vary from 50% to 85% with the reduction of espansion angle from 30^o to 10^o.

1 INTRODUCTION

Hydropower is the largest source of renewable power contributing to 92% of the total renewable energy generation in the world. It contributes to 16.3% of the total electricity generation of 18000 TWh/year in the world. The world's total hydropower potential is about 14000 TWh/year of which about 8400 TWh/year is considered to be economically feasible for development at present. About 2900 TWh/year is already been used and the remaining feasible developments are mostly in Asia and South America. South Asia's present hydropower generation is only about 100 TWh/year, which is about 16% of the total electricity demand (IHA 2000, IHA 2003, IEA 2004, IEA 2006).

Table 1 gives the projection of estimated deployment of large and small hydropower plants in the world by year 2010. Small hydropower plants are generally run-of-river type with no impoundment, and are more environmentally acceptable than the large hydropower plants with impoundments. For example, the green house gas emission rate is estimated to be about 2 kt eq. CO_2/TWh per energy unit from the run-of-river type hydro power plants. Whereas, that for the hydroelectric power plants with impoundments is estimated about seven times, and for the diesel electric power plant is about 400 times (IHA 2003). Therefore, the deployment of run-of-river hydropower plants, which is a clean source of electricity, will be of great interest to meet the ever increasing energy demand.

Development of the run-of-river type mini hydropower plants is being given increased attention in Sri Lanka at present owing to the incentives announced for developers of renewable power generation projects during the last decade by the Sri Lankan government (MPESL, 1997). The sources for most of the run-of-river type mini hydropower plants are the mountainous streams where the discharges experience significant seasonal variation with frequent flash floods. The catchments of these streams are generally steep and under increasing trend of soil erosion due to cultivations and other human activities. Therefore, the stream flows carry high sediment loads during seasonal floods. These sediment-laden flows enter into the headrace canals feeding water to the turbines of the min hydropower plants.

Table 1. Projection of deployment of large and small hydropower plants (IHA, 2003)

Distribution	**Type**	**Deployment in 1996 (TWh/year)**	**% of small scale projects (<10 MW)**	**Deployment in 2010 (TWh/year)**	**% of small scale projects (<10 MW)**
Worldwide	Large	2265		3990	
	Small	115	5	220	6
Asia	Large	291		1000	
	Small	42	14	100	10

Sediments in the water passing through the turbines with high velocity erode the contact surfaces of turbine components. The erosion of turbine components leads to drop in hydraulic efficiency and high maintenance cost of turbines. The erosion takes place due to the combined mechanisms of gouging and hammering, and the intensity of erosion depends on sediment properties, flow properties, material properties and hydraulic design of the turbine (Singal and Singh 2006, Bhola.and Dahlhaug 2003). Removal of sediment carried with the flow through the turbines of run-of-river mini hydropower plants is therefore an important issue for the sustainability of the mini hydropower industry.

Several arrangements are adopted in order to reduce the sediment entering into the turbines of run-of-river hydropower plants. At the diversion weir, the intake to the headrace canal is designed to minimize the sediment entering into the canal. Though coarse sediments are prevented from entering into the canal at the intakes, fine sediments find their way into the canal with the flow. Therefore, desilting tanks (also called as silt traps or sedimentation tanks) are provided in series with the headrace canals to remove the fine sediments including sand and silt. They are designed as settling basins to settle sediments greater than a targeted size (Janssen, 2004).

The shape and the size of the desilting tank are major factors affecting the sand trapping efficiency a desilting tank. Several empirical and semi empirical relations for the efficiency of sediment removal of desilting tanks have been obtained (Ranga Raju et al. 1999 and Atkinson 1992). Ranga Raju and Kothyari (2004) provides an empirical relation for efficiency based on analysis of all the available data where efficiency is related to the area of cross section areas of the desilting tank and the approach channel, and the shear velocity in the desilting tank. Andaroodi (2005) described the Bieri and Büchi type desilting tanks. In Bieri type, the sediments which settle in the basin are flushed vertically through the opening (fixed and movable plates) at the bottom into a free flow channel and back to the river. For the Büchi type, a separate flushing channel does not exist and the sediment flushing is done by drawdown of the desisting tank. Andaroodi (2005) also provided design criteria for Bieri type tanks. However, the effect of the shape of the desilting tank on the efficiency of sediment removal has not been given attention. This paper presents the results of a series of laboratory experiment carried out using scale model of a desilting tank to investigate the effect of entrance expanding angle of the entrance zone on the sand trapping efficiency of desilting tanks.

2 EXPERIMENTAL SETUP

The experiments were carried out at the Hydraulic Laboratory of the University of Peradeniya, Sri Lanka under steady subcritical flow condition using a 1:6 scale model of a rigid boundary canal set up with a desilting tank typical to mini hydropower plants in Sri Lanka. The flows were established considering the Froude similarity for a typical discharge of 3 m^3/s in a concrete-lined canal with a slope of 1:1000, width of 1.5 m, a flow velocity of 1.5 m/s, and a desiliting tank of 15 m X 6m X 2 m. Accordingly, the velocities in the model channel and the model desilting tank were 0.61 m/s, 0.20 m/s respectively and the discharge in the model channel was 20 *l*/s. The model canal was 0.25 m wide and 7m long and the model desilting tank was 2.5 m X 1 m X 0.33 m (Ratnayake and Dissanayake, 2005). The model was constructed by timber. Steady discharges into the channel was fed from a constant head overhead tank through a pipe with control valves during the experiment.

There is no sharp cut-off in the ability to abrade turbine blades. For the purpose of the design of conventional desilting tanks, the targeted largest sediment size is in 200 to 500 µm range (Agrawal and Pottsmith 2005, Canyon Ind. 2005). Here, the target size of the sediment in the prototype desilting tank is taken as 300 µm. Flows in the canal and the desilting tanks are in the turbulent region. Therefore, quartz sand in the range of 90 – 125 µm were used in the model experiment while relaxing the geometric similarity condition of sediment in order keep the sediments in the range of sand. During the experiments, sand was fed to the upstream of the channel to serve channel bed as the sediment feeder so that the approach flow carried the sand at its transport capacity into the desiliting tank. The sand transported into the tank and settled inside the tank was measured.

3 EXPERIMENTAL PROCEDURE

In order to investigate the effect of entrance zone angle on the trapping efficiency of the desilting tank, a series of tests were carried out changing the entrance expanding angle of the desilting tank while keeping the length of the tank constant (Fig 1). Details of the tests carried out for five different expanding angles for each of the three steady discharges of 15 *l*/s, 20 *l*/s and 25 *l*/s are given in Table 1. Experiments (Ratnayake and Dissanayake, 2005) have shown that the high tapping efficiency is obtained at expanding angles below 30 degrees. Therefore, expanding angles of 7^o, 10^o, 20^o, 30^o and 90^o deg have been selected in this experiment. In each test, 1 kg of dry quartz sand in the size range of 90-125 µm were fed at the upstream and the dry weights of the sand trapped were measured.

Fig 1 Experimental set-up

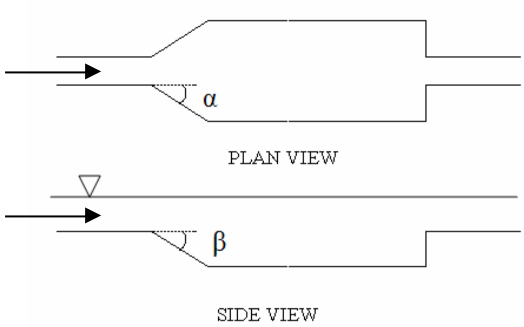

Fig 2: Sketch of the desilting tank
a = expanding angle, ß = entrance slope

4 RESULTS AND DISCUSSION

The sediment trapping efficiency in the desilting tank was defined as the ratio between dry weight of the sand settled in the tank to the dry weight of the sand transported into the desilting tank by the flow.

Observations obtained from 63 number of tests carried out are summarized in Table 1. Fig.3 depicts the variation of the trapping efficiency with the expanding angle of the entrance zone in the desilting tank. Accordingly, the trapping efficiency can be increased by about 20% (from 60% to 80%) for the targeted sediments by introducing a suitable entrance expanding angle to the desilting tank while keeping the overall length and width of the tank same. The present investigation shows that the maximum trapping efficiency corresponds to an entrance expanding angle of about 10 degrees.

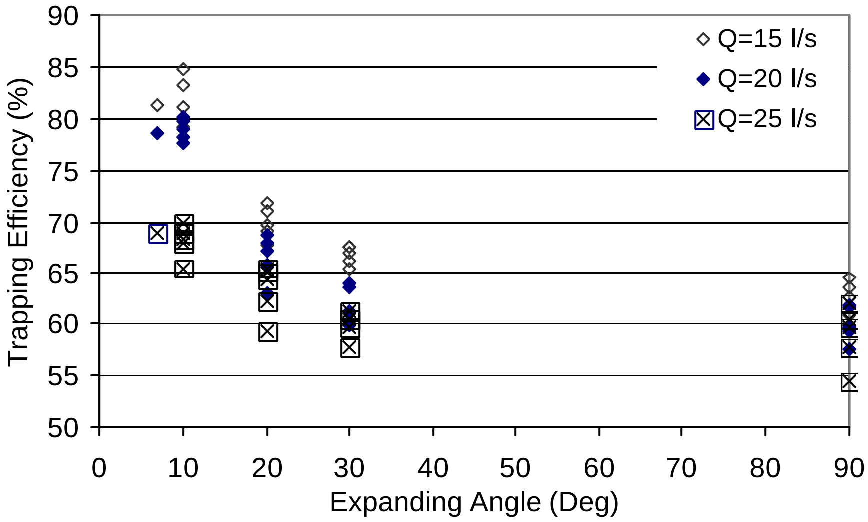

Fig.3 Variation of trapping efficiency with expanding angle

Settling of sand particles in the desilting tank is adversely affected by short circuiting where the active flow does not cover the available cross section to the flow and by high turbulence. When there is no gradual increase in the cross section of the desiliting tank, e.g. at the expansion angle of 90 deg, flow separates from the walls and large eddies are introduced causing high intensity of small scale turbulence in the tank. These features in the flow result in short-circuiting of sand particles and hindering the settlement. When gradual expansion of the cross section is introduced to the tank, flow is gradually decelerated and intensity of turbulence is reduced. The plot in Fig. 2 shows that the trapping efficiency begins to increase with the reduction of expansion angle from 30 deg. The optimum expansion angle for maximizing the trapping efficiency seems to be about 10 deg. The discharges lower than the design discharge always resulted in a high sand trapping efficiency. In contrast, the discharges greater than the design discharge always resulted in a low sand trapping efficiency. In mini hydropower plants, the headrace canals experience higher discharges usually when the stream carry flood flows. These high flood discharges usually carry high sediment concentrations too and thus the low sediment trapping efficiency in the desilting tanks under greater flows than design flow needs careful attention in the operation of turbines during high flows in the stream.

The present experiments considered only the effect of the expansion angle and the accompanied slope angle on the trapping efficiency. No attention was made to the other methods of increasing the trapping efficiency such as by installation of screens in the tank to reduce turbulence intensity.

5 CONCLUSIONS

The entrance zone of the desilting tanks has a considerable impact on the trapping efficiency of the sediment in the desilting tanks. The trapping efficiency of the tank increases with the reduction of the expansion angle of the entrance zone in the desilting tanks, the optimum expansion angle is found to be about10 deg. Nevertheless, more investigation considering different sediment sizes are recommended.

Table 1: Test cases and trapping efficiencies

Expanding angle, a (deg)	Nominal discharge (l/s)	Water depth in channel (m)	Velocity in the channel (m/s)	Actual discharge (l/s)	Froude Number in the channel flow	Sand retained (kg)	Trapping efficiency (%)
7	15	0.13	0.48	15.6	0.11	0.813	81
	20	0.16	0.52	20.9	0.12	0.786	79
	25	0.19	0.60	28.4	0.13	0.689	69
10	15	0.13	0.47	15.3	0.11	0.849	85
		0.13	0.49	15.9	0.11	0.833	83
		0.13	0.47	15.3	0.11	0.781	78
		0.13	0.47	15.3	0.11	0.812	81
		0.13	0.48	15.6	0.11	0.792	79
	20	0.16	0.52	20.9	0.12	0.797	80
		0.16	0.52	20.9	0.12	0.802	80
		0.16	0.52	20.9	0.12	0.789	79
		0.16	0.50	20.2	0.11	0.782	78
		0.16	0.54	21.5	0.12	0.776	78
	25	0.19	0.57	27.2	0.13	0.689	69
		0.19	0.57	27.2	0.13	0.679	68
		0.19	0.59	28.0	0.13	0.655	65
		0.19	0.56	26.8	0.13	0.699	70
		0.19	0.56	26.4	0.13	0.684	68
20	15	0.13	0.47	15.3	0.11	0.710	71
		0.13	0.49	15.9	0.11	0.692	69
		0.13	0.45	14.8	0.10	0.678	68
		0.13	0.47	15.3	0.11	0.698	70
		0.13	0.49	15.9	0.11	0.719	72
	20	0.16	0.55	21.9	0.12	0.687	69
		0.16	0.53	21.2	0.12	0.680	68
		0.16	0.52	20.9	0.12	0.659	66
		0.16	0.51	20.5	0.12	0.672	67
		0.16	0.51	20.5	0.12	0.630	63
	25	0.19	0.57	27.2	0.13	0.655	66
		0.19	0.57	27.2	0.13	0.643	64
		0.19	0.56	26.4	0.13	0.593	59
		0.19	0.54	25.6	0.12	0.651	65
		0.19	0.56	26.4	0.13	0.621	62
30	15	0.13	0.45	14.8	0.10	0.675	68
		0.13	0.47	15.3	0.11	0.663	66
		0.13	0.48	15.6	0.11	0.670	67
		0.13	0.45	14.8	0.10	0.676	68
		0.13	0.48	15.6	0.11	0.654	65
	20	0.16	0.52	20.9	0.12	0.636	64
		0.16	0.54	21.5	0.12	0.599	60
		0.16	0.52	20.9	0.12	0.602	60
		0.16	0.51	20.5	0.12	0.611	61
		0.16	0.53	21.2	0.12	0.638	64
	25	0.19	0.59	28.0	0.13	0.6047	60
		0.19	0.57	27.2	0.13	0.5973	60
		0.19	0.57	27.2	0.13	0.6128	61
		0.19	0.56	26.4	0.13	0.6049	60
		0.19	0.56	26.8	0.13	0.5781	58
90	15	0.13	0.47	15.3	0.11	0.635	64
		0.13	0.47	15.3	0.11	0.617	62
		0.13	0.48	15.6	0.11	0.609	61
		0.13	0.47	15.3	0.11	0.646	65
		0.13	0.46	15.0	0.10	0.625	62
	20	0.16	0.52	20.9	0.12	0.575	58
		0.16	0.51	20.5	0.12	0.596	60
		0.16	0.52	20.9	0.12	0.592	59
		0.16	0.54	21.5	0.12	0.618	62
		0.16	0.50	20.2	0.11	0.616	62
	25	0.19	0.57	27.2	0.13	0.620	62
		0.19	0.59	28.0	0.13	0.605	61
		0.19	0.57	27.2	0.13	0.596	60
		0.19	0.57	27.2	0.13	0.577	58
		0.19	0.58	27.6	0.13	0.545	55

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