Sediment Extractor

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Abstract— A hydropower project is a renewable, efficient technology for the production of energy. In these types of projects, settling basin or sedimentation tank is the most important part of the project. This will extract the sediments which are coming from the intake site due to the reason that sediment is the biggest enemy of the any hydro power projects. Most of the hydro power plants are affected by excessive sediment. Sediments decrease the capacity of reservoir, erode the hydraulic structure of settling basin, harmful for turbine structure or erosion of turbine components and also harmful for intake and divide wall.in this paper attempt has been made to review the different types of desilting devices being deployed hydro power plants.

Key words: settling basin, vortex tube, removal efficiency

I. Introduction

Rivers have sustained human civilizations for several centuries. The needs of drinking water, irrigation, electric power and navigation are often met by river systems. Hydropower plant development generally contains the construction of a reservoir and, in case the power house is located far away from the reservoir, the water will have to be conducted through a tunnel or a canal. The today's world wide yearly loss of storage capacity due to sedimentation is already higher than the increase of capacity by the construction of new reservoirs for irrigation, drinking water and hydropower. Hydro power plant being most reliable and environmentally benign energy technology for electricity generation plays an important role in development of a region/nation. In our country India, most of the hydro power project exists in Himalayan region. We know that the rivers which are in Himalayan region, carry large amount of silts which are very harmful for the equipment used in hydro projects. Settling basin is the one of the important part of the hydro project which separates the sediments from the flowing water and protects the hydro mechanical equipments from the harmful silt carried by the conducting system. Settling basins extracts clean water by settling particles, which are then drained back to the river by flushing system. Settling basin are used on water treatment plants and hydropower channels to remove objectionable sediment of a specified size and quantity. Coarser sediments cause excessive abrasion and aggravate cavitational affects on turbine parts. it is proposed that all the sediments coarser than 0.2 mm size be extracted from the water before it enters the headrace tunnel. The erosion of turbine component depend on: (i) eroding particles - size, shape, hardness, (ii) substrates–chemistry, elastic properties, surface hardness, surface morphology, and (iii) operating conditions – velocity, impingement angle, and concentration and like that. Depending on the gradient of the river and distance traversed by the sand particles, the shape and size of sediment particles vary at different locations of the same river system, whereas mineral content is dependant on the geological formation of the river course and its catchments area.

II. Sediment Extractor or Settling Basin

For the reduction of amount of sediment that enters the canal at the head work, several methods have been discussed. After this also a large amount of sediments may enter the canal and create a harmful situation. In this type of situation it is very necessary to removal of this excess of sediment downstream of regulator. This purpose will be achieved by constructing the sediment extractor or sediment extracting structure in the canal. This will be called sediment extractor or ejectors.

For proper functioning of sediment ejectors proper location of sediment ejectors in the canal is essential. It should not be located at a long distance from downstream of the canal head because the material entering the canal may deposit in that reach and raise the bed level. For the solution of this problem the heard reach of the canal be designed with steeper slope than the rest of the canal, thereby enabling the transport of the course material entering at the head. The sediment extractor or ejector should not be too closed also to the head regulator either in that case; the high intensity of turbulence immediately downstream of the head regulator may keep course material which should not be normally removed by the ejector, in suspension.

A. Settling basin

Settling basin is provided to reduce undesirable sediment particles in water from entering the head race tunnel or channel. The main principal is to provide a section wide and long enough so that the resulting reduced flow velocity will allow the sediment to settle out. Such reduction in the velocity also reduces the bed shear stress and the turbulence. Decrement or reduction in velocity, shear stress, and the turbulence, if adequate, stop the bed material from moving and also causes part of the suspended material to deposit. The flow into the basin is regulated by gates at intake. The sediment which will be settled is flushed out of the basin through the flushing conduit/tunnel back into the river

Settling basin is one of the most effective devices for the removal of sediments particles from flowing water. Much no of settling basin have been designed in U.S.A and they are working satisfactory. When the size of sediment to be removed has been decided, the design of settling basin involves determination of the depth and length of the basin and after that choice of the method of removal of the deposited material.

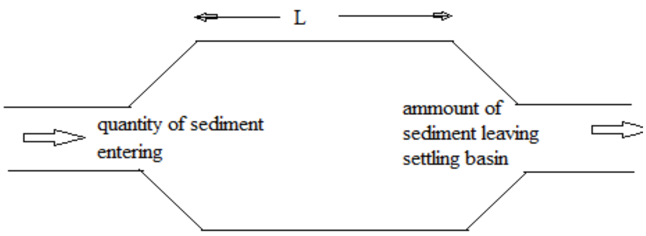

Fig 2.1: Layout of settling basin

The amount of sediment load deposited in a settling basin is expressed in terms of the removal efficiency of the basin, which is defined as follows

$$\eta = \frac{q_{si} - q_{se}}{qsi}$$

$$\eta = 1 - \frac{q_{se}}{q_{si}}$$

United States Bureau of Reclamation (USBR) gives the following simple equation for removal efficiency η

$$\eta = 1 - \frac{q_{se}}{q_{si}} = 1 - \exp\left(-\frac{\omega_0 L}{UD}\right)$$

Summer studied the settling of a sediment particle in an open channel assuming logarithmic velocity distribution and the diffusion coefficient ϵ_s to be given by

$$\frac{\epsilon_s}{u_* D} = 6\frac{y}{D}\left(1 - \frac{y}{D}\right)$$

And

$$\eta = 1 - e^{-\left(\frac{k\lambda}{6}\right)\left(\frac{Lu_*}{UD}\right)}$$

The measured value of removal efficiency were considerable different from those given by Camp USBR and Summer. They analyzed the data to express the efficiency of the settling basin , η (expressed in %)

$$\eta = \eta_0\left(1 - e^{-\frac{CL}{D}}\right)$$

Where η_0 and C are function of ω_0/u_*. Here u_* is the shear velocity in the settling basin and ω_0 the fall velocity of the sediment particles in clear water.

The value of η_0 and C for different values of ω_0/u_* as obtained by them are given in graph and table

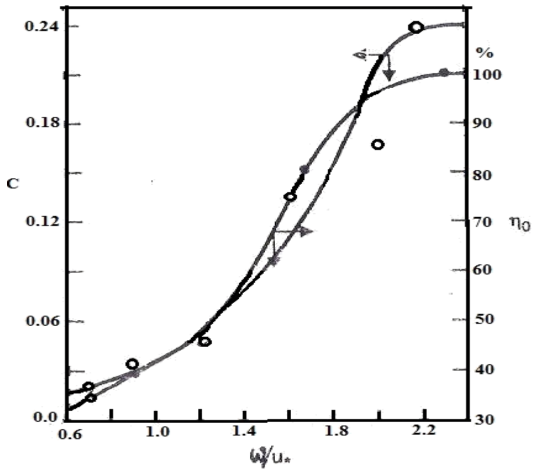

Fig. 2.2: Garde's curve Variation of η_0 and C with ω_0/u

ω_0/u_*	0.60	0.70	0.90	1.20	1.60	2.0	>2.2
C	0.015	0.02	0.030	0.060	0.140	0.215	0.240
η_0	32	34	40	50	70	97	100

Table 1: Variation of η_0 and C with ω_0/u

Ranga Raju found that the following equation yields better results than above efficiency equation, and recommended it for use when $\omega_0/u_* < 2.5$

$$\eta = 11.7\left(\frac{\omega_0}{U}\right)^{0.81}\left(\frac{LB}{B_C D_C}\right)^{0.23}\left(\frac{D^{\frac{1}{6}}}{n\sqrt{g}}\right)^{0.98} \quad \ldots\ldots\ldots\ldots(3)$$

Here D_c is the depth of flow in the approach channel of width B_c, B is the width of the basin

1) Dongre (2002)

Dongre performed laboratory experiments on the efficiency of settling basin and he also checked the accuracy of the available relation for efficiency. Finding that none of the available relations was satisfactory over a wide range of variables, he derived the following relationship for efficiency based on analysis of all the available data

$$\eta = 102.5\left(1 - \exp\left(-0.3\frac{A_b}{A_a}\right)\right)\left(1 - \exp\left(-0.1\frac{L}{h}\right)\right)\left(1 - \exp\left(-0.42\frac{\omega_0}{u_*}\right)\right)$$

This equation is applicable for settling basin without flushing.

2) Classification of settling basin

No.	Basic of classification	Types
1.	Mode of construction	Natural Artificial
2.	Mode of operation	intermittent continuous
3.	Method of cleaning	manual mechanical hydraulic
4.	Type of flow	open channel closed channel
5.	Configuration/ layout	single unit multiple unit

B. Vortex tube sand trap

To develop sediment ejectors based on the development of vortex tube, considerable amount of research has been conducted at Fort Collins (U.S.A) and Wallingford (U.K.). The vortex tube sand trap is an open tube placed across the canal bottom either normal to the flow or at some angle such as 300 or 450 to the flow.

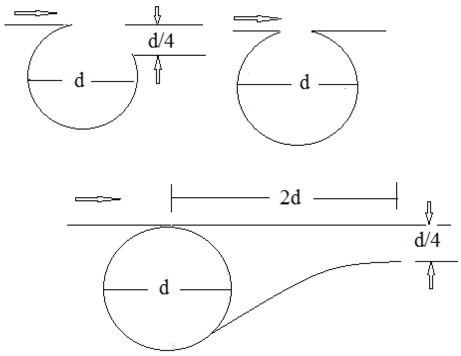

Fig. 2.3: Various type of the vortex tube sand traps tested by Parshall

The rate of outflow at the downstream end of the vortex tube is controlled by the gate. Koonsman and Albertson have found that the maximum efficiency is attained when both the lips of the tube at the same level and the Froude number over the tube is unity. It has been recommended by Brown and Robinson that the diameter of vortex tube should be equal to the depth of flow at Froude number of 0.80.

Froude number $(NF) = \frac{V}{\sqrt{gd}}$

Where $d = \frac{a}{t}$

If the incoming sediment load is high or vortex tube is too long, the vortex tube may get clogged and thus stop function. The solution of it by dividing the vortex tube length-wise into section, each one discharging independently through a separate pipe at the end of which a gate is provided. Froude number of the order of .80 is recommended at the location of the vortex tube can be attained either by contracting the channel or by providing a hump. In unlined channel Froude number is usually about 0.20 - 0.30

C. *Tunnel Extractor*

Coarse material can also be removed by tunnel extractor or ejectors. This type of extractor has been used on the Salampur feeder in Punjab shown in figure below.

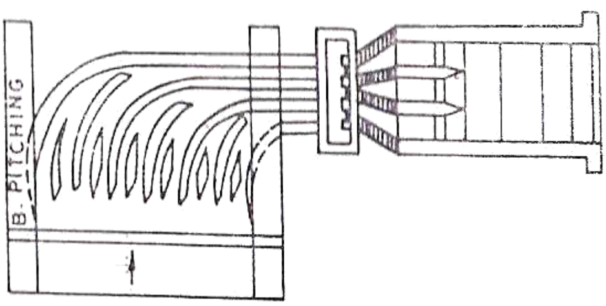

Fig. 2.4: Tunnel extractor on Salampur feeder (India)

It consist a horizontal slab a little above the canal bed which separates the sediment laden bottom layer into an escape channel. In each tunnel there are sub-tunnels which are formed by constructing curved vanes. The downstream end of the tunnels is located in the bank from which the escape channel takes off, the tunnel usually converge at the downstream end.

The tunnel height at the mouth is generally ¼ to 1/5 of the depth of water. The tunnel roof extend beyond the mouth for a length of about 0.60 m. at the downstream each tunnel is provided with a gate for the regulation of the discharge.it has observed that minimum head of 0.75 is required for successful operation of the ejector. In the tunnel the velocity is kept at about 3 m/s. 20% to 25% of the canal discharge is needed for the operation of the ejectors.

The width of the tunnel should be the least for the shortest tunnel and should increase gradually to the largest value for the longest tunnel to give the same discharge through each of them under available head. The size can be obtained by using a friction equation like the Darey-Weisbach equation. Vital and Rao have given a method of measuring the height of diaphragm wall. The theoretical efficiency of the ejector may be calculated by assuming that all of the incoming sediment below the diaphragm will be ejected. This efficiency will be larger than the actual efficiency (the actual efficiency being defined as the difference in sediment concentration of incoming and outgoing flows divided by the sediment concentration of incoming flow) because of the disturbance caused by the tunnel themselves, which may force some sediment to higher elevation, thereby bringing down the efficiency of ejection

D. *Vortex settling basin*

A relatively recent method of sediment ejection is the vortex settling basin. The vortex settling basin (VSB), is a continuous device which applies a certain fraction of flow for flushing the sediment particles out of the diverted stream (Gard and Ranga raju, 2000). Classical settling basins generally suffer from two main disadvantages:

– Requirement of large dimensions of basin compared with other types,
– Longer settling time for sediment particles.

Sediment extractors of vortex type would overcome the mentioned disadvantages (Keshavarzi and Gheisi, 2006). Vortex settling basin utilizes centrifugal forces to generate a vortex motion around its central axis to remove sediment particles from the incoming flow by means of secondary currents in the chamber through the central flushing orifice (Ziaei, 2000). In this device the high velocity flow is introduced tangentially into cylindrical basin having an orifice at the center of its bottom. This gives rise to the combined vortex conditions (Rankine type) having a forced vortex near the orifice and a free vortex at the outer region towards the periphery of the basin. As a result, sediment concentration gradient builds up across the vortex and a diffusive flux, proportional but opposite to the centrifugal flux, is induced (Athar et al., 2002). Resulting secondary flow causes the flow layers adjacent to the floor of the basin moving towards the central outlet orifice. Therefore, the sediment particles reaching the center of the chamber could be flushed out continuously through the orifice and a relatively sediment free water would leave the basin through its overflow weir crest (Mashuri, 1986)

Recent method of sediment removal is the vortex settling basin investigated by Salakhov, Cecen and Bayazit, Ogihara and Sakaguchi, Mashauri Paul et al and Zhou et al. the flow enter tangentially in the vortex settling basin along the periphery of a circular basin and leaves neatly tangentially as overflow over a weir on a part of the circumference. Through the pipe located at the center of the bottom of the circular basin, the settles sediment is removed. Due to the bottom of basin slopes towards the center, it helps in collection of sediment near the center. The combination of redial flow and vortex type flow towards the center caused by outflow through the outlet produces spiral flow which greatly increases the effective length of the basin and assists settling. Sediment particles travel along the spiral path; it is forced towards the center by the centripetal force acting on it. As a result, a larger percentage of sediment load collects on the bottom of the circular basin and near the outlet where it is continuously flushed out. If the sediment in canal is course and its distribution in the vertical is very nonuniform, it is desired to provide a horizontal diaphragm near the bed at an elevation of one third the flow depth and divert the lower flow into the basin, the flow in the upper layers remaining in the canal. However if the sediment is relatively fine, the total channel flow passes the vortex settling basin.

Wallingford (U.K), Paul et al have the following design criteria for vortex settling basin on the basis of a review of earlier studies and the experimental work conducted at Irrigation and Power Research Institute, Punjab and Hydraulic Research Station

- Diameter of circular basin D_b should be about 5 to 8 times the bottom width of the channel B
- The bottom of the basin should slope towards the center at a slope of less than 1 to 10
- The inlet channel should be tangential to the basin, the exit channel should also be tangential as far as possible
- The diameter D_F of the flushing pipe should be such that D_b/D_F lies between 25 and 40
- For removing material coarser than 0.50mm in diameter, only the lower one third of the flow be diverted into the basin. However, if finer material is also to be removed, the whole flow must pass through the basin.
- The basin depth at the periphery should be 0.20 D, where the D is the depth of flow in the channel
- The depth of flow over the outlet should be such that no vortex forms over it

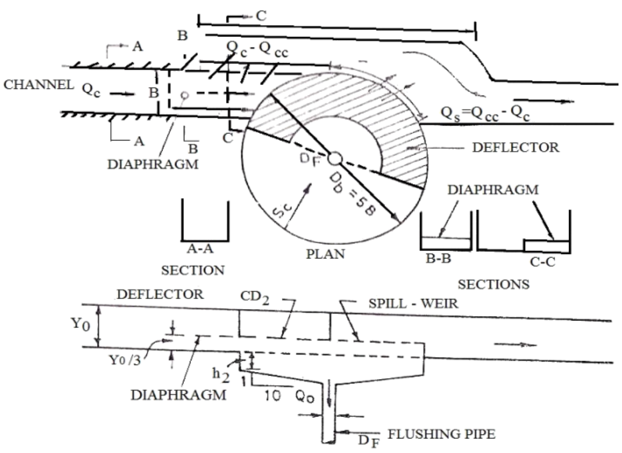

Fig. 2.5: Vortex settling basin

The advantages of vortex settling basin are its high sediment removal efficiency, low water requirement, lower construction and maintenance cost and relatively small size.

Investigator	Relationship
Cun et al (1979)	$\eta_0 = 1.74 + ln\left[\frac{d_0^{0.11}(\gamma_s/\gamma_f)^{0.88}}{Q^{0.58}}\right]$
Mashauri (1986)	$\eta_0 = 0.835 - \frac{0.0292}{k_1} + 1.71 \times 10^{-2} \times \frac{d}{d_0} - 5.93 \times 10^{-4}\frac{d}{d_0 k_1}$
Paul et al (1991)	$\eta_0 = 73.4 + 8\log\left(\frac{\omega_0}{W}\right)$
	$\eta_0 = 2.16\left(\frac{\omega_0}{V_{T0}}\right)^{0.04}\left(\frac{Q_o}{Q_i}\right)^{1.27}$
	$\eta_0 = 9 + .92\, log\left(\frac{\omega_0}{W}\right)$
	$\eta_0 = 97.8\left(\frac{\omega_0}{V_{to}}\right)^{0.0045}\left(\frac{Q_o}{Q_i}\right)^{0.01}$
Athar et al	$\eta_0 = k_0\left(\frac{Q_o}{Q_i}\right)^{0.25}\left(\frac{Z_h}{h_p}\right)^{0.35}\left(\frac{\omega_0 d_s}{\upsilon}\right)^{0.15}\left(\frac{Q_w^2}{gR^3 h_p^2}\right)^{0}$

Table 2: Previously published relationships

III. CONCLUSION

The main objective or purpose of this review paper is to give an overview in the development of desilting basin. Classification of desilting basin, development and the challenges of desilting devices and detailed literature review have been presented. The vortex chamber mainly contains a cylindrical hopper, a bottom cone and a tangential inlet. This type of sediment extractor has overcome the disadvantages of conventional settling basins, i.e. the requirement of large dimensions and long residence time. The size of a vortex settling chamber is small, as compared with conventional settling basins treating the same volume of water and sediment. It is concluded that efficiency of vortex chamber is better than simple settling basin for same discharge.

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