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Feasibility of Sluicing Operations for Run-Of-River Schemes in Himalayan Region

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Abstract: *Sedimentation in reservoirs, which eventually leads to detrimental loss of storage capacity, is one of the most serious problems in dam engineering. In this paper, problems faced by Run-of-River schemes in the Himalayan region due to sedimentation are highlighted. Three general strategies for addressing reservoir sedimentation currently utilized are: reduction of incoming sediments, minimization of sediment deposition, and removal of sediments from the reservoir. This paper addresses the feasibility of reservoir sluicing for abating the sediment deposition near the power intake and simultaneously maintaining the minimum water level required for power generation in Run-of-River schemes. A brief overview of the factors governing the efficiency of sluicing operations, studied till date has been presented in this paper. In addition to this, the procedures and results obtained by physical model tests on sluicing operations carried out till now have also been illustrated. The various physical parameters affecting the geometry of the scour cone formed during the sluicing has been dimensionally analysed and the subsequent dimensionless π terms are enlisted.*

Keywords: *hydropower, power intake, Run-of-River scheme, sluicing, scour cone, sedimentation management.*

I. Introduction

One of the major issues with dam construction is reservoir sedimentation. For most of the rivers, the inflow and outflow pattern of the sediments is approximately balanced. This balance is dramatically altered due to the construction of the dams as it leads to an increase in the flow depth and drastically decreases the flow velocity causing the sediments and heavier sand particles to settle. This settling of particles causes an impounding action in the river. This impounded reach will in turn cause accumulation of sediments and will result in a loss of storage capacity until a balance is again achieved which would normally occur after the impoundment becomes completely filled up with sediments, no longer facilitating water storage and other benefits. This can be a problem as the reservoir cannot function as originally thought. Reservoir conservation and sediment management is an effective approach to maintain existing storage capacity, thus minimizing the need to construct new dams. A plethora of sediments accumulate over the years, resulting in an ephemeral life span of the reservoir. Sediment related problems keep increasing in severity and more and more sites get affected. In order to achieve long term sustainable use of the dam or reservoir, it becomes necessary to manage the above cited problem of sediment accumulation.

The working and efficiency of the hydraulic machineries and turbines is greatly reduced as the sediments enter and obstruct power intakes, greatly accelerating abrasion of the turbine blades which in turn causes an increase in the maintenance cost. The above discussed phenomenon and the related problems mostly prevail in the Run-of-River schemes as the rivers here are characterized by a large rate of sediment deposition. To tackle this problem of sediments, several new techniques have been emerged in the recent years. This paper emphasizes on feasibility of sluicing operations in order to achieve maximum removal of sediments.

1.1 Hydropower Scenario in India

At the time of independence, the installed power generation capacity of India was 1362 MW with the share of 532 MW of hydropower. Presently the installed power generation capacity has grown to 210937 MW of which the hydro is 39324 MW (18.6%). Hydroelectricity is one of the cheapest and preferred sources of electricity. Out of the total hydro potential of India, 78% lies in Himalayan region. The main river systems are: Sindhu (19988 MW), Ganga (10715 MW) and Brahmaputra (34920 MW) [1]. The North- East region alone accounts for 31,857 MW which constitutes 38% of India’s total hydro potential. Thus, a vast untapped hydro potential exists in the Himalayan region and North- East region. Since relatively simple and geotechnical sound sites for hydro development in the country have almost been exhausted, the sites for future development lies in Himalayan and Sub- Himalayan regions where most of the untapped hydro-potential awaits utilization.

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1.2 Run of River Schemes

The Himalayan terrain is characterized by high mountains, deep narrow valleys, and complex geological strata with occasional problems of stability of hill slopes and has high levels of seismicity. These rivers carry enormous silt loads especially during monsoon months. This gives rise to flash floods and huge amounts of sediment load which would ultimately settle in the reservoir to reduce its capacity.

In Run-of-River system, running water is diverted from a river and guided down a channel, or a penstock, which leads to a generating house. Here the force of moving water spins the turbine, which then drives a generator. Used water is fed back into the main river further downstream. A dam usually smaller than one used for traditional hydro, is required to ensure there is enough water to enter the water conductor system that leads to the turbines situated at lower elevation. Installation of such project is comparatively cheap and has very little environment impact. Run-of-River schemes rely on coursing rivers to generate electricity, as opposed to store water. Most schemes use a dam or a weir to ensure enough water enters the penstock. In short it is advantageous to adopt these ROR schemes in areas where:-

1. Mountainous streams with steep gradients and in catchment areas which are highly erodible.
2. Capacity / inflow ratio i.e. big reservoirs to hold 100 years accumulation of sediments is not practicable and economical.
3. Emptying of reservoirs is feasible for generating faster velocity throughout the fetch.

Hence the need for adopting Run-of-River schemes especially in the Himalayan regions is the best possible option to generate hydroelectricity as compared to the construction of large storage reservoirs. The fig.1 given below gives us an idea about the ROR scheme.

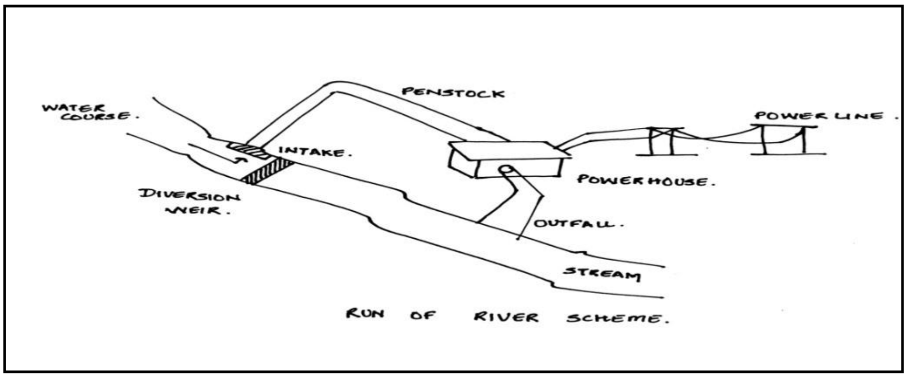


Fig.1: This image represents Run-of-River scheme wherein water is drawn from the main stream through the intakes and the water is further carried to the power house generation via the penstock.

1.3 Layout of Power Intakes

The layout of power intakes with respect to spillway is very important. In the Himalayan region, the power houses are planned at about 10-30 km away to gain the head .The power intakes are located along the reservoir banks in the vicinity of low level orifice spill way and are kept higher than the spill way crest so that the silt deposition near the intake is cleared during the drawdown flushing through the low level spillway gates. In earlier period, the difference between the power intake and spillway crest used to be 2-3 m, which was later increased to 10-15 m due to successful flushing experience in the prototype [2].The fig.2 given below shows the layout of the power intake and spillway in the plan.

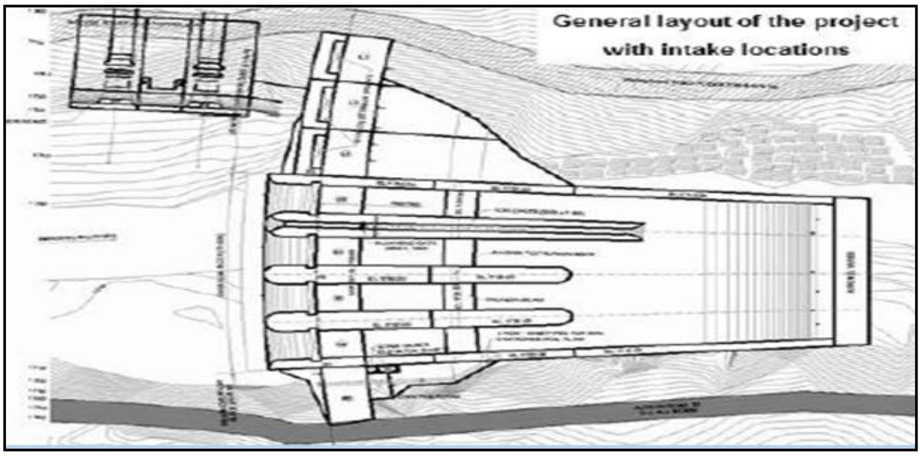


Fig.2: The figure shows the plan of general layout of power intake and the spillway. [2]

1.4 Sediment Problems in ROR Schemes

Run-of-River schemes involve the construction of a diversion structure like a weir or a barrage of relatively small height and are used when the water demand is less than the minimum available river flow. It is generally believed that such schemes cause fewer disturbances to river regime than those that involve the construction of high dams and large capacity reservoirs. The river on which these ROR schemes are constructed, are steep and pass through geologically fragile areas through narrow gorges. Thus the construction of a diversion structure results in the reduction of the flow velocity and most of the sediments get deposited at the bottom. The Central Water Commission of India (CWC) carried out siltation studies on certain reservoirs in India and they found out that 23 reservoirs had already lost 23.11% of live storage by 2006. Due to such a high rate of sedimentation, we are losing about 1.95 billion cubic metre capacity annually. One such example is the Matatila reservoir which has lost about 38% of its gross capacity between 1956 and 1998-1999. The dead storage up to the original Minimum Draw down Level (MDDL) of 295.66m is completely filled with silt. Total capacity loss by 1999 = 430.47 MCM (million cubic metres) [3]. Generally sediments coarser than 0.2 mm in size is harmful for turbine blades and abrasion of the runner and other turbine parts may be serious, resulting in reduced efficiency and lifespan of the turbine thus have to be eliminated from power channels. While exclusive volume is provided for storage of sediment in a storage project, ROR schemes provide no scope for storage of sediment and the difference between the bed level and the level of the intakes is very less in the reservoirs . This is depicted in the fig.3 given below.

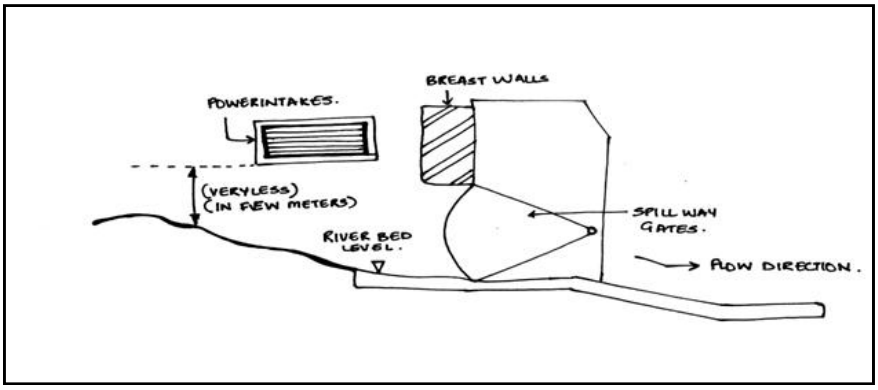


Fig.3: This image indicates the cross section of dam showing breast wall and spillway gates. Here it is clearly visible that the level difference between the river bed and the bottom of power intake is very less generally in few meters for the Run-of-River schemes. This difference gets filled up by sediments thereby hampering the function of turbines as the sediments begin to enter into the intakes.

Hence in ROR projects, either sediment load entering the reservoir has to be minimized through upstream measures in catchment or the entered sediments have to be efficiently flushed / by-passed downstream of dam.

1.5 General Deposition Pattern of the Sediments in a Reservoir

When a stream enters an impounded reach, the flow velocity decreases and the sediment load begins to deposit. The balance between the inflow and outflow pattern of sediments is dramatically altered due to the construction of the dams as they increase the flow depth and drastically decrease the flow velocity causing the sediments and heavier particles to settle. The deposition patterns will vary from one reservoir to another depending on the pool geometry, discharge and grain size characteristics of the inflowing load and reservoir operation. The generalized depositional zones in a reservoir are shown in fig.4.

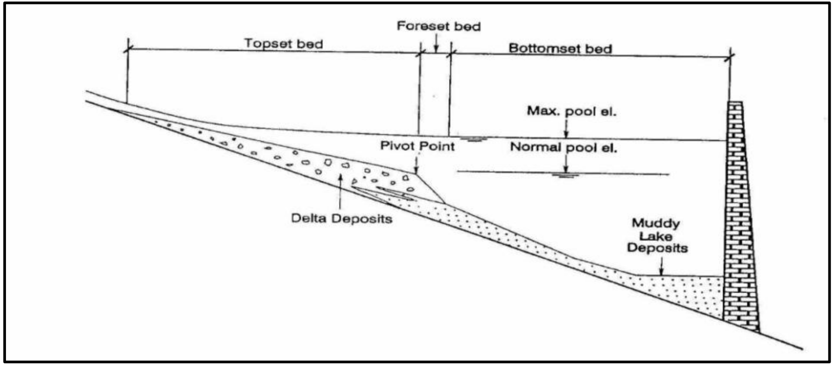


Fig.4: The figure shows the various levels of reservoir when a stream enters an impounded reach, the flow

velocity decreases and the sediment load begins to deposit. The generalized depositional zones and the delta formation in a reservoir can also be seen in the above figure.

1.6 Sediment management in ROR schemes

As we know that excess sedimentation leads to a plethora of problems, various methods and techniques need to be applied in order to mitigate these detrimental effects of sedimentation. The main management methods associated with minimizing sediment deposition are construction of sediment bypass structures, sediment pass through (sluicing) and venting of sediment laden density current.

Sediment bypass structures do not interfere with regular reservoir operations, however this method is difficult to apply and cannot be utilized in arid climates where the need for water is high. Sluicing depends upon the existing structure of the dam and requires careful monitoring. Density current venting is only effective under certain circumstances and is thus seldom used due to its reliance on its existence and surveying of a density current. Drawdown flushing has been found to work optimally on narrow, gorge shaped reservoirs where water can be fully drawn down. Dredging, the most commonly used sediment management technique, is a highly expensive and time consuming practice, although efficacious when complimented by other methods, particularly for settling basins at the inlet of the reservoir. Also due to drawdown flushing there is immense damage caused on the downstream side of the reservoir, thus now days it is not permitted to be carried out by the government.

Hence considering all the limitations and advantages of the above mentioned methods the most effective method to control the problem of sedimentation is sluicing which is a new technology and is greatly effective for the rivers in the Himalayan region where there is a great problem related to collection of sediments on the upstream side of the reservoirs. During the sluicing process, sufficient amount of water is available on the upstream side of the reservoir and hence continuous generation of hydroelectricity can be done without stoppage. The water pressure exerted on the downstream side are considerably less hence causes subsequent less damage and destruction on the downstream side of the reservoirs. Thus sluicing has become a very important technique and needs to be adopted effectively to overcome the problem of sedimentation.

II. Sluicing Of Reservoirs

Sluicing is a way of abating sediment deposition in the reservoirs. In this method, the reservoir level is drawn down during the flood season and water is allowed to flow through the sluice gates to maintain the incoming sediment in suspension [4]. When particles enter the low velocity area of the reservoir, they settle and form a delta consisting first of the heavier coarse sediments, then further on a more shallow layer of fine sediment is formed. This phenomenon can be seen in the figure below. A depiction of the sluicing technique to reduce the development of this delta is shown in the fig.5.

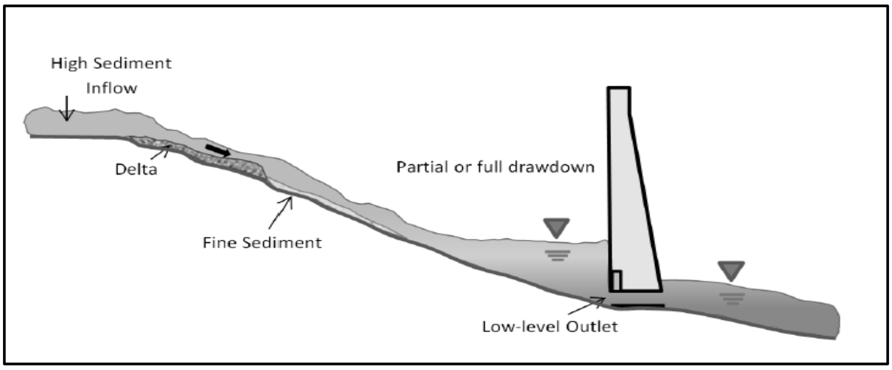


Fig.5: Longitudinal reservoir profile with sediment sluicing is depicted in the above figure. When the low-level outlet gate is opened, the sediments on the upstream side of the reservoir pass through it and the water level drops down simultaneously. This in turn reduces the delta formed on the upstream side.

2.1 Feasibility of Sluicing Operations

For the sluicing operation to be carried out effectively, certain surrounding conditions as well as the design parameters of the reservoir play an important role. A 1988 assessment of several countries on sluicing techniques have recommended that the sluice gates to be provided at a height of 1.5 to 2.5 meters [5].They also advised that only the width of the gate should be changed to increase the effectiveness. Several researchers have reported that sediment sluicing, especially practiced by drawdown flushing, can be very successful [6].Xia and Han (1980) have reported that from 11 to 71 % of the original storage capacity can be restored depending on the shape of the reservoir. Wide reservoirs with extensive floodplain deposits are not as amenable to sluicing as narrow, gorge-like reservoirs.

In addition, Bogardi [7] suggested that the sluicing technique is most effective when:

i. Water depths are low and discharge is high.
ii. Sluice gates are wide and located near the bottom of the dam.
iii. The original stream bed is steep and the reservoir has a short, straight bottom.
iv. The reservoir is in an advanced stage of siltation and the deposits consist of fine grained, recently settled material.

With these specifications met, sluicing has been found effective in many instances especially in China, where it is practiced routinely due to high sediment loads [8].

2.2 Requirements of Hydropower Plants in Himalayan region

The general requirement for the hydropower projects in Himalayan region for its continuous functioning and production of hydroelectricity are:

i. Continuous supply of water is required for generation of electricity, which would have not been available if flushing was to be carried out for the purpose of removing the sediments.
ii. Inflow of sediments should be equal to outflow i.e. equilibrium condition should be maintained. The level of sediment deposited should not affect the intake of reservoir.
iii. The water level should not go below MDDL i.e. maximum drawdown level which is the minimum head required for harnessing the hydropower.
iv. The sediments discharged should cause minimum disturbance on the downstream side.

All these requirements can be fulfilled by the process of sluicing and hence needs to be studied in detail.

2.3 Scour Cone

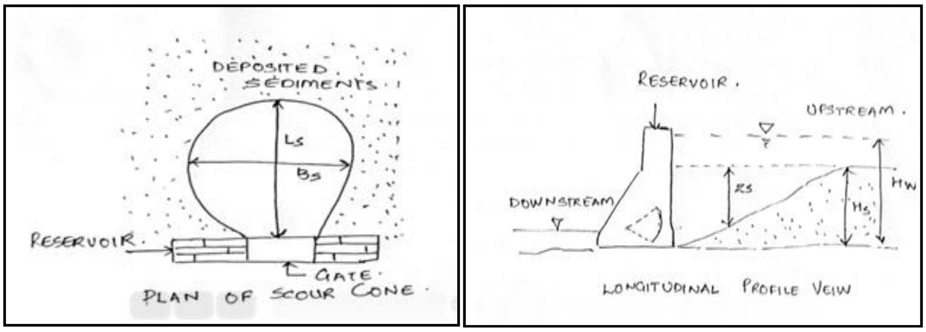
With the help of sluicing, a large amount of sediments will be consequently released into the downstream along with the passage of water from the sluice gates leading to the formation of a scour cone just behind the dam wall in the upstream region. In an attempt to attain the equilibrium condition, clear water will get released through the bottom intake and a funnel shaped crater will be developed with an angle of repose of the sediment. Once this cone has been formed and there are no sediments moving into this cone, the water flowing through the opening will be clear, and the formation of the cone will be fairly stable and no sediments will be removed from the cone afterwards. White and Bettess studied how far releases affect the sediment deposits. They provided a diagram indicating the interrelationship between the limit distances of the scour (in static water), reservoir depth and outlet discharge. Their results thus indicated that by decreasing the water level in the reservoir, the rate of developing of scouring cone increases towards upstream for a given discharge.

The scour cone geometry will be fairly influenced by factors including hydraulic conditions in front of the bottom outlet; such as water depth, flow discharge, depth of deposited sediments, sediment properties such as size, specific weight and its kind (cohesive or non-cohesive), the geometry of outlet etc. Thus our basic aim will be to measure this scour cone geometry such as its length, width and depth at the end of each experiment with the help of a point gauge and then using this data to establish the inter-relationship between the various dimensionless parameters through which the optimum values of the governing parameters will be determined.

In general, the functions of the scouring cone are to reduce the sediment concentration around the entrance of the intake and to prevent the hydraulic structures from abrasion. Although the effect of the funnel scour is restricted to the zone close to the intake, it has a very important role in preventing the coarse sediments from entering into the power station. Not much studies have been carried out in formation of scour cone by sluicing till date which can reduce the sediment deposition on the upstream and sediment inflow at the intakes.

III. Dimensional Analysis

During sluicing operation, the following variables should be considered: Q_{out} – Discharge at outlet, Z_s – Depth of scour, L_s – Length of scour, B_s – Width of scour, D_s – Diameter of sediments, H_w – Height of water level, H_s – Height of deposited sediments, g – Acceleration due to gravity, ρ_s – Mass density of sediments and A_{out} – Area of outlet. Following fig.6 shows the schematic representation of various parameters of a scour cone used in dimensional analysis.



(I) (b)

Fig.6:- Plan and longitudinal view of the scour cone formed near a zone close to the intake just behind the sluice gate: (a) Plan view indicating length and width of the scour cone. (b) Longitudinal view of the scour cone depicting its width in the upstream region.

Using the “Buckingham” theory for dimensional analysis, function of variables is then presented as:

$f(H_{w}, Q_{out}, ϛ_{s}, Z_{s}, L_{s}, B_{s}, D_{s}, H_{s}, g, A_{out}) = 0$

Hence, Number of variables (n) = 10

Number of dimensions contained in variables (m) = 3

$\therefore$ Number of π terms = (n-m) = 7

Considering different combinations of repeating variables ($H_{w}, Q_{out}, ϛ_{s}, A_{out}, g$)

For repeating variables ($H_{w}, Q_{out}, ϛ_{s}$)

$$f_1\left(\frac{Zs}{Hw}, \frac{Ls}{Hw}, \frac{Bs}{Hw}, \frac{Ds}{Hw}, \frac{Hs}{Hw}, \frac{Aout}{Hw^2}, \frac{Hw^5 g}{Qout^2}\right) = 0$$

For repeating variables ($A_{out}, g, ϛ_{s}$)

$$f_2\left(\frac{Qout}{Aout^{1.25}\sqrt{g}}, \frac{Zs}{\sqrt{Aout}}, \frac{Ls}{\sqrt{Aout}}, \frac{Bs}{\sqrt{Aout}}, \frac{Ds}{\sqrt{Aout}}, \frac{Hw}{\sqrt{Aout}}, \frac{Hw}{\sqrt{Aout}}\right) = 0$$

For repeating variables ($A_{out}, Q_{out}, ϛ_{s}$)

$$f_3\left(\frac{Zs}{\sqrt{Aout}}, \frac{Ls}{\sqrt{Aout}}, \frac{Hs}{\sqrt{Aout}}, \frac{Bs}{\sqrt{Aout}}, \frac{Ds}{\sqrt{Aout}}, \frac{Hw}{\sqrt{Aout}}, \sqrt[5]{Aout}\, g\right) = 0$$

For repeating variables ($g, Q_{out}, ϛ_{s}$)

$$f_4\left(\frac{g^{0.2}\,Zs}{Qout^{0.4}}, \frac{g^{0.4}\,Aout}{Qout^{0.8}}, \frac{g^{0.2}\,Bs}{Qout^{0.8}}, \frac{g^{0.2}\,Ds}{Qout^{0.4}}, \frac{g^{0.2}\,Hw}{Qout^{0.4}}, \frac{g^{0.2}\,Hs}{Qout^{0.4}}, \frac{g^{0.2}\,Ls}{Qout^{0.4}}\right) = 0$$

These are the dimensionless parameters involved in the physical process of sluicing. In order to find out the exact functional relationship of scour cone geometry with the various parameters involved, experimental investigations needs to be carried out.

IV. Experimental Data Available On Reservoir Sluicing Till Date

A) Rollin Hull Hotchkiss from the ST. Anthony Falls Hydraulic Laboratory [8], University of Minnesota carried out an extensive experimental and numerical analysis on reservoir sedimentation and sediment sluicing. He simulated reservoir sedimentation and sediment sluicing in laboratory and numerical experiments wherein the experiments were conducted on a 12.2 meter long, 0.38 meter high, 15 centimeters wide flume. A sluice gate extending completely across the flume width was installed about 9 meters downstream from the entrance for the first set of experiments. Later this sluice gate was replaced with a simulated dam 1.5 meters into the expanding section. The dam was fitted with three sluice gates, each 0.15 meters wide. All gates were manually operated; each gate could be set separately. All experiments were performed with lightweight sediment consisting of crushed walnut shells with a mean diameter of 0.67millimeters. The purpose of the investigation described herein is to perform basic research on sediment sluicing as a method to restore or maintain reservoir storage capacity. Sediment sluicing is defined as the evacuation of sediment from a reservoir by passing water and sediment through sluice gates located at or near the bottom of a dam. With the help of this technique, scouring is limited to the local vicinity upstream of the sluice gate and hence the water levels must be lowered significantly upstream to move sediment to the sluice gate area.

Experiments were conducted in both the uniform width flume and the flume with the expanding channel upstream of the dam. The purposes of the experiments were:

1. To observe general characteristics of aggradation and degradation for different flow, sediment, and sluice gate settings.
2. To determine the characteristics of the depositional delta and its equilibrium position in relation to sluice gates of different openings.
3. To gather data on the time needed to achieve equilibrium in the flume once the sluice gate settings change.

4. To examine the properties of the bed slope in the laterally expanding reservoir like portion of the flume upstream from the dam.

Experimental Procedure

Several runs were made in the uniform width flume and the flume with an expanding channel upstream from the dam, A typical run consisted of the following steps:-

I. Select the desired water and sediment discharge rates.
II. Estimate the bed slope for uniform open channel flow.
III. Set the tail water control gate to produce near-uniform flow throughout the flume for open channel flow conditions.
IV. Set the desired sluice gate elevation if the sluice gate is to be used.

With the help of these experiments, hydraulic data, bed from data, velocity profile data, sediment sluicing data and sediment transport data was collected and entered in a tabular format which helped to formulate the required results specific to the uniform width flume and the expanding region. To conclude upon raising the sluice gate in the laboratory flume, the water level upstream immediately begins to drop. Sediment transport increases in the vicinity of sluice gate, and its soon increased throughout the flume as water surface drops in upstream direction.

B) Samad Emamgholizadeh, M. Bina, M. Fathi-Moghadam and M. Ghomeyshi [9] from the Water Sciences Engineering College, Ahwaz, Iran studied the process of development and the geometric characteristics of the funnel shaped scour cone caused by conducting pressurized flushing on a hydraulic rectangular flume. The flume was 7m long, 1.5m wide and 1.5m in height. When the bottom outlets were opened, the motion of the flow caused the subsequent movement of deposited sediments and after a few minutes a scour cone at the vicinity of the bottom outlet was formed. Experiments were conducted until an equilibrium condition was reached such that the sediment concentration was negligible at the end of the experiments. After the water inside the scouring cone was discharged, cross section profiles of the physical model were measured by a point gauge and the corresponding volume of the scour cone was calculated. This scour cone and its volume is influenced by various factors such as outflow discharge, water depth, type and diameter of the sediments etc. Furthur, dimensionless analysis of the above parameters governing the volume of the scour cone was carried out and a relationship between the scour cone and the above said parameters were studied.

However these studies were based on the process of pressurized flushing which is one of the most widely used sediment management techniques. Although pressurized flushing has many added disadvantages in certain type of reservoirs mainly reservoirs used for hydropower generation as it reduces the head required for the operation of the turbines below its minimum value. The technique of sluicing over comes this problem and results in the removal of the accumulated sediments without hampering the hydropower generation process of the reservoir.

IV. Conclusion

In Himalayan region due to sedimentation problem in ROR schemes, it is becoming difficult to harness power continuously. Also present methods available for sedimentation management, have not been found to be very effective in such situations. Further, flushing of reservoir is not desirable as water level in the reservoir drops below the power intake level, which hinders the power generation. Reservoir sluicing, by keeping the water level on the upstream side at a sufficiently high level to operate the hydro power has potential advantages over all the above said methods since it is not necessary to drain down the entire water and scour cone formed on the upstream side avoids the entry of sediments into the intakes . Also, the sediments in the form of live load remain in suspension and are carried downstream through the gate opening. Thus Reservoir Sluicing is feasible for ROR schemes in which, power generation is the primary goal and not storage, provided that the intake lies in the scour cone and bed level near intake drops well below the intake level.

Only preliminary experimental investigations have been done till now on the various physical parameters affecting scour cone geometry. it is the need of the hour to carry extensive experimentation to understand the sluicing in a better way and to develop mathematical relationships between various parameters.

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