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A Case Study of Sedimentation Management Plan of 243MW Warsak Power Station

Engr.Abdul Rahman Badshah[1], Engr.Nadeemullah[2]

[1,2] *Department of Civil Engineering, Iqra National University, Peshawar, Pakistan*

Abstract — *Warsak hydroelectric dam, located in North-West Pakistan, is subjected to massive sedimentation related problems which has not only resulted in complete silting up of its reservoir but also frequent wear and tear of its 06No power generating units. In this case study previous research work carried out by various agencies has thoroughly been scrutinized. The studies revealed that an average annual sediment transport through the turbines of the plant is 75Metric tons/year with silt contributing towards 50% of the total. In the absence of silt excluding infrastructure the only viable option left is to manage the reservoir operation to effectively cater for this problem. Previous studies results has deduced that no structural measures can do anything positive about the sediment transport problem, since they will always encroach on the reservoir and reduce the available flow section, increasing flow velocity and the sediment concentration. It has been found that the sediment transport capacity is exponential with most of the transport occurring in a small period of time. It is thus possible to avoid a large percentage of the sediment intake to the turbines and to reduce the rate of erosion of the turbines by stopping power generation during high flow conditions. If the powerhouse is shut down whenever the river flow goes over 80,000 cusecs, the sediment intake reduces to 04 Mtons (33% reduction in sediment intake), while the power production will go down to 1090 GWh per year (2% reduction in power production). During the stoppage period, the available flow can be used to flush the reservoir, taking care of keeping the downstream sediment concentration in acceptable values (8 to 16 g/L), and increasing settling capacity on the reservoir. Concerning the hopper system, with 90% efficiency in terms of bed load capture, they will reduce the intake of coarse sediment (coarse sand and pebbles) by 180,000 to 250,000 tons per year, depending on shutdown flow. These are large absolute values that justify the construction of the hopper system. A prefabricated trash cleaning system with much higher cleaning capacity with fixed rakes operating each of the six trash racks can solve the existing trash problems with greater efficiency.*

Keywords- *Hydroelectric dam; sedimentation; hopper system.*

1. INTRODUCTION

Warsak Hydroelectric Power Station is constructed across River Kabul near the city of Peshawar. The project consists of a concrete gravity dam and an adjacent Power complex and switchyard. The dam is 250ft high and 460ft long. The dam has 09 No radial spillway gates each having a total discharge capacity of 60,000 cusecs. The hydropower complex consists of 06No generating units having a total combined generating capacity of 243MW. In order to run all the generating units a discharge of 24000cusecs is required. The area of the reservoir is about 04 sq miles with designed storage capacity of 62,000 acre ft with dead storage contributing 36,700 acre ft while live storage contributing to 25,300 acre ft. The primary purpose the Warsak Dam was power generation and hence it provides a head of 144ft to contribute 243MW of clean and green energy to the national grid. In dam, no low level flushing tunnel or outlet has been provided and the water available below the level up to 1230ft is being considered as dead storage. According to the sediment management studies of Warsak Dam, sediment load at subject dam was estimated as 75M tons/year, on average, when flow exceeds 30,000 cusecs. The composition of sediment is estimated as 25% sand, 51% silt and 24% clay. The sediment load in the Kabul River is very high and to minimize silt and bed load transportation into the intake passage, a skimming wall with a crest at elevation of 1,240 ft was constructed at upstream of the intake. At present, the Warsak reservoir has no live storage. During a year, almost 70% of the energy is produced during the high-flow season. With a reservoir operation at elevation of 1,269 ft, it is estimated that about 50% of the suspended load passes through the turbines. The coarser-sized portion of the suspended load is deposited between the skimming wall and the trash racks, and then propagated in the intake and penstock, increasing head losses and substantially reducing power generation. In actual conditions, the effect of the skimming wall is also very limited to control sediments transport in suspension. The sediments have filled a large part of the reservoir and obstructed part of the existing power intakes. As a result, the existing Warsak plant operates as a run-of-the-river barrage, head loss has considerably increased and the turbines are exposed to a high degree of erosion. Sediment varies month to month and yearly but on average the sediment is 75 Metric tons/year.

Figure 1.1: Deposited sediments in Reservoir of Warsak Dam

Figure 1.2: Deposited Sediments in front of Power Intake

2. RSWI (CANADA) STUDY

The RSWI study considered that in the prevalent conditions at the power intake of the Warsak site, the sediments would inevitably pass over the existing skimming wall crest to be deposited behind the wall, on a downward slope directly facing the trash racks. The sediments are then conveyed from this area into the power intake and towards the powerhouse if they are not stopped by the trash racks. During power production, the sediments will flow towards the trash rack. Any particle smaller than size of 12.7 cm (5 inches) will eventually enter the power tunnel. The bed load is usually removed with a flushing system in typical run-of-river applications. No flushing system exists at Warsak and hence full-scale reservoir flushing is not an option. In general, for a run-of-the river scheme, the suspended load can be effectively removed from water at velocities within a range of 20~50 cm/s (on the basis of the particle size) by incorporating a de-sanding structure in the flow path. At the existing Warsak facility, desanders have not been implemented. Floating debris such as roots, trees, etc. are found in large numbers in the river and these often remain trapped in the trash racks. This also favors the deposition of sediments in the area between the skimming wall and the trash racks. It should be noted that initially there was no working trash rack cleaning machine on site. A log boom was previously installed near the intake area but was washed out by the river in 1981. It was also observed that about 75% of the trash rack area is blocked by debris and silt, producing high head losses. Based on site conditions the following options were considered:

i. Installation of a new trash rack cleaning machine to serve the existing trash racks.
ii. Implementation of new sediment flushing structures hoppers type to reduce sediment flow and deposition into the area located between the skimming wall and the trash racks.

3. FRANCIS FRUCHART REPORT

After a global analysis of possible solutions for the sedimentation problem this report proposes several "realistic" solutions against some difficult ones. The report proposes construction of a bottom outlet at the dam or use of the old derivation tunnel used during the dam construction. The proposed solutions are:

i. Recovery of a minimum storage capacity of the reservoir for decantation of sediments and to obtain gradient of concentration in the reservoir by flushing.
ii. Reactivation of the skimming wall – by dredging upstream of the wall
c. Construction of a flushing tunnel for sediments under the skimming wall
d. Long term: regular scheduled flushing to maintain the minimum storage capacity

Flow		Flow Velocity (ft/sec)	Sediment Concentration g/m³	Bed Load (%)	Total Sediment (kg/sec)	Bed Load (kg/sec)
Cusecs	Cumecs					
15000	426	1.9	1.8	23.4%	0.76	0.2
20000	567	2.5	14.0	15.4%	8.01	1.2
25000	709	2.9	36.1	12.1%	25.6	3.1
30000	851	3.3	67.8	10.1%	58.0	5.9
35000	993	3.6	107.1	8.9%	107.2	9.6
40000	1135	3.8	146.8	8.2%	166.4	13.6
45000	1277	4.1	234.1	7.2%	299.4	21.6
50000	1419	4.6	397.2	6.3%	565.1	35.5
60000	1702	5.5	901.4	5.1%	1526	78.3
70000	1986	6.4	1762	4.4%	3470	153
80000	2270	7.4	3305	3.9%	7557	294
90000	2554	8.3	5258	3.6%	13486	484
100000	2837	9.2	7900	3.4%	22477	757
110000	3121	10.1	11335	3.2%	35453	1136
120000	3405	11.1	15670	3.1%	53457	1647
130000	3688	12.0	21005	3.0%	77640	2318
140000	3972	12.9	27442	2.9%	109266	3181

Table 1: Sediment transport for different flow conditions

4. CONSIDERATIONS ON SEDIMENT TRANSPORT

It can be seen from the table above that the sediment transported by the river grows exponentially with the river flow. For a river flow equal to the power plant capacity (21,000 cusecs) the total sediment concentration is 15 g/m³, for a total sediment intake of about 1.4 kg per second per unit, of which 15% is bed load that can be retained by the hoppers. For a 60,000 cusecs flood, which occurs in 73% of the years, the sediment concentration is 60 times higher (900 g/m³) for a total of 75 kg/s of silt per unit. The average number of days per year with flow higher than 60,000 cusecs is 21. For an 80,000 cusecs flood, which occurs in 37% of the year, the sediment concentration is 200 times higher than for 21000 cusecs (3300 g/m³), for a total of 320 kg/s of silt per unit. The average number of days per year with flow higher than 80,000 cusecs is Finally, for a 100,000 cusecs flood, which occurs in 15% of the years, the sediment concentration is 530 times higher (3300 g/m³) for a total of 790 kg/s of silt per unit. The average number of days per year with flow higher than 100,000 cusecs is 0.6. It can then be seen that a large part of the sediment intake into the turbines occur during very high flow periods, which are quite infrequent. Stopping the turbines during these periods may reduce very significantly the sediment intake, increasing turbines life with a relatively modest impact in power production.

5. CONSIDERATIONS ON BED LOAD

While the bed load is only a small fraction of the total sediment load, it still represents an important absolute quantity of coarser sediment that has a very significant erosive capacity. For a river flow equal to the power plant capacity (24,000 cusecs) the bed load at the intake is about 0.2 kg/s per unit, which is 17 tons per day per unit. For a 60,000 cusecs flood, the bed load per unit is 3.8 kg/s, which is a total of 330 tons per unit and per day. For an 80,000 cusecs flood, the bed load per unit is 12.5 kg/s, which is a total of 1050 tons per unit and per day. For a 100,000 cusecs flood, the bed load per unit is 27 kg/s, that is, a total of 2300 tons per unit and per day. So, the collection of this coarser sediment upstream from the intake, by using a hopper system with independent flushing may prove promising in extending the life and the availability of the turbines.

6. CONSIDERATIONS ON FLUSHING OF THE RESERVOIR

During the high flow periods in which the power plant will eventually be shut down to reduce the erosive wear of the turbines, the high flow can be used to flush part of the sediment deposited in the reservoir. To be effective, that water must be flushed with a higher sediment content for which it is necessary to increase the flow velocity at the downstream end, by opening the spillway gates and lowering the reservoir level near the gates. Since the maximum spillway capacity under FSL is higher than even the largest floods, this will always be possible. For instance, for an inflow of 60,000 cusecs, the average flow velocity through the reservoir will be about 5.5 ft/s, with a sediment concentration of 900 g/m³, that is, a sediment inflow of 1,5 ton/s (table 7.1). If we increase the flow velocity in the downstream section of the reservoir to 9.2 ft/s (by lowering the reservoir level), the sediment concentration of the outflow will rise to about 8 kg/m³ (13,5 tons/s), still a reasonable value that will not cause too much problems downstream. Under these conditions, we will be flushing out of the reservoir a net sediment mass of 12 tons/s, which is more than a million tons per day. Assuming a sediment density of 1.65 tons/m³, about 600,000 m³ capacity will be freed in the reservoir per day. During the 21 days available on average each year, we could then liberate a capacity about 12,000,000 m³ (10,000 acre-ft), while keeping the downstream sediment concentration at reasonable levels. It will be possible to flush more than this volume by opening more the gates, lowering the reservoir level and increasing the flow velocity. For instance, by increasing the flow velocity to 11 ft/s, the outflow sediment concentration will double to 15.5 kg/m³, which could eventually be acceptable downstream. This corresponds to a net flush of 14 kg/m³, that is 2.1 Metric tons/day or 1.25 Mm³ per day (1000 acre-ft per day). These numbers mean two things: Flushing during the high flow periods can be effective in creating new capacity in the reservoir, which is important in terms of reducing the future intake of sediments by the powerhouse, since the sediment that will refill the new capacity will decrease the quantity of sediment that is available to pass through the turbines. Flushing can be very dangerous, if not done properly, since the spillway capacity is very large and an excessive opening of the gates can cause an excessive scouring and the discharge of too much sediment that could choke the downstream irrigation channels. Flushing shall only be done with the power plant operation being halted, otherwise a large part of the scoured sediment will pass through the turbines thereby rendering the effects of flushing the reservoir during this period as useless.

7. CONCLUSIONS

1. The Warsak sediment situation cannot be significantly changed, given the huge quantity of sediments that are transported by the river (about 24 metric tons per year). Any flushing of the reservoir will provide only temporary relief and requires the stoppage of the turbines, because during flushing, the sediment concentration will increase to very high values.
2. No structural measures can do anything positive about the sediment transport problem, since they will always encroach on the reservoir and reduce the available flow section, increasing flow velocity and the sediment concentration. Since structural measures cannot significantly solve the problem, operational changes must be adopted. It has been found that the sediment transport capacity is exponential, most of the transport occurring in a small period of time. It will then be possible to avoid a large percentage of the sediment intake to the turbines and so reduce the rate of erosion of the turbines by stopping production during high flow conditions, with a relatively small loss of power production.
3. If the powerhouse is shut down whenever the river flow goes over 80,000 cusecs, the sediment intake reduces to 4 Metric tons (33% reduction in sediment intake), while the power production will go down to 1090 GWh per year (2% reduction in power production). During the stoppage period, the available flow can be used to flush the reservoir, taking care of keeping the downstream sediment concentration in acceptable values (8 to 16 g/L), and increasing settling capacity on the reservoir.
4. Concerning the hopper system, with 90% efficiency in terms of bed load capture, they will reduce the intake of coarse sediment (coarse sand and pebbles) by 180,000 to 250,000 tons per year, depending on shutdown flow. These are large absolute values that justify the construction of the hopper system.
5. A prefabricated trash cleaning system with much higher cleaning capacity with fixed rakes operating each of the six trash racks could solve all of the existing trash problems.

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