The flushing of the sediments near the power intakes in the Dez Reservoir

S. Emamgholizadeh[1,2], H. Samaadi Borojeni[2,3] & M. Bina[1]
[1]*Shahid Chamran University, Iran*
[2]*The Khuzestan Water and Power Authority (KWPA), Iran*
[3]*Sharekord University, Iran*

Abstract

The Dez Dam was constructed in 1963 on the Dez River with the purpose of power generation, irrigation, water supply and flood control. It is a double curvature concrete arch dam with a height of 203 meters and initial storage capacity of 3315MCM. In this operational period, a sedimentation rate of 15 to 20 MCM/year had caused the sediment level behind the dam to raise up to 12 m below the power intakes (with a rate of 2 m/year) and the delta front has progressed 0.5 to 1 km/year towards the dam. Currently, the major issue which threatens the Dez Dam is the continual accumulation of silt in the reservoir near the dam. This situation has potential impact on the physical operations at the dam, including power generation and reservoir operation in general. Thus it is vital that the sediment level near the power intakes be decreased. Current research has shown that by using cone flushing via three outlets which are located at el. 222.7 m within the central blocks of the dam body (129 m below the full supply level of the reservoir), we can remove nearly 0.3 MCM and draw down the height of the sediments near the power intake about 13 to 15 m. In addition a bathymetry of the scour cone after a complete pressure flushing shows that the submerged slope of the reposed sediments is variable from 45% to 6%.
Keywords: reservoir, sedimentation, flushing, Dez Dam.

1 Introduction

During the past few decades dams and reservoirs have been built with increased frequency, and even more are under considering or construction. Without dams, the eroded soil is transported by river flows to the sea. However, when dams are built, the still water in the reservoirs allows the transported sediment to deposit. This can be a problem as the reservoir cannot function as originally thought, due to its filling up with sediments. There are around 40000 large reservoirs worldwide used for water supply, power generation, flood control, etc. Unfortunately most of them deal with the problems of sedimentation as the worldwide average annual rate of storage loss due to reservoir sedimentation is on the order of 0.5 to 1% of total storage capacity. This amounts to having to replace approximately 300 large dams on an annual basis worldwide, at an estimated cost of $9 billion just to replace existing storage capacity (not counting the cost to deal with environmental and social issues [1]. In some developing countries, where watershed management measures are not carried out effectively, reservoir storage is being lost at a much larger rate. This amount in the Asian nations is generally higher than the world average [7]. Reservoir conservation and sediment management in reservoirs is an effective approach to maintaining existing storage capacity, thus minimizing the need to construct as many new dams. It is also advisable to design new dams in a manner that will facilitate sediment management and long-term reservoir conservation.

1.1 Sediment management techniques

Existing sediment management techniques that have been successfully applied to conserve reservoir storage space are as follows:

- Catchment's Management,
- Flushing,
- Sediment Routing / Bypassing
- Mechanical Removal

Although the reduction of sediment yield via a watershed management program is the best option for reducing the rate of reservoir sedimentation, flushing may be one of the most economic methods which offer recovering lost storage without incurring the expenditure of dredging or other mechanical means of removing sediment. Hydraulic flushing is one of the many methods available to deal with sedimentation problems in reservoirs. It is used for the scouring out of deposited sediments from reservoirs through the use of low level outlets in a dam by lowering water levels (free flushing) or without lowering water levels (Pressure flushing), and thus increasing the flow velocities in the reservoir. A detailed presentation of procedures and features of empty (or free-flow) flushing, and pressure (or drawdown) flushing techniques, is found in Morris and Fan [5].

The studies of HR Wallingford on 50 reservoirs which are being, or have been flushed, show that in some cases the flushing was successful, and in others there was little or no success. Also studies show that successful flushing depends on some characteristics such as the catchment area, the storage capacity of the reservoir, the shape of the reservoir basin, the deployment of full or partial draw down, the low-level outlet facilities provided and downstream impacts.
However this technique is not widely practiced because

- It is usually only effective in narrow reservoirs.
- It involves large volumes of water being passed through the dam.
- It requires the reservoir to be emptied.

However it has been proved that flushing can be highly effective at some sites. For example the Baira reservoir in India, Gebidem reservoir in Switzerland, Gmund reservoir in Austria, Hengshan reservoir in China, Honglingjin reservoir in China, Mangahao reservoir in New Zealand, Naodehai reservoir in China, Palagneda reservoir in Switzerland, Santo Domingo reservoir in Venezuela [3], and Sefid Roud reservoir in Iran.

2 The study area

Iran is a huge country with a total land surface area of 1648195 km^2 and a population of about 70×10^6 inhabitants. The weather condition is dry and semi dry with an annual average rainfall of 250mm. Its surface is traversed by many rivers. The Karun and Dez are the biggest rivers in Iran. The catchment's area of the Dez is 23250 km^2 which is nearly 1 percent of the land area of Iran. Its sediment yield is 614 ton/km^2 and it is one of the prolific sediment yielding rivers in Iran. The intense rains, lack of plant cover and the high slopes in the basin are the main natural causes for the high soil erosion in the region. Traveling in the region it is possible to see several eroded areas, presenting soils completely unprotected and slopes slippers along the catchment especial in the Sezar sub basin. The Dez River is the main river in the Dez catchment and it flows through the Zagros and Bakhtiari Mountains prior to entering the Khuzestan Plain. The Dez River itself is composed of two branches upstream of the Dez Dam, called the Bakhtiari and the Sezar rivers. These rivers respectively contribute 55% and 45% of the watershed's resources. Talezang hydrometric station is located on the Dez River (15 km upstream of Dez Reservoir) and its upstream catchment area is 16130 Km^2. The average water discharge of the Dez River at the Talezang hydrometric station is 270 m^3/s.

2.1 The Dez Dam

The Dez Dam was constructed in 1963 upon the Dez River and it is located approximately 25 km north of the city of Dezful and 22 km from the city of Andimeshk in the Khuzestan Province (fig. 1). It is one of the most important dams in Iran because it has a very important role in power generation (520MW) and frequency control of the national power network, the provision of water (125 thousand hectares of irrigated lands) and flood control. It is provided with three low-level outlets, within the dam body, having a centerline at el 222.7, which is 129.3 m below the reservoir full supply level of el 352m. The original purpose of the low-level outlets was to provide irrigation releases downstream during periods of low flow through the turbines. In addition, these outlets were to provide a means of emergency release from the reservoir if required. It is not certain whether the valves were originally designed to discharge sediment but they have been used for this purpose, at various times, since 1994. Twin powers intakes are provided with inverts set at el 270 m. Fig. 2 show the arrangement of the Outlets.

Figure 1: Dez Reservoir. Figure 2: The arrangement of the Outlets.

2.2 Dez Reservoir sedimentation

Sediment deposition process within the Dez Reservoir has progressed through at least three phases:

- Valley deposition during construction.
- Early reservoir filling, start of the delta.
- Present situation since about 1983, delta deposition, lake deposition and turbidity current.

The early deposition consisted of the filling of valleys upstream from the cofferdam and this process carried on until reservoir impounding was initiated. After several years of impounding, the delta began to develop and the slow settling of fine sediments continued within the lake portion of the reservoir. The present day process involves the ongoing delta growth and the lake settling plus a turbidity current occurring occasionally during wet season storms. The original design estimate for sediment accumulation in the Dez reservoir was for a 50 year volume of 840 million cubic meters, i.e., equivalent to the filling of the dead storage within the reservoir to el 290 m. This estimate was made on the basis of there being upstream sediment retention structures and a reforestation program. However, these programs were not carried out. Nevertheless out of an initial reservoir volume of $3{,}315.6 \times 10^6$ m^3 (at elevation 350 m), the available storage in 2002/2003 was found to be $2{,}698.5 \times 10^6$ m^3 (it was determined from reservoir surveys and contour maps) which corresponded to a volume loss of about 19%. Much of the sediment drops out along the upper reaches to form a delta, which is slowly progressing to the dam, as shown in fig. 3. As previously mentioned the Talezang hydrometric station is located on the Dez River upstream the Dez Reservoir. Fig. 4 shows the sediment entering the Dez Reservoir at Talezang Station. The turbidity current which is a high density flow, laden with a high concentration of suspended sediment, flows beneath a body of lower density, clear water. The turbidity current can transport a substantial part of the suspended load from the delta to the Dez dam where it is then deflected upstream at the dam, eventually settling as a lake deposit. Field measurements of the turbidity current in the Dez Reservoir that commenced in December, 2002 and finished in June 2003, carried out by Water Research Center of Iran, showed that, 11-15% of the annual sediment inflow into the Dez reservoir is in the form of a turbidity current which travels through the lower reservoir downstream of the delta, reaches the dam and deposits there, thus causing the level of sediment surface near the dam to raise at a rate of 2 m/year, as a result the reservoir bed at the face of the power intakes has risen significantly from an original elevation of 160 m to 258 m in 2004, which is only 12 m below the invert level of the power intake at elevation 270m as shown in Fig. 3. Also the delta front has progressed 0.5 to 1 km/year toward the dam (fig. 5). The size distribution and density of the material deposited within the Dez Reservoir was determined using gravity cores of the material. It showed that the median particle of all samples taken from near the dam to the delta region was less than 0.01 mm and it is composed of 60% silt and 40% clay. Fig.6 shows the sediment distribution of the sediments which was taken 100m upstream of the Dam. Also the bulk density of the sediments ranged from 640 to 1800 kg/m^3 from near the dam to the delta deposited region. The Dez reservoir plant is comprised of eight 65 MW units with vertical Francis turbines. The maximum operating head for the turbine, given on the nameplate, is 180 m. Each turbine has a butterfly-type turbine inlet valve. The priority for KWPA is the managing of the reservoir sedimentation process with the objective of protecting the units from damaging sediment-laden flows. Therefore sediment management in the Dez reservoir is essential and of great importance.

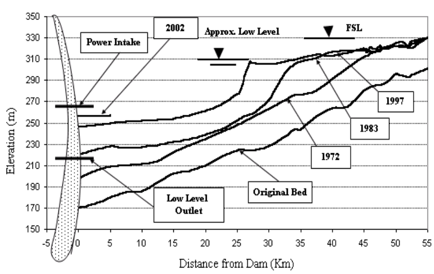

Figure 3: Progressive deposition in Dez Reservoir.

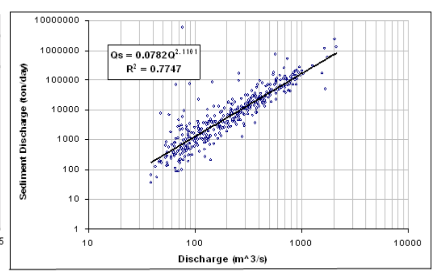

Figure 4: Discharge and sediment discharge relationship in Talezang station.

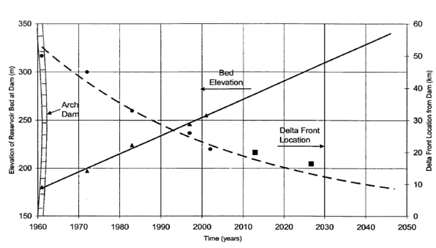

Figure 5: The situation of the bed elevation and delta front of the sediment at the different years.

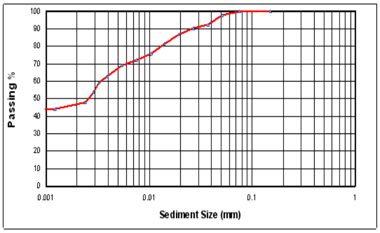

Figure 6: The sediment distribution of sediment (100m upstream of Dez Dam).

3 A history of the flushing carried out in the Dez Dam

The increasing of erosion and thus the increasing of sedimentation in the Dez Reservoir has caused the sediment level near the power intakes to increase significantly. According to the Hydrography carried out in 1982 the sediment level was 220m which was only 2.7m below the centerline of irrigation outlets, but the Hydrography in 1994 showed that the sediment level was 242.7m which is 20m above to the centerline of irrigation outlets. This shows that there has been an increase in sediment and thus risk of sediment entering the power intakes. In 1994 it was decided to use of irrigation outlets as sluiceway for release of accumulate sediments for the first time (fig.7). The opening of irrigation outlets in 1994 caused the sediment elevation to drop down to 3m below the centerline of the irrigation outlets. In this year due to the long duration of the flood, the irrigation outlets were opened 65 days for flood releasing and also discharging of the sediment. After this date and solely for the purpose of the discharge of accumulated sediment, the irrigation outlets were used seven times from 1994 to 2005. The water elevation of the reservoir and also the discharges of the irrigation outlets, spillway and turbines when they were in operation in purpose of flushing have been given in table 1.

Figure 7: The irrigation outlets after the opening.

Flushing was carried out for the second time in February 1995, and the irrigation outlets were opened 4 days. In this period the reservoir level was below quite low, therefore the emergency spillways were not in operation. On the other hand the amount of discharge which was released through the turbines was 180m^3/s, and this amount of discharge could not dilute the sediment discharged from the irrigation outlets, therefore the aquatic life of river downstream the dam was endangered and serious environmental damage occurred.

For carrying out the flushing for the third time in April 1995, the first and second irrigation outlets were opened respectively. Unfortunately the conduit of the second outlet becomes obstructed with tree trunk. Therefore in order to eliminate the problem in the second irrigation outlets, the first irrigation outlet was closed after 4 days of operation. Nearly after 2 weeks the tree trunk was released from the outlet. After it the irrigation outlets were opened for 4 days.

In April 1996, for the 5th time the irrigation outlets were used for carrying out flushing operation. In this year a big flood occurred and the outlets were opened 16 days. The minimum discharge of the spillways was 496.6m^3/s. The mean discharge of turbines and spillway were more than 2100 m^3/s, therefore it caused the discharge of the outlets to be diluted; subsequently hence there was no environmental damage downstream.

In 2000, for the 6th time the irrigation outlets were opened for carrying out flushing, but after one day one of the outlets was obstructed by a big stone. To eliminate the problem the valve was closed and after one week it exited the outlet. Subsequently the outlets were opened.

Also for the 7th time for carrying out flushing the irrigation outlets were opened in 2001, the duration of this flushing was 30 hours. Finally the most recent flushing was in June 2003.

Table 1: The water elevation of the reservoir and the discharges of the irrigation outlets, spillways and turbines.

No	Start of Flushing	End of Flushing	Duration (day)	Discharge of Outlets (m^3/s)			Discharge of Turbines (m^3/s)			Discharge of Spillway (m^3/s)			Water Elevation of Reservoir (m)		
				Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
1	1Nov. 1994	7 Feb 1994	65	10	117	147	165	249	302	0	280	2637	335	337.9	348.2
2	25 Feb 1995	28 Feb 1995	4	19	36	42	130	181	241	0	0	0	305	305.2	305.6
3	4 May 1997	7 May 1997	4	2.1	21	51	273	348	424	0	40	121	351	351.3	351.8
4	22 May 1997	24 May 1997	4	17	35	51	272	279	305	0	5	19.6	352	352.2	352.2
5	30 March 1998	14 April 1998	16	24	94	148	90.5	189	261	497	1125	1806	339	342.6	347
6	1 March 2000	13 March 2000	6	16	48	99	92	174	219	0	125	159	341	341.2	342.1
7	17 June 2003	18 June 2003	2	25	63.4	101	114	181	313	276	517	518	352	351.8	351.8

4 The amount of flushed sediments from the reservoir

With the purpose of releasing accumulated sediments in Dez Reservoir, the irrigation outlets were used seven times until now, but unfortunately the sediment concentration from the outlets were not measured in certain time interval except in 2000. In 2000 the measurement of concentration was carried out completely and perfectly as possible at one hour interval period.

The variation of water discharge and sediment concentration during the flushing of 2000 has been showed in fig.8 and fig.9. In this flushing the maximum outflow sediment concentration was measured as being about 1000gr/lit which was nearly equal to the sediment specific weight. Approximately after 56 hours from the start of the flushing, the outflow discharge from the outlets has been cleared. After 36 hours the outflow sediment concentration was reduced drastically to 2gr/l. Accordingly to the measured of sediment concentration during the flushing, 0.9 MCM of sediment were removed and disposed from the reservoir.

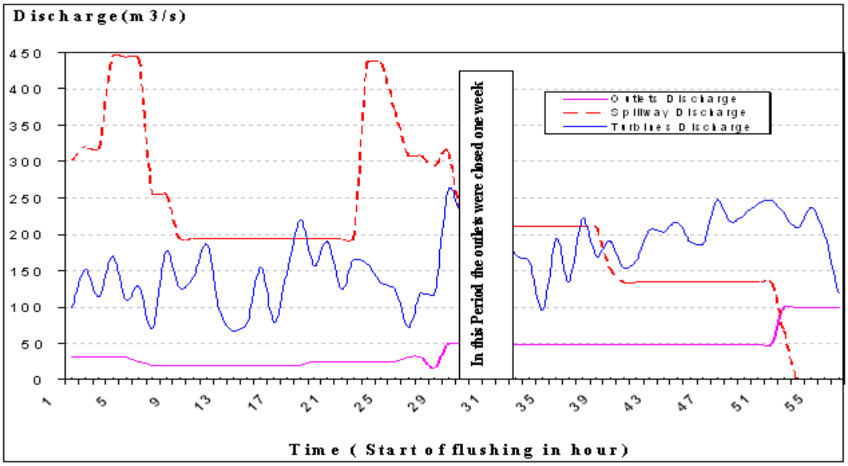

Figure 8: The variation of water discharge during the flushing in 2000.

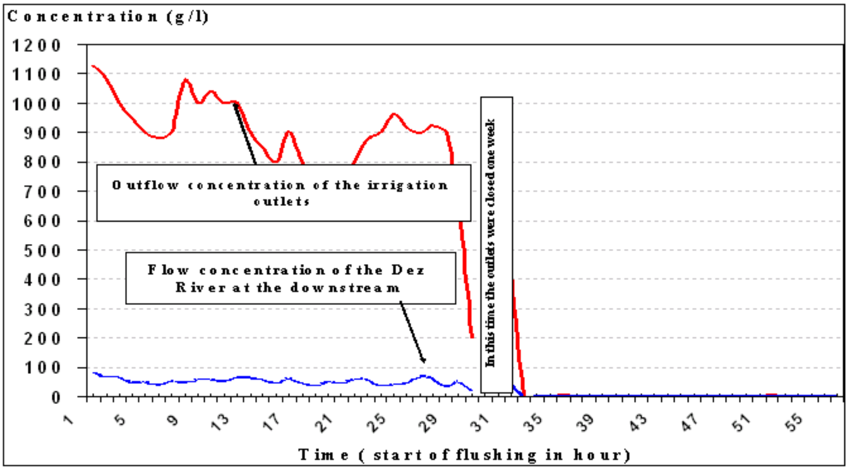

Figure 9: The variation of sediment concentration during the flushing in 2000.

As mentioned in June 2003 sediments had already accumulated at the face of the dam up to elevation 256 m, which was over 30 m above the centerline of the irrigation outlets. Therefore cone flushing was performed on June 17, 2003. The hydrography after flushing showed approximately 300,000 m^3 of sediment flushed from the reservoir. After the flushing, cone was completely filled by the turbidity current of April 23/24, 2003 (fig. 10). Also the effect radius of cone flushing was nearly 100m. The longitudinal bed profile of the centerline of the reservoir after carrying of the flushing in 2003 has been given in fig. 11.

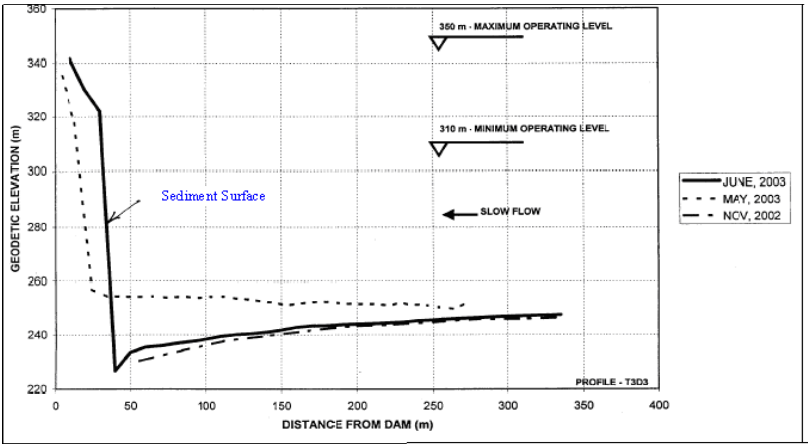

Figure 10: Sediment surface before and after the flushing on June and May 2003 upstream from Dez Dam.

5 Scour cone geometry

In generally, the scour cone geometry which can be typically developed in the reservoirs after a pressure flushing, influenced by factors including submerged angle of repose of the sediment, inflow and outflow of water and sediment, outlet geometry, characteristic of the sediments, etc. Angle of repose in reservoir scour cone in the direction extending upstream from the dam along the longitudinal axis is an important parameter. As mentioned previous sediments had already accumulated at the face of the dam up to elevation 256 m in June 2003, which was over 30 m above the centerline of the irrigation outlets. Therefore cone flushing was performed on June 17, 2003 via the irrigation outlets. After about 4 hour of flushing operation, the outflow discharge from the outlet has been cleared and a scour cone (wedge) was developed through the sediment of deposits just upstream of the dam. After complication of the flushing, WRC performed a bathymetric survey in the area of the scour. In this study the bathymetric map is used to assess the scour cone geometry. Based on the results the longitudinal profile of the cone can be divided into three parts as shown in figure 11. First part is from face of dam to 10 m upstream which has a slope of repose of the sediment as about 45%. Second part is located from 10 m to 100 m of upstream which has a slope of repose of the sediment as about 12%. The third part is located upstream of the second part and has a slope of repose of the sediment less than 6%. Also the effect radius of cone flushing was nearly 400m and the volume of the scour cone which is equal volume of the sediment discharged during flushing operation, was calculated about 300000 m^3.

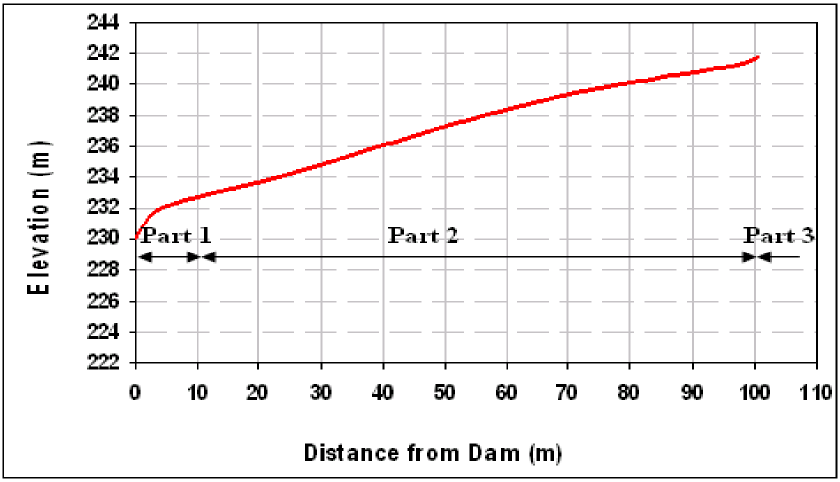

Figure 11: The longitudinal bed profile of the reservoir centerline after carrying of the flushing in 2003.

Acknowledgments

The writers of this article would like to express their deepest appreciation to the Khuzestan Water and Power Authority (KWPA), The Research Department of Dam and Power and especially Dr. F.Izadjoo.

References

[1] Annandale, G.W., April 2001, Reservoir Conservation and sediment management (invited speaker) World Bank, Washington D.C.
[2] Dez Dam rehabilitation project, Task 1, 2004, Reservoir operation review and sediment study, ACRES and Dezab Consulting.
[3] E. Atkinson, 1996, The feasibility of flushing sediment from the reservoir, Report OD 137.
[4] H.Samadi_Borujeni, S. Emamgholizadeh, Sediment Flushing through the delta of the Dez Reservoir. *Int. Conf. and exhibition, Hydro 2004*, Portugal.
[5] Morris, G. l., Fan, J., Reservoir sedimentation handbook. McGraw-Hill co. New York, 1998.
[6] Jansson, M.B., Erlingsson, U., Measurement and quantification of a sedimentation budget for a reservoir with regular flushing: *Regulated Rivers-Research and Management*, v. 16, no. 3, p. 279-306.
[7] J. Liu et al, Reservoir sedimentation management in Asia. *5th int. conf. on Hydro- science and engineering*, ICHE, 2002.
[8] Rodney White W. 2000, HR Wallingford, UK, Flushing of Sediments from Reservoirs, ICOLD, World Register of Large Dams.