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Energy Dissipation Problems Downstream of Jinnah Barrage

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Abstract

Jinnah barrage is one of these barrages recommended by the Evaluation Consultants for rehabilitation and modernization works. Feasibility study for "Rehabilitation and Modernization of the Jinnah Barrage" noted that the hydraulic jump do not form over the glacis rather sweeps on the floor. The un-dissipated energy is causing damage to the impact blocks, the adjacent concrete floor and downstream loose stone apron. Feasibility consultants suggested curative measures, such as the construction of subsidiary weir at a distance of about 800ft downstream of the barrage and river training works upstream of the barrage. The finalization of rehabilitation works (either subsidiary weir or its alternative) is in progress and subsequently the detail design of the selected alternative will be carried out. The main focus in this study is to review previous studies/investigations, energy dissipation mechanism, river survey, sounding and probing data to establish the extent of damages and precisely the root cause for the damages.

Keywords: Jinnah barrage; rehabilitation and modernization; subsidiary weir

1. Introduction

Statistics and studies made by International Commission on Large Dams (ICOLD) show that more than 20% of dam accidents occurred due to poor provision of energy dissipation arrangements [1]. Typical damages are; abnormal displacement of the flexible stone apron, failure of structures like retaining walls and floor slab of stilling basins, etc. In case of barrages, local scouring and excessive retrogression are the main reasons for failure/damage to downstream protection works.

The concept of stilling pool was conceived and rational design procedures were developed after a long process of evolution. The energy dissipation mechanism for a hydraulic structure can be designed by understanding the flow pattern and using rational design procedures. Ingram [2] and Moore [3] noted that three types of jumps are formed at a drop; they are 'B' jump, 'A' jump, and a 'W' Jump and developed mathematical equations for these jumps. Moore [3] verified experimentally the proposed equations over a fairly wide range of drops. Rand [4] in his studies forced to develop hydraulic jump below a drop and a sluice and defined forced jump by 'K' factor.

Extensive studies on energy dissipation mechanism were made by Bradley [5]. Guidelines for the design of low Froude number stilling basins are given by Peterka [6] and noted that a model study of the stilling basin (Basin IV) is imperative. Furthermore, Peterka [6] recommended that the tail water depth should be 10% greater than the conjugate depth. Based on additional model tests, the U.S. Bureau of Reclamation (USBR) developed a modified stilling basin for low Froude number approach flows Gorge [7]. The modified basin is relatively short and is provided with chute blocks, baffle piers and dentated end sill.

2. Barrage Details

Jinnah barrage is situated 3 miles (4.8 km) downstream of Kalabagh town, 126 miles (203 km) and 16 miles (25.7 km) downstream of Tarbela and proposed Kalabagh dams, respectively. Thal canal with remolded capacity of 10000 cusec (283.2 cumec) off-takes from left side of the barrage and irrigates 2.2 million acres of agricultural land in Southern Punjab. Jinnah barrage hydropower project is under construction on right side of the barrage and will provide about 120 MW of electricity to the National Grid.

Jinnah barrage consisted of 42 weir bays; two under-sluices each consisting of 7 bays with clear span of 60 ft (18.3 m). Two fish ladders and a navigation bay have also been provided in the barrage. Barrage width between the abutments is 3781ft (1152.4 m), whereas

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the clear waterways for the weir and undersluices sections are 2520 ft (768.1 m) and 420 ft (128 m), respectively.

Pond level is being maintained with the help of sluice gates provided in all bays of the barrage and canal head regulator. Normal pond level is at EL692 which will get raised to EL694 to meet 10000 cusec (283.2 cumec) of remodeled capacity of Thal canal. Jinnah barrage is designed for a flood of 950000 cusec (26725.6 cumec); however, a flood of 1100000 cusec (30945.8 cumec) can be passed as the barrage guide banks have enough freeboard. In the Year 1992, a supper flood of 842000 cusec (23687.6 cumec) has already been passed through the barrage.

3. Problems Downstream of Jinnah Barrage

Various studies/investigations have been carried to assess structural health of the Jinnah barrage. Mahboob [8 & 9] and Evaluation report [10] reviewed the design of Jinnah barrage and found it acceptable. They emphasized that the energy dissipation downstream of the barrage remain within acceptable limits for various discharges. However some element of retrogression was noted in Evaluation report [10].

After the supper flood of September 1992, launching of loose stone apron d/s of the barrage was noted in the Year 1993. Damage to first two rows of impact blocks and adjacent concrete floor were detected in the Year 2001. This damage was repaired during Year 2002 and 2003. Appraisal report [11] and Feasibility report [12] highlighted that the jump is not forming on the glacis and un-dissipated energy is causing damage to inverted filters, impact blocks and loose stone apron.

Furthermore, they also emphasized that the retrogression downstream of the barrage has reached at alarming level.

Hashmi [1] studied the formation of hydraulic jump and energy dissipation mechanism and noted that "hydraulic jump is not forming properly but is repelled away from the glacis toe for most of the discharges except for very low flows". It is really important that a thorough study/investigation be carried out to identify hydraulic problems downstream of the barrage. For this purpose the following studies were carried out:

- Analysis of river survey downstream of the barrage.
- Analysis of sounding and probing data.
- Energy dissipation and hydraulic jump formation studies.

4. River Survey/Sounding and Probing Data Analysis

River survey for the Year 2007 was thoroughly reviewed and noted that immediately downstream of the barrage, deep scour pits have been developed and stone apron is abnormally displaced. During a field visit, it was noted that at weir section, the concrete block floor is exposed and a few blocks at the end are missing.

River sounding data for the Year 1990 to 1994 show that the super flood of Year 1992 aggravated the development of scour and consequently the stone apron became exposed and abnormally displaced (Figure 1). River sounding data to-date reveals that in the past the loose stone replenishment was not carried out considering its stability as per downstream pit conditions and water velocity.

5. Retrogression, Energy Dissipation and Hydraulic Jump Studies

5.1 Retrogression

Downstream of a barrage, some retrogression is always anticipated. Reasonable value for future retrogression should be incorporated while designing a barrage/weir. The excessive retrogression enhances downstream velocity, residual energy and damage the downstream protection works.

Water level variation, downstream of the Jinnah barrage for various discharges from the Year 1948 to 2007 was analyzed. The data is plotted in pre-Tarbela and post-Tarbela context. It was noted that the rate of drop of water level slowed down by the Year 1976 and got accelerated after the Year 1976, when the Tarbela dam started operating. However, for about last fifteen years, water levels became stable and no further retrogression occurred as depicted in Table 1 and Figure 2.

The damages occurred downstream of barrage are mainly of two types:

1) Damage to impact blocks and adjacent concrete floor.
2) Launching of flexible stone apron.

Damage to impact blocks and adjacent concrete floor occurred mainly in the weir section of the barrage, which can be explained by comparing flow characteristics at weir and undersluices sections of the barrage. At low flows the jump sweeps and develops

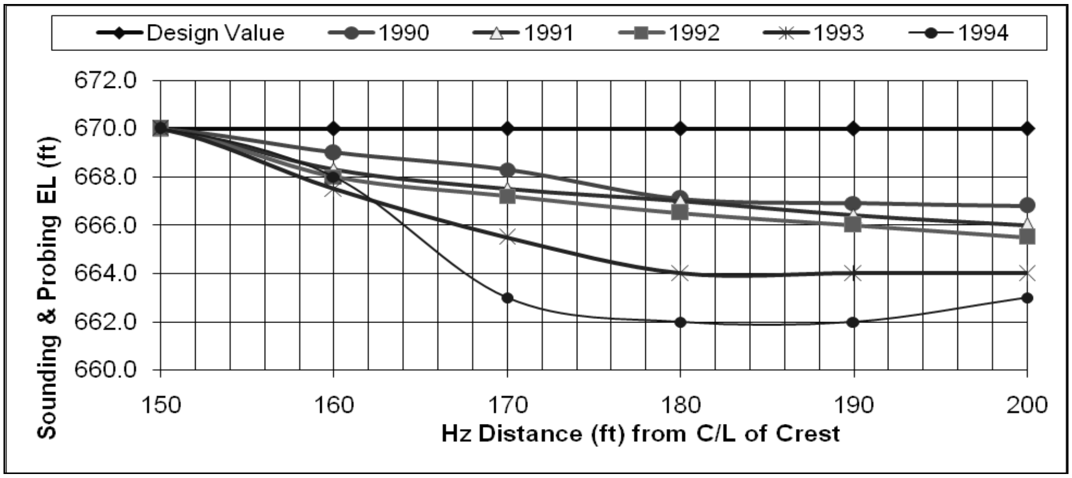

Figure 1: sounding data analysis d/s of the Barrage for BAY NO. 26

Table 1: Water level variation downstream of the Jinnah barrage.

Discharge (cusecs)	Designed (EL)	Observed 1948 (EL)	Observed 1976 (EL)	Observed 1992 (EL)	Observed 1998 (EL)	Observed 2002 (EL)	Observed 2005 (EL)
20000	674.75	676.50	677.10	674.00	673.35	672.55	672.50
50000	679.00	679.60	677.95	674.90	674.20	674.07	673.30
100000	682.25	682.05	681.1	675.90	675.18	675.05	675.00
200000	685.55	683.80	683.15	678.20	677.00	676.96	677.10
300000	687.55	685.48	685.30	680.35	679.11	679.85	680.20
`400000	688.80	687.58	685.20	681.10	681.40	682.40	682.25
500000	689.95	688.70	686.82	683.54	683.14	683.14	683.20
600000	690.85	------		------	------	------	------
700000	691.50	690.50	690.50	------	------	------	------
800000	692.15	------	------	688.20	------	------	------
900000	692.80	------	------	------	------	------	------
1000000	693.10	------	------	------	------	------	------

on the horizontal floor of the weir section. Impact blocks take the force of water directly and help to stabilize and terminate the jump over the paved floor (Figure 3 & 4). The striking water with high velocity causes abrasion/damage to the blocks and surrounding concrete floor. At undersluices the jump develops on the glacis and no damage has been reported to the impact blocks and concrete floor.

The impact blocks and adjacent concrete floor were repaired/replaced during Year 2002 and 2003, first time after the construction of the barrage. At present no appreciable damage to impact blocks concrete floor and is noted.

The displacement of loose stone apron occurs at higher velocity/residual energy. Evaluation Report [10] noted that the limiting velocity which initiates the displacement of loose stone at the Jinnah barrage is about 9ft/sec. The velocity downstream of the jump, both at weir and undersluices sections, for various discharges was computed and is given in Table 2. Velocity remained less than 9ft/sec for the discharge up to 400000 cusec but at higher discharges the velocity exceeds the limiting velocity. The velocity became 12.2 ft/sec (35.6% higher than limiting velocity) during the super flood of year 1992 (842000 cusec) at the weir section of the barrage and consequently the loose stone apron was displaced.

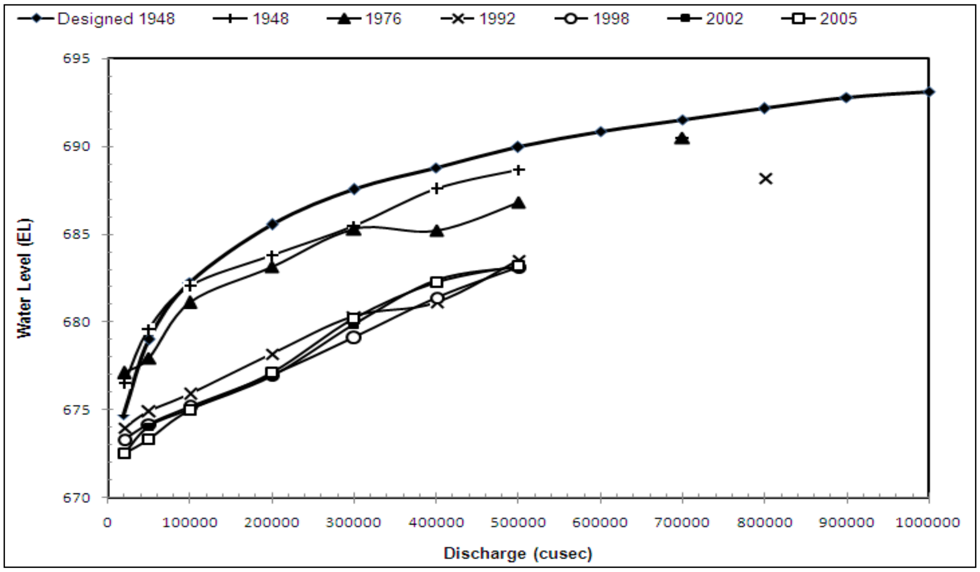

Figure 2: Water level variation downstream of the Jinnah barrage.

Table 2: Observed and projected velocities downstream of the Jinnah Barrage.

Discharge (cusec)	D/S Water Depth (ft)	Velocity (ft/sec)	
		at Weir Section	at undersluices Section
50000	3.30	4.00	2.09
100000	5.00	5.28	3.30
300000	10.20	8.14	6.92
500000	13.25	9.99	8.14
700000	15.50	11.91	9.98
842000	18.2	12.20	10.48
950000	20.21	12.40	10.80

Figure 3: Hydraulic Jump formations at weir and undersluices sections for the discharge of 240,000 Cusecs. (Noted on 15-06-2007)

Figure 4: Hydraulic jump formations at weir and undersluices sections for the discharge of 99,000 cusecs. (Noted on 07-11-2007)

5.2 Studies and Analysis of Energy Dissipation and Hydraulic Jump

Jinnah barrage energy dissipation mechanism can be approximated as USBR type IV stilling basin, in which instead of dentated sill, two rows of concrete blocks are provided. These blocks control water depth at low discharge as shown in Figure 5, dissipate some of the energy and allow passing of gravel and pebbles. This arrangement is quite efficient for the gated control low flows and is not very sensitive to downstream water depth [9].

Hydraulic jump develops over the glacis if downstream water depth becomes higher than the conjugate depth. Water surface profiles for such cases can be approximated as S_1. If downstream water depth becomes less than the conjugate depth, M_3 profile develops before the development of the hydraulic jump. Since length of M_3 profile is quite large which necessitate a long stilling basin. In such situations, special arrangements such as impact blocks/ friction blocks etc. are provided to terminate the jump over the paved floor. Hydraulic design of such additional arrangements in terms of their location, size and shape is finalized by physical model studies.

Performance of energy dissipation mechanism at the Jinnah barrage was further investigated by taking field observations at the barrage. On 15th June 2007 the discharge at the barrage was about 240,000 cusec (6795 cumec). At the weir section the jump swept, however impact and friction blocks helped in developing and terminating the jump over the paved floor (Figure 3). Energy dissipation in the jump

Figure 5: Hydraulic jump formations at the barrage for the discharge of 27,000 cusecs. (Noted on 24-12-2007)

Figure 6: Sand and shingle deposited upstream of the barrage. (Noted on26-01-2007)

was satisfactory as the velocity downstream of the jump remained less than 9 ft/sec (Table 1). At the undersluices sections the hydraulic jump was developed over the glacis and the energy dissipation was good (Figure 3 & Table 1). A second technical visit was conducted from 7th to 9th November, 2007. The discharge in the river was about 100000 cusec (2831 cumec). Hydraulic jump characteristics at undersluices and weir sections were almost similar as were observed for the discharge of 240000 cusec, Figure 4.

Third technical visit was conducted on 24th & 25th December 2007 and river flows were 27000 cusec (764.4 cumec) and 12,700 cusec (360 comec), respectively. At these discharges the friction blocks retain water and develop higher depths along with dissipation of some of the kinetic energy (Figure 5). Finally, another site visit was carried from 25th to 28th January, 2008. The gates at the undersluices were completely open and the flow was mainly through undersluices and silt excluder. The hydraulic jump was formed over the glacis of the undersluices.

On upstream, the right side creeks were active and there was no flow in left side creek. A parallel flow on upstream was noted from right to the left undersluices. Just upstream of left undersluices, a huge quantity of sand was deposited (Figure 6), indicating that the upstream end of left guidebank is not streamlined with the incoming flow. Shingle deposits were noted upstream of the weir bays 23, 24 and 25.

6. Conclusions

Jinnah barrage rehabilitation and modernization is a real challenge for the designers/researchers. On the basis of these studies/investigations and after reviewing previous reports/sounding and probing data, it is concluded that at higher discharges (greater than 500000 cusec), under the prevailing water level conditions, velocity downstream of the barrage becomes higher than the limiting values (9ft/sec) which initiate the displacement of loose stone apron. The downstream velocity became 12.2ft/sec (35.6% higher than the limiting velocity) during the super flood of Year 1992 (842000cusec) at weir section of the barrage which aggravated the displacement of loose stone apron. At present, immediately downstream of barrage, deep local scour persist and loose stone apron is abnormally displaced.

The jump sweeps at weir section of the barrage whereas the impact and friction blocks help to develop, stabilize and terminate the jump over the paved floor. Water continuously strikes the impact blocks, adjacent concrete floor and consequently erode/damage/de-shape them. Furthermore, the gravelly material traveled along with water also strikes the blocks and damage them. The impact blocks and adjacent concrete floor were repaired/replaced during 2002 and 2003, first time after the construction of the barrage. At present, the impact blocks and concrete floor are not damaged but the replenishment of loose apron stone is needed.

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