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REHABILITATED TAUNSA BARRAGE: PROSPECTS AND CONCERNS

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Abstract

A sub-weir was constructed at a distance of 900 feet downstream of Taunsa barrage in the year 2007 to manage the retrogression by raising the tail water level. The barrage showed poor performance during the flood 2010 which caused uncontrolled breach in its left marginal bund. The sub-weir raised water level; the question may arise regarding sedimentation between barrage and sub-weir at low flows and discharge capacity of the barrage. This study investigates the performance of energy dissipation system and discharging capacity of Taunsa barrage in pre- and post-construction scenarios of the sub-weir. The study also indicates that hydraulic functioning of the sub-weir is rather complex and energy dissipation system is not performing efficiently. Moreover the presence of a sub-weir downstream of Taunsa barrage is conceptually erroneous. It seems that the sedimentation between barrage and sub-weir at low flows was not considered before the construction of sub-weir. Field evidences show that functioning of the undersluices is also being compromised after the construction of sub-weir.

Keywords: Taunsa barrage, Undersluices, Sub-weir.

Introduction

Punjab Irrigation Department started a mega project for the rehabilitation and modernisation of its barrages and irrigation infrastructure with the foreign financial aid. Taunsa barrage was rehabilitated in the years 2005-07, with the expenses of above 11 billion rupees. During rehabilitation of Taunsa barrage, baffle and friction blocks of stilling basin were replaced by chute blocks and an end sill, respectively (Punjab Irrigation Department, 2004; Chaudhary, 2009a; Chaudhary, 2010); while 3 feet thick reinforced concrete floor was laid by replacing 2 feet top layer of existing concrete floor. Moreover at a distance of 900 feet from main weir, a sub-weir was constructed across the river (Punjab Irrigation Department, 2004; Chaudhary, 2009a). The upstream marginal bunds were also strengthened to pass the flood safely through the barrage.

The supper flood of year 2010 was safely passed through Jinnah and Chashma barrages but at Taunsa barrage it breached the left marginal bund. The unrelenting flood of more than 250,000 cusecs (7,079 cumecs) through this breached section drowned/destroyed the entire district of Muzaffargarh.

This raised serious questions regarding the existing discharging capacity and the rationality of rehabilitation works carried out at the Taunsa barrage. Supreme Judicial Flood Commission Report (2010) noted "as was the fact, with a critical but controversial change in design, the left marginal bund had been armored by stone pitching under multi-billion rupee project executed in the years 2005-06 and 2008-09, disregarding professional reservations about structural innovations thus enforced at the cost to public and the nation. Furthermore, the sub-weir had also reportedly contributed to raise the pressure on left marginal bund". Report (2010) also noted that discharging capacity of Taunsa barrage has been enhanced up to 1,100,000 cusecs (31,149 cumecs) after the expenses of more than 11 billion rupees but only 960,000 cusecs (27,184 cumecs) of water could pass through barrage (Flood Inquiry Commission, 2010).

Undersluices of the barrage help in removing the deposited silt from the undersluices pocket. At low discharge the flushed sediments may be settled down on upstream of sub-weir and build up an additional barrier to the flow. Situation may become more critical on drawing of 100,000 cusecs (2,832 cumecs) of water by the proposed Taunsa Hydropower Project.

It shows that the hydraulic performance of the undersluices/silt excluders is badly affected due to the sub-weir. There is every possibility that the hydraulic functioning and discharge capacity of the undersluices may have been compromised after the construction of sub-weir. Energy dissipation at

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Taunsa barrage is carried out through hydraulic jump formation. The auxiliary devices, such as, baffle bbcks and friction blocks, provided in the stilling basin help in dissipating kinetic energy and stabilising hydraulic jump even if tail water depth becomes less than the conjugate depth. Almost all the barrages in Pakistan and India are provided with such auxiliary devices (Chaudhary, 2009b).

This raised some serious questions concerning the controversial design modifications/innovations made at the Taunsa barrage. Whether the design modifications, innovations and the construction of sub-weir fall within the scope of rehabilitation and modernization of a barrage or not, the construction of sub-weir and the substitution of baffle and friction blocks with chute blocks and end sill required to be argued at a competitive level for better understanding and decision making in the future.

Barrage details

Taunsa barrage (Fig. 1 and Table 1) comprises 53 main weir bays and 11 undersluices bays as shown in Fig. 1, and details given in Table 1. The clear waterway of the barrage is 3,862 feet wide. Two divide walls separate the main weir section of the barrage from undersluices part. Two fish ladders are provided along each divide wall. Each undersluices section of Taunsa barrage consists of 22 feet wide navigation bay and silt excluder. The designed capacity of the barrage is 1,000,000 cusecs (28,317 cumecs); but a super flood of above 1,265,000 cusecs (35,821 cumecs) can be passed safely through the barrage (Punjab Irrigation Department, 2007).

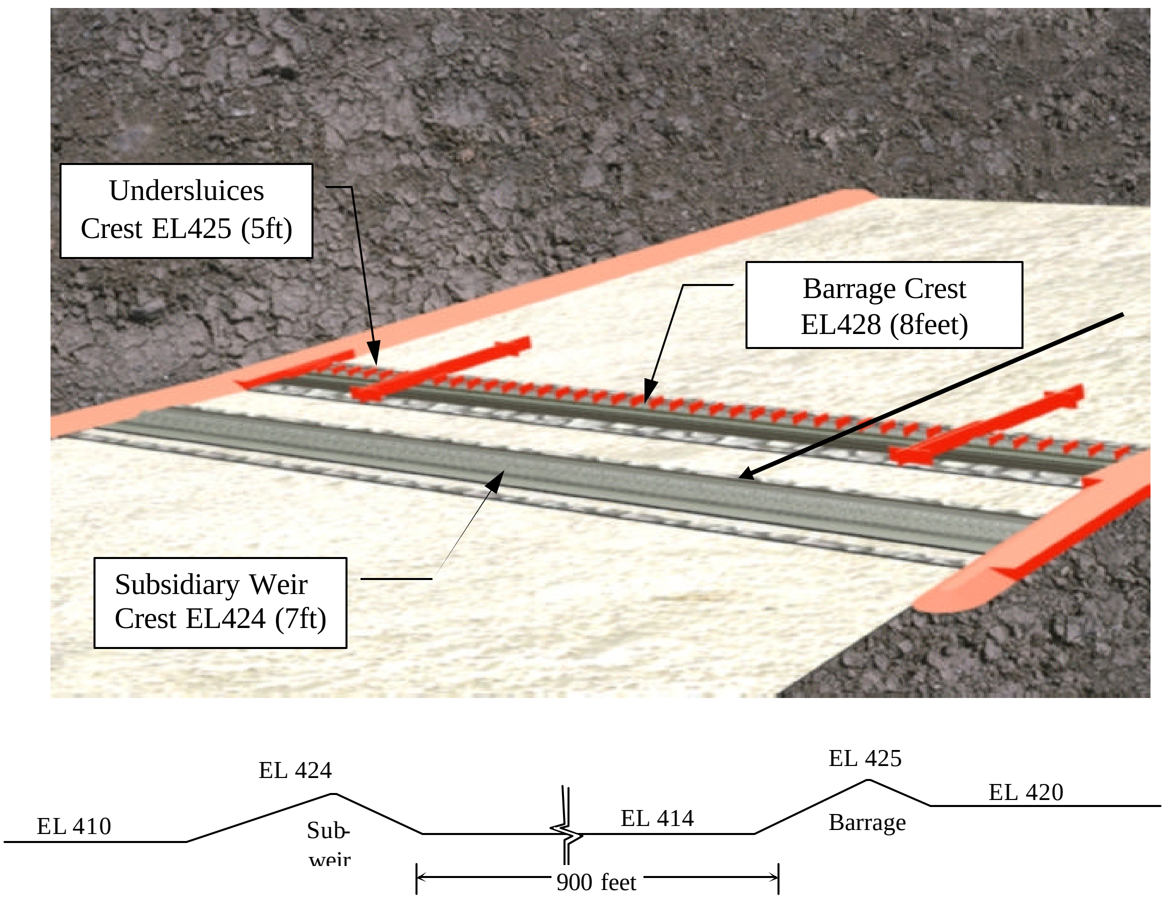

Fig. 1. Taunsa barrage and the sub-weir plan and cross-section through undersluices.

Sub-weir

A sub-weir is constructed at a distance of 900 feet downstream of the Taunsa barrage. Fig. 1 shows that the crest level of the sub-weir (EL 424) is almost equal to that of barrage (EL 425). A 22 feet wide navigation bay and a fish ladder is constructed close to left abutment while second fish ladder is constructed adjoining to right abutment. Navigation bay, fish ladders and the weir are separated by three divide walls of 7 feet thickness each. Although the provision of this sub-weir is dubious but the rationale of divide walls and fish ladders in the sub-weir are really understandable. The sub-weir, divide walls, navigation bay, etc is a barrage without gates. In fact, 'Taunsa barrage' (sub-weir) downstream of the Taunsa barrage is being replicated, which is a unique example in the entire world. This concept may be called as "doubling of an existing barrage".

Discharge capacity of Taunsa barrage

Punjab Irrigation Department (2007) noted that the discharge capacity of Taunsa barrage is 1,000,000 cusecs (2,8317 cumecs) against pond

Table 1. Barrage and the sub-weir details.

Sr. No	Description	Barrage	Sub-weir
1	Total width between flanks	4,346 feet	4,346 feet
2	Design discharge	1,000,000 cusec	-
3	Discharge coefficient (without weir)	3.0	-
4	Design capacity	1,118,000 cusec	-
5	Discharge capacity	1,265,000 cusec	-
6	Highest flood level (upstream and downstream)	EL* 447, EL 441.4	EL 441.4, EL 433.4
7	Crest level (weir section)	EL 428	EL 424
8	Crest level (undersluices section)	EL 425	EL 424
9	U/S (upstream) stone apron	55 feet	67 feet long and 5.5 feet thick
10	D/S (downstream) stone apron	80 feet	90 feet long and 6 feet thick
11	U/S** concrete floor	121 feet long and 4 feet thick	28 feet long and 4 feet thick
12	D/S*** concrete block floor	179 feet	50 feet long and 4 feet thick
13	Concrete flared out walls	Two U/S and Two D/S	Two U/S and Two D/S

Source: Design Report 2007 and 71st Pakistan Engineering Congress Proceedings

EL* = Elevation U/S** = Upstream D/S*** = Downstream

level of EL 445.5 rather than pond level EL 447 as assumed in original design. Punjab Irrigation Department (2007) further noted that barrage shall pass a flood of 1,118,000 cusecs (31,658 cumecs) at EL 447 feet and 1,265,820 cusecs (3,5844 cumecs) at EL 448 feet, using more pragmatic value of discharge coefficient of 3.3.

In the year 2010, the barrage passed 960,000 cusecs (27,184 cumecs) at the pond level of 446.6, whereas this pond level should be at about 1,100,000 cusecs (31,149 cumecs). It may be due to the presence of sub-weir and the accretion of sediment between barrage and sub-weir. If flood of about 1,250,000 cusecs (35,396 cumecs) had passed through the barrage, the pond level may have gone much higher than the expected level (EL 447) without the sub-weir.

Fig. 1 shows that sub-weir height in front of undersluices is 10 feet. The blocking of deep channels by constructing 10 feet high wall is difficult to justify hydraulically. Just one feet difference between crest level of both structures raises drowning ratio; consequently the water level increases when flow becomes un-gated.

Retrogression at Taunsa barrage

The progressive lowering of downstream levels due to picking of sediments by river water is known as retrogression. The word “Retrogression” has been used frequently while designing the rehabilitation projects both for Taunsa and Jinnah barrages (Punjab Irrigation Department, 2004; IRI, 2005; Chaudhary, 2010; Zaidi et al., 2011).

The retrogression 7 feet and 5 feet at low and high discharges, respectively, was observed (Punjab Irrigation Department, 2004). This caused the sweeping of hydraulic jump and, as a result, the repeated ripping of stilling basin floor and uprooting of impact blocks (Punjab Irrigation Department, 2004). Punjab Irrigation Department (2005) has given the same kind of statements regarding the retrogression at Jinnah barrage.

The difference between the highest flood level and tail water level indicated in Table 2, was just 5.5 feet during flood 2010 at the Jinnah barrage which showed no retrogression existed. Almost same tail water levels on upstream of the sub-weir (Table 2) and at physical model indicating no retrogression at low discharges. Tail water level maintained in physical model study at 1,000,000 cusecs (28317 cumecs) is EL433.4 feet, which looks wrong by about 6.5 feet. Low tail water levels clearly lead the sweeping of hydraulic jump. Therefore, the sub-weirs envisaged on the basis of excessive retrogression, both at Jinnah and Taunsa barrages are difficult to be justified.

Hydraulics of barrage with and without sub-weir

At high flows, the barrage performs as a hump (Table 3) with Froude Number less than 1.5 and negligible velocity change in stilling basin. The flood water passes through the barrage safely at normal pond level. At low flows (up to 400,000 cusecs) the jump remained at or above the toe of glacis. (Zaidi et al., 2011). It is mentioned earlier that the tail water levels in physical model study were wrongly extrapolated which indicates that energy dissipation mechanism at Taunsa barrage is jump type with adequate tail water levels at low and high flows.

Table 2 indicates that at 100,000 cusecs (2,832 cumecs) rise in water levels on upstream of Taunsa and Jinnah sub-weirs is 2.5 feet and 5.1 feet, respectively, while corresponding increase is 7.1 feet and 3.3 feet. At 100,000 cusecs (2,832 cumecs) water level variation (5.1 feet - 2.5 feet = 2.7 feet) is almost equal to difference betw een basin and crest elevations of the barrages whereas at higher discharges the difference of 3.3 feet – 7.1 feet = - 3.8 feet looks illogical. It is clear that the tail water level at higher flows (> 500,000 cusecs) were not extrapolated accurately, rather the water levels are on lower side. The tail water depth maintained on Taunsa barrage scale model at 1,000,000 cusecs (28,317 cumecs) was inaccurate approximately by 6.5 feet (3.8 feet + 2.7 feet = 6.5 feet).

No significant change in energy dissipation is noted after the construction of sub-weir. However, raised tail water levels on the upstream side of sub-weir caused an increase in submergence particularly of undersluices and pond level may go up.

At low flows, inspection and maintenance of main weir can be carried by diverting the entire flow towards the undersluices but after the construction of sub-weir, the undersluices cannot function as low level outlets. It seems that the sub-weir devastates undersluices and silt excluder's functioning. The situation becomes more critical after the construction of Taunsa Hydropower Project.

Table 2. Water level at the Taunsa and Jinnah barrages.

Discharge (cusecs)	Taunsa Barrage (Water Level)				Jinnah Barrage (Water Level)		
	Pool level 2010 flood	U/S** sub-weir 2010 flood	Upstream sub-weir	Maintained	Pool level 2010 flood	Downstream gauge 2010 flood	IRI* model study (2008) U/S sub-weir
100,000	445.5	425.9	428.0	425.5	694.0	675.3	680.4
200,000	445.5	428.7	430.0	428.0	694.0	----	682.2
300,000	445.5	430.4	432.0	429.5	694.0	680.9	684.0
400,000	445.5	431.5	433.5	430.5	694.0	682.5	685.5
500,000	446.0	432.9	435.0	431.1	694.0	684.4	686.9
600,000	446.0	434.9	436.2	431.7	694.0	-----	688.3
700,000	446.0	435.5	437.5	432.2	694.0	-----	689.7
800,000	446.4	437.1	438.5	432.7	694.0	689.0	691.5
900,000	446.8	437.8	439.5	433.2	694.0	689.5	693.0
1,000,000	447.0	438.4	440.5	433.4	695.5	690.0	693.3

Source: Model study report and 71st Pakistan Engineering Congress Proceedings

IRI* = Irrigation Research Institute   ** U/S = Upstream

Table 3. Critical and provided weir heights at the barrage.

Design discharge (cusec)	Specific discharge (cusec/ft)	Pond level (feet)	Water depth (y_1) (feet)	Velocity (V_1) feet/sec	Critical depth (y_c) feet	Critical Weir height (feet)	Provided (feet)	
							Weir Section	Undersluices
600,000	155	442	21	7.4	9.1	8.2		
700,000	181	443	22	8.2	10.1	8.0		
800,000	207	444	23	9.0	11.0	7.8	7	4
900,000	233	445	24	9.7	11.9	7.6		
1,000,0000	259	446	25	10.4	12.8	7.5		

Model Study Results

Up to 400,000 cusecs (11,327 cumecs) discharge the difference between water levels upstream of sub-weir and at scale model is negligible (Table 2). At high flows, the sweeping of hydraulic jump was observed on scale model because of inaccurately maintained downstream gauge. The jump location and energy dissipation therefore remain unchanged before and after the construction of sub-weir. Interestingly the water level raised by sub-weir at scale model was higher than corresponding value at the prototype. Fig. 2 shows that construction of sub-weir will prominent the afflux particularly through undersluices.

Benefits/consequences of the sub-weir

The construction of sub-weir is not beneficial in terms of loose stone protection. It is rather difficult to carry out the inspection and maintenance activities downstream of the barrage in deep water due to the presence of sub-weir. There is more operation and maintenance cost for the two independent structures.

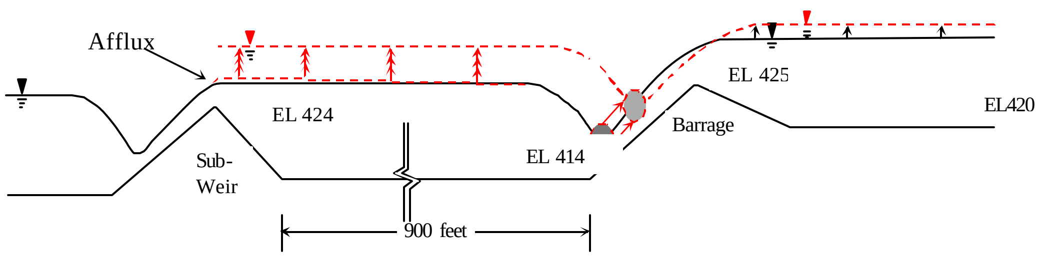

Fig. 2. Jump submergence and the rise in water level at Taunsa barrage after the construction of sub-weir.

Deposition of sediments occurring at low flows between two structures raises the river bed and consequently the water level which ultimately affects the performance of undersluices and silt excluders. Moreover, the blocking of deep channels in front of undersluices by 10 feet high sub-weir may have serious consequences. At the same time, the increase in drowning ratio and decrease in differential head reduces the discharging capacity of the barrage. The velocity remains low (less than 40 feet/sec) and there is hardly a chance of cavitations in the stilling basin. Therefore, the damage/abrasion to barrage stilling basin floor with and without the sub-weir remains unchanged.

Conclusion

The study noted that the retrogression both at Taunsa and Jinnah barrages was quite normal. The construction of sub-weirs downstream of Jinnah and Taunsa barrages might be hard to justify. The presence of sub-weir downstream of a barrage is not beneficial; rather it is a threat to the safety of upstream protection bunds besides affecting the performance of undersluices. The existing barrages may be rehabilitated, using prototype data; rather relying on physical model studies. At Taunsa barrage, the real cause of damages in stilling basin was the poor quality of concrete; rather than the tail water level variations.

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