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PROVISION OF SUBSIDIARY WEIR AS A SOLUTION FOR DAMAGES CAUSED BY RETROGRESSION AT JINNAH BARRAGE

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Abstract- The process of retrogression initiates temporary soon after the construction of hydraulic structures on the alluvial rivers. Retrogression resulted in unusually high speeds downstream of the barrage, resulting in repeated structural damage to friction blocks, reverse filter blocks, and stone apron. Operational problems of sluice gates and hoists. The main objectives of this research work are to study how damages were controlled caused by Retrogression and to check different discharges with their effects of D/S for safety. The hydraulic performance was checked for different flows starting from 20,000 cfs. In first case no additional retrogression was considered with 20% flow concentration. In second case 3ft additional retrogression was considered due to Kalabagh dam and 20% flow concentration. The results indicate that the lowest jump formation level with Blench equation with 20 % concentration of flow and additional 3 feet retrogression downstream of the proposed weir is at RL660.28. Maximum water level downstream of Barrage in main weir portion is RL693.14. Moreover, subsidiary weir provided will stop downstream erosion of barrage.

Keywords- Subsidiary Weir, Retrogression, Jinnah Barrage, Discharge

1 INTRODUCTION

Agriculture is the backbone of Pakistan. It represents 21% of the GDP and represents, with agri-food products, 80% of the total export revenues of the country. More than 48% of the workforce is involved in this sector. Most of Pakistan's area is in an arid and semi-arid zone. This leads to overcoming the water needs for agriculture through irrigation as rainfall is not sufficient. Pakistan's irrigation system is the largest integrated irrigation system in the world, serving about 18 million hectares of cultivated land. There are 3 large storage tanks, 19 dams, 12 inter-river linkage channels, 45 independent irrigation canals and more than 140,000 watercourses.

Dam is an artificial barrier across a river to stop floods, assist with irrigation or navigation, or to generate electricity by tidal power. A weir / dam is an important structure used to divert water from the river through a canal system for irrigation and other useful purposes. If the difference between the pond level and the peak level is less than 1.5 m, the level of the pond can be maintained by means of roller shutters. However, if the difference is greater than 1.5 m, a weir controlled by a door is necessary, what is called a "Barrage". It is designed based on surface flow and subsurface.

The downstream riverbed was lowered due to retrogression. The barrage was unsafe and could have caused partial or total failure. Retrogression resulted in unusually high speeds downstream of the barrage, resulting in repeated structural damage to friction blocks, reverse filter blocks, and stone apron. Operational problems of sluice gates and hoists.

Ali et al. [1] investigated the impacts of varied spaced corrugated decks on downstream local scouring due to the formation of submerged jump, keeping the Froude number between 1.68 and 9.29. A case of flat aprons was considered to evaluate the impact of corrugated decks on scour hole dimensions. The results showed that the triangular corrugated decks minimize the depth of scour and the length of fine sand in average percentage of 63.4% and 30.2%, respectively and 44.2% and 20.6%, respectively. It was also concluded that the use of corrugated decks downstream of the hydraulic structures is an effective technical approach to minimize the area of the scour holes.

Chaudhry et al. [2] evaluated efficacy of downstream energy dissipation system and capacity of Taunsa Dam in pre-construction and post-construction underwater weir scenarios. They concluded that the presence of sub-dam downstream of the Taunsa Dam was not beneficial and the real cause of the damage in the plenum was the poor quality of the concrete; rather than variations in the level of the tail water. Chaudhry [3] reviewed previous studies / investigations, energy dissipation mechanisms, hydrographic surveys, soundings and soundings to estimate the damage and its cause and have concluded that at higher flow rates (> 0.5 Million cusecs), prevailing water level conditions becomes greater than the limit values (9 FPS) which trigger the displacement of the loose stone deck. The downstream speed became 12.2ft / sec (35.6% higher than critical limit) during the super flood of the year 1992 (842000 cusec) at the dam section which aggravated the displacement of the loose stone deck.

Hamidifar et al. [4] studied local scouring downstream of a rigid deck using a bed sill and investigated the effectiveness of scour reduction with a single downstream threshold. of the apron and evaluated its effectiveness at different distances. the end of the apron. As a result, they determined that the maximum scour downstream of the apron reduces up to 95%. In addition, variations in the characteristic lengths of the scour hole have been studied. In addition, it has been observed that completely buried thresholds may not be useful.

Khassaf et al. [5] computed depth of local scour around bridge pier using downstream bed sill (sand) as a countermeasure in the laboratory. A circular section pier model was used with clear water flow condition. They investigated three different size of pier diameter with four different water depths and four different flow velocities. As a result, they analyzed that the usage of sill as a countermeasure structure has a beneficial reduction of scour around pier around 25% for flow intensity 0.95 and the increasing diameter of pier with bed sill was given increasing scour depth. Hamidifar et al. [6] provided the most effective solution for bed protection downstream of hydraulic structures to investigate the usefulness of two countermeasures, i.e., bed sill and riprap - to decrease the scour depth adjacent to horizontal rigid decks. They concluded that upstream rip rap is proposed as an alternative method for protecting an erodible bed downstream of an apron.

Imran et al. [7] evaluated the use of corrugated beds and rough beds to reduce jump length and sequential depth, and these two measurements showed a large amount of downstream energy dissipation. Compared to a smooth bed, the jump length and sequential depth are also greatly reduced. As a result, the use of corrugated beds and rough beds reduces the scour length and depth and the cost of installing a plenum. Moreover, it was found that applying corrugated beds and roughness always performs better than smooth beds. Sharma et al. [8] studied the Singapore dam built across the Tapi River (Gujarat). Since its construction, significant damage has been reported during the recent floods in 2013 and 2014, during which significant scouring and settlement of concrete blocks was observed, ultimately threatening the main spillway structure. Regression hydraulic jumping conditions have been found to have prevailed at lower flow rates (<4000 m3 / s for 60%) even beyond stone protection due to deficient tail water conditions, which were the main because of the first reach of the spillway.

Castillo et al. [9] investigated the construction of the Pat Cardenello dam, and the expected changes in the Pat river. To assess the stability and safety of the structure, the shape and size of the erosion produced downstream of the dam due to the action of landfills and exits were verified, and to study through three complementary procedures: the empirical formula and the prototype obtained in the model, semi-empirical method based on pressure fluctuations, erodibility index and simulation of fluid dynamics. This method led to the proposal of a pre-excavated sedimentation tank. The pool will produce an effective water mattress. In addition, this will reduce sedimentation due to excavation and material carried by the river, especially during tank washing operations. The previously excavated basin will also allow for a symmetrical and regular flow, thus reducing the risk of possible landslides. Dehghani et al. [10] noted that some deficiencies of the spillway can be resolved by combining with valves. A disadvantage of valves is that they retain floating materials, which can be resolved if combined with landfills. This type of flow, generally in the form of jets, can have considerable potential for hydraulic flushing on the downstream side of the structure. Form wash holes.

The conceptual model of the confluent downstream flow field below the spillway and gate shows that there is an interaction between the spillway over the spillway and the spillway below the obstacle, and the scrub holes are alternately cut and filled. Local cleanup is formed downstream of the structure, and scrubbed sediment accumulates as a bump downstream of the cleanup hole.

Hassan [11] conducted experimental studies to study the dimensions of the scour hole downstream of the combined weir and gate structures. Twelve models have been designed and each model consists of a composite weir consisting of two geometric shapes and three types of rectangular, semi-circular and triangular shaped doors, where several factors have been studied to discover the effect of changing geometry. spillway and valve, discharge flowing in the channel and concluded that the maximum depth of the scour values was recorded in models with circular door compared to other models with rectangular and triangular doors. The size of the deposits changes with the depth of the scour hole where each time the depth of the hole is increased due to the free fall of water from the edge of the compound weir, the sediment deposition was more, while the flow through the door helps to remove these sediments and make the deposit form flatter.

Habib et al. [12] reported scouring the loose sand bed downstream of the hydraulic jump formed on a rigid deck. Different kinematic conditions are produced to study scour holes and their development. Experimental data are used to study the relationship between scour depth and deck length. Some photographic investigations are made to show the influence of the structure of the flow in the area of the jump roller and the characteristics of the turbulence at the end of the jump on the scrubbing process. It was concluded that scour depth decreased with increasing length of rigid deck. In addition, photographic research was performed showing the large-scale turbulence characteristics of the roll area. Periods of vortex pairing, and immigration were observed, which caused an oscillation of the toe location of the jump with a remarkable shift of broken swirls in the tail water. These processes are considered to be the main cause of the instability of sand particles downstream of the jump. The main objectives of this research work are to study how damages were controlled caused by Retrogression and to check different discharges with their effects of D/S for safety.

2 STUDY AREA

The Jinnah Barrage consists of 42 bays and two undersluice portions. Each of undersluice portion consisted of 7 bays, with a clear waterway of 18.3 m. The total barrage width is 1152.4 m, and the clear waterway width of 768.1 m and 128 m for the main weir and undersluice portions, respectively. The elevations crests of main weir and undersluice crests are EL206.81 and EL204.20, respectively. Whereas, upstream and downstream floor levels are EL205.72 and EL203.29, respectively. Two dividing walls, 106.7 m long, divided weir and sluice sections upstream of the weir. In the left and right sluices, two fish ladders are constructed along the dividing wall. Jinnah Barrage right and left sluices have a 6.1m wide navigation bay and sediment removal system, respectively. The barrage is designed for a design flood of 26725.6 cumecs; however, because of the provision of sufficient freeboard, flood of 30945.8 cumec can be passed safely. The normal pond water level is at EL210.9 and will be raised to EL211.5 to meet the Thal Canal remodeled capacity of 283.2 cumecs.

3 METHODOLOGY

3.1 Discharge Calculations for proposed Subsidiary Weir

Proposed subsidiary weir is designed as fully ungated weir using formula,

$$Q = C'.b.E^{1.5} \tag{1}$$

Where:
Q is the discharge over crest (cusecs); b is clear width of weir (ft) and E is u/s TEL – crest RL

Existing barrage is a gated structure and in its original design, the value of C=3.20 was used and is still being used for high flow conditions without considering the submergence ratio. For gated flow condition, when bottom level of gate is submerged C=0.81 is used for calculating discharge without considering the submergence ratio. For gated flow condition, when downstream water levels are below bottom level of gate C=3.20 is used for calculating discharge without considering the submergence ratio. Coode & Partners, the designers of various barrages under IBP including Marala and Qadirabad followed Gibson method and used the submergence ratio for calculating the discharge. The parameters of new Khanki Barrage are also fixed using Gibson formula.In the case of submergence, the free flow discharge coefficient (C=3.8) is multiplied by a reduction factor C'/C.

Table 1: Values of reduction factor

h /E	**C '/ C**	**C '**
0.4	0.96	3.65
0.5	0.94	3.57
0.6	0.91	3.46
0.7	0.86	3.27
0.8	0.78	2.96
0.9	0.62	2.36
0.95	0.44	1.67

3.2 Equations used for different Design parameters

i) Discharge (Q) = ft^3/sec

It is the volume metric flow of water during per unit time.

ii) Discharge Intensity (q) = $ft^3/sec/ft$

Discharge flowing through per unit width of a structure which is;

$$q = Q/B \quad (2)$$

$$q = 1.70E^{3/2} \quad (3)$$

iii) Velocity of Approach

The velocity of flowing water approaching to a metering section is called velocity of approach which is;

$$H_{ap} = V^2/2g \quad (4)$$

iii) Energy Line (E)

It is equal to depth of water + velocity of approach.

$$E = Y + H_{ap} \quad (5)$$

iv) Lose of Head

Head lose is equal to U/S Total Energy Line – D/S Total Energy Line, HL = TUEL – TDEL

v) Critical Depth (dc)

It is the depth of water at which Specific Energy is minimum.

$$d_c = [q^2/g]^{1/3} \quad (6)$$

vi) Scour Depth (R)

It is the maximum depth measured from the High Flood Level (HFL) to the lowest bed point which is eroded/ scoured as an outcome of water current.

$$R = 1.35(q^2/f)^{1/3} \qquad (7)$$

vii) Wetted Parameter (P)

It is the surface area of any cross section which is wetted by the flowing water.

$$P = 4.75\sqrt{Q} \qquad (8)$$

Where P is the wetted perimeter and is given as B + 2D.

For rivers 'D' is negligible comparing to 'B' therefore P = B,

hence B = 4.75 √Q

viii) Conjugate Depth (d_1, d_2)

These are the depth of water it is before and after the formation of Hydraulic jump.

4 RESULTS AND DISCUSSIONS

The subsidiary weir at 600ft from the gate center line of main barrage is constructed only for weir section of the barrage**.**

4.1 Surface and subsurface flow analysis

The main weir is designed for the discharge of 950,000cusec; however, the hydraulic performance was checked for different flows starting from 20,000 cfs. In first case no additional retrogression was considered with 20% flow concentration. In second case 3ft additional retrogression was considered due to Kalabagh dam and 20% flow concentration. The water surface profiles formed due to both cases are shown in Figure 1 and Figure 2.

4.1.1 Case-1: No additional retrogression but 20% flow concentration

In case 1, additional retrogression was not provided; however, 20% flow concentration was assumed to counter the possibility of cross currents which may be hazardous to weir and caused excessive erosion. Water surface profile formed in this case is presented in Figure 1. It is clear that a smooth transition from super critical flow to sub critical flow with very small undulations was produced, the reason behind this is the non-presence of retrogression phenomenon as erosion is not taking place. Moreover, the jump is formed above the toe of glacis which is making it an acceptable scenario; however, retrogression was not considered in this case which is not possible in when hydraulic structures were constructed on alluvial rivers.

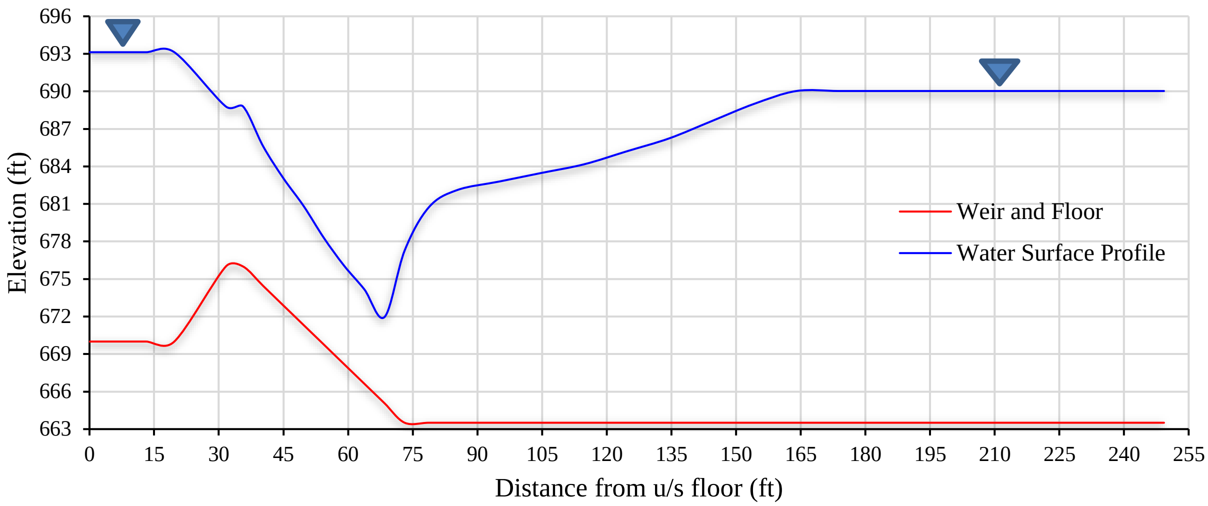

Figure 1: Water Surface Profile for No retrogression

4.1.2 Case-2: 3ft additional retrogression due to Kalabagh dam and 20% flow concentration

In this case, 3 ft additional retrogression was considered along with 20% flow concentration due to the Kalabagh dam. Water surface profile for this case is shown in Figure 2. Contrary to previous case when no retrogression was considered, a very rough transition from super critical flow to sub critical flow produced accompanied with large undulations. The major reason behind this is the occurrence of retrogression phenomenon. Due to erosion, velocities on d/s will increase and resultantly Froude's number will become greater and it will rise eddies formation from bed to surface. Therefore, subsidiary weir fixed with crest elevation at EL676 was proposed in physical sectional model. The slopes of the upstream and downstream glacis were designed to be 1V: 2H and 1V: 3H, respectively. Given that the Kalabagh Dam may have an additional 1 m retrogression after construction, the ground height of the water retention basin is set at EL659. The existing dam structure, including the concrete block floors, must be kept intact. The main weir and undersluice sections of subsidiary weir must be divided by extending the existing downstream dividing wall.

The study revealed that the energy dissipation system at Jinnah Barrage is impact/jump type. Conduction of subsidiary weir at Taunsa barrage has proven its efficiency by passing 973,000 cusecs discharge during the extreme flood event of 2010; therefore, the option of providing subsidiary weir downstream of hydraulic structures may considered after extensive physical and numerical model studies.

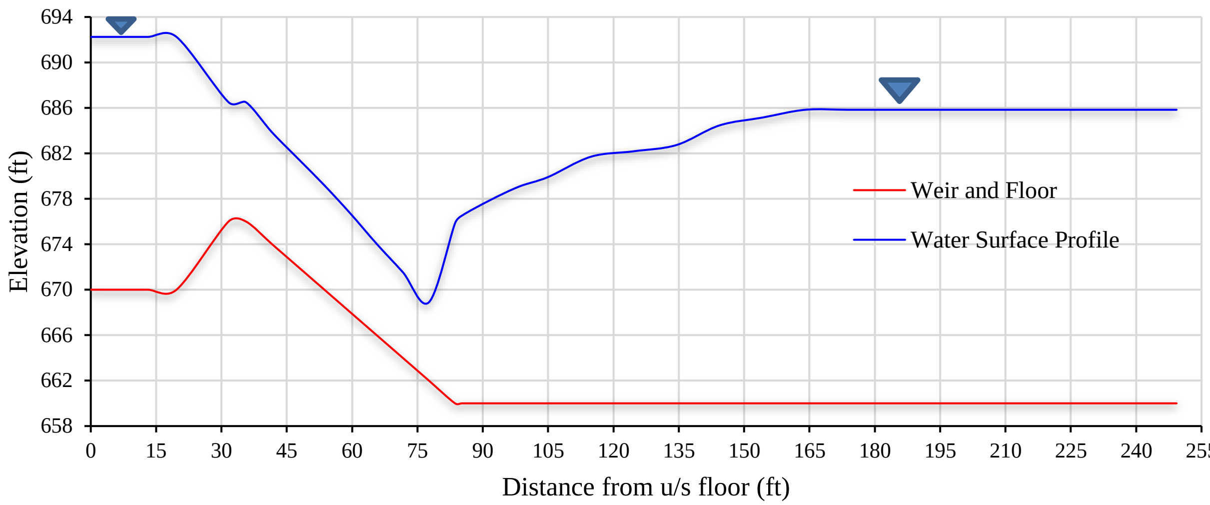

Figure 2: Water Surface Profile for 3ft retrogression

5 CONCLUSIONS

Major conclusions are given below:

- Subsidiary weir is check at different discharges for;
  - i. More than design discharge which caused the high afflux on U/S side which is not safe.
  - ii. Less than designed discharges upto 20,000 cumecs, which is safe and will not affect D/S designed parameters.
- The lowest jump formation level with Blench equation with 20 % concentration of flow and additional 3 feet retrogression downstream of the proposed weir is at RL660.28. So, the floor level fixed at RL 660.00 is Ok.
- Maximum water level downstream of Barrage in main weir portion is RL693.14.
- Subsidiary weir provided will stop downstream erosion of barrage.
- It is concluded that subsidiary weir may be a good option in reducing the retrogression effect and thereby minimizing the downstream floor damages. However, comprehensive physical numerical model studies should be performed for the better testing of the weir designed and to eliminate the effect of retrogression phenomenon under different conditions.

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