THE CHINIOT DAM – SHEET PILE DESIGN ASPECT

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Abstract- The hydraulic structures can be built on either of permeable or impermeable foundations. The structures built on permeable foundations are subject to seepage pressures and the optimal cost of these structures is a non-linear function of the factors that cause the seepage force under the structure. However, the basic parameters of hydraulic structure, such as the depth of sheet piles or cut edges, and the length and thickness of the floor, cannot be determined in a cost-effective manner. In designing hydraulic structures, sheet piles are needed to reduce uplift force and hydraulic gradient. Usually, two sheet piles are required. The upper pile is used to reduce the uplift force, and the d/s pile is used to reduce the hydraulic gradient. The results show that if the d/s pile is deeper than the upper cutting wall, the resulting lifting force will increase. The increase in the depth of the d/s pile and the increase in the overall length of the floor result in a decrease in the resulting hydraulic gradient. When the two piles meet at the end of the hydraulic structure, the exit is lower than when the pile in the d/s direction is larger. On the other hand, the obtained results provide the best optimal parameters in terms of seepage flow, length and floor thickness. Use safe exit gradient and filters, respectively to incorporate soil type and hydrological conditions into the dam design.

Keywords- Chiniot barrage; Chiniot river; sheet pile; Khosla theory

1 INTRODUCTION

The surface water in Pakistan is the perennial influx from the Indus River and its tributaries (i.e., the Jerum River and the Chana River). Though, the flow of these rivers varies greatly from year to year and seasonally. Approximately 84% of river flows occurs in the summer months (April, May, and June), and due to a lack of available storage capacity, a significant portion of this discharge flows into Arabian Sea unused. Conversely, there is an urgent need to develop available water resources to sustain irrigated agriculture, which uses about 97% of the available river flows. Therefore, previous developments in the related water and hydroelectric power sectors suggested establishing a surface water storage plan through dam construction, to retain excess river flow for use when river flow is low and use the hydraulic head for power generation.

Warsak was the first dam built on the Kabul River in 1960. Its height is approximately 76 m and it created a small storage with an initial capacity of 493 Mm^3. The construction of the dam helped in the development of irrigated agriculture and created an additional power generation capacity of 240-megawatt. On the other hand, due to excessive sedimentation, the storage capacity of 18,784 Mm^3 built in Mangla, Tabela and Chashma continues to decrease. The loss of storage capacity of approximately 5,884 Mm^3 requires urgent replacement. Studies have been conducted at the 7,894 Mm^3 Diamer Basha Dam and the 7,400 Mm^3 Akhori Dam to use the remaining flow from the Indus River. Similarly, Mangla Dam Project have been raised for additional storage of 3,454 Mm^3 on Jhelum River. However, a storage on Chenab River is also required to store flood flows to be used in low flow seasons. The historical record it is evident that Chenab River huge floods which inundate adjoining areas near the Chiniot town for which British Govt constructed a dike about 4 to 5 km from the river to avoid submergence of villages in early 19th century. However later on, people have established several villages in and around the dyke which led to displacement during high flood season causing loss of lives and properties. The flood discharge also goes waste without utilization for the agriculture.

Tariq [1] studied the expected annual damage for the Chenab River floodplain using the multidirectional conjunctive approach to analyse the different measures to avoid extensive damage. Iqbal [2] and Hyder and Iqbal [3] worked upon the damages to household and agricultural land in Chiniot District and their coping mechanisms and found that the households are very exposed to flood in 2014 and even with the seventy percent of the area being warned of the floods, the citizens were unable to avoid the damages the were to come with the flood. Tariq [4] worked upon optimization of management measures for the floods in Pakistan and came with something similar to a guideline for managers to use available resources to their advantage and reduce the flood plain. The concept of the creep length for the flow under hydraulic structure was introduced by the Bligh [5]. The creep length was defined as the path of the seepage line which is in contact with the hydraulic structure. The Bligh theory assumed that hydraulic gradient remains constant along creep length. According to the theory the uplift pressure is linear as it varies linearly with the creep length due the linear energy loss along the creep length. The weighted theory of creep length was introduced by Lane [6] after investigating over 200 damaged hydraulic structures. According to the theory the horizontal creep length is different as compared to vertical creep length. The theory assigned the coefficients of 0.33 and 1.0 for total horizontal and vertical creep length respectively. Another method to estimate the distribution of the uplift pressure was presented by Khosla and Bose [7] using schwarz-christofel transformation method for weir design and for flat foundation type. Analytical solution for finite-depth seepage for following two cases was presented by Pavlovsky [8], [9]: flat aprons with single cut-off and depressed floors without cut off. In another research by Koupaei [10], it was stated that the quantum of uplift pressure determined by using Lane and Bligh is less than Khosla.

Salmasi et al. [11] employed relief wells below the dam to reduce the lifting force. These wells collect seeping water from the bottom of the dam, thereby preventing the formation of excess pore pressure. This helps to stop the piping phenomenon at the emerging d/s end of the dam. Some researchers use semi-impermeable blankets to counter the lifting force and seepage [12]. Usually, the blanket is made of compressed clay and will increase the creep length. This leads to more energy loss compared to the case where there is no blanket on top of the hydraulic structure. Nourani et al. [13] studied the best location for vertical drainage in a gravity dam. The finite element method (FEM) is used to predict the lifting force (U) of the vertical outlet based on the gravity dam. The design of irrigation canals can be considered from two perspectives: (1) the leakage of unlined ground channels; (2) the lifting force of lining channels [14]. Salmasi et al. [13] Reduced height by using longitudinal drain pipes with underlined channels. Jafari et al. [15] placed a filter housing around the drain pipe below the bottom of the concrete channel. This reduces the lifting force under the channel and extends the service life of the pipeline lining.

Shayan and Tokaldany [16] investigated that in the addition the seepage discharge due to increase in the seepage velocity increases the movement of soil particles which ultimately arises the phenomena of piping and undermining and the safety of the structure against the piping phenomena primarily depends upon the exit gradient while designing the structure. Novak et al. [17] found that seepage through the hydraulic structures should always be encountered the for the safety of structure. The construction of the cut off below the structure and on the flanks of if necessary, will control the seepage through the structure. The cut off can be formed by from wide trenches backfilled with clay or by drilling and grouting depending upon the type of soil strata. Ahmed and Bazaraa [18] attempted the calculation of water seepage through the hydraulic structure is generally evaluated through 2-dimensional (2D) analysis which is particularly suitable for cases where soil formation is homogenous, or the geometry is regular and subsequently it simplifies the problems.

It is evident from the above-mentioned studies that the selection of the correct parameters in the design of hydraulic structures plays pivotal role in the success of these projects. As of now, more than 14 hydraulic structures are proposed and/or under rehabilitation process in Punjab province. Therefore, present study aims to check the impact of high specific discharge on the length of pile sheets, scouring depth using Khosla theory which has been extensively used in subcontinent for the design of hydraulic structures on alluvial rivers.

2 STUDY AREA

Pakistan possesses a number of rivers (Figure 1). The Chenab river is formed at the confluence of the Bhaga and Chandra river. These two rivers joined each other at Tandi to form river Chenab. The highly elevated part of Chenab catchment is snow covered area located in the northeast part of the Himalayas. From Tandi to Ahnur, the river runs through the mountains. The river is 1,232 kilometers long and has a basin area of 41,760 square kilometers. The river enters Pakistan above Cape Mallard, and the slope changes very abruptly. The Chiniot Dam Project is located on Chenab River in Tehsil and District Chiniot, Faisalabad Division, Punjab at about 100 km downstream of Qadirabad Barrage and 5 km from the Chiniot city and about 100 meters upstream of existing Railway Bridge on Chenab River. The Chenab River at proposed dam/barrage site gets divided and then passes through narrow gorges. During floods, the narrow gorges obstruct the flow and create a backwater effect. Historical evidence reveals that when water levels are high, the flood water inundates a vast area (about 485 sq. km) upstream proposed dam site.

Figure 1: Location of Chiniot dam project on river Chenab

Chenab River is measured at Marala, which is located about 10 km below the Line of Control. Here it drains an area of about 29,560 km^2 and has an average annual inflow 31,703 Mm^3 (25.702 MAF) as shown in Figure 2.

During the months of November to February, the flow of the Chenab River at Marala is very low. During this period, India will be able to resolve the problems upstream of Marala Barrage (existing and proposed hydroelectric dams) and block the flow of 168.3 Mm^3 into the Chenab River for 21 days. If India takes advantage of its ability to manipulate upstream structures, something alarming may happen in future.

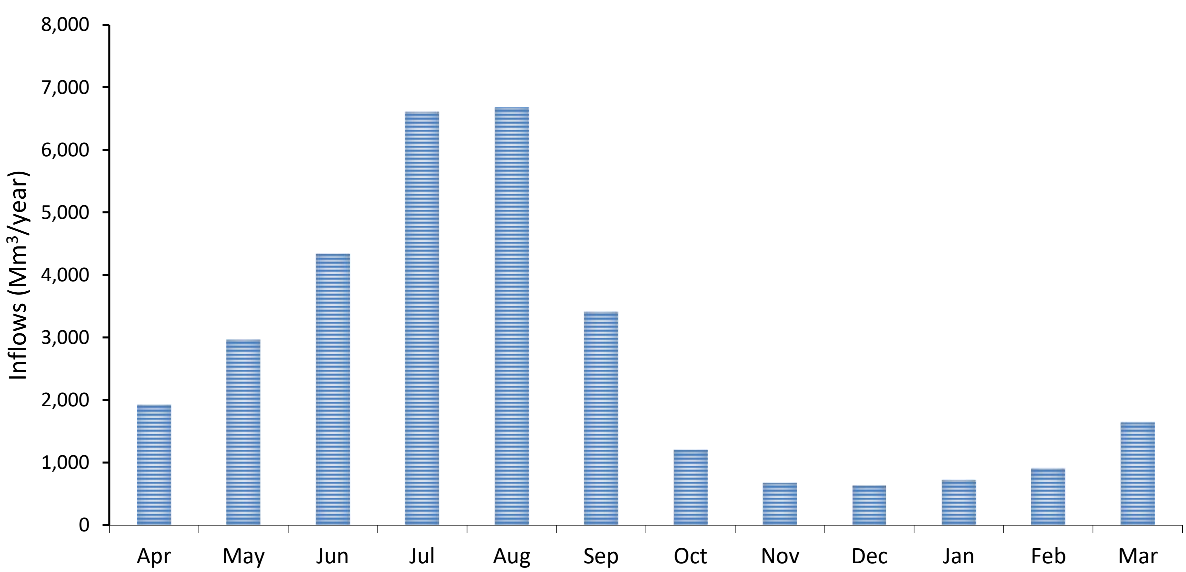

Figure 2: Mean monthly variations in inflows at Marala station of Chenab river (1976-2017)

3 RESEARCH METHODOLOGY

3.1 Waterway

Flood data was analysis and flood estimated for a return period was estimated using Gumbel Distribution. The flood value is in order of 35300 m^3/s. The bed level of the river at barrage site is 178m, the same adopted for the crest level under sluices and weir height of 1.5 m assumed.

Three considerations control the waterway of a hydraulic structure. They are a variety of designs, Lacey designed waterway and looseness factors. It is generally believed that by restricting waterways, the formation of shoal can be eliminated. However, although the length of the structure is short, this increases the discharge intensity, so the undersluice part becomes heavier as the height of the gate increases and the cost increases.

3.1.1 Lacey's Design Waterway

Lacey's wetted perimeter formula for estimating the waterway is given as follows:

$$P = 4.75\sqrt{Q} \qquad (1)$$

Where P is the Lacey's wetted perimeter and Q is the design discharge in cumecs (m^3/sec).

3.1.2 Looseness Factor

The ratio of the actual width to the calculated width is the "loosness factor", which is the third parameter that affects the width of the structure. The value used varies from 1.9 to 0.9, and the largest coefficient was used in the previous design. Usually, it ranges from 1.1 to 1.5. Judging from the performance of these structures, there is a feeling in some respects that when the looseness coefficient is high, it tends to form shoal in front of the structure, causing damage and maintenance problems. The consultant will use the most favorable looseness factor to provide reasonable flexibility while minimizing adverse effects.

3.1.3 Afflux

The maximum flood height in the river caused by dam construction is defined as Afflux. Although the flow is initially limited to a small section of the river when it rains, it gradually extends too far until the final slope of the river is formed at the source.

The minimum waterway was determined using lacey formula which is about 908 m long. From the computed value of lacy's waterway it appears that a minimum width required is 908 m. The width at barrage site need to be widened by cutting the gorge so that the designed flood could safely pass the barrage. From the site markings it is evident that whenever a flood of more than 700,000 cusecs occurred the entire areas on both banks of Chenab River submerged. The upstream total energy level calculated was 191.321 m. Keeping in view the total upstream energy level free board was adopted 4 m above the full reservoir level i.e. 193.5 masl with 20% retrogression. as the dykes are made of embankment overflow will damage entire reservoir.

3.2 Design for sheet piles

The calculations for seepages pressures for the design of sheet piles is done on the basis of Khosla theory which is an updated method compared to Lane's and Bligh's theory. The calculations are done for the pool level or no-flow condition as it results in the maximum head difference available for seepage.

First of all, the specific discharge is calculated by dividing the max. anticipated flood by the waterway obtained as above. Then the depth of piles is obtained using the scour depth (R) relation. The upstream pile depth is kept 1.25R and downstream pile depth is kept 1.5R.

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

$$G_E = \frac{H}{d} \cdot \frac{1}{\pi\sqrt{\lambda}} \qquad (3)$$

Where, R is normal scour depth, q is the discharge intensity between two piers and f is silt factor, G_E is the exit gradient, H is the maximum seepage head across the structure, d is the depth of downstream sheet pile, value of $\frac{1}{\pi\sqrt{\lambda}}$ can be read out from blench curves corresponding to values of b/d and b represent is the total floor length.

The pressures are calculated using blench curves and then the corrections are applied where necessary based upon interference of piles, thickness of floor and slope of the floor. And after all this, the exit gradient is checked to be in safe limits for the design to be considered safe.

4 RESULTS

For the design of Chiniot dam for a flow of 35,354 m^3/s, Khosla's traditional two-dimensional seepage method was adopted. The pile depth of this method is limited to detailed considerations and the floor length is determined to achieve the allowable safe exit gradient. The undersluice is designed for high floods. The length of the stilling basin is 39 m. The safe exit gradient 1:6 depends on the type of soil on which the dam is based. The length of downstream cutoff wall of 22.6 m is about twice the length of upstream cutoff wall of 11 m. The design of the floor length upstream and downstream takes into account the slope of the safe exit gradient, and the nominal thickness of the floor is required on the upstream side of barrage, and the lifting pressure is balanced on the upstream side of the ponding water. However, the minimum thickness of the upstream floor should be 1 m, and the thickness of the floor should be 1.0 m along the floor and 1.5 m lower than the top.

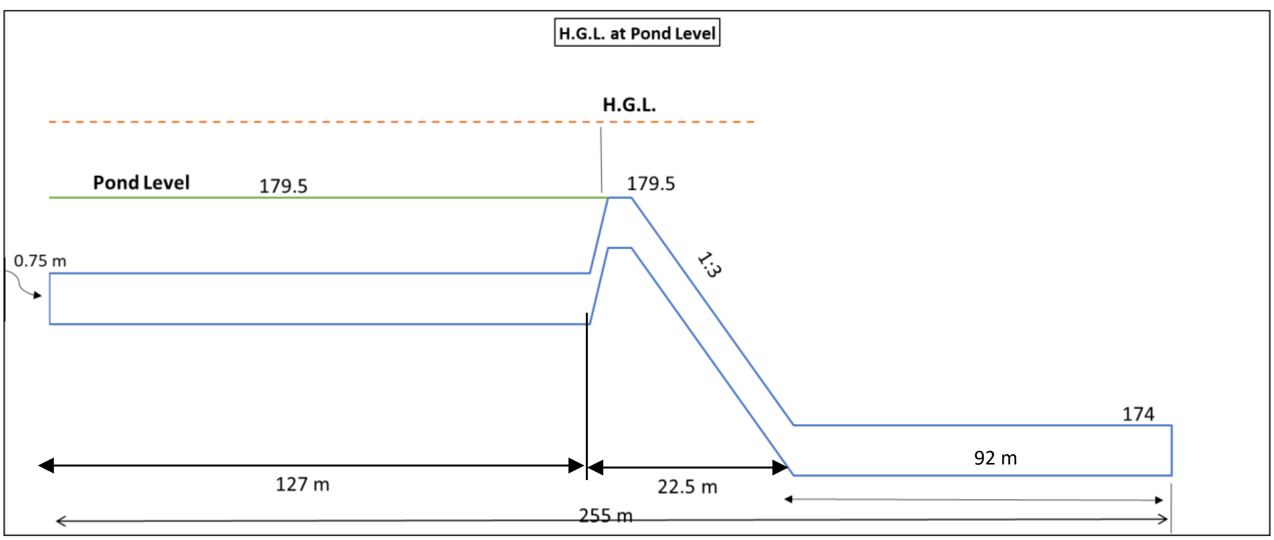

Figure 3: Cross-sectional view of Chiniot barrage

However, the downstream thickness should be evaluated from the nominal thickness of the entire length of the floor. In the past (in the mid-19th century), barrages were designed and built in India based on the experience of the time. Some of them are based on Bligh's slip theory, which proved to be unsafe and expensive.

Table 1 U/S and D/S Pressure calculation summary

Condition	D/S water level	U/S water level	Head	Elevasi of Sub Soil High Line Above Datum					
				Upstream Pipeline			Downstream Pipeline		
				ΦE_1	ΦD_1	ΦC_1	ΦE	ΦD	ΦC
	m	m	m	100	81.6	73.88	27.40	19	0
No Flow	182.14	188	5.86	5.86 188	4.78 186.92	4.33 186.47	1.61 183.75	1.11 183.26	0 182.14
High Flood	189.5	191	1.50	1.50 191	1.22 190.72	1.11 190.61	0.41 189.91	0.29 189.79	0 189.50

The upstream and downstream protection works are also designed by using empirical and convectional formulas. Considering the economic and other related factors block protection is adopted for the protection works.

From the calculation the scour depth about 31m which is significantly high values and the RL of bottom of sheet pile is 158 m. From scour depth there are significant chances that both upstream and downstream piles will have effect on each other. The uplift forces are prominent and requires huge protective measures to avoid any catastrophic failure of barrage. Moreover, model study is required to be undertaken for such a high scour depth and pile sheets. As it was already expected from long piles sheets that a comparatively longer floor length will be required to increase the seepage and losses beneath the structure so that exist gradient will be zero and pressure at downstream pile C2 must be zero. A middle pile is also required to reduce the effect of unbalanced head at the toe of glacis.

5 CONCLUSION

Following conclusions can be drawn from the conducted study:

The present work shows that the design of Chiniot dam on impermeable foundations is economical and safe under conditions of infiltration and increased water pressure. Barrage design uses a traditional approach. The results obtained provide the best barrage parameters, including upstream and downstream sheet piles / cross-section depth, floor length and thickness. Soil type and hydrological conditions are combined in the design of the dams through the safety outlet slope and the seepage head respectively. The conclusions of this study can be summarized as follows.

- Compared with downstream pile and total length of floor, the upstream pile depth is less sensitive to the SGE value or the head of the leakage.
- The assumed minimum floor thickness will affect the design parameters and hence the total cost of the dam from practical considerations, the nominal value is crucial to reduce the overall cost of dam.
- As the head of seepage increases, the depth of the d/s piles and the length of the bottom plate increases. Deep d/s piles can cause excessive water build-up in the barrage. Therefore, the upper limit of the sheet pile depth must be set to reduce the degree of pondage in the barrage, while the overall cost is not excessively increased.

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