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Research Article

Understanding the Morphological Behaviour of River Chenab: A Case Study

Muhammad Abdul Rehman[1], Naveed Anjum[1], Muhammad Hamza Ali[1], Muhammad Danish Kaleem[1], Zaheer Ahmed[1], Junaid Ahmed Sidiqy[1]

[1] *Khwaja Fareed University of Engineering & Information Technology (KFUEIT) Rahim Yar Khan 64200, Department of Civil Engineering, Pakistan,*
adanshah305@gmail.com, naveed.anjum@kfueit.edu.pk , hamza2k7125@gmail.com , muhammaddanishkaleem07@gmail.com, dr.zaheer@kfueit.edu.pk, junaid.ahmed@kfueit.edu.pk

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Abstract – Ongoing research focuses on the morphology of the Chenab River upstream (U/S) of the Panjnad (PJD) Barrage, Pakistan, particularly addressing erosion concerns from Reduced Distance (RD) 50+000 to 30+000 along the Right Marginal Bund (RMB). A meticulous 18 km field survey, employing plane table survey techniques, leveling tools, compasses, and plane table boards, aimed to map the terrain surrounding the Right Guide Bank (RGB), Left Guide Bank (LGB), RMB, and Left Marginal Bund (LMB). The topography, studied from the main weir, revealed islands near bay number 13–50 due to reduced Chenab flow. Examining RD: 30+000 to 50+000, the section displayed braiding, sandbars, and sediment influx during monsoons, impacting canal diversion and morphology. Despite previous interventions, including j-head spurs and mole head spurs, erosion persists along the Chenab's right bank. Sutlej-induced flooding damages LMB up to J-Head Spur RD 5+500 LMB, threatening the upper curved segment of RGB. U/S island formation obstructs the Annex weir, hampering PJD's discharge. A permanent island from RD 36+000 to 50+000 divides Chenab streams, posing an infrastructure threat along RMB. Addressing these issues is crucial for sustainable river management and mitigating potential environmental and infrastructural risks.

Keywords – River flow pattern Shifting, Tendency Erosion & Sedimentation, Damage of Spurs, Island Formation.

I. INTRODUCTION

Alluvial channels are categorized as straight, meandering, or braided [1-2]. Straight rivers exhibit minimal sinuosity at bank full conditions while meandering rivers feature alternating curves with low gradients, prone to bank erosion [3]. Channel patterns align closely with bar nature, influencing the style of meandering or braiding [4]. River channels self-organize through interactions among bars, channels, floodplains, and vegetation, shaped by sediment sorting processes and bank erosion [5]. Researchers developed a numerical model to predict the bed topography for channels with erodible cohesive banks [6]. Many studies have focused on the river planform evolution with the aim of studying the river bank line migration for sand bed rivers [7]. Researchers predicted the bank erosion and determined the influence of groynes on flow and for a reach of Sacramento River using the excess shear stress approach and numerical model, respectively [8]. Many researchers proposed different criteria to differentiate these channel patterns which are based on slope and bank full discharge, slope and mean annual discharge and median particle size, form parameter and bank sediment friction angle [9]. The factors that result the bank erosion from the previous studies concluded that four possible flow properties emerged as controls on hydraulic erosion rates of cohesive riverbanks [10].

Additionally, research gaps exist in understanding how climate change affects water flow and basin hydrology, requiring improved models to assess the socioeconomic impacts on local communities. The lack of information on riverine ecology and biodiversity emphasizes the need for comprehensive surveys and conservation strategies, especially concerning human-induced effects like damming. The study also highlights a lack of insight into stakeholders' water needs, policy effectiveness, and societal implications of water scarcity, calling for extensive research to enable sustainable water management and fair distribution.

The primary focus is on understanding the flow patterns and morphological dynamics of the Chenab and Sutlej Rivers upstream (U/S) of the Panjnad (PJD) barrage. It is crucial to grasp the inherent rightward tendency of the Chenab's main current. Proposing effective protective measures for the Right Marginal Bund (RMB) and its associated structures/river training works is essential. Investigating the fundamental causes behind the river's erosive nature is a central objective. Overall, the goal is to gain insights into the behavior and tendencies of these river systems, particularly to understand the current state of vulnerable structures while comprehending the underlying reasons for their erosive nature.

II. MATERIAL AND METHOD

Study Site:

The primary landscape of the Chenab River was examined through a ground survey using plane table surveying methods and Google Earth maps. The study area covered the U/S portion of the PJD Barrage, delineated by the left and right marginal flood embankments. The plane table survey, involving the analysis of river stream dynamics like flow length, width, meandering pattern, erosion, and sedimentation, provided detailed information about the shape of this terrain. The starting point of the survey was at Reduced Distance (RD): 50+000 of the RMB U/S. The main course of the Chenab River spans from RD: 50+000 to RD: 30+000 along the RMB, where recurring flood damages occur due to erosion during each flood season. To mitigate the impact of flooding and protect the RMB, various hydraulically designed structures and spurs have been erected along this stretch. The predominant geometric shapes observed in this area include solid stone studs, sloping spurs, J-head spurs, and Mole-head spurs. Additionally, stone pitching is present along the riverside slope of the RMB.

One of the sub-streams flows alongside the RMB and approaches the barrage, while the other runs on the left side. Between Bay No. 1 and 12, these two sub-streams reunite at RD: 3+000 U/S of the main weir and combine with the mainstream to approach the main weir. Approximately 15 km to the south (measured through Google Earth Software), the Sutlej River also joins the Chenab River in a left-side sub-stream. Between these sub-streams, from the starting point to the junction at RD: 3+000 U/S, a permanent island has formed. This island is positioned about 800 feet from the main weir, spanning from Bay No. 13 to 50. The primary reason for island formation is the year-round low supply at PJD Barrage. This island reduces the barrage's ability to handle floods and diminishes the effectiveness of the barrage.

Surveying:

In this research project, we conducted a hands-on examination by employing a Plane Table Survey of the Chenab River landscape, stretching from RD 50+000 of the RMB to the upstream main weir of the PJD Barrage. Plane table surveying emerges as the most effective method for swiftly gathering data. In this surveying approach, the creation of the plan and on-site observations can happen concurrently. When utilizing a plane table for surveying, the topographical intricacies are mapped on the plan after capturing the geometrical conditions of the site using the plane table and alidade. The plane tabling procedure was carried out using the required tools. Observations regarding the objects were noted while scaling down the distances, and these objects were marked on a drawing sheet (depicted in Figures 1 and 2). A Dumpy level, an optical instrument, was employed to verify points in the horizontal plane. Additionally, Google Earth Map was utilized to comprehend river reaches and highlight vulnerable areas.

Figure 1. Checking meridian line

Figure 2. Marking river meander at RD 48-49 RMB

During the on-site survey at J-head Spurs RD: 36+700, J-Head spur RD: 40+900, Mole Head Spur RD: 42+200, and J-Head Spur RD: 48+800 RMB U/S of PJD Barrage, sounding observations were conducted to assess flood damages along these hydraulic structures. A sounding boat, equipped with a sounding rod and sounding rope, was utilized for field observations. Following the sounding observations and the plotting of cross-sections for all structures along various lines, it became evident that the entire stone aprons of these structures had suffered damage along all the cross-section lines. Varying degrees of damage, ranging from minor to moderate and heavy, were observed along different cross-section lines of these structures, as depicted in Figures 3 and 4. Specifically, the cross-section lines 300 and 400, U/S of J-head RD: 36+700 RMB, illustrate the damaged stone apron due to erosion.

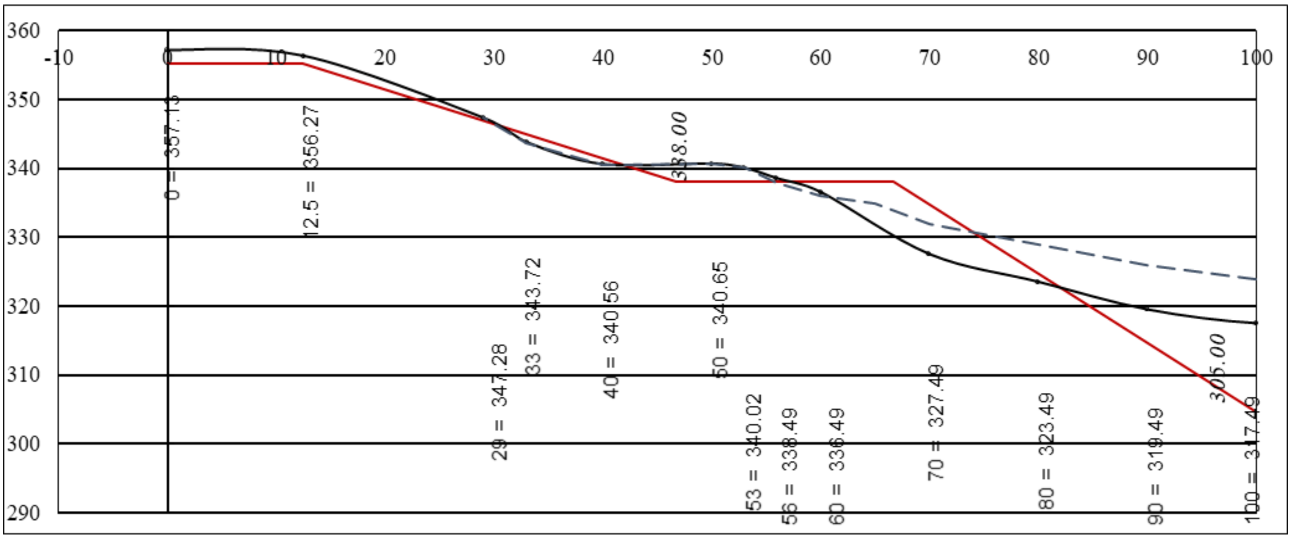

Figure 3. X-section at line 300

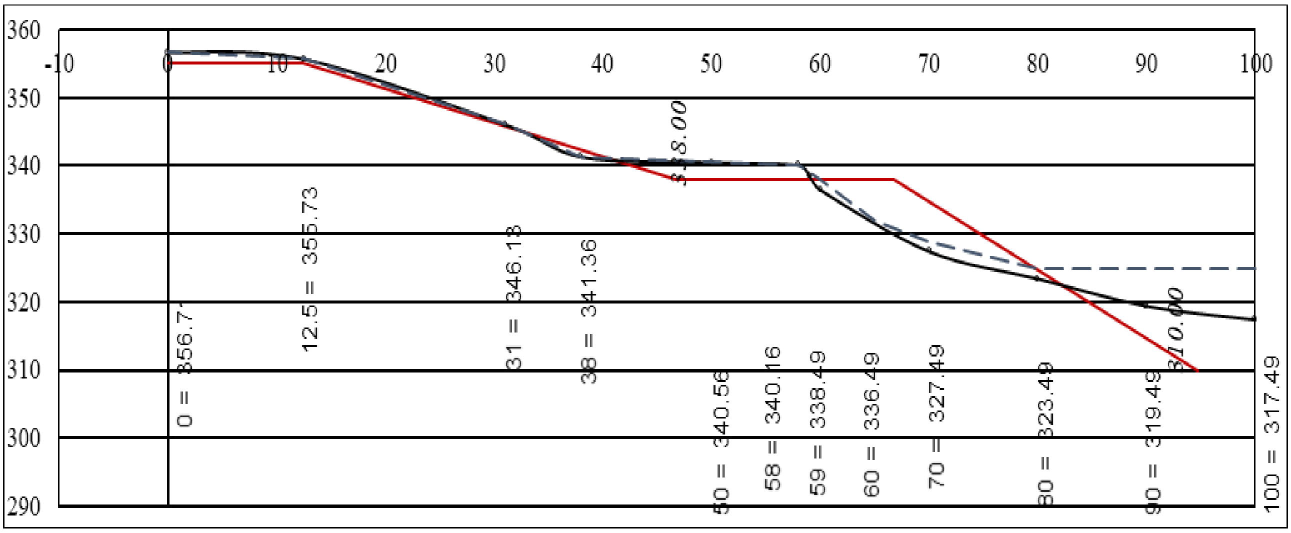

Figure 4. X-section at line 400

III. RESULTS AND DİSCUSSİON

River Chenab Shifting Tendency:

From RD: 52+000 to RD30+000 RMB U/S, the river flows towards the right along RMB in a single stream. To safeguard public infrastructures and the RMB from river erosion and damage, river training works including J-Head spurs, Mole head spurs, sloping spurs, stone studs, and apron along RMB are implemented in this stretch. This section consistently remains exposed to the risk of flood damage because the primary current of the river flows rightwards along RMB. Figures 5 and 6 depict the river's course from RD 30+000 to 52+000 along the RMB U/S of the barrage, highlighting the flow of the Chenab's main current. However, this specific stretch faces a potential threat of erosion along the RMB and the associated structures, such as spurs. These protective measures, installed with the explicit goal of safeguarding public infrastructure and the RMB, are susceptible due to the force and direction of the river's flow. The intricate nature of these observations emphasizes the complex and interconnected relationship between the river's flow patterns, the functionality of the barrage, and the ecological impact on the surrounding areas. A profound understanding and strategic approach to address these complexities are essential for devising effective mitigation strategies and ensuring the sustainability of infrastructure.

Figure 5. Vulnerable Reach RD30-52 RMB

The extensive field investigation carried out during data collection provided insight into the complex dynamics within the Chenab River's course, especially in relation to its interaction with the PJD Barrage. At a critical point roughly 2000 ft. (field measurement) U/S of the main weir, the convergence of the river's primary streams occurs as sub-streams join, aligning prominently with the left side along the Left

Marginal Bund (LMB). However, the breadth of this mainstream flow, estimated at approximately 1000 ft. (field measurement), becomes a crucial aspect, especially at bay no. 1-12, due to the variable nature of the river's supply at the PJD Barrage.

Figure 6. Vulnerable Reach RD40+000 RMB

This part of the study focuses on the river stretch from RD 52+000 to RD 30+700 U/S of the PJD Barrage along the RMB. The river flows towards the right along the RMB in a single stream, presenting challenges related to river erosion and potential harm to public infrastructure. To counter these risks, various river training works have been implemented in this section, including J-Head spurs, Mole head spurs, sloping spurs, stone studs, and apron along the RMB. The importance of this research lies in the continuous threat of flood damage in this specific stretch due to the rightward flow of the primary current along the RMB. Despite the protective measures in place, this area remains at risk of erosion along the RMB and associated structures like spurs. Vulnerability arises from the force and direction of the river's flow, affecting the efficacy of protective spurs. The intricacy of these observations underscores the complex relationship between river flow patterns, the functioning of the barrage, and the ecological impact on the surroundings. To effectively address these complexities and ensure the sustainability of infrastructure, a deeper understanding is necessary.

In the extensive field study, data collection offered insights into the dynamics of the Chenab River, particularly its interaction with the PJD Barrage. At a critical point about 2000 ft. U/S of the main weir, the main streams of the river converge, aligning notably with the left side along the LMB. The width of this mainstream flow, estimated at around 1000 ft., becomes pivotal, especially at bay no. 1-12, due to the variable nature of the river's supply at the PJD Barrage. In technical terms, the challenges in this section stem from the rightward flow of the river, necessitating robust training works to mitigate erosion risks. The implemented structures, including J-Head spurs and stone studs, aim to redirect and manage the river's course, protecting the RMB and associated infrastructure. However, the persistent threat of erosion indicates the need for continuous monitoring and potential adjustments to the training works. The convergence of the main streams near the main weir introduces complexities, influencing the width of the mainstream flow. This variability, particularly in bay no. 1-12, underscores the dynamic nature of river supply at the PJD Barrage. Understanding these dynamics is crucial for devising effective mitigation strategies and ensuring the sustainability of infrastructure.

Sub-Stream Formation:

In Figure 7, it is depicted that the main flow of the Chenab River is separated into two sub-streams at RD 36+700 RMB U/S of the PJD Barrage. These two sub-streams individually approach the Barrage and merge at RD: 3+000 U/S of the PJD Barrage. Following the confluence of these sub-streams, a primary stream is formed, proceeding towards the main weir in front of Bay No.1-12. One of the sub-streams, on the right side, flows along the RMB towards the Barrage, while the other flows on the left side, parallel to the LMB. The river Sutlej joins the Chenab River in this left side sub-stream approximately 15 km (measurement taken by Google Earth Software) U/S of the main weir. A permanent island has emerged between the aforementioned sub-streams from the starting point to the Barrage due to the limited water supply at the Barrage throughout the year. This island spans from Bay No.13-50, situated just 800 ft. (field measurement) away from the weir on the U/S side. The formation of this island diminishes the efficiency and flood-passing capacity of the Barrage.

Figure 7. Sub-streams formation at RD 36+700 RMB

Island Formation:

In Figure 8, it is illustrated that the Chenab River approaches the barrage with two primary streams originating from RD30+000 U/S RMB and merging just 2000 ft. U/S (field measurement) of the main weir. This supply displays inconsistency throughout the year, mainly designated for canal off-takes. Consequently, to uphold the U/S pond level and cope with the variable supply, it becomes essential to keep the barrage gates closed. This underscores the challenges associated with the fluctuating river supply. The repercussions of this supply fluctuation are notably evident in the formation of islands or Bela in front of the main weir, particularly between gates no. 13-50, situated only 800 ft. (field measurement) U/S of the main weir. This Bela formation intensifies challenges during flood seasons, significantly reducing the barrage's capacity to pass floods and disrupting the smooth flow of the river's primary current towards the barrage. This critical scenario emphasizes the intricate impact of the river's varying supply on the operational efficiency of the barrage and its ability to effectively manage floodwaters.

Figure 8. Aerial view of Panjnad barrage

IV. CONCLUSION

- The PJD barrage, positioned to the left of Chenab's original flow plain, induced a consistent rightward shift in the river's course.
- Alterations in the Chenab's flow pattern post-barrage construction are responsible for the erosion observed along the RMB and its associated river training structures/spurs U/S of the barrage.
- The continual deviation led to persistent erosion along the RMB and its affiliated constructions. To mitigate this, various spurs were erected along the embankment to redirect the flow towards the barrage without compromising the structure's integrity.
- Due to the ongoing erosion, sedimentation occurred, resulting in the formation of islands and sandbars U/S of the barrage. The continuous growth of islands altered the natural course of the Chenab, causing the river to split into two major streams. This separation occurred at RD: 36+000 U/S due to erosion and subsequent siltation, fostering the annual growth of islands.

In this research, we focused on studying the Chenab River upstream of the Panjnad Barrage, specifically addressing erosion concerns along the RMB from a Reduced Distance (RD) 50+000 to 30+000. Through an 18 km field survey using plane table survey techniques, leveling tools, compasses, and plane table boards, we mapped the terrain around key areas. Our examination revealed islands near bay number 13–50 caused by reduced Chenab flow, impacting the area from RD 30+000 to 50+000 with braiding, sandbars, and sediment influx during monsoons. Despite previous interventions, erosion persists along the Chenab's right bank, with Sutlej-induced flooding damaging LMB up to J-Head Spur RD 5+500 LMB, posing a threat to the upper curved segment of RGB.

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