Engineering and Technology Journal
Journal homepage: https://etj.uotechnology.edu.iq

Effect of Bridge Piers Locations and Flow Intensity on Morphological Change in a 180-Degree River Bend

Abdurazaq K. Abdulwahd*, **Jaafar S. Maatooq**

Civil Engineering Dept., University of Technology-Iraq, Alsina'a street, 10066 Baghdad, Iraq.
*Corresponding author Email: bce.19.44@grad.uotechnology.edu.iq

HIGHLIGHTS

- Maximum scour depth, is 1.8 times the pier width for the bridge at 90° and much lower at the pier at 150°
- The change of discharge value with the same intensity creates symmetric morphology vicinity of the piers
- The findings showed that the intensity component was more significant than the discharge

ARTICLE INFO

Handling editor: Mahmoud S. Al-Khafaji

Keywords:
Flow intensity
Bridge piers
Morphology
Experimental investigation
180-degree bend

ABSTRACT

Bridges when it crossing rivers often required multiple piers for support. One of has a limited investigation is the impact of piers on scouring and morphological aspects when a bridge crossing sharp-bend of river. Consequently, it is crucial to investigate the hydraulic behavior of water flow in these areas due to the presence of these piers. In present study, an experimental program was conducted on a laboratory flume featuring a two-pier bridge within a 180-degree (sharp) bend to accomplish this. The piers were strategically positioned at 90 and 150 degrees within the bend. The results indicated that the bridge within the 90°, under the threshold intensity condition, led to significant local scour depths around the piers. Specifically, the scour depths were found to be 1.80 and 1.15 times the width of the pier for the piers close to the outer and inner banks, respectively. The discharge increased from 240 l/min to 280 l/min while maintaining the same intensity of 0.85, resulting in a symmetric local scour depth at the pier near the outer bank. In contrast, the local scour depths in response to the piers in the 150° were considerably lower; at the threshold with a discharge of 280 l/min, the scour depths were measured to be 0.65 and 1.18 times the pier width for the inner and outer piers, respectively. Similar bed morphology was observed when the bridge was positioned at 150° for two discharge values (280 and 240 l/min) with the same intensity of 0.85. The findings showed that an increase or decrease in discharge value, with a constant intensity, did not influence the local scour depth and its extension around the pier close to the outer bank, indicating that the intensity component was more significant than the discharge.

1. Introduction

Scouring is the major cause of bridge destruction, according to statistics and information obtained in some countries [1]. The scour event near the pier significantly reduces its retention length. It exposes the base of the foundation to flow currents, which causes the pier to collapse and inevitably causes the bridge to fail [2]. The water flow colliding with the bridge pier moves to the jet, causing local scour in the bed close to the pier. This phenomenon is linked to flow separation phenomena and vortex formation vicinity of the bridge pier. A horseshoe-shaped vortex in front of the pier and various flow patterns formed vicinity of the pier are characteristics of this phenomenon, which is one of the main reasons for bridge failure [3]. Natural rivers rarely flow straight; their paths typically include bends, meanders, or braids [4]. Most studies have concentrated on scouring at a bridge pier in a straight channel. Among the most studies in the case of a straight line under clear water conditions where that intensity range $0.5 < V/Vc < 1.0$ are: [5-9]. The results of these studies show that the maximum scour depth relative to pier width was informed in a wide variety from 0.75 to 2.5, and a peak of scour depth was seen in most cases at $V/Vc = 1$. Ettema et al. [10] Employed Polystyrene particles to cover the bed of the experimental flume to simulate scour at bridge piers, with an intensity range of 0.8 to 8.5. The results show that the maximum scour depth increased with flow intensity. The most incredible scour depth was 3.3 times the pier diameter at an intensity of 8.5 and followed a logarithmic curve. Although local scour at a bend is extremely important, and numerous studies have been undertaken to date, most of the research within the curve was based on the incipient motion at threshold intensity, some of which were as follows: [11-18].

http://doi.org/10.30684/etj.2023.140134.1455
Received 07 May 2023; Accepted 17 June 2023; Available online 01 July 2023
2412-0758/University of Technology-Iraq, Baghdad, Iraq

Emami et al. [19] studied scour in a straight and U-shape channel with a central angle of 180o for intensities (V/ Vc) 0.56, 0.66, 0.75, and 0.79. Masjedi et al. [20] conducted the study in a laboratory flume with a 180-degree curve for adopting a single ogival model pier under clear water condition. Rasaei et al. [21] created a physical model with a converging bend at an angle of 90^o under clear water condition to measure local scour which formed around a cylindrical pier positioned at 0^o, 30^o, 45^o, 60^o, and 75^o. Previous research discovered that the investigation of the influence of intensity and discharge together was not addressed, particularly when employing two-oblong piers in clear water conditions. This research highlights the most influential factors on local scour around piers for multi-oblong bridge piers constructed on curved river paths, specifically focusing on factors such as discharge and intensity.

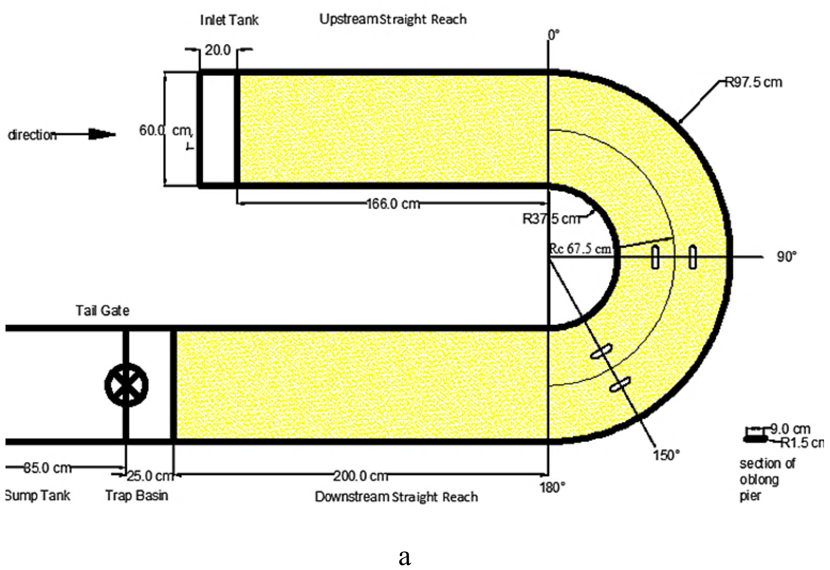
2. Methodology

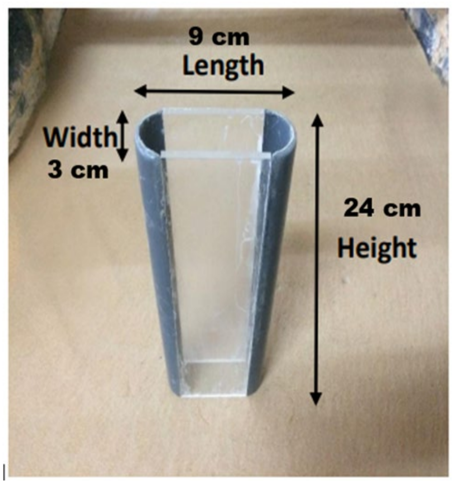
2.1 A laboratory U-shaped Flume

A laboratory flume1.66 and 2 meters in length of the straight reaches located upstream and downstream of the U-shaped bend in the hydraulic laboratory of the civil engineering department at the University of Technology-Iraq, was used for the experimental program of the present study. The working portion that joins these two reaches is U-bend at an angle of 180 degrees. Its radius of curvature is 0.375 m at the inner bank, 0.675 m at the centerline of the flume, and 0.975 m at the outer bank, as depicted in Figure 1a. The width of the flume for all straight and bend segments is 0.6 m to confirm that Rc/B =1.125 < 3, sharp bend as recommended by [22], where Rc is the radius at the centerline of the bend, and B is the width of the bend. A centrifugal pump's capacity flow rate of 280 l/min (4.67 liters per second), powered by a rotameter-type flow meter that acted as a discharge measurement device, was used to deliver water from a sump tank to the flume. A manually controlled valve selected the desired discharge. The depths of the bed at the end of each run were determined using a point gauge and a laser instrument which have been used by many researchers as [13, 14, 16, 21, 23, 24] .

2.2 Setup and Procedure

The flume bed was covered with homogenous sand to a depth of 12 cm, with median particle size d50 = 0.305 mm, and the degree of uniformity of the particle size distribution is σg = 1.278. This value is smaller than 1.3, which was used to measure sand particle uniformity [25]. Two oblong piers with 12 cm in length and 3 cm in width are equally center to center spaced at 0.2 m from the flume sides, and the span in between has been installed to simulate a bridge crossing; the rectangular pier's length must be at least three times its width as recommended by [7]. To avoid the wall impact on scouring, [25] recommends that the pier diameter not exceed 10% of the flume width. This bridge crossing was installed once at sector 90^o and again at sector 150^o with different discharge and flow intensity to understand the effect of both the intensity and the discharge on the local scour depth and morphological aspect near the bridge crossing consisting of two-oblong piers, as shown in Figure 1b. The bed's topography has been measured using point gauge equipment and a laser distomat device, which divided the flume on mish taken around the piers by taking the center angle, every 1 or 2 degrees, and the transverse distance, every 2 cm. For the remaining part of the bend, are taken every 10 degrees centrally and every 2 cm transversely. The duration for all experiments is 6 hours; this period was adopted based on the recommendations of previous studies that adopted nearly similar flow conditions through which the scour approached an equilibrium state [20, 21, 26, 27]. Then the water was allowed to slowly drain down the channel for a period of 24 hours to preserve the topography and prevent any potential impact. It is important to note that all experiments should be conducted under clear water conditions and subcritical flow.





b

a

Figure 1: a) Photo of pier and b) Plan sketch of the flume illustrates the dimensions and locations of the bridge crossing undertaken

3. Results and Discussion

Previous investigations of stream flow within the bend revealed that the apex area (90º sector) is subjected to the greatest secondary flow strength [14]. To study the effect of intensity and discharge within the second part of the bend, the 150º sector was chosen. Table 1 shows the position of two-oblong piers with two different discharges and intensities used.

Table 1: Shows the bridge located at the bend with various discharges and intensities

Case No.	Bridge location	Discharge l/min	Intensity V/Vc	Depth of water (cm)
1	90º	280	0.98	3.5
	90º	280	0.84	4
	90º	240	0.85	3.5
2	150º	280	0.98	3.5
	150º	280	0.84	4
	150º	240	0.85	3.5

3.1 Effects of Intensity and Flow Rate on Local Scour and Morphology When Bridge Located at Mid-Sector of Bend

The bridge at sector 90º of the bend is exposed to two flow rates and three flow intensities. Traditionally, the sediments accumulate on the inner bank due to centrifugal forces and the difference in water height between the outer and the inner banks of the flume, which causes the secondary current moves from the outside to the inside at the bed of the flume and transports the sediments from the outer bank, thereby increasing the amount of sediment feeding from the external bank [28-29]. This hydrodynamic phenomenon leads to resulting less scour vicinity of the inner pier. At threshold case where discharge and intensity 280 l/min and 0.98, respectively, the local scour at the pier near the internal bank is 1.15 times of pier width while the local scour vicinity of the outer pier is up to 1.8 times of pier width and remains adjacent the inner leeward of the outer pier's flank as the depicted in Figure 2c that is attributed to of the maximum velocity oriented to the outer bank at the flow surface and take its higher action at the apex of bend (sector of 90º). This action causes an increase in the downflow velocity at the nose of the pier close to the outer bank [30]. Whereas rises in secondary flow strength led to increased sediment movement from the outer to the inner bank, as illustrated in Figure 2a and Figure 2b. Noteworthy, these figures depict the sediment accumulation downstream of the pier close to the inner bank, which is transported from the outer bank, and the action of the horseshow vortex vicinity of the pier close to the internal bank. While Figure 2c shows that the area between the piers is susceptible to erosion due to contraction scour.

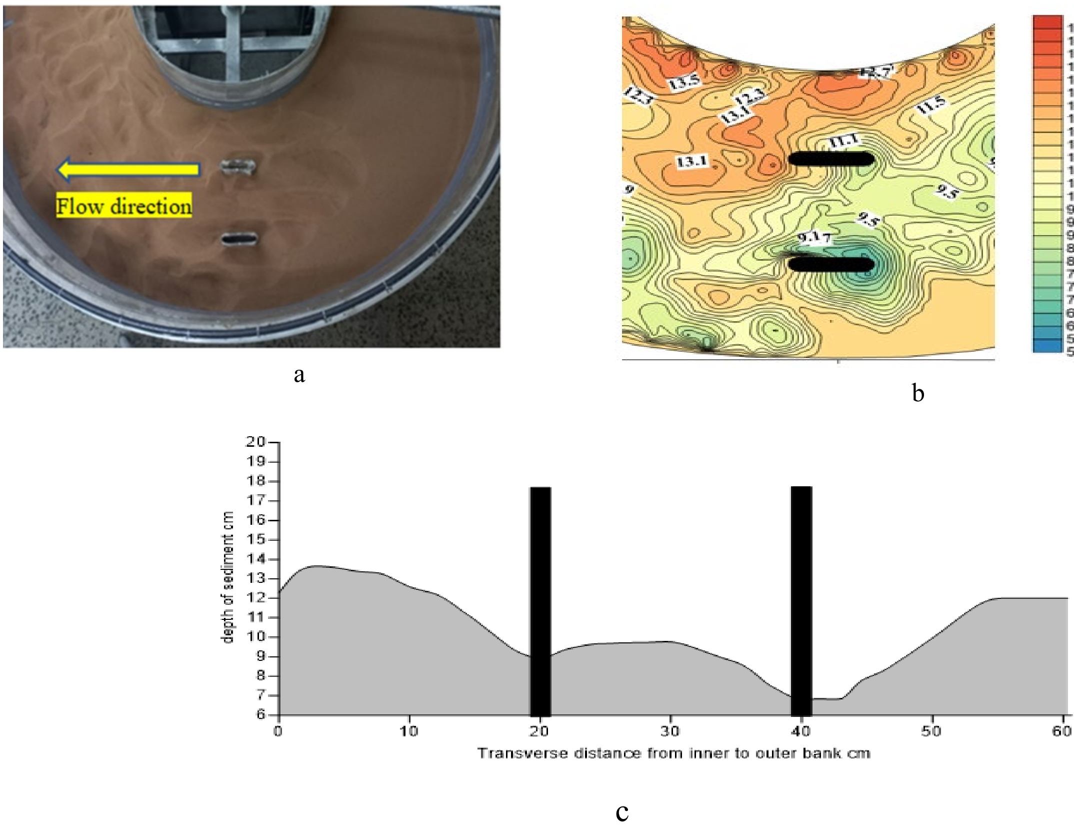


Figure 2: Idge located at a 90° sector with Q = 280 l/min, V/Vc = 0.98 :a) photo at the end of experimental, b) Topography of bed flume vicinity piers, c) transverse profile of bed from the inner to outer bank at 90° angle

Figures 3 (a,b and c) and Figures 4 (a,b and c) show the morphology at the bend with bridge presence at 90º for two values of discharge 280 and 240 l/min with nearly the same flow intensity of 0.85. It is noteworthy that the same morphology, despite the discharge, altered. It also observed that the bed within the bend reach kept in the plan without the formation of ripples or dunes up to 90º sector except near the inner bend, which effect by the initiation of the secondary current action. In general, a decrease in intensity causes a rise in the local scour vicinity of the pier close to the inner edge, continuing next to the inner leeward of the inner pier, and a decrease near the pier close to the outer edge. While increased intensity, on the other hand, causes a reduction in the local scour vicinity of the pier near the inner edge and an increase around the pier near the outer edge. This is attributable to the concentration of the streamlines moving towards the inner edge of the channel within the apex area, while at the second half of the curve, the streamlines shaft towards the outer edge.

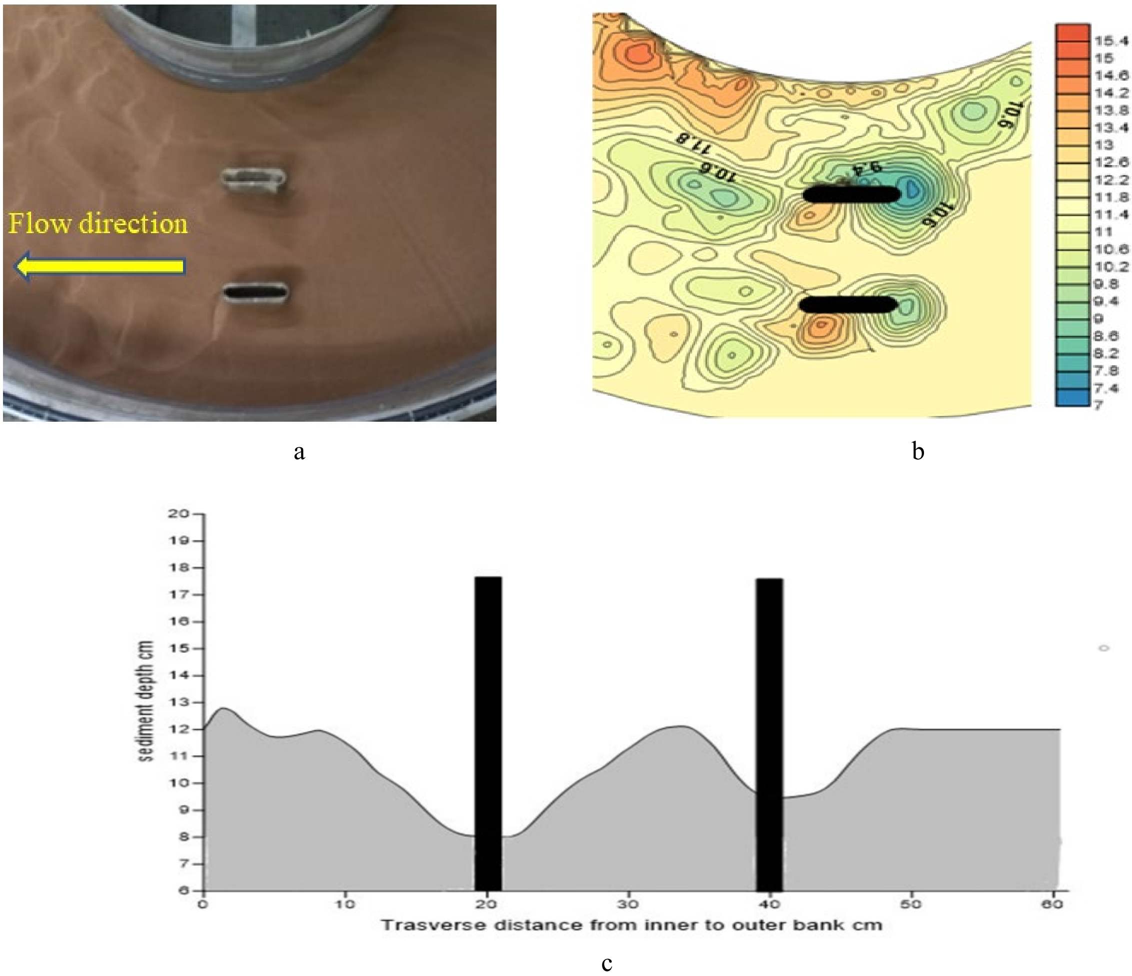


Figure 3: Piers located at sector 90º with Q = 280 l/min, V/Vc = 0.84: a) photo at the end of experimental, b) Topography of bed flume vicinity piers, c) transverse profile of bed from the inner to the outer bank

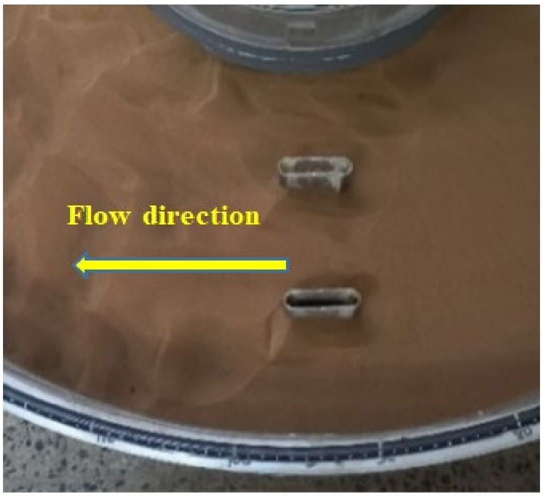
Figure 5a and Figure 5c shows local scour depth at the pier noes near the inner bank at sector 90º for different discharge and intensities. It observed that when the discharge of 280 l/min and the intensity of 0.98, the local scour depth is equal to 1.0 times of pier width which is less than the local scour depth at the intensity of 0.85 with two discharges of 280 and 240 l/min, causes an increase in local scour measured 1.46 and 1.6 times the pier width respectively, that's because at high intensity the amount of sediment transported from outer to inner reduces local scour at the pier near the internal bank more than in the case where the intensity 0.85. As a result, the local scour increased significantly with decreasing intensity with the same discharge. In contrast, it increased slightly with a decrease in the discharge for nearly the same intensity, which indicates that the intensity has more effect on local scour phenomena than the discharge.

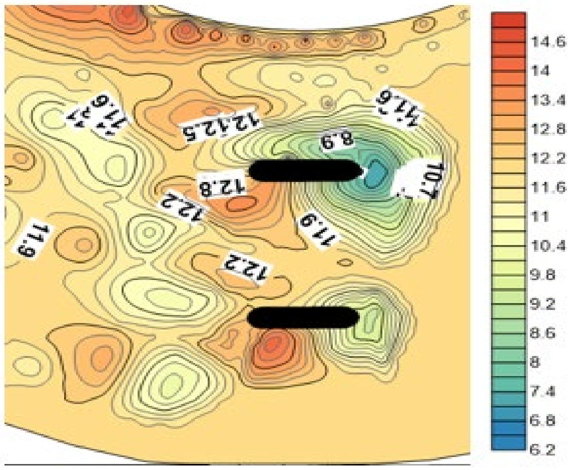
Figure 5b and Figure 5c shows the local scour depth at the pier close to the outer bank; it is clear that high scour was recorded with the intensity 0.98, at which the scour measured 1.8 times the pier width, while the local scour depth is significantly decreased with intensity at 0.84 for the same discharge, where it becomes 0.93 times the pier width. On the other hand, it is evident from Figure 5c that the change in discharge with keeping the intensity nearly constant does not significantly affect local scour. Furthermore, the intensity of 0.98 with a high flow rate causes sediment to be carried from the zone of local scour at the outer pier to the site of the inner bank, hence accelerating local scour in the outer pier.

3.2 Effects of Intensity and Flow Rate on Local Scour and Morphology When Bridge Located at Sector 150°

As is apparent when the bridge at sector 150° of bend with two flow rates and three intensities. Conventionally, the small depth of local scour at the piers closed to the inner and outer banks due to the moderately distributed velocity, secondary flow gradually weakens, and the core vortex weakens [31].

At the threshold case, which discharge and intensity of 280 l/min and 0.98 correspondingly, the erosion slope increases slightly towards the outer pier and increases suddenly to the external bank; the local scour depths are 0.65, 1.18 times of pier width for the inner and outer piers respectively as depicted in Figure 6a and Figure 6b. According to Figure 6c that the area impacted by erosion vicinity of the outer pier is enormous, which is attributed to the orientation of secondary currents in the second half of the curve moving from the external to the inner bank at the flume bed, causing the erosion area to extend towards the flume's internal bank.





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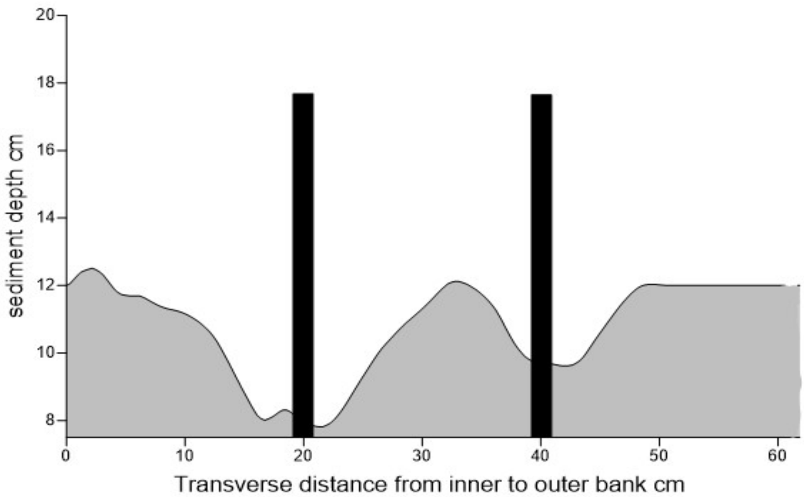

c

Figure 4: Piers located at sector 90° with Q =240 l/ min, V/Vc = 0.85: (a) photo at end of experimental, (b) Topography of bed flume vicinity piers,(c) transverse profile of bed from the inner to outer bank

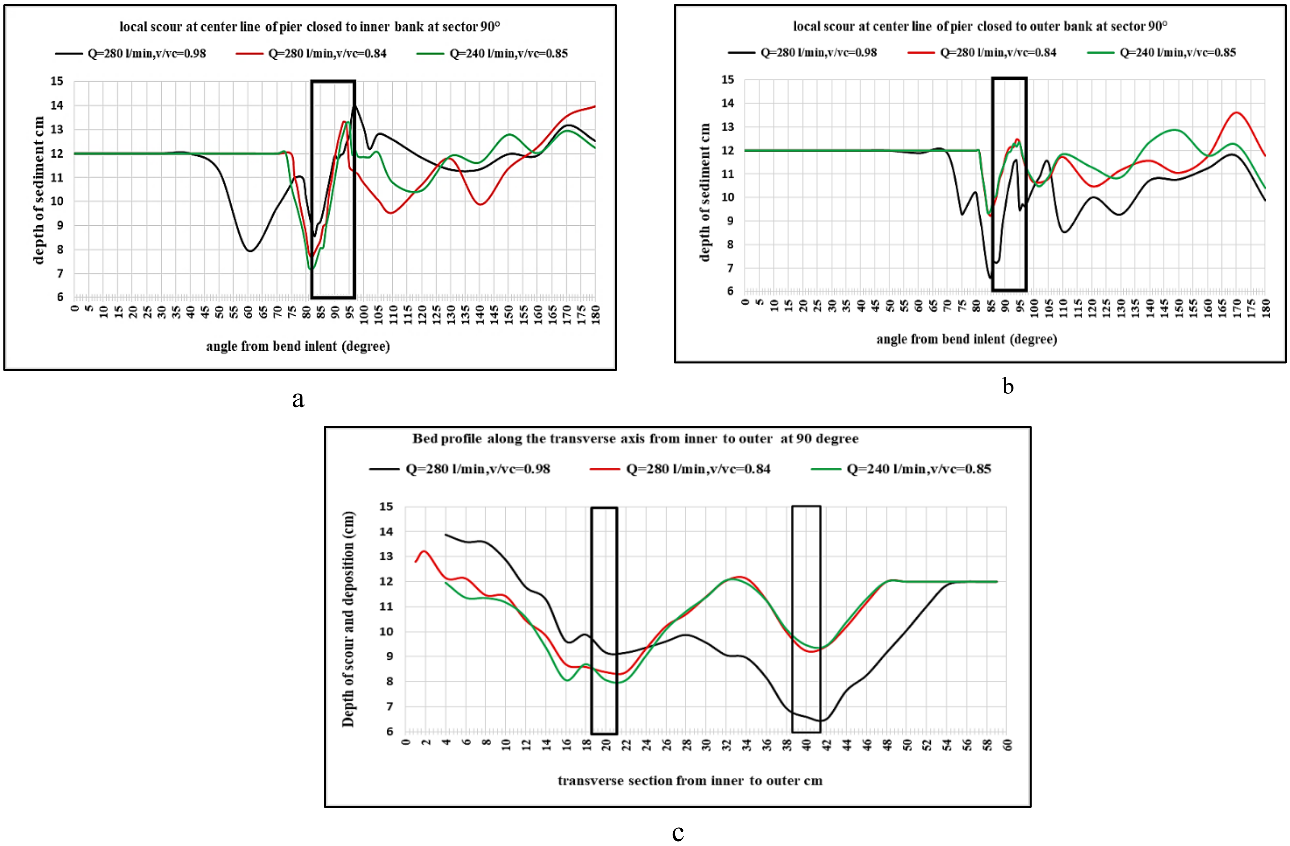

Figure 5: Profile of bed when bridging located at sector 90° with Q = 280, 240 l/min and V/Vc = 0.98, 084 and 0.85, a) Longitudinal profile of bed at the pier close to the inner bank, b) Longitudinal profile of bed at the pier close to the outer bank, c) transverse profile of bed from the inner to external bank with change in discharge and intensity

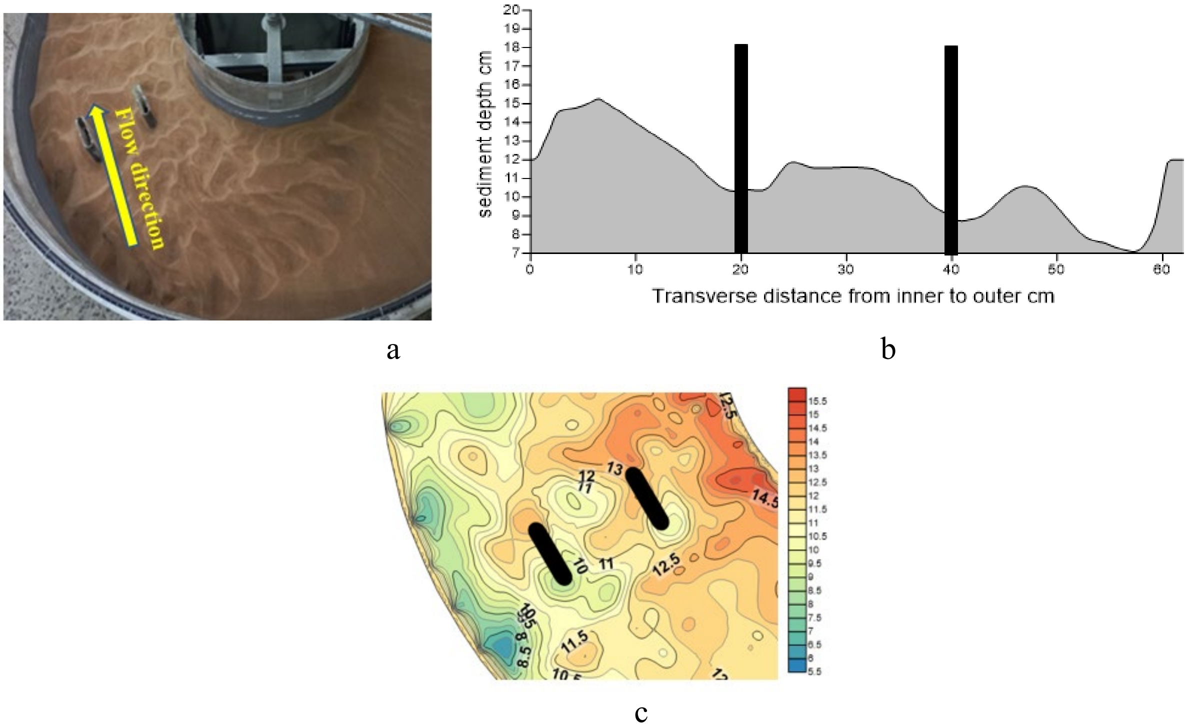

Figure 6: Bridge located at a sector 150° with Q = 280 l/ min, V/Vc = 0.98, a) photo at end of experimental, b) Topography of bed flume vicinity piers, c) transverse profile of bed from the inner to outer bank

Figure 7 (a,b and c) and Figure 8 (a,b and c) show, respectively, the morphology at the bend with bridge presence at 150° for two values of discharge 280 and 240 l/min with the same intensity of 0.85. It is significant that the same morphological, despite discharge, altered with slightly increased erosion at raised discharge. It also observed that the intensity drops to 0.84 with a constant discharge of 280 l/min, and the local scour depth increases at the pier closest to the inner edge, as shown in Figure 7b and Figure 7c; this is attributed to the high discharge causes huge transports sediment from the outer edge to the inner edge, whereas the decrease in intensity causes a decrease in local to scour depth. While the reduction in discharge and intensity leads to the decline in local scour depth for both piers, this is attributed to an insufficiency of sediment movement and the behavior of the streamline in the bend as a straight line, as illustrated in Figure 8b.

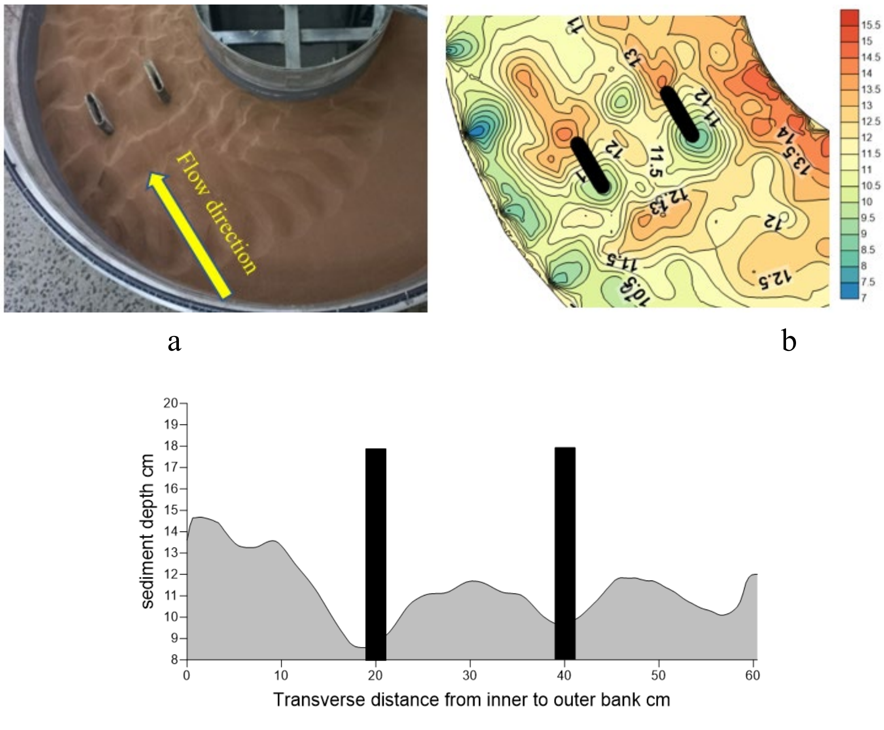

Figure 7: Bridge located at a sector 150° with Q = 280 l/min, V/Vc = 0.84, a) photo at end of experimental, b) Topography of bed flume vicinity piers, c) transverse profile of bed from the inner to outer bank

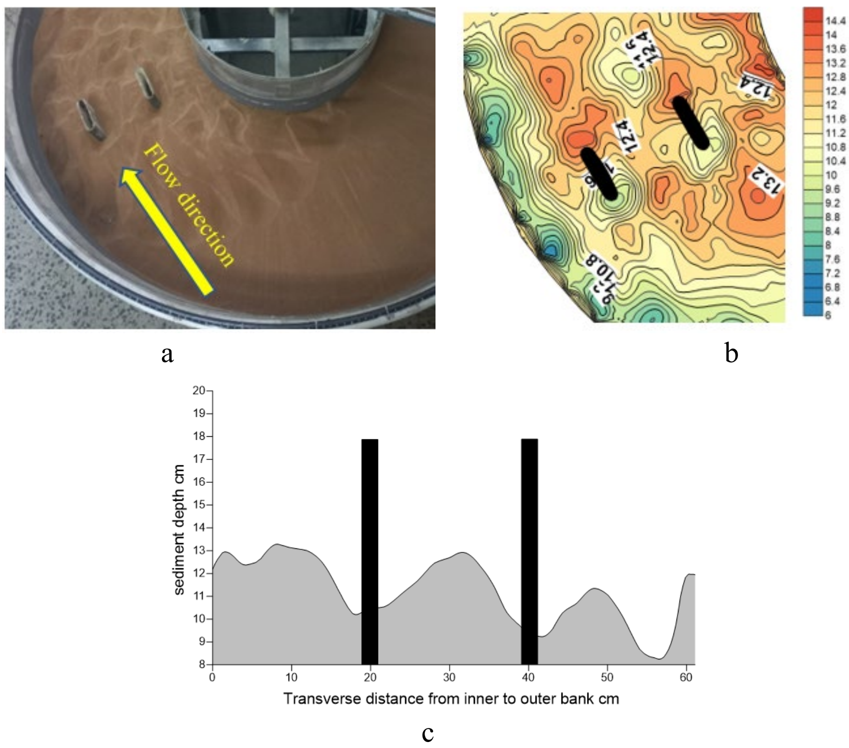

Figure 8: Bridge located at a sector 150° with Q = 240 l/ min, V/Vc = 0.85, a) photo at end of experimental, b) Topography of bed flume vicinity piers, c) transverse profile of bed from the inner to outer bank

Figure 9 (a , c) shows decrease in the local scour at the pier close to the inner bank at sector 150° when the intensity and discharge are increased or decreased simultaneously. At discharge increases, that causes an increase in downflow and scouring up to the nose of the pier. In contrast, intensity increases rationale a rise in secondary current and transport of the sediment from the outer bank to the location of local scour at the inner bank, reducing the downflow effect at the pier close to the inner bank. Conversely, when intensity and discharge decrease, the impact of downflow and sediment movement decreases, and local scour decreases. However, local scour increases due to the effects of downflow on the pier as discharge increases and the absence of sediment transport to the area near the inner bank as intensity decreases.

Figures 9 (b,c) illustrate the local scour at the pier close to the outer bank at sector 150°, which was observed to rise in discharge and intensity, leading to a slight increase in scouring depth, but more eroded in the extended and lateral areas vicinity of the piers. As a result, the volume of scouring has increased. It should be noted that even when the flow rate alters and the intensity is constant, the depth and distribution of local erosion surrounding the external pier remain constant.

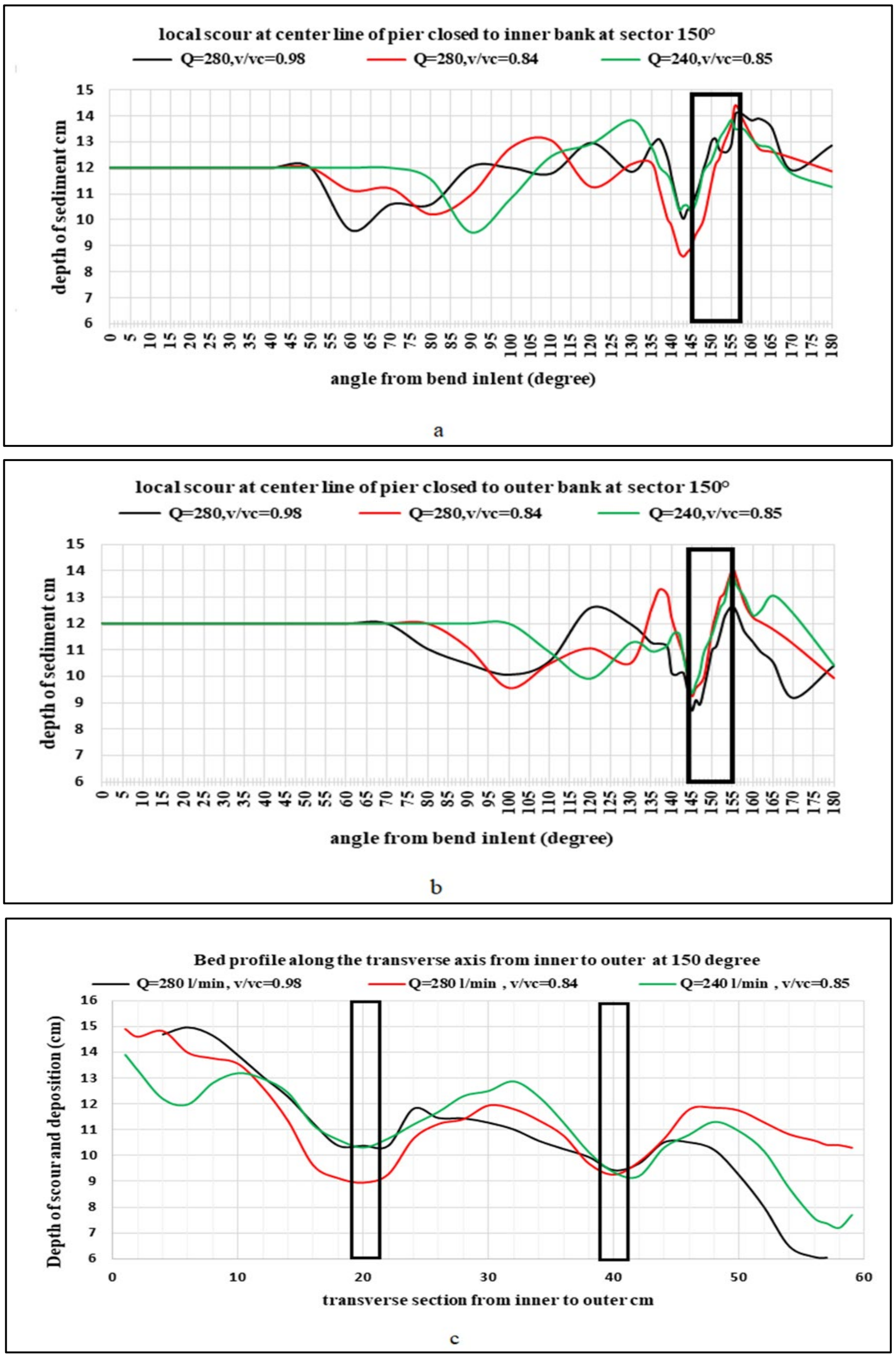

Figure 9: Profile of bed where bridge located at sector 150° with Q = 280, 240 l/ min and V/Vc = 0.98,084 and 0.85, a) Longitudinal profile of bed with change in discharge and intensity at the pier close to the inner bank, b) Longitudinal profile of bed with change in discharge and intensity at the pier close to the outer bank, c) transverse profile of bed from the inner to outer bank with change in discharge and intensity

4. Conclusion

After a detailed review based on the analysis of laboratory results, it is useful to summarize the conclusions below;

1) When the bridge crossing the apex area of the bend, at the threshold case with discharge 280 l/min, the maximum local scour at the pier closed to the outer and inner bank 1.80 and 1.15 times of pier width, respectively, which leads to the action of secondary current to increase the movement of sediment from the outer to the inner bank.
2) With increasing intensity of flow, it was noted that at sector 90o, there was a decrease and increase in the local scour depth at the pier close to the inner and outer banks, respectively. This can be attributed to the increase in the effectiveness of sediment movement and its transfer from the outer bank towards the inner bank due to the characteristics of centrifugation and secondary vortices. An increase in the discharge from 240 l/min to 280 l/min with the same intensity of 0.85 has a symmetric local scour depth at the pier close to the outer bank. Furthermore, the flow intensity has more impact on the local scour than the discharge.
3) When the piers were installed at sector 150°, the local scour depth at the pier close to the inner was less than that recorded around this located near the outer banks. Furthermore, the local scour depth at the pier close to the inner edge decreases when the flow rate and intensity increase or decrease simultaneously. At the threshold case, with discharge and intensity of 280 l/min and 0.98, the erosion slope increases slightly towards the outer pier, suddenly increasing close to the outer bank; the local scour depths are 0.65 and 1.18 times the pier width for the inner and outer piers respectively. The same bed morphology has been observed when bridge presence at 150º for two values of discharge 280 and 240 l/min with the same intensity of 0.85.
4) A slight increase in local scour was recorded at the pier close to the outer bank when installing the bridge at a sector of 150° with the increase of discharge and flow intensity, but that increase was more erosive at the extended and lateral areas adjacent to the piers. It should be noted that even when the flow rate increases or decreases and the intensity is constant, the depth and distribution of the local scour surrounding the outer pier remain almost constant.
5) The intensity is the main impact factor controlling sediment transport from the outer to the inner bank.

Author contributions

Conceptualization, A. Abdulwahd, and J. Maatooq; methodology, A. Abdulwahd, and J. Maatooq; Software, A. Abdulwahd; validation, A. Abdulwahd, and J. Maatooq; formal analysis, A. Abdulwahd, and J. Maatooq; investigation, A. Abdulwahd; resources, A. Abdulwahd, and J. Maatooq; data curation, A. Abdulwahd, and J. Maatooq; writing—original draft preparation, A. Abdulwahd; writing—review and editing, A. Abdulwahd, and J. Maatooq; visualization, A. Abdulwahd, and J. Maatooq; supervision, J. Maatooq; project administration, A. Abdulwahd; funding acquisition, A. Abdulwahd, All authors have read and agreed to the final version of the manuscript.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Data availability statement

Not applicable

Conflicts of interest

The authors of the current work do not have conflicts of interest

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