BJES Basrah Journal for Engineering Sciences

Basrah Journal for Engineering Sciences, Vol. 25, No. 2, (2025), 75-82

Original Article

Journal homepage: https://bjes.edu.iq/bjes
ISSN (Online): 23118385, ISSN (Print): 18146120

Impact of Contraction Scour in Tigris River on Al-Nuhairat Bridge in Basrah Governorate

Abdulsattar A. Alhasan [1]*, Mohamad Alyounis [2], Mohammed H. Al-Tofan [3]

[1,2,3] Department of Civil Engineering, College of Engineering, University of Basrah, Basrah, Iraq
E-mail addresses: pgs.abdulsattar.abdul24@uobasrah.edu.iq , Mohamad.essa@uobasrah.edu.iq , mohammed.sabhan@uobasrah.edu.iq

Article Info

Article history:
Received: 25 August 2025
Revised: 9 September 2025
Accepted: 22 September 2025
Published: 31 December 2025

Keywords:
Clear water,
Cohesive soil,
Live bed, Scour depth,
Al-Nuhairat bridge,
Hydraulic.

https://doi.org/10.33971/bjes.25.2.8

Abstract

This study addresses of contraction scour affect in Tigris River on Al-Nuhairat Bridge on the Basrah Governorate. It includes an analysis of key hydraulic variables and their interaction with the geological nature of the river and structural behavior of the concrete bridge, influencing the development of erosion. The data were entered and analyzed into the Federal Highway Administration (FHWA) hydraulic toolbox. The data were collected through a field survey of the bridge site and information obtained from the Directorate Irrigation of Basrah, some tests was also conducted at the Soil Laboratory of the University of Basrah. Two computational methods were used to determine the scour depth, erosion through clear-water and live -bed scour and cohesive soil erosion. The results of the study showed that the depth of scour in the live-bed and clear water flow method increases by 25% approximately with each increase in the depth of flow and the amount of discharge. However, in the cohesive soil method, it depends on the effect of the shear force resulting from the velocity and depth of flow, which is much less, as its effect is 1% approximately with each increase in these parameters. The results of each method were discussed in detail, and the necessary recommendations were made to mitigate the effects resulting from the occurrence of such a type of scour and its impact on the Al-Nuhairat bridge.

1. Introduction

Contraction scour occurs when a river flow narrows due to natural conditions or human activity, such as river migration or bridge construction, as show in Fig. 1 (a) and (b). The constricted area experiences increased flow velocity due to the reduced flow area, which increases the shear stress on the riverbed and its sides. This leads to soil erosion, bed subsidence, and expansion.

There is a subscriber effect between contraction scour on the one hand and general scour and local scour on the other hand, as it is linked to local scour by the presence of the bridge structure that constitutes an obstacle to flow, which causes an increase its speed and the occurrence of erosion in both cases. As for its link to general scour, erosion occurs in both of them in the river basin in general, but general scour is along the river course for long distances, while contraction scour is limited to the bridge area only [1]. One of the natural causes that lead to the narrowing of a channel or river is the presence of any natural obstacle such as earthen dams on both sides of the river, which leads to a reduction in the flow through the bridge opening, causing the removal of materials from the river bed and banks in all or most of the width of the channel [2]. Presence of embankment on both sides of the river leads to reducing the high flow area of water associated with intense floods, which leads to an acceleration of the water flow by creating a complex flow that exceeds the bridge opening, which may cause serious destruction of the bridge foundations, especially if the foundations are not deep [3]. The rise in the water level of rivers and the acceleration of the flow due to rainfall and its passage through the area of the river that is leads to a reduction in the area of flow in this region as a result of the presence of bridge piers, supports, bends, etc., the flow of water generates high kinetic energy that transforms the soil into fine particles, a portion of which remains in place while the other portion is carried with the water current in the body of the river, where the transfer of sediment increases with the increase in flow [4]. Increase flow velocity across the bridge opening when it is narrower than the natural section of the river is usually stronger during floods and causes the removal of sediments from the sides and bottom of the river. Several factors may be involved in influencing the contraction scour process, including the geometry of the channel and bridge, the hydraulic properties of the flow, the properties of the components of the river soil, in addition to the properties of the floodplains [5]. The reduction in the cross-sectional area of the river channel due to bridge structure such as piers and abutments in river channels causes an increase in the flow velocity and the occurrence of increased shear stresses that can overcome boundary shear stress of bed, moving sediments and creating shrinkage erosion [6-8]. Contraction scour occurs in two cases of water flow, either through clear water flow, which is the case in which the water does not carry soil sediments in the river bed, or the flow of live water that is laden with sediments during flow, in which the interaction between the transport of sediments and the erosion process takes place. The effect of clear water flow is more severe due to the sediment not being transported to the contract area to compensate for the lost sediments, unlike the flow of live.

water that leads to a reduction in the depth of scour as a result of the sediments carried [7]. Contraction scour occurs in the case of live water flow when the flow velocity in the upstream reaches of the river is greater than the critical flow velocity to transport D_{50}, contraction scour occurs in the case of clear water flow when the flow upstream in the upper reaches is less than the critical flow velocity D_{50} [9]. Depression of the watercourse bed in the contracted area at the bridge opening may be uniform or non-uniform, as it may be deeper in some parts of the cross-section, and that the contraction scour may be periodic or linked to floods. determine contraction scour occurs in four common cases, in the first case, when there is a floodplain on both banks of the river and the flow is outside the natural course when the discharge quantity increases or through floods, leading flow is outside the natural course when the discharge quantity increases or through floods, leading to the return of water through the bridge opening to natural course, in three cases, when the bridge supports are inside the river channel, the natural course of the area river decreases and the flow velocity increases significantly, or on the borders of the river channel and the area of the floodplain is completely blocked, so the flow returns to the natural course of the river, or at a distance from the river channel on the area of the flow in the floodplain decreases. As for the second case, when the water flow is limited within the natural course of the river, but shrinkage occurs in part of it, either naturally, or due to the presence of bridge supports inside the river, the flow velocity increases. In the third case, there is a relief bridge in the upper bank area of the river, with the lack of transport of bed materials in the upper bank by the flow of clear water. The last case is the presence of a relief bridge on a secondary channel on the upper bank of the river, with the presence of a transfer of bottom materials through the living water [10]. Contraction scour can be mitigated in several ways during the design phase through hydraulic and structural Preventive measures that rate I took (NCHRP, 2009) [11], including avoiding sudden expansion and contraction of water flow due to wide piers surfaces that increase the disability area and lead to the formation of eddy swirling water currents that cause erosion. Also, through widening bridge openings when designing piers submerged in the river [7, 12]. Recent studies show that using principal component analysis (PCA) with support vector modeling (SVR) improves the accuracy of predicting contraction scour depth in channels and reveals the most important influencing factors, providing more reliable tools to treatment and risk analysis [13].

Al-Nuhairat Concrete Bridge was selected as a case study as it is one of the important bridges at the entrance to Basrah Governorate, located at the end of the Tigris River extension. The study aims to add more information about contraction scour and its impact on bridge damage in Basrah Governorate through sudden hydraulic events, geomorphology of the river course, and bridge engineering. Took all variables in previous studies that interact with the river soil and bridge structure that effects in contraction scour. This study is considered an important step towards improving the future design capacity of bridges in the governorate, taking into consideration periodic monitoring of bridges, especially after abnormal climatic conditions or changes in river courses

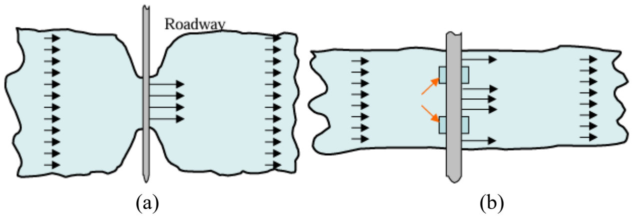


Fig. 1 Cases of riverbed contraction: (a) caused by a narrowing of the channel bed, (b) due to the presence of bridge supports [14].

2. Methodology

This study was conducted to analyze the phenomenon of contraction scour in the Tigris River at the site of the concrete Al-Nuhairat Bridge in Basrah Governorate, as shown in Fig. 2, resulting from the narrowing of the river flow due to the construction of the bridge. Engineering software was used to demonstrate the relationship between the impact of hydraulic parameters on the depth of soil erosion in that area and the extent of its impact on the safety and stability of the bridge. It has done discussion of the results with finding effective the solutions and measures to mitigate the impact of this phenomenon. The necessary recommendations also developed to address future challenges that may pose a threat to the operation of bridges in Basrah Governorate.

Fig. 2 Photograph of the bridge structure in the contraction area.

2.1. Data collection

The assistance from the Basrah Irrigation Directorate was e to obtain hydraulic data by conducting a field survey of the study site using M9. This device is an American SonTek-M9 multi-frequency Doppler sonar sensor used for measuring discharge and mapping longitudinal and cross-sectional rivers by combining depth and flow velocity data. It features high-resolution hydraulic data collection and bed form mapping using acoustic scanning technology, as shown in Fig. 3 (a) and (b). In addition to benefiting from the hydraulic variables previously recorded in the directorate's archives for this site., which constitutes an important part of the research study.

System Information	
System Type	RS-M9
Serial Number	1861
Firmware Version	4.10
Software Version	4.0

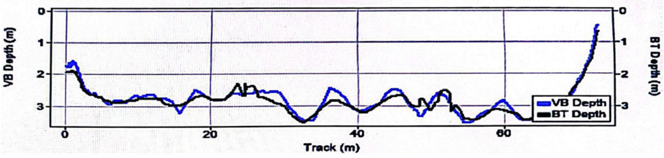
System Setup	
Transducer Depth (m)	0.00
Screening Distance (m)	0.00
Salinity (ppt)	0.0
Magnetic Declination (deg)	0.0

Units	
Distance	m
Velocity	m/s
Area	m2
Discharge	m3/s
Temperature	degC

Discharge Calculation Settings			
Track Reference	Bottom-Track	Left Method	Sloped Bank
Depth Reference	Vertical Beam	Right Method	Sloped Bank
Coordinate System	ENU	Top Fit Type	Power Fit
		Bottom Fit Type	Power Fit
		Start Gauge Height (m)	0.00
		End Gauge Height (m)	0.00

Discharge Results	
Width (m)	67.195
Area (m2)	155.474
Mean Speed (m/s)	-0.390
Total Q (m3/s)	-60.633
Maximum Measured Depth	3.806
Maximum Measured Speed	1.046

(a)



(b)

Fig. 3 Data recorded by M9 sonar device (a) Hydraulic readings of the river, (b) Diagram of the riverbed shape (Shot from device screen).

2.2. Laboratory analysis

Soil samples from river-bed were extracted from the study site and analyzed in the Soil test of the Civil Engineering Department at the University of Basrah. Sieve analysis and hydrometer test by ASTM D6913/D6913M-17, American Standard Test Methods of the Particle Size Distribution (Gradation) of Soils Using Sieve Analysis [15]. Tests performed to extract the average particle size D_{50} from the relationship between the percentage passing and the particle size, as shown in Fig. 4.

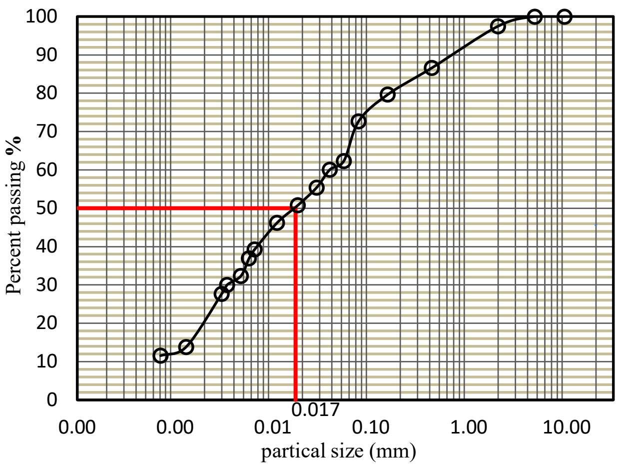


Fig. 4 Grain size distribution curve for soil sediment.

2.3. Data analysis

Used Hydraulic Toolbox to Federal Highway Administration (FHWA) that is custom to hydraulic calculations by enter a Parameters to the program Which applied engineering equations to extract the results.

2.4. Engineering equations used

The specific equations for each of the following methods are used to calculate the scour depth, as follows:

To determine the flow condition in which contraction scour occurs, the average flow velocity is compared to the critical flow velocity for the layer size to be moved, D_{50} as follows:

$$If \quad V_C > V \quad Clear-water\ contraction\ scour.$$
$$If \quad V_C < V \quad Live-bed\ contraction\ scour.$$

$$V_c = K_u y^{\frac{1}{6}} D^{\frac{1}{3}} \tag{1}$$

Where, V_c = Critical velocity above which bed material of size D and smaller will be transported (m/s), y = Average depth of flow upstream of the bridge (m), D = Particle size for V_c in unit (m), D_{50} = Particle size in a mixture of which 50 percent are smaller in unit (m), K_u = 6.19 SI

2.4.1. Equation of live-bed contraction scour

A modified version of the Laursen equation1960 is used for live-bed scour [16].

$$\frac{y_2}{y_1} = \left(\frac{Q_2}{Q_1}\right)^{\frac{6}{7}} \left(\frac{W_1}{W_2}\right)^{K1} \tag{2}$$

$$y_s = y_2 - y_0 \tag{3}$$

Where, y_1 = average depth in the upstream main channel (m), y_2 = average depth in the contraction (m), y_0 = existing depth in the contraction before scour (m), Q_1 = flow in the upstream channel transporting sediment (m^3/s), Q_2 = flow in the contraction channel (m^3/s), W_1 = bottom width of upstream main channel that is transporting bed material (m), W_2 = bottom width of upstream main channel in contraction section less pier width (m), k_1 = exponent determined below:

$$k = 0.59 \quad when \quad \frac{V^*}{T} < 0.5$$

$$k = 0.64 \quad when \quad \frac{V^*}{T} < 0.5\ to\ 2.0$$

$$k = 0.69 \quad when \quad \frac{V^*}{T} > 0.2$$

Where, $V^* = \left({\tau_\circ}/{\rho}\right)^{\frac{1}{2}} = (g y_1\, s_1)^{\frac{1}{2}}$, shear velocity the upstream section (m/s), T = fall velocity of bed material based on the D_{50} (m/s) Fig. 5, g = acceleration of gravity 9.8 m/s^2, S_1 = slope of energy grade line of main channel (m/m), $\tau_\circ$ = shear stress on the bed Pa (N/m^2), ρ = density of water (1000 kg/m^3)

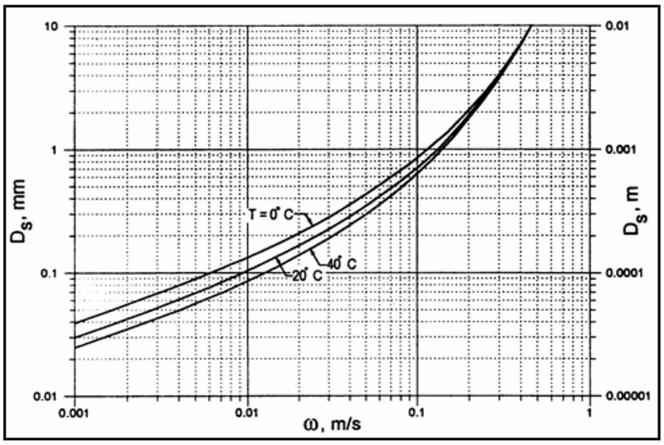


Fig. 5 Fall velocity of sand-sized particles with specific gravity of 2.65 in metric units [10].

2.4.2. Equation of clear-water contraction scour

The following equation, developed by Laursen 1963, is used to calculate clear-water contraction scour [17].

$$y_2 = \left[\frac{K_u Q^2}{D_m{}^{2/3} W^2}\right]^{3/7} \quad (4)$$

$$y_s = y_2 - y_0 \quad (5)$$

Where, y_2 = average equilibrium depth in the contracted section after contraction scour (m), Q = discharge through the bridge or on the set-back overbank area at the bridge associated with the width (m^3/s), D_m = diameter of the smallest no transportable particle in the bed material (1.25 D_{50}) in the contracted section (m), D_{50} = median diameter of bed material (m), W = bottom width of the contracted section less pier widths (m), y_o = average existing depth in the contracted section (m), K_u = 0.025 SI units.

2.4.3. Equation of contraction scour in cohesive soil

The following equation was used for the ultimate corrosion of cohesive materials, based on an analysis of laboratory data by Briaud et al. 2011 [10].

$$y_{s-ult} = 0.94\, y_1 \left(\frac{1.83 V_2}{\sqrt{g y_1}} - \frac{K_u \sqrt{\frac{\tau_c}{\rho}}}{g n y_1{}^{1/3}} \right) \quad (6)$$

Where, y_1= upstream average flow depth (m), V_2 = average flow depth in the contracted section (m/s), τ_c = critical shear stress (N/m^2) Fig. 6, n = manning, K_u = 1.0 for S.I.

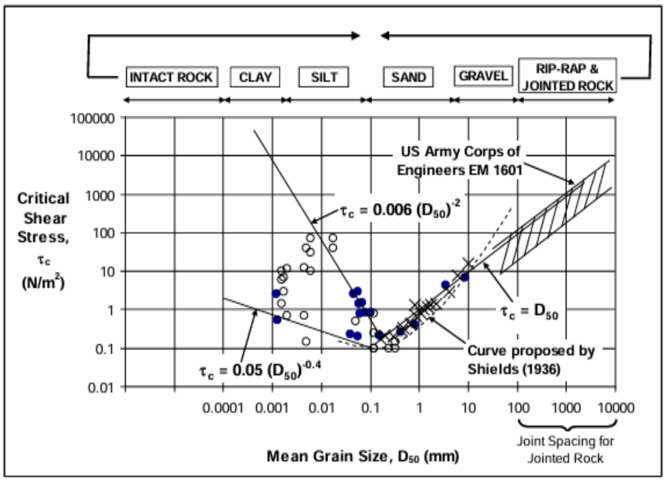


Fig. 6 Critical shear stress versus particle size [10].

2.5. Results evaluation

After extracting the results and discussion, a comparison is made between the results of the methods is used in the calculations to determine the parameters most effective on the scour depth so done to study the extent of their impact on the bridges foundations and develop the necessary recommendations to limited their activity.

3. Results and discussion

The results were analyzed and discussed through the following methods:

3.1 Clear-water and live-bed scour method

This type of erosion occurs as a result of the interaction of soil by water flow, especially in in downstream. When the water flow is no sediment carries or very little sediment, this case called clear water flow. It removes the soil of the channel bed in the contraction area due to the effect of the increased water pressure, which contributes to the deepening of channels or the formation of gullies. The second type of erosion occurs when the flow enters the contraction area laden with sediment and silt, this case called live-bed. This type of water flows at high speed, so it possesses kinetic energy capable of carrying and eroding additional materials. It occurs especially during floods or surface runoff. Although containing sediment, it continues the erosion process due to its speed, leading to scour in the depth and soil drift at the edges, which leads to the expansion of the channel.

Table 1, referred the effect of changing the upstream flow depth on the erosion depth by live water runoff. When is depth 3.9 m, the scour depth is unaffected. As the flow depth elevation, the discharge and velocity flow increase, enhancing the flow's ability to remove river bed soil and carry sediment, leading to an increase in scour depth until the reaches 0.45 m at a flow depth of 4.4 m, Fig. 7 shows that the relationship increases linearly. As for the clear water flow, it remains constant and unchanged because, even with changes in the upstream depth, it does not carry sediments, limiting the erosive capacity of the flow.

Table 1. Scour depth for clear water and live-bed method vs. Change in average depth upstream of contraction.

Average depth upstream of contraction	Scour depth for clear- water method	Scour depth for live-bed method
3.9	0.025	0
4	0.025	0.06
4.1	0.025	0.15
4.2	0.025	0.25
4.3	0.025	0.35
4.4	0.025	0.45

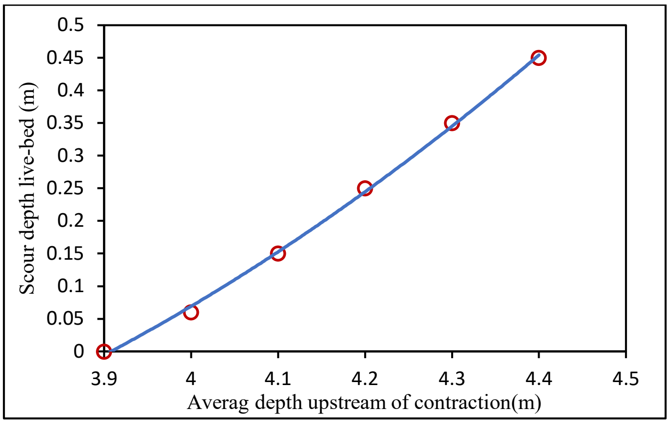


Fig. 7 Relationship between depth upstream of contraction and scour depth live-bed.

From Table 2, the effect of the flow depth in the live-bed and clear water flow method on the scour depth in the contraction area is shown. Notice that when the flow depth is 3.8 m, there is no soil erosion in the live-bed flow, while the scour depth in the clear water is 0.35 m. When the flow depth decreases, the scour depth increases gradually in both methods. This indicates that the decrease in the flow depth in the contraction area leads to an increase in the hydraulic force on the river bed and thus erosion occurs. But, effect of the clear water flow is greater than the live water method, due to the absence of sediments transported to the contraction area to reducing sediments lost through drift unlike live-bed. Figures 8 and 9 show the size of the inverse relationship in both methods.

Table 2. Scour depth for clear water and live-bed method vs. Change in depth prior to scour in contracted.

Depth prior to scour in contracted section	Scour depth for clear water method	Scour depth for live-bed method m
3.8	0.35	0
3.75	0.4	0.01
3.7	0.45	0.06
3.65	0.5	0.11
3.6	0.55	0.16
3.55	0.6	0.21

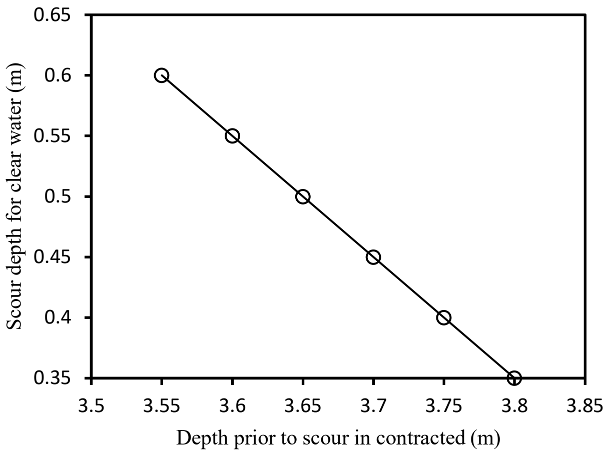


Fig. 8 Relationship between depth prior to scour in contraction and scour depth for clear water method.

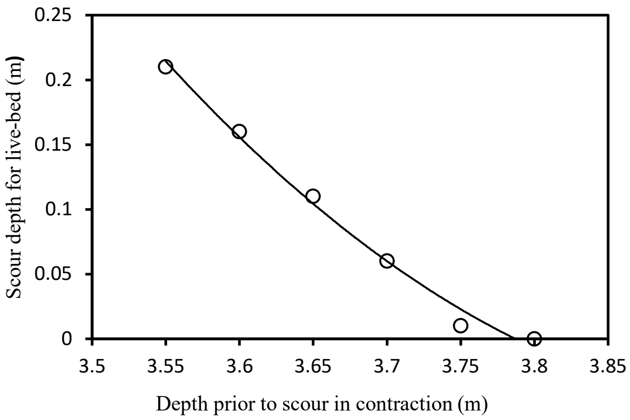


Fig. 9 Relationship between depth prior to scour in contraction and scour depth for live-bed method.

From Table 3, note the effect of the discharge quantity in the contraction area on the scour depth using both the clear and live water methods. At a discharge quantity of 60 m^3/s, the scour depth is 0.2 m with the clear water flow, and no erosion occurs with the live water flow. As the discharge quantity in this area increases, the scour depth increases more gradually. When the discharge quantity reaches 80 m^3/s, the scour depth rises to 0.87 m by the clear water method and 1.36 m by the live flow method. noted that there is a difference between the two methods due to the presence of sediments carried by the live method that compensate for some of the lost sediments, that are not present in the other method. This shows that the effect of the high discharge quantity leads to the speed and strength of the flow, which contributes to the removal of geological materials from the river bed. note this relationship more clearly through Figs. 10 and 11.

Table 3. Scour depth for clear water and live-bed method vs. change in discharge in contraction.

Discharge in contracted section	Scour depth for clear water method	Scour depth for live-bed method
60	0.21	0
65	0.5	0.09
70	0.79	0.35
75	1.08	0.61
80	1.36	0.87

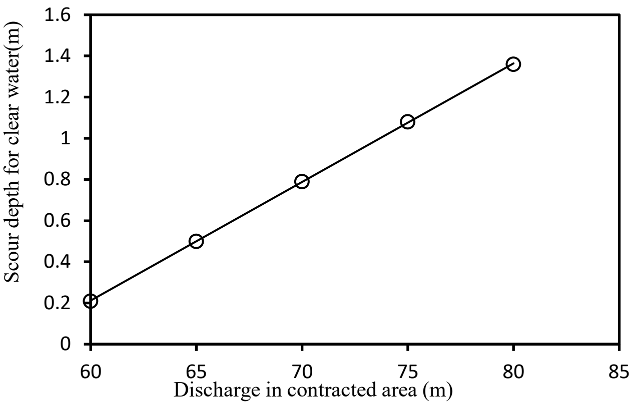


Fig. 10 Relationship between discharge in contracted area and scour depth for clear water method.

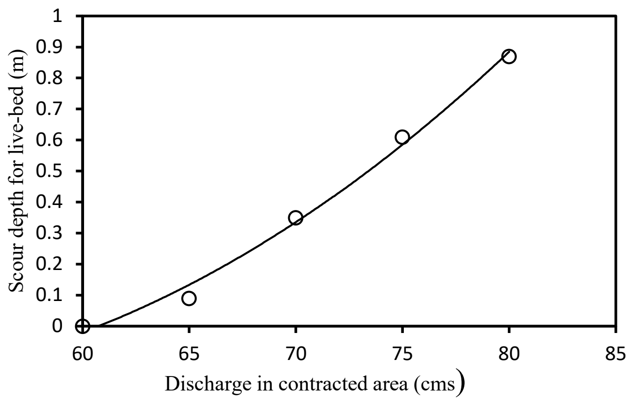


Fig. 11 Relationship between discharge in contracted area and scour depth for live-bed water.

Table 4, shows the effect of the discharge quantity in the upstream area on the scour depth using the clear and live water flow methods. notice that when the discharge is 45m^3/s, the scour depth by the live flow is recorded at 0.71 m. When the discharge quantity increases gradually, the scour depth decreases little by little until it disappears completely, it becomes 0. When the discharge reaches 57 m^3/s. the relationship to explained in Fig. 12. While the scour depth remains constant using the clear water method, regardless of the increase in the discharge quantity. This is because with the increase in the discharge quantity, the live water flow carries more sediments to the contraction area until it reaches the equilibrium stage, where the incoming sediments compensate for the loss of sediments coming out of the river bed, while there are no sediments in the clear water, they are not affected by the increase in the discharge quantity.

Table 4. Scour depth for clear water and live-bed method vs. change in discharge upstream that is transporting sediment.

Discharge upstream that is transporting sediment	Scour depth for clear water method	Scour depth for live-bed method
45	0.25	0.71
48	0.25	0.46
51	0.25	0.24
54	0.25	0.04
57	0.25	0

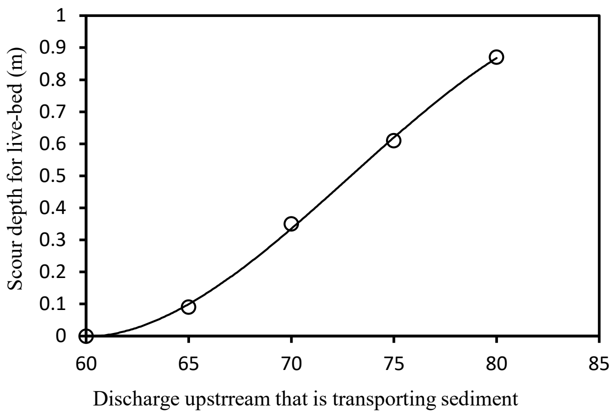


Fig. 12 Relationship between upstream that transporting sediment and scour depth for live-bed.

3.1. Cohesive soil

Erosion in this way occurs in cohesive soils that often contain a high percentage of clay and have internal cohesive strength due to the strength of the bonding of their particles, which makes it difficult for rapid erosion to occur in them, but they are exposed to slow erosion in stages due to the continuous flow of water.

Table 5, indicates the relationship effect of the average depth in upstream on the erosion depth in the contraction area at the bridge site. When the flow depth is 3 m, the scour depth is recorded as 0.28 m. With the increase in the flow depth, the scour depth increases until it reaches 0.36 m when the flow depth is 5.5 m. The relationship is a quasi-linearly relationship, as shown in Fig. 13. It should be noted that the increase in the scour depth in cohesive soil is relatively limited ranging between 0.01-0.02 m, as a result of the cohesion of its particles due to the bond force, which achieves relative stability in the hydraulic behavior of cohesive soil under the influence of the flow depth.

Table 5. Scour depth vs. change in average depth upstream.

Average depth upstream	Scour depth
3	0.28
3.5	0.3
4	0.31
4.5	0.33
5	0.35
5.5	0.36

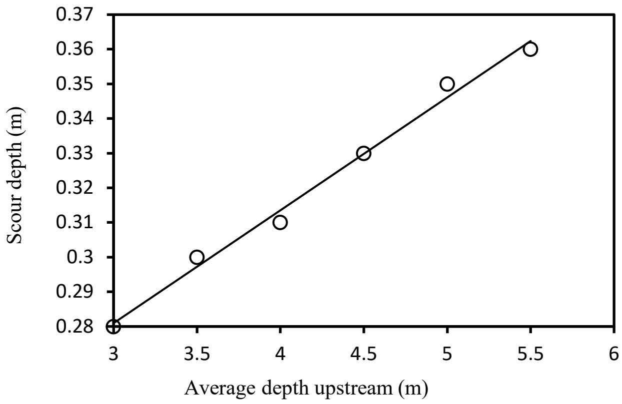


Fig. 13 Relationship between depth upstream and scour depth.

Table 6, shows the effect of flow velocity in contracted area (bridge location) on the scour depth in this area. When the flow velocity is 0.2 m/s, the scour depth is 0.09 m, then the scour depth increases gradually as the flow velocity increases until it reaches the highest rate of 0.95m when the flow velocity reaches 1 m/s. This relationship is linear and increases directly, as shown in Fig. 14. Note that the effect of flow velocity is stronger in cohesive soil than in the rest of the variables, which reflects its ability to dismantling down the internal cohesion force of cohesive soil more quickly.

Table 6. Scour depth vs. average velocity in contracted area.

Average velocity in contracted section	Scour depth
0.2	0.09
0.4	0.31
0.6	0.52
0.8	0.74
1	0.95

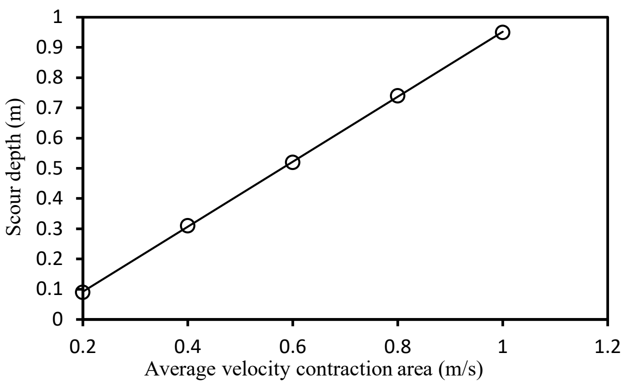


Fig. 14 Relationship between average velocity contraction area and scour depth.

From Table 7, detailed the effect of the critical shear stress of on the scour depth, where when the critical stress value is 0.2 Pa, the erosion depth is 0.32 m, and when the critical stress value increases gradually, the scour depth decreases until it reaches its 6 Pa. This relationship is an inversely decreases, as shown in Fig. 15. This means that the cohesive soil that has the highest shear stress has a greater ability to resist erosion resulting from the effect of the water flow velocity, which reduces the process of river bed Scour.

Table 7. Scour depth vs. critical shear stress.

Critical shear stress (tau c)	Scour depth
0.6	0.24
0.5	0.25
0.4	0.27
0.3	0.29
0.2	0.32
0.1	0.35

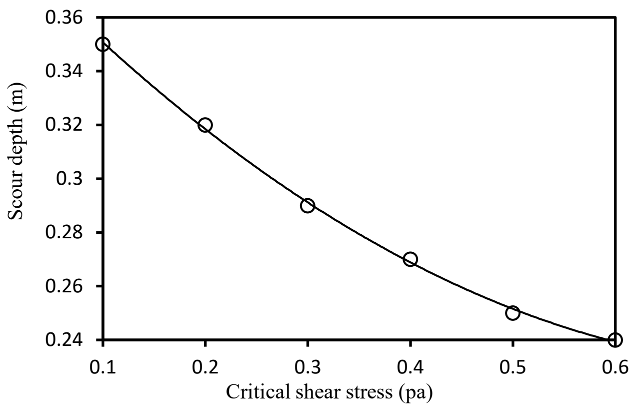


Fig. 15 Relationship between critical shear stress and scour depth.

4. Conclusions

The conclusions and recommendations of the current study are summarized as follows:

By analyzing the data, the following conclusions can be conducted. When comparing the results of the clear and live-bed water flow cases, it is evident that relying on a single case is insufficient for assessing the hydraulic impact on riverbed soil erosion in constriction area when bridges and may lead to inaccurate results that could threaten the safety of water structures. The results showed that the clear water flow case often provides high estimates of scour depth, especially at shallow depths and high discharges. As well as it does not take into account sedimentation resulting from suspended soil particles, which may make it unsuitable for active river environments. The live water flow case may represent more realistic values for the effect of scour depth through sediment movement and its interaction with the flow. However, it is to consider study both flow cases and determine the one that most affects scour depth. The results of the study showed that the depth of the upstream flow has a varying effect on erosion, as its role is weak and ineffective in the case of clear water flow, while it is clearer and more effective in the case of live flow, noting the existence of an inverse relationship between the depth at the upstream and the depth in the contracting area who is effective in both cases, in affecting the scour depth. The discharge at the upstream also has a significant effect on the scour depth, as its effect increases in live flow, while its not affected in clear water flow, but the discharge in the contracting area is significantly effective in both cases. As for the effect of the scour depth in the case of cohesive soil, the results proved that its behavior differs from that of non-cohesive soils, as it is characterized by properties that play an important role in neutralizing the scour depth, such as critical shear stress. The greater strength of the bond between soil particles due to internal cohesion, the greater the resistance of the internal soil in reducing the effect of flow, which requires studying the geological properties of river bed soil and taking them into account when designing bridges.

References

[1] C. Wang, X. Yu, and F. Liang, “A review of bridge scour: mechanism, estimation, monitoring and countermeasures”, Natural Hazards, Vol. 87, No. 3, pp. 1881-1906, 2017. https://doi.org/10.1007/s11069-017-2842-2

[2] S. H. Hong, and I. Abid, “Physical model study of bridge contraction scour”, KSCE Journal of Civil Engineering, Vol. 20, No. 6, pp. 2578-2585, 2016. https://doi.org/10.1007/s12205-015-0417-x

[3] R. Saha, S. O. Lee, and S. H. Hong, “A comprehensive method of calculating maximum bridge scour depth”, Water, Vol. 10, No.11, pp. 1572, 2018. https://doi.org/10.3390/w10111572

[4] A. Syarifudin, and D. Sartika, “A Scouring Patterns Around Pillars of Sekanak River Bridge”, In Journal of Physics: Conference Series, Vol. 1167, No. 1, 2019. https://doi.org/10.1088/1742-6596/1167/1/012019

[5] L. Deng, and C. S. Cai, “Bridge scour: Prediction, modeling, monitoring, and. Countermeasures”, Practice periodical on structural design and construction, Vol. 15, No.2, pp. 125-134, 2010. https://doi.org/10.1061/(ASCE)SC.1943-5576.0000041

[6] S. Hamlaoui, A. Guettala, M. L. K. Khouadjia, and C. Belebchouche, “Influence of the scour phenomenon on the degradation of structures: the case of bridges in Algeria”, Studies in Engineering and Exact Sciences, Vol. 5, No. 1, pp. 3520-3531, 2024. https://doi.org/10.54021/seesv5n1-175

[7] L. J. Prendergast, and K. Gavin, “A review of bridge scour monitoring techniques”, Journal of Rock Mechanics and Geotechnical Engineering, Vol. 6, No. 2, pp.138-149, 2014. https://doi.org/10.1016/j.jrmge.2014.01.007

[8] J. L. Briaud, F. C. Ting, H. C. Chen, R. Gudavalli, S. Perugu, and G. Wei, “Sricos: Prediction of scour rate in cohesive soils at bridge piers”, Journal of Geotechnical and Geoenvironmental Engineering, Vol. 125, No. 4, pp. 237-246, 1999. https://doi.org/10.1061/(ASCE)1090-0241(1999)125:4(237)

[9] L. Brandimarte, A. Montanari, J. L. Briaud, and P. D’Odorico, “Stochastic flow analysis for predicting river scour of cohesive soils”, Journal of hydraulic engineering, Vol. 132, No. 5, pp. 493-500, 2006. https://doi.org/10.1061/(ASCE)0733-9429(2006)132:5(493)

[10] F. Edition, Evaluating Scour at Bridges, U.S. Department of Transportation, Federal Highway Administration, FHWA-HIF-12-003 (HEC-18), 2012. https://rosap.ntl.bts.gov/view/dot/42053?utm_source=chatgpt.com

[11] B. E. Hunt, Monitoring scour critical bridges, Transportation Research Board, Vol. 396, 2009. https://nap.nationalacademies.org/catalog/22979/monitoring-scour-critical-bridges?utm_source=chatgpt.com

[12] R. W. P. May, J. C. Ackers, and A. M. Kirby, Manual on scour at bridges and other hydraulic structures, London, UK: Ciria, Vol. 551, 2002. https://books.google.com/books/about/Manual_on_Scour_at_Bridges_and_Other_Hyd.html?id=P2l_AAAACAAJ&utm_source=chatgpt.com

[13] Y. Wang, Y. Liu, Z. Cao, and D. Zhang, "Prediction of contraction channel scour depth: Based on interpretability analysis and PCA-enhanced SVR", Journal of Hydroinformatics, Vol. 26, No. 12, pp. 3287-3305, 2024. https://doi.org/10.2166/hydro.2024.386

[14] S. I. Khassaf, and S. I. Ahmed, "Development an empirical formula to calculate the scour depth at different shapes of non-uniform piers", In Journal of Physics: Conference Series, Vol. 1973, No. 1, IOP Publishing, 2021. https://doi.org/10.1088/1742-6596/1973/1/012179

[15] D. ASTM, standard test method for particle-size distribution (gradation) of fine-grained soils using the sedimentation (hydrometer) analysis, ASTM International: West Conshohocken (PA), D7928 − 17, 2017. https://www.astm.org/d7928-17.html?utm_source=chatgpt.com

[16] E. M. Laursen, "Scour at bridge crossings", Journal of the Hydraulics Division", Vol. 86, No. 2, PP. 39-54, 1960. https://doi.org/10.1061/JYCEAJ.0000426

[17] E. M. Laursen, "An analysis of relief bridge scour", Journal of the Hydraulics Division, Vol. 89, No. 3, pp. 93-118, 1963. https://doi.org/10.1061/JYCEAJ.0000896