

Comparing Scour Characteristics Around Different Bridge Piers - A Review

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Abstract

The technique of scouring involves removing silt from bridge piers and abutments using the hydraulic force of flowing water. Moving water flows create horseshoe-shaped vortices around bridge supports and piers, leading to a process known as scouring. Several researchers have investigated experimentally and statistically the damage that local scour causes to hydraulic and civil infrastructure. Local scour around bridge piers has been highlighted as a complicated process and the challenge of counteracting the local scour impact in comparison to flow hydraulics. In this study, many researchers analyzed several of the numerous variables influencing the scour pattern around piers. The pier's shape, the inclination angle between its axis and the flow direction, the orientation of its piers concerning the flow direction, the size of the bed material, and several other variables. The use of many uniform and complex shapes will contribute varying values to reducing erosion, and studies have agreed that the shape with a higher area will provide a higher depth of scouring compared to the smaller area and shapes with smooth or round side corners for values up to 60%. And about 50% if it uses a permeable-filled stone pier. Additionally, the use of collars will help to reduce scour by up to 90%. By wrapping the pier with a cable at various angles, erosion can be decreased by 52%. Erosion is reduced by 21.5% when double circular piers are used instead of three circular piers. A 0.3 mm increase in bed material diameter can reduce scour by up to 1.2 times, while covering with vegetation can reduce erosion by 15%. Elliptical, oblong, lenticular, and lenticular curve models can minimize erosion by up to 28%, while the hexagonal pier model at a rational angle of 2.5° will reduce erosion to 35%. When compared to rectangular pier shapes with rectangular foundations, hexagonal will give 69% less scour.

1. Introduction

The natural occurrence of scouring is brought on by the movement of water in rivers and streams. To withstand floods of a specific magnitude, bridges are constructed to achieve this. However, scour is the primary cause of many bridges collapses. It happens when the typical equilibrium condition of sediment transportation in the alluvial channel is disturbed and obstructed by the installation of a bridge pier in a waterway. The bed around the pier has scoured as a result. To design bed protection to prevent or reduce the danger of bridge collapse, engineers are thus curious about the size of the scour hole [1, 2].

2. Mechanism of Local Scour

The following three mechanisms associated with local scour at piers are illustrated in [1-4] the basic mechanisms that cause local scour at cylindrical piers may be summarized:

1. On the pier's upstream face, the flow velocity drops to zero close to the structure. The water's surface rises as a result of the stagnation pressure in front of the pier, creating a surface roller known as a bow wave. As seen in Fig.1, the following downflow functions as a vertical jet, eroding a groove in front of the pier base and weakening the scour hole slope formed above.
2. As downflow rolls up once again, and as it combines with the incoming flow, it forms a complex vortex system known as a horseshoe vortex, as seen in Fig.1. The horseshoe vortex is a component of a series of turbulence structures that form the main erosive flow processes along the pier's edges, in addition to downflow and flow acceleration.
3. Wake vortices are created at the pier's downstream face by the approach flow moving downstream and the separation of the pier's side flows. Around the pier, the horseshoe and wake vortices both erode silt from the base region. Similar to limited tornadoes, the wake vortices lift silt from the bed and carry it downstream with the flow.

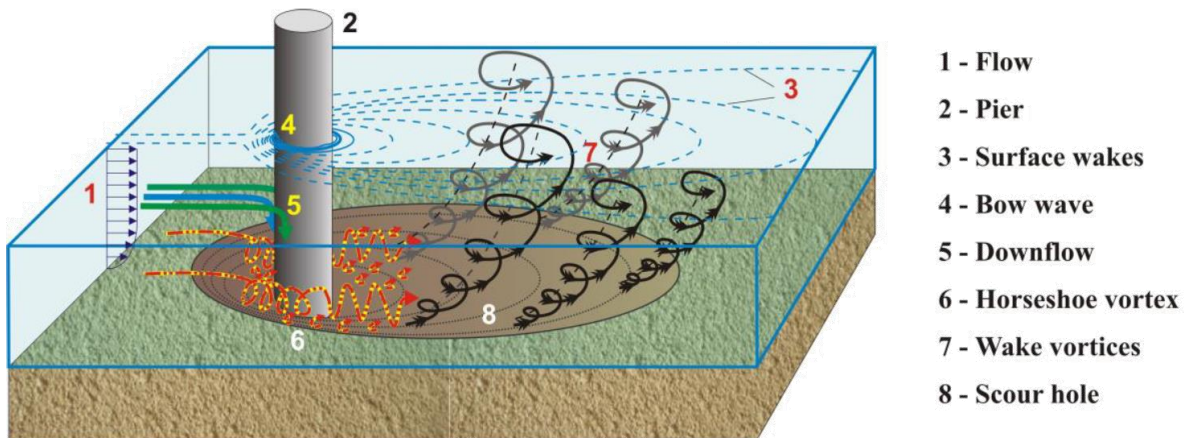


Fig 1. Mechanics of flow structure and Local Scour around a Circular Pier [1].

3. Scouring types around piers

The process of scouring occurs when water flows over a bridge's abutments or piers, eroding and removing soil or silt. Instability and structural damage to the bridge might result from this. A bridge might get one of several types of scouring:

1. General Scour: A consistent lowering of the streambed elevation surrounding the bridge pier or abutment is known as general scour. It happens when the water flow velocity is high enough to cause the surrounding soil of the bridge foundation to erode [5]. equation (1) represents general scour around the pier [6].
2. Local Scour: the erosion of soil or silt surrounding certain piers or abutments as a result of water flowing around the structure and creating a vortex. Instability may result from this kind of scour, which might leave a hole around the bridge's base [6, 7]. Standard local scour has a factor of safety of 1.3 [8], but significant computed local scour may cause it near to 1 [9].
3. Contract Scour: the soil erosion that happens as water flow is restricted at a bridge pier or abutment. Erosion and instability may result from a concentration of flow and an increase

in velocity brought due to this. If clear-water or live-bed flow is present upstream of the bridge, the contraction scour may be calculated using equation (2) [10].

4. Channel Scour: is the soil or sediment loss that happens next to the bridge in the actual flow channel. Such may result in modifications to the flow patterns and channel structure, which may have an impact on the stability of the bridge construction [6].

4. Countermeasure of the bridge local scour effect

Evaluating the degree of scour at multiple piers is an issue of great importance for hydraulicians. Pier group arrangements are becoming more and more important in bridge design due to their physical and financial advantages. It is too difficult to determine the scour depth from a single-pier experiment, and the process of scour and flow typical for multi-pier arrangements is likewise very complex. Several researchers, including [3, 4, 11-29], were interested in studying the erosion occurring around the cylindrical piers and studying the vortices formed as a result of the presence of piers. Both [11, 12] relied on the use of symmetrical cylindrical piers, and they showed that the distances between them have a significant impact on the amount of erosion at the eccentric rear pier. [12, 13] also emphasized that increasing the distance between the supports will increase the amount of erosion in the longitudinal direction. In addition, [4, 13] explained that the erosion at the single pier is less than for the double pier. The reference [13] worked on finding equation (3) for the purpose above. The use of a double circular compared to three circular piers reduces erosion by 21.5% [4]. While [17, 19, 20, 30] have shown that the greatest erosion obtained at circular piers is by increasing the distance between the piers, which reduces erosion, but at a distance x/D ratio greater than 4.6, the effect of distance on erosion is very small. As [31], explained that the use of two line piers affects the flow characteristics completely different from the case of a single pier, since the ratio of the distance between the piers to the diameter $3 \leq \frac{L}{D} \leq 2$ has the greatest effect on the depth of erosion around the first pier. Also, [32] found that the use of two line piers and a distance twice as much as the diameter will have the greatest effect by reducing erosion, in addition to its effect in reducing scour at downstream piers, as a result of the sheltering effect, equation (4) were extracted to find erosion at both the front and rear of the piers. Moreover, [26] based his study of the flow around two circular piers that the horseshoe vortex was elongated towards the downstream of the distance between the two piers, and the flow will accelerate between the two piers to make the greatest flow, and shear stress inside the erosion hole at the base of the pier by twice values. The shear stress is applied to the other sides of the pier, so the presence of an erosion hole is a consequence of changing the behavior considerations of the vortex shading. This corresponds to [29], who based his study on piers with two equivalent triangular sills facing the flow direction using different azimuthal plans $0^\circ, 45^\circ, -45^\circ, 90^\circ, -90^\circ$, through which he observed the vortex effect of the rear piers by an amount higher than the front, where the vortex strength of the eccentric pier was always observed higher in the inlet front pier. This was confirmed by [33] through his study that bed shear stress when the deepest bed level was shifted to the region between two piers. In addition, Fig. 2 for [27], confirmed that the erosion around the circular piers at different planes $0^\circ, 90^\circ, 180^\circ, \text{ and } 270^\circ$, by the fact that the plane 0° carried the highest values of erosion (this agrees with [26, 34]), but the lowest was at plane 180° , since the power of the horseshoe vortices around downstream pier lower than upstream, while at mainstage it has more scour at 90° and 270° plans as compare with 0° and 180° , and this corresponds to [35]. But, over time

(a few times), the scouring process at 90° and 270° takes place more slowly and the scour process is at plane 0° yield. [36] also worked on finding a general equation 5 for obtaining erosion around cylindrical piers by the effect of changing the discharge and the diameter of the pier. [20, 25, 30, 36-38] also confirmed that increased drainage will increase erosion. On the other hand [30], general scours can be effective in estimating local scour, which in turn is greatly influenced by the shape of the obstacle interface, as shown by the proposed equation 6.

Also, [14, 15, 20] mentioned that the size bed material affects the amount of erosion around the cylindrical piers since increasing the size of the grain size bed material will reduce it. Where, according to [14], the increase in the diameter of the material from 0.5 mm to 0.7 mm reduced scour by up to 1.2 times. Furthermore, [15] found equation 7 which considered the bed material size in it.

While [17, 19, 20, 30] they explained that the greatest scour among the proposed models (oblong, tri-nosed elliptical and round-nosed, circular) is at the circular piers, though [24] found that square piers are higher compared to circular ones. Whereas the greatest erosion by [25] was for rectangular supports compared to the circular. As for [22], an equation (equation 8) was found to calculate the erosion around the circular piers.

Although many studies have neglected the time of erosion, [33, 39-41] all led to the fact that local scour is a time-dependent process. In addition, the flow model shows that the turbulent kinetic energy was much more intense in adjacent piers and this is consistent with [40]. Besides, [39] proposed the equation 9. In addition, erosion will develop during the initial time and very quickly, and then the rate of erosion will decrease over time [42].

Additionally, [23, 27, 36, 43] found that increasing the diameter of the circular abutment will increase erosion as well as increase the distance between prosperous piers. However, according to [23], the use of many opening ratios will reduce erosion. Also, [43] was separated in the fact that the reduction in the amount of erosion due to the use of openings contributed to its reduction by values up to 55.56% 53.33%, and 10% at the diameters of piers 16 cm, 11 cm, and 5 cm, respectively.

3.1 Bridge Local Scour Effect by Bend River

Sometimes, the bridge piers are installed in convergent sections of a river bend due to the concentration of roads or the lack of river stability in other paths. As a result of this, the flow pattern in the bend will become more complex when piers are present. The axial force, which arises from its interaction with the lateral pressure gradient that generates the secondary flows, is the main force acting on the flow in a bend. Helical flows are complicated flows generated along a path by integrating minor flows into the primary flow. Whereas Erosion in the outer bend and sedimentation in the inner bend are due to this.

Hence many bridge piers are located within curved parts of the stream, and this curvature has a direct effect on erosion around the piers as a result of the change in the direction of flow and therefore the shape of the eddies. Several researchers, including [3, 42, 44-46], have studied this situation in detail.

On the other hand, the flow was in a transition state near the bend entrance, and therefore, was more complex. [47-50] were among the researchers who studied the effect of pier geometry on the flow field and scour depth around the pier. Where [44] found that using a hexagonal pier model at a rational angle of 2.5° will reduce the amount of greatest erosion by up to 35%, while elliptical, oblong, lenticular, and lenticular curve models will reduce erosion

by up to 28%, he also recommends that the size of soil particles be 1.4-0.1 mm around the piers to provide the least possible scour around the piers located on curved parts of the stream. As for [31], showing that bending at an angle of 90° for rectangular and circular piers, it recommends using soil $d_{50}=1\text{mm}$, and erosion using circular supports is less compared to the square shape, and the shape of the erosion hole will take a symmetrical shape around the center of the bend, and in the direction of the inner bend. In addition, [42] shows that the use of super dikes to protect eroding bank rivers will contribute to the protection of bridge piers, where they are used at bending 80° and with the pier at an angle of 60° (the angle of incidence of the support measured from the inlet of any bend to the line joining the center curve), where it will be noted that the greatest scouring occurs at an angle of 0° and 20° along the inner wall, and at an angle of 60° and 80° along the outer wall. Also, increasing the distance to bend from the support will reduce the measured erosion, so the study advised to use super dikes at an angle of 20° , Fig.3.

As for [46], showed the presence of piers at an angle of 30° will affect the erosion behavior, through the use of Polygon (hexagonal) geometric shape piers such as at these bends will contribute to reducing the amount of erosion by up to 36%, while the use of no conventional shapes such as lenticular curve will give better results for erosion reduction values up to 44%.

3.2 Bridge Local Scour for Aligned Pier

Many researchers, including [34, 38, 51-53], have noted that it is important to reduce erosion around the piers of bridges, and one of the most important technologies used for this purpose is providing inclined bridge pier, as increasing the slope will double the force of the horseshoe vortices eddies and thus reduce the amount of erosion depth around the piers, and this corresponds to all [38, 51-53]. Also, [33, 34], where noted that using an angle of 45° as a pattern staggered gives the highest values of erosion at the front of the rear pile. In addition, [34] stated that the results showed the best pier configuration for tandem piers has the lowest resulting erosion at an angle of skew angle of 60° .

[51] noted that the use of two piers aligned in the direction of the flow will be the greatest erosion occurring at the front of the piers and for a distance between the two piers is 2.5 times the diameter of the pier will be 22% higher than one pier. The use of piers having a ratio of the distance between the two piers /diameter of the piers (L/D) =1, has the highest resulting erosion at the front of the piers, which will be equal to its value if it was one pier.

While [52] used two piers placed diagonally in an inclined manner at an angle of 10° and 15° will reduce erosion, especially at the upstream pier, he worked out equation 10, and Fig.4, for this purpose. Also, [53] shows using a piers group placed on the rectangular foundation, and installing these piers at different angles, the result was that both angles 28° and 38° have the highest and lowest scoring depth values, respectively, and the use of rectangular foundation worked as a collar and thus reduced the erosion occurring when installing the piers at a vertical angle, Fig.5. In addition, [38] studied the rectangular shape bridge piers model for angles 0° , 7° , 12° , 15° , and 19° with the column, where the greatest scoring is at 0° and the least at 19° . As for [54], it was stated that using an angle of 70° (attack angle) will reduce the depth of the greatest scoring amount compared to angles 90° , 85° , 80° and 75° with a total reduction of up to 36%, by changing the heads angle from 90° to 70° the sediment ridge approaches the pier and shows that the rising currents have lost the ability to carry sediments downstream.

4.3 Reducing Scour Around the Bridge piers

The use of hybrid approaches in the design of scour countermeasures has been suggested to lower the risk of failure caused by scour. [55, 56] relied on the use of accumulation of rectangular debris installed on the surface of the river bed, where according to [55] this debris reduced erosion by 10% at shallow depth and for a distance twice the diameter, but increasing the relative depth y/D 1.67-1 will increase erosion by 10%, by decrease again at y/D 2-3 as a result of immersion of the debris to increase flow and thus it will affect the vortices, and thus reduce erosion up to 14%. This is in agreement with [57] by using a triangular prism effectively reducing erosion by 2.5 times the diameter of the pier and with an efficiency rate of 65%. [58] also confirmed that the use of right triangular implementation with high width and low height has a significant effect in reducing the greatest pressure and shear force affecting the bed river. This was also agreed upon [56] the essential importance of using debris on general behavior stressed, as well as the need to take into account the location of this debris within the scour hole morphology. This, in addition to the fact that [41] used rectangular abutment, contributed to a 29.6% reduction in scour as a result of reducing the activity of vortices horseshoe and reducing delays time for the scouring started checking from the initial time.

Increased flow causes increased erosion, which is in agreement with [20, 25, 30, 37, 38, 55]. Where [37] is intended for any scour reduction using industrial production as a countermeasure. As for the [40, 59], the nose angle countermeasure will be used to reduce scour, and reducing the angle of the countermeasure works to increase scour, with the highest angle being 45° . Hence the efficiency of the nose angel pier appeared high for Froude number less than 0.4, which will give the least change in reducing the amount of greatest scour, while increasing the skew angle gives promising maximum score reduction, this corresponds to [33, 34, 45, 52].

[61 ,60] also confirmed that using a threshold at the stent provider works to shift the greatest scour value away from the stent, and it also works to reduce erosion by up to 63%. [61] confirmed that using a threshold upstream, and downstream will reduce scour at the middle of the pier by 62.79%. As for [62], it was agreed with the above that the use of the threshold reduces scour, but on the other hand, the presence of the sill for rectangular piers will have a less noticeable effect on circular piers, and by increasing the distance to the threshold at the pier will reduce the impact of this threshold on reducing erosion. The largest reduction using the threshold will also be for round-nosed sill piers at (length pier/width pier=1) by 32.5%.

As for [16], worked on trying to reduce scour around the cylindrical piers using a pier with a different slope angle, since even a small side slope will reduce scour to values of up to 36% and 53% at both upstream and downstream, respectively, at an inclination of 15° .

In an attempt to reduce scour,[20] showed that the shape of the pier model will reduce scour by up to 30% if an elliptical shape pier is used instead of a diamond. Also, [63], adopted horn shaped collar to mitigate erosion around the supports, where it found the most important factors that lead to reducing erosion, represented by the bottom diameter of the collar, vertical high collar, and contour shape index, so the optimal model of the collar will reduce scour around the piers with a reliability rate of up to 90 %, as suggested by equation 11, Fig.6. While the increase in length weakens the protection provided by the collar to be less than 2% [63]. This is what [28, 64, 65] agreed with, since [64]confirmed that by 90% scour will reduce the use of collars around circular piers. This is what [66] agrees with for different case toe collar

diameters and different arrangements the percentage of reduction of scour ranges from 11 to 100%. Also, [28] confirmed that the use of both square and round collars will reduce scour, but the square collar will be more effective, by 70% and 50% for both square and round collars, respectively.

Correspondingly, according to [67], it is possible to further reduce erosion when using a collar by adding roughness to the pier, which further reduces the amount of erosion by up to 83%. The use of multi-vent bridge piers will reduce scour by 65%. The use of deflectors will contribute to increasing the amount of scour reduction by 10%. The use of the mobile bed collar around a rectangular pier with rounded edges, reduced erosion by 100% at an attack angle 0° . Furthermore, the depth of erosion will decrease by 26.9% by using one collar at an angle of 15° , and the erosion depth reduction reaches 69.78% by using two collars, and this is consistent with the general behavior resulting from the researcher [28]. While [68] used the ring around a circular pier as a means of scour control. According to [28, 65], installing the collar at the floor level will further reduce scour, and according to [29, 69], with a diameter of 1.5-2.5 times the diameter of the pier, it will effectively contribute to reducing scour, according to equations (12-13) [65, 69], respectively. Also, the use of three collar plates according to [69] with a diameter of collar 2.5 D, 3D will reduce scour by 79% and 82%, respectively.

While [70, 71] relied on the presence of a hook collar, [70] used a rectangular shape with a width of 1.5 times the width of the pier with a side wall height of 0.3 times the width of the pier, is the best dimension of hook collar to reduce erosion by 52.2%, while [71] used lenticular hooked collar to have the least scour for width collar/width pier is greater than 2. For a collar higher than the bed surface, it will achieve the lowest scour round pier with the highest reduction, by 61.1% using a conical core, according to [72].

Too, [74, 73] demonstrated the possibility of reducing scour by using warp cable around the pier, and changing the flow collision angle from the downstream flow water. Hence, its effect on the reduction of the depth of the scour, [73] noted that the use of the cable deliberately reduced the scouring of the round corner rectangular with 10% of the pier diameter with a 15° twist angle, and 22% for round corner rectangular with cable 15% of pier diameter with 12° twist angle of cable. As for [74], the use of mesh wire will reduce scour by 52% after 48 hours.

To improve the protection of nudity, [76, 75] use of solid sacrificial pile, especially permeable filled with stone, where [75] shows the best gravel size is $0.21D-0.25D$ and a distance of $3D$ between pile and pier, where it will work to add scour by weakening the bed, as a result, added the amount of flow around the pier. Also, the fact that the pile itself is permeable will lead to the formation of a difference between the pressure inside and outside, in addition to affecting the speed of the vortex system, and shear stress on the sides of the permeable pier, which will somehow reduce erosion by up to 50%. Adding a collar to the stent according to [76] will increase the amount of erosion reduction to reach a percentage ranging from 87.05-48.4% for two circular piers aligned $0^\circ - 45^\circ$ of attack.

3.4 Bridge Local Scour Effect by Flood Hydrograph

As the flow in the stream is unsteady, the scouring process becomes very complicated. Flood discharge of the same intensity never remains for the same period, but it occurs for very few days instead of the whole period. Each of [18, 77, 78] conducted scour studies on piers for various flood hydrographs, where [18] noted that the rate of scour during the initial time and at each step of the hydrograph is supplementary and decreases over time, and the greatest depth

of scour at symmetric flood is more reliable than at delay and advanced flood hydrographs, and the greatest erosion depends on the size of the sedimentation and peak time.

In addition, [77, 78] said that the greatest scour is observed more at the rising limb of hydrograph with a constant increase of about 80%, which agrees with [78], and by 90% according to [77], where this percentage as a ratio to the final value of the depth of scour occurring. [79] used a stepped flood hydrograph, found that the scour depth would be in the case of a single peak hydrograph less for the same peak discharge for steady-state conditions. While [80] said for a known period, the peak value of the design flood hydrographic will be obtained, which will reduce the total cost of construction.

3.5 Bridge Local Scour for Different Pier

Many researchers have studied various types of forms of piers, [12, 13, 78] they were interested in studying multiple regular shapes compared with the traditional circular model, including square, triangle [12], and rectangle [13, 81], to be individually or a group of supports, where it was noted that the amount of erosion length at triangular piers is less than for Square and group, As for the depth of erosion only [13], the circular pier had less than the square one, whether the pier was single or double. Also, [81] confirmed the behavior of the rectangular pier during the time, where the scour rate reaches 87% of its greatest value during the first two hours, and the length of the scour hole increases by 80% of the greatest length of the scour hole. To improve the scour around the rectangular supports, [82] proposed using a different pile cap to dominantly affect the generation of vortices from the pile-cap corners which may act as a collar for score protection. [4] used oblong compared to circular will reduce the scour volume by 55.63%. As for the [83], using two piles with curve faces slotted oblong will reduce scour by 49% of the greatest scouring value. In a study to demonstrate the effectiveness of piers with multiple regular shapes, [24] arrangements were recorded for a group of regular-shaped piers according to their efficiency by dispersing the scour occurring around the piers from the best to the least impact square with the circular nose, then circular pier, then oblique rectangle pier column and square shape, which were the worst models of erosion behavior and percentages compared with the best, explicitly 11%, 89% and 178% and 244% for both oblique rectangle Pier column and square with circular nose, circular pier and square, respectively. [24, 25, 74, 84-86] agreed with that the rectangular shape has the highest area, therefore, the depth of exposure is greater compared to the rest of the forms. Where, according to [25], the use of the streamlined geometry shape will have the least scour (3 cm) because it has the least area and is without side corners, therefore it works to reduce erosion around the piers by 60% compared with various forms relied on by the researcher; (rectangle, circular, octagonal, oblong, joukoswky, chamfered, hexagonal, elliptical, sharp nose). [30] agreed with this in terms of the fact that the round pier was the highest compared to the round end. Also, the [17] using triangular noise pier will provide a reduction in erosion and will be the lowest by a value of 22 mm compared to oblong with 29mm and circular section 36mm. While, [19] showed that the use of lenticular shape will reduce erosion by 40% compared to rectangle, circle, square, octagonal and elliptical. [85, 86] showed that the presence of different types of footing will affect erosion compared to the absence of a foundation in certain proportions. As [86] shows it will reduce erosion by 47%, 49% and 56% for each rectangle, oblong and hexagonal footing, respectively. Where the irregular shape represented by hexagonal will provide 69% less scour compared to rectangular pier shape with rectangular footing. [85] also confirmed that the use

of display that positioning of the foundation below bed level, leads to less values of depth around bridge pier.

3.6 Bridge Local Scour with Vegetation Covered

Flow patterns in compound channels are completely different with flood plains covered with vegetation, and this issue can affect the amount of scouring in the area of bridge piers. However, the combined effect of these factors has not been systematically investigated. Therefore, due to the complex nature of the local scouring. [87] showed that an increase in vegetation density will reduce erosion by an average of 15% for the same floodway devoid of vegetation, and this is consistent with [88], where he confirmed that the distance between the piers and the vegetation cover is less, as the less erosion reaches 52%.

3.7 Bridge Local Scour with Ice Cover

A floating ice cover in a field may easily modify its height to match the fluctuating water level. Depending on the ice's properties, it can even partially protrude into the flowing water. As a result, it's feasible that a floating ice cover may cause an increase in flow below it, which would cause scour behaviors that are comparable to those of a fixed; somewhat submerged ice cover. Furthermore, rougher ice cover produces more erosion than smooth ice cover, and erosion will increase as the velocity of flow increases. While [89] explained that ice-jammed flow will increase the velocity of erosion around the pier, he worked out equation (14) for this purpose. In [90], it was mentioned that there is an inverse relationship between the amount of erosion and the ratio between the amount of flow depth to the diameter of the pier, with ice cover. In addition, [31] showed that erosion on the convex bank stretch will be more influential compared to the concave bank, and the Froude coefficient also has a significant impact on the amount of erosion on the convex bank stretch compared to the concave bank.

3.8 Bridge Local Scour for Complex Shape

Many researchers have resorted to studying erosion on complex shaped supports, for which erosion equations often cannot be applied directly, and some of them have depended on using artificial neural networks, including harmony search [91]. Where the CS model according to [92] promises the best reducing erosion. While [93] uses a model located within the Piura region, and collar has been added to study the improvement achieved by erosion with a reduction rate of 15.73-43.77%. [57] found that the erosion around its pier is complicated to show the effect of time with erosion, where he noted that the top of the foundation stops the development of erosion after several hours depending on the size of the foundation and the depth of the foundation. [94] highlighted the importance of the pile cap, meanwhile, the greatest erosion reduction is when the pile cap is not fully exposed to flow.

Table 1. Summary of Selected Research Equations

<i>Equation No.</i>	<i>Model/Pier</i>	<i>Equation</i>	<i>Ref.</i>
1	Cylindrical	$d_{sg} = Z d_f$	[6]
2	Cylindrical	Live-bed Contraction Scour Determination $\frac{y_2}{y_1} = \left(\frac{Q_2}{Q_1}\right)^{\frac{6}{7}} \left(\frac{W_1}{W_2}\right)^{K1}$ Clear-water Contraction Scour $y_2 = \left(\frac{0.0077Q^2}{D_m^{\frac{2}{3}} W^2}\right)^{\frac{3}{7}}$	[10]

3	Cylindrical	$d_s/y = 0.92D/y + 0.27D/b + 0.001L/D + 4.2F_r + 0.006D/d_{50}$	[13]
4	Square nose; Round nose; Circular cylinder; Sharp nose	$\frac{d_s}{b} = 2.2K_{pw}K_{psh}K_{pa}K_{psp}(2.6 \cdot F_r - Fr_c)^{0.7}$	[32]
5	Cylindrical	$\frac{L_s}{D} = 3.39 \left(\frac{d_s}{D}\right)^{0.54} F_r^{0.32}$ $\frac{W_s}{D} = 2.1 \left(\frac{d_s}{D}\right)^{0.33} F_r^{0.91}$ $\frac{V}{D^3} = 0.99 \left(\frac{d_s}{D}\right)^{1.95} F_r^{1.96}$	[36]
6	Circular Round-ended Elliptical	Circular $S_L = 0.943S_G^{1.209}$ Round-ended $S_L = 1.537S_G^{0.991}$ Elliptical $S_L = 2.941S_G^{0.873}$	[30]
7	Cylindrical; rectangular	$\frac{d_s}{b} = 3.4 - \frac{30}{\left(\frac{b}{d_{50}}\right)} \exp \left[0.088 \left(\ln \left(\frac{D}{d_{50}} \right) \right)^2 \right]$	[15]
8	Circular	$\frac{d_s}{D} = 1.39(F_r)^{0.77} \left(\frac{y}{D}\right)^{0.036} \left(\frac{D}{d_{50}}\right)^{-0.194}$	[22]
9	cylindrical	$\frac{ds}{d_{se}} = \exp \left[0.065 \left(\frac{V}{Vc}\right)^{0.35} \left(\frac{y}{D}\right)^{0.19} \ln \left(\frac{t}{te}\right) \right]$	[39]
10	cylindrical	$\frac{ds}{D} = 1.163 \left(\frac{d50}{D}\right)^{0.25} \left(\frac{V}{Vc}\right)^{1.047} \alpha^{0.828}$ $\alpha = 90 - \beta$	[52]
11	horn-shaped collar	$\frac{dse}{D} = e^{-\frac{0.424}{\delta} + 2.23}$	[63]
12	pier with collar	$\frac{dse - dsec}{ds} = 0.20 \left(\frac{bc}{D}\right)^{0.17} \left(\frac{h}{y}\right)^{0.48}$	[65]
13	oblong pier with Collar Plate	$\frac{ds}{D} = A \left(\frac{bc}{D}\right) + B \left(\frac{Cs}{D}\right) + C \left(e^{\frac{Zc}{D}}\right) + D(\ln h) + E(e^{Fr}) + F$	[69]
14	Cylindrical; Round end- shaped; rectangle	$\frac{ds}{y} = 10.928 \left(\frac{Ti}{y}\right)^{0.247} \left(\frac{V0}{\sqrt{g}y}\right)^{1.483} \left(\frac{Qi}{Qw}\right)^{0.177} \left(\frac{d50}{D}\right)^{-0.416} Kz^{1.288}$	[89]
<p>K_{pa} aspect ratio influence factor.</p> <p>K_{psh} pier nose shape influence factor.</p> <p>K_{psp} pier spacing influence factor for pier groups arranged side by side.</p> <p>K_{pw} flow shallowness factor for pier scour depth.</p> <p>L_s scour hole length.</p> <p>W_s scour hole width.</p> <p>\hat{b} effective width of the pier.</p> <p>V scour hole volume.</p> <p>A – E Regression coefficients of various predictor variables.</p> <p>B channel width.</p> <p>bc collar diameter.</p> <p>Cs Spacing between the collar plates.</p>		<p>df Scoured depth below design floodwater level.</p> <p>g gravitational acceleration.</p> <p>H depth of the collar from the water surface.</p> <p>Kz pier shape factor.</p> <p>Q_2 Flow in the contracted section.</p> <p>S_G general scour.</p> <p>S_L local scour.</p> <p>t Time.</p> <p>te time to equilibrium.</p> <p>T_i the thickness of an ice jam.</p> <p>W_1 Bottom width upstream of the bridge.</p> <p>W_2 Bottom width in the contracted section.</p>	

D	pier diameter.	V	mean velocity.
D_m	Diameter of the smallest non-transportable particle in the bed material.	V_c	critical mean velocity associated with the initiation of particle motion on the bed.
d_s	maximum scour depth.	y	approach flow depth.
d_{50}	bed sediment grain size at 50% passing.	Z_c	Vertical location of Collar Plate.
d_{se}	maximum equilibrium scours depth at the longitudinal direction.	δ	curvature steepness of the horn-shaped collar.
d_{se}	scour depth approaches.	Fr_c	critical Froude.
d_{sec}	maximum equilibrium scours depth in the presence of a collar.	β	inclination angle of piers.
d_{sg}	General scour depth		
			Multiplying factor (0.5 for straight reach, 0.6 for moderate bend, 0.7 for severe bend).
Z			
Fr	Froude number.		
K_1	Exponent depending upon the mode of bed material transport.		
L	spacing between piers from centreline to centreline.		
Q	flow discharge.		
Q_i	ice discharge rate.		
Q_1	Flow in the upstream of the bridge transporting sediment.		

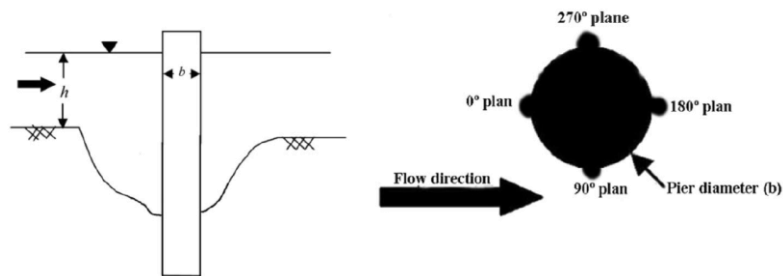


Fig. 2. Definition sketch of circular pier [27].



Fig. 3. (Photometric view of bed, when spur dyke installed at angular displacement $\theta = 20^\circ$) [42].



Fig. 4. Local scour formation after running the experiment (C1) [52].



Fig. 5. Local scour of the piers group with 38 degrees [53].



Fig. 6. Scour hole appearance of a pier with collar [63].

5. Conclusion

Since local scouring at bridge piers is thought to be a complicated problem, this research focuses on it. Numerous research projects have been undertaken to define the factors influencing the formation of scour locally. As a result, some researchers have created useful techniques that assist in scour depth reduction. Based on the investigation, the use of a set of piers compared to a single pier will contribute to increased erosion, and increasing the distance between these supports will increase erosion because of its effect on the vortex waves. Increasing the discharge will increase the acceleration of the liquid flow, which in turn will increase the shear stress near the base of the pier. The material of the bed river has a significant impact, as increasing the thickness of the particles and the presence of vegetation will reduce erosion in a behavior that is the opposite of what happens when there is ice cover. The time factor also has a consequence in terms of erosion developing at the beginning of time significantly, so this development is reduced over time. For the reduction of erosion, the researchers used various methods for this purpose, including the use of multi-shaped debris at the pier contributes to moving the eddies further away from the support and thus reduces erosion by up to 63% depending on the type of this debris.

This, in addition to using the super dikes at curved streams, will work in the same way as the debris method and will reduce erosion by up to 36% with the presence of inclined piers at an angle of 70, which are considered (inclined pier) is one of the methods of reducing erosion

In addition, the use of many uniform and complex shapes will contribute varying values to reducing erosion, and studies have agreed that the shape with a higher area will provide a higher depth of scouring compared to the smaller area and shapes with smooth or round side corner for values up to 60%. And about 50% if it uses a permeable-filled stone pier. The addition of collars will also contribute significantly to the reduction of scour by up to 90%. Using a cable around the pier at multiple angles will reduce scour by 52% within 48 hours. Thus, many researchers have come up with many equations for this matter. A 0.3 mm increase in bed material diameter can reduce scour by up to 1.2 times, while covering with vegetation can reduce erosion by 15%.

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