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Effect of a Group of Piles on Scour Depth of an Isolated Bridge Pier

Rahul MALIK [a,1] and BALDEV SETIA [b]
[a] *School of Engineering and Computing Dev Bhoomi Uttarakhand University, Dehradun, India*
[b] *Department of Civil Engineering National Institute of Technology, Kurukshetra, India*

Abstract. Bridges are symbols of a country's infrastructure. In order to link people, products, and transportation, bridges are necessary. A nation's economic development can be halted by the closing of a bridge. It is possible to finish services that are no longer provided by bridges. Bridges are used to move cargo and resources from one location to another. Over bridges, one can get away from the bustle of daily life. The things might be delivered by customers. Due to the increase in the world's population, the bridges are constructed in close proximity to each other. Due to close proximity, it can significantly affect the scour depth of the bridge piers. The present paper discusses the effect of a group of piles on the scour depth of an isolated bridge pier. A typical 12 m long, 0.60 m wide, and 0.70 m deep tilting bed water flume was used for the experiments. The pier models that were utilized were 42 mm and 62 mm in size. The uniform-sized river sand utilized in the movable bed studies had an average mean size of d_{50} = 0.23 mm. From the experimental results, it can be observed that when two rows of groups of piles are placed in front of the isolated bridge pier the scour depth around the bridge pier is found to be minimum.

Keywords. Group of pier, staggered arrangement, isolated pier, clear spacing

1. Introduction and Literature Review

In the last few decades, the population of the world is continuously increasing at a rapid rate. An increasing number of bridges are being built near to one another as a result of urbanization and population growth. Only a few researchers take attention towards the negative effects of the close proximity of bridges. These are having a significant effect on local scouring due to the interference effect. Scouring is the process of removing sand from the sand bed surrounding the bridge pier, resulting in the development of a scour hole. In the scouring phenomena, initially, the scouring process is slow but after that, as the time increases the scouring depth also increases, but after some time it will attain an equilibrium stage. Several researchers i.e. Kothyari, Garde, and Rangaraju [7], Gangadharaiah [18], Dey [3], and Setia [16] worked around the single bridge pier but less attention was taken by the researcher towards the group of bridge piers. Only a few researchers like Tison [17], Hannah [6], Hoffman and Verheij [5], Ettema [4], Chiew [2], Nouh [13], Muzzammil [9], Movahedi [8], Malik

[1] Rahul MALIK, Corresponding author, School of Engineering and Computing Dev Bhoomi Uttarakhand University, Dehradun, India; E-mail: malikrahul30@gmail.com.

and Setia [11,12], Nazariha [14], Beg [1], and Melville et. al. [10] worked on the group of bridge piers.

According to Breusers et al [19], scour is caused by the erosive action of flowing water that removes and erodes materials from river bottoms and banks, as well as the region surrounding bridge piers and abutments. According to previous researchers, scouring is the phenomenon when bed material is removed as a result of water action. Due to an unfavorable pressure gradient, the process starts with a three-dimensional separation of flow on the upstream front of the pier. This separation results in the formation of a vortex in a vertical plane that encircles the pier and has a plan with a horseshoe-like shape at the junction of the sediment-pier interaction. According to Setia [15], the horseshoe vortex system is what causes the scouring around the pier by scraping material from upstream of the pier and releasing it in suspension at the back of the pier.

2. Experimental Setup

Experiments were carried out in the Fluid Laboratory of the National Institute of Technology Kurukshetra India. As indicated in table 1, the studies were carried out in a standard recirculating tilting bed water flume measuring 12 m long, 0.60 m wide, and 0.70 m deep. The measurements of the pier models utilized were 25 mm and 62 mm. The uniform-sized river sand utilized in the movable bed studies had an average mean size of d50 = 0.23 mm. A perspex side wall has been provided on both sides of the flume to facilitate visual observation. The depth of flow ranged between 14 cm to 16 cm, thus giving an h/D range of 2.25 and 2.5 and h/d equal to 5.6 and 6.4. For a velocity range of 0.25m/s to 0.26m/s, this gave a maximum Froude number 0.20, Pier Froude number 0.33, Pile Froude number 0.52. The depth of flow ranged between 14cm A pier without any pile on the upstream side after having been exposed to a uniform flow for 300 minutes, showed a non-dimensional scour depth of 1.08D and 1.1D This forms the reference to observe the effect of various geometric arrangements of piles on the scour depth around the pier. At the end of the recirculating flume is a regulating gate that allows to adjust the flow's velocity and depth of flow. Figure 1 shows the pictorial view of the recirculating flume.

Table 1. An overview of the setup used for the experiment.

Items	Specifications
Dimensions of flume	12: 0.6: 0.7
Goals	Interference, Mechanism
Bed Used	Mobile bed
Size of Sediment	0.23 mm
Size and shape of piers	62mm and 25mm, Cylindrical
Material used (piers)	Perspex and Glass
Arrangement	Group of piers

Figure 1. Pictorial view of the recirculating tilting flume.

3. Results

3.1. Effect of a Pile Group on the Scour Depth of an Isolated Bridge Pier

Experiments on other patterns with piles of the same diameter (25mm) and the same sediment (d_{50} =0.23mm) were extended under similar flow conditions but now their impact on scour around a circular pier of diameter 62 mm was also found. For the experimental investigation, five distinct types of arrangements were used: an arc with five piles (A4), a staggered arrangement with nine piles in two rows (4+5) (A5), an equilateral triangle with three piles (A3), and a row with three piles (A1) as shown in figure 2 and table 2.

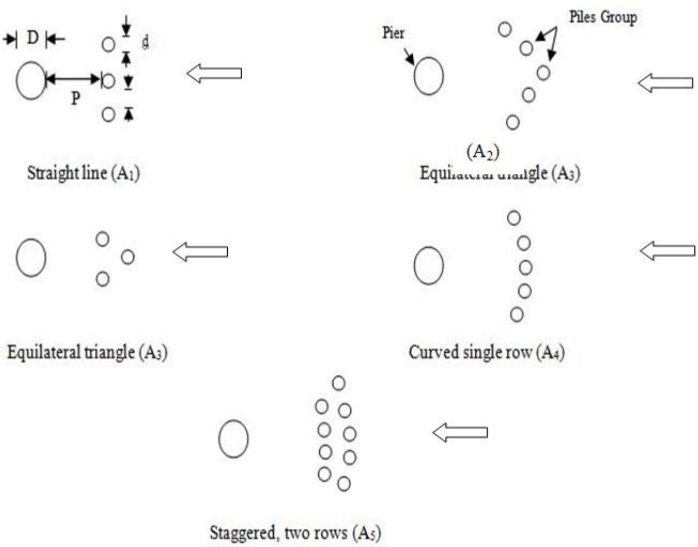


Figure 2. Definition sketch of the different patterns using a group of piles.

Table 2. Different types of arrangements of piles

Content	Dimensions	piles	Diameter of piles (mm)	Depth of flow (cm)
A_1	Straight line	3	25	14
A_2	Equilateral triangle	3	25	15
A_3	Equilateral triangle	5	25	16
A_4	Curved single row	5	25	15
A_5	Staggered, two rows	(5+4) 9	25	14

3.2. Effect of Group of Piles on Isolated Pier

Cylindrical piers measuring 62 mm and 42 mm in diameter were placed in the center of the recirculating flume. Different types of arrangement with circular piles in front of the piers were used to calculate the interference effect of the circular bridge pier on the scour depth. The results relating to the different patterns have been shown in table 3 and figure 3.

Table 3. Results of the experimental work (Diameter = 62mm and 42mm).

Arrangement used	H_s/D		$(H_s/H_o))$ %	
Pattern	62mm	42mm	62mm	42mm
A1	0.67	0.90	38	18
A2	0.67	-	38	-
A3	0.70	0.68	36	38
A4	1.04	0.8	0.04	28
A5	0.65	0.67	40	41
A_0	1.08	1.1	-	-

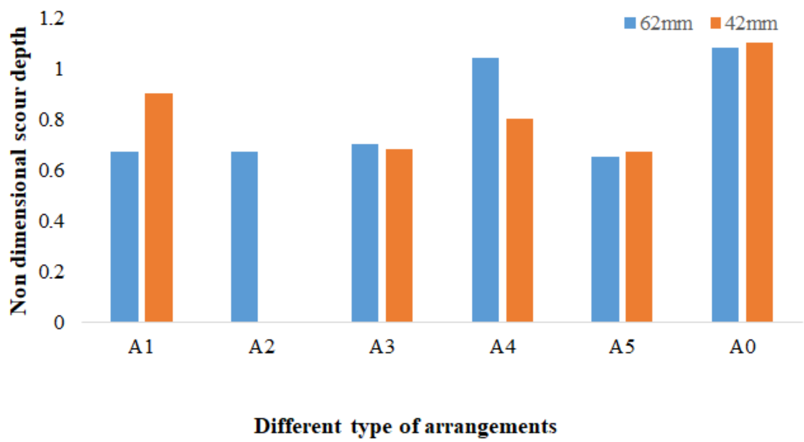


Figure 3. Effect of the different pattern of a group of piles on the scour depth (Diameter, D = 62mm and 42mm).

From figure 3, Out of the five arrangements, A_4 shows the maximum scour depth (1.04D), and arrangements A5 (0.65D), the least, A1 (0.67D), A2 (0.70) and A3 (0.67D) fall in the middle with A2 being marginally better.

Arrangement A4 is the least efficient of all arrangements used in the experimental study and arrangement A5 showed minimum scour depth around the single bridge pier. The corresponding less scour depth for the two piers stands at 40% and 41% respectively.

Therefore, the staggered arrangement of two rows of piles which showed the maximum efficacy in preventing between the piles and the isolated bridge pier was accepted as the choice for scour prevention at the upstream of the pier. This arrangement may not be responsible for a full decrease at the pier yet it provides a better factor of safety as if has a row of piles in its rear.

3.3. Interference Effect of a Pipeline with a Bridge Pier

For considering this kind of situation where a pipeline crosses a river close to a bridge (Definition sketch in figure 4) and is likely to affect the scour around a pier, a set of 18 experiments were performed under this category. The findings are presented in table 4 and figure 5.

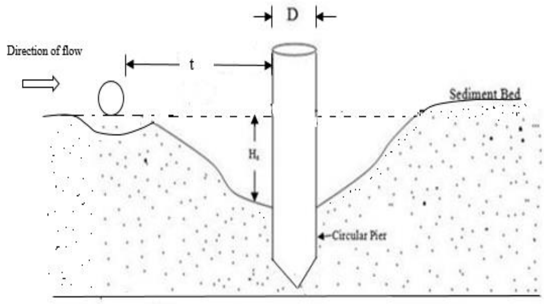


Figure 4. Line Diagram of bridge pier and Pipeline on the surface of mobile sediment.

Figure 5 has been plotted to show the result of having a noticeable gap between the pipeline and the bridge pier. The curves show that there will be higher scour depth if there is less space between the pipeline and the bridge pier. Following that, the pier and pipeline did not affect one another when the distance between them was greater than three times the pier's diameter.

Table 4. Results of the Experimental Study.

Experimental Run No.	Diameter of Pipe (d) (mm)	Discharge (Q) (m^3/s)	Velocity of flow (V) (m/s)	Depth of flow (h) (mm)	Spacing (t/D)	Remarks
1	25	0.02964	0.26	19.0	0	Scour
2		0.02880	0.25	19.2	1	
3		0.02750	0.24	19.1	2	

4		0.03126	0.27	19.3	3	
5		0.02995	0.26	19.2	4	
6		0.02979	0.26	19.1	5	
7	30	0.02995	0.26	19.2	0	Scour
8		0.02964	0.26	19.0	1	
9		0.03126	0.27	19.3	2	
10		0.02964	0.26	19.0	3	
11		0.02880	0.25	19.2	4	
12		0.02750	0.24	19.1	5	
13	40	0.02995	0.26	19.2	0	Scour
14		0.03094	0.27	19.1	1	
15		0.02895	0.25	19.3	2	
16		0.02736	0.24	19.0	3	
17		0.02995	0.26	19.2	4	
18		0.02979	0.26	19.1	5	

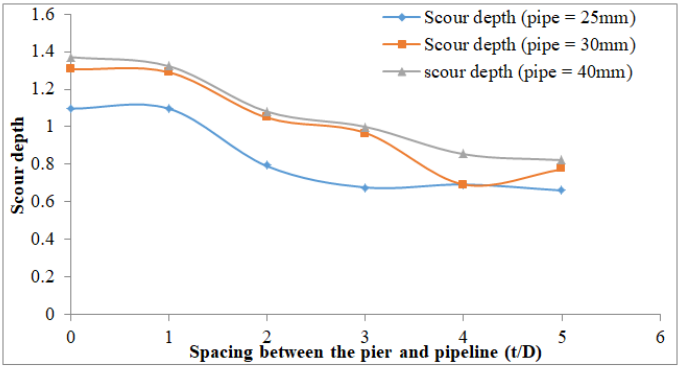


Figure 5. Comparison of the scour depths (d = 25 mm, 30 mm, and 40 mm) along the bridge pier.

Figure 5 shows that at zero spacing between the pier and the pipeline, maximum scour depth is recorded for the stipulated duration of the experiment for all three piers of different sizes. The scour depth curves of all the pipe sizes at all spacing between the pier and the pipe follow the trend of maximum scour depth for the biggest size of the pipe and minimum scour depth for the smallest size. The maximum scour depth value as obtained at zero spacing continues for a clear spacing of 1D for all three pipelines. The maximum scour depth follows a decreasing trend for all the pipes and all spacing of 1D. The trend lines for the three pipes are given by the following equations (Eq. 1 (a, b and c)).

(Pipeline, dp = 40mm) $h_s/D = 1.3978e^{-0.113(t/D)}$ 1 (a)

(Pipeline, dp = 30mm) $h_s/D = 1.3654e^{-0.13(t/D)}$ 1 (b)

(Pipeline, dp = 25mm) $h_s/D = 1.0905e^{-0.116(t/D)}$ 1 (c)

3.4. Mutual Interference between the Pier and the Group of Piles

A comparative low-velocity zone is formed in front of a single pier by a cluster of piles creating a foundation upstream of the single pier, creating as many turbulent wakes as the number of piles. This way the intensity of flow experienced by the pier is significantly reduced, due to which the strength of the horseshoe vortex decreases and there is a consistent decrease in pier scour depth.

A set of four experiments with 25mm diameter PVC circular piles were performed under this category. Table 5 gives the four arrangements of piles and their flow details (single row, two rows, three rows, and four rows) selected for the investigation. A definition sketch of the arrangement of the group of the piles is shown in figure 6. The findings of the present research work are also presented in the form of a bar chart in figures 7 (a, b, c, and d).

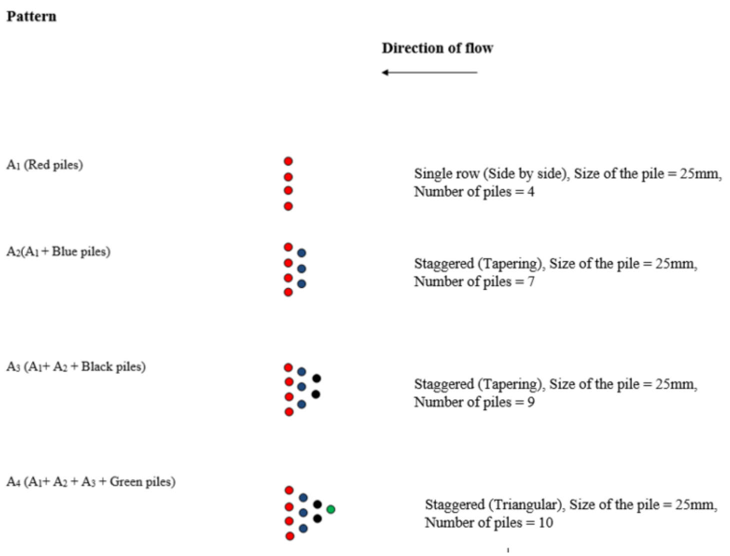


Figure 6. Definition sketch of different arrangements in a group of piles.

Table 5. Different Number of Piles Used for the Investigation($d_{50} = 0.23$mm, $\sigma_g = 1.5$).

Sequence of the experimentation	Code	Geometric arrangement	Number of piles	Diameter of pile	Velocity of flow
1	A_1	Single row (Straight line)	4	25mm	0.26
2	A_2	Two rows (Staggered, Tampering)	7	25mm	0.26
3	A_3	Three rows (Staggered, Tempering)	9	25mm	0.26
4	A_4	Four rows(Staggered, Triangular)	10	25mm	0.26

The four experiments were carried out in the order of their increasing number of piles i.e. Arrangement A1 of a single strength row of four piles was the first one to be tried. End to end it covered a perforated space of 7d (175mm) but with only 4d fully blocked. In a flume of width 600mm, the ratio of blockade was 1in 6. This was followed by A_2 which was a staggered tapering pattern of two rows with a total of seven piles, three in the front row facing the flow and four in the rear row. In sequence, this was followed by arrangement A_3 and A_4 with nine piles and ten piles, respectively.

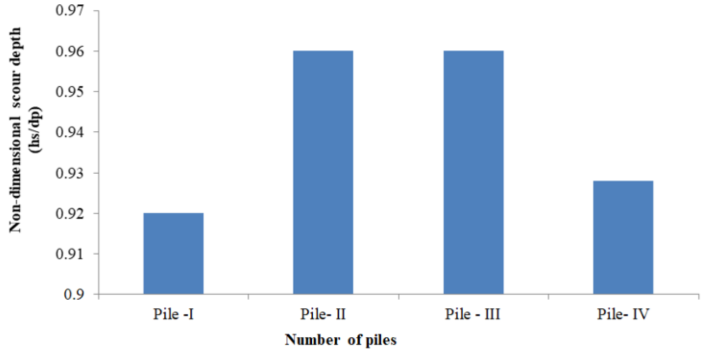


Figure 7. (a) Comparison of scour depth in a group of piles.

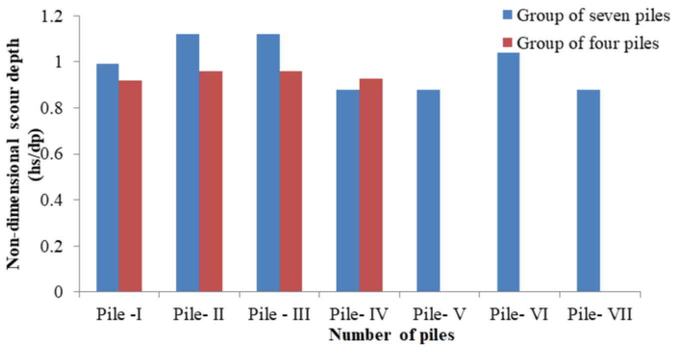


Figure 7. (b) Comparison of scour depth in a group of piles.

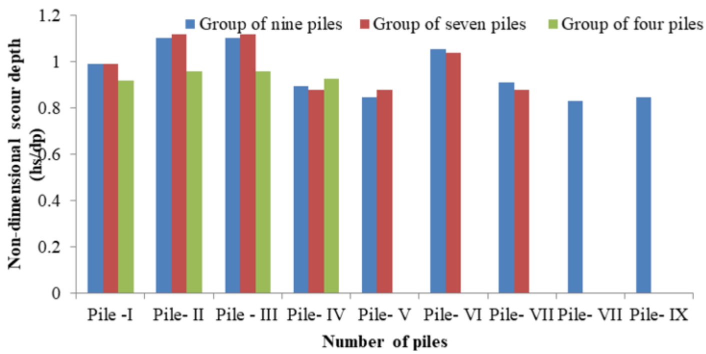


Figure 7. (c) Comparison of scour depth in group of piles.

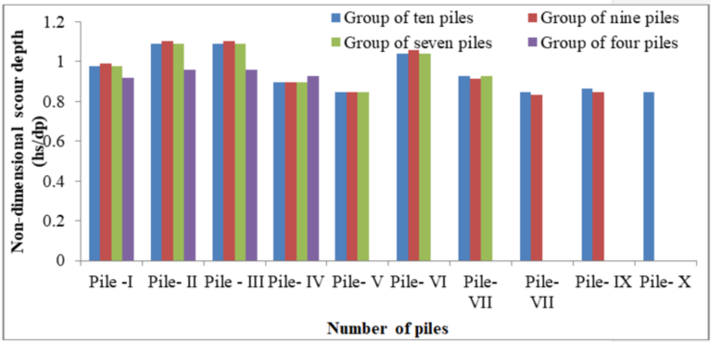
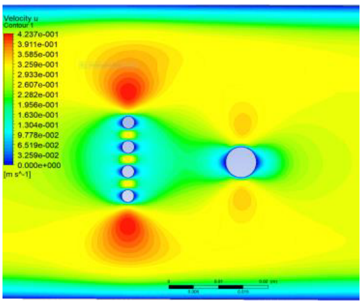


Figure 7. (d) Comparison of scour depth in a group of piles.

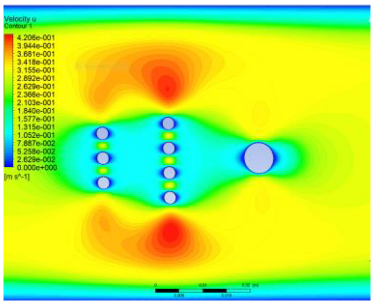
4. Analyze Results Using ANSYS

4.1. Influence of Pile Count on the Isolated Bridge Pier's Scour Depth

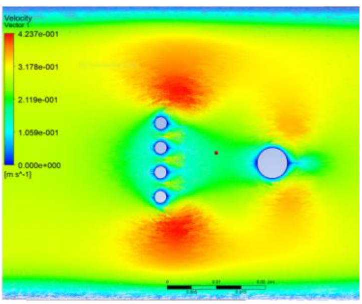
A computational analysis of the behavior of piers within a group was conducted using ANSYS. Figure 8 presents the findings of the present study.



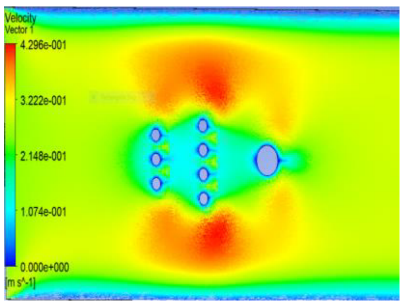
(a) Four piles, diameter = 25mm, 1 Pier, Diameter = 62mm, Velocity contours



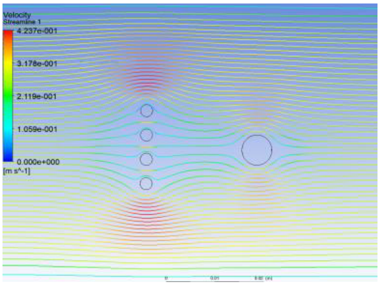
(a) Seven piles, diameter = 25mmv, 1 Pier, Diameter = 62mm, Velocity contours



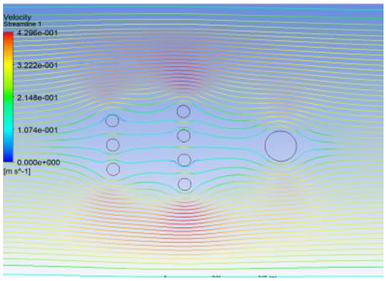
(b) Four piles, diameter = 25mm, 1 Pier, Diameter = 62mm, Velocity vectors



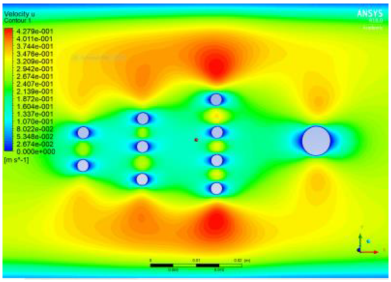
(b) Seven piles, diameter = 25mm, 1 Pier, Diameter = 62mm, Velocity vectors



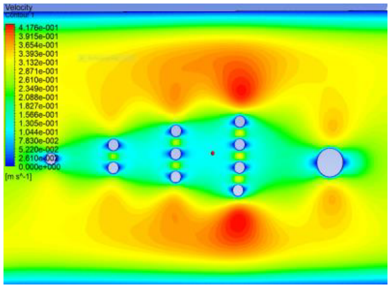
(c) Four piles, diameter = 25mm, 1 Pier, Diameter = 62mm, Streak lines



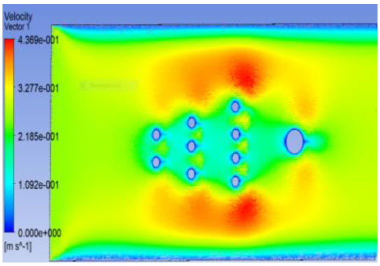
(c) Seven piles, diameter = 25mm, 1 Pier, Diameter = 62mm, Streak lines



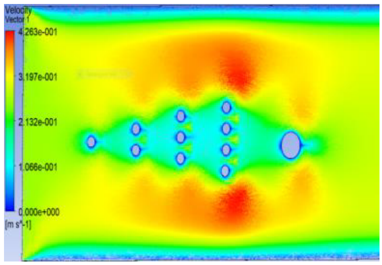
(a) Nine piles, diameter = 25mm, 1 Pier, Diameter = 62mm, Velocity contours



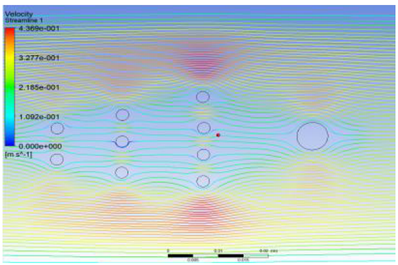
(a) Ten piles, diameter = 25mm, 1 Pier, Diameter = 62mm, Velocity contours



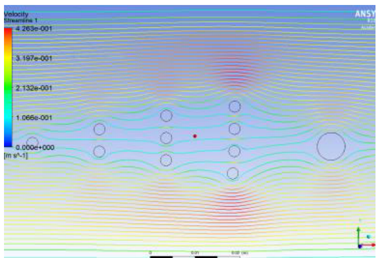
(b) Nine piles, diameter = 25mm, 1 Pier, Diameter = 62mm, Velocity vectors



(b) Ten piles, diameter = 25mm, 1 Pier, Diameter = 62mm, Velocity vectors



(c) Nine piles, diameter = 25mm, 1 Pier, Diameter = 62mm, Streak lines



(c) Ten piles, diameter = 25mm, 1 Pier, Diameter = 62mm, Streak lines

Figure 8. Visualization of flow features using ANSYS 17.2 and 18.0. (a) Velocity contours (b) Velocity vectors (c) Streaklines.

5. Conclusions

The experimental study around a group of bridge piers is most important for fulfilling the needs of the population. In the present research work five different types of arrangements, namely Row (A_1), Equilateral triangle (A_2), Equilateral triangle (A_3), Arc (A_4), and Staggered two rows (A_5) are used to check the interference effect around the bridge piers. Out of the five arrangements enumerated above, arrangement A_4 shows the maximum scour depth (1.04D), and arrangements A_5 (0.01D), the least, A_1 (0.61D), A_2 (0.32) and A_3 (0.58D) fall in the middle with A_2 being marginally better. In the group of piles in the staggered arrangement (A_5), two rows of the scour depth around the bridge pier were found to be minimum. This arrangement is suitable for decreasing the scouring at the rear pier yet in addition, a superior factor of safety as far as the downstream line of piles which fills in the second line of barrier. To minimize interference between the bridge pier and horizontal pipes, install the pipeline or pier at least three times the diameter of the bridge pier.

Symbols

D	Diameter of the cylindrical pier
Hp	Height of the pile
Q	Discharge
V	Velocity of flow
F_r	Froude number
d_p	Diameter of the pipeline
hs	Scour Depth around piles
d	Pipeline Diameter
t/d	Clear space between pier and piles

Acknowledgment

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Statement on Conflict of Interest

No conflict of interest was found in the present study.

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