ENGINEERING RESEARCH JOURNAL (ERJ)
Vol. 51, No.2 April. 2022, pp156-161
Journal Homepage: erj.bu.edu.eg

Studying the Shape Effect of Piers On the Vortices in Open Channels

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Abstract : Scour is one of the most important natural phenomena that directly affect the safety of water structures. Scour is formed due to vortices formation in the water flow in river and open channels. It also works to move materials from the bottom and banks of the watercourse near the bridge structures. The main objective of this paper is to study pier shape effect on minimizing vortices formation and consequently scouring. To achieve this objective, experiments were carried out using a flume in Imbaba Flight Institute Hydraulic Laboratory, Egypt. Five different shapes of piers with a constant discharge were used, which are circular, square, oblique square, a square with circular noses, and oblique rectangular piers. From the obtained results, it was concluded that the best shape of the pier is the square with circular noses achieving the least length and width of the formed scour holes behind it. While the worst shape is the square pier achieving the largest length and width of the formed scour holes behind it. The values of difference of the scour holes length for the oblique rectangular, the circular pier, the oblique square pier, and the square pier compared to the square with circular noses are more by 46%, 114%, 124%, and 243%, respectively.

The values of difference of the scour holes width for the circular pier, the oblique rectangular pier, the oblique square pier, and the square pier compared to the square with circular noses are more by 40%, 108%, 117%, and 220%, respectively.

KEYWORDS: scouring – sedimentation – water structures –bridges – piers

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1. INTRODUCTION

Many mathematical models have been developed to simulate the flow in the nearby areas of the vertical obstructions in open channels. Through these models, the effects of changing the flow variables can be predicted, which was not easy for laboratory experiments. Several different equations have been developed for the prediction of local scour around piers or piles in non-cohesive soil, based on essentially laboratory data.

Richardson et al. (1993) developed an equation applicable for both clear-water and live-bed scour.

Abdou (1993) investigated the effect of sediment gradation coefficient and the effect of increasing the size of the coarse material fraction that existed in a sediment mixture on a pier scour. Large-scale experiments were performed, where the study included six different sediments mixtures with constant mean diameters. Equations were established based on dimensional and regression analyses.

Noguchi et al. (1997) studied the relation between the maximum scour depth of a hydrograph and the steady long-duration flow. Equations were developed based on laboratory data and regression analyses.

Melville (1997) derived an equation for both piers and abutments and both live-bed and clear-water scour. The factors included in the developed equation were found in tables or formulas derived by the author.

Melville and Chiew (1999) investigated the temporal development of clear-water local scour depth at cylindrical bridge piers in the uniform sand bed, and predicted a method for the determination of the time to develop the equilibrium scour. It was concluded that the scour depth after 10% of the time to equilibrium was about 50% and 80% of the equilibrium depth depending on the approach velocity.

Sheppard (2004) predicted relations for wide pier scour for both clear-water and live-bed scour.

Olivet and Hager (2002) studied the pier and abutment scour under clear-water conditions using a similarity approach and extended laboratory experiments, and proposed an equation for scouring evaluation.

Muzzammil and Gangadhariah (2003) studied experimentally the primary horseshoe vortex that formed upstream of a cylindrical pier which is the main factor leading to scour. An equation was developed to predict scour.

Barbhuiya and Dey (2004) studied the size, velocity, and strength of vortices in terms of the relevant hydraulic and geometric parameters and the temporal scour hole evolution. In contrast to many studies, a general procedure was established to determine the velocity distribution.

Zahraa F. Hassan et al. (2020) investigated scour depths experimentally for upstream and downstream of piers. The depth of scouring upstream pier was greater than that downstream pier. Also, the scour depth for the two in-line piers was 10% higher than that for a single pier.

The main objective of this study is to study the shape effect of piers minimizing the vortices and consequently scouring.

Cardoso et al. (2021) studied the equilibrium scour depth at single vertical piers. The critical value of flow intensity at scouring was not constant but rather a function of the relative flow depth. The relative sediment size factor was not constant for values of D50 above 25 – 50, as it was frequently assumed, but it rather decreased in the range 100 < D50 < 500.

The main objective of this study is to get the pier shape that responds best to minimize the scouring effect.

2. Materials and Methods

To achieve the objective of this paper, experiments were carried out using a flume employing five different shapes of piers with a constant discharge. The experiments were carried out in a recalculating flume with width of 60 cm and length of 2.6 m, as shown in Figure 1, and all its external parts and sides were made of metal. The channel was divided from the inside using transparent fibers so that all the changes and results formed within the flume could be studied. The part dedicated to experimenting had a width of 24 cm and a length of 1.82 m.

The flume was connected with the main tank with a head of 1.5 m and two glassy secondary tanks equipped with thin hoses to inject water in different colors to clarify and study the impact of the different shapes of the piers on the scour hole formation.

A laser device was used to measure the depth of the water inside the flume. A high-quality camera was used to photograph the different shapes of the vortices and to clarify the extent of their overlap.

In this study, as shown in Figure 2, five different shapes of piers were considered:

1) A circular pier with a diameter of 0.05 m.
2) A square pier with a length of 0.05 m and a width of 0.05 m.
3) An oblique square pier with a length of 0.05 m and a width of 0.05 m.

4) A square pier with two circular noses with a length of 0.10 m, a width of 0.05 m, and a radius of 0.025.

5) An oblique rectangular pier column with a length of 0.09 m and a width of 0.05 m.

Fig1. The Flume

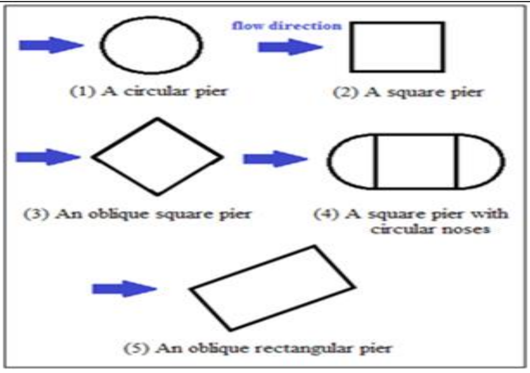

Fig 2. The Piers

3. Results and Discussion

The experiments were done for five shapes of the piers, as shown in Figure 3. The depth of water in the flume was 0.20 m, the velocity of water was 0.35 m/s, the discharge was 0.0168 m^3/s, and the time of experimental for each pier was 5 sec. At the fifth second, the length and width of the vortices formed became constant.

It was noted that the square column had the most impact on the shape of the formed vortices, as it achieved the largest width and length of the vortices. While the square column with a circular nose performed the least effect, as it achieved the least width and length of the vortices formed, as shown in Table 1 and Figure 4.

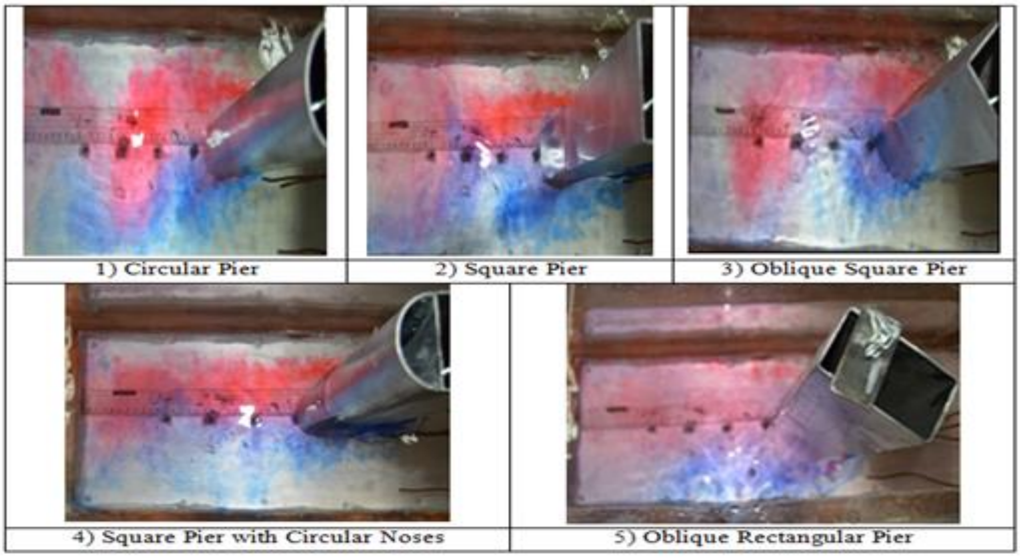

Fig3. Vortices for Different Piers

Table 1. Vortices Length and Width for Different Piers Columns

Pier Shape	b, cm	L_v, cm	W_v, cm	L_v /b	W_v/b
Circular	5.00	15	13.00	3.00	2.60
Square	5.00	24	20.00	4.80	4.00
Oblique square	7.00	22	19.00	3.14	2.71
Square with circular noses	10.00	14	12.50	1.40	1.25
Oblique rectangular	10.30	21	18.00	2.04	1.75

Where: b = pier length in the flow direction, Wv, Lv = width, and length of the vortex area

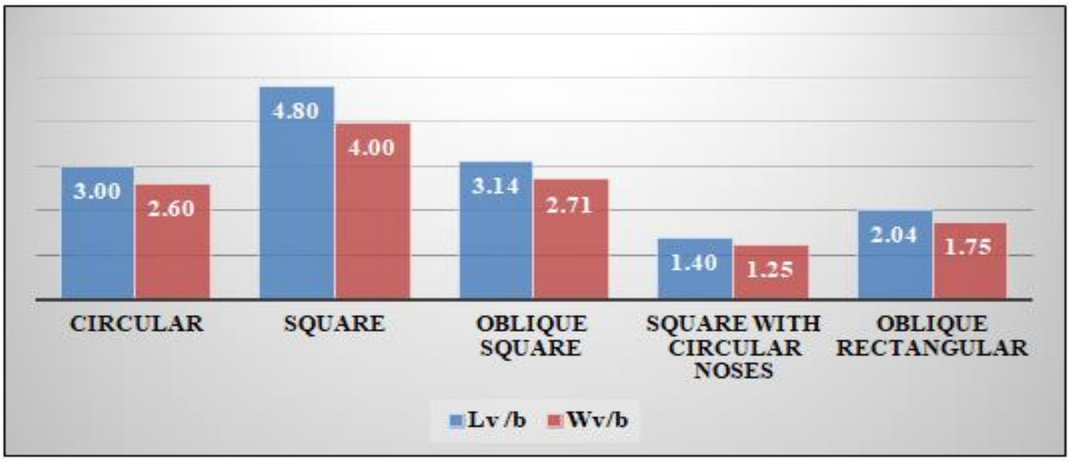

Fig 4. Vortices Length and Width for Different Piers

When the water flowed perpendicular to the pier used for 5 seconds, it was noticed that the length and width of the vortices formed behind the pier increased with time till they became constant, as shown in Figures 5 through 9.

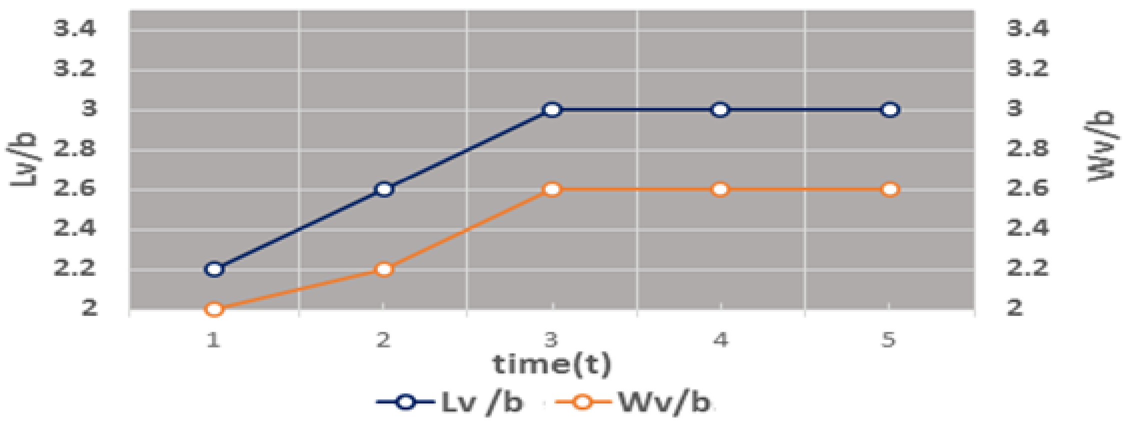

Fig 5. Dimensionless Vortices Length and Width for Circular Pier

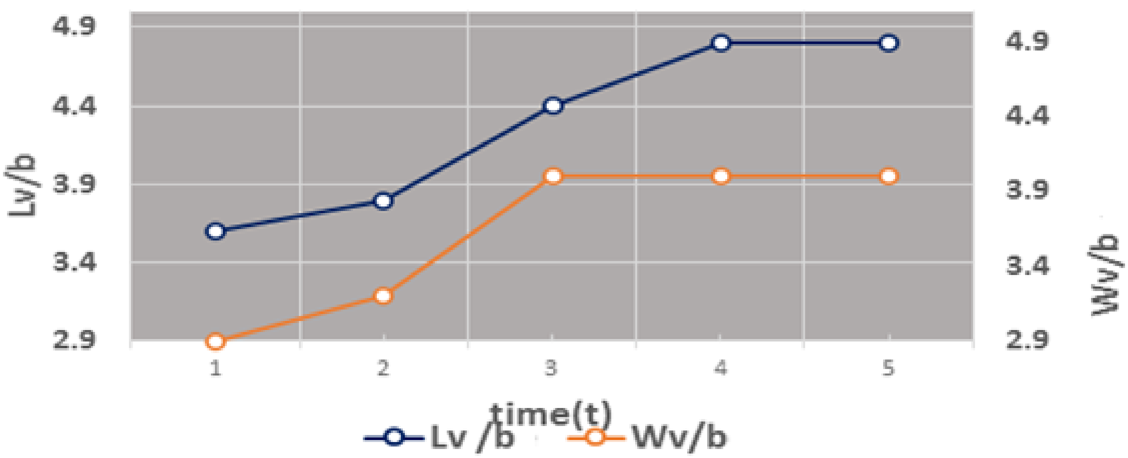

Fig 6. Dimensionless Vortices Length and Width for Square Pier

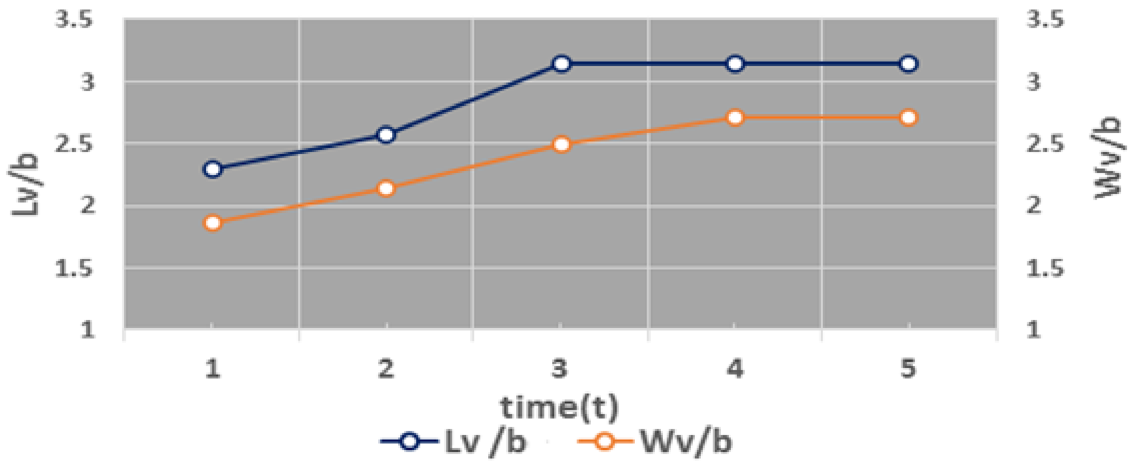

Fig 7. Dimensionless Vortices Length and Width for Oblique Square Pier

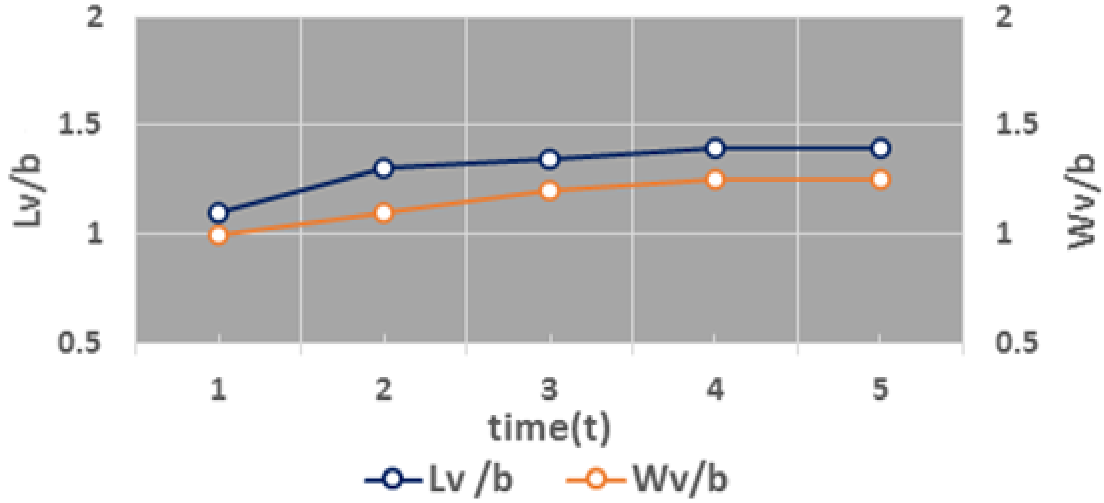

Fig 8. Dimensionless Vortices Length and Width for Square with Circular Noses Pier

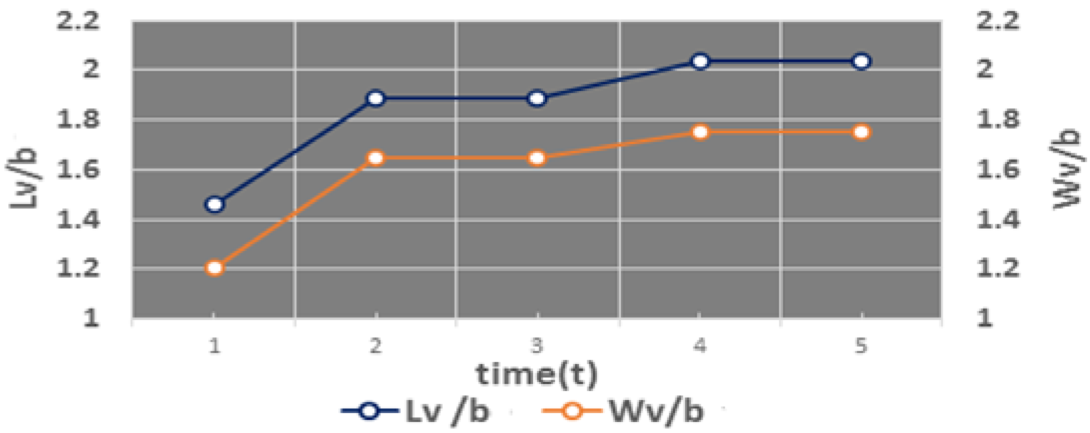

Fig 9. Dimensionless Vortices Length and Width for Oblique Rectangular Pier

The worst shape is the square pier achieving the largest length and width of the vortices formed behind it.

The differences of increase of the vortices length for the oblique rectangular, the circular pier, the oblique square pier, and the square pier are 46%, 114%, 124%, and 243%, respectively.

The differences of increase of the vortices width for the circular pier, the oblique rectangular pier, the oblique square pier, and the square pier are 40%, 108%, 117%, and 220%, respectively.

4. Conclusions

It was concluded that the best shape of the pier is the square with circular noses as it achieved the least length and width of the vortices formed behind it.

The oblique rectangular pier is the second rank, followed by the circular pier, and the oblique square pier takes the fourth rank.

The worst shape is the square pier as it achieved the largest length and width of the vortices formed behind it.

5. References

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