SCOUR INVESTIGATION AROUND SINGLE AND TWO PIERS SIDEBYSIDE ARRANGEMENT

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Abstract

Laboratory experiments concerning scour development around single and two piers side by side arrangement have been conducted in order to provide a comparison of scour depths and patterns. The experiments are carried out under unidirectional currents of clear-water scour conditions. A variety of conditions including different flow depths, pier diameters and pier spacing are considered to have significant influence on the development of the potential scour hole. The research on local scour around single and two piers side by side arrangement are studied by using a 15.24 m long, 0.46 m wide and 0.4 m deep flume in the Hydraulics and Hydrology Laboratory, Universiti Teknologi Malaysia (UTM).Experimental results describing the scour-hole depths and patterns are discussed. The results show that the magnitude and extent of the scour depth depends directly on pier size, pier spacing and flow condition. Piers, which are larger in diameter, produced greater scour depth. It also shows that by increasing the pier spacing, the scour depth around two piers decreases and closes to values of single pier. The two piers act as an obstruction which disturbed the flow field and caused large turbulence levels to be generated. Thereby, a further increase in the scouring velocity is produced giving relatively higher scour depth values. The prime factors governing the local scouring process associated with piers are pier spacing, horseshoe vortex, reinforcing and sheltering. The results show that good agreement with previous study where the down flow causes of increased scour for a single pier case. Meanwhile, the horseshoe vortex appears to be the main cause of scour in the case of two piers side by side arrangement.

Keywords: *Scour depth, Flow pattern, Single pier, Side by side piers, Pier spacing, Horseshoe vortex*

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1. INTRODUCTION

Scouring is an important phenomenon in river mechanics. It generally takes place in alluvial channels and around man-made structures such as bridge piers, spur dikes and embankments. When an alluvial stream is partially obstructed by a bridge pier, the flow pattern in the channel around the pier is significantly changed. The pier produces an adverse pressure gradient just upstream of the pier. The boundary layer upstream of the pier undergoes a three-dimensional separation. The shear stress distribution around the pier is drastically changed due to the formation of a horseshoe vortex, resulting in scour around the pier which, in turn, changes the flow pattern [1].

Pier scour is the greatest causes of bridge failures. Due to extreme scour around piers, scouring has long been acknowledged as a severe hazard to the performance of bridge piers. This phenomenon has motivated many investigators to explore the causes of scouring and to predict maximum scour depth at bridge piers [2,3,4]. According to Cheremisinoff[5], the interaction between the flow around a bridge pier and the erodible bed surrounding it is very complex. Mubeen[6] also stated that the presence of group of bridge piers can generate a complex in the hydrodynamic characteristics of the flow field near the piers and lead to the occurrence and development of a scour process. Flow observations reveal that a complex ordered flow pattern (Fig -1) occurs even in a case of simple geometry hydraulic structure [7]. Therefore, a comprehensive understanding of the complex flow field and erosion mechanisms can provide a way out of this problem.

Ahmed and Rajaratnam[8], Ettema et al. [9], Thamer*et al*. [10], Kirkil*et al*. [11], Padmini and Asis[12], Yasser and Ahmed[13], Guney*et al*. [14] andElsebaie[15] have made some studies and gave information for a better understanding of the flow pattern and turbulent flow around single pier. There are a large number of studies around pier groups and complex piers that focused on the prediction of maximum scour depth [16, 17, 18,19] and the effect of the pier spacing on the scour depth [20]. Several laboratory studies have been carried out to investigate the relationship between pier spacing and maximum scour depth around two piers side by side arrangement [21, 22, 23. 24]. Fig -2 shows a sketch of the flow pattern and local scour around side by side piers arrangement. The mechanisms which affect scour pattern around side-by-side piers, includes: reinforcing effect, sheltering effect, shed vortex and compressed horseshoe vortex [25].

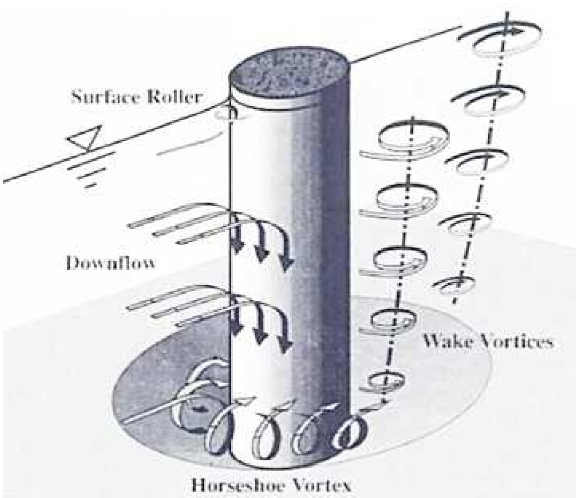

Fig -1: Flow pattern around cylindrical pier with a developed scour hole

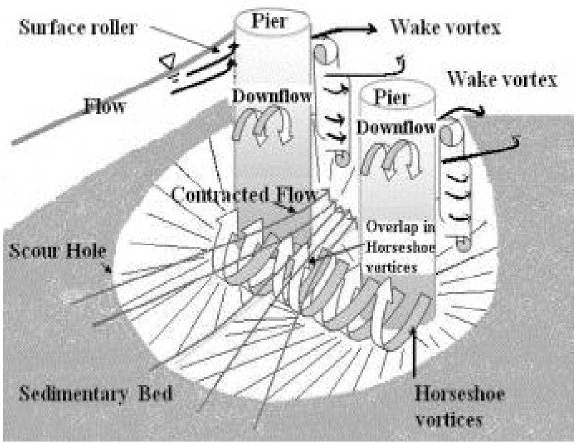

Fig -2: Flow pattern and local scour around side by side piers arrangement

Experimental investigations on the scour around single and two piers side by side arrangement have been undertaken. The main objective of this study is to carry out a detailed experimental investigation of the influence of flow on scour development around two piers side by side arrangement. Extensive laboratory have been conducted to study the scour-hole patterns in the vicinity of piers. As a reference study, the experiments have also been conducted around a single pier. The study is focused on the influence of flow depth, pier diameter and pier spacing on the development of the scour hole and pattern.

2. EXPERIMENTAL SETUP

A series of experiments is carried out for single and two piers side by side arrangement in a flume at the Hydraulics Laboratory, Faculty of Civil Engineering, Universiti Teknologi Malaysia (UTM). The dimensions of the flume are 15.24 m long, 0.46 m wide and 0.4 m deep. For the experimental works, a portion of recess 4.50 m long, 0.46 m wide and 0.15 m deep are provided in the middle section of the flume to serve as the working section. The slope of the flume for all tests is fixed to 0.0006 and uniform graded sand with a d_{50} of 0.3 mm is used as its bed material.

In order to investigate the effect of pier diameters on the scour characteristics, sizes of 32 mm, 42 mm and 60 mm pier diameters are selected. The bottom of the pier model is welded to a square base plate of 100 mm dimension and 5 mm thickness. The base is placed on the flume bottom. The pier is placed vertically at the centerline of the test section. Fig-3 and Fig -4 show the schematic diagram of pier configurations tested in the flume.

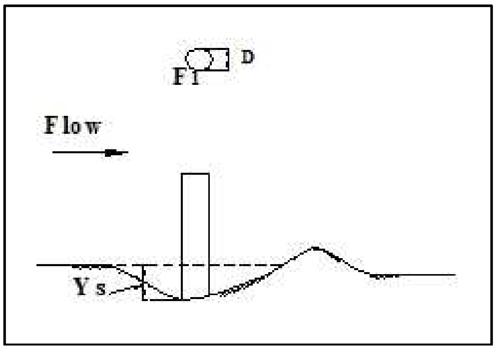

Fig -3: Single pier

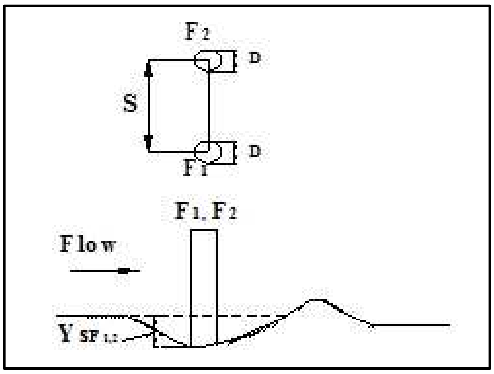

Fig -4: Two piers with side by side arrangement

For these experiments, the water depths are measured by mean of a point gauge mounted on the carriage which could be moved along the rails attached to the top of the flume side walls. The point gauge could be read accurate to nearest of 0.1 mm. In order to investigate the effect of flow depths on the scour characteristics, two different water depths (Y_0 = 160 mm, 190 mm and 230 mm) are adopted in the study. The scour-hole geometry is also determined using the point gauge at the end of each run. Longitudinal and transverse coordinates of the point gauge measurements are obtained using scales marked on the instrument carriage as well as the positioning scales at the rails of the flume.

Flow velocities are measured using Acoustic Doppler Velocimeter(ADV). With the use of appropriate software, the values of the velocity are gathered and stored in computer. In this experiment, a 3-D down looking probe is used to plot the velocity profiles which relate to unidirectional flow distribution along a channel. Velocity data are collected at the upstream, middle and downstream end of the piers to determine the main velocity components affecting the scour depth around the piers. The average flow velocities of 232 mm/s, 206 mm/s and 175 mm/s are measured for three flow depths (Y_0) namely 160 mm, 190 mm and 230 mm, respectively.

3. RESULTS AND DISCUSSION

The effects of flow depth, pier diameter and pier spacing on the scour development around single and two piers side by side arrangement are studied in the laboratory. The contour plots show the scour depth characteristics in mm. Negative contour values indicate erosion while positive values indicate deposition. The plots have been produced by using SURFER 16 software which is a computer graphics system for displaying data in the form of contoured plots. Experimental results describing the scour patterns around a single pier are discussed in Section 3.1. For scour patterns around two piers side by side arrangement results are described in Section 3.2. This is followed by a discussion on the effect of flow depth, pier diameter and pier spacing on the scour patterns, as described in Sections 3.2.1, 3.2.2 and 3.2.3 respectively.

3.1 Scour Patterns around a Single Pier

Local scouring around a single bridge pier has been attempts firstly investigated to generate basic observation of scour patterns and serves as a control. Figures 3, 4 and 5 illustrate plots of scour patterns produced by three different pier diameters (D = 32 mm, 42 mm and 60 mm) and two different water depths (Y0 = 160 mm and 190 mm). The formation of single scour holes immediately around the pier is observed.

Fig-5shows that the formation of one big scour hole immediately around the pier is seen. The maximum scour depth around the pier is 30 mm. Meanwhile, the maximum deposition is 15 mm which only occurs at distance of 400 to 500 mm along the channel. Similar scour pattern is observed in Fig-6. Due to increases of pier diameter from 32 mm to 42 mm, the formation of scour hole around pier is seen slightly greater than the previous scour hole. However, the maximum scour hole is also 30 mm. The maximum deposition is 20 mm. Fig-7 also shows that the formation of scour hole immediately occurs around the pier. The scour hole is slightly greater and deeper than other pier sizes. The maximum scour depth around the pier is 45 mm. Meanwhile, the maximum deposition is 25 mm. It can be concluded that the extent of the scour hole was slightly greater and deeper in the case of bigger pier sizes and shallower flow depths due to the increased flow velocity.

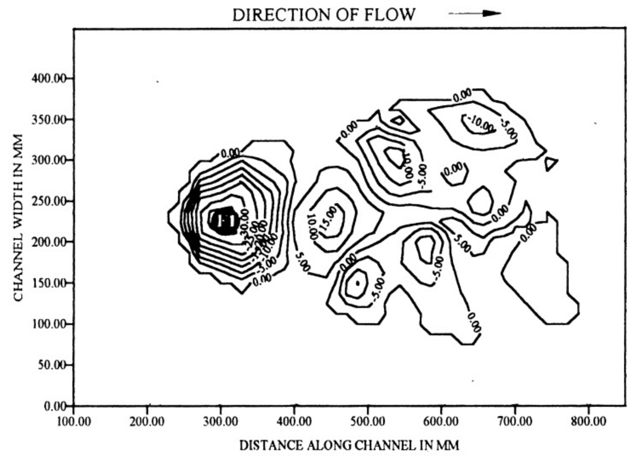

Fig -5: Scour hole due to unidirectional flow for a single pier (D = 32 mm and Y0 = 160 mm)

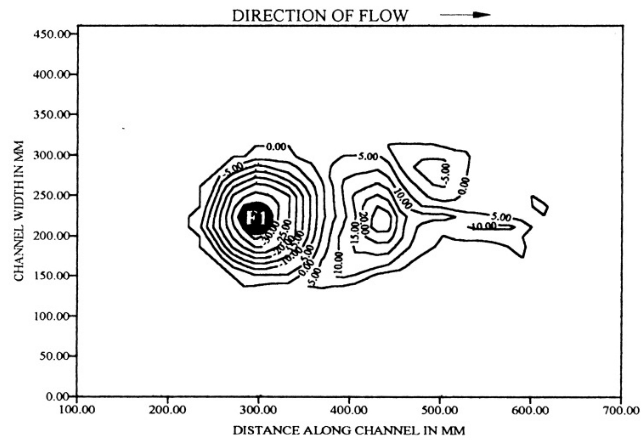

Fig -6: Scour hole due to unidirectional flow for a single pier (D = 42 mm and Y0 = 190 mm)

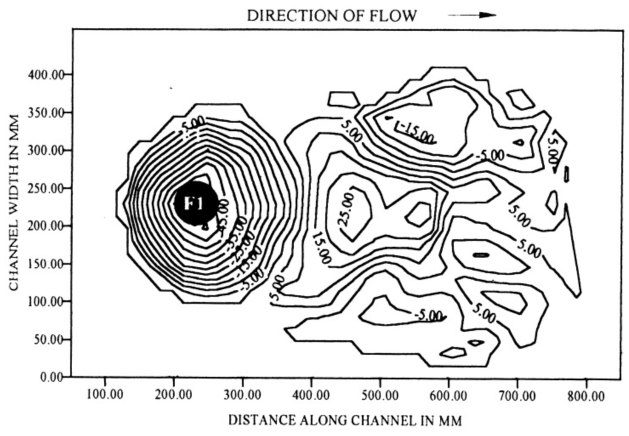

Fig -7: Scour hole due to unidirectional flow for a single pier (D = 60 mm and Y0 = 160 mm)

3.2 Scour Patterns around Two Piers Side by Side Arrangement

Local scour associated with two piers in side by side arrangement is discussed in this section. Results from six different measurements have been described to show the characteristics of local scour depth formation associated with the effect of flow depth (Y_0), pier diameter (D) and pier spacing (S). The plots of the scour-hole contours represent the scour depth formation in mm.

3.2.1 Effect of Flow Depth

Fig-8andFig -9 represent the scour and deposition patterns produced by two piers of similar sizes (D = 60 mm) and pier spacing (S = 2D) which are placed at two different flow depths (Y_0 = 160 mm and 230 mm)in a side by side arrangement. In both cases, the formation of two separate scour holes immediately around the first and second front piers is seen. Similar scour patterns are observed.

Fig-8 shows the maximum scour depth around the piers is 60 mm. Meanwhile, the maximum scour depth for Fig-9 is 30 mm. Thus, the extent of the scour hole is slightly greater and deeper in the case when the piers are placed under a shallower flow depth which produced a higher velocity. Since both the first front and second front piers are equally exposed to the flow, the scour depths in front of them are identical.

Fig-8 also shows the maximum scour depth around the two piers side by side arrangement is about 35% higher than the single pier. When the piers are placed in deeper flow depth as shown in Fig-9, the maximum scour depth decreased about 50% compared to shallower flow depth condition. It occurs due to the flow velocity decreases as the flow depth increases. In addition, the two piers act as an obstruction which disturbed the flow field and caused large turbulence levels to be generated. Thus, a further increase in the scouring velocity is produced giving relatively higher scour depth values [25].

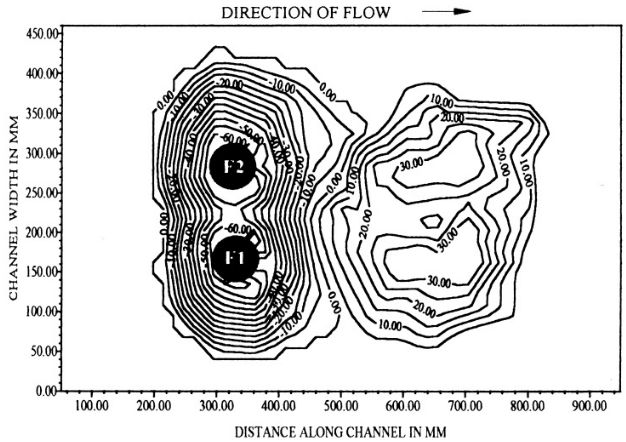

Fig -8: Scour hole due to unidirectional flow for two piers in a side by side arrangement (D = 60 mm, Y_0 = 160 mm and S/D = 2)

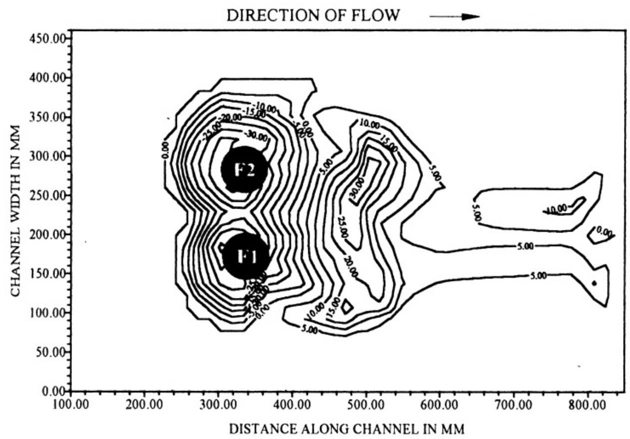

Fig -9: Scour hole due to unidirectional flow for two piers in a side by side arrangement (D = 60 mm, Y_0 = 230 mm and S/D = 2)

3.2.2 Effect of Pier Diameter

Fig-10 and Fig -11 indicate that the bed contour plots of scour pattern and maximum scour depth for different pier sizes (D = 32 mm and 42 mm) at similar pier spacing (S = 1.5D) and flow depth (Y_0 = 160 mm). In this case, a single scour hole was observed. The observed scour patterns formation for both piers are similar. This is because of both the first and second front piers are equally exposed to the flow causing the scour depths in front of them to be identical. A slightly different scour pattern is produced when two different pier sizes are used. It is also revealed that by increasing the pier sizes, the scour depth around side by side piers also increases.

Fig-10 shows the maximum scour depth around the piers is 35 mm. Meanwhile, the maximum scour depth for Fig-11 is 55 mm. From there, it is found that the maximum scour depth for the piers size of 42 mm is about 60% higher than the piers size of 32 mm condition. The flow between two piers with greater size is accelerated into scour hole so that it influences the vertical and deflections of the flow around and especially between them [21]. Thus, a further increase in the pier size is produced giving relatively higher scour depth values.

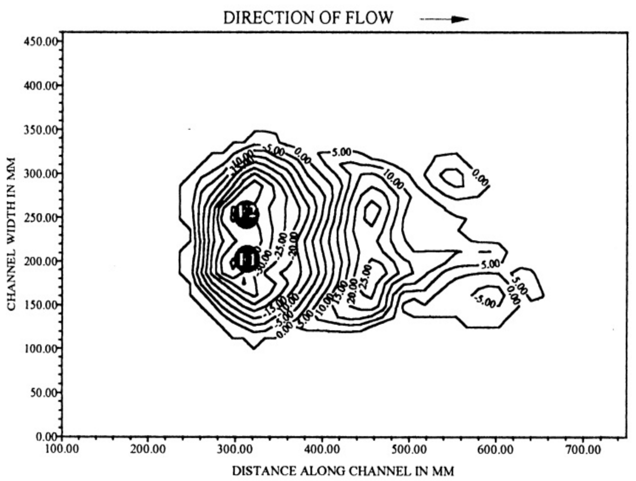

Fig -10: Scour hole due to unidirectional flow for two piers in a side by side arrangement (D = 32 mm, Y_0 = 160 mm and S/D = 1.5)

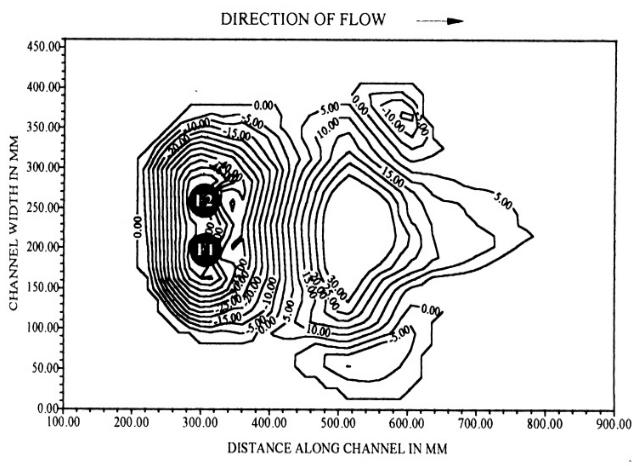

Fig -11: Scour hole due to unidirectional flow for two piers in a side by side arrangement (D = 42 mm, Y_0 = 160 mm and S/D = 1.5)

3.2.2 Effect of Pier Spacing

Fig-12 and Fig-13 illustrate the scour patterns and maximum scour depths for two different pier spacing (S = 2D and 5D) for similar pier diameter (D = 32 mm) and similar flow depth (Y_0 = 160 mm). From these figures, it is observed that a single scour depth is seen at 2D pier spacing and two isolated scour depths are observed at 5D pier spacing. A significantly different scour pattern is observed for larger pier spacing compared to that of the smaller pier spacing. At S = 5D, each pier will have its own scour hole with no scour holes overlapping as in the case of 2D pier spacing.

The maximum scour depth around the piers for Fig-12 is 50 mm. Meanwhile, the maximum scour depth for Fig-13 is 35 mm. It is found that the maximum scour depth for greater the pier spacing, 2D is about 45% higher than the pier spacing of 5D condition. When the piers placed close together, the interference between the horseshoe vortices caused the deepest scour depth in front of the piers. The results also show that by increasing the space between piers, the interference between the horseshoe vortices decreases [22, 26]. By increasing the pier spacing, the scour depths around the piers decreases and similar patterns observed as single pier. It occurs due to the lower magnitude of down flow and vertical turbulence intensity as well as turbulence kinetic energy between the larger spacing piers.

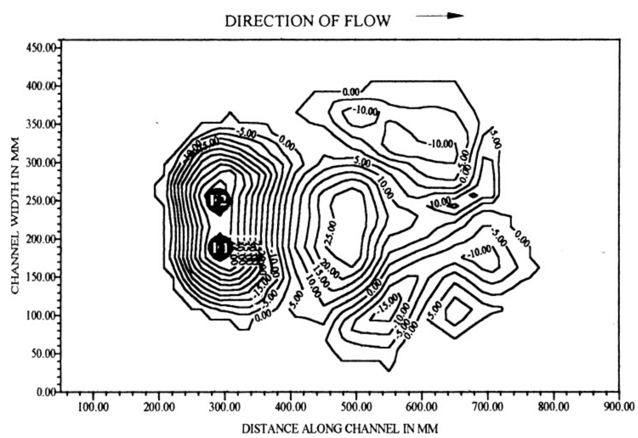

Fig -12: Scour hole due to unidirectional flow for two piers in a side by side arrangement (D = 32 mm, Y_0 = 160 mm and S/D = 2)

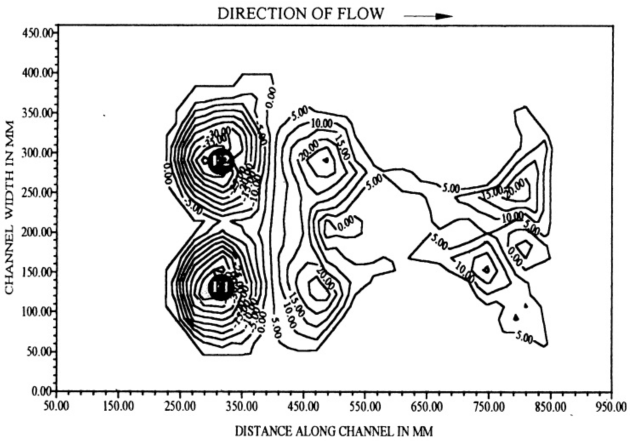

Fig -13: Scour hole due to unidirectional flow for two piers in a side by side arrangement (D = 32 mm, Y_0 = 160 mm and S/D = 5)

CONCLUSIONS

This paper presents the results of an experimental study of scour around single pile and two piers with side by side arrangement. Different water depths, pier diameters and pier spacing on the development of the potential scour hole have been investigated. The conclusions drawn from the present study can be summarized as follows: Comparison with a single, horseshoe vortex caused the scouring to be more in side by side arrangement piers. The magnitude and extent of the scour depth depends directly on pier size, pier spacing and flow condition. Piers, which are larger in diameter, produced greater scour depth. The two piers act as an obstruction which disturbed the flow field and caused large turbulence levels to be generated. Thus, a further increase in the scouring velocity is produced giving relatively higher scour depth values.

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