Effect of Interaction between Bridge Piers on Local Scouring in Cohesive Soils

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Abstract

Local scour at the piers is one of the main reasons of bridge foundation undermining. Earlier research studies focused mainly on the scour at a single bridge pier; nevertheless, modern designs of the bridges comprise wide-span and thus group of piers rather than a single pier are usually used to support the superstructure. The flow and scour pattern around group of piers is different from the case of a single pier due to the interaction effect. Reviewing the literature of local scour around bridge piers group revealed that the local scour around bridge piers group founded in cohesive soil bed was not investigated, and most of the scour studies were related to scour in cohesionless soils. The objective of the present study is to investigate the effect of the interaction between two in-line (tandem) circular bridge piers of variable spacings founded in cohesive soil on the local scour. A set of laboratory flume experiments were conducted under the clear-water scour condition to investigate this effect. This study is the first that investigates experimentally the scour around group of bridge piers in cohesive bed. It was found that the maximum scour depth at the upstream pier of the two in-line piers occurred at a spacing of two times the diameter of the pier, scour at the downstream pier was reduced due to a sheltering effect, the interference effect will be reduced for pier spacings larger than three times of the pier diameter. A recent pier scour equation was used to estimate the scour depths at the two in-line piers in cohesive soil and compare the estimated value with the measured scour depths in the laboratory. The comparison indicated that the proposed scour equation overestimates the scour depths at both the upstream and the downstream pier.

Keywords: Tandem Piers; In-line Piers; Bridge Pier Interaction; Cohesive Soils; Sand-clay Bed.

1. Introduction

Local scour around the piers and abutments of bridges is a primary risk of structural instability and collapse. Local scour occurs due to the erosive action of the flowing water that excavates and carries away the soil from around the bridge piers and abutments when they are constructed in erodible beds. Therefore, the understanding of the scour mechanisms at the foundations of a bridge must be considered for design purposes. Studies of bridge pier scour have been conducting since the 1950s, and numerous design methods and predictive equations were developed for the assessment of the local scour depth around bridge piers from various points of view and under different conditions. There are a considerable number of research studies about the scour and flow structures around a single bridge pier, on the other hand fewer researches were done about the scour and flow field around group of piers.

In recent practice the designed bridges are typically of wide-spans and thus group of piers rather than a single pier are used to support the superstructure. The scour processes at pier groups are more complicated because of the interaction of the flow structures and consequently, the scour pattern differs from that of a single pier. Local scouring around bridge pier groups in cohesionless soil beds was investigated in researches of [1-13, 15]. Laursen and Toch [1] presented the scour patterns at the foundation of two bridge piers arranged in-line and parallel to the flow direction, they observed that the scope of scour cultivates as the two piers orientation diverges from the approach flow direction. Hannah [2] observed that the maximum scour depth is influenced by the dimension of the piers group from the upstream direction, he found that the worst case in clear water scour around group of two piers happens at a spacing of 2.5 of the pier widths. Elliott and Baker [3] examined experimentally the impact of bridge pier group spacing on the local scour. From the results of the experimental runs, the effect of pier spacing on scour depth was quantified using empirical formulae. However, those formulae were developed considering clear water scour, one pier arrangement, one case of flow shallowness and one bed material type. Nazariha [4] also investigated local scouring at groups of bridge piers with the aim of developing design relationships for the prediction of local scour under clear water steady uniform current. The developed equations involved two important parameters describing the group effect, these are pier spacing to pier diameter ratio and the flow attack angle.

Zarrati et al. [5] examined in their study the efficiency of pier collars and riprap layer in reducing the local scour depth around bridge pier groups. They conducted an experimental study and compared their findings with those of earlier studies on single piers with collars and pier groups without collars. The results showed that in the case of two in-line piers with continuous collars and a riprap layer produced the most significant reduction in the scour depth, equal to 50 and 60% for the front and rear piers, respectively. In the other cases, individual collars around each one of the two in-line piers showed better efficiency than a continuous collar around both piers. The results indicated that collars are not so effective in reducing the scour around two side by side piers. Heidarpour et al. [6] extended the experimental investigation of the effect of collars on the reduction of scour around group of two piers to include three piers, they used circular collars around the front and the rear piers. They concluded that collars are effective in reducing the scour around two and three in-line piers, the scour reduction was more when the collars covered the space between the piers completely, the efficiency of the collars in reducing the scour depth in the rear pier was more than that at the front pier due to a weaker down flow at the rear pier and the collars presence slowed the scour development at the piers.

Ataie-Ashtiani and Aslani-Kordkandi [7] studied experimentally the flow field around two circular piers placed side-by-side for two bed configurations, with and without a scour hole. They used a synthetic glue to freeze the bed and investigate the flow field only. They presented the features of the flow field in details and stated that it is different from that of a single pier and the interference between the horseshoe vortices is responsible for the greater scour depth observed between the two piers. Saghravani and Azhari [8] investigated the local scour around a single and three in-line circular piers by laboratory flume tests and numerical simulations. They used a 2-phase Eulerian model to simulate the local scour in bed of uniform sand under clear-water scour condition. They got number of findings from their research as follows. (1) The laboratory tests and the numerical simulations showed the same scour pattern, which means that the 2-phase Eulerian model was able to simulate the local scour around the bridge piers, (2) in the all tests the resulting scour depth was larger at the front pier, less at the middle one and the smallest at the rear pier and (3) an 8% increase in the scour depth at the front pier in the group of 3 in-line piers as compared to the single pier because of the effect of the reinforcement of the turbulence flow structures. Ataie-Ashtiani and Aslani-Kordkandi [9] conducted another research to study the flow field around two in-line bridge piers founded in a relatively rough flat bed. They compared the features of the flow field at a single pier to that at the group of piers. The results indicated that the interaction between the piers changes the flow structure to a great extent, particularly in the near-wake region. The velocity of the flow near the rear pier decreases to 0.2–0.3 times of the approach flow velocity which indicates the sheltering effect of the front pier. It was found that the formation of flow with different Reynolds number along the flow depth because of bed roughness and pier spacing influences the type of flow regime around two in-line piers.

Beg [10] studied the characteristics of the local scour hole around two unequal sized bridge piers installed in-line with flow direction. They investigated experimentally the influence of mutual interference of two piers of various spacing subjected to steady flow and under clear-water scour. Kim et al. [11] presented a numerical study for the flow and local scour around two circular piers positioned in staggered line with different spacing ratios (S/D) and alignment angles (θ). The spacing ratio of center-to-center distance between the piers (S) to the pier diameter (D) varied from 1.25 to 5.0 and the alignment angles ranged from 0° to 90°. The simulation was done by using a large eddy simulation (LES), a Lagrangian sediment transport model and a morphodynamical model. The results of the study showed that the scour depth is more influenced by the spacing ratio and alignment angles at the rear pier. For small alignment angles, the scour rate at the rear pier increased with the increase in the spacing ratio. For larger alignment angles (45°-60°) the scour depth at the rear pier increased subsequently.

Keshavarzi et al. [12] derived a formula for the prediction of the maximum scour depths around two inline bridge piers aligned with the flow, their formula involved the influence of bridge piers spacing and they evaluated the

predicted scour depths with that of the most common scour equations and arrived at accepted results. Das et al. [13] investigated the local scour around a group of three piers, where two in-line piers are placed parallel to the flow and a third pier is placed eccentrically in middle of the tandem piers. They conducted a set of laboratory experiments to explore the pattern and location of scour formed around the piers group and the dune formed downstream of this arrangement. They used various spacing between the tandem piers to identify the spacing that produces the maximum scour depth. The investigation showed that for such three piers arrangement, the scour at the staggered piers was maximum and the scour around tandem downstream pier was minimum. They also proposed empirical equations to estimate the scour depth around each pier of the piers group individually.

Most of the implemented research work on local bridge pier scour was concerning non-cohesive soils riverbed. Scour around piers in a cohesive soil is more complicated than the scouring in cohesionless soil, in addition to the complex flow structures, the chemical and physical bonding of the cohesive soil particles are involved in the scour influencers. In cohesionless soils of gravel/sand the gravity forces and the submerged density of the soil particles are the main resistance forces to scouring; while in cohesive soils the inter-particle bonding forces resist scouring and control the scouring rate. Few researchers studied the scour around bridge piers in cohesive soils. Debnath and Chaudhuri [14] conducted an extensive experimental study on local scour around single bridge piers in clay–sand mixed bed. They stated that "it is the combined effect of shearing resistance of soil bed and the applied shear stress generated by flow that determines the location of maximum scour depth at the pier, and that the scour initiates at the sides of the pier and then propagates to downstream". Li [15] conducted a research that involves an experimental program to study the scour at bridge pier of complex geometry using Porcelain clay as a channel bed material. The effect of pier groups was studied, and correction factors were proposed to enable a more accurate estimate of scour depths at side by side bridge piers. The study by Li [15] was the only reported research in the literature that considered scour around group of piers founded in cohesive soils. They presented a method of scour depth estimation at side-by-side piers with different spacings but there was no description for the pattern of scour hole nor the effect of pier interaction on scour depth development.

This paper is dedicated to explaining the effect of the interaction between two in-line (tandem) circular bridge piers on the local scour hole around bridge piers founded in cohesive soil by using physical modeling and laboratory experiments. For this purpose, in the next sections the materials and experimental setup used in the study were explained, the results of local scour hole geometry and maximum scour measurements were also presented, finally, a comparison of the measured maximum scour depths versus values computed using a pier scour equation was presented.

2. Materials and Methods

To investigate the effect of bridge pier interaction on the local scour, several experiments were conducted in a rectangular-section flume 14 m long, 1 m wide and 1 m deep located at the Porous Media Laboratory, Amirkabir University of Technology, Tehran, Iran. The bed and sides of the flume were made of glass supported by a metal frame. The flume is equipped with a vertical sluice gate which regulates the approach flow depth and velocity. The discharge into the flume was by an inlet valve and the flow rate was measured by a sharp crested rectangular weir located at the flume outlet. The tests were conducted in the sediment recess 5.0 m downstream of the flume inlet, which is 2.5 m long and 0.30 m deep (Figure 1).

A circular plexiglass pier models of 5 cm diameter (D) were used. Experiments were conducted using a single pier and two in-line (tandem) piers placed parallel to the flow direction. The piers were placed at the longitudinal centerline of the flume in the sediment recess. For the two in-line piers experimental runs, the center-to-center spacing between piers (S_p) were selected to vary as S_p = 2D, 2.5D, 3D, 4D, 6D and 8D. Figure 2 displays a graphical representation of the two in-line circular pier models placed in the test section of the flume.

A cohesive soil mixture made up of kaolinite clay mixed with uniform fine sand having d_{50}=0.15 mm was used as the bed material in the scour experiments. The cohesive soil compresses 30% clay mixed with 70% fine sand by dry weight. The sand-clay mixture was placed in the sediment recess in the flume and the flume filled with water to saturate the soil for a duration of 3 hours. This step allows the clay-sand mixture to form cohesive bonds similar to the natural cohesive soils. The bed material preparation procedure was based on the observations and recommendations of previous researchers who studied scouring in the cohesive soils [14-18]. Soil tests were performed for the sand-clay mixture after saturation and before the inanition of the scour experiments, soil-testing procedures were according to the ASTM. A summary of the cohesive soil properties is given in Table 1.

A set of experimental runs were conducted using a single pier and two in-line piers having various spacings. Each experimental run lasted for a 24-hr duration. This time interval was enough to arrive at the state of no observed sediment movement around the piers. All the experiments were carried out under clear water scour conditions. The approach flow velocity was selected to be near the critical velocity, V_c, for the sand fraction in bed material and was predicted using the Shield's method. The flow intensity (V/V_c) was set to 0.94. The applied flow rate to achieve these

conditions was 37.5 l/s. The approach flow depth (y) was constant and equal to 15 cm. At the end of each experiment, the flume was drained slowly and carefully. Then, the bed level around the piers was measured using a laser-meter. The scour depth and scour hole geometry around both piers were measured. It is worth to mention that the size of the flume, pier models and other dimensions were selected to satisfy the universal criteria for scouring experiments and avoid scale effects.
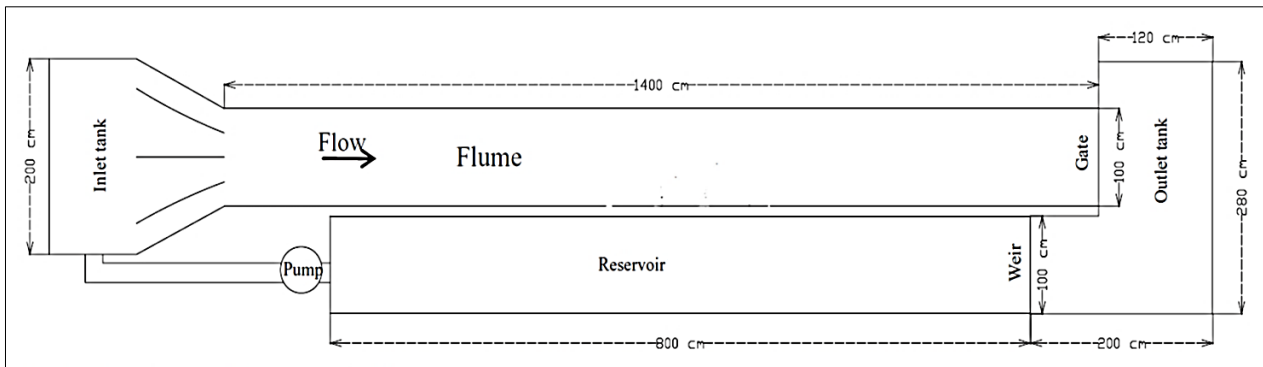

Figure 1. A schematic representation of the flume used in the experiments
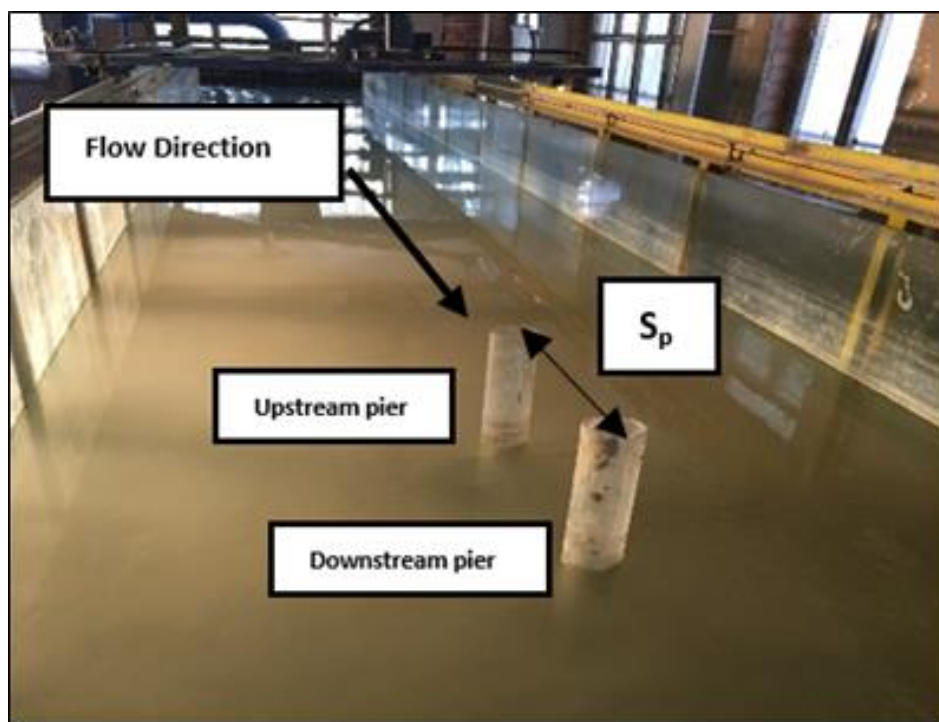

Figure 2. A graphical representation of the two in-line circular pier models arrangement

Table 1. A summary of the cohesive soil properties.

Soil property	Value
Liquid limit (%)	19
Plastic limit (%)	12
Plasticity index (%)	7
Water content (%)	21.5
Specific gravity	2.64
Median size, d_{50} (mm)	0.085
Undrained shear strength (KPa)	13.5

3. Results and Discussion

3.1. Scour Hole Patterns at Single and Two In-line Piers in Cohesive Soil

Table 2 presents the results of 7 experimental runs that were conducted to investigate the effect of bridge piers interaction. It was reported in the literature that the local scour hole around a single bridge pier founded in sand starts at the front of the pier and propagates to the downstream and the maximum scour depth is observed at the pier sides. For the case of scour in cohesive soils, the scour mostly starts from the pier sides and the scour depths at the two sides of the pier may not be identical. These observations were reported by Ansari et al. [18], Debnath and Chaudhuri [14]. In this study, the first experimental run was for a single circular bridge pier of D = 5 cm founded in sand-clay soil and subjected to a steady flow of 37.5 l/s. After duration of 24 hr, the final scour hole was recorded and the maximum scour depths at four scales 0°, 90°, 180° and 270° were measured. The result of this test agreed with the previous observations of researchers.

The flow field around a group of bridge piers is different from that of a single pier and it is more complex. In the study published by Ataie-Ashtiani and Aslani-Kordkandi [9] the flow field around two tandem piers and around a single pier was compared based on laboratory flume experiments. The results illustrated that the existence of the downstream pier alters the flow structures principally at the rear region of the upstream pier. A sheltering effect due to the upstream pier reduces the flow velocity near the downstream pier to 0.2–0.3 of the velocity at wake of a single pier. In tandem arrangement, higher values of turbulence characteristics were observed at the downstream pier. The results also indicted a weakness in the vortices at the rear of the tandem piers as compared to single one.

In this study, the resulted scour hole patterns at single and two in-line piers with variable spacings in cohesive soil are displayed in Figure 3. For a pier that is a part of two in-line piers parallel with the flow direction, reinforcement and sheltering affect the local scour depth. A reinforcement is observed when a downstream pier is placed at a distance from the upstream pier that their scour holes intersect. This effect increases the removal of the bed soil from around the upstream pier and thus increasing its local scour depth. It was found that the scour at the downstream pier was reduced due to the sheltering effect resulting from the upstream pier that reduced the effective flow velocity for the downstream pier and consequently reduced the scour depth at the downstream pier.

For large ratios of pier spacing to pier diameter (S_p/D), it was observed that the sheltering effect is pronounced on the scour depth at downstream pier (Figure 3). Based on the piers spacings range, S_p, that were investigated, the following observations were made. Smaller pier spacing results in a larger interference of flow structures between the piers. When the spacing ratio ($S_p/D \leq 2.5$) the piers group will behave as one pier. The interaction effect will be reduced for pier spacing of ($S_p/D > 3$) with the consideration of the pier-group arrangement. These findings were in general agreement with those of previous research on local scour around two in-line piers in cohesionless soil [1-13].

It was observed that the sediment that was eroded from the scour hole at the piers was transported and deposited at the downstream of the piers. The sediment deposit at the downstream was variable for the piers' arrangement. It was simple and little in the case of single pier, while it extended wider in the case of two in-line piers. The formation of the downstream hill deposit had different shape for two in-line piers varied with the space between the piers as it is shown in Figure 4.

Table 2. Experimental measurements for the effect of piers interaction

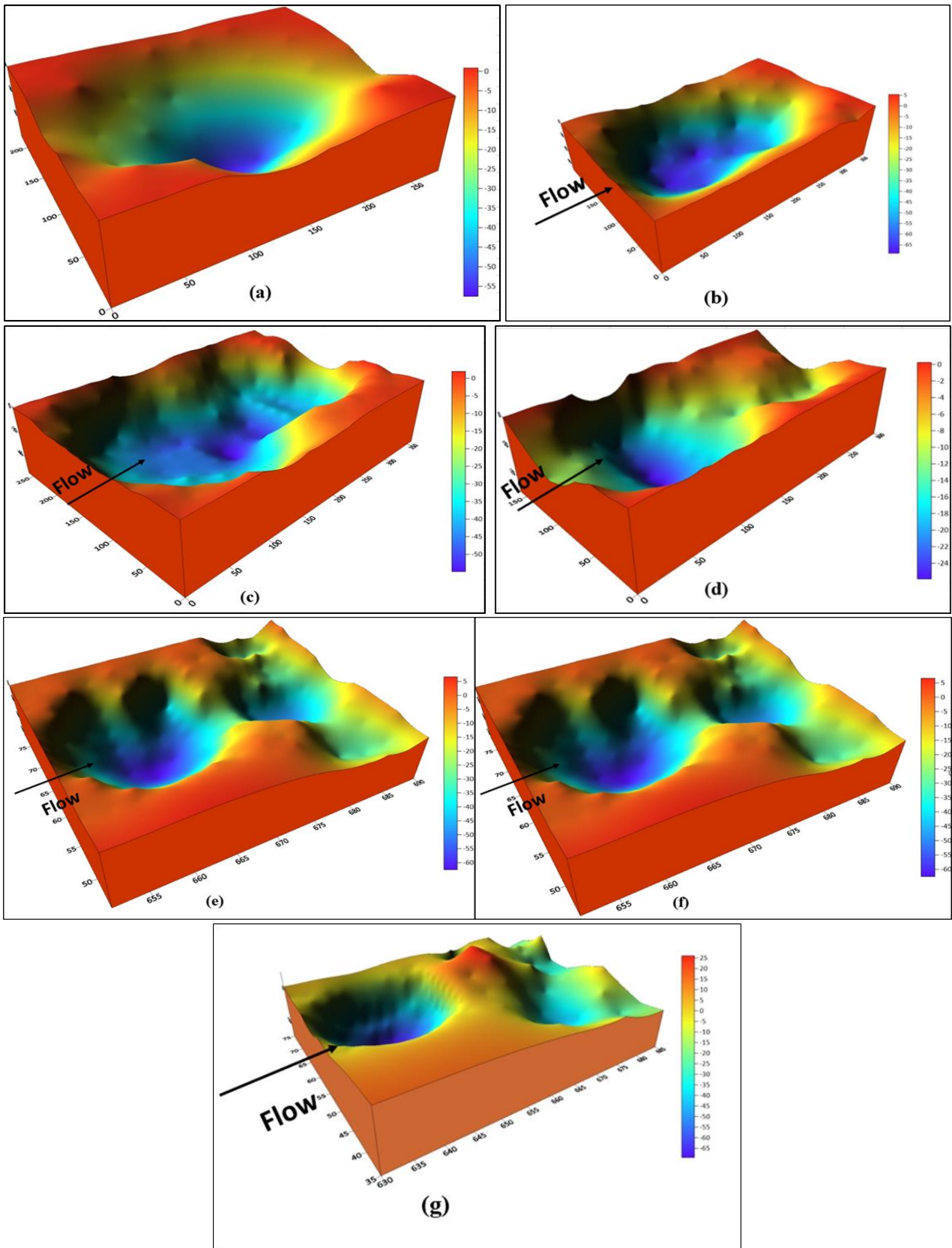| Run	S_p/D	d_s (mm)	d_{s1} (mm)	d_{s2} (mm)	d_{s1}/d_s	d_{s2}/d_s
1	Single	61			-	-
2	2		67	59	1.10	0.97
3	2.5		55	52	0.90	0.85
4	3		51	48	0.84	0.79
5	4		61	51	1.00	0.84
6	6		60	45	0.98	0.74
7	8		64	38	1.05	0.62

Figure 3. Scour hole patterns at circular single pier and two in-line piers with variable S_p in cohesive soil. (a) Single (b) S_p=2D (c) S_p=2.5D (d) S_p=3D (e) S_p=4D (f) S_p=6D (g) S_p=8D
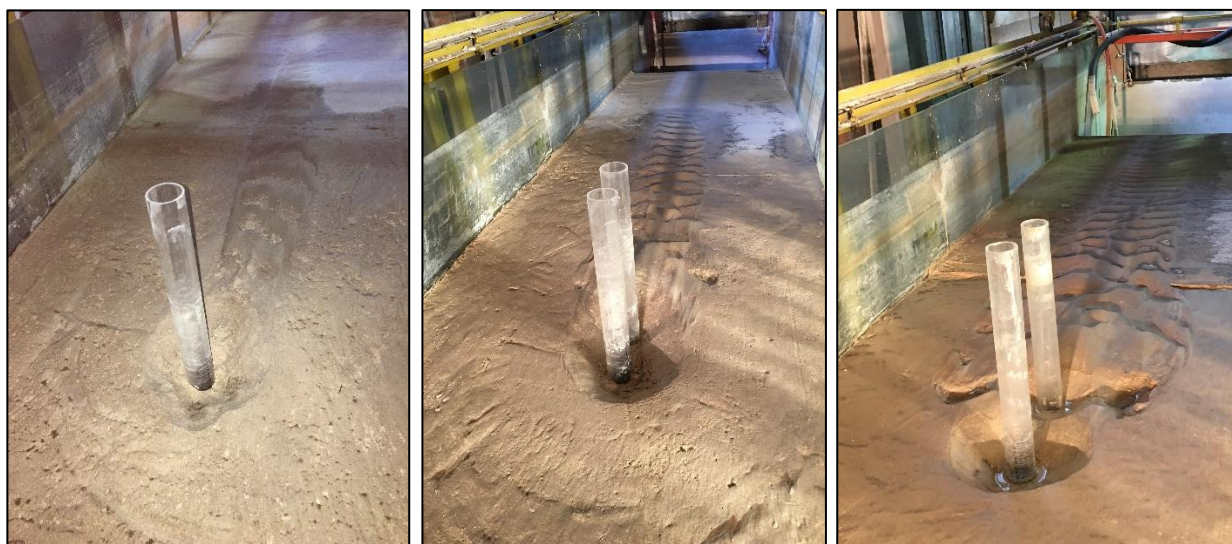
Figure 4. Sediment deposition at the downstream of the scour hole for the case of single pier and two inline piers with different spacing

3.2. Maximum Scour Depths at Two In-line Piers in Cohesive Soil

Referring to Table 2, the experimental data of measured scour depths at the upstream pier and the downstream pier shows that at spacing equals 2D the scour depth of the upstream pier was maximum. Igarashi [19] found that "the maximum drag force around a two in-line piers occurs when the spacing between them is less than 2.5D". Gao et al. [20] pointed out that "two recirculation regions surrounded by the shear layers can be observed at the rear of two in-line piers of $S_p/D = 2.4$". Therefore, the reported result in this study matches the observations by Igarashi [19] and Gao et al. [20] where they studied the local scour around group of piers in cohesionless soils. In Addition, in this study it was observed that the maximum scour depth was 10% greater than that of the single pier which is in consistent with the observation by Keshavarzi et al. [12]. Keshavarzi et al. [12] also stated that "the maximum scour depth might occur at a spacing ratio between 2 D and 3 D. For the case of the spacing between piers is 1D, the observed scour depth was like the scour depth for the single pier case" [12]. The scour depth at the upstream pier increased when the spacing between the piers increased to 2.5 D and decreased when the spacing increased above 3D. At the spacing ratio $S_p/D > 4$ the local scour depth converges to that of the single pier. This observation may be attributed to the found by Igarashi [19]. In the present study, the piers spacing was the effective parameter that was investigated and was tested in a range of 2D to 8D (D = pier diameter). The range of pier spacing were selected according to the most common conditions in the field and the recorded scour depths at the piers were equal to the scour depth at the single pier.

Figures 3 and 4 and Table 2 show the effect of interaction between two in-line circular piers on the maximum scour depth at the upstream and downstream pier. From the results, it is obvious that the scour depth at the downstream pier is always smaller than the single pier case. The reason for that is the destruction of the horseshoe vortex in front of the downstream pier as was illustrated by Hannah [2] and Keshavarzi et al. [12]. The scour depth at the upstream pier is always larger than that of the downstream pier. It was reported in the literature that "not only under steady state flow the maximum scour depth at the upstream pier is greater than that of the downstream pier, results of an experimental study conducted by Tafarojnoruz et al. [21] showed that this performance was observation also under hydrograph test when the flow varies with time. Possibly it is due to the sheltering effect that created by the upstream pier. The sheltering effect is observed when the piers spacing ration S_p/D is less than 10, which causes a decrease in the approach flow velocity at the downstream pier and consequently decreasing the scour depth" [12].

3.3. Comparison of the Predicted Maximum Scour Depths with the Measured Data

The measured scour depths at the upstream pier and the downstream pier are compared with scour depths predicted by the TAMU-scour method developed by Briaud [22]. This method was developed for the prediction of the scour hole depth at bridge supports taking into consideration the soil erosion characteristics. It is one of the recent methods that were presented in the literature to predict the local scour around bridge piers in cohesive soils. The equation for the maximum local scour depth at a bridge pier in cohesive soil is given by:

$$\frac{d_{s(pier)}}{\grave{b}} = 2.2 K_{pw} K_{psh} K_{pa} K_{psp} \left(2.6 \cdot F_{r(pier)} - Fr_{c(pier)}\right)^{0.7} \tag{1}$$

Where $d_{s(pier)}$ = maximum pier scour depth; $\grave{b}$ = effective width of the pier; K_{pw} = flow shallowness factor for pier scour depth; K_{psh} = pier nose shape influence factor; K_{pa} = aspect ratio influence factor (the aspect ratio L/B is the

ratio of pier length L over pier width B for non-circular piers); K_{psp} = pier spacing influence factor for pier groups arranged side by side; $F_{r(pier)}$ = pier Froude number based on the approach flow velocity V; and $Fr_{c(pier)}$ = critical pier Froude number based on critical velocity for soil particles motion. This critical velocity is estimated for the cohesionless soils from the Shields method or tested in an erosion apparatus (such as the erosion function apparatus EFA that developed by Briaud et al. [23]) for cohesive soils. The effective width $\grave{b}$ is found as:

$$\grave{b} = b\left(\cos\theta + \frac{L}{B}.\sin\theta\right) \tag{2}$$

Where θ = attack angle, which is the angle between the flow direction and the pier main axis. The correction factors involved in the TAMU-scour method can be calculated as below. The shape correction factor K_{psh} is presented in Table 3. The correction factor for the aspect ratio is considered by using the effective width $\grave{b}$, K_{pa} value is always 1.

Table 3. Pier nose shape correction Factors (Kpsh)

Shape	Kpsh
Square nose	1.1
Round nose	1.0
Circular cylinder	1.0
Sharp nose	0.9

$$K_{pw} = \begin{cases} 0.89\left(\frac{y}{\grave{b}}\right)^{0.33} & for\ \frac{y}{\grave{b}} < 1.43 \\ 1.0 & else \end{cases} \tag{3}$$

$$K_{psp} = \begin{cases} 2.9\left(\frac{S}{\grave{b}}\right)^{-0.91} & for\ \frac{S}{\grave{b}} < 3.22 \\ 1.0 & else \end{cases} ,\ S\ is\ pier\ spacing \tag{4}$$

$$F_{r(pier)} = \frac{V}{\sqrt{g.\grave{b}}} \tag{5}$$

$$F_{rc(pier)} = \frac{V_c}{\sqrt{g.\grave{b}}} \tag{6}$$

Briaud [22] evaluated the TAMU-method by using 10 data sets. The data sets included laboratory flume test results and field measurements for the scour depth. The evaluation process indicated that multiplying the estimated scour depth of TAMU-method by a factor of 1.5 gave safe estimations for the design purposes.

For the present study, the local scour depth at a circular pier in cohesive bed is predicted by the TAMU-scour method developed by Briaud [22] and the computed results were compared to the measured scour depths at the upstream and downstream pier in the laboratory. The results of the prediction are showed in Figures 5 and 6 for upstream and downstream piers, respectively. From the comparison it is apparent that the TAMU-scour method consistently overestimates the measured scour depths. The TAMU-scour method considers the effect of piers spacing in a direction perpendicular to the flow direction and considers its effect on the scour depth up to a spacing ratio of ($S_p/D < 3.22$). The overestimation in the downstream pier scour depth was more than that of the upstream pier. The TAMU-scour method involves a parameter to describe the bed soil erodibility which gives different scour depth prediction in different soils. This parameter is presented in the critical pier Froude number in equation (1), which can be estimated for the case of sand or cohesionless soils as the critical velocity for particles motion from Shields methodology. Or for the case of cohesive soils from the erosion function test (using the EFA). For the prediction of the scour depth at the two in-line piers in this study, the critical velocity for initiation of motion of the sand fraction in the clay-sand bed soil was used to predict the critical pier Froude number. The overestimation in the scour depths at the two in-line piers that is observed when using the TAMU-scour method by Briaud [22] may be attributed to this reason. Moreover, equation (1) predicts the local pier scour depth assuming a constant flow velocity that lasts long enough to reach the maximum equilibrium scour depth. In the present study, the experiments were conducted for a duration of 24 hr until a stable scour hole depth was reached. These scour depths might be considered as final scour depths after a specific time interval.
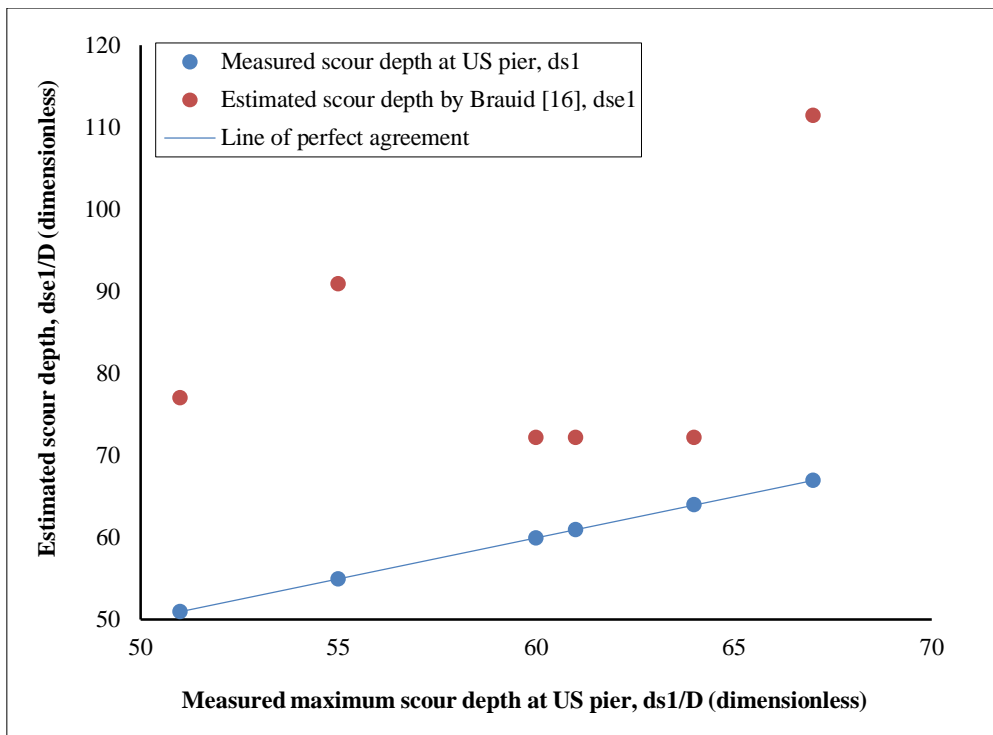
Figure 5. Estimated vs. measured scour depths at upstream pier of two in-line iers.
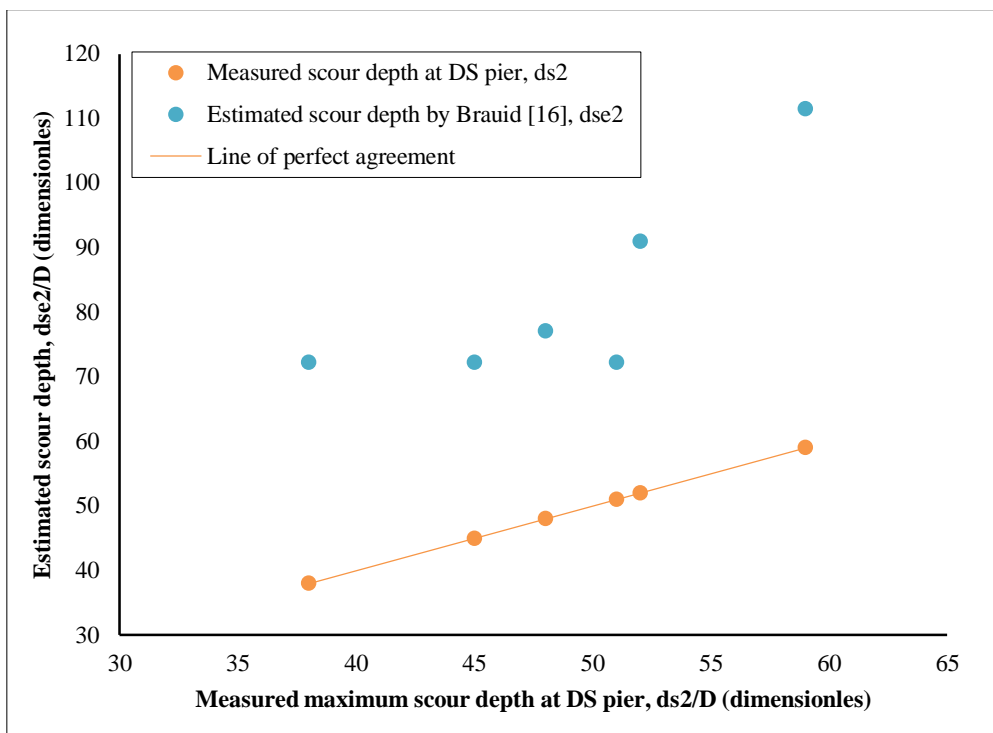

Figure 6. Estimated vs. measured scour depths at downstream pier of two in-line piers

4. Conclusion

Local scour around bridge piers is one of the main reasons of bridge failures. It occurs due to the erosive action of the flowing water that excavates and carries away the soil from around the bridge piers, that may result in the exposure of the bridge foundation to the water flow and consequently causes structure's undermining. Extensive research studies about the scour and flow structures around a single bridge pier were conducted, while on the other hand fewer researches were done about the scour and flow field around group of piers. The modern bridges of wide spans consist of group of piers that used to support the superstructure. The scour processes at pier groups differs from that for the case of a single pier. Many of the researchers who investigated the local pier scour related the scour depth to the flow

parameters and pier geometry without considering the erosional characteristics of the bed. A few researchers considered the effect of the cohesive soil characteristics on the scour depths. However, most of the studies on local scour in cohesive soils were restricted to single bridge pier. A new research is proposed to study the local scour around group of bridge piers founded in cohesive soil bed. It is based on a set of laboratory flume experiments that were conducted to investigate the effect of the interaction between two circular bridge piers placed in-line parallel to the flow direction on the local scouring.

The size of the used flume, pier models and other dimensions for flow parameters and bed sediment were selected to satisfy the universal criteria for scouring experiments and to avoid scale effects. The following observations were noted based on the experimental measurements. The scour depth measured at the upstream pier was greater than that measured at the downstream pier in the all experiments. The maximum recorded scour depth for the two in-line piers observed at a space ration of $S_p/D < 2.5$ and this scour depth was 10% higher than the scour depth at the single pier. For large spacing ratios ($S_p/D > 3$), the upstream pier scour depth approximates to the single pier scour depth. An important conclusion that can be drawn from this research is that the scour patterns and sediment transportation characteristics both changes in case of group of bridge piers. From this investigation, the scour hole geometry and downstream sediment deposition characteristics are configured for the effect of piers interaction. However, the observed effects of the interference of piers of a bridge could be seen for many pier spacing and pier arrangement of any bridge. A recent pier scour equation, namely TAMU-scour method, was used to predict the scour depths at the upstream and downstream piers in sand-clay bed. The results of the proposed equation were compared with the measured scour depths in the laboratory. The comparison showed that the proposed equation overestimates the scour depths at both the upstream and the downstream pier.

5. Conflicts of Interest

The authors declare no conflict of interest.

6. References

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