# EXPERIMENTAL EVALUATION OF SCOUR DEPTH AROUND BRIDGE PIER GROUP

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ABSTRACT: Scouring around a single pier exposed to the steady currents has been extensively investigated. However, scouring around pier groups is still a field of active research. In this work, laboratory experiments on pier group with circular piers embedded in uniform sediment were carried out in a flume of 4 m long, 0.41 m wide, and 0.25 m deep. The experimental condition is considered to be clear-water condition. Six kinds of pier group arrangement aligned with the flow were tested, including the side-by-side arrangements of piers, tandem arrangements of piers, and 2×2, 2×3, 2×4, and 3×2 pier groups. The models consist of three circular piers with diameters of 16 mm, 22 mm, and 28 mm. The pier spacing varied from zero to 6 times of pier diameter. The variations of scouring depth with the pier spacing as well as the number of rows normal to the flow and number of columns exposed to the flow were investigated. It is observed that the scour-hole depth for some cases of pier group increases as much as two times more than its magnitude for the case of single-pier. However if the pier spacing is more than a critical value this influence of pier group would be diminished. Comparisons between the experimental data and those predicted by techniques presented in the Federal Highway Administration, Hydraulic Engineering Circular No.18 (HEC-18) are presented as well. The HEC-18 predicted values were found to be conservative for pier group under the conditions tested. A procedure based of this experiments and data from other studies was developed and is proposed for consideration.

Keywords: Scour-hole depth, Pier group, Hydraulic model, Bridge foundation

## 1 Introduction

The safe and economical design of bridge piers requires accurate prediction of maximum scour depth around them. Since circular piers are the most commonly used, many investigators have studied the problem of scour in its various aspects. For geotechnical and economic reasons, pier groups have become more and more popular in bridge design. This type of pier can significantly reduce construction costs compared to spread footer (gravity) structures when sediment scour is a consideration. Vittal et al. (1994) replaced the solid pier by a group of three smaller piers to reduction of scour. They observed that the scour reduction due to a full pier group in its best orientation is about 40%. However, the scour mechanisms for pier group are much more complex, and design local scour depths more difficult to predict.

Scouring at a single pier has been more extensively investigated than at pier groups. When the scour proceeds due to the presence of a group of piers, some mechanisms occur that make the phenomenon more complex. Four of these mechanisms which affect scour at pier groups and are not present in scouring at single pier are: 1) reinforcing, that leads to increased scour depth at the upstream pier and overlaps with that of the rear piers; 2) sheltering by the upstream pier can reduce the effective approach velocity for the downstream pier and reduce the scour depth; 3) vortices shed from the upstream pier are convected downstream ( if the downstream pier is close to the path of vortices, this will assist scouring by lifting material from the scour hole ); and 4) compressed horseshoe vortex. When piers are placed transversely to the flow, each will have its own horseshoe vortex. The interaction between piers in a group intensifies the reinforcing and compressed horseshoe vortex effects.

Only a few investigators have studied the scouring in pier groups, e.g., Hannah (1978), Vittal et al. (1994), Salim and Jones (1996), and Zhao and Sheppard (1998).

The purpose of the present study is to investigate in a systematic manner the scour-hole depth around pier groups. The study basically focuses on the variations with the pier spacing.

## 2 Experimental Set-up

All the physical model experiments presented in this paper were conducted in a 4 m long, 0.41 m wide, and 0.25 m deep flume located in the Hydraulics laboratory in the Civil Engineering Department at the Sharif University of Technology, Tehran, Iran. The details of the flume and experimental setup are shown in Fig. 1.

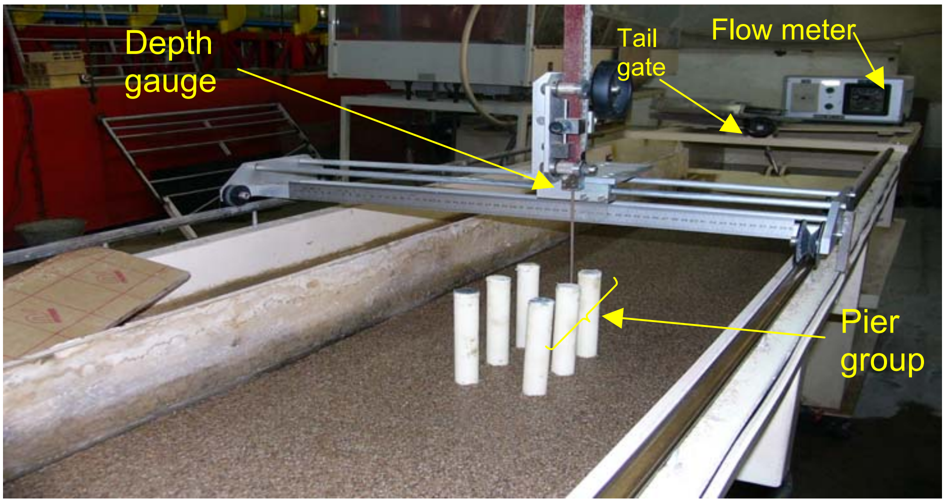


Figure. 1. Experimental set-up.

Six kinds of pier-group arrangements were tested (Fig. 2). The models consist of three circular-shaped piers with diameters, D, of 16 mm, 22 mm, and 28 mm and pier spacing, G, varied from zero to 6 times of pier diameter. The size of the models was chosen in such a way that the total blockage area did not exceed 13% of the total flow section in order to minimize contraction scour. In all the experiments, the pier surface acted as a hydraulically smooth surface. A false floor was constructed along the length of the flume at 8 cm above the bed. A uniformly graded sand of mean diameter $d_{50}$ = 0.98 mm was used. The experiment duration was kept 7 hours for most of the experiments, but several 17-hour experiments were also conducted to determine the effects of the duration. Studies by other researchers have shown that most of the scour occurs during the first three or four hours of the experiment.

All experiments were performed in the clear water scour range. The approach critical flow condition was predicted using Shields diagram and Melville and Sutherland (1988) equation. The velocity, water surface elevation, and scour-hole dimensions were recorded for each experiment. A summary of experimental conditions and results are listed in Table 1.

Table 1. Experiment conditions and results

| Type | Number of exp.s | D (cm) | Flow lepth, h (cm) | Flow velocity, $U_0$ (m/s) | G/D | Scour depth, S (cm) |
|---|---|---|---|---|---|---|
| 2×4 | 20 | 1.6–2.8 | 3.3–4.8 | 0.226–0.277 | 0–5 | 2.9–6.7 |
| 2×3 | 6 | 1.6 | 3.3–3.8 | 0.232–0.267 | 0.25–4 | 3–4.5 |
| 2×2 | 10 | 1.6–2.2 | 3.3–4.9 | 0.214–0.254 | 0.25–5 | 2.9–5.7 |
| 3×2 | 6 | 1.6 | 3.3 | 0.246 | 0.25–4 | 3.2–5.6 |
| 2×1 | 6 | 1.6 | 4.7 | 0.259 | 0.5–6 | 3.1–4 |
| 1×2 | 6 | 1.6–2.2 | 3.4–4.7 | 0.239–0.259 | 0.5–6 | 3–4.2 |

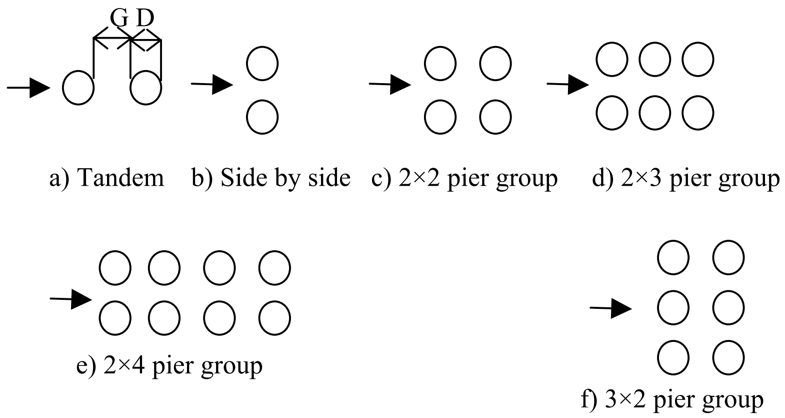


Figure. 2. Pier group types

## 3 Results and Analysis

### *3.1 Effect of Pier Spacing on Final Scour-hole Depth*

Spacing between the piers is one of the most important factors influences on local scour-hole depth around pier groups. Fig. 3 shows the equilibrium maximum scour-hole depth at pier groups with different arrangements normalized by scour depth at single pier ($S_s$) under exactly the same flow conditions versus the normalized pier spacing, G/D. The figure illustrates that the scour at the individual piers is increased considerably for very small pier spacing (increase by a factor of two when G/D→0.25). It can be seen that the scour-hole depth decreases as the spacing between the piers increases, and it reaches to scour depth of a single pier for large G/D ratio. A slight increase in scour depth was noted as G/D increased from zero (pier touching) to 0.25; otherwise the scour depth gradually decreased as the spacing increased.

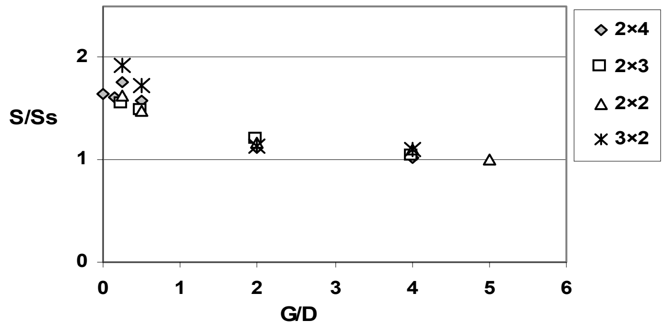


Figure 3. Equilibrium scour-hole depth plotted against pier spacing


Figure 4. Scour hole at equilibrium stage for 2×3 pier group: G/D = 2; D = 22 mm; h = 4.7 cm.

Fig. 4 illustrates the scour hole in the equilibrium stage for the 2×3 pier group with G/D = 2, D = 22 mm, and h = 4.7 cm.

### *3.2 Prediction of Maximum Scour Depth at Pier Groups*

The local pier scour equation recommended by Federal Highway Administration (FHWA, Circular HEC-18, Richardson et al., 1995) was selected as a frame of reference for this analysis. The equation is stated as:

$$\frac{S}{h} = 2.0 K_1 K_2 K_3 K_4 \left(\frac{D}{h}\right)^{0.65} \left(F_r\right)^{0.43} \qquad (1)$$

Where S = scour depth, m; h = flow depth directly upstream of the pier, m; $K_1$ = shape factor; $K_2$ = angle of attack factor; $K_3$ = dune factor; $K_4$ = correction factor for size of bed material; D = pier diameter, m; $F_r$ = Froude number = $U_0/(gh)^{1/2}$; and $U_0$ = mean velocity of the flow directly upstream of the pier, m/s.

The recommended procedure for applying this equation to a pier group is to assume a solid pier that has the dimensions of the pier group if the piers were packed to touch each other. This composite pier width would be used in equation 1 to determine depth of pier scour. This procedure was intended to be a conservative approximation if the piers are spaced at one or two pier diameters apart. This procedure was not, however, logical for very large pier spacing where the piers start to act as independent obstructions to the flow. In a procedure given by Salim and Jones (1996), the scour depth is calculated using equation 1 assuming an equivalent solid pile group with piles touching each other set at the same skew angle to the flow direction. Then multiply this scour depth by the following correction factors.

$$S_{\text{pile group}} = K_S \, K_{2\ \text{Spacing}} \, S \qquad (2)$$

$K_S$ = correction factor for spacing

$$K_S = 0.57\left(1 - e^{-G/D}\right) + e^{-0.5G/D} \qquad (3)$$

G = Spacing between the piles, as shown in Figure 2
D = the diameter of the piles
$K_{2\ \text{Spacing}}$ = correction factor for angle of attack on pile group.

In this correction factor ($K_S$), determining scour-hole depth at pier groups, the influences of the number of columns exposed to the flow and rows which are normal to the flow are not considered. This procedure was intended to be conservative when the number of columns exposed to the flow is 3 or more. In present study a new correction factor ($K_S$) is obtained for pier group aligned to the flow using results from present experiments and the data from Hannah (1978) and Zhao and Sheppard (1998).

$$K_S = 1.04(m)^{0.046} / \left[(n)^{0.479} (G/D)^{0.156}\right] \quad (4)$$

m = number of rows normal to the flow;
n = number of columns exposed to the flow.

Fig. 5(a) presents the comparison of this procedure and proposed procedures for HEC-18 and Salim and Jones (1996) methodologies with 68 lab measured scour-hole depths for pier group aligned to the flow. Fig. 5(a) illustrates that both methods over predicted almost data points. The over prediction for large pier spacing was expected from HEC-18 procedure, since it does not account for spacing between the piers. The Salim and Jones (1996) procedure also over predicted the scour-hole depth at pier groups with 3 or more columns exposed to the flow. It also under predicted the scour depth for tandem arrangement of piers. The proposed procedure predicted scour depths reasonably close to observed scour depths. Fig. 5(b) presents the comparison between observed scour depth from current experiments, Hannah (1978), and Zhao and Sheppard (1998), in comparison with the predicted scour-hole depth from proposed procedure in this study.

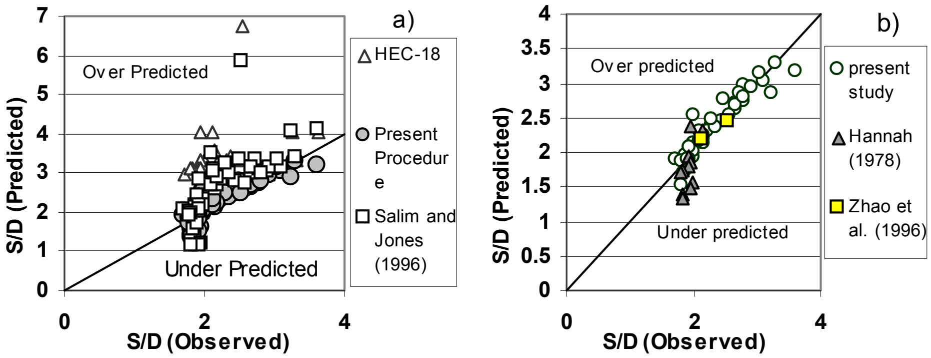


Figure 5. Comparison of (a) proposed and HEC-18 and Salim and Jones (1996) procedures; (b) Observed and predicted scour depth from proposed procedure (data from present experiments, Hannah, and Zhao and Sheppard).

## 4 Conclusion

In this work, laboratory experiments on pier group with circular piers embedded in uniform sediment were carried out in a flume of 4 m long, 0.41 m wide, and 0.25 m deep. The experimental condition is considered to be clear-water condition. Six kinds of pier group arrangement aligned with the flow were tested, including the side-by-side arrangements of piers, tandem arrangements of piers, and 2×2, 2×3, 2×4, and 3×2 pier groups.

It is observed that the smaller the pier spacing, the larger the interference between the piers. For very small pier spacing [G/D < O (0.25)] the pier group behaves as a single body. The interference effect disappears for pier spacing G/D > 5 – 7 or greater, depending on the pier group arrangement. The maximum scour depth for most of pier group arrangements occurs at G/D = 0.25.

Neither of the existing procedures tested in this study accurately predicted scour around pier groups with 3 columns or more. The methodology for predicting local scour near pier groups presented in HEC-18 is quite conservative. The procedure proposed by Salim and Jones (1996) has good agreement with observations when number of columns is less than 3. A new procedure based on adding components is proposed for general pier groups.

The number of variables associated with local scour depth near pier groups is large and even larger when the group is skewed to the flow. These experiments performed for pier group aligned to the flow. More data is needed before general conclusions can be drawn.

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