PIER SHAPE AND ALIGNMENT EFFECTS ON LOCAL SCOUR

Influence de la Forme des Piliers et de l'Incidence du Courant sur la Profondeur d'Affouillement autour des Piliers de Ponts

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ABSTRACT

Bridge piers may have several horizontal shapes and be built with different alignment angles towards the flow direction. The effects of pier shape and alignment have been studied by only a few researchers, the most well-known being Laursen and Toch [1956]. In the present study, 55 long-duration laboratory tests were run under steady, clear-water flow close to the threshold for initiation of sediment motion, to address the effect of shape and skew-angle on the equilibrium scour depth. Five different pier shapes were considered: circular, rectangular square-nose, rectangular round-nose, oblong and piles group; the tested skew-angles were 0, 30, 45, 60, and 90°. Relevant contributions were achieved on the effect of shape at skewed piers and performance of the equation suggested by Richardson and Davis [2001] to account for the pier alignment factor.

KEY WORDS

Bridge piers, scour, pier shape, pier alignment

RESUME

Les piliers de ponts peuvent avoir plusieurs formes et être construits avec des angles d'alignement différents vers la direction de l'écoulement. Seulement quelques chercheurs, parmi lesquels Laursen et Toch [1956] sont les plus connus, ont étudié les effets de la forme des piliers et de leurs alignements. Dans la présente étude, 55 tests de longue durée ont été exécutés sous conditions d'écoulement stationnaire et vitesse proche du seuil d'initiation du mouvement des sédiments pour examiner les effets de la forme et de l'angle d'incidence du courant sur la profondeur d'équilibre de l'affouillement. Cinq formes différentes des piliers ont été testés: circulaire, rectangulaire nez-carré, rectangulaire nez-rond, oblongue et groupe de pieux; les angles testés sont 0, 30, 45, 60 et 90°.Des contributions pertinents ont été obtenues concernant l'effet de la forme en piliers obliques ainsi que sur la performance de l'équation proposée par Richardson et Davis [2001] pour tenir compte du facteur de l'alignement des piliers.

MOTS-CLEFS

Piliers de ponts, affouillement, forme des piliers, angle d'alignement des piliers

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1. INTRODUCTION

Local scour at bridge foundations is a common cause of bridges' failure and the prediction of the equilibrium scour depth is a major concern in bridge engineering.

The scour depth, d_s, around uniform piers depends on the flow depth, d; slope of the energy line, S; acceleration of gravity, g; fluid density, ρ; kinematic viscosity, ν; median grain size, D_{50}; gradation coefficient, σ_D; density of the bed material, ρ_s; pier width, D_p; alignment and shape of the horizontal cross-section; channel width, B; bed slope, S_0; cross-section geometry; time, t. Piers alignment and shape may be accounted for by the coefficients K_θ and K_s, respectively.

For clear-water uniform flow, in a wide rectangular flatbed channel whose bed is composed of uniform, non-ripple forming sand, constant flow intensity, $U/U_c \approx 1.0$ (U is the average approach flow velocity and U_c is the critical average velocity for the beginning of sediment motion), and fully turbulent flows within the scour hole, the non-dimensional equilibrium scour depth becomes, Lança [2013]:

$$\frac{d_{se}}{D_p} = \varphi\left(\frac{d}{D_p}, \frac{D_p}{D_{50}}, K_s, K_\theta\right) \tag{1}$$

The pier shape factor, K_s, is defined as the ratio between the scour depth at a pier with a given shape of the horizontal cross–section and the scour depth at the standard section-shape pier. Likewise, the pier alignment or orientation factor, K_θ, is defined as the ratio between the scour depth at a pier aligned at a given angle with the flow direction and the scour depth at an equal pier aligned with the flow direction.

Few studies report the effects of pier shape and alignment on scouring. Among them the most well-known is Laursen and Toch [1956]. The objective of this experimental study is to revisit the influence of pier shape and alignment on local scouring.

2. EXPERIMENTAL SETUP AND PROCEDURE

Fifty five tests were performed in a 28.00 m long, 2.00 m wide and 1.00 m deep flume of the Universidade da Beira Interior. Sixteen of these tests were already published by Lança *et. al.* [2013a]: four correspond to cylindrical piers; twelve correspond to pile-groups, where piles are adjacent. Five different pier shapes were considered in the study. All, except the circular piers, were 200 mm long and installed with different angles of alignment, θ, *cf.* Table 1, where D_p stands for pier width/diameter.

Piers Shape	D_p (mm)	θ (º)
Circular	50; 100; 150; 200	--
Rectangular square-nose	50; 100; 150	0º ; 30º ; 45º ; 60º ; 90º
Rectangular round-nose		
Oblong		
Pile-group		

Table 1: Tested pier shapes, sizes and alignment angles

The depth of scour hole was measured approximately every 5 minutes during the first hour of the experiment. After the first day, only a few measurements were carried out each day. In agreement with Simarro *et al.* [2011], the experiments were stopped after 7 days.

Further details on the experimental setup and procedure may be found Lança *et al.* [2013.a].

3. RESULTS AND DISCUSSION

Contraction scour was absent since $10 \leq B/D_p \leq 40$ and no bed degradation was observed over the contracted cross sections; the viscous effects are negligible since pier Reynolds number varied between 15500 and 62000; the flow depth was kept constant, d = 0.20 m and the values of the flow shallowness were $d/D_p \approx$

[1.0, 1.33, 2.0, 4.0]; sediment coarseness, D_p/D_{50} = [58.14, 116.28, 174.42, 232.56]. The effect of sediment coarseness reported by Sheppard *et al.* [2004], Lee and Sturm [2009] and Lança *et al.* [2013b] was active. However, it does not influence K_s and K_θ since each pair of scour depths needed to define a given factor was obtained at the same D_p/D_{50}; equilibrium scour was not attained in any of the experiments. For this reason, scour depth records were extrapolated to infinite time so as to obtain the equilibrium scour depth, d_{se}, as suggested by Lança *et al.* [2010].

In this study, the standard-shape pier was assumed to be the circular pier. The values of K_s at equilibrium are presented in Figure 1. It should be pointed out that all the non-dimensional parameters controlling scouring, including sediment coarseness and flow shallowness, are exactly the same for each K_s value. It is clear that the influence of L/D_p is minor or non-existent for $1.33 < L/D_p < 4.00$: the shape factor, K_s, can be taken as K_s = 1.0, for rectangular round-nose and oblong cross-section piers, and K_s = 1.2, for rectangular square-nose and pile-group cross-section piers.

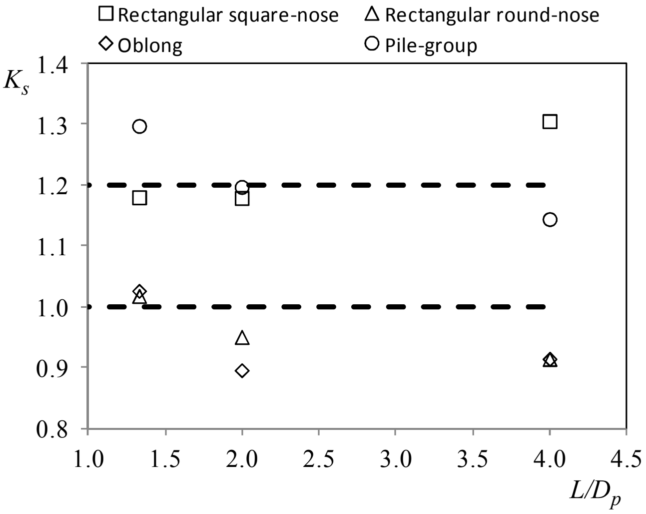

Figure 1: Shape factor, K_s

The pier alignment (or skew-angle) factor, K_θ, is the ratio between the scour depth at a pier with a given shape, implanted at a given skew angle, θ, and the scour depth at the same pier for θ = 0º.

The pier alignment factors obtained in this study are presented in Figure 2 together with the predictions derived through the predictor suggested by Richardson and Davis [2001]. It must be reminded that θ = 90º becomes, finally, θ = 0º, which means that this configuration may be treated through appropriate shape factors.

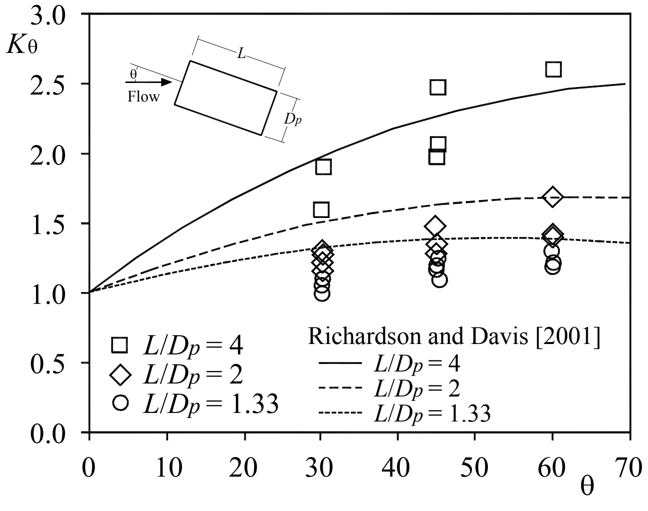

Figure 2: Alignment factor, K_θ

From the inspection of Figure 2, it is clear that the predictor suggested by Richardson and Davis [2001] constitutes a precise predictor of K_θ for $L/D_p = 4.0$, while it tends to over-estimate K_θ for $L/D_p = [1.33, 2.0]$.

4. CONCLUSIONS

This study revisits the effects of pier shape and alignment on the equilibrium scour depth. Four different pier shapes are considered. From the previous discussion, it can be concluded that:

- the shape factor, K_s, can be taken as $K_s = 1.0$, for rectangular round-nose and oblong cross-section piers, and $K_s = 1.2$, for rectangular square-nose and pile-group cross-section piers.
- the predictor of K_θ suggested by Richardson and Davis [2001] is accurate for $L/D_p = 4.0$, but tends to over-estimate K_θ for $L/D_p = [1.33, 2.0]$.

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