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EFFECT OF TRIANGULAR COLLAR WIDTH ON LOCAL SCOUR AT BRIDGE PIER UNDER VERY LOW FROUDE NUMBERS

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ABSTRACT

Bridges are supported by piers. The presence of piers changes the local environment of the flow around the pier. The result is a local scour which may be severe in many cases. Protection of piers against scour is important to safeguard the structure. Among the methods used to minimize the scour at bridge is the use of thin sheet around the pier at the level of the bed, which is called collar. In this paper, a triangular collar is used to protect the pier from the resulting scour. The paper presents and discusses the flow patter due to the presence of pier emphasizing on the effect the Froude number and the contact angle. The effect of collar width, in the lateral direction, on the local scour at the bridge pier is investigated. The best width of the collar in dimensionless form that minimize the local scour is concluded.

KEYWORDS:

Hydraulics, Local scour, bridge pier, collar, erodible bed

INTRODUCTION

Local scour may be defined as deepening and widening of water channel under the influence of local concentrated attack of the flowing water with high velocities or with a high shear stress. It causes the erosion of bed material from around piers, abutments, and river embankment. Local scour at bridge piers is a result of vortex system developed in front of and behind the pier. The vortex generated by the pier erodes bed materials away from the base region of the pier. If the transport rate of out-sediment exceeds the rate of in-sediment in the region, a scour hole develops. Numerous investigations are available in the literature on the local scour at bridge pier, e.g. [1-9]. The effect of grain size distribution and pier size were studied by Raudkivi and Ettema [8]. The shape and alignment of pier were studied Laursen [5]. The scour at bridge crossings was investigated by Laursen [4]. The local scour at skewed piers was studied by Ettema et. al. [2]. The efficiency of a thin circular collar placed at different elevation above the mobile bed was experimentally studied by Ettema [3]. Sacrificial piles placed upstream of a bridge pier as piles for the purpose of protecting it from local scour was described by Melville and Hadfield [6]. Effect of weeds accumulation on scour depth around bridge piers was investigated by Mowafy and Wl-Asyed [7]. The characteristics of scour hole around pile groups was investigated by Zarrati et.el. [9]. Different shapes and dimensions of protective plates were implemented around bridge piles to defense the local scour at the bridge pile by Abdel-Aal et al. [1]. In this paper, triangular collar with different widths is tested as a protection measure against local scour at bridge pier.

IDENTIFICATION OF MAIN PARAMETERS

Dimensional analysis was used to correlate the maximum relative scour depth with other independent parameters, using Buckingham theory. The involved variable in the phenomenon being studied are defined in Figure 1. These variables are reduced to the dimensionless parameters defined by Eq.(1) based on Buckingham theory.

$$D_s/y_t=f(B/b,\ \Theta,\ F_t,\ W/B) \quad (1)$$

In which, B, is the collar width, b, is the pier width, Θ, is the apex angle of collar, Ft, is the tail Froude number, and, W, is the channel width.

Since Θ and W/B are kept constants, Eq.(1) reads:

$D_s/y_t=f(B/b, F_t)$ (2)

EXPERIMENTAL WORK

The experimental work was carried out in a re-circulating channel with 4m length, 20cm depth and 60cm width. The discharge was measured using a pre-calibrated orifice meter. The point gauge was used to measure the scour depths formed in the mobile bed. Perspex Pier with width 3.0cm, and 40cm length was installed in the channel centerline. A triangular collar with different widths equals to 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, and 5.0 times the pier width is tested under Froude number ranging from 0.188 to 0.532. The apex angle of the collar is 122^o. Typical test procedure consisted of (a) selected discharge was allowed to pass (b) the tail water depth was adjusted to a certain depth (c) the mobile bed was leveled (d) the discharge and the water levels are recorded. 9e) after 30 minutes the discharge was stopped (f) scour mesh was measure (g) steps from b to f is repeated for another tailwater depth until satisfied. (f) the procedure is repeated for the specified rage of discharges or the desired range of Froude number.

ANALYSIS AND DISCUSSION

FLOW PATTERN AROUND THE BRIDGE PIER

Figure 2 shows the flow pattern at different Froude numbers. When, the water flow approaches the bridge pier, it is forced to separate and pass beside the pier. The separation of the flow at the sides of the pier called wake vortices. These vortices act as little tornadoes lifting the sediment from the bed and form their own scour hole. The flow pattern around the bridge pier can be described as follows:

At the upstream of the bridge pier, there are streamlines starting nearly beside the nose of the pier and reaching to the bridge abutment. In addition, other streamlines started from the convergent point, at the connection point between the abutment and wing walls, and crossing the previous streamlines to form (zone 1 and zone 1`). In addition, at the downstream of the bridge pier, there are a stream lines starting at nose of the pier and reaching to the wing walls. In addition, other stream lines started from the divergent point, at the connection point between the abutment and wing walls, and crossing the previous stream lines to form (zone 2 and 2`).

It can be observed that, in the case of low Froude number the contact angle (θ) is high and the almost scour formed at the upstream of the pier (see Fig. 3). Moreover the deposition was formed at beside the first third part of the pier. Also, it was noticed that as the Froude number increases the contact angle (θ) decreases and the main scour holes formed at the upstream and at the beginning of the two sides of the pier, (see Fig. 4), and two small scour holes formed at (zone 2 and 2`). Moreover the deposition transported downstream of the pier.

Figure 5 show the relationship between the contact angle(θ) and Froude number. It can be observed, as the Froude number increases the contact angle (θ) decrease. Also Fig. 6 shows the relationship between the relative scour depth and the contact angle (θ). In which, the relative scour depth decreases as the contact angle (θ) increases and vice versa. The last observations were fixed firmly using Figs. 3 and 4.

EFFECT OF COLLAR DIMENSION (B_o)

Figure 7 show the relationship between the maximum relative scour depth and tail Froude number at the different relative widths, $B_o=B/b$, of the collar. It is clear that, the maximum relative scour depth increases with increases of Froude number for all relative widths of collar (B_o). Moreover, it can be noted that when the relative width of collar increases the maximum relative depth of scour decreases.

From the previous results, as the relative width of the collar increases, the protective area on the bed increases, leading to a decrease of the contact area between the downward flow velocity and the mobile bed, which finally leads to decreasing of the maximum relative scour depth.

Figure 8 depicts relationship between the maximum relative depth of scour (d_s/y_t and relative width of collar(B_o) at different Froude numbers, for triangular collar shape. It can be noted that when the relative width of collar increases the maximum depth of scour decreases for different Froude numbers. On average, the maximum relative scour depth was reduced by 22% , 42% , 56% , 63% , 71% , 77% , 82% and 84% for B_o= 1.5, 2.0 , 2.5 , 3.0, 3.5, 4.0, 4.5 and 5.0 respectively compared to the no collar case.

Typical scour patterns are presented in Fig. 9 (a, b, c, and d for different B_o at F_t= 0.532 to demonstrate the effect of relative width of collar on the scour at bridge pier. These figures show that, the main scour hole was formed at the upstream edge of the collar around the apex angle, especially for large relative width of collar (B_o= 5.0, 4.0, 3.0). Moreover, two small scour holes formed at the two sides of the pier. But for the smaller widths of the collar B_o= 1.5, only one scour hole formed at the upstream nose of the pier.

CONCLUSIONS

The following conclusions could be listed as:

1- The relative scour depth increases as the tail Froude number increases and vice versa.
2- The collar around bridge pier was consider a good tool for reducing the formed scour hole dimension.
3- The triangular collar reduces the maximum relative scour depth by 84% for B_o= 5.0 and by 22% for B_o=1.5 respectively compared to the no collar case.
4- For small relative width, $B_{o,}$ of triangular collar the main scour hole is formed upstream the pier nose while for large B_o, the main scour hole is formed around the apex angle of collar.

NOMENCLATURE

B, collar width
b, pier width
Ɵ, apex angle of collar
F_t, tail Froude number
W, channel width.
ds, maxium local scour depth
y, is the upstream depth of flow
y_t tail water depth
B_o the relative collar width (B/b).

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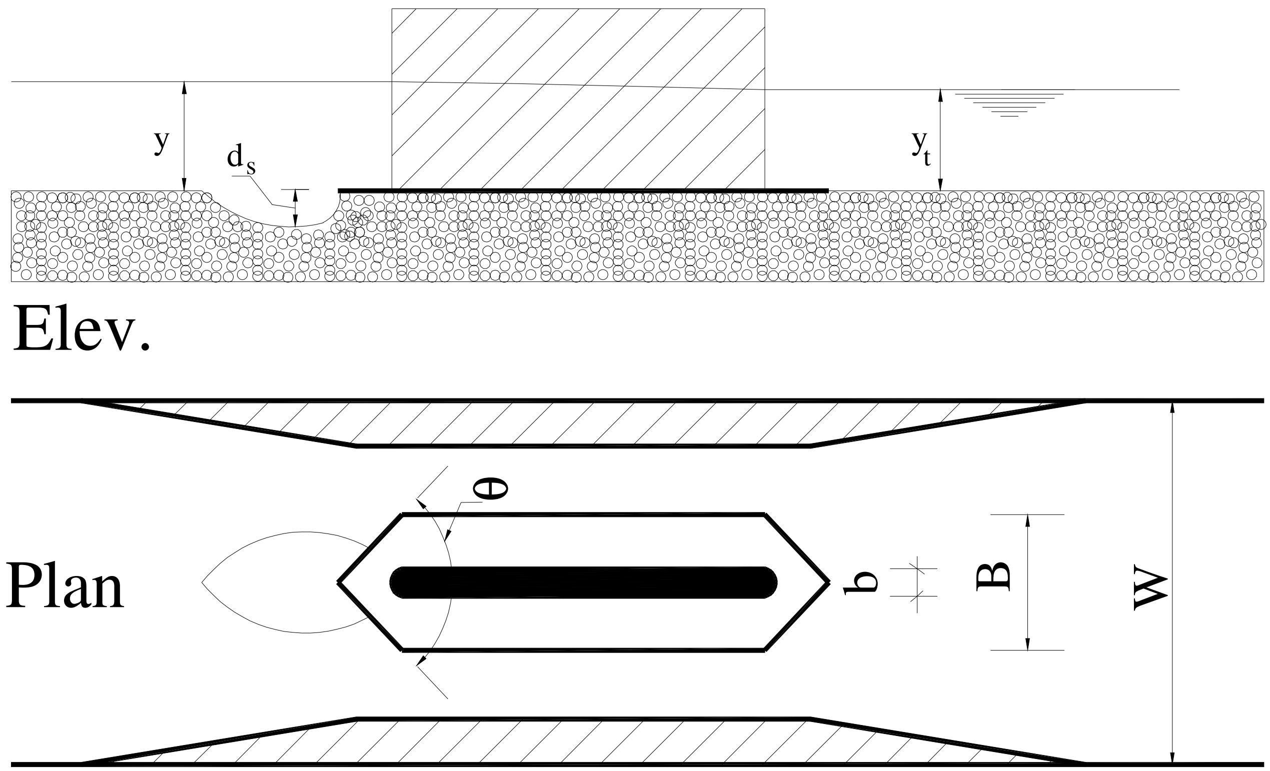

Fig. 1 Definition sketch for the experimental model

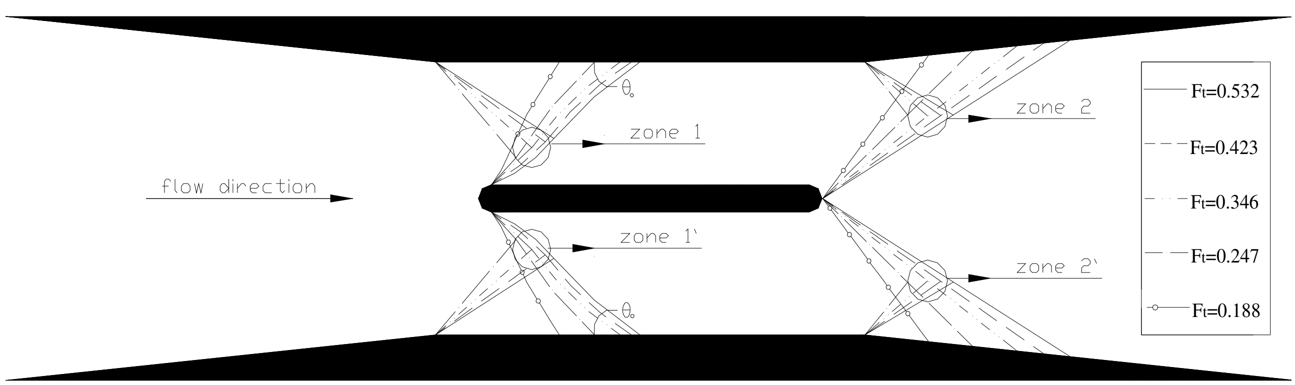

Fig. 2 Flow pattern around bridge pier.

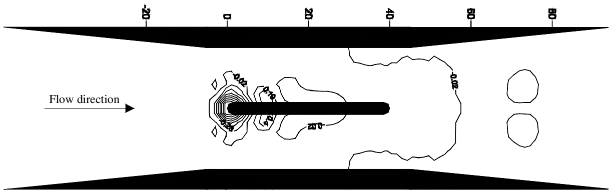

Fig. 3 Scour contour map for Ft= 0.247

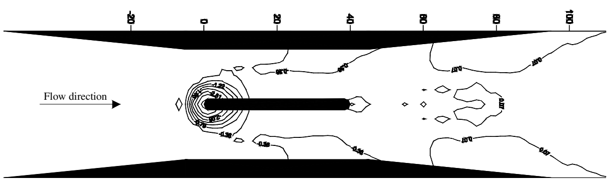

Fig. 4 Scour contour map for Ft = 0.532

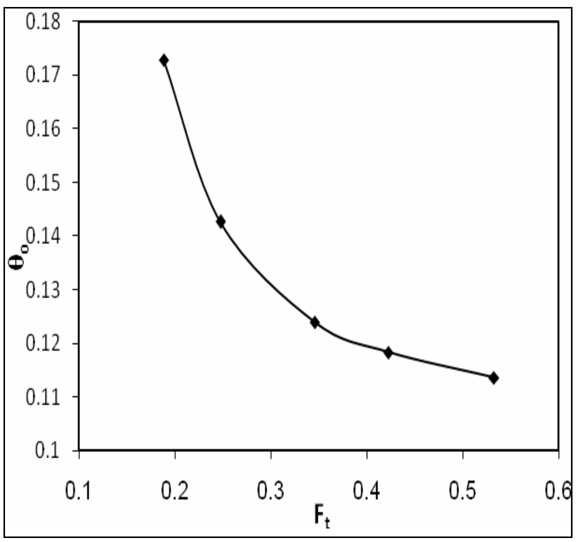

Fig. 5 The dimensionless contact angle versus tail Froude number

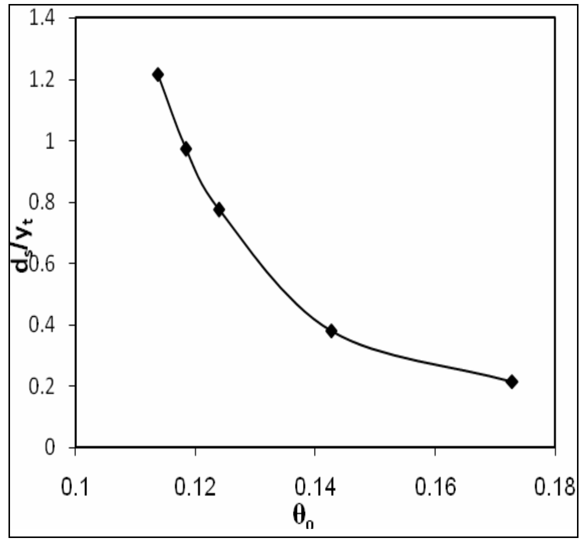

Fig. 6 The maximum relative scour depth versus The dimensionless contact angle .

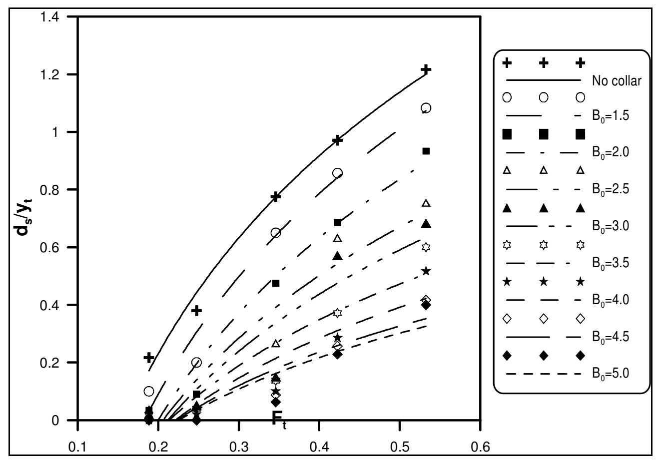

Fig. 7 The relationship between the maximum relative scour depth and the tail Froude number at different B_o

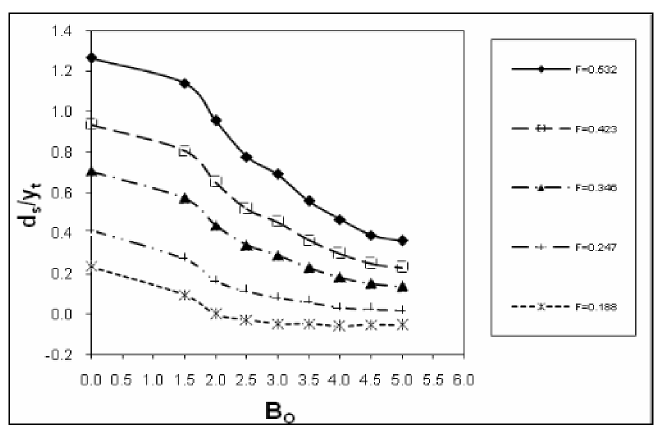

Fig. 8 The relationship between the maximum relative scour depth and B_o at different F_t

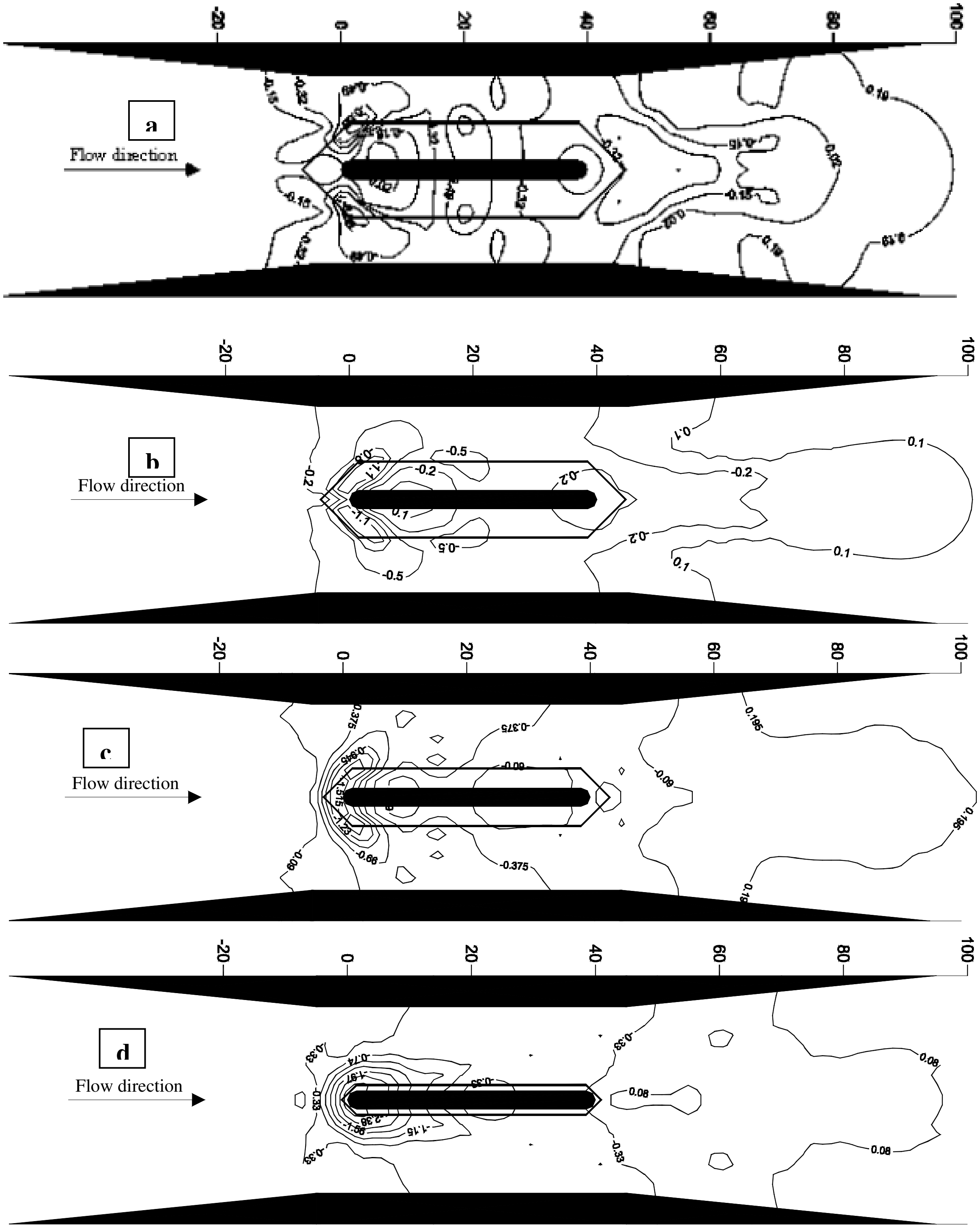

Fig 9 The scour pattern for Ft= 0.532 and a) Bo= 5, b) Bo=4 , c) Bo=3, and d) Bo=1.5