OPTIMAL SHAPE OF COLLAR TO MINIMIZE LOCAL SCOUR AROUND BRIDGE PIERS

Abdelazim M. Negm [1], Gamal M. Moustafa [2], Yasser M. Abdalla [3] and Amira A. Fathy [4]

[1]Vice Dean for Education and Students Affairs and Professor of Hydraulics,
[2]Professor of Hydraulics, [3]Assistant Professor, and [4]Post-Graduated Student
Water and Water Structures Eng. Dept., Faculty of Engineering
Zagazig University, Zagazig, Egypt
E-mails: amnegm85@yahoo.com, amnegm@zu.edu.eg.

ABSTRACT

Scour around bridge piers is one of the most important fields of hydraulic researches. The scour phenomenon may endanger the whole structure after long or short run depending up on the extent of scouring processes. So, the present paper, presents a protective tool to minimize the maximum local scour around bridge pier and hence minified the endanger process due to local scour. Collars of different shapes (triangular, circular, trapezoidal, and rectangular) were used as protective plates around bridge pier. Each collar shape was tested under similar subcritical flow conditions with tail Froude number ranging from about 0.2 to 0.55. A recirculating flume with 4m length, 20cm depth and 60cm width was used to conduct the experimental work. Water surface and scour profiles were measured and analyzed. A statistical equation was developed and proposed to predict the maximum relative scour depth around the bridge pier. It was concluded that the use of the optimal shape (rectangular collar) greatly reduces the maximum relative scour depth around the bridge pier to the extent of 90% when the collar width is 5 times the pier width compared to the no collar case.

Keywords: Bridge pier, Local scour, Collar, and Protective plates, Hydraulic structures

INTRODUCTION

The flow deflected by sediment embedded bridge piers causes scour at its foundations and may endanger the stability of the hydraulic bridge structure. In which, the local around the bridge pier can greatly reduce the bearing capacity of the surrounding bed material and may cause the structure to fail. The total scour at a river crossing consists of three components general scour, contraction scour, and local scour, Cheremisinoff et al. [3]. The basic mechanism causing local scour at bridge piers and abutments is the formation of vortices at their base. The vortex removes bed material from the base of the pier. As the sediment transport rate, outgoing from a particular place is higher than that coming into, a scour hole develops.

Review of literature indicated that huge amount of research work and reports are available. Only few will be mentioned here. The scour at bridge crossing was studied by Laursen and Toch [7]. Also, the shape and alignment of pier were investigated by Laursen [6]. Moreover, the effect of grain size distribution and pier size were studied by Raudkivi and Ettema [14]. The local scour at skewed piers was studied by Ettema et al. [4]. On the other hand, the scour around circular pier was experimentally studied by Ettema [5]. Sacrificial piles as pier scour countermeasures were described by Melville and Hadfield [10]. Effect of weeds accumulation on scour depth around bridge piers was investigated by Mowafy and El-Sayed [13]. The effect of constructing two adjacent bridges on the flow characteristics and local scour around bridge piers was presented by Mowafy [12].

Three-dimensional flow field in a scour hole around vertical-wall (rectangular section), 45^o wing-wall (45^o polygonal section) and semicircular was studied by Abdul Karim and Subhasish [2]. Reduction of local scour in the vicinity of bridge pier groups using collars and riprap was studied by Zarrati et al. [15]. Neural network modeling for estimation of scour depth around bridge piers was introduced by Lee et al. [8]. Experimental installation for the non-intrusive high-resolution measurement of developing scour-holes at a sand-embedded cylinder was studied by Link et al. [9]. The effect of different shapes and dimensions of collars were studied to control and minimize the local scour around the bridge pile by Abdel-Aal et al. [1]. The effect of triangular collar around piers was studied experimentally by Mohamed et al. [11]. In this paper, the effect of different collar shapes and dimensions on local scour around bridge piers was investigated in order to obtain the design criterion of the optimal shape of collar that minimize the local scour around bridge pier.

DIMENSIONAL ANALYSIS

The Dimensional analysis was used to define the dimensionless variables based on the selection of all variables governing the maximum scour depth upstream the bridge pier, see Fig. 1. The maximum relative scour depth was correlated to the other independent parameters using Buckingham theory as follows:

$$ds/y1 = f(B/b, F_t, D_{50}/b, W/b, \varphi) \quad (1)$$

in which, B, is the collar width, b, is the pier width, $F_t = V_t/(gy_t)^{1/2}$ is the tail Froude number, V_t is the tail velocity where the depth of flow is y_t, g is the gravitational acceleration. D_{50}, is the mean size of sand particles, W, is the channel width, and φ represents the pier shape factor.

Since W/b, D_{50}/b are kept constants, Eq. (1) becomes:

$$ds/y1 = f(B_o, F_t, \varphi) \quad (2)$$

in which $B/b=B_o$

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 trapezoidal, circular, and rectangular 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 are tested under tail Froude number ranging from 0.188 to 0.532. A 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. (e) after 30 minutes (at which the scour depth reach more than 85% of the stable scour depth) the discharge was stopped (f) scour mesh was measured (g) steps from b to f is repeated for another tailwater depth until satisfied. (h) the procedure is repeated for the specified rage of discharges or the desired range of Froude number. (i) collar was fixed and steps from a to f were repeated (j) the procedures were repeated for the other shapes of collars.

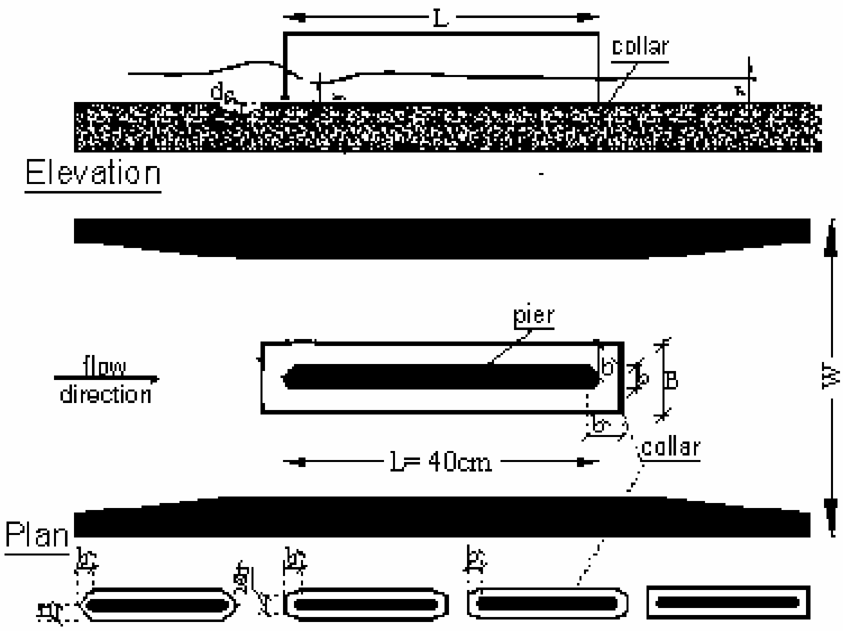

Fig. 1 Definition sketch for the experimental model

ANALYSIS AND DISCUSSIONS OF RESULTS

Effect of Different Collar Shapes

The scour and water surface profiles for the no-collar case and the other collar shapes (triangular, trapezoidal, circular, and rectangular) was shown in Figure 2 for a typical values of B_o= 3.5 and F_t=0.54. It is clear that the rectangular shape has a minimum scour values (d_s=1.4 cm) compared to the circular (d_s= 1.6 cm), trapezoidal (d_s= 1.8 cm), triangular (d_s= 2.0 cm) and the no collar case (d_s= 3.65cm).

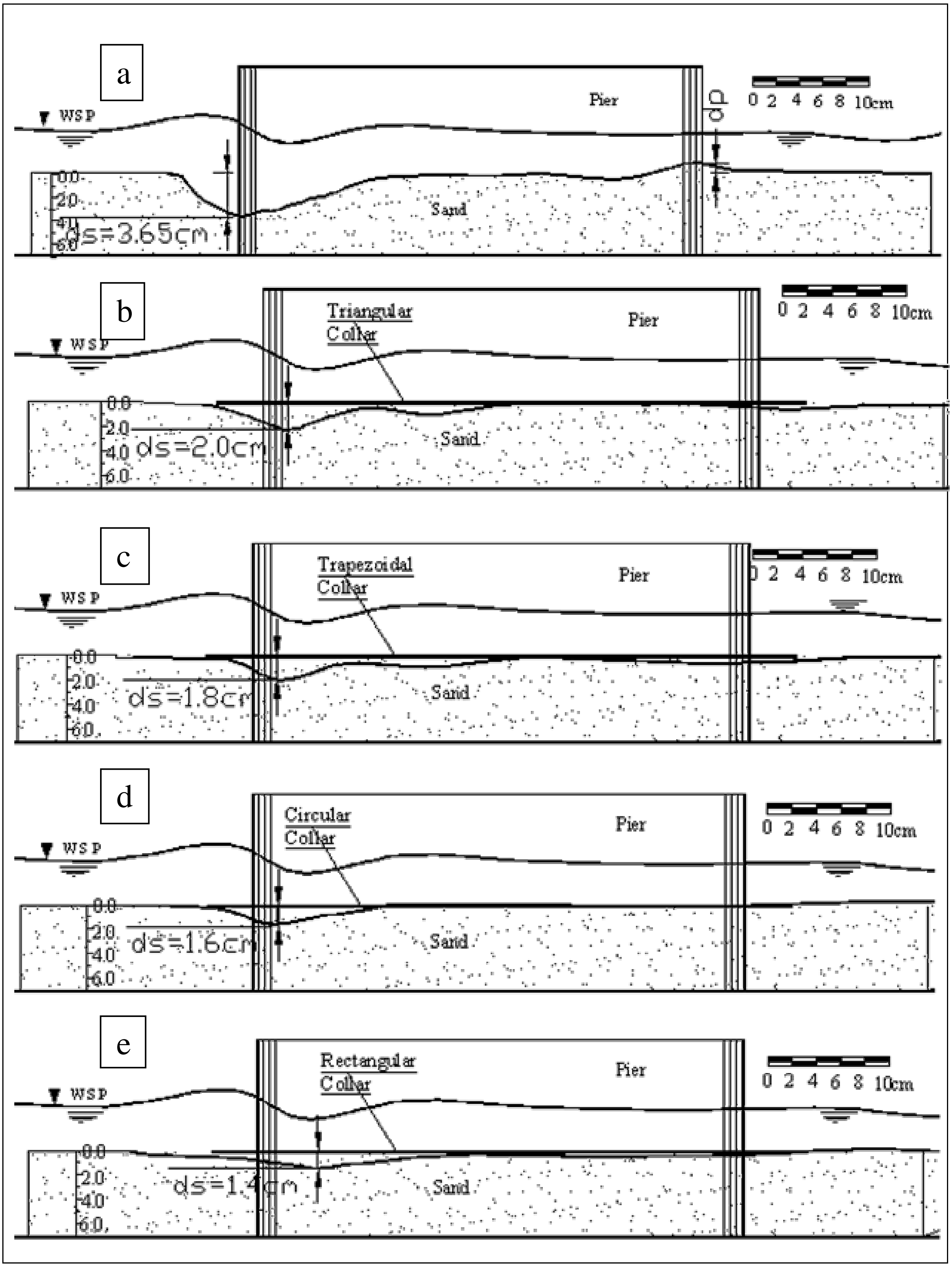

Fig. 2 Water surface and scour profiles in case of B_o=3.5 at F_t=0.54 for:
a) No-collar case, b) Triangular collar, c) Trapezoidal collar, d) Circular collar, and e) Rectangular collar

The scour contour maps around the bridge pier for different collar shapes at B_o=3.0 and F_t=0.43 was introduced in Figure 3. It was noticing that the scour hole has large dimensions for the no collar case. In addition, the best collar shape which gives small scour hole dimensions is the rectangular shape.

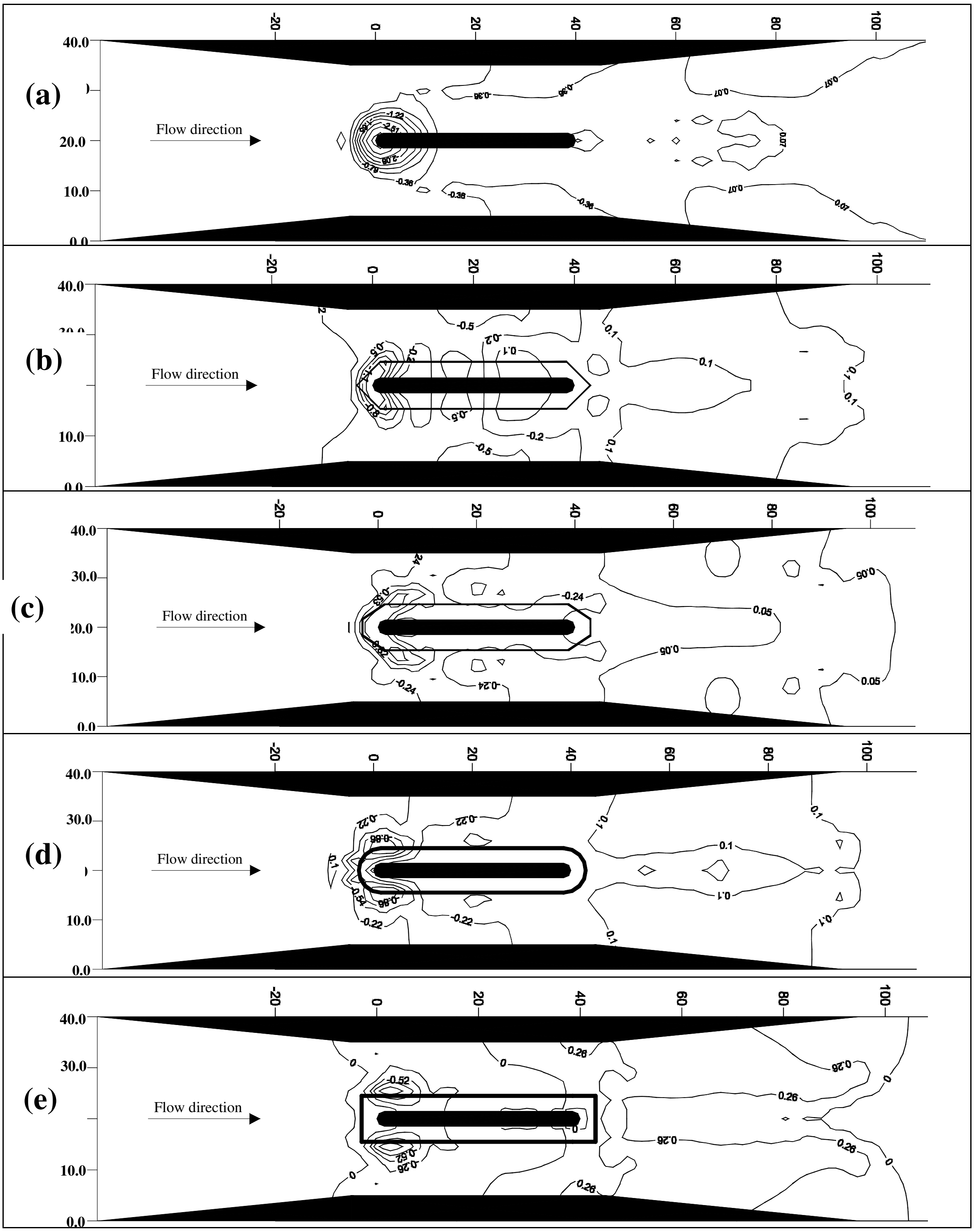

Fig. 3 Scour contour maps around bridge pier for (B_o=3.0) for F_t=0.423 for collar shapes: a) No-collar case, b) Triangular collar, c) Trapezoidal collar, d) Circular collar, and e) Rectangular collar

In addition to the above, Figures 4, 5 and 6 show the maximum relative scour depth versus the tail Froude number for different shapes of protective plates at B_o=1.5, 3.0, and 5.0 respectively. From these figures, it is noticed that the rectangular collar was the best protection shape among the other collar shapes. It causes great reduction of local scour upstream the pier compared to the no-collar and other shapes of protective plates. The rectangular collar shape has a larger protection area over the mobile bed than other collar shapes (Trapezoidal, Triangular and Circular shapes) and hence it absorbs more downward velocities formed at the upstream nose of the pier.

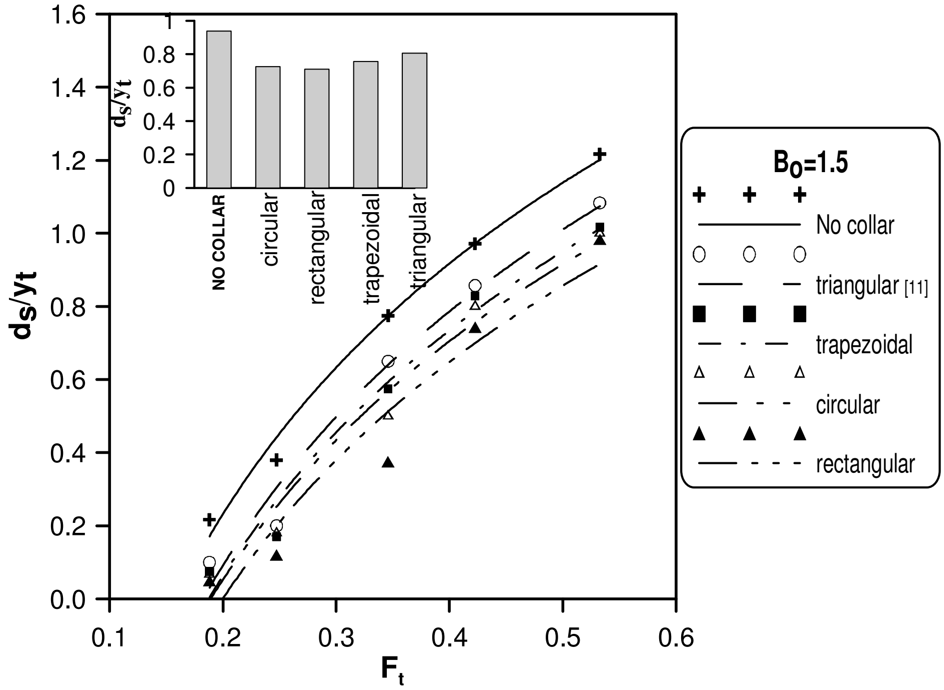

Fig. 4 Relationship between d_s/y_t and F_t for B_o=1.5 for different collar shapes

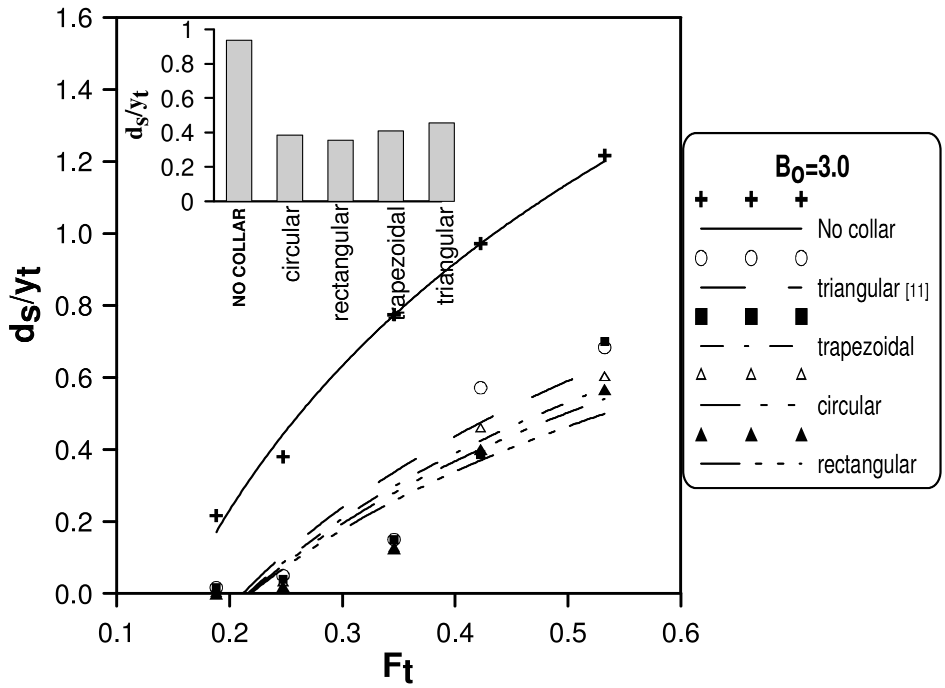

Fig. 5 Relationship between d_s/y_t and F_t for B_o=3.0 for different collar shapes

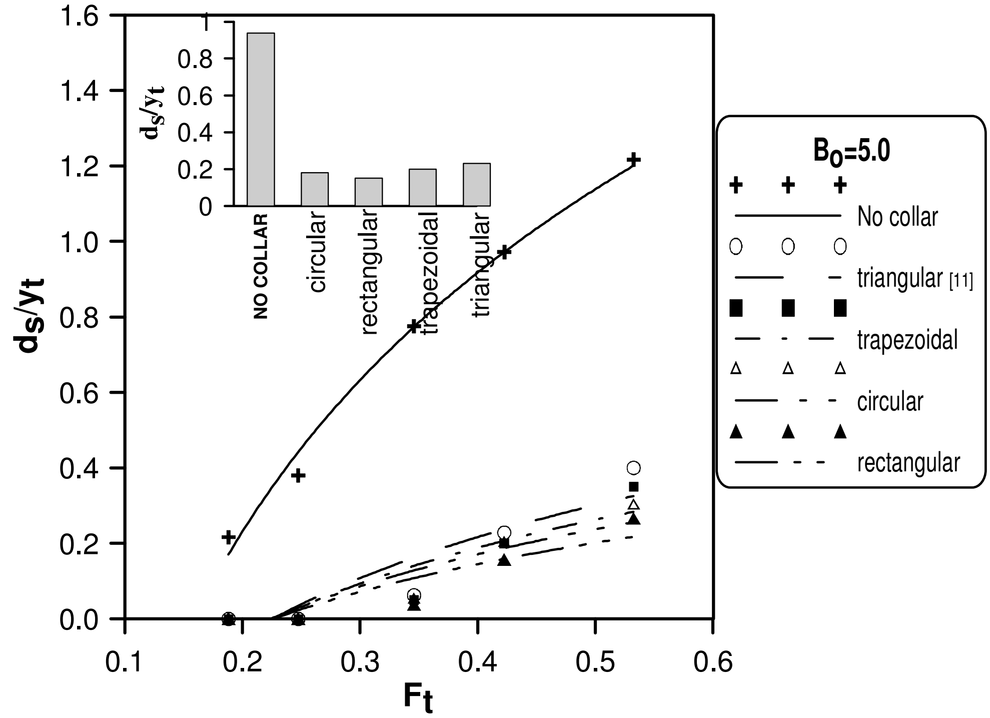

Fig. 6 Relationship between d_s/y_t and F_t for B_o=5.0 for different collar shapes

Effect of Collar Dimensions (B_o)

Figure 7 presents the same comparison between three typical values and the dimensions of rectangular collars (B_o= 5, 3, and 1.5) at F_t=0.54. It was obvious that as the relative width of collar increased the scour depth was decreased.

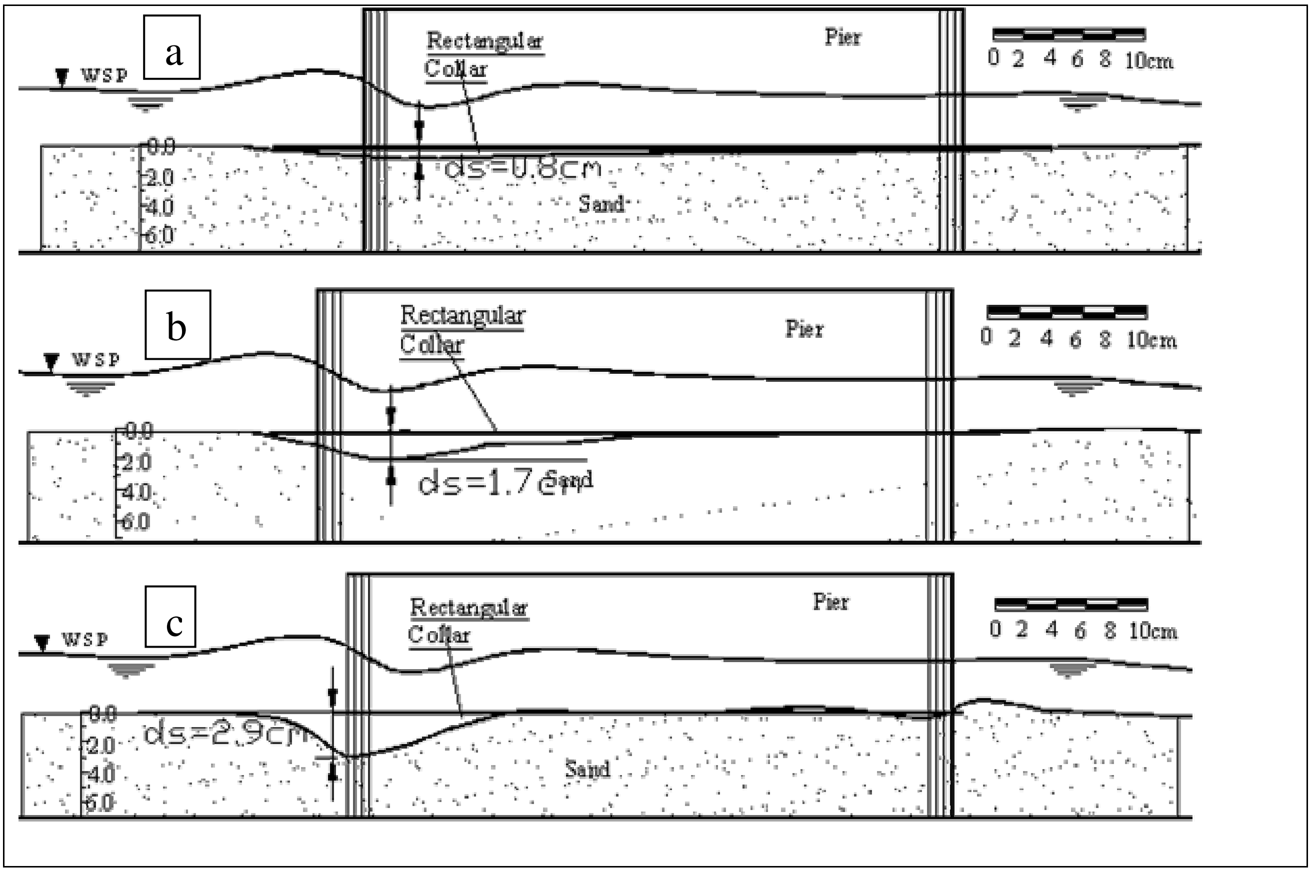

Fig. 7 Water surface and scour profiles in case of rectangular collar at F_t=0.543 for: a) B_o=5.0 b) B_o=3.0 c) B_o=1.5

Moreover, Figures 8, 9 and 10 show the relationship between the maximum relative scour depth (d_s/y_t) and tail Froude number (F_t) for different relative widths of trapezoidal, circular and rectangular collar shapes, respectively. It is clear that, for all collar shapes, the maximum relative scour depth increases as tail Froude number increases for different (B_o). Moreover, as the relative width of collar increases the maximum relative depth of scour decreases for all shapes of collars. By increasing the relative width of the collar, the protective area on the mobile bed increases, leading to a decrease in the contact area between the downward velocity and the mobile bed, which finally leads to a corresponding decrease of the maximum relative scour depth.

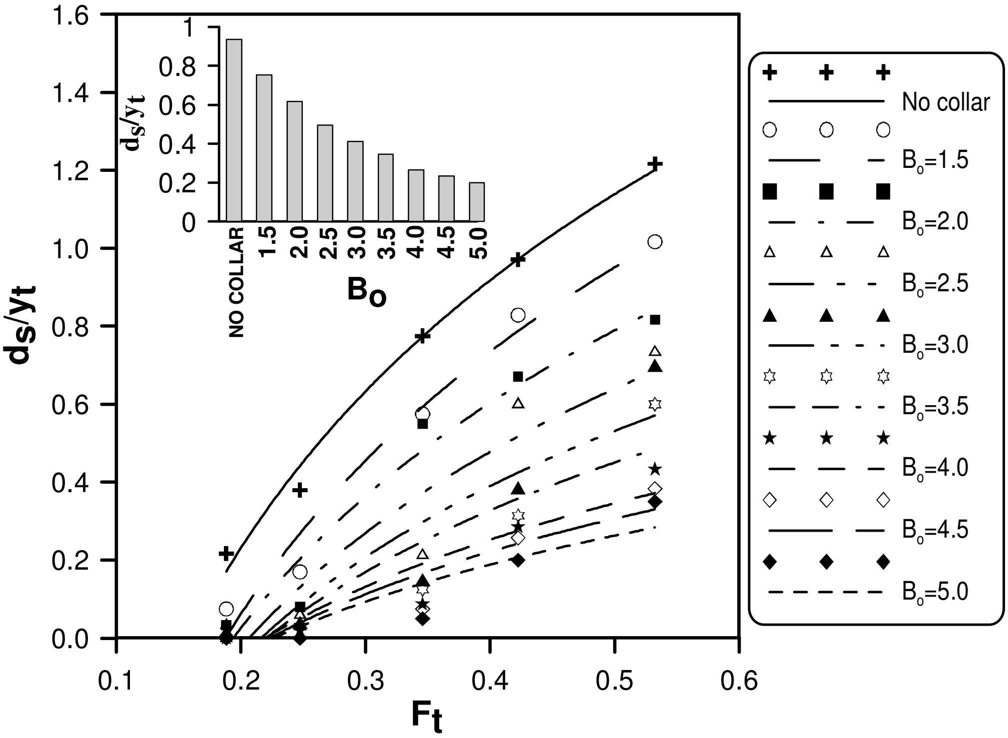

Fig. 8 Relationship between d_s/y_t and F_t for trapezoidal collar for different collar width B_o

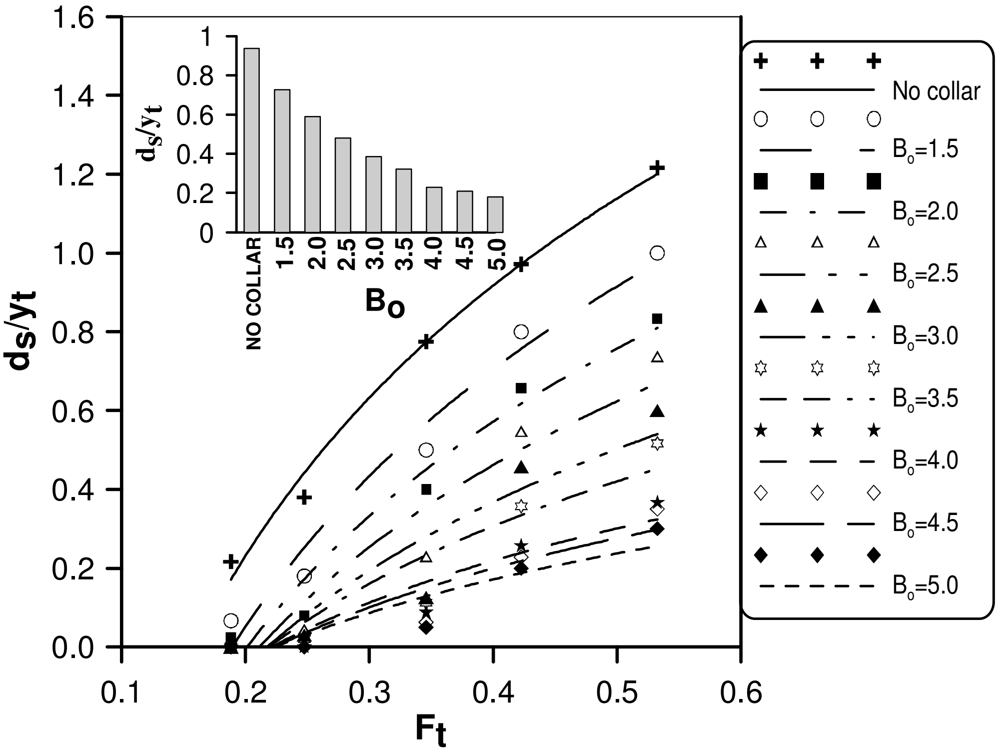

Fig. 9 Relationship between d_s/y_t and F_t for circular collar for different collar width B_o

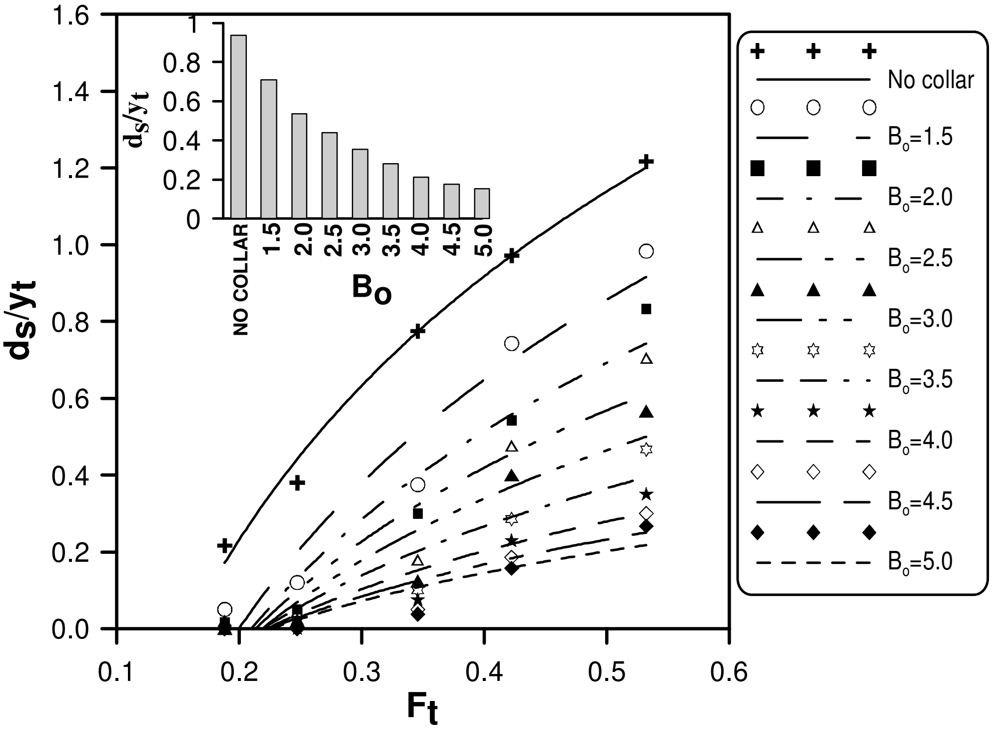

Fig. 10 Relationship between d_s/y_t and F_t for rectangular collar for different collar width B_o

Percentage Reduction and Optimal Shape of Collar

The average reduction in the relative maximum depth of scour for each relative width of collar for he tested range of tail Froude number was calculated and presented in Table 1. The corresponding values of the triangular collar were also presented. Analyzing these values, it is clear that the rectangular collar is the optimal shape at all values of the relative width. The triangular is the worst one. Both of the trapezoidal and circular produce mostly similar reduction at the B_o. This table can be used as a guide in the design process to compromise between percentage reduction and costs of collar and construction and maintenance costs. It is a matter of fact that increasing the collar dimensions will automatically increases the costs. At the time, the reduction in the scour dimensions will be more and hence the structural safety will be higher.

Table. 1 Reduction percents of d_s/y_t for different collar shapes at different B_o

Collar shape	Reduction percents of d_s/y_t for different B_o							
	B_o=1.5	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**	**4.5**	**5.0**
Triangular [11]	22	42	56	63	71	77	82	84
Circular	32	48	61	69	75	83	85	87
Trapezoidal	29	43	58	68	73	80	83	86
Rectangular	**40**	**55**	**65**	**70**	**79**	**84**	**87**	**90**

Prediction of Scour Depth

Using the statistical tools, Eq. (3) was developed to correlate the relative maximum scour depth to the tail Froude number, F_t, the relative width of collar, B_o, and the collar shape factor, φ.

$$d_s / y_t = \exp(5.48F_t - 0.16B_o - 1.32\varphi - 2.5) \quad (3)$$

The correlation coefficient and the standard error of estimate for Eq. (3) are 90% and 0.09 respectively.

CONCLUSIONS

The following conclusions could be listed as:

1- The relative scour depth increases as the tail Froude number increases and vice versa is true.

2- For all shapes of collars, the relative scour depth decreases as relative width of collar increases and vice versa is true.

3- The reduction percents in the average of scour depth for different collar shapes fixed over the mobile bed are 0.62, 0.65, 0.68, and 0.72 for triangular, trapezoidal, circular, and rectangular collar shapes, respectively.

4- The rectangular collar is considered the best shape of collars that reduces the maximum relative scour depth by 0.40, 0.55, 0.65, 0.70, 0.79, 0.84, 0.87, and 0.90 for B_o = 1.5, 2.0, 3.0, 3.5, 4.0, 4.5, and 5.0, respectively.

5- A statistical model for predicting the maximum relative scour depth was developed and proposed to predict the relative maximum scour depth in terms of the tail Froude number, the relative width of collar and the collar shape factor.

NOMENCLATURE

B	collar width
B_o	the relative collar width (B/b)
b	pier width
d_s,	maximum local scour depth
F_t	tail Froude number
W	channel width
y_t	tail water depth
φ	index to the collar shape factor

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