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EXPERIMENTAL STUDY ON THE EFFECT OF PERMEABLE BLOCKAGE AT FRONT OF ONE PIER ON SCOUR DEPTH AT MULT-VENTS BRIDGE SUPPORTS

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ABSTRACT

Debris accumulation around bridge supports can constrict and redirect flow through the muti-vents bridges resulting in significant bridge foundation scour. The experimental study of this paper, aims to investigate the effect of different porosities of partial blockage at front of bridge pier on local scour depth formed around bridge supports. The permeable blockage with different relative heights (H/B_p= 0.4, 0.8 and 1.2) was fixed on and above the mobile bed. It was found that, for 15% porosity ratio of permeable blockage, the local scour depth at the left pier and right abutment was increased by 11.3% and 20% respectively compared to the no-blockage case. In addition the permeable blockage that placed at the water surface produces more local scour depth at multi-vents bridge supports compared to its location on the mobile bed.

Keywords: Local scour, Pier, Abutment, Permeable blockage, Hydraulic structures

1. Introduction

The piers and abutments are important elements of the bridge structure, can be susceptible to structural damage as a result of scour phenomenon. Debris flows composed of tree trunks leaf litter, logs and garbage bins. Debris accumulations can be considered as an obstruction, that resulting in higher velocities and vortex that create larger dimensions of scour holes around bridge foundation. It was recognized, that the increase in the expected scour depth owing to debris accumulation during the tail of high-flow events could be dangerous for the bridge, Franzetti et al [7]. Maatooq [13] described the scour, which is formed around bridge pier neighboring abutment. Abouzied et al. [1] studied the effect of the distance between piers, the diameter of the pier, shape of piers and bed sediment size on the local scour. Alabi [3] studied the time development of local scour at

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bridge pier fitted with a collar. The effects of the angle of inclination of pier, and the pier shape and number on the local scour depth were studied by Mohammed, et al. [16]. Sanoussi and Habib [19] presented experimental results on the effect of the slope of the upstream pier face on the formation of local scour depth. Zha [24] carried out an experimental study for time-dependent scour depth under bridge-submerged flow. Khwairakpam [11], investigated the effect of varying inflow depths and densimetric Froude numbers on scour around a single pier. Ismael et al. [10] examined the effect of change the position of bridge pier to reduce the scour. Mohamed et al. [14] and [15] studied experimentally and numerically the scour at bridge abutment provided with different arrangements of collars. The local scour at single cylindrical pier (or groups) and the protection given by a rectangular slot through the pier, was studied by Farhan and Nalluri [6]. Mohamed et al. [17] studied experimentally the local scour depth around multi-vents bridge piers. Akib, et al. [2] examined the relationship between scour depth in complex pier groups and combined piles bridge and various parameters, including the variation of flow velocity, distance, and time. Douglas et al. [5] pointed out that large woody debris structures reduced velocities in the region adjacent to the bank toe and induced sediment deposition and retention. Lee, et al. [12] studied numerically the effect of bridge blockage resulting from floating containers and woody debris on local scour depth. Effects of debris on bridge pier scour were studied by Zevenbergen, et al. [23]. Effect of blockage and densimetric Froude number on circular bridge pier local scour was studied by Hodi [9]. Reynaud [18] developed guidelines for predicting the size and geometry of debris accumulations at bridge piers and methods for quantifying scour at bridge piers resulting from debris accumulations. The important factors affecting the blocking probability at bridge decks during flood events were evaluated by Schmocker and Hager [20]. The effect of blockage on cylindrical bridge pier local scour was studied by D’Alessandro [4]. The effects of blockage ratio and relative coarseness on clear water bridge pier scour were analyzed by Tejada [21]. Gamal et al. [8] predicted the maximum Scour around bridge piers due to Aquatic weed racks. Weeks [22] presented two equations to describe the entrance loss and energy loss coefficient for a culvert experiencing partial debris blockage while operations under outlet control conditions. In the present paper, the effect of different ratios of porosity of partial permeable blockage at front of bridge pier on local scour depth was investigated. In addition, the location of such these permeable obstructions either at mobile bed or water surface was studied also experimentally.

2. Experimental work

The experimental work was conducted in a re-circulating channel 0.4 m wide, 0.20 m deep and 5.70 m length. The discharge was measured using a pre-calibrated orifice meter. The scour depths formed in the mobile bed was measured by point gauge has 0.01 accuracy. Sand is uniform with D_{50}=0.75mm, at which the geometric stander deviation of the particle size distribution is less than 1.3, in which geometric mean = $(D_{85}/D_{15})^{0.5}$ =1.27. Three different ratios of porosity (15%, 32% and 50%) were studied. The selected debris clusters were constructed with rectangular wire mesh baskets filled with gravels. The gravels ranged in diameter from (0.4 to 1.4cm) were placed into each debris cluster in a random orientation to achieve desired porosity of 50%, 32%, and 15% of the gross volume. Clear water scour occurs for the velocities up to the threshold for the general bed movement. Two piers of the bridge model have 2.5cm thickness and length (Ĺ) equals to 40cm with circular shape at the nose and tail are used between the two abutments. The width of each vents is10cm. The values of Froude number are ranging from 0.33 to 0.54. Typical test procedure consisted of (a) the mobile bed was leveled with the apron. (b) Selected discharge was allowed to pass. (c) The tail water depth was adjusted to a certain depth. (d) After 6 hours (at which 90% of the equilibrium scour depth was achieved) the discharge was stopped. (e) The sand was drained from water slowly to survey the scour hole using a mesh with dimension 1.0 cm x 1.0 cm between piers and 5.0 cm x 5.0 cm at upstream and downstream of them. (f) Steps from (a) to (e) were repeated for another tail water depth until satisfied. (g) The procedures were repeated for the desired range of Froude numbers. (h) a porous blockage with constant volume and height was used on the bed in front of the right pier and repeat steps from (a) to (f). The relative width of the blockage is 1.4. The different heights of partial permeable blockage with constant size at each previous porosity ratios are changed three times as shown in table (1).

3. 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 follow:

$$d_s/y_t = f\left(F_r, H/B_p\,, h/B_P\, L/w\,, n\right) \tag{1}$$

In which, d_s is the maximum depth of scour, y_t is the downstream tail water depth, F_r, is tail Froude number ($F_r=v/(gy_t)^{0.5}$, g is the gravitational acceleration, and v is the mean flow velocity), H is the height of blockage, B_p is the Pier width, h is the vertical distance from mobile bed to the base of blockage, L is the Length of blockage, w is the width of blockage and n is the porosity ratio.

Table 1.
Arrangements of debris height and width at nose of right pier

Debris Characteristic	Location	Debris Height (cm)	Debris Width (cm)	Debris Length (cm)	Width/Length
porosity 15%	at bed	1	7	5	1.4
		2	5	3.5	
		3	4	2.9	
porosity 32%		1	7	5	
		2	5	3.5	
		3	4	2.9	
porosity 50%		1	7	5	
		2	5	3.5	
		3	4	2.9	
	at surface	1	5	7	
		2	3.5	5	
		3	2.9	4	

4. Analysis and discussions of results

4.1 Effect of porosity of permeable obstruction (n) over mobile bed on local scour depth.

The effect of porosity of rectangular obstacle with constant size and relative height of permeable obstruction (H/B_p) = 0.4 on local scour depth was investigated. Three different ratios of porosity (n= 15%, 32% and 50%) were inspected. Figures 2 through 5 show the relationship between d_s/y_t and F_r at different bridge supports, i.e., right pier (P_r), right abutment (A_r), left pier (P_L), and left abutment (A_L). The permeable obstruction was fixed at front of (P_r) over the mobile bed, see Fig. 1. Figure 2 presents the local scour depth formed at (P_r). It was found that, the permeable obstacle leads to pass flow through the porous media and uniform velocity distribution around (P_r) will be obtained. So, the local scour depth was decreased for all porosity ratios (n) compared to the no-blockage case. From this figure also, it was noticed that, for the increasing of the porosity ratio from 15% to 32%, the scour increases because of the flow passing through the pores increases vortices generated next to the pier thus increasing Scour. However the increase in the proportion of porosity up to 50% decreases scour comparing to porosity ratio 32%. At which, more voids through the obstacle leads to calm flow and decrease velocity around the pier. Figures 3 and 4 show that the permeable obstruction at front of (P_r) leads to increase the local scour depth at (P_L) and (A_r) compared to the no-blockage case. The local scour depth upstream (P_L) was increased by 11.3%, 4.5% and 3.5 %, for the porosity ratios (15%, 32% and 50%) respectively. While, the local scour depth upstream the (A_r) was increased by 20%, 12.3% and 4.4% for the same previous porosity ratios. For, the small porosity ratio, maximum values of local scour depth around (P_L) and (A_r) were generated compared to the base condition (no-blockage). Larger values of the porosity ratio share to increase the flow passing through the porous media at front of (P_r) and decrease the reverse flow directed to (P_L) and the (A_r) (neighboring supports).The permeable obstacle has little effect on the local scour depth formed at (A_L) which far from (P_r), as shown in this Fig. 5. In which, the flow around left abutment has minor effect with the obstruction at (P_r). The scour iso contour lines for the no-blockage and other impermeable blockage cases are shown in Fig. 6. It is clearly shown that the local scour depth generated at (P_L) is high compared to the other bridge supports. In addition, as porosity of partial blockage decreases the scour hole dimension for the two adjacent bridges supports increases, i.e. (A_r) and (P_L).

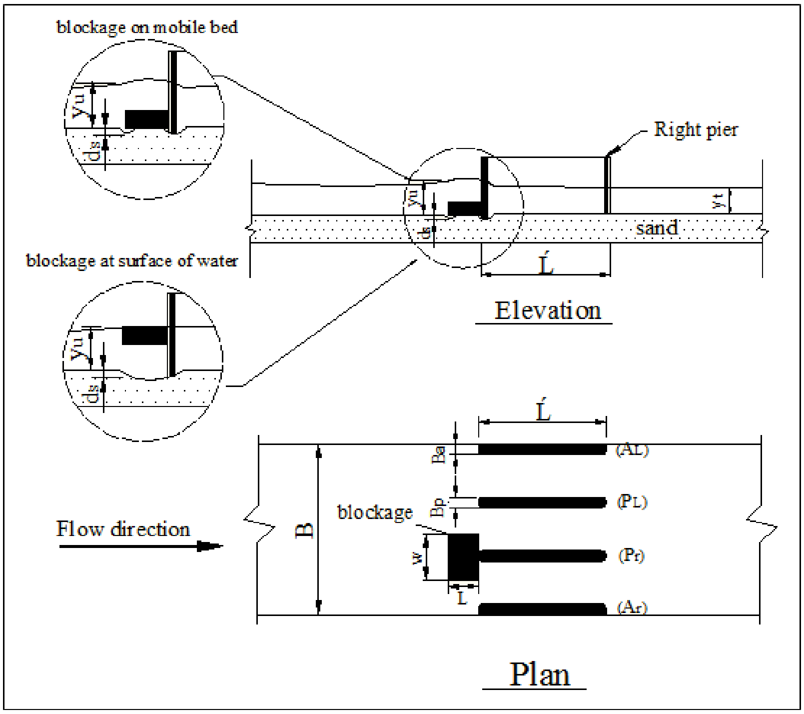


Fig. 1. Definition sketch for the experimental model

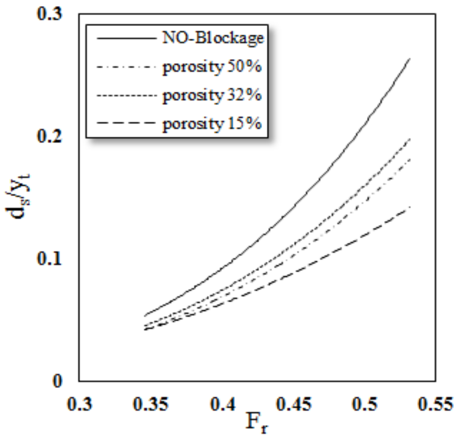


Fig. 2. The relationship between d_s/y_t and F_r for the <u>right pier</u> (P_r)at W/L=1.4, H/B_P=0.4 and different porosity ratios

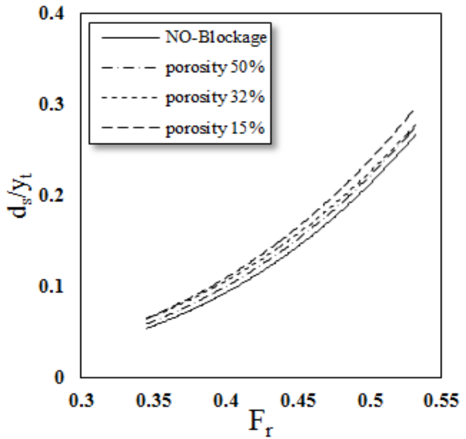


Fig. 3. the relationship between d_s/y_t and F_r for the <u>left pier</u> (P_L) at W/L=1.4, H/B_P=0.4 and different porosity ratios

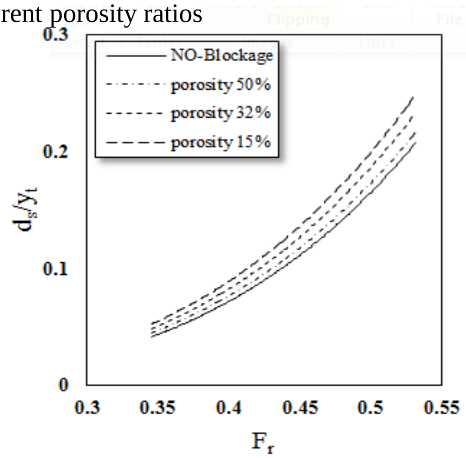


Fig. 4. The relationship between d_s/y_t and F_r for the <u>right abutment</u> (A_r) at W/L=1.4, H/B_P=0.4 and different porosity ratios

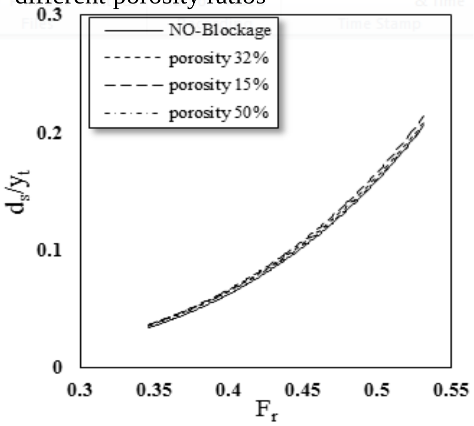


Fig. 5. The relationship between d_s/y_t and F_r for the <u>left abutment</u> (A_L) at W/L=1.4, H/B_P=0.4 and different porosity ratios

4.2 Effect of the location of permeable obstruction with different thickness on local scour depth.

The effect of debris location was investigated using permeable partial blockage with 50% porosity, 1.4 relative width (*W/L*) and different relative heights (H/B_P). The permeable blockage cluster were fixed as follow; i) over the mobile bed, and ii) the top surface of porous obstacle coincides with the water surface and has different ratios of H/B_P. Figure 7 presents the relationship between Froude number and relative scour depth with porosity (*n*) equals 50%, *W/L* equals 1.4 and deferent ratios of (H/B_P). It was found that, the local scour depth increases as the relative height of obstruction and Froude number increase. In addition, the local scour depth formed for case of permeable obstruction at the water surface had greater values compared to the case if permeable blockage on the bed. Moreover, the presence of permeable blockage at water surface increases the local scour depth at (P_r) by 4.97 times compared to the situation of its presence at the mobile bed. The permeable partial blockage with relative porosity ratio (n= 50%) at water surface increases local scour depth at

(A_r) by 64.3%, 58.96% and 52%, for different relative heights of blockage (H/B_P= 1.2, 0.8, and 0.4) respectively, compared to the no-blockage case.

The local scour depth, which formed at the upstream of (P_r) increases by (87%, 73% and 58%) for the studied ratios of H/B_P respectively, in case of the obstacle at water surface, conversely the existence of such obstacle on the bed decreases the local scour depth upstream (P_r) by 62%, 57% and 30.5% for the studied ratios of H/B_P respectively, compared to the no-blockage case. The scour iso lines for the obstacle at water surface with porosity (*n*= 50%) and different relative height were shown in Fig. (8). It was noticeable from this figure that, greater scour occurs at (P_r), which holding the obstacle. In addition the local scour depth at the bridge supports (P_L, A_r, and A_L) increases as the thickness of the debris blockage increases.

5. Statistical analysis

The multiple linear regressions are applied to predict statistical equations. The proposed equations correlate the relative scour depth d_s/y_t with other independent parameters at multi-vents bride supports, i.e. (P_L, P_r, A_r,, and A_L). These equations have the follow forms;

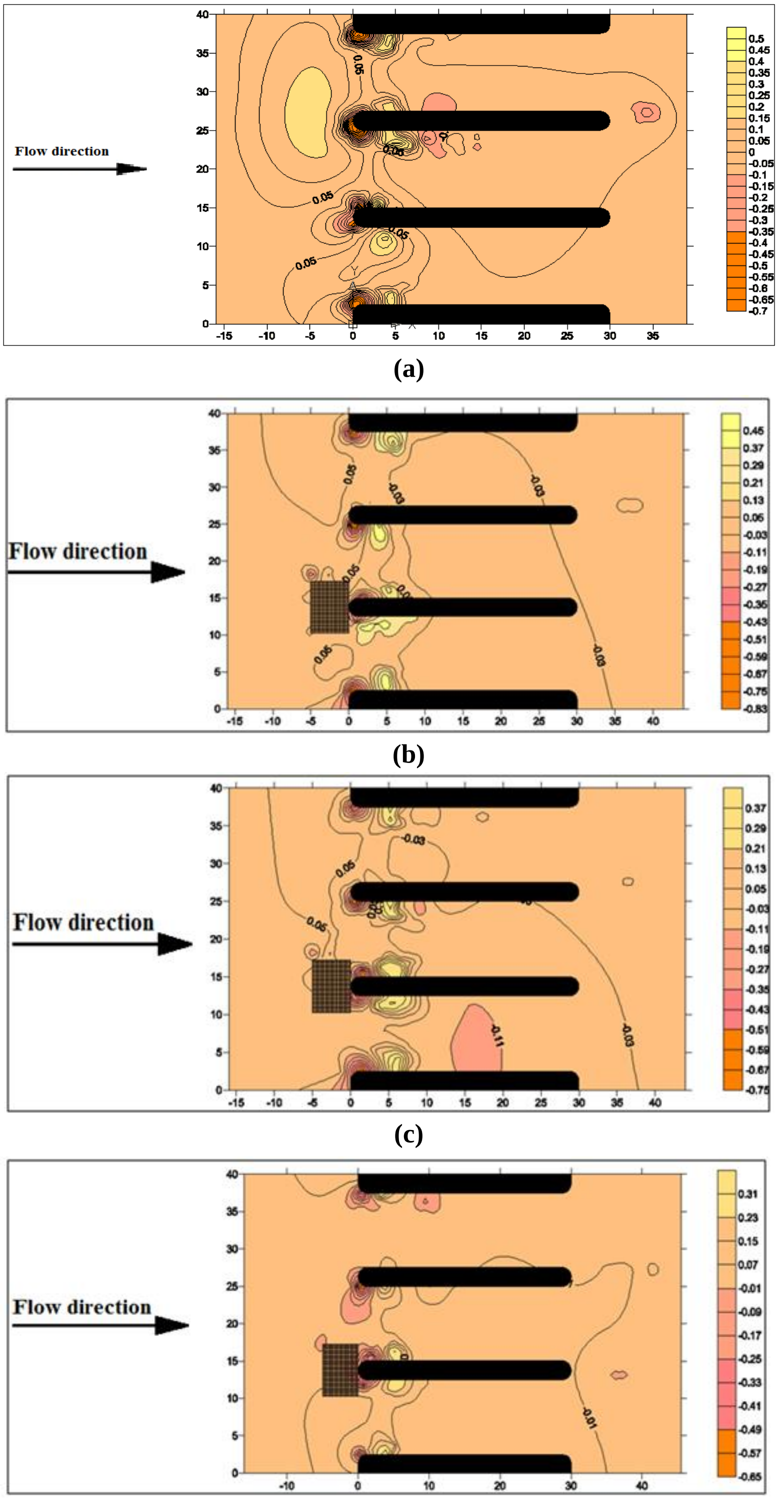
$$\left(\frac{d_s}{y_t}\right)_{P_L} = -0.42 - 0.04(n) + 0.05\, H/H_p + 0.05\, h/H_p + 1.3F_r \tag{2}$$

$$\left(\frac{d_s}{y_t}\right)_{P_r} = -0.35 - 0.07(n) - 0.03\, H/H_p + 0.013\, h/H_p + F_r \tag{3}$$

$$\left(\frac{d_s}{y_t}\right)_{A_r} = -0.41 - 0.020\, n + 0.049\, H/H_p + 0.028\ \ h/H_p + 1.24F_r \tag{4}$$

$$\left(\frac{d_s}{y_t}\right)_{A_L} = -0.31 - 0.006(n) + 0.01\, H/H_p + 0.02\, h/H_p + 0.95F_r \tag{5}$$

Figures 9 through12 present the predicted values for P_L, P_r, A_r, and A_L versus both of measured data and residuals, respectively. The coefficient of determination and standard error are (92%, and 0.03), (54%, and 0.07), (92%, and 0.02), and (94%, and 0.01) for Eqs. 2, 3, 4, and 5 respectively. These results indicate that, the predicted models for relative local scour depth at bridge supports express well the measured data.



(a)

(b)

(c)

(d)

Fig. 6. Scour iso lines for (a) no-blockage (b) 15% porosity, (c) 32% porosity and (d) 50% porosity with H/B_P=0.4 and W/L=1.4 at F_r=0.53.

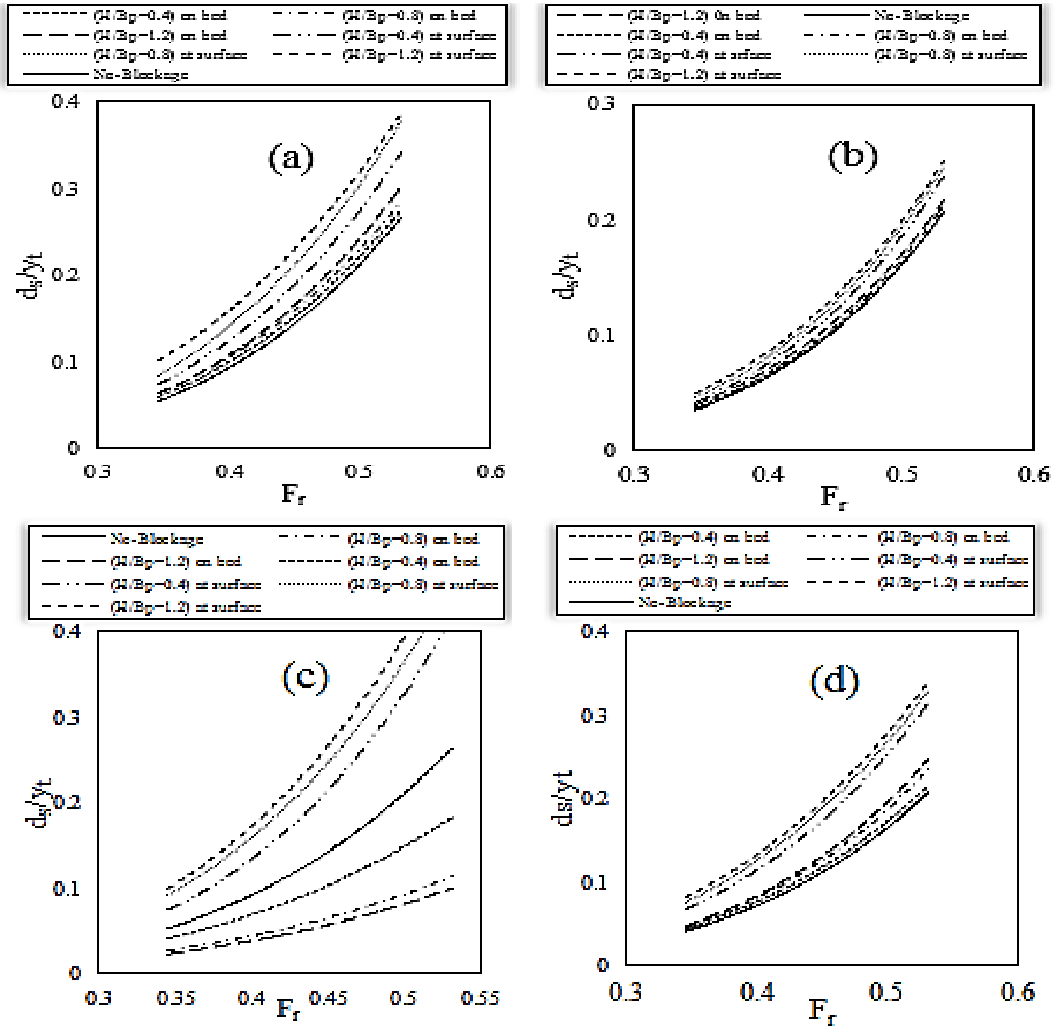
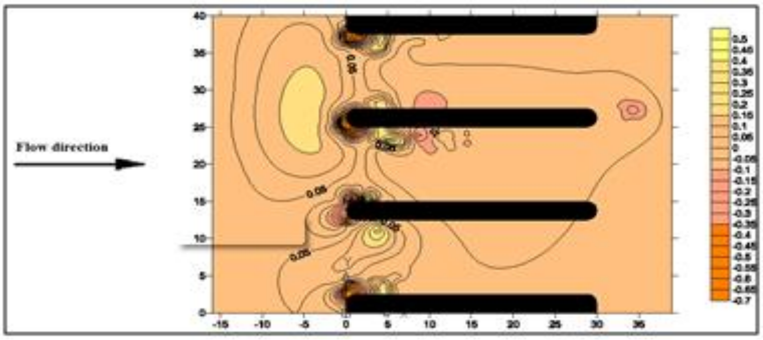
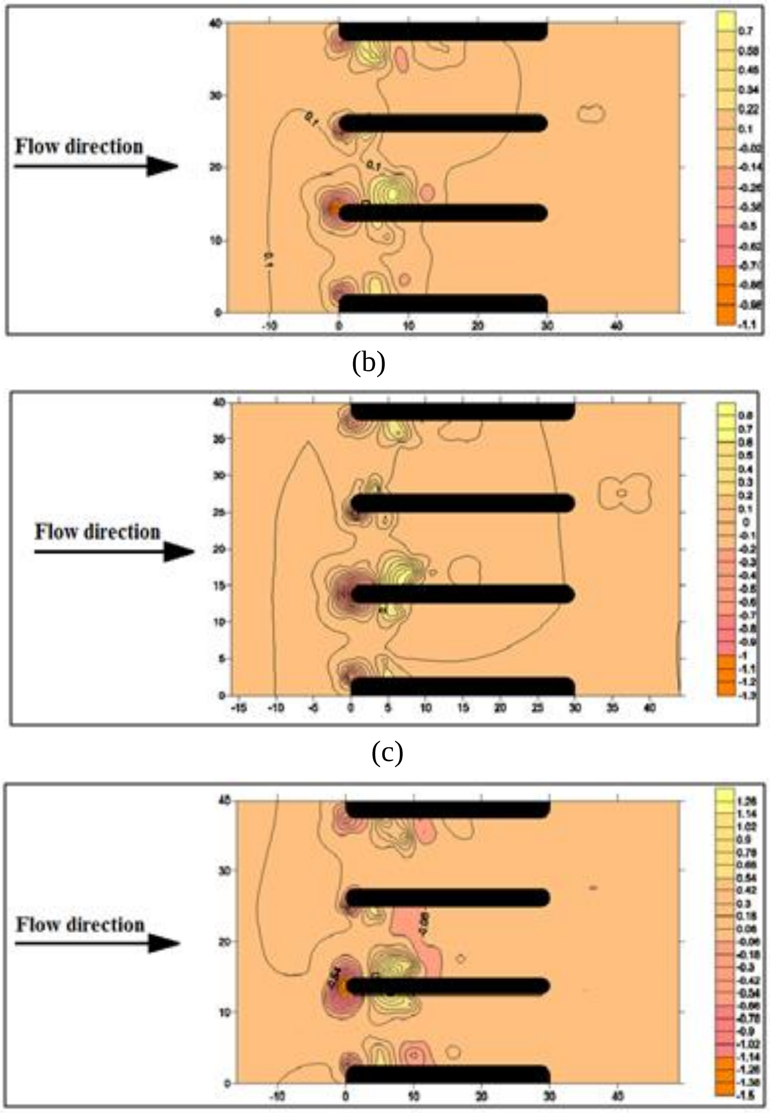


Fig. 7. The relationship between d_s/y_t and F_r, for (a) left pier (P_L), (b) left abutment (A_L), (c) right pier (P_r), and (d) right abutment (A_r) at porosity ratio n= 50%, W/L=1.4 and different ratios *of* H/B_P



(a)



(b)

(c)

(d)

Fig. 8. Scour iso lines for permeable obstruction at water surface for (a) no-blockage case, (b) H/B_p=0.4, (c) H/B_P=0.8 and (d) H/B_P=1.2 with n= 50% , W/L=1.4 and F_r=0.53

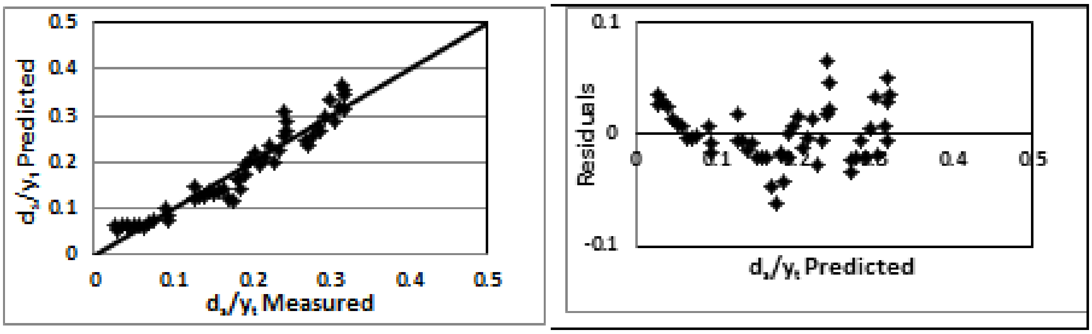


Fig. 9. Eq.2 presents the predicted (d_s/y_t) data versus measured data (ds/yt) and residuals, for P_L.

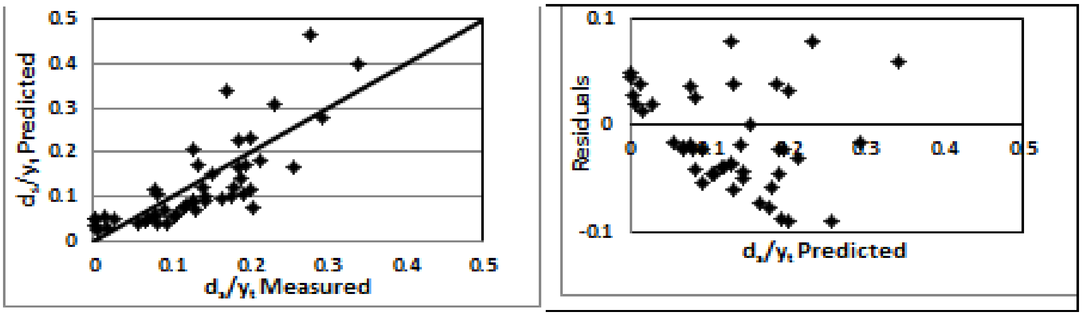


Fig. 10. Eq.3 presents the predicted (d_s/y_t) data versus measured data (d_s/y_t) and residuals, for P_r.

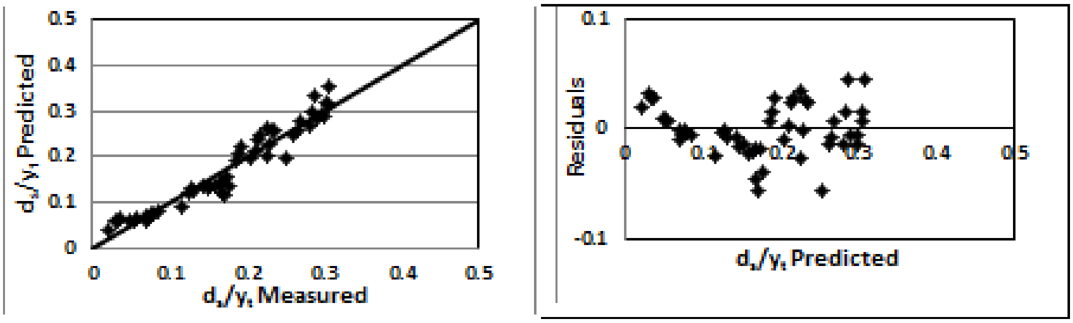


Fig. 11. Eq.4 presents the predicted (d_s/y_t) data versus measured data (d_s/y_t) and residuals, for A_r.

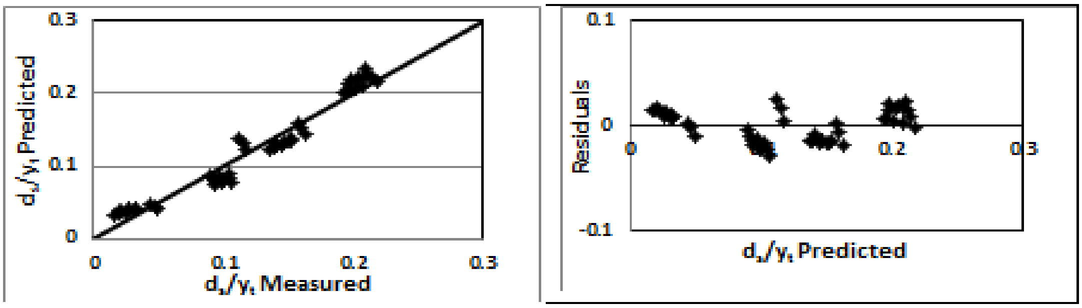


Fig. 12. Eq.5 presents the predicted (d_s/y_t) data versus measured data (d_s/y_t) and residuals, for A_L.

6. Conclusions

The following conclusions could be summarized as follow;

1) The relative local scour depth increases as the porosity ratio of the obstruction decreases.
2) The permeable obstruction rested on the bed in front of pier resulted in greater depths of scour at adjacent pier and abutment than no-blockage condition.
3) The 15% porosity ratio of obstruction over the mobile bed increases the local scour depth at adjacent pier and abutment by 11.3%, and 20% respectively, compared to no-blockage condition.
4) The pier infected by permeable obstruction over mobile bed has lower values of local scour depth compared to no-blockage condition while this obstruction adversely affect the rest of the other bridge supports

5) The permeable partial blockage at water surface with n= 50%, increases local scour depth at the infected pier (A_r) by 64.3%, 58.96% and 52%, for H/B_P= 1.2, 0.8, and 0.4 respectively, compared to the no-blockage case.
6) The porosity blockage with relative width=1.4 and relative height =1.2 and its top surface coincide with water surface causes greater scour at the right piers by 4.97 times of the scour created by the obstacle rested on the bed.
7) The statistical equations, predicting local scour depth at multi-vents bridge supports, agree well with the measured data.

Nomenclature

A_L	left abutment
A_r	right abutment
B	channel width
B_p	pier width
D_{50}	median particle diameter
d_s	maximum depth of scour
g	gravitational acceleration
H	height of blockage
h	vertical distance from mobile bed to the base of obstruction
L	length of blockage
P_L	left pier
P_r	right pie
Q	flow rate
v	mean velocity
W	width of blockage
y_t	downstream tail water depth
ρ	density of water
ρ_s	density of the movable soil particle

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دراسة معملية لتأثير العائق المسامي امام أحد الدعامات علي عمق النحر عند ركائز الكوبري المتعدد الفتحات

المستخلص العربي

تراكم المخلفات حول دعائم الكباري يؤدي الي إعاقة وإعادة توزيع السريان علي فتحات الكوبري مما يولد زيادة في ابعاد واعماق حفر النحر حول اساسات هذه المنشآت الهيدروليكية. هذه الدراسة المعملية تهدف إلى دراسة تأثير مسامية الاعاقة الجزئية لهذه المخلفات أمام احد دعامات الكوبري علي النحر المتكون حول باقي الدعامات لهذا المنشأ. بالإضافة لذلك تهدف الدراسة الي بحث تأثير مكان هذا الانسداد الجزئي ذو الارتفاعات النسبية المختلفة سواء تم وضعة علي قاع التربة المتحرك او مثبتا بعيدا عن القاع بحيث ينطبق سطح هذا العائق مع سطح الماء علي عمق النحر المتكون عند هذه الدعامة والدعامات المجاورة. وجد انه لاحد نسب المسامية لهذا العائق الجزئي الموضوع امام البغلة اليمني ان النحر المتكون عند الدعامة المجاورة (البغلة اليسري) والكتف المجاور (الايمن) لكوبري يزيد بمقدار 11.3% و20% علي التوالي مقارنة بحالة عدم وجود انسداد. كما ان الانسداد الجزئي ذو المسامية والمثبت عند السطح يولد قيم للنحر اكبر من مثيلتها مقارنه بحاله تثبيت نفس هذا الانسداد الجزئي فوق القاع المتحرك مباشرة.