Journal of Engineering Sciences
Assiut University
Faculty of Engineering
Vol. 45
No. 1
January 2017
PP. 17 – 27

CONTRACTION EFFECT UPSTREAM ABUTMENTS ON VELOCITY AND SCOUR: EXPERIMENTALAND THEORETICAL STUDY USING IRIC SOFTWARE

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Received 15 September 2016; Accepted 20 October 2016

ABSTRACT

This paper studies scour features and velocity field using experimental and numerical models at rectangular piers under influence of contraction upstream abutments. A bridge model of two vents of 8cm width each is built to conduct experiments. Extra-piles are proposed upstream rectangular abutments. Different relative extensions of piles are tested. In addition, a new abutment of a relative width ranges within 0.0 to 1.25was proposed instead of piles. The flume's dimensions are 40cm width, 20 cm deepness and 400cm length. Some design rules are deduced to reduce scour upstream rectangular piers. Cases of locating piles upstream abutments are simulated numerically using SToRM solver in iRIC software. The numerical results indicate that, piles of a relative extension to vent width = 4.812 produce the minimal flow velocity near rectangular piers.

Keywords: experiments, numerical, simulations, scour, iRIC and SToRM solver**.**

1. Introduction

Scour may endanger the protection of hydraulic structures. Deng and Cai (2010) indicated that, scouring activities are the major reason for about 60% of bridge collapse in US. Mohammed et al., (2007) indicated that scouring can be reduced by 15% using the profile of streamlined pier. Oben-Nyarko and Ettema (2011) indicated that locating the pier near to abutment amplified scouring at abutments by <10%.Asimplified scour equation was given by Chitale (1962), see Sheppard (2011). It was built on actual measuring for scour in some channels in India.

$$s_c/y_u = 6.65F_u - 0.51 - 5.49{F_u}^2 \tag{1}$$

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In which:s_c: the deepness of scour, y_u: thedeepness of flow just upstream piers,F_u: upstream Froude value, $F_u = v_u/\sqrt{gy_u}$

The modification of existing bridges may affect scour at rectangular piers. Mowafy and Fahmy (2001) inspected the constructing effect of a new bridge near an existing one on scour and flow conditions. The optimum space between two rectangular piers was proposed to be zero to minimize scour at downstream pier. Mowafy and EI-Sayed (2000) inspected the influence of weeds gathering on scour process. Negm et al. (2009) proposed a deflector to control scouring. The total scour decreased by 68%. Many researchers inspected scour close to abutments at presence of some plates like collares as Gogus and Dogan (2010), and Li et al. (2006).

Radice and Davari (2014) suggested roughening elements as a device to control scour at abutments. Mojtaba et al. (2012) inspected scouring at three types of abutments. The deepness reduction of hole is 19-31.2% and 6-26% of buried wing and the wing walls, respectively in the comparison with vertical wall.

The numerical simulation is a simple way to obtain fast and accurate results. Many numerical simulations in open channels were published to simulate the velocity and sediment transport in Nile River and its branches as Elfiky, et al. (2002, 2004 and 2010), Negm, et al. (2010) and Nassar (2011). In addition, the implementation of numerical simulation to detect scour or velocity values near bridge supports were applied as Esmaeili, et al., (2009), Mohamed, et al.,(2015).

In this study, scour and velocity upstream rectangular piers are inspected experimentally and numerically under influence of contraction upstream abutments. The research focuses on the extensions of the contraction. Controlling parameters are given. The major results are discussed in details. In addition, results of statistical analysis and numerical simulations using SToRM solver are detailed.

2. Controlling parameters

The controlling parameters of scour at rectangular piers can be derived based on the dimensional analysis, Melville (2008).The following dimensionless parameters presented in equation (2) are obtained:

$$s_{cr} = function\ of(y_r, F_{down}, V_r, w_r, L_r) \tag{2}$$

In which:

$s_{cr} = (s_c/y_t)$: the related deepness of scour,

$y_r = y_u/y_t$: the related upstream water depth,

y_t: the deepness of flow downstream the bridge,

F_{down}: Froude value downstream the bridge,$F_{down} = V_t/\sqrt{gy_t}$,

$V_r = V_c/V_t$: the related critical flow velocity of soil,

V_c: the critical flow velocity for the soil,

V_t: the average velocity downstream the bridge,

$w_r = w_p/b$: the new abutment’s related breadth,

w_p: the new abutment's breadth,

$L_r = L_p/b$: the related extension of piles to abutments' breadth, and

L_p: the extension of new piles.

Figures (1and 2) give the major variables appeared in the study.

3. Lab works

The experiments are collected in the hydraulics laboratory at Engineering Faculty, Zagazig University using a flume of 40×20×400cm for width, deepness and length, respectively. Figure (2A) presents the flume details. A calibrated orifice-meter is utilized to measure discharges. The flow depths are measured using point gauges. Figure (2B) shows an image for the bridge model with extra-piles upstream abutment. The location and extension of constructed new piles can be seen from the figure.

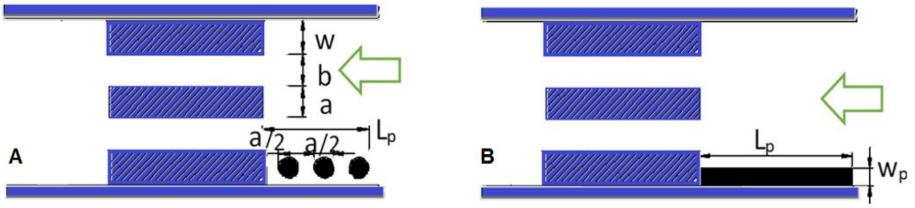

Fig. 1. Model details [A] the extra piles case [B] the extra abutment case

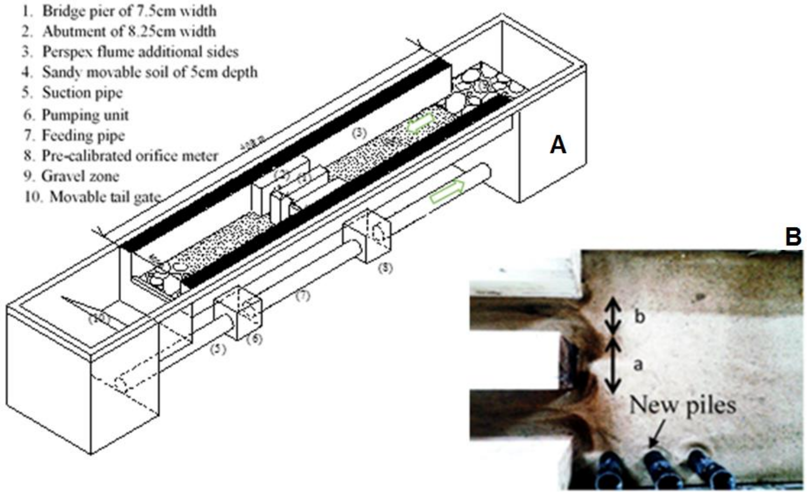

Fig. 2. [A] the flume details [B]an image of the extra-piles case

The bridge model consists of two square nose abutments and pier (see figure 1A). The pier width and length are 7.5cm and 40 cm respectively. The abutment width and length are 8.25cm and 40cm respectively. The two vents width is 8cm (see figure 2B). The used soil has 5cm depth. The median diameter of soil d_{50}is0.88mm.The water depths at the flume end are altered in the following range (3.7 to 6.5 cm). The velocity downstream the bridge ranges within6.6 to 11.6 m/sec. The time for each test was set as 60 minute. It equals the double values proposed by Negm et al. (2009).

The study clarifies the effect of existing extra-piles on scour at a rectangular pier. The piles are of following characteristics (diameter and spacing= a/2). Five relative extensions of new piles are tested (L_r = 1.312, 2.187, 3.062, 3.937 and 4.812) (see figure 1A). Also, the study clarifies the effect of new abutment upstream old abutments on scour at rectangular pier. Three relative breadths of new abutment of w_r = 0.5, 1.031 and 1.25are tested (see figure 1B). The lengths of new abutments are the same as the old ones.

4. The results and comparisons

4.1. Comparison with available scour equations

Figure (3A) shows relationships between related depths of scour s_{cr} and F_{down} for the base case and Froechlich & Chitale equations. It can be seen that, the measures are acceptable. Figure (3B) shows the relationship between the developed and the measured depths of scour in cm unites. The measures are scattered near the perfect line for Froechlich and Chitale equations with RSQ= 75.9% and 72.4%, respectively.

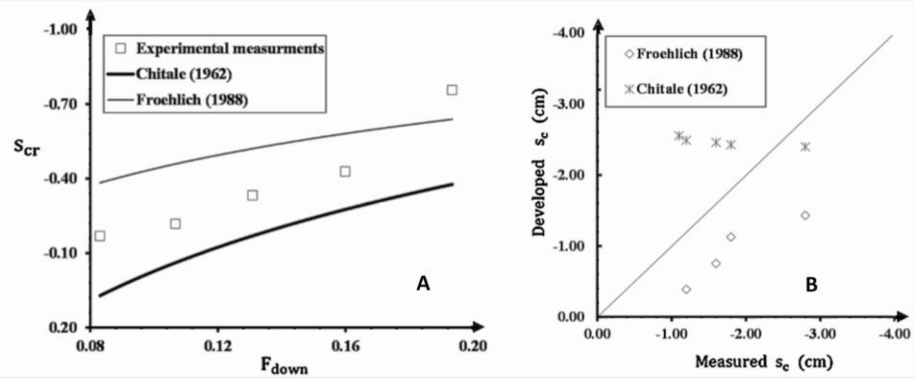

Fig: 3. [A] Relationships between s_{cr} and F_{down}[B] Relationships between developed and measured s_c

4.2.The effect of extra-piles upstream abutments

Figure (4A) shows relationships between s_{cr} and F_{down} for different relative extensions of piles (*i.e.*, L_r = 1.312, 2.187, 3.062, 3.937 and 4.812). It yielded that, L_r = 4.812 gives the least s_{cr}. In contrast, L_r = 3.937 gives extreme values of s_{cr}.Median value of s_{cr}upstream bridge increases by about 50%. Figure (4B) displays relationships between s_{cr} upstream piers and $L_r$for different F_{down}. It yielded that, s_{cr} growths for 1.312 <L_r< 4.812.

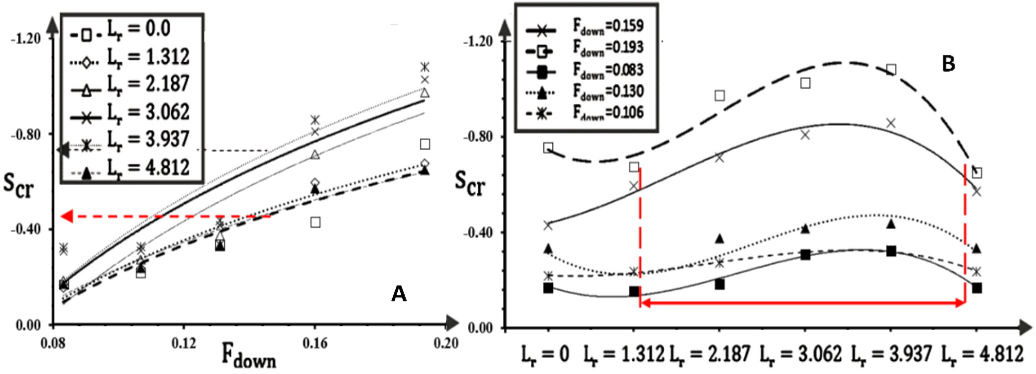

Fig. 4. Results for the first group of measures [A] Relationships between s_{cr} and F_{down}[B] Relationships s_{cr} and L_r

4.3.The effect of extra-abutment upstream abutments

Figure (5A) shows relationships between s_{cr} and F_{down} for different relative breadths of additional abutments (i.e., w_r = 0.5, 1.031 and 1.25). It yielded that, $w_r = 1.25$ gives extreme values of s_{cr}. It increased the median s_{cr} by 95%. In contrast, $w_r = 0.5$ gives the minimum s_{cr}. Figure, (5B) shows relationships between s_{cr} and $w_r$for different F_{down}. It yielded that s_{cr}increasesas $w_r$increases. The minimum value of $s_{cr}$is obtained for the case of no additional abutment upstream old bridge (seefigure5B).

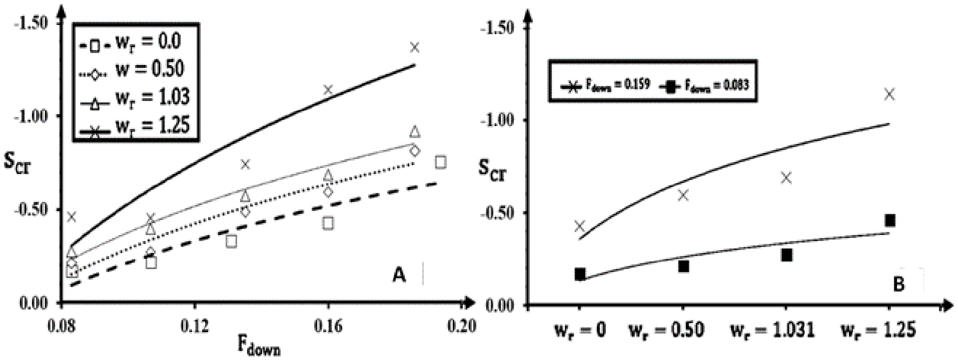

Fig. 5. Results for the second group of measures [A] Relationships between s_{cr} and F_{down}[B] Relationships between s_{cr} and w_r

4.4. A comparison between optimum results

Figure (6A) shows relationships between s_{cr} and F_{down} for the ideal cases of two groups of measures. It yielded that, L_r= 4.812 gives the minimums_{cr}compared to the locating of abutments upstream old bridge. In fact, L_r = 4.812 keeps scour upstream old bridge constant compared with locating new abutments upstream old bridge (see figure 6B).

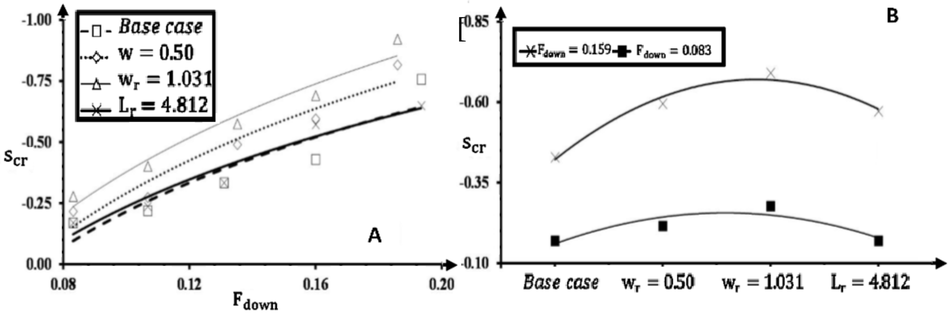

Fig. 6. Results for the two groups of measures [A] Relationships between s_{cr} and F_{down} [B] Relationships between s_{cr} and the optimal cases.

5. Statistical formulations

Equations (3&4)are developed by the employment of theoretical Eq. (2) for the two groups of experimental measures.80% of data is applied to create these equations and the rest is used for validation. RSQ of equations (3&4) are 89.6% and 91.6%, respectively. It indicates the capability of equations to fit collected points perfectly. Figures (7A and 8A) display relationships between the predicted and the measured $s_{cr}$by equations (3&4), respectively. It yielded that, there is a reasonable agreement between the predicted and the measured s_{cr}. Figures (7B and 8B) display relationships between the errors and the predicted s_{cr} using Eqs. (3&4), respectively. There is no apparent trend of errors. Table (1) presents the measured parameters of Eqs. (3&4).

$$s_{cr} = -40.15 + 43.77\,\ln V_r + 0.003{L_r}^3 - 6.58V_r - 2.93y_r - 0.09L_r + 49.85\,F_{down} \tag{3}$$

$$s_{cr} = 8758.47 - 526.03\,\ln V_r - 0.228{w_r}^3 - 8999.78\,{F_{down}}^{0.05} + 3.77V_r + 75.17y_r + 0.06w_r + 61.67\,F_{down} \tag{4}$$

Table. 1.
Statistical measures of equations (3 & 4)

	Equation (3)		Equation (4)	
	Training	Validation	Training	Validation
RSQ	94.0%	89.6%	93.5%	91.6%
Correlation	96.9%	94.6%	96.7%	95.7%
RMSE	7.07%	12.4%	8.1%	10.4%

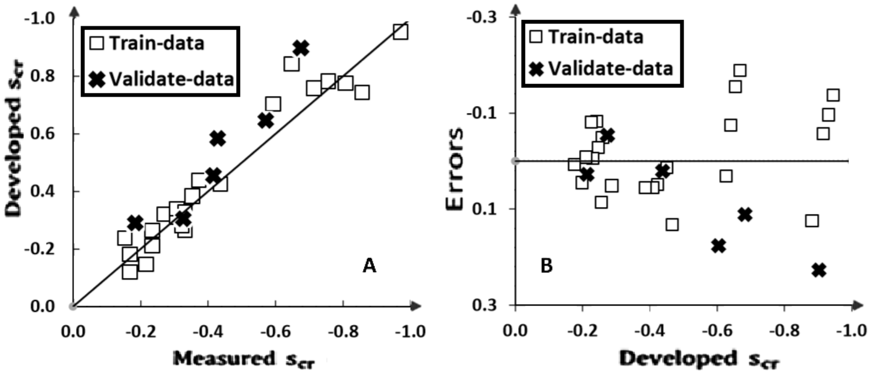

Fig. 7. [A] Relationships between the developeds_{cr} using Eq. (3) & the measured ones [B] Relationships between the errors of Eq (3) & the developeds_{cr}.

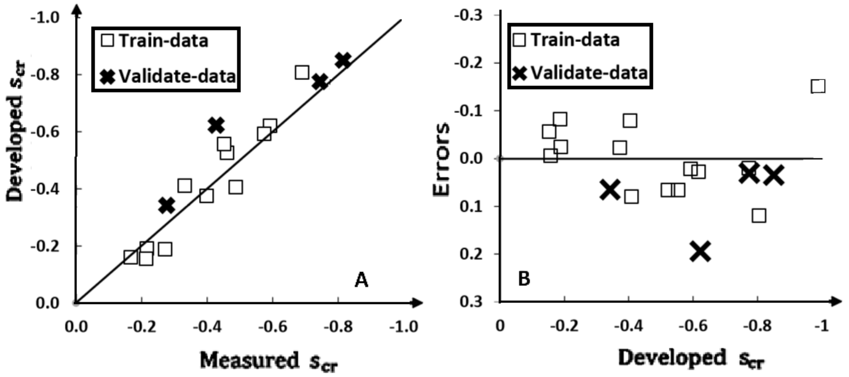

Fig. 8. [A] Relationships between developeds_{cr}using Eq. (4) and the measured ones [B] Relationships between the errors of Eq (4) and the developeds_{cr}.

6. Numerical application

SToRM (**S**ystem for **T**ransport and **R**iver **M**odeling) in iRIC software [6, 8] is applied to simulate the velocity in the tested model. It is software for the simulation of flow field and it was applied in open channels [6]. SToRM solver is a 2D numerical model in the plan. It simulates the free surface water flow. The major equations are given by Francisco Simões, (2013).

6.1. Schematization and the major conditions

The mesh is divided into irregular cells (see Fig. 9a). The total length and breadth of a domain are 2m and 0.4m, respectively. The cell's extreme area is defined as 0.001m^2.The location of abutments, the rectangular pier and the piles were defined using the hole region option for inspected cases ($i.e.,$ L_r=0, 1.312, 3.062 and 4.812) (seefigures9a, 9b, 9c, and 9d). The corners of hole regions are defined by coordinates of experiments.

The inflow and outflow conditions are defined as follows: the inflow discharge = 0.00172m^3/sec and the outflow stage = 0.038m. Manning condition is adopted for the calculations.

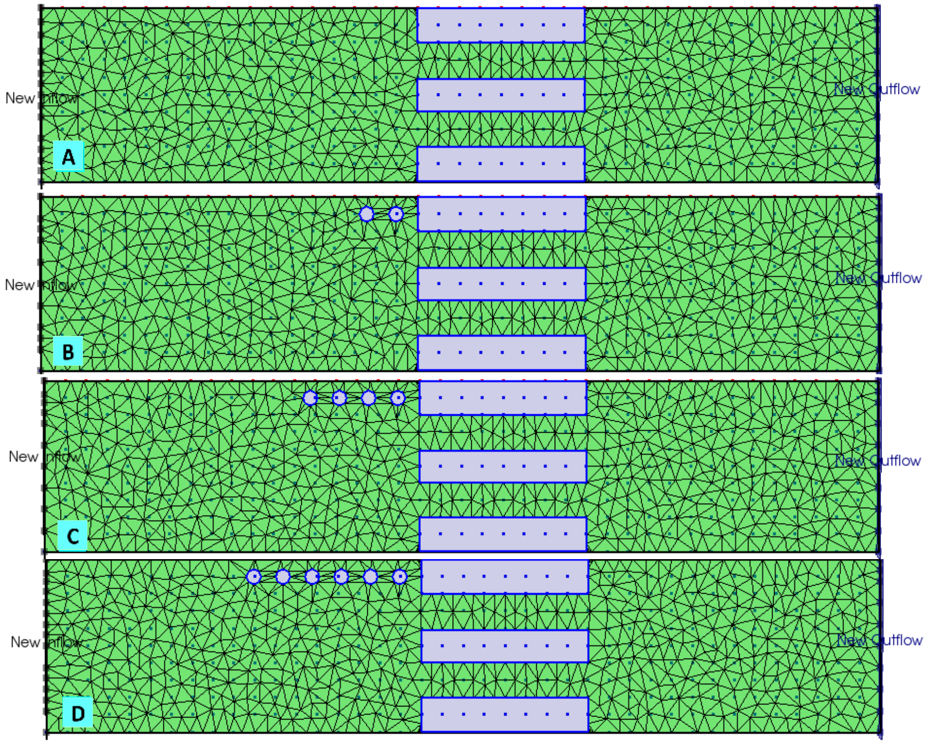

Fig. 9. The mesh of inspected cases [A] Base case ($L_r = 0$) [B] $L_r = 1.312$ [C] $L_r = 3.062$ [D] $L_r = 4.812$

6.2. Numerical results

The major objective is to investigate the effect of locating extra-piles on the flow field near the rectangular pier. Four cases are numerically modeled. It included that, the base case (i.e., on extra piles), and three cases of different relative extensions of new piles ($i.e., L_r = 1.312, 3.062 and 4.812$). The tested circular piles are of diameter ≅ a/2.

Figure (10) shows contour maps of velocity magnitude for inspected cases. It yielded that, the area of high velocity is obviously increased near the rectangular pier for $L_r =$ 3.062 (see figure 10C). It becomes more than the critical flow velocity of median diameter of soil (V_c=0.355m/sec.). It may cause scour increasing near the bridge pier. For $L_r =$ 1.12, it can be seen that, the zones of high velocity are generated upstream abutment of bridges (see figure 10B). For $L_r = 4.812$, the velocity near pier's corners and abutments are very small in comparison with others(see figure 10D).

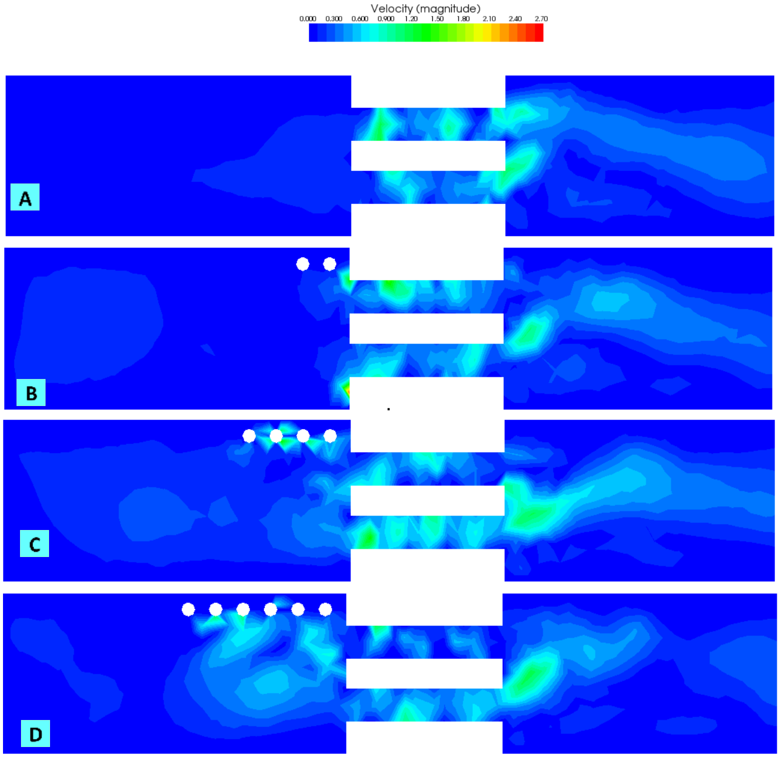

Fig. 10. The maps of velocity magnitude of inspected cases [A] base case [B] $L_r = 1.312$ [C] $L_r = 3.062$[D] $L_r = 4.812$

Figure (11) shows the velocities victors for different inspected cases. The velocity near the rectangular pier for $L_r = 4.812$ is lower than the other cases (see figure 11D). In contrast, the velocities victors of $L_r = 1.312$ are very long at the upstream corners of the abutments (see figure 11B). In addition, velocity victors of $L_r = 3.062$ are very long at the upstream corners of piers.

When$L_r = 1.312$, a small wake zone is formed beside the piles (see figure 11B). It transformed a part of flow directly to the abutment in the other side. As a result, the velocity's victors are very long at the upstream corners of the abutments. It may affect the scour process at the abutment.

When$L_r = 3.062$, a small turbulence zone is formed beside the piles and a small wake zone is formed upstream piers (see figure 11C). It directed a part of flow to pass out of the other vent of the bridge. As a result, the velocity's victors are very long near the pier and at the upstream corner of the abutment. There is a weak zone upstream bridge of $L_r = 4.812$. This zone acts as a block against the major flow lines. The noticeable result is reducing the flow velocity values near the rectangular pier (see figure 11D).

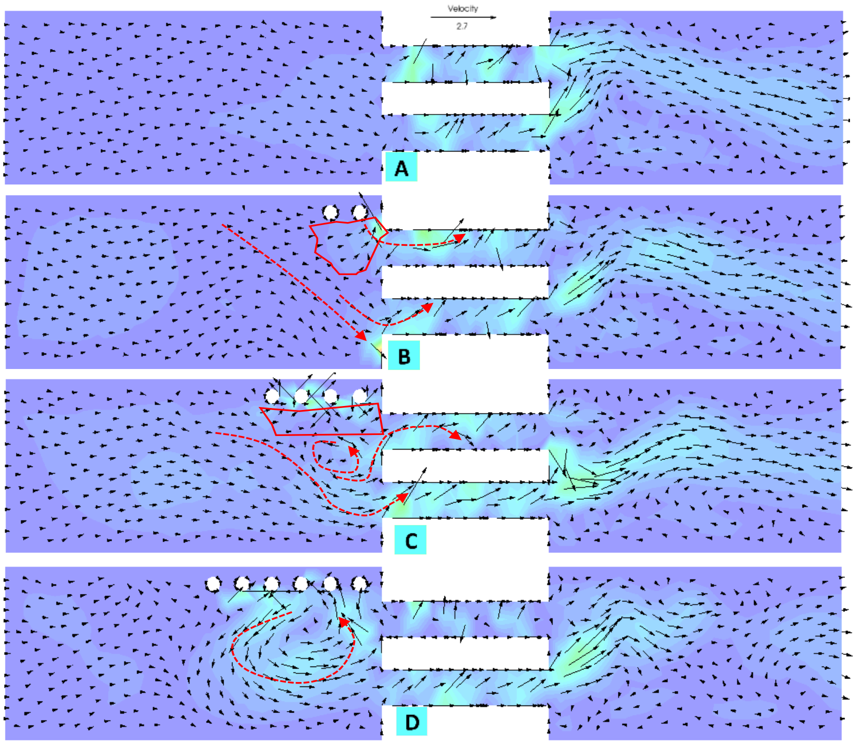

Fig. 11. The horizontal flow velocity victors [A] base case [B] $L_r = 1.312$ [C] $L_r = 3.062$ [D] $L_r = 4.812$

7. The conclusions

The modeling of scouring and flow velocities at rectangular piers at the presence of extra-supports is offered in this research with the following conclusions:

1. The additional piles of$L_r = 4.812$ produces the minimal s_{cr}upstream bridge. In contrast, $L_r = 3.937$ gives extreme values ofs_{cr}. Median value of s_{cr}upstream bridge increased by about 50% in comparison with the base case.s_{cr} upstream rectangular pier increased for 1.312 <L_r< 4.812.
2. The additional abutment of$w_r = 1.25$gives extreme values ofs_{cr}upstream rectangular pier. It increased median s_{cr} by 95%,
3. Simple predicting equations for s_{cr}were developed. RSQ of developed equations are 89.6% and 91.6% %, respectively.
4. The results using SToRM solver in iRIC yielded that, the piles of $L_r = 4.812$produces the minimal flow velocity at rectangular piers. The area of the high velocity was increased for $L_r = 3.062$, while it was at the minimal value near the abutments and pier for$L_r = 4.812$.

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تأثير الاختناق امام اكتاف الكباري على السرعة والنحر:
دراسة معملية ونظرية باستخدام برنامج إيريك

ملخص:

يدرس هذا البحثمعمليا وباستخدام النماذج الرقمية خصائص حفرة النحر ومجال السرعة حول البغال المستطيلةتحت تأثير الاختناق امام اكتاف الكباري، حيث تم بناء نموذج لإجراء التجارب على كوبرى مكون من فتحتين عرض الواحدة 8 سم، كما تم أقتراح وجود ركائز إضافية امام أكتافالكوبرى، وقد تم اختبار الامتداد النسبي للركائز الإضافية، كما تم اقتراح إضافة كتفجديد بدلا من الركائز الاضافية بعرض نسبي يتراوح بين 0 -1.25، علما بان القناة المعملية المستخدمة ذات عرض 40سموعمق 20 سم وطول 400سم، وقد تم استنباط بعض قواعد التصميم للحد من النحر امام البغال المستطيلة، بالإضافة الى عمل المحاكاة الرقمية لحالة وجود ركائز إضافية اماماكتافالكوبرى باستخدام SToRM solver في برنامج إيريك، وتشير النتائج الرقمية الى ان الركائز الإضافية ذات نسبة امتداد الى عرض فتحة الكوبرى = 4.812 تنتج الحد الأدنى من سرعة التدفق بالقرب منالبغال المستطيلة.