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Volume 41 | Issue 1 Article 9

6-30-2020

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Recommended Citation

Abddalla, M.; Abdel Hady, M.; and Ahmed, M. (2020) "Studying Scour Hole Development around Rectangular Bridge Piers.," *Mansoura Engineering Journal*: Vol. 41 : Iss. 1 , Article 9.
Available at: https://doi.org/10.21608/bfemu.2020.99373

Mansoura University
Faculty of Engineering
Mansoura Engineering Journal

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دراسة تطور حفرة النحر حول البغال المستطيله للكباري

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KEYWORDS
Local Scour, Soil Sample, Pier Models, Froude Number, Bridge Pier, Wireless Camera, Open Channels, Clear Water Scour & Scour Hole.

الملخص العربي: **-- يتناول هذا البحث دراسة معملية للنحر الموضعي حول بغال الكباري المستطيله الشكل علي القنوات المائية المكشوفه. وقد تم إجراء الدراسة علي نموذجين لبغال الكبارى المستطيله بتغير فى طول البغله باستخدام تصرفات مختلفه. ومن خلالها تم دراسة الخصائص الهندسية لحفرة النحر والمتمثله فى طول وعرض وعمق الحفره. القناة المعملية المستخدمه مغطاه بقاع صناعي من الخشب. التربه تم استخراجها من قاع نهر النيل (كفر الطويله-فرع دمياط) متوسط قطر الحبيبات 0.29مم وتم تصنيف العينه الى رمل . تم استخدام كاميره لاسلكيه مثبته داخل النموذج لملاحظة تغير عمق حفرة النحر مع الزمن وكاميرا اخري مثبته فوق النموذج لملاحظة التغير الكلي لحفرة النحر. خلال اجراء التجارب تم تغيير اعماق السريان وبالتالي الحصول على سرعات وقيم مختلفه لرقم فرويد (Fr) مختلفه. تم استنتاج مجموعة من العلاقات الرياضية والتي تربط الخواص الهندسية لحفرة النحر بخواص السريان. تبين من نتائج الدراسه ان عمق النحر يصل الى قيمه متوسطه حوالي 87% من اقصي عمق نحر اول ساعتين، اما بالنسبه للابعاد الافقيه فانها تزيد بنسبة 80% من اقصي عرض لحفرة النحر فى اول ساعتين.**

Abstract: - **This paper presents an experimental study of local scour around rectangular bridge pier through open channels (clear water scour). Tests were carried out on two rectangular pier models with a change in the pier length using different flow discharge. Through this, geometric properties of scour hole were studied such as length, width and depth. The bed of used flume was covered by false wooden bed. The soil was extracted from Nile river bed (Damietta branch, kafr el-tawila) d_{50} equal to 0.29mm and the soil was classified to poorly graded sand (SP). A wireless camera fixed on the model was used to observe the change in scour depth with time and other outer camera fixed above the model to observe the change in the total scour hole. Through conducting the experiments the flow depths were changed, therefore the velocities and difference Froude number (F_r) were gotten. A group of mathematical relationships were obtained which gathering the geometric properties of scour hole with flow properties. It's noted that from the study result, the depth of scour hole is reaching to average values of 87% from the maximum scour depth in the first two hours, but the horizontal dimension of scour hole is increasing by 80% from the maximum scour length.**

INTRODUCTION

Local Scour is one of the main and most important phenomena leading to bridges failure. The erosive action of the flow that causes of the scour lead to the collapse of bridges at their foundation that consists of piers and abutments.

Scour around bridge piers or abutment can be classified into three categories; the first one is the local scour which occurs around and locally the bridge foundation. The second one is contraction scour which occur when the flow contracted by bridge abutment and pier foundation. The third one is the general scour, which occurs due to increase flow velocity through the channel. The depth of scour is independent of the sediment size in live bed scour. Although it may appear paradoxical, it has been supported by experiments (Henderson, 1970).

Asis and Khwairakpam (2009) made an extensive study for local scour around hydraulic structures and they found that it is important to control the local scour depth at downstream of hydraulic structures to ensure

RECEIVED: 22 FEBRUARY, 2016 – ACCEPTED: 21 MARCH, 2016

safety of these structures. In spite of numerous investigations by many researchers, the problem of scour has not been effectively resolved as yet.

The transport physics of sediment which was cohesive is different based on particle size and its gradation. Fine sediment particles which have a size ranging from less than 1 μm to more than 63 μm are mainly responsible for the cohesive sediments and the muddy. (Debnath and Chaudhuri, 2010).

The presence of clay in mixtures of clay-sand is reduced scour depth significantly as well as transverse and longitudinal extent of scour hole. For sand, the process of scouring started from the front of the pier which was the position to give the maximum scour depth, but with clay incensement, scouring started from the sides of the pier which was the position to give the maximum scour depth. (Debnath and Chaudhuri, 2010).

The local scour around bridge piers could be reduced using collar in rear piers than the first pier and when the distance between the piers increases the area which have no protection between the piers is washed away resulting scour hole with deeper depth at the rear piers. (Heidarpour et.al, 2010).

Prediction of local scour holes developed downstream of hydraulic structures plays an important role in their design. Excessive local scour can progressively undermine the foundation of the structure. Because of a complete protection against scour is too expensive, generally, the maximum scour depth and the upstream slope of the scour hole have to be predicted to minimize the risk of failure. (Zidan et.al, 2011).

Local scour can be classified into two categories according to the sediment transport, namely, clear-water scour and live-bed scour as shown in Fig.(1).

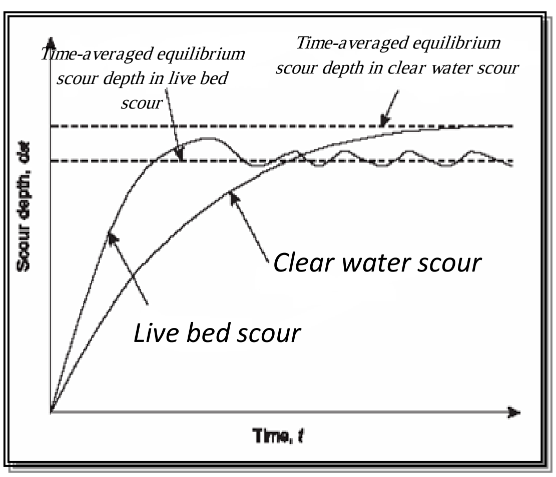

Fig.(1): Time development of clear-water and live-bed scours. (After Chabert and Engeldinger, 1956)

Clear-water scour happens in the absence of sediment transport into the scour hole.

Live-bed scour happens when the scour hole is continuously provided with sediment.

Chabert and Engeldinger (1956) found that the maximum clear-water scour depth is about 10% greater than the live-bed scour depth. (Zidan et.al, 2011).

Temporal evolution of scour depth around single bridge pier has been investigated by many researchers (Kothyari et al., 1992; Melville and Chiew, 1999; Oliveto and Hager, 2002, 2005; Chang, 2004; Kothyari et al., 2007). Kothyari et al. (1992) conducted a series of experiments on temporal variation of scour depth around circular bridge pier with different diameters, sediment and under steady and unsteady clear-water flow conditions and developed a procedure for computing the temporal variation of scour depth. (Movahedi et.al,2013).

Mohamed.et.al,(2015) studied the protection of local scour using collar around multi-vents bridge piers, this collar reduce the local scour by 65%.

In 1973 he Federal Highway Administration (FHWA) State that 383 bridges were failure because of catastrophic floods showed that 75 percent involved damage in abutment and 25 percent involved damage in pier. (Goswami and Barua, 2015).

Nohani and Ghannad, (2015) studied the impact of collar on the cylindrical bridge pier by using three difference dimensionless ratio of collar length to pier diameter, they say that the shape of oval collar have the effective impact on reducing the scour.

2. EXPERIMENTAL WORK

This experimental study was carried out using a mild laboratory flume has dimensions of 12 m long, 40 cm depth and 40 cm width with 2 m long perspex part, Fig. (2). plates (1a though 1c) illustrate the flume plane and side view and soil extracting .

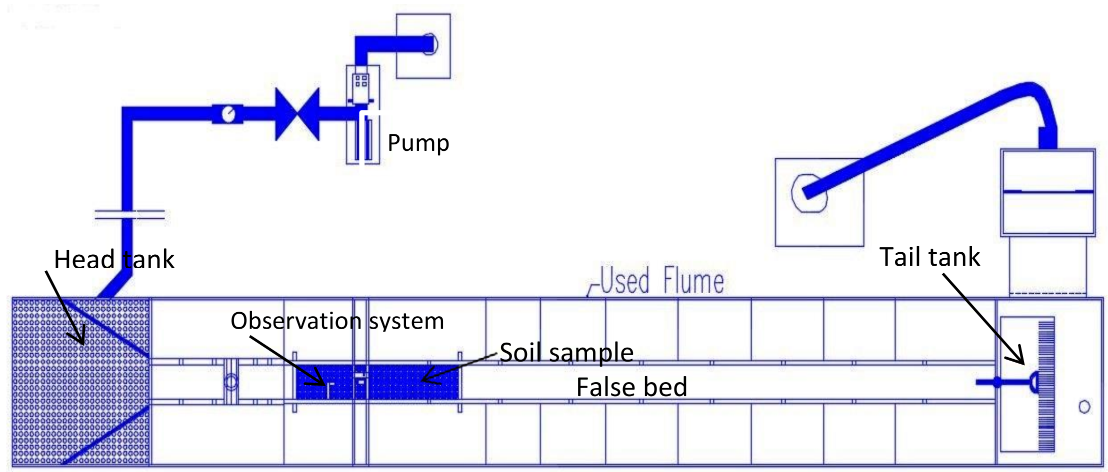

Fig. (2) Plan of the used flume

(a) ***(b)*** ***(c)***

Plates (1): Flume (a) Plane of flume (b) side view of flume (c) during soil extracting

A wireless camera was used for observe the scour development with time; this camera was fixed into the pier model. Other external camera was also fixed above the pier model to observe the full scour hole. Plate (3) shows the observation system.

- Physical Model

Two pier models of rectangular cross section were selected in this study. These models are made of glass having a dimension of 5 cm×15 cm and 5 cm×10 cm as shown in plate (4). These works was carried out using movable bed of Poorly Graded Sand "PS. Table (1) shows some important gradient of soil

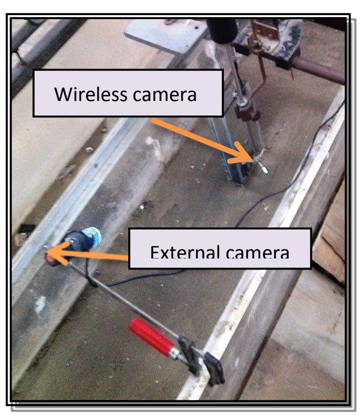

Plate (3) observation system

Plate.(4) Rectangular pier models

Table (1) some characteristics of soil sample

d_{10}	d_{30}	d_{50}	d_{60}	d_{90}
0.18mm	0.22mm	0.29mm	0.32mm	0.55mm

Experimental Procedure

The experiments were carried out using the aforementioned rectangular models with sand sample with the following procedure:

1. 1-The used channel was calibrated and adjusted.
2. 2-Phsical models were prepared and adjust in the flume.
3. 3-The used soil sample was adjusted in the perspex part.
4. 4- The level of sand surface is kept constant from the upstream to the downstream channel.
5. 5-The tail gate was adjusted to give the calculated flow depth which required for the clear water scour.
6. 6-Three different dischargers of 7.85 lit/sec, 10.8 lit/sec and 13.48 lit/sec were used and calibrated by the flowmeter fixed on the inlet pipe.

For each run he following parameters was measured:
- Flow velocity.
- Water depth.
- Development of scour depth with time.
- Scour hole length and width.

3. THEORETICAL APPROACH

The suitable mathematical technique which deals with the dimensions of the physical quantities involved in the phenomenon under study is the dimensional analysis. It is used to obtain a functional relationship between the dependent and independent variables.

It was developed to get some relationships between the maximum scour hole dimension and the other physical variables of the flow involved in the phenomena.

These variables could be defined as:
v= water velocity;
y= downstream water depth;
g= gravitational acceleration
B= channel width;
d_s= maximum scour hole depth;
L_x= maximum scour hole width;
L_y= maximum scour hole length;
L= pier length;
ν= kinematic viscosity;
b= pier width;
ξ= represents pier nose shape;
t= run time;
d_{50}= geometric mean size.
Fig. (3) Shows the scour hole dimension.
The final obtained relationship using π-theory is:

$$\frac{d_s}{y} = \emptyset(F_r, R_e, \frac{L_x}{y}, \frac{L_y}{y}, \xi, C_r, \frac{L}{B}, t)$$

In which; F_r= Froude number, C_r= contraction radio ($\frac{b}{B}$).

As the channel width is 40 cm and the water depth (y) was found to vary between 9.5 cm and 19.3 cm from the experimental work, then the value of (B/y) ranges from 2.07 to 4.21, this means that the channel could not be assumed to be wide. For all experimental work, value of Reynolds number varies between 19000 and 32810, then viscosity of water has no effect and the values of Reynolds number could be neglected. As he pier nose shape is constant though the whole work, ξ could be neglected.

The contraction ratio for the model under study is 0.875 as the pier width is constant and equals 5 cm.

The final relationships could be:

$$\frac{d_s}{y} = \emptyset(F_r, \frac{L}{B}, t) \quad \text{.........} \quad \text{..................} (1)$$

$$\frac{L_x}{y} = \emptyset(F_r, \frac{L}{B}, t) \quad \text{.........} \quad \text{..................} (2)$$

$$\frac{L_y}{y} = \emptyset(F_r, \frac{L}{B}, t) \quad \text{...........} \quad \text{................} (3)$$

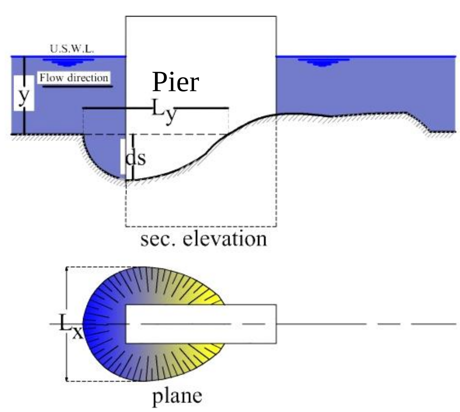

Fig. (3) Scour hole dimension

4. RESULTS AND ANALYSIS

Maximum Scour Depth (d_s)

The depth of scour hole varies with run time as 87% of the maximum obtained depth occurred at the first two hours and the rest exceeds to the third hour and consequently the final run time is three hour for the whole work.

To represent the propagation of scour depth with time at different Froude numbers using the two selected pier models, Figs. (4) though (9) were drawn at three different discharges, 7.85 lit./sec (as minimum discharge), 10.8 lit./sec (as average discharge) and 13.48 lit./sec (as maximum discharge)

At Q_{min}= 7.85 lit./sec

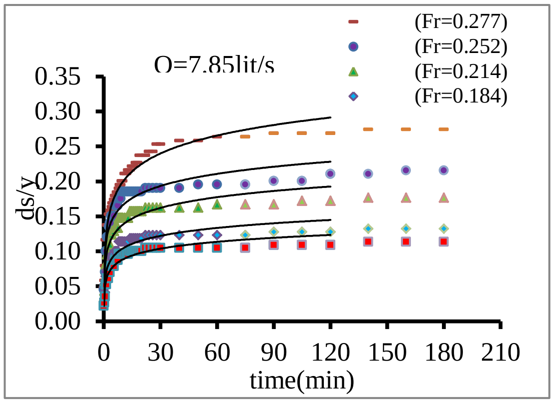

Fig.(4): Scour depth propagation at (L/b=3)

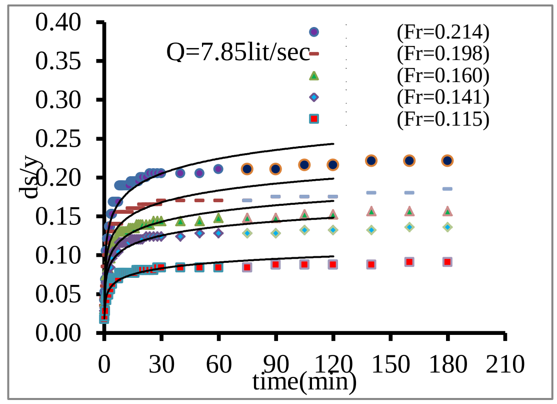

Fig.(5): Scour depth propagation at (L/b=2)

At Q_{ave}= 10.8 lit./sec

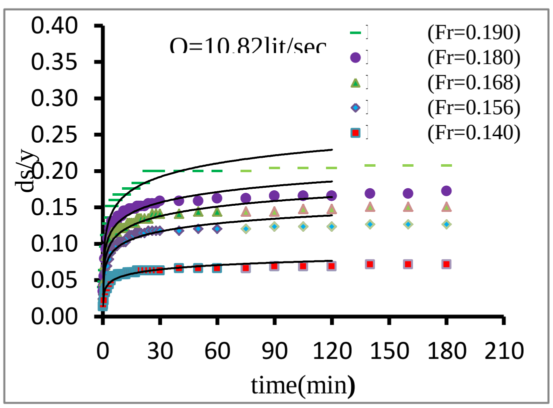

Fig.(6): Scour depth propagation at (L/b=3)

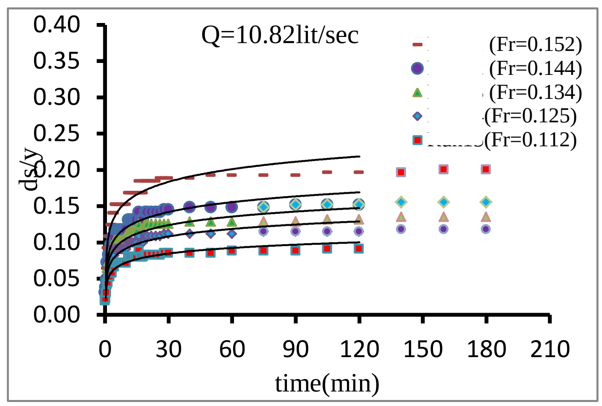

Fig.(7): Scour depth propagation at (L/b=2)

At Q_{max}= 13.48 lit./sec

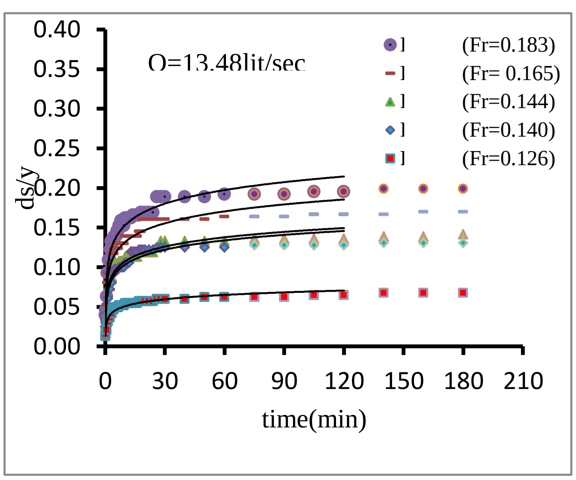

Fig.(8): Scour depth propagation at (L/b=3)

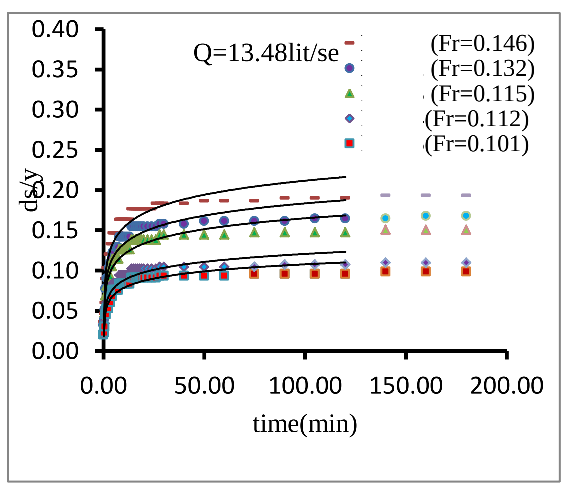

Fig.(9): Scour depth propagation at (L/b=2)

It was found from the aforementioned figures that logarithmic function gives the best determination coefficient (R^2). The scour hole depth is proportional with Froude number.

Fig.(10) exhibit the relationships between (ds/y) and Froude number for L/b=3 and L/b=2 at Q= 13.48 lit./sec

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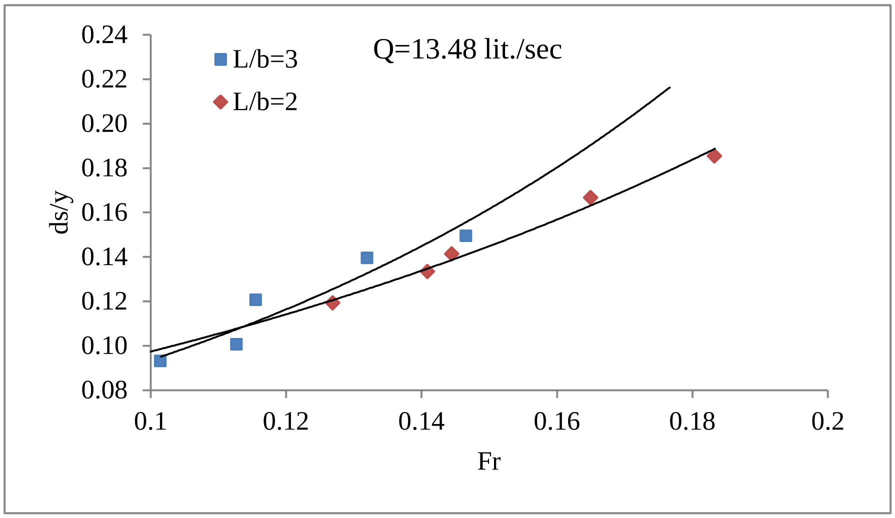

Fig.(10): relationships between (ds/y) and Froude number for L/b=3 and L/b=2 at Q= 13.48 lit./sec

From these figures the following equations (1, 2) are deduced:

At L/b= 3 $ds/y=0.0313e^{10.947Fr}$ (R^2 = 0.903)..(1)

At L/b=2 $ds/y=0.044e^{7.9419Fr}$ (R^2 = 0.9892)…(2)

Maximum Scour Length (L_x, L_y)

The length of scour hole varies with run time as 80% of the maximum obtained depth occurred at the first two hours and the rest exceeds to the third hour and consequently the final run time is three hour for the whole work.

At Q_{min} = 7.85 lit./sec

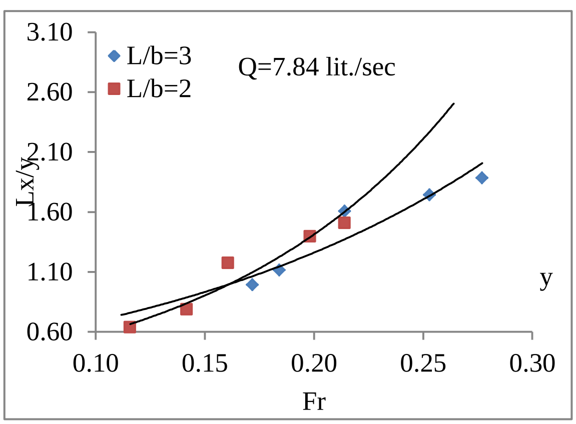

Fig.(15): Relationship between (L_x/y) with Froude number at (L/b=3) and (L/b=2) for Q=7.84 lit./sec.

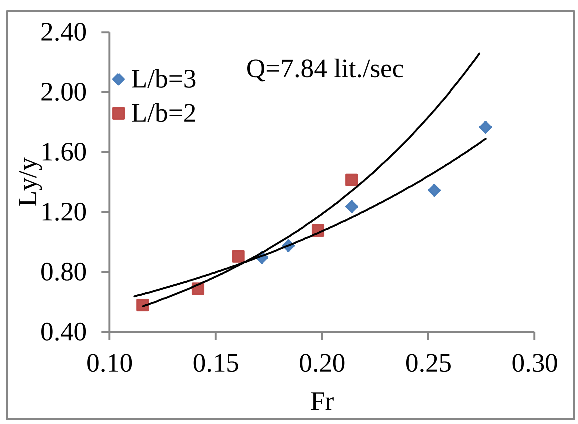

Fig.(16): Relationship between (L_y/y) with Froude number at (L/b=3) and (L/b=2) for Q=7.84 lit./sec.

At Q_{ave}= 10.8 lit./sec

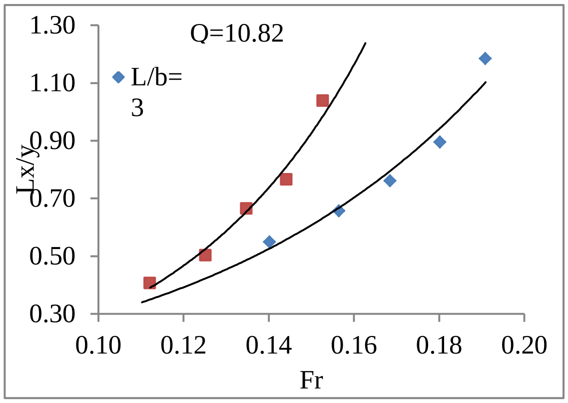

Fig.(17): Relationship between (L_x/y) with Froude number at (L/b=3) and (L/b=2) for Q=10.82 lit./sec.

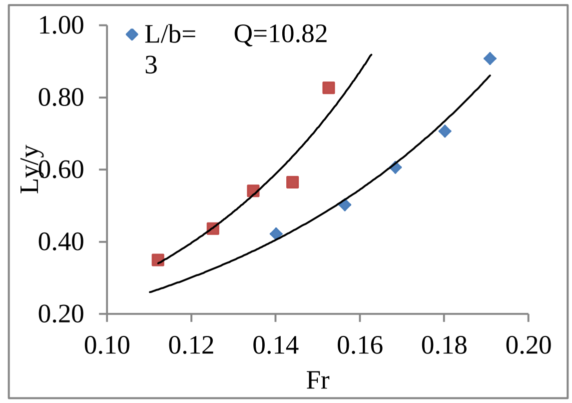

Fig.(18): Relationship between (L_y/y) with Froude number at (L/b=3) and (L/b=2) for Q=10.82 lit./sec.

At Q_{max}= 13.48 lit./sec

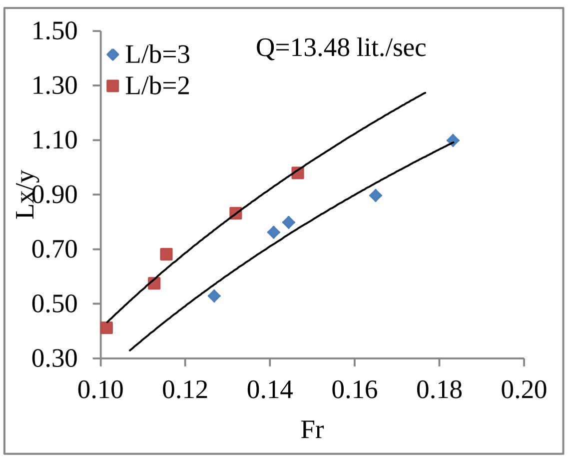

Fig.(19): Relationship between (L_x/y) with Froude number at (L/b=3) and (L/b=2) for Q=13.48 lit./sec.

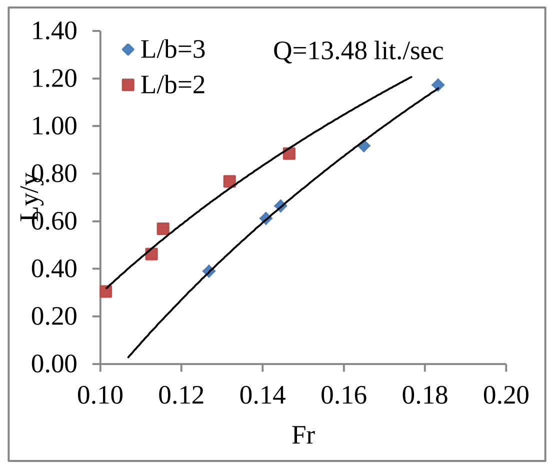

Fig.(20): Relationship between (L_y/y) with Froude number at (L/b=3) and (L/b=2) for Q=13.48 lit./sec.

It was found from the aforementioned figures that the horizontal dimensionless of scour hole is proportional with Froude number. For all figures shown the width of scour hole is larger than the length. The exponential function gives the best determination coefficient (R^2). The exponential equations for rectangular model (L/b= 3) for minimum discharge 7.85 lit/sec gives as follows in equation 3 through 4.

$$\frac{Lx}{y} = 0.3777e^{6.0281Fr} \quad (R^2 = 0.8941) \ldots \qquad \ldots\ldots(3)$$

$$\frac{Ly}{y} = 0.3294e^{5.9002Fr} \quad (R^2 = 0.9558) \ldots \qquad \ldots\ldots(4)$$

The exponential equations for rectangular model (L/b= 2) for minimum discharge 7.85 lit/sec gives as follows in equation 5 through 6.

$$\frac{Lx}{y} = 0.2358e^{8.9511Fr} \quad (R^2 = 0.9332) \ldots\ldots \qquad \ldots(5)$$

$$\frac{Ly}{y} = 0.2089e^{8.6866Fr} \quad (R^2 = 0.9687) \ldots. \qquad \ldots(6)$$

The exponential equations for rectangular model (L/b= 3) for average discharge 10.8 lit/sec gives as follows in equation 7 through 8.

$$\frac{Lx}{y} = 0.0684e^{14.565Fr} \quad (R^2 = 0.9657) \ldots\ldots \qquad \ldots(7)$$

$$\frac{Ly}{y} = 0.0508e^{14.826Fr} \quad (R^2 = 0.9805) \ldots\ldots \qquad \ldots(8)$$

The exponential equations for rectangular model (L/b= 2) for average discharge 10.8 lit/sec gives as follows in equation 9 through 10.

$\frac{Lx}{y} = 0.0303e^{22.796Fr}$ $(R^2 = 0.9817)$ …… …(9)

$\frac{Ly}{y} = 0.0375e^{19.659Fr}$ $(R^2 = 0.942)$… ……(10)

The exponential equations for rectangular model (L/b= 3) for maximum discharge 13.48 lit/sec gives as follows in equation 11 through 12.

$\frac{Ly}{y} = 1.4146\ln(F_r) + 3.49$ $(R^2 = 0.9555)$.. (11)

$\frac{Lx}{y} = 2.097\ln(F_r) + 4.717$ $(R^2 = 0.9981)$ … (12)

The exponential equations for rectangular model (L/b= 2) for maximum discharge 13.48 lit/sec gives as follows in equation 13 through 14.

$\frac{Lx}{y} = 1.519\ln(F_r) + 3.908$ $(R^2 = 0.9819)$ ..(13)

$\frac{Ly}{y} = 1.603\ln(F_r) + 3.986$ $(R^2 = 0.9822)$… (14)

From the aforementioned study, using SPSS program (statistical analysis) the final equations associate all parameters could be given in equation (15).

$\frac{d_s}{y} = 1.408F_r - 0.02098(\frac{L}{b}) - 0.02398$ …….. (15)

Sample of contour map of the maximum scour hole around the rectangular pier (L/b=3) at (Fr= 0.1118) were plotted using software Surfer 12 showed on Fig.(21) with Longitudinal cross section on scour hole at section 1-1on Fig.(22).

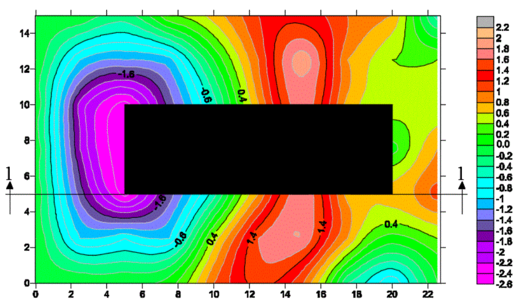

Fig.(21): Contour plot of the local scour around rectangular pier(5 cm×15 cm)

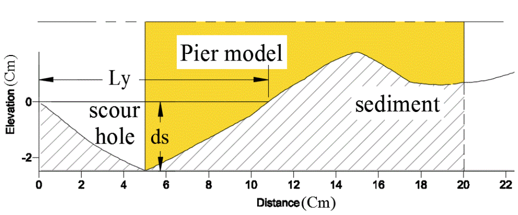

Fig.(22): Longitudinal cross section on scour hole at section 1-1

CONCLUSION

- Two rectangular models were experimented to describe the behavior of scour hole with the physical properties of flow; these experiments were conducted under clear water scour condition using three different discharges.
- The scour hole was observed using two cameras to record the development of scour hole dimensions. The experimental data were applied to compute the formula of scour hole depth with time and horizontal dimension of scour hole with varying Froude number.
- The scour depth is larger in model (L/b=3) than model (L/b=2) for Froude number more than 0.115.
- The scour hole depth reached to 87% from the equilibrium depth at the first two hours. Also, the horizontal dimension of scour hole reached to 80% from the equilibrium at the first two hours.
- At minimum discharge (Q= 7.84 lit./sec.) the dimension of scour hole directly proportional with Froude number after Fr more than 0.16.
- At the average and maximum discharges, the scour hole width and length are larger in model (L/b=2) than in model (L/b=3).
- statistical analysis were performed using SPSS program to get the equation which represent the scour hole depth in rectangular pier model under the study conditions.

RECOMMENDATION:

- Making the experiments on local scour around more shapes of pier models but under discharge more than in this study.
- Studying the effect of local scour around bridge pier on varies shape with constant area.

REFERENCES

[1] Asis, M. and Khwairakpam, P. (2009)."Local Scour around Hydraulic Structures", International Journal of Recent Trends in Engineering, India, Vol. 1, No. 6, pp. 59-61.

[2] Debnath, K. and Chaudhuri, S. (2010) "Bridge Pier Scour in Clay-Sand Mixed Sediments at Near Threshold Velocity for Sand", Journal of Hydraulic Engineering, doi: 10.1061/ (ASCE) HY.1943-7900.0000221, pp. 1-46.

[3] Goswami, P. and Barua, M. (2015). "Slotted Pier as a Sour Control Measure", International Journal of Progress in Civil Engineering, Vol.2, pp. 38-42.

[4] Heidarpour, M, Afzalimehr, H. and Izadinia, E. (2010) "Reduction of local scour around bridge pier groups using collars", International

Journal of Sediment Research, United States, Vol.25, No.4, pp. 411-422.

[5] Henderson, F.M. (1970)."Open Channel Flow", the Macmillan Book Company, New York.

[6] Mohamed, A.Y.(2015). "Experimental investigation of local scour around multi-vents bridge piers", Alexandria Engineering Journal, Egypt, Vol. 54, pp.197-203.

[7] Movahedi, N, Dehghani, A. A, Aarabi, M, J. and Zahiri, A, R. (2013) "Temporal Evolution of Local Scour Depth around Side-by-side Piers", Journal of Civil Engineering and Urbanism, Iran, Vol. 3, pp.82-86.

[8] Nohani, E. and Ghannad, S.T. (2015). "Experimental investigation the impact of collar installation on the Cylindrical Bridge Piers in the Rivers Bend", journal of Scientific Research and Development, Nepal, Vol. 2, No .7, pp. 322-325pp

[9] Zidan, A. R, El Alfy, K.S., Abddalla, M.G. and Ibrahim, M.I. (2011). "Hydraulic Jump on Corrugated Beds and The Corresponding Downstream Scour", Msc thesis, Faculty of engineering, Mansoura University.