Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 5, Issue 1, Dec., 2013,P.P.85-104
Printed in Iraq

CONTROL OF LOCAL SCOUR DEPTH AROUND BTIDGE PIER USING DOWN STREM BED SILL

Prof. Dr. Saleh I. Khassaf — *Kufa University, Iraq* — *Email:alkhssafmustafa@yahoo.com*
Associated.Prof. Dr. Scott A. Yost — *Kentucky University, USA* — *Email:yostsa@engr.uky.edu*
Ali Adel Abulwahed — *Kufa University, Iraq* — *Email:aliadelalzuhairi@yahoo.co.uk*

Received: 27/ 9 / 2012; Accepted:17/5/2013

Abstract

This study is based on laboratory experiments for computing depth of local scour around bridge pier when a downstream bed sill using as a countermeasure.A circular section pier model has been used with clear water flow condition. However, sand was used as a bed sill.

Three different size of pier diameter are investigated with four different water depths and four different flow velocities. It is found that the diameter of the pier is an important parameter influencing the scouring process around pier.Bed sills at different distance from pier downstream and with different width and thickness, were used as a countermeasure to reduce the local scour depth. The level of sill crest was the same elevation of bed material. As a results of a study, the analysis of experimental data shows that the usage of sill as a countermeasure structure has a beneficial reduction of scour around pier around 25% for flow intensity 0.95.

Keywords: Pier, Bed sill, Local Scour, Bridge

السيطرة على عمق الانحراف حول دعامات الجسور باستخدام عتبة القاع في المؤخر

ا.د.صالح عيسى خصاف — **جامعة الكوفة / كلية الهندسة**
ا.د.يوسف سكوت — **جامعة كنتاكي الامريكية**
مهندس .علي عادل عبد الواحد — **جامعة الكوفة / كلية الهندسة**

الخلاصة

في هذا البحث تم اعتماد تجارب مختبريه لحساب عمق الأنجراف ألموقعي حول دعامات الجسور باستخدام مؤخرة عتبة القاع كوسيلة لتقليل الانجراف. لقد تم استخدام نماذج دعامات دائرية الشكل تحت ظروف الجريان الخالي من حمل الرسوبيات (clear-water condition) ، وباستخدام تربة الرمل كمادة للقاع.

تم دراسة ثلاثة أقطار مختلفة للدعامات واختبارها بأربع ارتفاعات للماء وأربع سرع أيضا.لقد بينت الدراسة ان قطر الدعامة هو عامل مهم ومؤثر على عملية الانجراف حول الدعامات. كما تناول البحث وضع عتبة القاع على مسافات مختلفة خلف الدعامة ولعرض وسمك متغير لدراسة تأثيرها على تقليل عمق الانجراف ألموقعي حيث ان منسوب العتبة ومادة القاع متساوي.

أظهرت نتائج الدراسة وبالاعتماد على المعلومات المختبرية ان الفائدة من استخدام ألعتبه كمنشأ مضاد هي في تقليل الأنجراف حول دعامات الجسور بنسبة 25% تقريبا عندما تكون شدة الجريان 0.95.

1. Introduction

A common reason of bridge failures is local scour around bridge foundations such as piers and abutments. Local scour erodes the soil around the piers and reduces the lateral capacity of the foundations (Rambabu et al., 2003).

Local scour is the engineering term for erosion of the soil surrounding an obstruction caused by flowing water. The key element in the scour process is the formation of vortices due to pressure differences that occur when the water velocity profile meets the obstruction.

There are many reports about failure of bridges around the world due to scouring (Johnson et al., 1998, Melville and Coleman, 1999). This shows the importance of research on scouring in bridge design.

Flow pattern and mechanism of scouring around a bridge pier is very complex and has been reported by various investigators (Chabert and Engeldinger, 1956, Hjorth, 1975, Melville, 1975 and Dargahi, 1990). Briefly, the approach flow velocity goes to zero at upstream face of a pier and this cause an increase in pressure. As the flow velocity decreases from surface to the bed the dynamic pressure on the pier face also decreases downwards. This pressure gradient drives the flow down the pier resembling a vertical jet (Figure1). When this down flow impinges the streambed, it digs a hole in front of the pier and rolls up and by interaction with the coming flow forms a complex vortex system. This vortex extends downstream and passes the sides of the pier. Owing to its similarity to a horseshoe this vortex is called horseshoe vortex. The horseshoe vortex deepens the scour hole in front of the pier until the shear stress on the bed material becomes less than its critical shear stress.

The accelerating flow at two sides of the pier creates two slots in the streambed, which facilitates the transport of removed sediment from the scour hole

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 5, Issue 1, Dec., 2013,P.P.85-104
Printed in Iraq

at the upstream perimeter of the pier. The separation of the flow at the sides of the pier creates so called wake vortices. These vortices are unstable and shed alternatively. These vortices act as little tornadoes lifting the sediment from the bed and form their own scour hole.

Development of scouring with time depends on flow condition. If shear stress on bed is less than the threshold of sediment motion (clear water), scour develops first very rapidly and then approaches equilibrium asymptotically, whereas in live bed scour develops rapidly and its depth fluctuates in response to the passage of bed features, (Chabert and Engeldinger, 1956) (Figure 2). Maximum scour depth occurs at the threshold of sediment motion (Breusers and Raudkivi, 1991).

Grimaldi et al. (2009a) views the reduction of local scour as the main purpose of scour countermeasures. Lagasse et al.(2007) defines countermeasures as ‘measures incorporated into a highway-stream crossing system to monitor, control, inhibit, change, delay, or minimize stream instability and bridge scour problems.

The goal of the present work is to show the effectiveness of using a bed sill at specified location in the downstream as a counter measure against local scour which formed around pier.

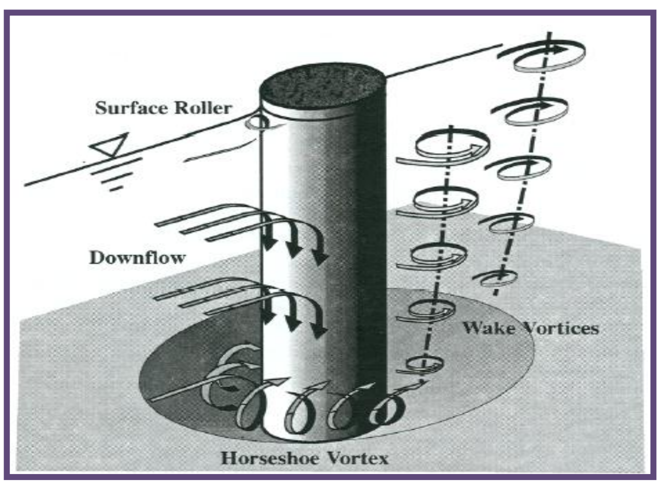

Fig.1 Flow Pattern around Pier.

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 5, Issue 1, Dec., 2013,P.P.85-104
Printed in Iraq

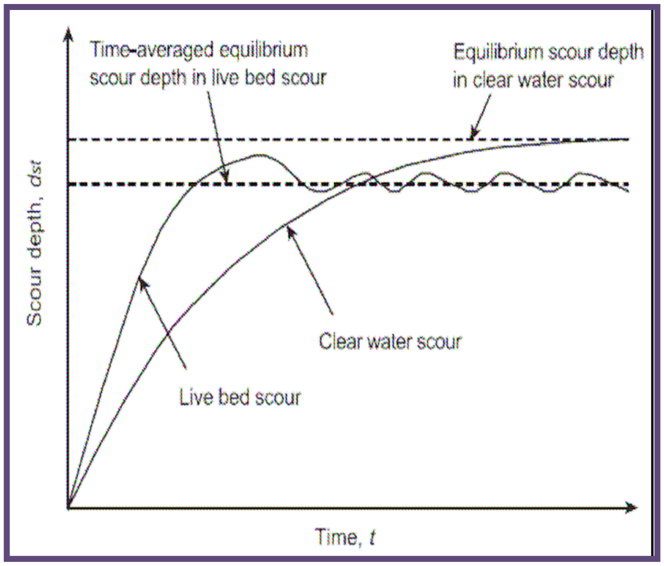

Fig.2 Scouring in Clear Water and Live Bed.

1. *Experimental Program*

The laboratory flume used in this study is shown in Figure 3.The main flume structure is a glass fiber moulded in steel stiffeners which has a 6.6 m length, 0.4 m wide and 0.4 m depth.

The flume consists of an inlet tank 1m length in upstream, a working section 5.6 m is divided into three parts, in the middle layer of sand with depth and the length 0.1m and 2m respectively, it is filled with erodible uniform sediment. The upstream and downstream portion each have 1.25m length and the bed is raised 0.1m with compressed, coated and non swelling wood to obtain more stable water surface. The tank consists of three screens to avoid entering of any unwanted particles and debris into the working section of the flume.

The flume has closed system water. Water is supplied from the reservoir under the ground by a centrifugal pump that is situated on a fabricated steel base plate. The centrifugal pump lies beside the flume at upstream.

The depth of flow is controlled by an adjustable tail gate at the downstream of trap basin. For flow discharge measurement a sharp crested rectangular weir is

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 5, Issue 1, Dec., 2013,P.P.85-104
Printed in Iraq

fabricated which have width of 0.4m and the height of 0.25 and it is mounted at the upstream section of flume.

All depth measurements are carried out using a point gauge with accuracy ±1mm mounted on a carriage which can move to any position above the working area transversely and longitudinally. The scour hole is obtained by performing 4-hours continuous run under clear water condition.

At the end of each experiments, the flume is carefully drained and sand bed level is straightened for next experiments with a scraper.

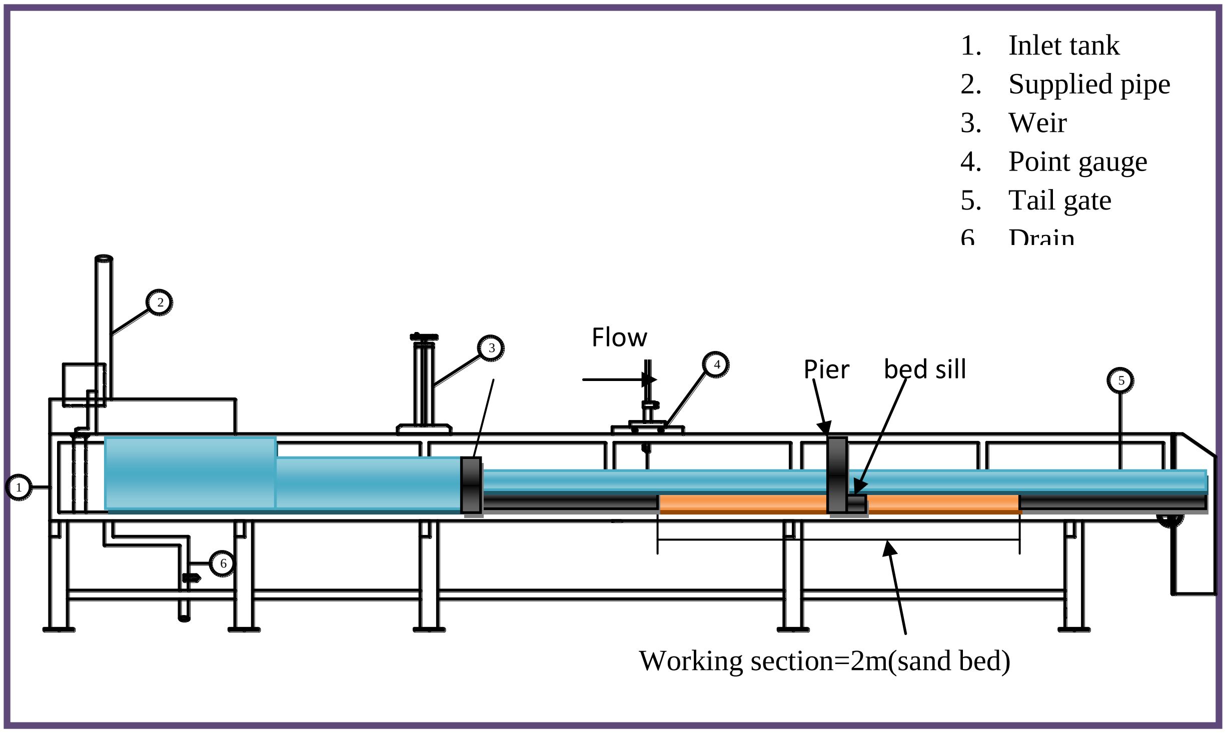

Fig.3 Laboratory Flume.

3. Pier Models

The pier model is fabricated from Polyvinyl Chloride (PVC) pipe. The bed sill used in the experiments was made of wood with a different thickness.

Three different sizes of circular piers of diameter 25 mm, 32 mm and 40 mm are used in the experimental program to simulate different practical situations

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 5, Issue 1, Dec., 2013,P.P.85-104
Printed in Iraq

(Figure 3). Different dimensions of bed sill are introduced and the spacing between the bed sill (Figure 4) and pier are changed to cover the aims of this work; see Table 1.

Fig.4 The Pier Group.

Fig.5 Different Width of Bed Sill.

Table 1 Dimension of Sill.

Thickness of sill	6 mm	12 mm	18 mm	24 mm
Width of sill	100 mm	200 mm	300 mm	400 mm

4. Sediment

The result of test showed that the bed material consists of cohesionless sand with a median particle size (d_{50}) equal to 0.714mm. The geometric standard deviation of the sand size (σ_g) equal to 1.318.

According to classification of Alabi,2006 ($\sigma_9 = \sqrt{d_{84}/d_{16}}$), this size distribution is uniform .The sediments used in this study were well uniform, so that the results do not include the effect of sediment no uniformity in order to eliminate the reduction of local scour that would be expected to occur in non-uniform sand due to armoring effect.

As recommended by Melville 1997, the effect of sediment size can be ignored if the pier size to mean sediment size exceeds 25. This recommended have been conducted in present work.

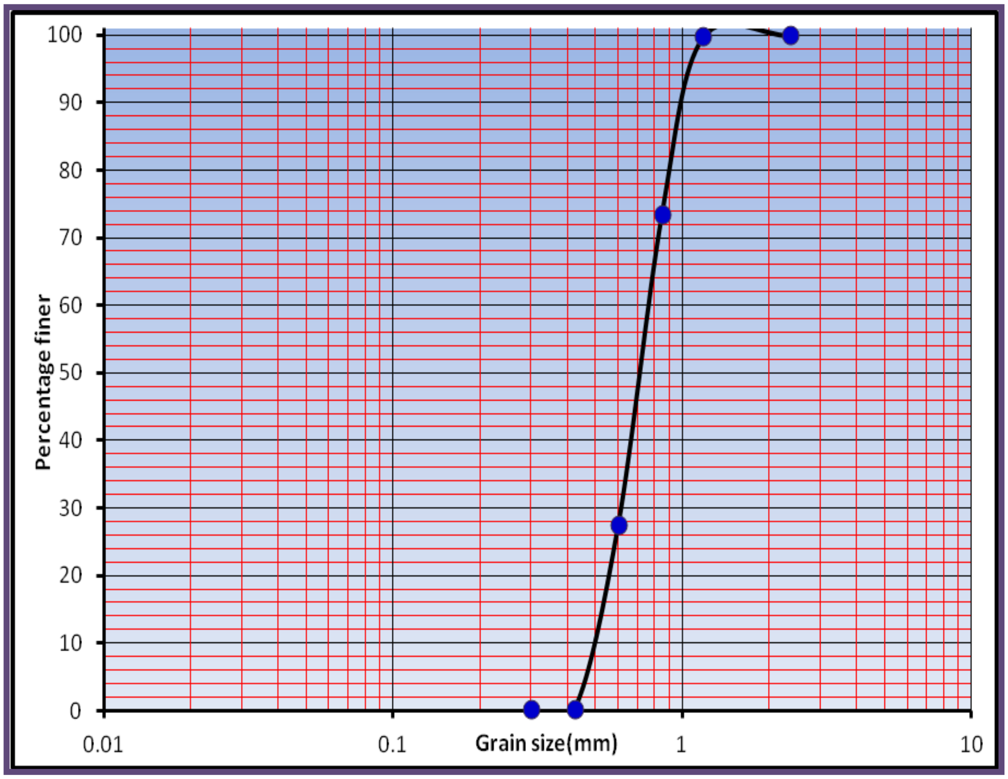

Fig.6 Grain Size Distribution Curve for Bed Material.

5. The Experimental Work and its Purpose

The first four runs are made to determine the scour time at which the scour hole reaches to the equilibrium state with and without bed sill.

The runs from 5 to 25 test the flow velocity and depth of water with different pier diameter when the bed sill remains at same distance from the pier and the same dimensions. The runs from 26 to 34 test the spacing between the pier and bed sill

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 5, Issue 1, Dec., 2013,P.P.85-104
Printed in Iraq

for different diameter of piers when the flow velocity, water depth and bed sill dimension remain constant.

The runs from 35 to 43 test the thickness of bed sill for different diameter of piers when the flow velocity, water depth, width of bed sill and spacing between pier and bed sill remain constant.

The runs from 44 to 52 test the width of bed sill for different diameter of piers when the flow velocity, water depth, thickness of bed sill and spacing between pier and bed sill remain constant.

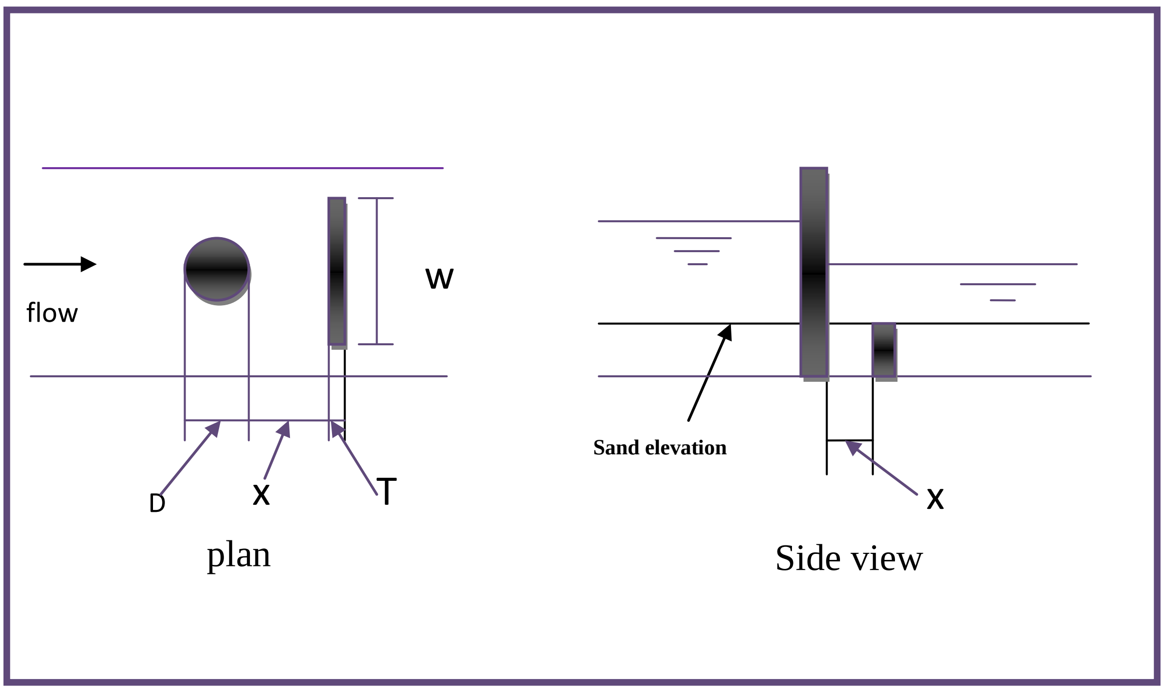

Fig.7 Sketch Show the Parameter.

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 5, Issue 1, Dec., 2013,P.P.85-104
Printed in Iraq

Table 2 Experimental Data.

Run	Y (mm)	V (m/sec)	D (mm)	Vc (m/sec)	X (mm)	T (mm)	W (mm)	v/vc	Ds (mm)
1	20	0.23	25	0.2429	*	*	*	0.95	36
2	20	0.182	25	0.2429	*	*	*	0.75	18
3	20	0.23	25	0.2429	0	12	400	0.95	27
4	20	0.182	25	0.2429	0	12	400	0.75	11
5	25	0.241	25	0.2537	0	12	400	0.95	28
6	25	0.228	25	0.2537	0	12	400	0.9	22
7	25	0.215	25	0.2537	0	12	400	0.85	19
8	25	0.19	25	0.2537	0	12	400	0.748	10
9	35	0.19	25	0.27	0	12	400	0.703	11
10	45	0.19	25	0.282	0	12	400	0.6734	11.5
11	55	0.19	25	0.2917	0	12	400	0.6511	12
12	25	0.241	32	0.2537	0	12	400	0.95	33
13	25	0.228	32	0.2537	0	12	400	0.9	29
14	25	0.215	32	0.2537	0	12	400	0.85	25
15	25	0.19	32	0.2537	0	12	400	0.748	12.5
16	35	0.19	32	0.27	0	12	400	0.703	13
17	45	0.19	32	0.282	0	12	400	0.6734	13.5
18	55	0.19	32	0.2917	0	12	400	0.6511	14
19	25	0.241	40	0.2537	0	12	400	0.95	37
20	25	0.228	40	0.2537	0	12	400	0.9	33.5
21	25	0.215	40	0.2537	0	12	400	0.85	28
22	25	0.19	40	0.2537	0	12	400	0.748	15
23	35	0.19	40	0.27	0	12	400	0.703	15.5
24	45	0.19	40	0.282	0	12	400	0.6734	16
25	55	0.19	40	0.2917	0	12	400	0.6511	16.5

* Without bed sill

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 5, Issue 1, Dec., 2013,P.P.85-104
Printed in Iraq

Table 2 Cont.

26	25	0.241	25	0.2537	10	12	400	0.95	31
27	25	0.241	25	0.2537	20	12	400	0.95	32
28	25	0.241	25	0.2537	30	12	400	0.95	34
29	25	0.241	32	0.2537	10	12	400	0.95	37
30	25	0.241	32	0.2537	20	12	400	0.95	38
31	25	0.241	32	0.2537	30	12	400	0.95	39
32	25	0.241	40	0.2537	10	12	400	0.95	41
33	25	0.241	40	0.2537	20	12	400	0.95	42
34	25	0.241	40	0.2537	30	12	400	0.95	43
35	25	0.241	25	0.2537	0	6	400	0.95	30
36	25	0.241	25	0.2537	0	18	400	0.95	27
37	25	0.241	25	0.2537	0	24	400	0.95	26
38	25	0.241	32	0.2537	0	6	400	0.95	34
39	25	0.241	32	0.2537	0	18	400	0.95	32.5
40	25	0.241	32	0.2537	0	24	400	0.95	32
41	25	0.241	40	0.2537	0	6	400	0.95	38
42	25	0.241	40	0.2537	0	18	400	0.95	36.5
43	25	0.241	40	0.2537	0	24	400	0.95	36
44	25	0.241	25	0.2537	0	12	100	0.95	28.5
45	25	0.241	25	0.2537	0	12	200	0.95	28
46	25	0.241	25	0.2537	0	12	300	0.95	28
47	25	0.241	32	0.2537	0	12	100	0.95	34.5
48	25	0.241	32	0.2537	0	12	200	0.95	33
49	25	0.241	32	0.2537	0	12	300	0.95	33
50	25	0.241	40	0.2537	0	12	100	0.95	40
51	25	0.241	40	0.2537	0	12	200	0.95	37
52	25	0.241	40	0.2537	0	12	300	0.95	37

6. Equilibrium Time

In order to find a more realistic equilibrium scour time, four preliminary tests is made on single circular pier D = 25, for both cases without and with bed sill. Scour is recorded at different time intervals using a point gauge to measure the maximum scour at the nose of upstream pier.

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 5, Issue 1, Dec., 2013,P.P.85-104
Printed in Iraq

As shown in the Figure 8, the scour depth has sharply increased during first 100 min of test duration and the development of scour become approximately constant. It is noticed that 95 % of the local scour can be achieved in 3.5 hours in both models that is refer that the sill located as a countermeasure does not have any appreciable influence on the equilibrium time of scour hole. For more accuracy a four hours were selected to be as equilibrium time.

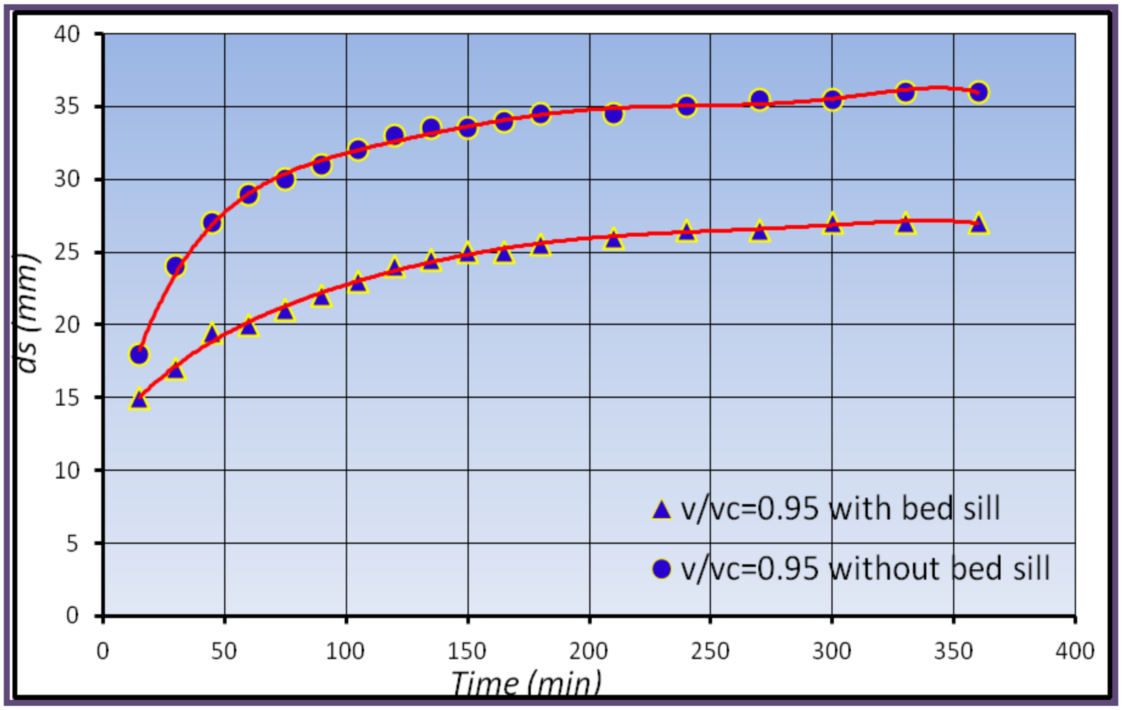

Fig.8 Development of Scour Depth with the Time for Pier with and without Bed Sill.

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 5, Issue 1, Dec., 2013,P.P.85-104
Printed in Iraq

Plate 3 Before Run 19.

Plate 4 During Run 19.

Plate 5 After Run 19.

7. Analysis and Discussion of Results

Estimating of maximum possible scour depth around bridge piers is an important step in the design of bridge pier foundation. To examine such a phenomenon, sets of experiments are performed using cylindrical models to represent the main shape used for bridge pier. Different pier size, flow depth and

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 5, Issue 1, Dec., 2013,P.P.85-104
Printed in Iraq

flow intensity $(^{v}/_{v_c})$ have been conducted in the experimental program to show the geometric and flow parameters on scouring process. Table 2 illustrate these parameters.

The effectiveness of bed sill is about 25% reductions in the maximum scour depth in the front of the pier when the flow intensity equal to 0.95. It should be noted that the critical bed shear velocity for initiation of motion (vc) were calculated by adopting the following equation as recommended by Melville and Coleman (2000), viz.

$$V*c = 0.0115 + 0.0125(d_{50})^{1.4}. \qquad 0.1mm \langle\ d_{50}\ .\langle\ 1\,mm ....eq.(1)$$

$$V*c = 0.0305(d_{50})^{0.5} + 0.0065(d_{50})^{-1} \qquad 1mm \langle d_{50} \langle\ 100\,mm ....eq.(2)$$

The corresponding critical velocity, v_c, which is dependent on the flow depth, can be determined from the logarithmic and from the velocity profile, that is

$$\frac{V_C}{V_C}. = 5.75\log\left(5.53\frac{y}{d_{50}}\right) ....eq.(3)$$

Spacing Between Pier and Bed Sill

A set of experiments (12 runs) is conducted for evaluating the relationship between spacing between pier and bed sill and the scour depth. The resulting of the scour depth shown in Figure 9.

For X=0 the bed sill totally excludes the wake vortex system from the scour volume around the pier and alters the flow field, which is probably influencing on the horse shoe vortex. For X>0, the bed sill seems to act less on the horse shoe vortex, more on the lower part of the wake vortex system.

The scour depth increased 4.6% when the spacing between pier and bed sill increased from 0 to 30 mm. However the pier were further exposed at downstream sided as the sill distinct from its downstream. Figure 10 illustrate this visualization.

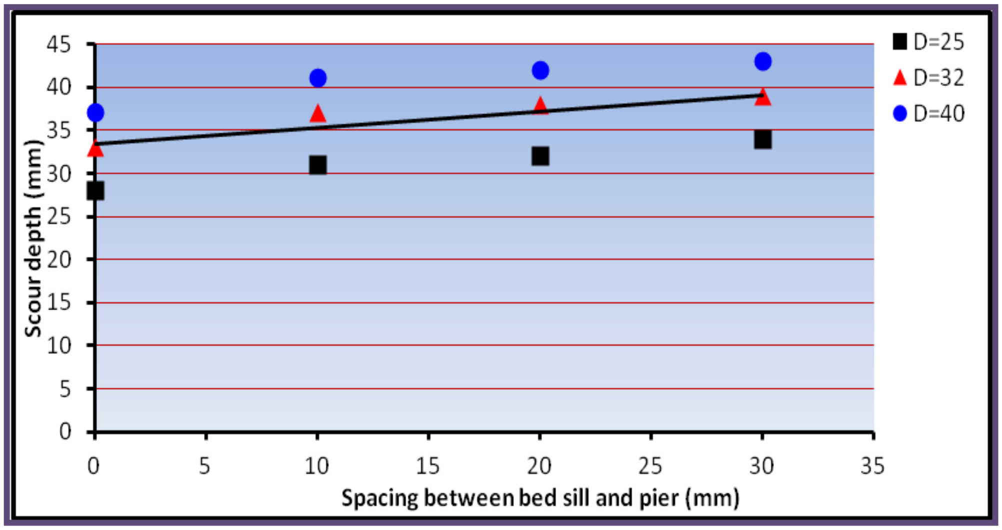

Fig. 9 Development of Scour Depth with Spacing between Pier and Bed Sill.

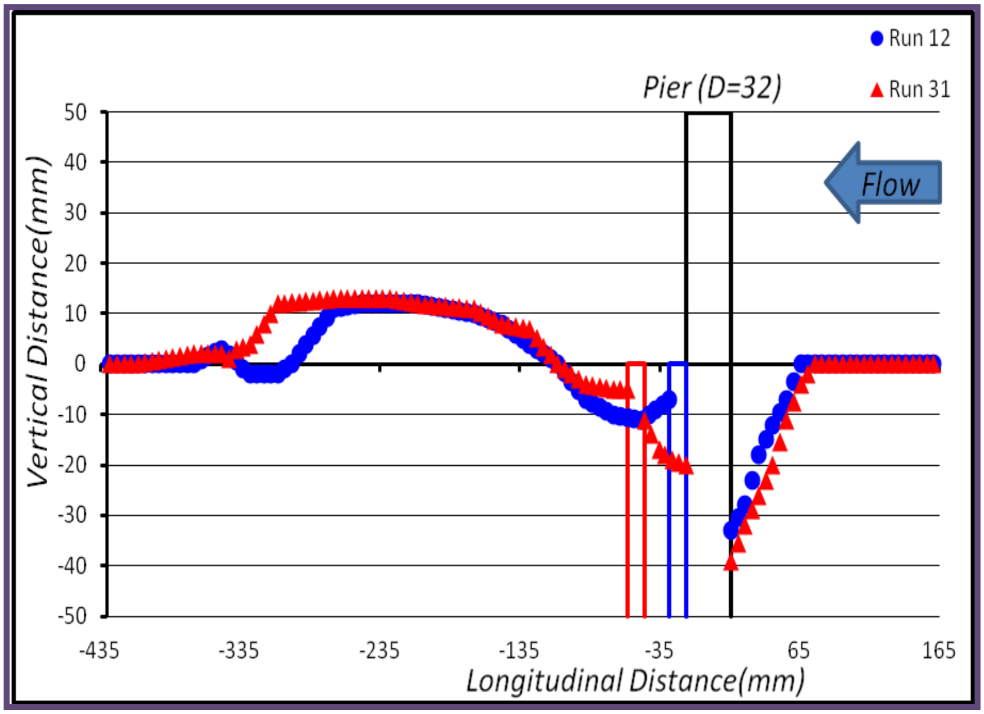

Fig.10 Longitudinal Profile of the Bed for Pier Showing the Effect of Spacing between Pier and Bed Sill on the Scour Depth.

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 5, Issue 1, Dec., 2013,P.P.85-104
Printed in Iraq

Thickness of Bed Sill

A set of experiments are conducting for evaluating the relationship between scour depth and thickness of bed sill. These experiments are shown in the Figure11.

The scour decreases with increase the thickness of bed sill; this is probably because the surface area of impact with the wake vortex is increasing. This surface area is influence on the wake vortex and weakens. This weaken wake vortex will be influence on the horse shoe vortex due to interact between them which is decrease the sour depth.

The scour depth decreased by 5.2% when bed sill has thickness 24mm instead of 6mm.

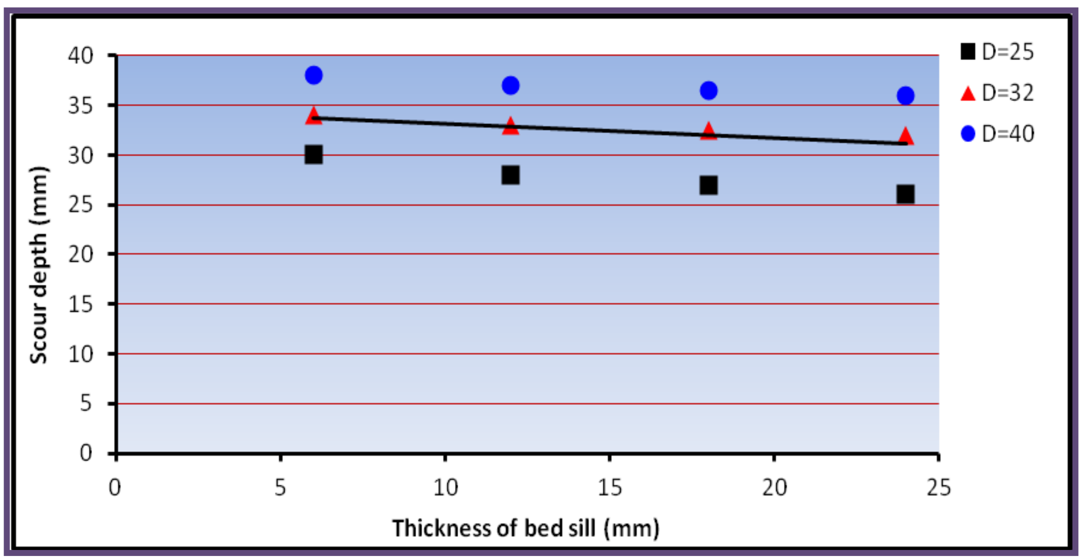

Fig. 11 Development of Scour Depth with Thickness of Bed Sill.

Width of Bed sill

The width of bed sill does not influence on the scour depth all the times. The width of bed sill will be influence when the transverse distance of the scour hole greater than the width of the bed sill. As in previous parameter three pier sizes are used with different thickness of bed sill in order to feel its effect on the scour depth. The spacing between pier and bed sill, thickness of bed sill, depth flow and flow velocity are remains constant for all runs.

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 5, Issue 1, Dec., 2013,P.P.85-104
Printed in Iraq

A set of experiments are conducting for evaluating the relationship between scour depth and width of bed sill. These experiments are shown in the Figure 12.

The value of the scour depth is probably increased by 7.5% when the transverse distance of the scour hole is greater than the width of bed sill because the transverse distance that conflict with wake vortex is decreased.

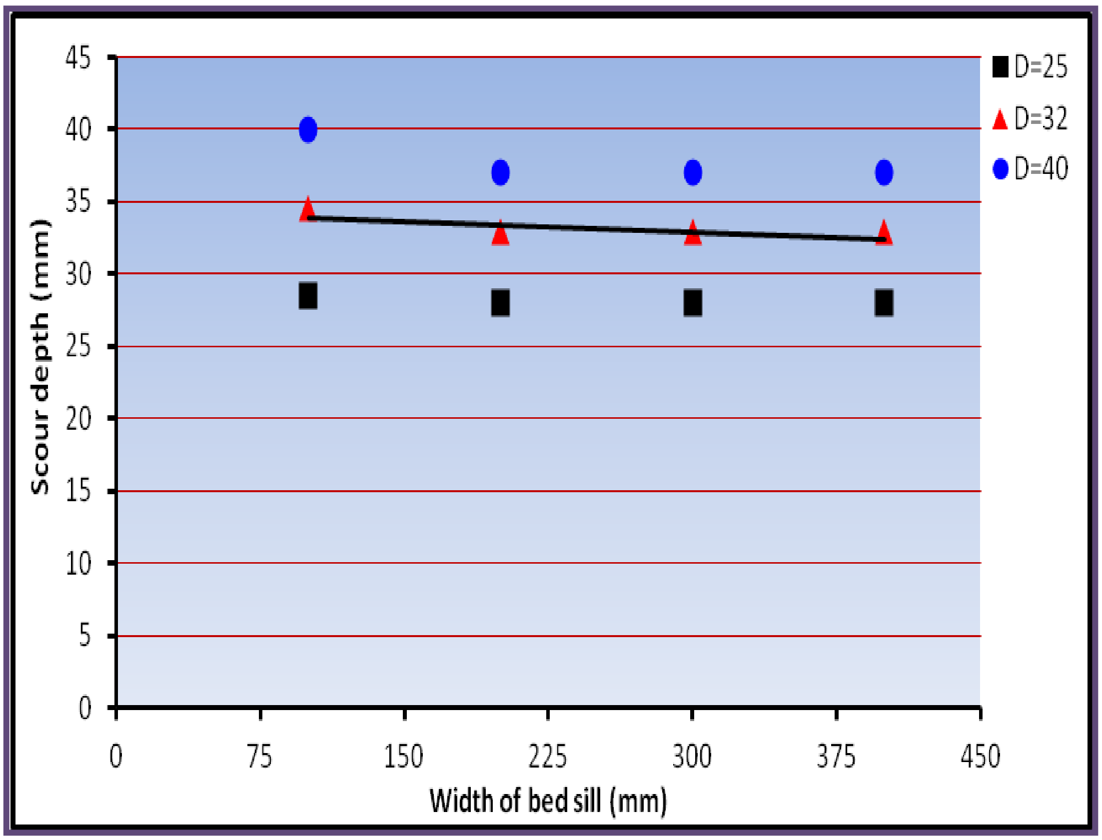

Fig.12 Development of Scour Depth with Width of Bed Sill.

8. Conclusions

The problem of local scour around the circular pier and it protection with downstream bed sill has been studied experimentally.Under the limitations imposed on this investigation the following conclusions can be drawn.

a) The effectiveness of bed sill is about 25% reductions in the maximum scour depth in the front of the pier when the flow intensity equal to 0.95.

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 5, Issue 1, Dec., 2013,P.P.85-104
Printed in Iraq

b) The increasing diameter of pier with bed sill is given increasing scour depth.

c) The scour depth increased for pier with bed sill by increasing the spacing between bed sill and pier, the scour depth increase by 4.6% when increased the spacing between pier and bed sill from 0 to 30 mm. Accordingly the experimental work and within the boundary conditions and limitation of a present study the well influences location of sill as a countermeasure were at x=0.

d) The scour depth decreased around 5.2% for pier with bed sill by increasing thickness of bed sill from 6mm to 24mm.

e) The beneficial reduction of scour depth to about 7.5% have been recorded with bed sill having the width more than the transverse distance of the scour hole that resulted without using a sill as a countermeasure.

f) As a conclusion, the sill located at x= 0 ,with a thickness T= 24mm and a transverse width =400 mm, having a more contribution towards a reduction of scour depth up to 25%. This conclusion however was a result of a boundary condition and limitation of a present work.

List of Symbols

ds Depth of scour around the pier
D Diameter of pier
d_{50} Median size of the sediment particle
Fr_p Pier Froude number ($Fr = V/\sqrt{gD}$)
g Acceleration due to gravity
ρ Water density
Re Reynolds number
V Mean approach flow velocity
V_c Critical velocity
y Flow depth
μ Dynamic viscosity

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 5, Issue 1, Dec., 2013,P.P.85-104
Printed in Iraq

X Spacing between pier and bed sill (face to face)
W Width of bed sill
T Thickness of bed sill

References

Ansari, S.A., Kothyari, U.C. and Rangaraju, K. G. (2002), "Influence of cohesion on scour around bridge piers", Journal of Hydraulic Research, Vol. 40, 2002, No. 6, pp.717-729, Dept. Of Civil Engineering, Aligarh Muslim University, Aligarh, India.

Breusers, H.N.C., Nicollet, G. and Shen, H.W. (1977), "Local scour around cylindrical piers", Journal of Hydraulic Research, Vol. 15, No. 3, pp.211-252.

Chabert, J and P. Engeldinger, (1956), "Etude Des Afouillements Autour Des Piles Des Ponts" Laboratoire National d'Hydraulique, Chatou, France.

Clopper, P.E., Lagasse, P.F. and Zevenbergen, L.w. (2007), "Bridge Pier Scour Countermeasures", paper presented to World Environmental and Water Resources Congress 2007: Restoring our Natural Habitat.

Dargahi, B., (1990), "Controlling Mechanism of Local Scouring", Journal of Hydraulic. Engineering, ASCE, Vol.116, No. 10, pp. 1197-1214.

Dey, S. and Raikar, R. V. (2007), "Characteristics of horseshoe vortex in developing scour holes at piers", Journal of Hydraulic. Engineering, 133 4, 399–413.

Ernest F. Brater, Horace Williams King, James E. Lindell, C.Y.Wei (1996), "Hand book of Hydraulics. Seventh edition", McGraw-Hill Book Company N.Y, ISBN 0-07007247-7.

Ettema, R. Melville, B.W. and Barkdoll, B. (1998), "Scale effect in pier scour experiments", Journal of Hydraulic Engineering, Vol. 124, No. 6, PP.42-639.

Grimaldi, C., Gaudio, R., Calomino, F. and Cardoso, A.H. (2009a), "Control of Scour at Bridge Piers by a Downstream Bed Sill", Journal of Hydraulic Engineering, Vol. 135, No. 1, PP.13-21.

Hjorth, P., (1975), “Studies on the Nature of Local Scour”, Dept. Water Res. Eng., Lund Inst. of Technology, Bulletin Series A, No. 46.

Johnson, P. A. (1991), “Advancing Bridge-Pier Scour Engineering”, Journal of Professional Issues in Engineering Education and Practice, Vol. 117, No. 1, PP.48-55.

Johnson, P. A., and Dock, D. A., (1998), “Probabilistic Bridge Scour Estimates”, Journal of Hydraulic Engineering, ASCE, Vol. 124, No. 7, pp. 750-754.

Lagasse, P.F., Clopper, P.E., Zevenbergen, L.W. and Girard, L.G. (2007),“ Countermeasures to Protect Bridge Piers from Scour”, National Cooperative Highway Research Program, Transportation Research Board, Ishington, D. C., USA.

Melville, B. W., (1975), “Local Scour at Bridge Sittes”, University of Auckland, NEW ZEALAND, phd. Thesis, Dept. of Civil eng. Rep. No. 117.

Melville, B.W. (1997), “Pier and Abutment Scour: Integrated Approach”, Journal of Hydraulic Engineering, ASCE, Vol.123, No.2, February, 1997, pp.125-136.

Melville, B. W. and Chiew, Y. M., (1999), “Time Scale for Local Scour at Bridge Piers”, Journal of Hydraulic Engineering, ASCE, Vol. 125, No. 1, pp. 59-65.

Melville, B. W. and Coleman, S. E., (1999), “Bridge Scour”, Water Resources Publications.

Melville, B.W. and Coleman, S.E. (2000), “Bridge scour. Water Resources Publications”, LLC, Colorado, U.S.A., 550 p.

Melville, B. W. and Hadfield, (1999), “Use of Sacrificial Piles as Pier Scour Countermeasures”, Journal of Hydraulic Engineering, ASCE, Vol. 125, No. 11, pp. 1221-1224.

Rambabu, M., Rao, S.N. and Sundar, V. (2003), Current-induced scour around a vertical pile in cohesive soil, In: Ocean Engineering, Volume 30, Issue 7, Elsevier

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 5, Issue 1, Dec., 2013,P.P.85-104
Printed in Iraq

Science B.V., Amsterdam, The Netherlands, pp 893-920.