Effect of Floating Debris on Local Scour at Bridge Piers

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ABSTRACT

This research studied the effects of dimensions and shapes of debris accumulations on river's bed scour at bridge piers by preparing and operating physical model and compared the results with that of applying a one-dimensional steady flow mathematical model using HEC-RAS software to the same geometry and boundary conditions of the physical model. The Results of studying three shapes of accumulation floating debris (wedge, rectangular and trapezoidal) on bridge pier using physical model show that the dimensions and shapes of accumulation debris have a clear effect on the patterns of bed scour and the maximum scour depth at the pier. There is a big difference between the measured and computed scour depths using the physical and the HEC-RAS models where the software exaggerates in the calculation of the scour depths and the widths of scour hole without taking into consideration the effect of debris shape on the shape of scour hole.

Keywords: Debris, scour, piers, one-dimensional, accumulation shape.

تأثير المواد الطافية على النحر الموقعي عند دعامات الجسر

الخلاصة

في هذا البحث تم دراسة تأثير أشكال وأبعاد الأنقاض المتجمعة عند دعامات الجسر على أعماق وأنماط نحر قاع النهر عند دعامات الجسر من خلال إعداد وتشغيل نموذج فيزيائي ومقارنة النتائج مع نتائج نموذج رياضي للجريان ذات البعد الواحد باستخدام برنامج HEC-RAS لنفس الأبعاد وشروط الجريان للموديل الفيزيائي. بينت نتائج دراسة ثلاث أشكال ذات أبعاد مختلفة من الأنقاض المتجمعة (وتد و مستطيل و شبه منحرف)عند دعامة الجسر باستخدام النموذج الفيزيائي أن هناك تأثيرات واضحة لأشكال وأبعاد الأنقاض المتجمعة على أعلى عمق للنحر وأنماط النحر عند دعامة الجسر.هناك فرق كبير بين أعماق النحر المقاسة باستخدام النموذج الفيزيائي و أعماق النحر المحسوبة باستخدام نموذجHEC-RAS حيث يبالغ البرنامج في حساب أعماق النحر و أبعاد حفرة النحر حتى من دون وجود الأنقاض . هذا النموذج يزيد من عمق النحر دون الأخذ بنظر الاعتبار تأثير شكل الأنقاض على شكل حفرة النحر.

INTRODUCTION

The water flows in rivers sometimes contains floating debris such as the twigs of trees falling rivers, reed, bulrush or any kind of materials that can float on the water surface. During floods, debris build-up at hydraulic structures spanning streams can be a serious problem. While the problems of floating debris in reservoirs have been more or less solved,

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debris which piles against run-of-the-river structures with no intervening pool to catch and slow down the load causes serious operational problems and is occasionally a threat to structural integrity.

Debris accumulations can obstruct, constrict, or redirect flow through bridge openings resulting in flooding, damaging loads, or excessive scour at bridge foundations. Debris accumulation at bridge structures openings is a widespread problem.

The problem of accumulating debris appears at hydraulic structures in Iraq clearly as consequent to repeated flooding and rainfall storms at the latest years as shown in **Figure (1)**. One of the most important and dangers effects of accumulating debris at bridge piers is the pier local scour. This phenomenon is need to analysis and studied by using physical and mathematical models.

In general the flow in river is studied using one dimensional hydraulic models because they required few data and provides flexibility to deal with the study of flow in rivers and gives good simulating to flow characteristics, despite of, in case of the analysis of scour and sediment the one dimensional hydraulic model depends on assumptions and empirical equations which reducing the results accuracy, one example HEC-RAS simulating the scour in one dimensional not in three dimensional, it adopted only the rectangular shapes of accumulating debris. As a consequent, to study and analyze the effects of the shapes and dimensions of accumulation debris on scour patterns, the flow must be simulated using a physical model and this physical model simulated in the HEC-RAS software to compare the results of two models. This research aims to study the effects of dimensions and shapes of debris accumulations on river's bed scour at bridge piers.

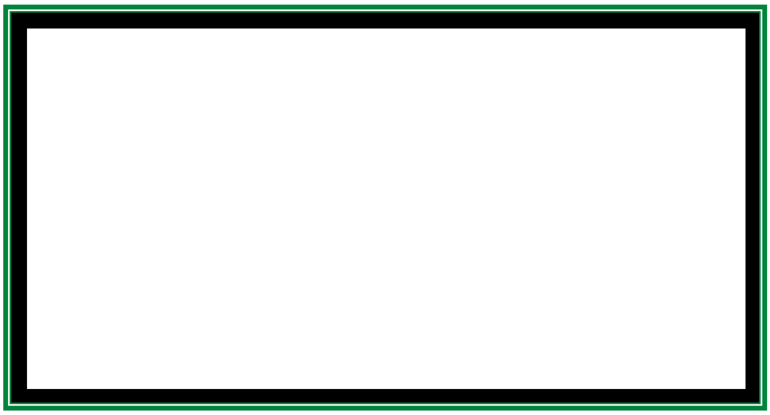

Figure (1): Suspended Bridge, Baghdad- Iraq.

Theoritical Background

Critical velocity equations with the reference particle size (D) equal to d_{50} are used to determine the velocity associated with the initiation of motion. They are used as an indicator for clear-water or live-bed scour conditions. The mean velocity (V_m) in the upstream reach is equal to or less than the critical velocity (V_c) of the median diameter (d_{50}) of the bed material, then contraction and local scour will be clear-water scour **(Gray 2008)**.

- Critical velocity equation for beginning motion by **Laursen 1963**

$$= \frac{{}^{2}(S \quad 1)^{1}}{} \quad \ldots \quad (1)$$

- Using =0.039,S_s = 2.65, and n = 0.041 $D^{1/6}$
-

$$= 6.19 \quad \ldots \quad (2)$$

Where:

=Critical velocity above which bed material of size D and smaller will be transported, m/s.

= Shields parameter.

S =Specific gravity of the bed material.

D=Size of bed material, m.

y=Depth of flow, m.

n=Manning roughness coefficient.

To determine pier scour, an equation based Colorado State University (CSU) equation **(Richardson, 1990)** are the HEC-18 is recommended for both live-bed and clear-water pier scour.

The equation predicts maximum pier scour depths is:

$$- \qquad \left(-\right) \quad \ldots\ldots \quad (3)$$

Where:

= Scour depth (m).

= Flow depth directly upstream of the pier (m).

= Correction factor for pier nose shape.

= Correction factor for angle of attack of flow.

K = Correction factor for bed condition.

a= Pier width (m).

=Froude Number directly upstream of the pier.

Experimental Work

Physical Hydraulic Model

The flume which is designed by the Laboratory of Hydraulic Models in the Engineering Study and Design Center (Ministry of Water Resources) to study the problem of sediment accumulation in part of Euphrates River in Al-anbaer City at water pumping station of Ana at July 2013, with a scale of H 1:150 and V 1:30 and range of discharges from 300 to 1500 m^3/sec was used, after completing this study, to study the effect of floating debris on local scour at bridge piers, **Figure (2)**. This flume was modified to be suitable to simulate the flow and scour around bridge pier. It is a rectangular wide flume with a cross section of 3.86 m width, 0.76 m depth and straight length of 8 m. with a stilling basin at the beginning of the flume.

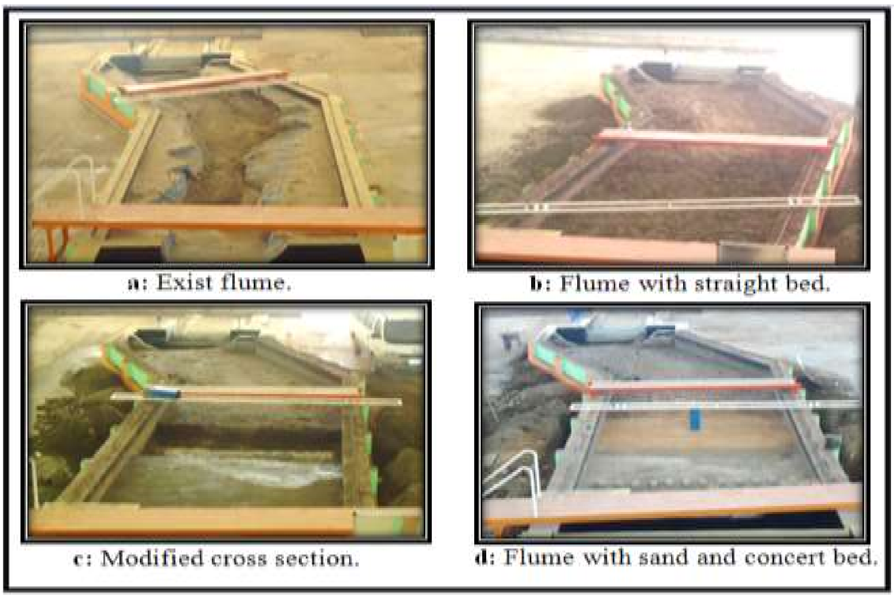

Figure (2): Stages of modifying the laboratory flume.

Similitude and Flow Conditions

In the present work, strict similitude between laboratory and the field was not sought for specific field conditions, and so the experiments covered a range of Froude numbers corresponding approximately to those that might conceivably be encountered in the field. In addition to the dynamic similitude involving parameters such as Froude numbers and strict similitude also requires geometric similitude, length-scale ratios in model and prototype should be the same. Again, because of conflicting requirements and the size of the available facilities, this will not necessarily be adhered to strictly.

To study the local scour at bridge piers in physical model the flume bed should be cohesionless (uniform sand bed has a known d_{50}) because the scour in cohesive soil is very slowly also when especially clear water conditions and subcritical flow should be applied, The range of V_m/V_c should be from (0.45 to 1), V_c depended on d_{50} of sand bed, V depended on the maximum operation discharge of the laboratory flume, the width of flume and the water depth as a consequent the water depth should be at a specific value to achieve the suitable velocity.
The scale and flow condition were selected to maximize the number of debris conditions that can be modeled because scour should develop rapidly at this scale and clear-water runs are also less time consuming.

The physical model was conducted in the flume at Laboratory under subcritical flow at clear-water condition and low flow under the bridge with plan bed. Water was supplied by one -diesel pump, up to a maximum flow capacity of 0.25 m^3/s. The flow conditions for all experimental work are listed in **Table (1).** According to **Laursen 1963**, equation **(2)**, the suitable V_c is 0.375 m/sec.

Table (1): Flow conditions for the case study.

Discharge No.	Q (m3/sec)	Y (m)	V_m (m/sec)	V_m/V_c	Fr
1	0.188	0.2	0.243	0.648	0.173
2	0.249	0.2	0.322	0.858	0.229

Implementation of Physical Model

Modifying the laboratory flume

The bed of the flume is not straight and has a cross sections suitable to previous study and they did not suitable to carry out the experiment work of local scour at piers. Therefore, it should be straight and the bed must be of uniform sand. The steps of modifying the flume, **Figure (2)**, are:

a. Modifying the cross section of the flume.
b. Casting the flume bed using concrete for 3 cm thickness and 4m length starting from the upstream of the flume.
c. 2m of the flume length (from station 4+00 m to 6+00 m of the canal length) filled with uniform sand of d_{50} =0.5 mm for 28 cm thickness.

Design of piers and flume bed

Square steel pier with a cross-section of 20×20 cm and 80 cm length was fabricated for the testing program, This scale selected to be suitable to the available water depth and classified under the term of transitional pier (0.2 < y/a < 1.4) when (y) is the water depth and (a) is the pier width **(Melville, 2000)**, and also it was selected to maximize the number of debris conditions that can be modeled because scour should develop rapidly at this scale and clear-water runs are also less time consuming. The pier was secured to the flume floor according to the test program as shown in **Figure (3)**. Pier was designed to be constructed to a height of 0.52 m above the sand surface. The sand bed is of 0.28 m thick. The sand had a median grain size d_{50} of 0.5 mm.

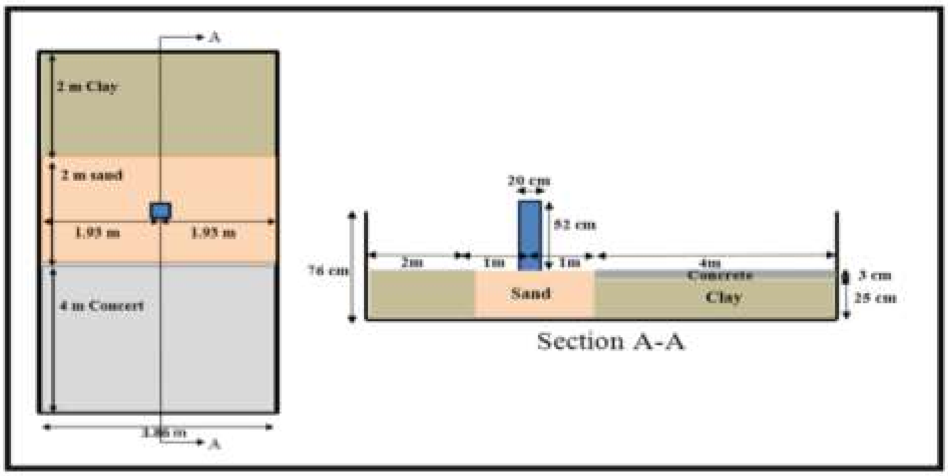

Figure (3): Layout of fabricated steel pier within the flume.

Accumulation of debris

The accumulation of floating debris is uncontrolled, it is accumulated with no uniform shapes may be covers all width of pier or extends to width larger than pier width by twice and even three time pier width. To study the effects of the shape of accumulation floating debris on local pier scour at physical model, the tests should include a range of debris characteristics including debris accumulation shape, thickness, width, and length, three different shapes of accumulation debris were designed from wood frame with different dimensions, wedge(rectangular in plan, triangular in section), rectangular and trapezoidal, wire mesh was then placed around the wood frame and then filled with small bases of wood with non-uniform shapes and dimensions. All debris hanging by yarns from four corners on railway at upstream face of the pier at height 10cm from the surface of sandy bed.

Flow and Geometry Conditions for Tests

Five tests were done with single pier installed at the center of the sandy bed as shown in **Figure (4)**,the duration for each run was 2 hr. Flow conditions for each test are as listed in **Table (2)** and shown in **Figures (5)** to **(8).**

Table (2): Flow conditions for the tests.

Run No.	Q ([illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] No.
1	0.249	0.2	Non	-	-	-	5
2	0.188	0.2	Non	-	-	-	5
3	0.188	0.2	Wedge	10	64	20	6
4	0.188	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7
5	0.188	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8

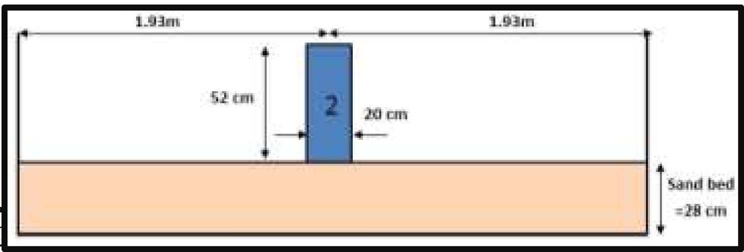

Figure (4): Cross section through the flume.

Figure (5): Run1and Run2, no debris.

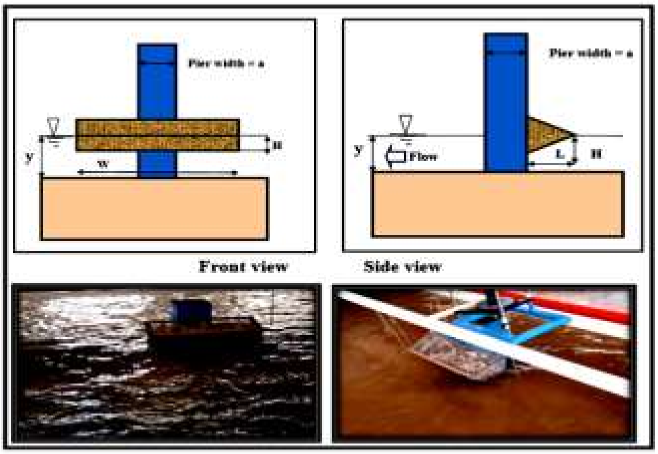

Figure (6): Layout of the wedge debris, Run3.

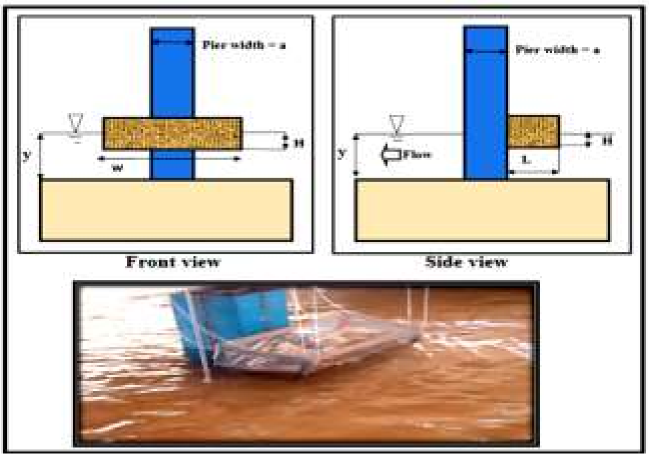

Figure (7): Layout of the rectangular debris, Run4.

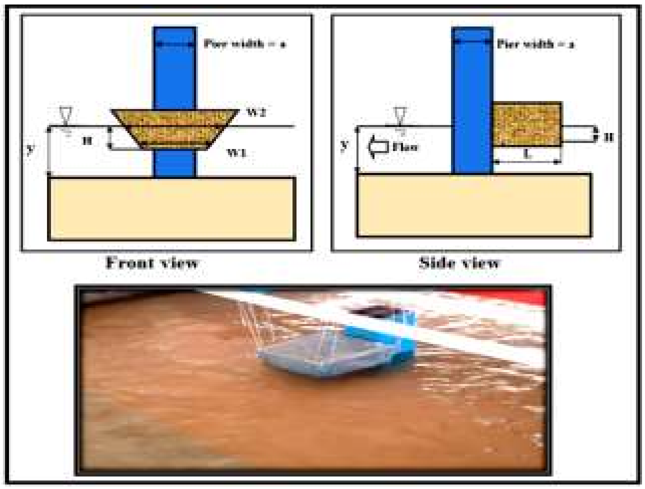

Figure (8): Layout of the trapezoidal debris, Run5.

Mathematical Hydraulic Model

The flow in laboratory flume was simulated by one dimensional hydraulic model (HEC-RAS), all geometry and steady data were taken from the physical model with the same flow conditions of the experiment works.

Geometric Data

The geometry data of the laboratory flume with 3.86 m width, 0.44m height over sandy bed of 8m length of flume, the position of pier after 5m from the beginning of the flume, as shown in **Figure (9).** Pier dimension was 0.2 m width; 0.52 m height over sand surface and center line station was as in the physical model. HEC-RAS deals with debris as a rectangular only and the data input were width and height, dimensions were (H= 10 cm for all debris), (W=64 cm for wedge debris, 54 cm for rectangular and 27 cm for trapezoidal debris) as shown in **Figure (10).**

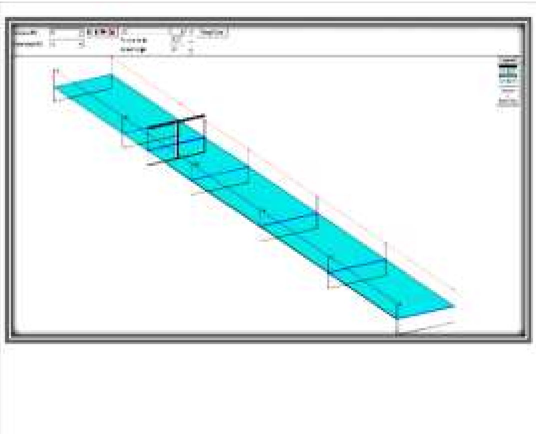

Figure (9): X-Y-Z perspective plot for laboratory flume.

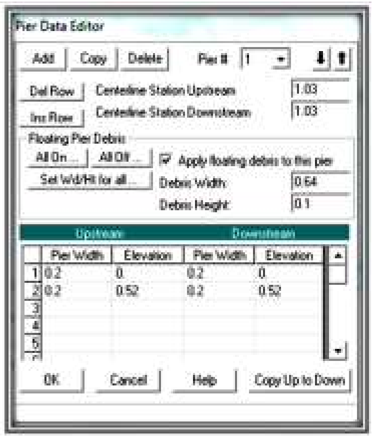

Figure (10): Pier and debris data editor

Steady Flow Data and Boundary Conditions

The number of profile and the discharge were the same for experiments works at physical model as shown in **Figure (11**), the flow conditions for Run3, Run4 and Run5 were same to that of Run2. The HEC-RAS model deals with the boundary conditions depending on the flow regime. In a subcritical flow regime, which is the flow regime in the river under consideration, boundary condition is only necessary at the downstream end of the river system and it is known water surface equal to 0.2m. **Hydraulic Design for Bridge Piers Scour**

The input data were, pier nose shape (K_1) =square nose, method CSU equation, the angle of attack for flow hitting the piers =90˚, the condition of the bed (K_3)=1.1 clear water scour and the size friction for the bed material (d_{50})= 0.5 mm, these data were the same for physical model and all other values are automatically obtained from the HEC-RAS output file from the geometry and steady data were interred at the modeling steps, as shown in **Figure (12)**.

Figure (11): Profile output table.

Figure (12): Hydraulic design – Bridge scour.

Results Analysis and Discussions

In order to find a more realistic equilibrium scour time, two preliminary tests were made, for two flow condition V_m/V_c =0.859 and V_m/V_c =0.648. Scour was recorded at different time intervals using a point gauge to measure the maximum scour at the nose of upstream pier. The results of these tests were shown in **Figure (13)**. These results show that the scour depth is sharply increased during first half of test duration and then the development of scour become approximately constant. It is noticed that 95 % of the local scour can be achieved in 80 min. For more accuracy the time is taken 2-hours. The scour holes patterns for the tests from Run1 to Run5 were as shown in **Figures** from **(14)** to **(18)**.

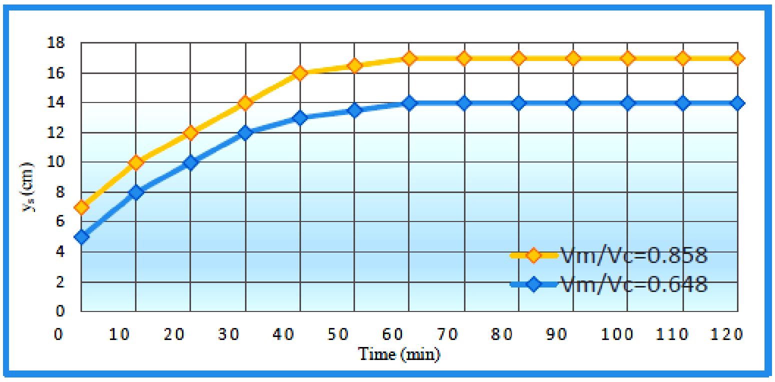

Figure (13): Development of scour depth with the time.

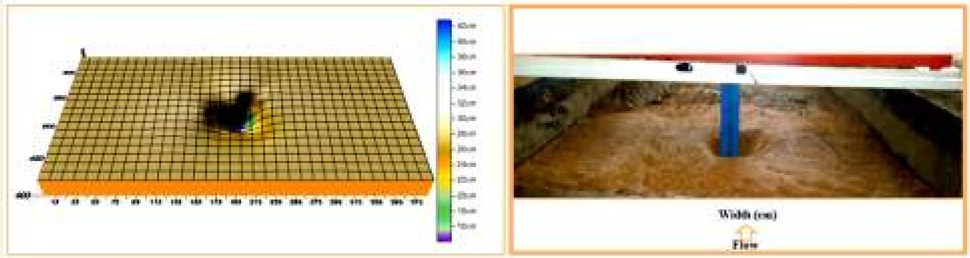

Figure (14): scour hole for Run1, no debris and Q=0.249m^3/sec.

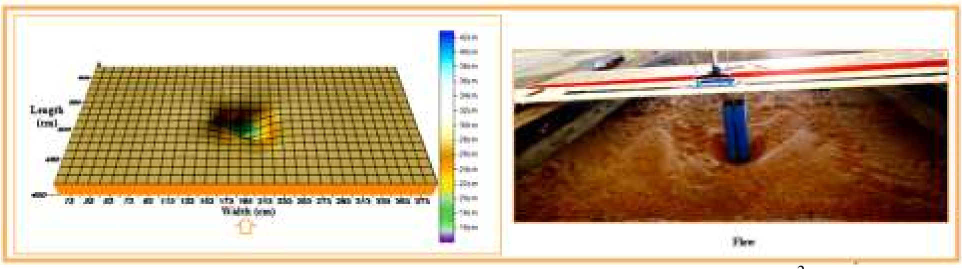

Figure (15): scour hole for Run2, no debris and Q=0.188m^3/sec.

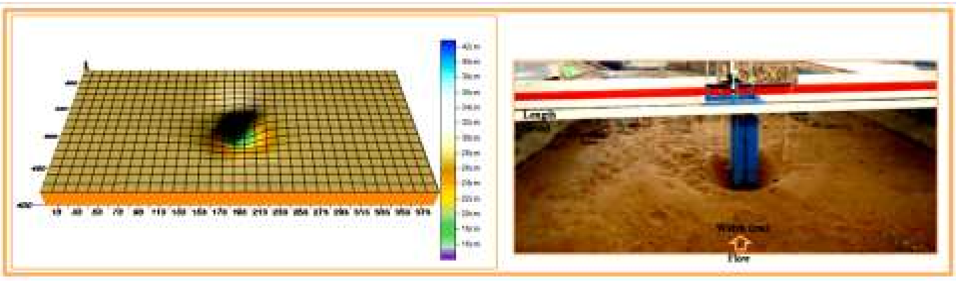

Figure (16): sour hole for Run3, wedge debris and Q=0.188m^3/sec.

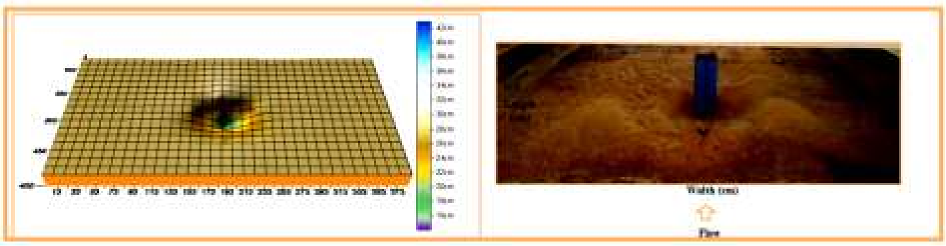

Figure (17): scour hole for Run4, rectangular debris and Q=0.188 m^3/sec.

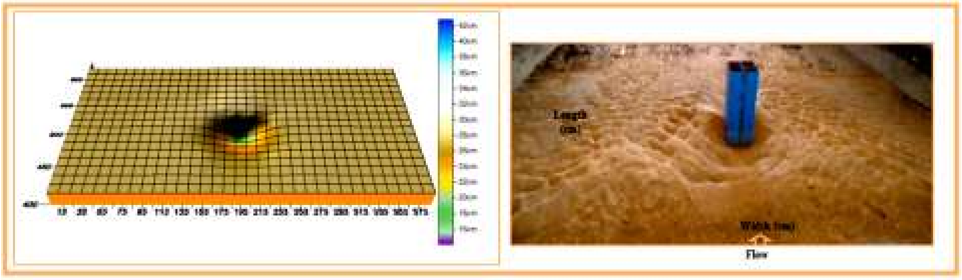

Figure (18): Scour hole for Run5, trapezoidal debris and Q=0.188 m^3/sec.

Effects of Floating Debris on the Local Scour at Bridge Pier were as follows:

Run5 (trapezoidal debris which has L=34 cm, W1=27 cm and W2=33.5 cm). The measured depths of scour hole at the most points of grid are less than these of the other tests. While at the points to the right and left of the pier surface are less than these of Run2 and Run3 and greater than those of Run4 as shown in **Figure (19)** which shows the upstream vertical sections of the bed across the flow at center line of the pier.

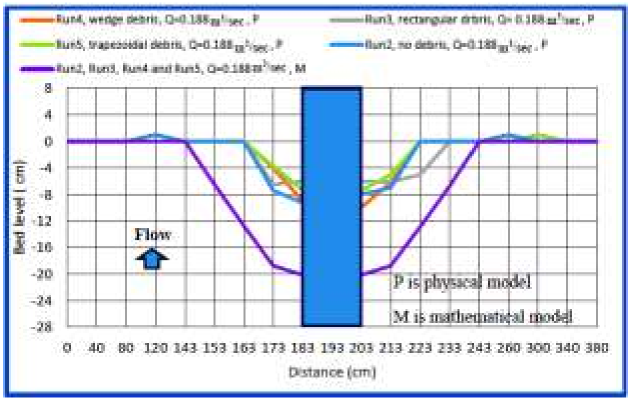

Figure (19): Effect of different shapes of floating debris on the scour depth (front view).

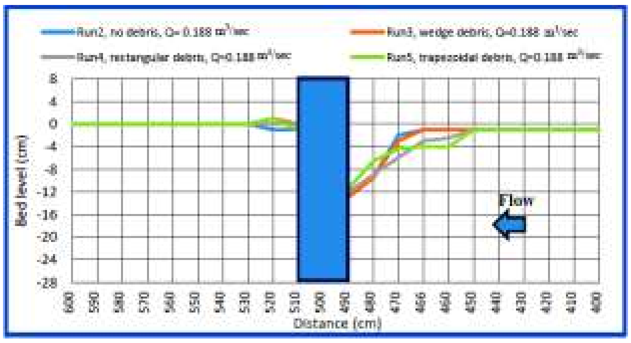

Figure (20): Effect of different shapes of floating debris on the scour depth (side view).

The length of scour hole extends from the upstream face of pier more than those of other tests when the maximum measured scour depth is the latest among these of other tests as shown in **Figure (20)** which shows the longitudinal profile of the bed for the center line of pier, it is clear that the measured scour depths at the points of grid are gradient and the different between them is approximately 2 cm and there is sand deposition at the downstream face of pier.

Run4 (rectangular debris which has L=24 cm, W=54 cm). The length of scour hole extends from the upstream face of the pier is greater than those of Run2 and Run3 and there are gradient in scour depths, the measured scour depths at the right and left surface of the pier are the smallest as compared with these of other tests. While the maximum measured scour depth is greater than this of Run5, there is no sand deposition at the center line of downstream face of pier.

Run3 (wedge debris which has L=20 cm). This test has a length of scour hole extends from the upstream face of pier greater than this of Run2 and less than these of Run4 and Run5 but the measured maximum scour depth is greater than those of other tests by about 18%**,** there is sand deposition at downstream face of pier.

The computed scour depths and top widths of the scour holes (using the HEC-RAS model) are approximately the same for the four tests, with very small difference in scour depth for the same flow conditions with different debris dimensions as shown in **Figure (19)**.

For the effect of floating debris on local scour at bridge pier comparison between the results of physical model for this study with the results of laboratory study of NCHRP report 653 **(Lagasse, 2010)** for the converge tests is as follow:

1. The maximum measured scour depth ($y_{s\ max}$.) for (V_m/V_c = 0.7, y=30.5 cm) without debris was 11.58 cm (Run no. 004-01) on pier B, for the same flow conditions and with debris have W=60.96 cm, L=60.96cm, H=20.4 cm, $y_{s\ max}$.=12.2 cm (Run no. 004-03 B) pier B, at NCHRP report 653, while in this study and with (V_m/V_c = 0.648, y=20 cm) without debris, $y_{s\ max}$.=12 cm (Run2), for the same flow conditions and with debris has W=30 cm, L=34cm, H=10cm, $y_{s\ max}$.= 11.4 cm (Run5).
2. For the same flow conditions (V_m/V_c = 1, y=30.5 cm) NCHRP report 653, for (Run no. 004-02) on pier B, without debris, $y_{s\ max}$. = 21.336 cm. while for (Run no. 005-02 B) on pier B, with debris have, W=60.96 cm, L=30.48cm, H=10.058 cm, $y_{s\ max}$. = 28.04 cm, as a compared with this study for Run2 (no debris), Run4, with debris has W=54 cm, L=24cm, H=10cm, $y_{s\ max}$.= 12 cm, this difference between the two studies may be due to the ratio of flume width to debris width which equal to 4 at NCHRP 653 report, while it is equal to 7 at this study.
3. For the same flow conditions (V_m/V_c = 1, y=30.5 cm) NCHRP report 653, for (Run no. 006-02A) on pier B, with debris have, W=60.96 cm, L=30.48cm, H=20.4 cm, $y_{s\ max}$. = 33.83 cm, while for (Run no. 004-04 B) on pier B, with debris have, W=60.96 cm, L=60.96 cm, H=20.4 cm, $y_{s\ max}$.= 20.1168 cm, this is consistent with the conclusion of this study that the increase in the length of the debris lead to reduce in scour depth and the greater effect of the length of the debris will be at the length equal to the water depth.

Conclusions and Recomendations

According to the analysis and discussions of the results of this research, the following conclusions can be extracted:

1. Accumulation of floating debris at the bridge piers causes increase in the length of scour hole upstream the piers and for rectangular and trapezoidal shapes the percentage of increase greater than this of triangular shape by about 45% because it has the smallest debris length.
2. Wedge shape produces greater maximum scour depth than those of rectangular and trapezoidal shapes by about 18%.
3. Although the difference between the width of debris for wedge and rectangular shapes is small (equal to 10 cm, 44%) and also the difference in debris length between the two shapes equal to (4 cm, 20%), this range of difference in dimensions have no influenced effects and the difference appears when the minimum increase equal to the pier width, therefore, the

difference in the measured scour depths and patterns of scour hole for these two shapes are clear. This due to the difference in the shape of debris accumulation.

4. Maximum effects of the length of accumulated floating debris on the increase of scour depths occur when this length equal to the water depth.
5. There is a big difference, 50%, between the measured (using physical model) and estimated (using HEC-RAS model) scour depths and top widths of scour hole, the software exaggerates in the calculations even without the existence of the debris. The model increases the scour depths without taking into consideration the effect of debris shape on the shape of the scour hole.
6. The estimated maximum scour depths and top widths of scour hole using the HEC-RAS model is greater than those measured using the physical model by about 62% and 100% respectively.

Accordingly, the following recommendations can be presented:

1- Results of estimating the scour at bridges piers in the case of debris accumulation by using HEC-RAS software cannot be adopted for design purposes since they are overestimated.
2- Studying the effects of accumulation of floating debris at the bridges piers on the scour holes shapes and dimensions through applying a three-dimensional simulation model by using the Computational Fluid Dynamic (CFD) software.
3- Studying the effect of the bed slope of the accumulated floating debris at the bridges piers on the scour holes shapes and dimensions.
4- Considering wider ranges of the ratio of flow velocity to critical flow velocity, debris accumulation shapes and dimensions (x, y and z).
5- Evaluating and specifying the suitable treatments and protection methods according to the shapes and dimensions of the accumulated floating debris.

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