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Reducing the local Scour around Bridge Piers by Using Semi-conical Piers.

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Reducing the local Scour around Bridge Piers by Using Semi-conical Piers

تقليل النحر الموضعي حول ركائز الكباري باستخدام ركائز شبه مخروطية

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KEYWORDS:
Bridge, Scour depth, Clear water, Scour reduction, Cone shaped pier, Countermeasure.

الملخص العربي - الهدف الرئيسي من هذه الدراسة هو ايجاد شكل عملي لركائز الكباري للعمل على تقليل النحر او الحد الموضعي. وقد اختيرت الركائز شبه مخروطية لقابلية استعمالهم للتطبيق على ارض الواقع. وتتصف الركائز المستعملة بكونها ذات زوايا ميل جانبية صغيرة ومقاطع مستطيلة. أما الهدف الثانوي لهذا البحث فهو كيفية رفع كفاءة الركائز سابقة الذكر في تقليل تأثير النحر الموضعي. ولتحقيق الهدف الرئيسي تم عمل مجموعة اولى ركائزها اسطوانية الشكل (زاوية ميلها الجانبية =0) و ثلاثة ركائز شبة مخروطية ذوات زوايا جانبية صغيرة (2.86,5.7&8.5). و قد اظهرت النتائج أن ازدياد زاوية الميل الجانبية يؤدي الى زيادة نسبة الحد من عمق النحر وحجمه (RPSDV). وقيم RPSDV كانت (18.33, 21.66, 25) و 40.2, 54.9, (60) على التوالي. ولتحقيق الهدف الثانوي تم تنفيذ المجموعة الثانية وقد تكونت من ثلاثة ركائز شبه مخروطية تم دمج أو تحوير مقدمتها مع وسائل للتقليل من النحر. هذه الوسائل هي فتحات وواجهة امامية على شكل سلم او منحني. وقد اظهرت النتائج بان قيم RPSDV قد تحسنت باستخدام هذه الوسائل بالمقارنة مع أقرانها من دون تلك الوسائل. وقد كانت تلك القيم كالتالي (3.3, 26.7, 37.8) و(1, 53, 68) .

***Abstract* - The main aim of this study is to find a practical shape of bridge pier being a local scour countermeasure. Therefore, the semi-conical piers have been selected to make their usage applicable in the field. These piers have small side slope angles and rectangular cross-section. Also, the secondary aim is to increase the efficiency of the above countermeasure. So, the first experimental set has been performed using a vertical cylindrical pier (its side slope angle = 0) and three semi-conical piers with different side slope angles (2.860, 5.70 & 8.50). The results show that increasing the side slope angle leads to increase the Reduction Percentage of Scour Depth and Volume (RPSDV). The values of RPSDV are (18.33, 21.66, 25) & (40.2, 54.9, 60), respectively. Also, the second set has been done and consists of the three semi-conical piers that their leading edge are integrated or modified with devices. These devices are: openings, up-stream ladder, and curved face. The values of RPSDV are improved using these devices compared with the semi-conical pier without device. The RPSDV are (3.3, 26.7, 37.8) & (1, 53, 68), respectively.**

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I. INTRODUCTION

Although bridges in any country play a vital role in cultural, social and economic improvement, they become globally serious problems due to tremendous amount of their failure and collapse in a number of countries (Jahan 2014, Zhai 2010, Les 1999). In literature, scour is resulted by the erosive action that is induced by the flowing stream. So, the scour depth is explained as an amount of reduction in the riverbed level below a natural level (Das et al. 2014). To decrease the scouring rate, various countermeasures have been used such as gabions, riprap, stone gabion with geo-textile filter, tetrapods, slots, collars, sacrificial piles, delta-wings, submerged vanes and slanting vanes (Beg & Beg 2013). However, there is no a consensus regarding to: the suitable design of local scour depth countermeasures, and the efficiency of these countermeasures (Santoro et al. n.d., Ismael et al. 2014). Therefore, Muke & Bhosale (2013) have insisted that although the protection against the scour depth can be too expensive, efforts should be made to reduce the failure of bridge. Besides, Ismael et al. (2013) have strongly argued that different shapes of bridge pier should be investigated experimentally to find the reliable effective protection. Consequently, the main aim of this study is to find the practical shape of bridge pier in oreder to be the local scour countermeasure. Then, the secondary aim is to improve the efficiency of this countermeasure in reducing the effect of local scour.

II. LITERATURE REVIEW

An attempt to understand the scour mechanism may assist to decrease the effects of this mechanism. According to figure1, when the pier is placed in the river, the downward flow is created because the water flow impinges the upstream face of this pier. This downward flow acts as a vertical jet that works to erode the bed. Also, at the base of pier, a formation of vortices is formed. These vortices are divided to horseshoe vortices and wake vortices. The horseshoe vortices act on the face of upstream pier and the pier sides. The wake vortices act on the downstream side of the pier.

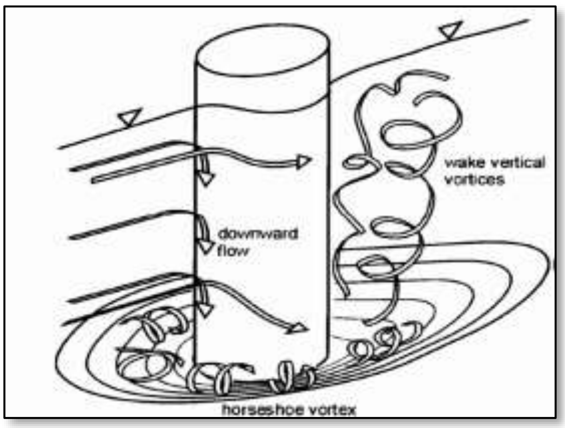

Figure 1. The pattern of flow and scour around the circular pier resulted by the scour mechanism (Vaghefi et al. 2015).

Figure 1. illustrates the effect of scour mechanism resulted by the presence of pier in creating the flow downward and vortices.

El-Ghorab (2013) has strongly illustrated that the initial cause of scour is the downward flow in addition to the horseshoe. Her opinion is that the horseshoe vortex is a result of scour and not a reason of it where it is initially weak and small. Al-Shukur and Obeid (2016), however, have a direct opinion that "scour at upstream is directly proportional to exposed area of upstream nose of pier".

From what mentioned above, it may be concluded that if a projected area will be reduced, the quantity of downward flow may be reduced. This leads to reduce the effect of scour mechanism. The projected area is the area of upstream face or nose of bridge pier. Generally, it is known that projected area is a product of the height and width unit. The pier height may not be controlled because it is governed by the water level. This level is either affected by flood or dry seasons. However, there is a possibility to reduce the pier width (or pier diameter) but without threatening the stability of bridge. In this case, the projected area may be considered as a function of pier width.

From figure 2, if the upper diameter or width of vertical cylindrical pier is reduced with fixing its bottom diameter (pier base, D_2) at the bed level, the projected area of this cylindrical pier will be reduced. In addition, the shape of cylindrical pier will be changed to the cone-shape pier. As a result the cone-shape pier has been adopted as the main aim of this study.

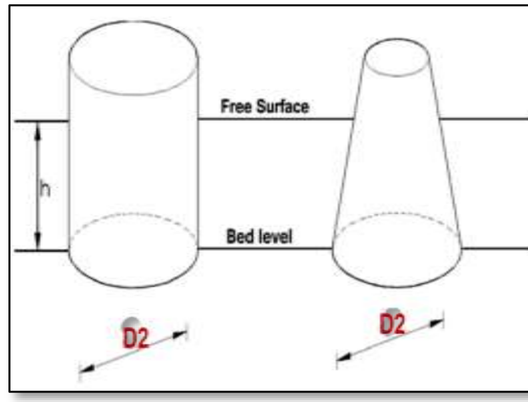

Figure 2. The vertical cylindrical and conical pier.

Figure 2. demonstrates that both piers have same base diameters (D_2) and different top diameters. So, this conical pier is known as the pier that has the constant base.

III. CONE-SHAPED PIER

Conical or semi-conical piers are referred to the piers with side slope (as shown in figure 3). This side slope or its angle (α) is defined as the slope of the leading edge of pier to the vertical plane.

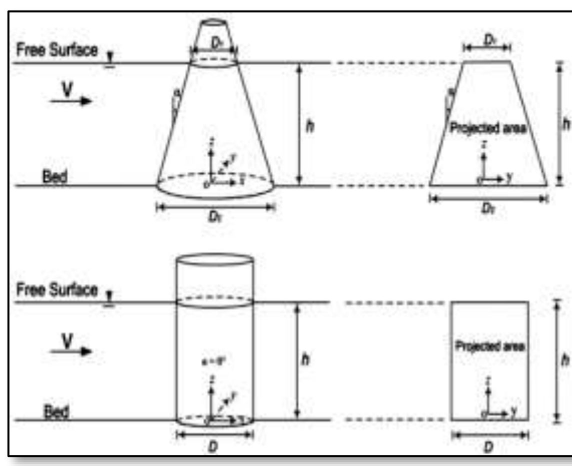

Figure 3. Difference between the vertical cylindrical and semi-conical pier with circular cross-section in terms of their side slope angle (α) (Aghaee-Shalmani & Hakimzadeh 2014).

In Figure 3., D_2 & D_1 are diameters or widths of the semi-conical pier at the bed and free surface level respectively; D is the diameter or width of the vertical cylindrical; h is the flow depth; V is the mean velocity.

According to Aghaee-Shalmani & Hakimzadeh (2014), The usage of cone-shape pier in rivers, unfortunately, is not prevalent as a structure pier. This is because the focus of almost existing experimental studies were restricted to study the semi-conical piers that may not be applicable on the ground as a bridge pier. For example, semi-conical piers, which have dealt with structures of flow and vortex shedding behind them, are almost very thin and tall without interaction from walls. Secondly, the previously used semi-conical piers, which are with large side slopes, require wide rivers because the bases of these piers require bigger width and rivers that are generally characterized by limited widths.

Therefore, in this study, the semi-conical piers have been subjected to a number of modifications (as illustrated in figure 4) to make their usage in the field practical and applicable.

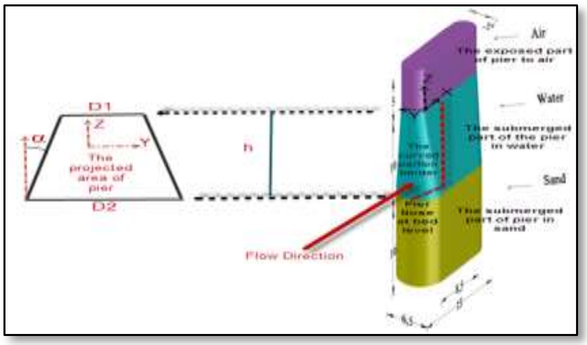

Figure 4. The modified semi-conical pier.

Figure 4. clarifies: modifications on this pier, and the border of curved portion in this pier. These modifications and border will be explained later. Also, it displays that this pier has three parts that are: submerged in water and submerged in sand, as well as exposed to air.

In terms of first modification, the piers with rectangular cross-section have been selected. Secondly, the side slope angle of these piers have restricted only in flow direction (Z-Y plane) to keep their length constant to be more suitable for the bridge width, or to be employed later for a number of devices that are proposed in this study. These devices have been placed in front of piers as local scour countermeasures. Thirdly, the side slope angle of these piers is chosen to be small to reduce the projected area of pier, and to prevent weakening of pier's bearing capacity in transporting loads from superstructure (deck) of bridge to the substructure (foundation) of bridge. Lastly, the base or diameter of modified piers in the bed level has been chosen to be constant or equal to the base of the cylindrical pier that has been widely used in rivers as the bridge pier.

The modified pier can be considered as one of semi-conical pier types. This is because this pier does not contradict with the definition of conical or semi-conical piers as it has side slope.

The submerged part of pier in water (figure 4) is the focus of this study. Consequently, the first set of experiments of this study has been carried out to study the local scour around the vertical cylindrical pier and modified semi-conical piers.

IV. DEVICES

To increase the efficiency of the modified semi-conical piers in decreasing the effect of local scour, a number of devices have been used as shown in figure 5.

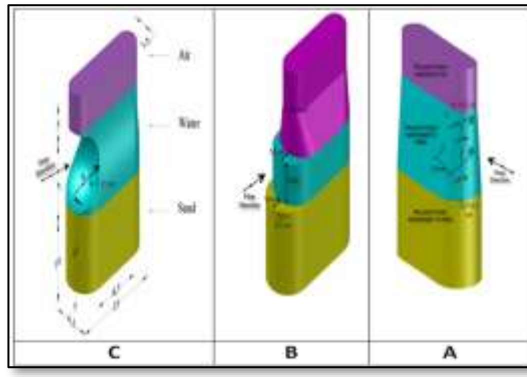

Figure 5. Devices integrated with modified semi-conical pier as scour countermeasures.

Figure 5. shows: (A) openings device integrated with the semi-conical pier, (B) the ladder face device integrated with the semi-conical pier, and (C) the curved face device integrated with the semi-conical pier. The dimensions in A,B, and C have been mentioned later.

If there is a desire to integrate these devices with modified semi-conical piers, these devices should be placed within the curved portion border of upstream modified pier (as displayed in fig 4). Also, this border should not be subjected to the bearings that transfer the load from deck (superstructure) to pier and foundation (substructure). In this study, the border of curved portion extends horizontally from the pier nose to the end of radius of pier base in the bed level and it raises vertically from this horizontal distance to the upper surface of pier at water level. As a result, the above devices have been integrated with semi-conical pier to introduce the second set in this study. The purpose of conducting this set is to compare the scour depth resulted by semi-conical piers integrated with devices and semi-conical pier without these devices.

V. OPENING DEVICE

According to El-Gorab (2013), the opening arrangement can be employed within the pier to decrease the impacts of downward flow. The idea behind opening arrangement is to harness the pressure difference to pass water through the pier by openings. This difference of pressure is around the upstream face of pier and its longitudinal sides. So, openings have been located in the upstream face of pier and its longitudinal sides. Also, all openings are at the same level.

So, it may be deduced that flow passing through openings leads to reduce the quantity of downward due to reducing the projected area of upstream face of pier. The conical shaped pier may not be tested experimentally with openings yet. As a results, one of piers of second set is the semi-conical pier integrated with openings (as shown in figure 5-A). Besides, the location of side opening should not be exceeded the border of the curved portion of semi-conical pier. From figure 5-A, The vertical distance between the opening and bed level = D, the vertical distance between two openings = 0.5D, diameters of openings = 0.2D, and the location of side opening, which is measured from the upstream face of pier, is = 0.3D, where the average diameter (D) in semi-conical piers is equal $(D_1+D_2)/2$. To clarify. The above dimensions have been adopted by El-Gorab (2013) but she does not work with the cone-shaped pier.

VI. UPSTREAM CURVED AND LADDER FACE PIER DEVICES

The devices of upstream curved and ladder face pier may be not previously integrated with the semi-conical pier. Firstly, it may be considered that the performance of ladder face device is like the performance of collar in reducing the strength of downward. So, one of piers of second set is the semi-conical pier integrated with ladder face device (as illustrated in figure 5-B). The total width of ladder rungs should not be exceeded the border of the curved portion of semi-conical pier. From figure 5-B, the first rung is placed at the bed level while the second rung is placed (D) above the bed level. The width of each rung is D/3.35 cm. The number of rungs can be increased if there is a desire to use this device but the total height of rungs should be within the flow depth and the total width of rungs should be within the border of the curved portion.

Secondly, the purpose of using curved face device is to elongate or luring the flow direction, and then to orient it to be reversed to the coming flow direction. The elongation and orientation could work to reduce the strength of downward. Therefore, one of second set piers is the semi-conical pier integrated with curved face device (as demonstrated in figure 5-C). The radius of curvature (R) should not be exceeded the border of the curved portion of semi-conical pier. From figure 5/C, the radius of curve (R) is adopted to be equal D_2-D_1 and this curve starts from the bed level up to the water surface level.

Finally, although the shape of projected area of second set piers, especially the semi-conical pier with upstream ladder and curved face, is different from the shape of projected area of first set piers, piers of second set are compared with one of first set piers because the D_1 and D_2 of those piers are the same value as well as they have same size. The definition of this size is explained later.

VII. EXPERIMENTAL SET-UP

The experiments have been conducted in a rectangular straight flume at the Hydraulic Laboratory of Irrigation and Hydraulics Department, Faculty of Engineering, Mansoura University, Mansoura, Egypt. The experimental set-up and its components are shown in figure 6.

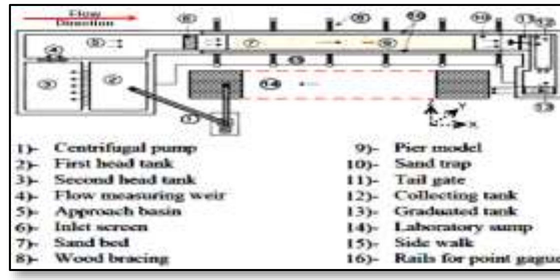

Figure 6. Plan view and details of the experimental flume.

The dimensions of the flume are 6.8m × 0.74m and the wall height of flume is 0.40 m. Also, the flow discharge has been measured in a rectangular weir. Moreover, the tail gate is located at the channel end to control water depth. As well, the measurements of water depth, bed levels and scour have been made with the mobile point gauge. The accuracy of mobile point gauge is ± 0.1mm.

VIII. BED MATERIAL

A sand bed of thickness 10 cm has been spread along more than 90% of the flume. So, the length and width of tested section are 6.1 and 0.74 m respectively. Also, the characteristic properties of sand are: the median particle size (D50) = 0.71 mm, and the geometric standard deviation (σg) = 2. As well, the bed material, prior to each experiment or run, has been compacted and leveled, especially around piers. Moreover, to avoid any disturbance in the bed material, prior to each run, a gate at the end of flume has been partially closed and the flume is gradually filled to provide a low flow velocity until getting the required discharge and flow depth.

IX. PIERS

Piers are made of wood and are painted using varnish (as a glue material) to avoid a penetration of water when they are placed in the flume. Also, after leveling the sand, piers have been placed in the center of transverse section of flume with orientation 0.0 degree to the flow direction to avoid the effect of flume sidewalls. In addition, piers, also, have been placed approximately in the middle of longitudinal section of flume to provide the condition of fully developed flow. Finally, the diameter of piers has been selected with respect to:

1- The value of the side slope angle of piers, in particular, D_1 and D.
2- Meeting the criterion of previous studies (the average diameter (D) / the flume width (W) < 0.16) to avoid the effect of potential flow blockage on the local scour around the pier (Raudkivi & Ettema 1983). In this study, this ratio is less than 0.1.
3- Meeting the criterion of previous studies (the diameter of base of pier or the diameter at bed level (D_2) / the median

sediment size for the possible coarsest armor (D50a) > 25) to avoid the sediment size effect on the scour depth (Breusers & Raudkivi 1991, cited in Bozkus & Cesme 2010, p.1626 and Aghaee-Shalmani & Hakimzadeh 2014). In this study, this ratio is 49.6, where D_2 in this study for all used piers is chosen to be constant ant it equals 6.5cm. Moreover, D50a equals ((D max)/1.8 = 1.3111mm) and D max is the maximum particle size and its value is 2.36mm.

X. Lab. Procedures

Firstly, the condition of steady clear-water has been applied only. Secondly, the flow discharge (21.1 l/s), the approach flow depth (h = 10 cm), the mean flow velocity (V= 0.285 m/s), and the flow intensity (V/Va = 0.788) have been chosen to be constant for all experiments. The flow depth has been selected to meet the criterion of narrow piers (the pier diameter (D) / the flow depth (h) < 0.7). The maximum and minimum ratio of D/h in this study is 0.65 & 0.5 respectively. The value of the flow intensity is selected to be suitable for what have been stated by Shrestha (2015) and available hydraulic possibilities in the lab where this study has been prepared. According to Shrestha (2015), when the value of flow intensity is to be higher, but at the same time it should be less than the unity, the non-uniformity effect will be minor if the flow is capable to entrain most of the particles of sediment. Finally, the time period for all experiments is 4 hours. Selecting this period depends on what have been mentioned by Mia (2003) and Yanmaz et.al (1991). They pointed out that 3 or 4 hours can show or provide the most occurrence of the scour depth.

XI. Lab. Measurements

First of all, the measurements of scour depth have been taken along two directions (X_1 and X_2) (figure 7) around cylindrical and semi-conical piers.

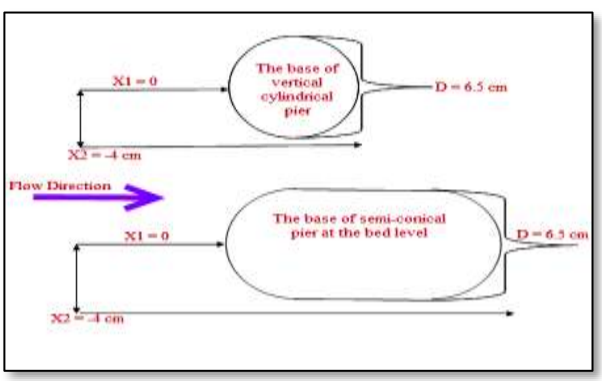

Figure 7. The locations of X_1, X_2 around the vertical cylindrical and semi-conical pier.

This figure illustrate that X_1 is along the center line of piers and it may be considered as an indicator to observe the strength of downward component of flow velocity and horse vortex in front of piers. As well, X_2 is the longitudinal direction and is near to the boundary of pier side and it is parallel to the pier center line (X_1). X_2 may be considered as the indicator to observe the strength effect of the horseshoe vortex that acts in the pier side. Also, the scour volume around piers has been determined by using Golden Software Surfer 13 version. Moreover, RPSDV have been determined by using the following equation as follows:-

(dsc-dss)/dsc *100 (for the first set)

Or

(dss-dsv)/dss*100 (for the second set)

And

(Vsc-Vss)/Vsc *100 (for the first set)

Or

$(\text{Vss} - \text{Vsv})/\text{Vss} * 100$ (For the second set)

Where:- dsc, dss, and dsv are the maximum scour depth around: the vertical cylindrical pier, semi-conical pier, and semi-conical piers integrated with devices respectively. Moreover, Vsc , Vss, & Vsv are the scour volume around: the vertical cylindrical pier, semi-conical pier, and semi-conical piers integrated with other devices respectively.

XII. Results and Discussion

First Set

The piers of this set are three semi-conical piers and the vertical cylindrical pier (as shown in figure 8 and table 1).

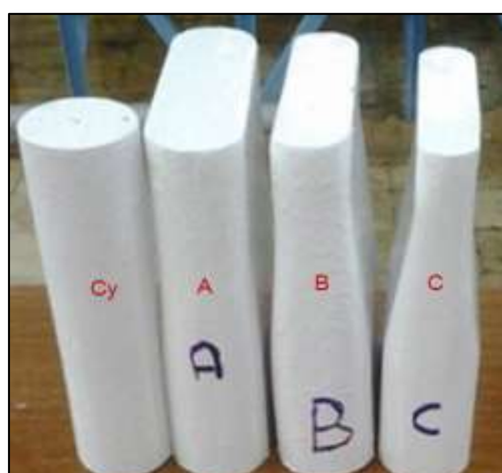

Figure 8. Piers of the first set.

TABLE 1. DETAILS OF TYPES, DIAMETERS, SIDE SLOPE ANGLES, AND LENGTHS BELONGING TO THE FIRST SET OF PIERS.

Piers of the first set

Types	D1 (mm)	D2 (mm)	D (mm)	α°	Length (mm)
Cylindrical pier	65	65	65	0	65
Semi-conical pier/A	55	65	60	2.86	180
Semi-conical pier/B	45	65	55	5.7	165
Semi-conical pier/C	35	65	50	8.5	150

From figure 8 & table 1, piers have the different value of: side slope angle (α^o), pier diameter at the flow surface (D_1), and mean diameters (D). Another different feature among piers is value of their lengths (L). In terms of semi-conical piers, their lengths have been specified by the ratio of D/L = 1/3 as mentioned by Chiew & Melville (1987) cited by Masjedi et al. (2010) while this ratio is D/L = 1 related to cylindrical pier. However, piers have the same value of the diameter at bed level (D_2). Also, all semi-conical piers have the rectangular cross-section. So, four runs have been conducted and the duration test of each run is 4 hours.

The results have shown that as the side slope angle is increased, the projected area of piers is decreased and this leads to:-

A). The scour depth variations in front of pier along X_1 (figure 9) are decreased.

B). The scour depth variations near the pier side along X_2 are reduced (figure 10).

C). The scour volume around piers is decreased (figure 11). Also, figure 12 is lab mages related to figure11.

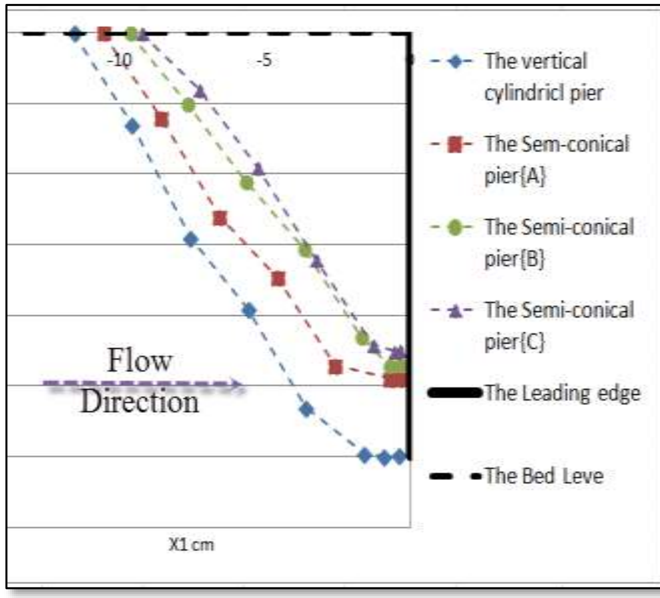

Figure9. The scour depth variations along the longitudinal X1 direction.

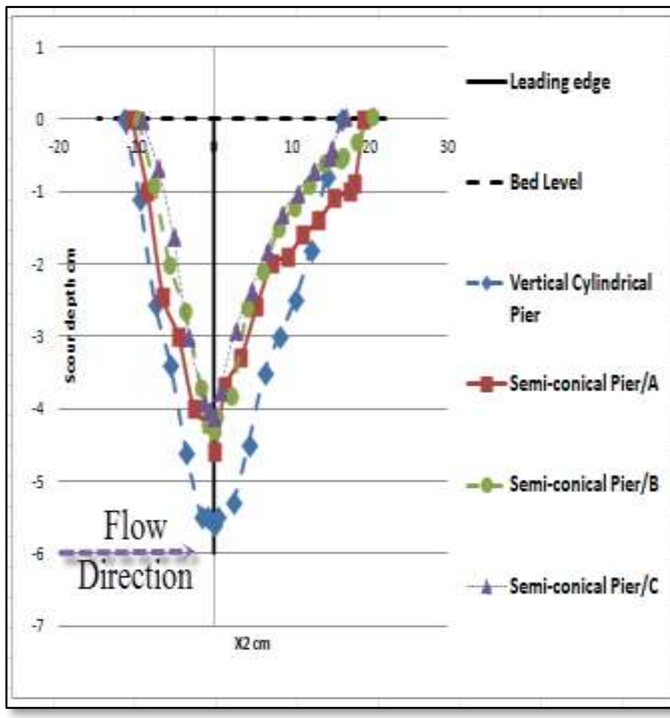

Figure10. The scour depth variations along the longitudinal X2 direction.

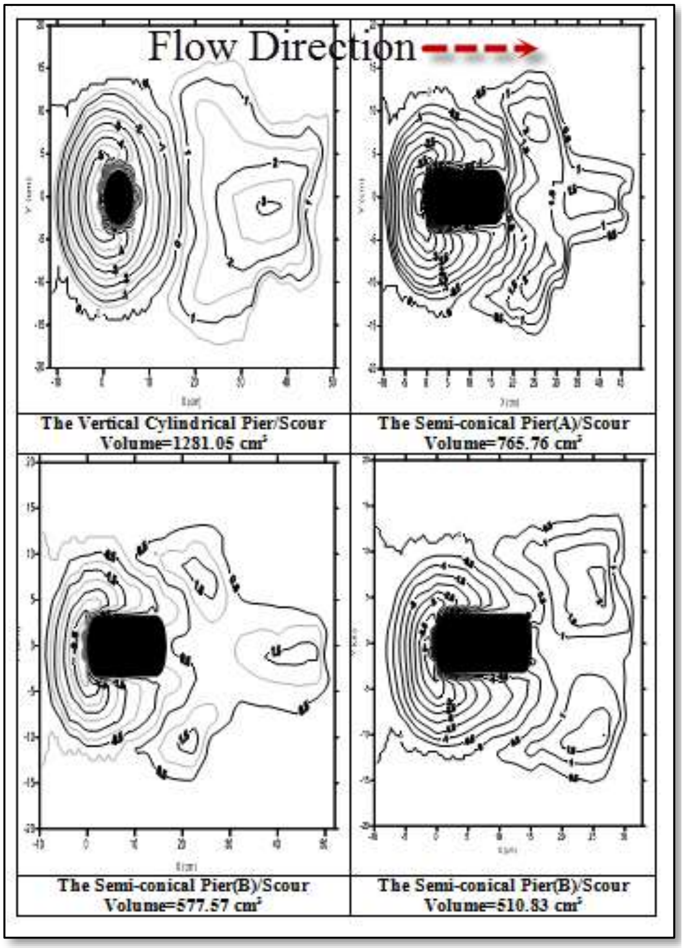

Figure11. Contour lines of the scour holes and sediments for the first set (the units: cm).

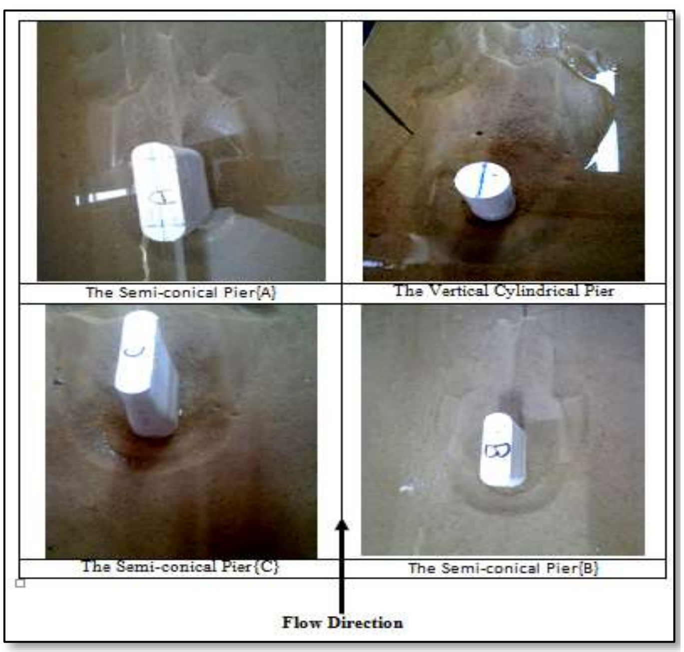

Figure 12. The lab images for the first set piers.

Because the maximum scour depth happens in front of piers (as seen in figure 9), the reduction percentage of scour depth has been adopted for this scour. Also, the reduction percentage of scour volume has been adopted from scour volume values in figure 11. As a result, the main conclusion of this set is outlined in table 2.

TABLE2. DETAILS OF RPSDV.

	The reduction percentage of the scour depth	The reduction percentage of the scour volume
Cylindrical pier	***********	************
Semi-conical pier/A	18.33	40.2
Semi-conical pier/B	21.66	54.9
Semi-conical pier/C	25	60

From table 2, RPSDV have been done between the cylindrical pier and other semi-conical piers. Moreover, because the semi-conical pier/C (figure 4) has given the maximum RPSDV, the size of this pier is selected to be the size of the piers used in second set. The size of pier means the length of pier (L) and average diameter (D). The purpose of this selection is to check the efficiency of semi-conical pier/C in reducing the scour depth and volume when this pier is integrated with devices that are previously mentioned and used in the second set.

Second set

Piers of this set have been integrated with a number of devices (figure 13), where E_1, E_2, and E3 represent the semi-conical pier modified with: openings, ladder face, and curvature face respectively. These devices have been placed within the curved portion of semi-conical pier. For example, The location of side opening is equal to 0.3D or 1.5 cm that is less than $D_2/2$ or 3.25cm (figure 5-A). Also, the total width of rungs of ladder are equal to 3cm that is less than $D_2/2$ or 3.25cm (figure 5-B). Finally the radius of curvature R is equal to D_2-D_1 or 3cm that is less than $D_2/2$ or 3.25cm (figure 5-C).

Figure 13 Piers of the second set.

As a result, three runs have been conducted and the duration test of each run is four hours. The results of this set have shown that when the semi-conical piers have been integrated with these devices, this leads to:-

A- The scour depth variations in front of pier along X_1 (figure 14) are decreased.

B-The scour depth variations near the pier side along X_2 are reduced (figure 15).

C-The scour volume around piers is decreased (figure 16). Also, figure 17 is lab mages related to figure16.

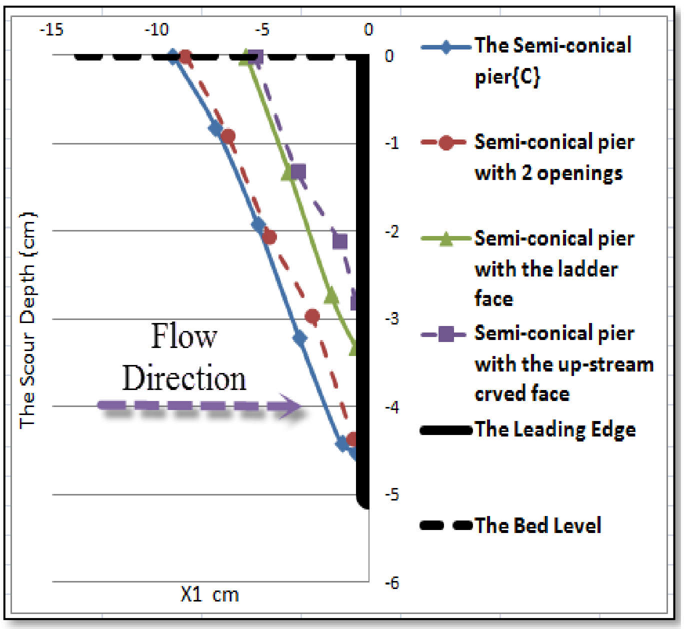

Figure14. The scour depth variations along the longitudinal X1 direction.

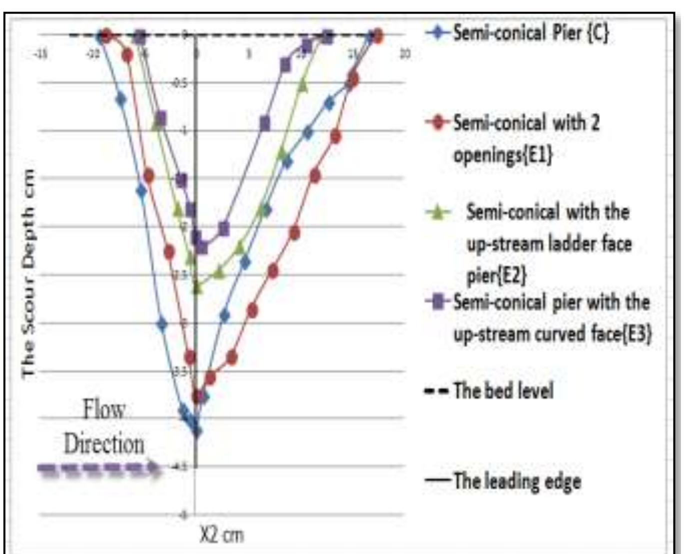

Figure15. The scour depth variations along the longitudinal X2 direction.

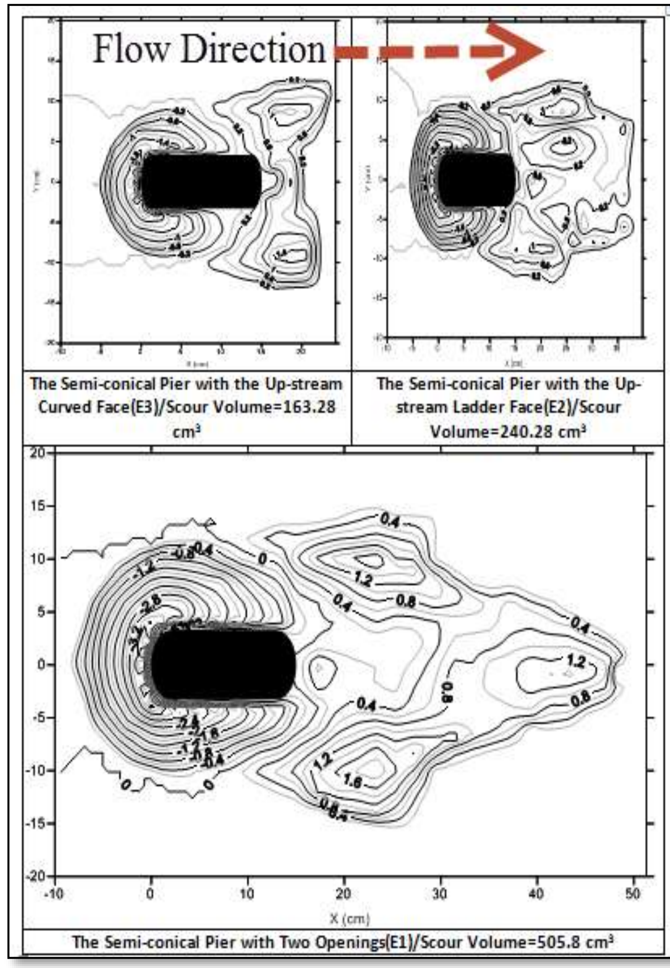

Figure16. Contours lines of the scour holes and sediments for the second set (the units: cm).

Figure 17. The lab images for the second set piers.

Finally, the main conclusion of this set has been adopted like its counterpart related to the first set but the comparison is done between semi-conical pier/C and semi-conical piers with devices (table 3).

TABLE 3. DETAILS OF RPSDV.

	The reduction percentage of the scour depth	The reduction percentage of the scour volume
Semi-conical pier{C}	**************	*************
Semi-conical pier with 2 openings {E1}	3.3	1.0
Semi-conical pier{E2} with the up-stream ladder face	26.7	53
Semi-conical pier(E3) pier with the up-stream curved face	37.8	68

XIII. THE GENERAL OBSERVATIONS

For all sets, although the armoring effect exists, it does not influence the trend that, firstly, the scour depth and volume are decreased when the side slope angle is increased. Also, the scour depth and volume are decreased when the device of : openings, up-stream ladder face, and up-stream curved face are integrated with the semi-conical piers. Furthermore, using: semi-conical piers instead of the vertical cylindrical pier, or semi-conical piers integrated with devices instead of the semi-conical pier without devices leads to reduce the strength of the local scour depth and volume around piers. As a result, reducing the scour depth & volume: may lead to decrease the request for any extra scour countermeasure like riprap: and may enhance the hydraulic performance of bridge pier. Moreover, related to semi-conical piers, the scour process starts from the right and left sides. This may indicate that the shear stress at the side of these piers is stronger than its counterpart at the up-stream side of pier. Then, with the development of scour depth, a position of maximum scour depth shifts from the right & left side to the up-stream side of the piers. Finally, the contours of scour hole seem to be uniformly spaced.

Secondly, for the second set, in terms of the semi-conical pier {E1}, RPSDV are very small compared with other piers of second set. This may because the slotted areas of two openings are very small. So, there is a possibility that RPSDV of this pier can be increased if it will be integrated: with more than two openings or with the larger area of openings. In addition, in term of the semi-conical pier {E2}, the scouring appears in the sediment body at the down-stream of this pier. The location of this scouring is at the left side; therefore the sediment body is not symmetric. If there is a desire to adopt the usage of this pier in the field, the down-stream area around this pier should be protected with resisting material against the scour.

XIV. SUMMARY AND CONCLUSIONS

Finding the practical shape of bridge pier for being a local scour countermeasure is the main aim of this study. So, the semi-conical piers have been chosen to make their usage applicable in the field. These piers have small side slope angles and rectangular cross-section. Also, the secondary aim is to raise the efficiency of used semi-conical piers in reducing the effect of local scour. Therefore, under the condition of steady clear-water scour and 4 hours as the duration test, two sets of laboratory experiments have been conducted. The first set has been carried out to compare the effect of local scour around the vertical cylindrical pier and three semi-conical piers with different side slope angles (2.860, 5.70 & 8.50). The results of this set demonstrate that increasing the side slope angle leads to an increase in RPSDV. Finally, the second set has been performed to improve the efficiency of the semi-conical pier used in the first set when this pier has been modified with a number of devices. These devices are: openings, the up-stream ladder face, and the up-stream curved face. All experiments have been conducted for a duration test period of 4 hours under the condition of steady clear water. The outcomes show that RPSDV are improved by using these devices.

XV. NOTATION

In this research study, the following symbols have been used:

α = The side slope angle of cone-shape pier (degree);
σg= The geometric standard deviation;
A=The flow area (m^2);
D= The main diameter of pier)m);
D_1 = The diameter of pier at the free surface level (m);
D_2 = The diameter of pier at the bed level (m);
D50 = The median particle size (mm);
D50a =The median sediment size for the possible coarsest armor (mm);
Dmax= The maximum particle size (mm);
dsc=The maximum scour depth around the vertical cylindrical pier (cm);
dss= The maximum scour depth around semi-conical pier (cm);
dsv= The maximum scour depth around semi-conical piers integrated with devices (cm);
h=The flow depth (m);
L= The length of pier (m);
Lab= Libratory
Q= The flow discharge (L/s);
V= Mean velocity (m/s);
Va= The mean approach flow velocity at the armor peak(m/s);
Vsc= The scour volume around the vertical cylindrical pier (cm^3);
Vss = The scour volume around semi-conical pier(cm^3);

Vsv= The scour volume around semi-conical piers integrated with devices(cm^3);
W= The flume width (m).

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