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Effect of soil particle size in reducing the Scour around bridge Piers at the Curved Channels

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Abstract: The local scour around bridge piers is one of the most common causes of bridges' failures. In general, scour phenomenon is extremely complex in nature and consequently in the past, many investigators have attempted to develop conservation, analytical, semi-empirical or empirical equations based on the understanding of mechanism of both local and general scouring. However, most of the researchers have studied the scour around bridge piers located in both straight and curved channels but did not recommend the best size of grains of soil downstream hydraulic structures. Especially with the piers rotating around its axis in the direction of flow with angles 2.5 and 5 degrees. A 30 degrees curved channel was investigated with various piers shapes that were placed in middle of the curved part of channel. The flume wall was made of glass with a rectangular cross section of (30x60 cm). Its length is 8 m; the middle segment is curved. Different conditions of Froude's number` from 0.162 to 0.33 were conducted using six different conditions with both angles 2.5 and 5 degrees for piers' rotation around its axis in the direction of flow. The remaining soil after the completion of scour has been collected around the pier and sieve analysis was done. Measurements using ultrasonic device were taken, analyzed, presented and discussed. It has been concluded that the hexagonal shape M_2 with rotation angle 2.5^0 showed the lowest scour depth.
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1- Introduction

In many countries, many bridges failed due to extreme velocities and vorteces that casue scour around bridge piers and abutments. Foundation of a bridge pier in an erodible channel is quite expensive, as it should be constructed at a certain depth to provide the minimum for the safety against scour. Therefore, the failure of bridges causes property loss and may result in fatal cases. Piers and abutments are integral parts of a bridge structure that obstructs the natural river flow causing local scour. It causes an acceleration of flow around the bridge foundation due to the contraction of cross section of the waterway. This paper presents the Effect of soil particle size in reducing the Scour around bridge Piers at the Curved Channels for different shapes of piers and different angles. Researches published were gathered and analyzed.

Many researchers checked local scour around bridge piers in water ways numerically, experimentally or theoretically. In 2010, Jueyi et al. recognized the scour of clear-water around semi-elliptical pillars with coated beds. Experimental study has been accomplished under the condition of clear water scour to examine the local scour around semi-elliptical model of bridge pillars with armor-layer bed, in comparison with the process of local scour around semi-circular abutment, with increase in the velocity of flow in all of the runs, the balance scour depth of the scour hole will be raised. In 2016, Abdual et al. examined ten various shapes from the piers. These shapes were used to check the effect of the bridge pier's shape on the local scour to reach the optimal shape that provides the minimum scour depth. The results' comparison show that the scour at upstream is directly proportional to the exposed of the pier upstream nose. The results present that the rectangular pier provides the largest scour depth (7.6) cm. Meanwhile, the streamline shape gives the lowest scour depth (3) cm. In 2008, concerning the curved channels, Yaser Emami et al. examined both U-shape channel and straight channels that have a central angle of 180°. A 6cm-diameter pier was located in the straight channel and also in sections 30 and 60 degrees in the bend, to study the local scour. This study presents the minimum amount of scour depth (ds) at each discharge that may be occurred at straight channel. The scour hole location in the bend is near to the outer wall of channel and also the point bar is near to the inner wall of channel. There are many studies that have been done in straight channels. The information about the scour at bridge pier in the curved channel is little (to the authors' knowledge). In 2017 Ahmed Helmy et al, Study of the local scour around unconventional bridge piers in the water ways, six models were suggested (i.e. Elliptical, Polygon (hexagonal), Oblong, Lenticular, and lenticular with curve), with three (3) angles 0, 2.5 and 5 degrees for piers' rotation around its axis in the direction of flow. The study designated that the conventional shapes are capable of reducing scour depth reasonably with different inclination angles and the polygon (Hexagonal) with angle 2.5º was able to reduce the scour depth by 36% relative to the maximum scour depth. Furthermore, it was the best shape in the conventional shapes. Concerning the non-conventional shapes, the Lenticular (curve) with angle 0.0º was able to reduce the scour depth by 44% relative to the maximum scour depth. In 2017 Mostafa Ali et el, Study the local scour around piers in the curved channels, six models were suggested (i.e. Elliptical, Polygon (hexagonal), Oblong, Lenticular, and lenticular with curve). The test program was designed to investigate the pier shapes after the equilibrium scour condition is reached. The conclusion was that the inclination angle of the pier has low-impact the relative scour depth (ds/y) for all studied shapes of the piers, except for the polygon (Hexagonal). In 2019 Mostafa Ali, Optimum Size of the soil Particles around Bridge Piers in the Curved Channels, It was concluded that the optimum particle size of soil around bridge pier in curved channels with zero degrees for piers' rotation around its axis in the direction of flow, where (Fr) ranges from 0.162 to 0.33 is achieved for relative soil diameter D50/B ranges from 2.33*10-4 to 3*10-3 where the scour depth decreases by a percentage range from 20% to 40%.

2- Research Objectives

The main objective of the current study is to determine the suitable fill grain size around bridge piers in the curved channels, and to make a comparison between this study and previous studies in this field.

3- Theoretical Approach

The relationships between all parameters, affecting the scour hole, were comprehended. According to the dimensional analysis technique of Buckingham's π- theorem, a relation between the effective parameters and the scour-hole depth was deduced, where the methods of dimensional analysis are built upon Fourier principle of dimensional homogeneity. This principle stated that any equation expressing a relationship between physical quantities, must be dimensionally homogenous. All parameters were defined on the figure 1. In this study the scour depth (ds), is a function of all other independent variables as follows: $d_s = \phi$ (B, b, L_s, T, T_o, t, L_b, y, Q, ϕ, ρ, g, μ, D_{50}, R, S.G,θ).

Where:

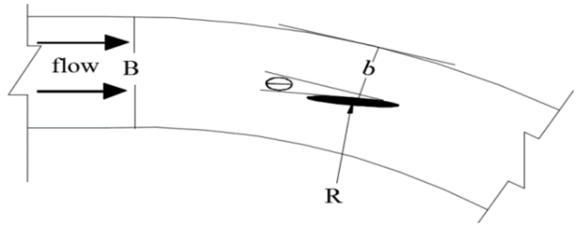


Figure (1) Definition sketch for the work-study

According to Buckingham π-theorem, the general form of the relationship between these variables as follows:

$$\frac{ds}{y} = \emptyset\left(\frac{Ls}{y}, \frac{b}{B}, \frac{Ls}{Lb}, \frac{D_{50}}{B}, Fr, \theta\right) \qquad (1)$$

4- Experimental Works

Hydraulic Laboratory of the Faculty of Engineering, Al-Azhar University Cairo, Egypt, has conducted experimental procedures in an experimental channel. Fig (2). The experimental channel´s shape is rectangular cross section of (30x60 cm) and its length is 8 m. The channel was supported by frames of steel with transparent vertical side. The test models were designed to investigate the shapes of the pier and the equilibrium scour condition. Table (1) presents the summary of the test conditions for each pier. The Experiments were conducted under different conditions for all Fr (i.e. 0.162, 0.243, 0.262, 0.30 and 0.33). The scour depth was measured and the reminder soil in bed are collected and sieve analyses for the collected soil are done and being compared to the original soil that had been investigated before. After that we re-do the experiments with using the soil collected.

Table (1) Tested models

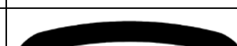
	Piers shape		
1	M_1	Elliptical	
2	M_2	Hexagonal	
3	M_3	Oblong	
4	M_4	Oblong (curve)	
5	M_5	Lenticular	
6	M_6	Lenticular (curve)	

Figure (2) Experimental Flume

Then re-measuring the previous variables is done.

Analysis

Sixty (60) experiments were carried out, where five (5) different discharges for the different six shapes and two angles, Sieve analysis was drawn and we get D_{15}, D_{50}, D_{85}. Measurements were done. Observations were recognized and the photos were taken. These measurements, observations and photos were documented and archived. They were analyzed, plotted on graphs and interpreted as follows:

1. Sieve analysis Results

The remaining soil was collected after the pouring around the sidewalk was completed and a sieve analysis was performed. Sieve analyzes were mapped by which D_{15}, D_{50} and D_{85} were determined for flow conditions and different shapes, some of which are shown in Figs. (3) to (8). Note that the D_{50}, D_{15}, and D_{85} are suitable for different shapes of pavements and different flow condition, after analyzing the numbers. Note that the optimum grain size distribution of the soil around the bridges (M_2 and M_6) has a 2.5 degree rotation angle ranging from 0.1 mm to 1.1 mm, and ranged from 0.2 mm to 1.4 mm for other shapes.

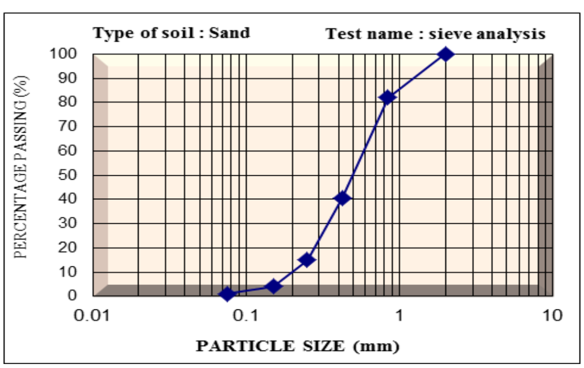


Figure (3) Grain size distribution (References study)

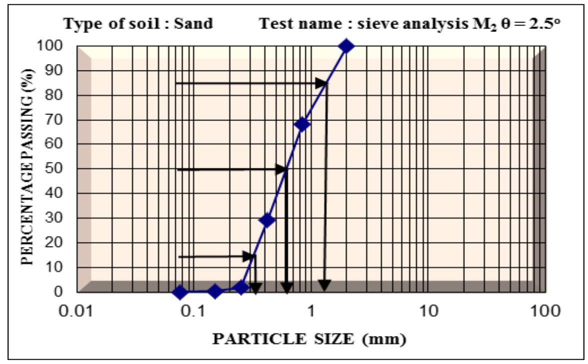


Figure (4) Grain size distribution

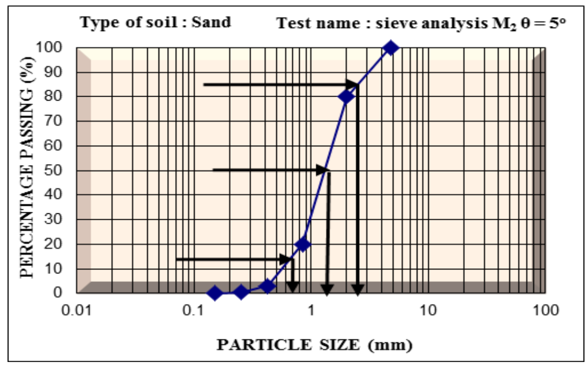


Figure (5) Grain size distribution

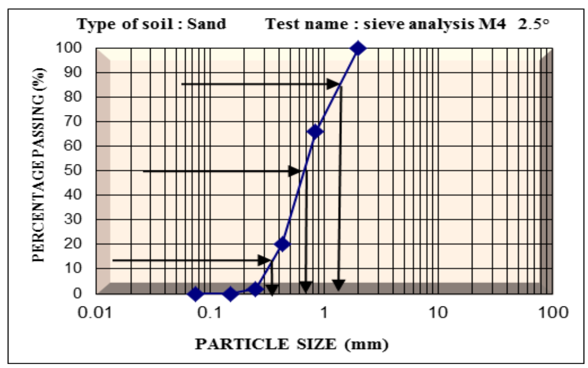


Figure (6) Grain size distribution

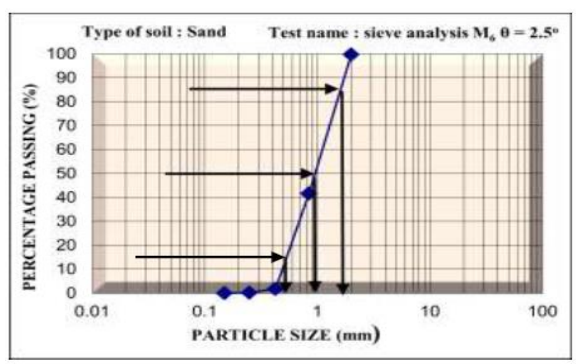


Figure (7) Grain size distribution

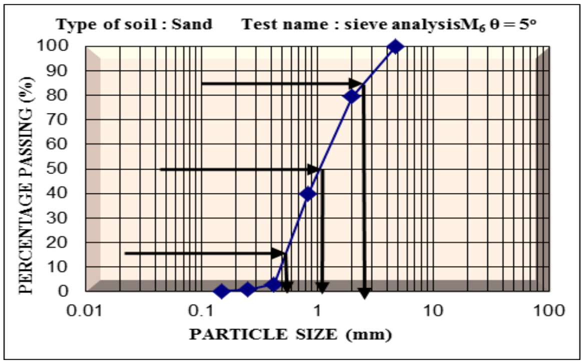


Figure (8) Grain size distribution

2. Scour depth Results

The relation between ds/y and Fr were documented and plotted, for all tested piers. Moreover, a regression analysis was carried out to correlate the two variables by means of polynomial equations in order to plot the best fitting curve. In the following figures (7) to (16), the Hexagonal (M_2) with angle 2.5 degree, and using soil diameter D_{50}/B range from 5.8×10^{-4} to 2.2×10^{-3} attained a better ability in scour depth reduction. In front of the pier, a significant impact on scour depth reduction was observed due to the fact that energy is dissipated in front of the pier. It reduced the scour by 55% of the maximum scour depth. The Oblong pier (M_3) was worst in the scour depth reduction, among the tested cases.

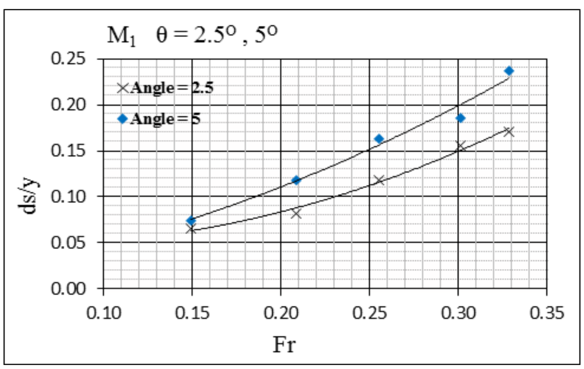


Figure (9) Relation between Fr and ds/y for M_1.

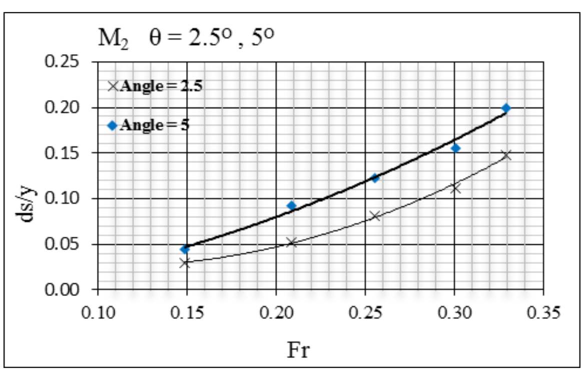


Figure (10) Relation between Fr and ds/y for M_1.

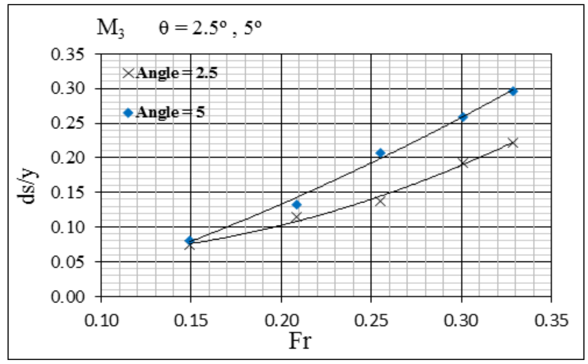


Figure (11) Relation between Fr and ds/y for M_3.

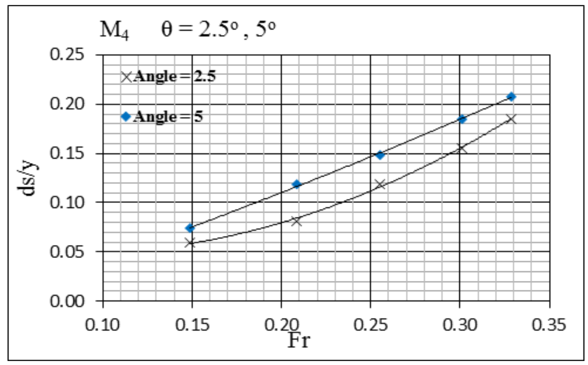


Figure (12) Relation between Fr and ds/y for M_4.

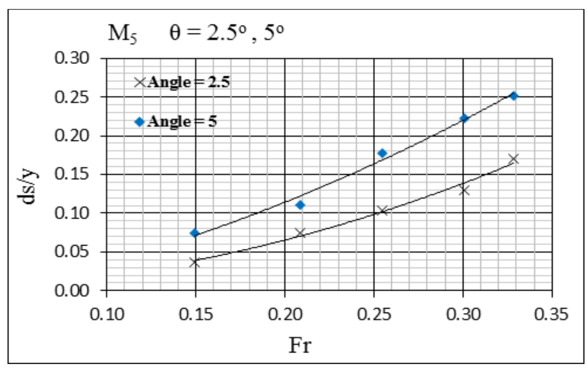


Figure (13) Relation between Fr and ds/y for M_5.

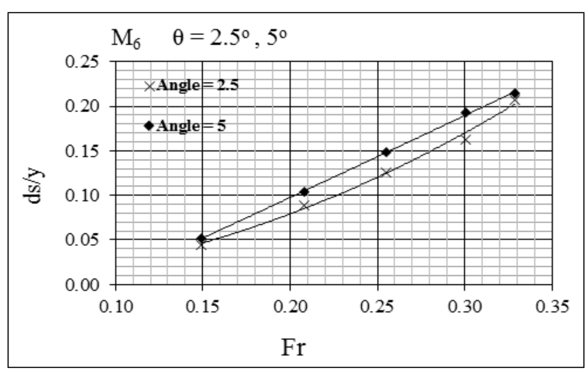


Figure (14) Relation between Fr and ds/y for M_6.

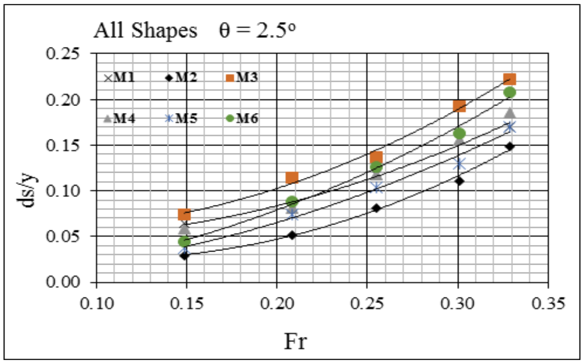


Figure (15) Relation between (Fr) and (ds/y) for all shapes.

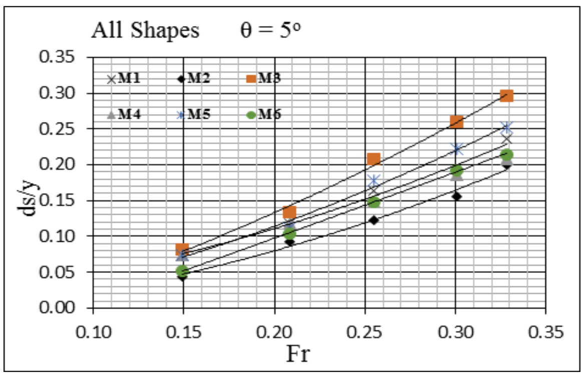


Figure (16) Relation between (Fr) and (ds/y) for all shape

Comparative Study

The measured results for different shapes and conditions have been plotted on charts, monitored and compared to reference study by Helmy A., (2017), some of which are illustrated in figures (17) to (24). The condition in which the hexagonal shape M_2 with rotation angle 2.5^0 using soil diameter D_{50}/B range from $5.8x10^{-4}$ to $2.2x10^{-3}$ led to the best scour depth reduction with a percentage of 22% to 35 %. On the other hand, this reduction is 18 % to 28 % for other shapes, with which the effect of rotation angle is simple.

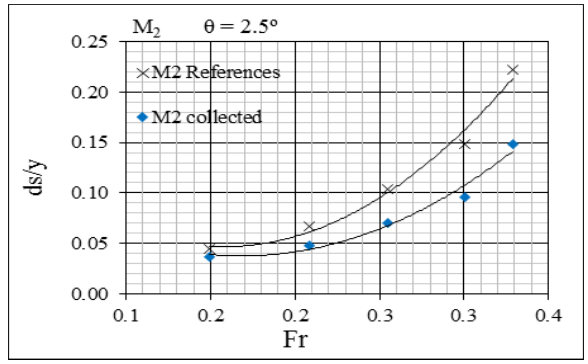


Figure (17) relation between Fr and ds/y for collected and References conditions.

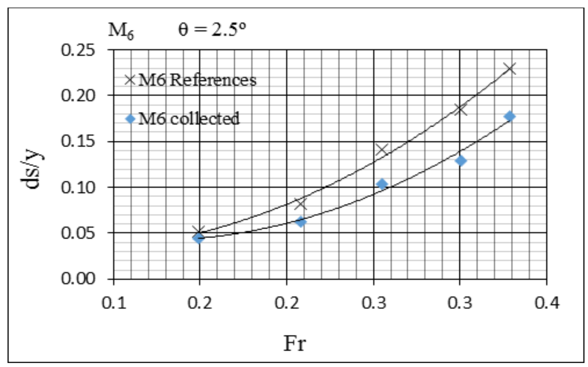


Figure (18) relation between Fr and ds/y for collected and References conditions.

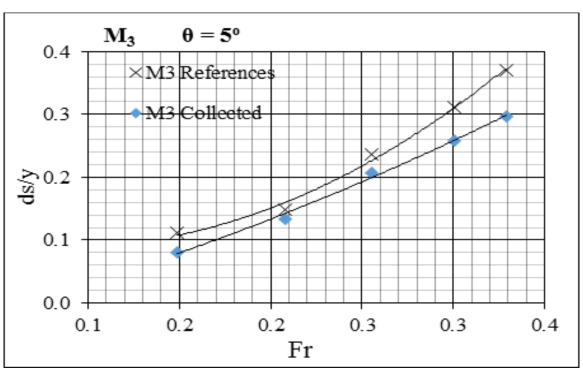


Figure (19) relation between Fr and ds/y for collected and References conditions.

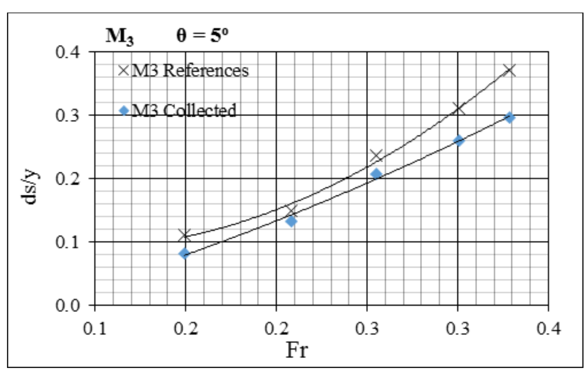


Figure (20) relation between Fr and ds/y for collected and References conditions.

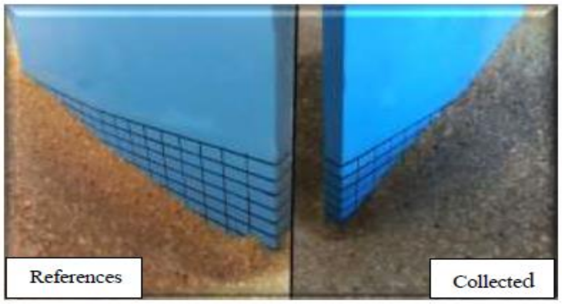


Figure (21) Local Scour (M_2 θ =2.5°)

Figure (22) Local Scour (M_3 θ =2.5°)

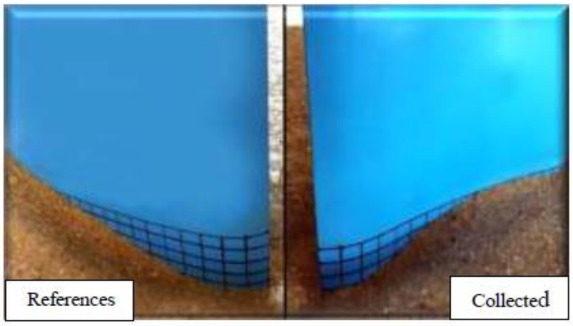


Figure (23) Local Scour (M_6 θ =2.5°).

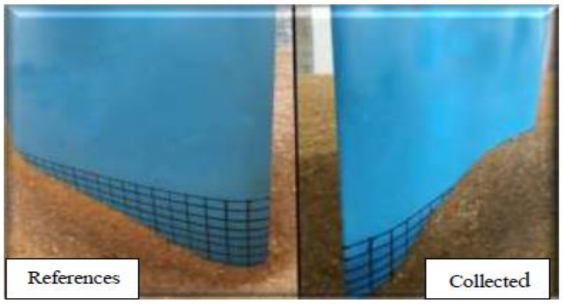


Figure (24) Local Scour (M_6 θ = 5°)

Conclusion

Size of soil particles around bridge piers in the curved channels has been studied experimentally for different conditions. From the current study, the following conclusions can be drawn:

1- The polygon (Hexagonal) (M_2), had the ability to reduce scour depth by 55% relative to the maximum scour depth.

2- The hexagonal shape M_2 with rotation angle 2.5° showed the lowest scour depth using soil particles diameter D_{50}/B range from $5.8x10^{-4}$ to $2.2x10^{-3.}$

3- The reduction of scour depth for M_2 with rotation angle 2.5^0 is 22% to 35 % lower than the maximum scour depth for the reference study while this reduction is 18 % to 28 % for other shapes.

4- Under the current study conditions, it is recommended to use soil particles of diameters range from 0.1 mm to 1.40 mm around bridge piers.

Notations:

B = Width of channel (L).
b = Distance from pier to the side (L).
R = Radius of curvature (L).
t = Thickens of piers (L).
Q = Flow rate (L^3T^{-1}).
Y = Normal water depth (L).
ρ= Mass density of fluid (ML^{-3}).
g = Gravitational acceleration (LT^{-2}).
T = Time interval (T).
T_O =Final time (T).
d_s = Scour depth (L).
L_S = scour length (L).
θ = Angle of orientation of pier with the direction of flow (dimensionless).
S.G = Soil Specific gravity (dimensionless).
D_{50} = Mean diameter of sediments (L).
μ =Dynamic viscosity ($ML^{-1}T^{-1}$).
d_s/y = Relative scour depth (dimensionless).
L_s/y = Relative scour length (dimensionless).
b/B = Contraction ratio (dimensionless).
Ls/L_b = Length ratio (dimensionless).
D_{50}/B = Relative soil diameter (dimensionless).
F_r = Froude's number (dimensionless).

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