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INVESTIGATING SCOUR DEPTH AROUND BRIDGE PIERS IN CURVED CHANNELS

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تعتبر عملية النحر حول ركائز الكباري في المجاري المائية من أكثر المشاكل التي تؤثر علي سلامة وأمان الكباري ويحدث النحر في قاع المجري المائي حول دعامات الكباري لأسباب كثيرة من أهمها تجاوز سرعة مرور التيار المائي حولها ووصولها للسرعات الحرجة التي تتحملها جزيئات مادة القاع وذلك نتيجة لاعتراضها بدعامات الكباري وقد تمت الكثير من الدارسات لدارسة النحر حول الركائز في مجاري المياه المستقيمة.

في هذا البحث سيتم دراسة النحر حول الركائز في القنوات المنحنية ومدي إمكانية تنفيذ ركائز في هذه المناطق وقدرة وكفاءة أشكال الركائز في تقليل طول النحر حول هذه الركائز. وقد تم اقتراح و استخدام أربع ركائز مختلفة الشكل والمقدمة (بيضاوي الشكل –مضلع (مسدس الشكل)- مستطيل ذو مقدمة نصف دائرة - مستطيل ذو مقدمة عدسيه). وقد تم دراسة تأثير اختلاف شكل الركيزة وكذلك شكل المقدمة علي طول النحر حول الركيزة. وقد أجريت دراسة نظريه باستخدام أسلوب التحليل العددي لإيجاد علاقة تربط بين الخصائص الأساسية والمتغيرات التي تؤثر علي تلك الخصائص وإيجاد علاقات نستطيع من خلالها تحليل تأثير تلك المتغيرات علي الخصائص الاساسيه .وأجريت دراسات معملية مكثفة علي قناة مستطيلة بقطاع (60سم *30 سم) وطول 8م تنقسم إلي ثلاثة أجزاء الجزأين الأول والأخير مستقيمان وبطول 3م لكل جزء والجزء الأوسط منحني ويميل بزاوية 30 درجة والقناة ذات جوانب شفافة وقد تم استخدام جهاز الموجات فوق ألصوتية لقياس أعماق النحر في قاع ألقناة حول الركيزة وقد تم وضع نمازج الركائز في منتصف الجزء المنحني الذي يميل بزاوية 15درجة علي الجزء المستقيم وكذلك في منتصف عرض القناة .

وتم تم دراسة كفاءة نوع وشكل نمازج الركائز علي التقليل من طول النحر حول النماذج وقد خلص البحث إلي أن أفضل شكل لتقيل طول النحر في حالة وضع الركيزة في منتصف المجري وبزاوية ميل علي المماس تساوي صفر كانت ذات الشكل المضلع(السداسي) وبنسبه تقل 17% عن أقصي طول نحر.

ABSTRACT

Local scour around bridge piers is one of the most common causes of bridge failures. Many researchers studied the scour around the piers of bridges in straight channels. However, there is little information about the scour at bridge pier in a curved channel. In this paper, scouring is studied in curved channel at 30 degrees. Various piers forms were investigated to study local scour in the middle of the channel. The experimental study was conducted in a glass-walled8 m long rectangular flume (i.e. 30 cm x 60 cm). It encompasses three parts (i.e. the first and last part are 3 m long, 60 cm wide and 30 cm high, the third part, at its middle, is curved with angle 30 degrees on the horizontal, 2 m length. The experimental program was designed to test relative distance (b / B = 0.5) under 5 discharges (i.e. 13.89, 19.41, 23.77, 28.04 and 30.64 l/sec). An ultrasonic device was used to measure the water levels and depths as well as the scour length so as the depth. This is achieved to investigate the pier type and shape efficiency in reducing the scour depth. It was found that the best performance was achieved in the case, where the substrate was placed in the middle of the waterway and the inclination angle was equal to zero, where the hexagonal reduced the scour depth by 34%,relative to the maximum depth of scour.

1. INTRODUCTION

Bridge structures are most important structures. If they crack or collapse major damage will be evident accordingly, many studies were conducted to determine the factors that affect these

structures. It is worldwide known that pier scour "is the erosion of the streambed in the vicinity of the pier foundation due to complex vortex system". This system consists of a horseshoe vortex and wake vortices. There is little information about scour around piers.
This research provides scour depth experimental results for different pier shapes placed in a curved channel in order to apprehend the effect of curvature on scour depths.
Many bridges failed in many countries due to extreme scour around bridge piers and abutments during floods, Shirole and Holt (1991). Accordingly, foundation of a pier of a bridge in an erodible riverbed is quite expensive. This is attributed to the fact that it should provide the minimum anchorage length for the safety of the foundation. Therefore, failure of bridges due to scour results in economical loss and might result in losses of human life.
Piers and abutments are integral part of a bridge structure that obstruct the natural river flow and result in local scouring around them. Local scour involves removal of material around piers and abutments. It is caused by an acceleration of flow around the bridge foundation. Local scour can be either clear-water or live-bed. Live-bed conditions occur when there is transport of bed material in the approach reach.
Clear-water conditions occur when there is no bed material transport. Live-bed local scour is cyclic in nature as it allows the scour hole to develop, (during the water rising stage), it refills during the falling stage. Clear-water scour is permanent as it does not allow a scour-hole refilling. Many researchers were involved in investigating the local scour around bridge piers in water ways, experimentally or numerically or theoretically. Many researchers investigated scour around bridge piers and abutments, among them, for example are: van Rijn, Leo C. (1993) Venkatadri, C. (1965), White W. R. (1973), Sheppard, D. M. (2004), Sheppard, D. Max, MufeedOdeh and Tom Glasser (2002), (2004), Sheppard, D. Max, Jeffrey Sheldon, Eric Smith, and MufeedOdeh (2000), Sheppard, D. Max, MufeedOdeh, Tom Glasser, and Athanasios Pritsivelis (2000) and Sheppard, D. Max. (2000). all this studies have been done in straight channels.
In order to study local scour, 6cmdiameter pier was located in the straight channel and also in sections 30 and 60 degrees in the bend. This study estimated the minimum amount of scour depth "ds" for different discharges, when a pier is located in the bend.
Based on the present study results, the location of scour hole in the bend is close to the outer wall of channel and the point bar is close to the inner wall of channel.
The main feature of a bend flow is the presence of spiral flow and lateral sediment transport across the channel bend. Particles at the surface of the flow in the bend tend to move towards the outer wall while at the bed elevation they tend to move towards the inner wall of channel (Odgaard and Bergs, 1988).
This paper presents the experimental results on scour at a multi shapes pier located at different sections in a 30 degrees channel bend.

2. RESEARCH OBJECTIVES

This study was initiated in order to investigate the local scour around bridge piers. 60 cm wide and 800 cm long flume was implemented to investigate curved channel (flume). Also, among the research objectives were to determine the best shape that could offer the least scour depth (ds).

3. THEORETICAL INVESTIGATION

A theoretical study was conducted using numerical analysis method to detect the relationship between the various parameters and variables for all pier shapes; figure1. Functional relationships were obtained for the relative depth of the scour hole (ds / ds_m) for the various shapes

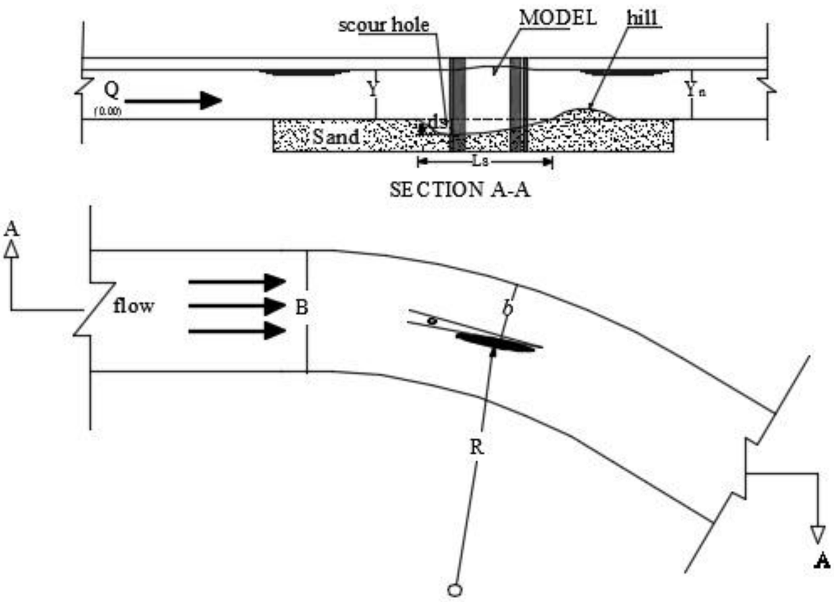


Fig.1 Definition sketch of all parameters.

The scour depth "ds" is the dependent variable .It can be expressed as a function of all other independent variables as follows.

ds : Φ (B , b ,ds_m, T ,T_o ,t, Ls, Ls_m, y, Q , ρ, g, μ, Ø, D_{50} , R ,S.G, θ) ………………..….(1)

Regarding the boundary characteristics, they are, as follows:
B**:** Width of channel.
B**:** Distance from pier to the channel side
R**:** The radius of curvature
t**:** Thickness of piers
g : Gravitational acceleration
As for the flow characteristics, they are, as follows:
Q**:** Discharge.
Y**:** water depth
Focusing on the fluid characteristics, they are, as follows:
P: Mass density of fluid.
V: Kinematic viscosity.
g: Gravitational acceleration
T:Time interval
T_O: Final time
Concerning the scour hole parameters, they are, as follows:
Ds: Maximum scour depth.
L_S: Length of scour hole.
θ : Angle Tilt pier with the direction of flow
ds_m: max scour depth
Ls_m: max scour Length
As for the soil characteristics, they are, as follows:
S.G : Soil Specific gravity.
D_{50}: mean diameter of sediments.
Where:
Q: the discharge
ρ: the density of fluid
g: the gravity acceleration
μ: the dynamic viscosity
S.G: the specific density
Ø: the selected soil diameter

R: The radius of curvature
Due to the fact that the implemented soil wasn't changed, parameters Ø and S.G could be removed from the variables.
According to Buckingham π-theorem, ten variables (π-terms and 2 repeated variables) are available.
These variables were arranged and the following non-dimensional π-terms were obtained

$\pi_1 = ds/B$ $\pi_2 = b/B$ $\pi_3 = ds_m/B$ $\pi_4 = Ls_m/B$

$\pi_5 = T/T_O$ $\pi_6 = L_S/ B$ $\pi_7 = B/Y$ $\pi_8 = QT/B^3$

$\pi_9 = D_{50}/B$ $\pi_{10} = Q2 / B^5 g$

Taking the properties of **π**-terms into account, the following relationship was obtained.

$$\phi = \left(\frac{ds}{ds_m}, \frac{Ls}{Ls_m}, \frac{b}{B}, \frac{D_{50}}{R}, \frac{T}{T_O}, \frac{V}{\sqrt{gy}}, \theta \right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

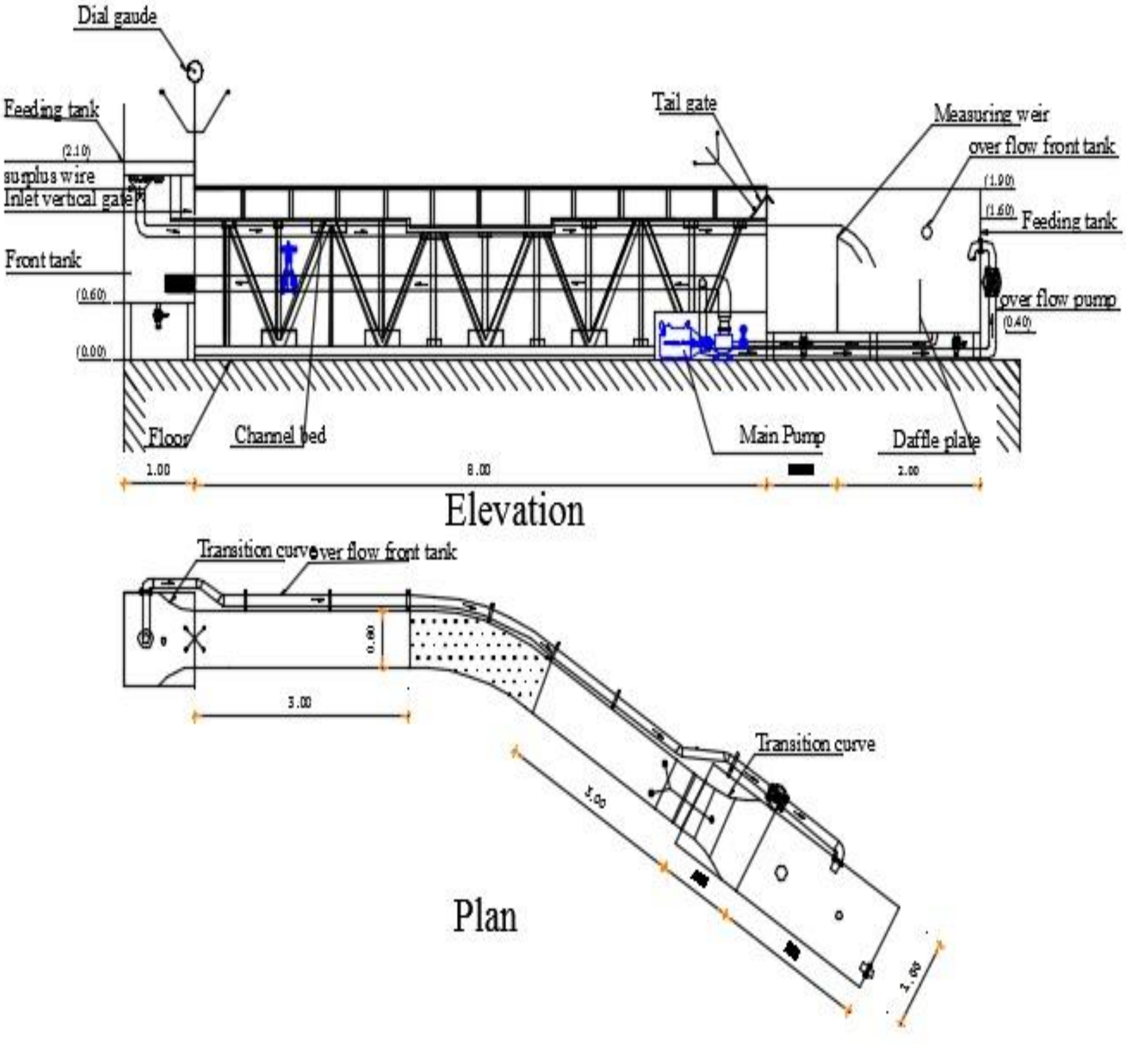
Where:
ds/ds_m is the relative scour depth
Ls/y is the relative length of scour hole to be protected
b/B is the, the contraction ratio
QT/y^2 is the time factor
V/√gy is Fr the Froude number through the channel
Accordingly, the following functions were obtained:

$$\frac{ds}{ds_m} = \phi\left(\frac{Ls}{Lsm}, \frac{b}{B}, \frac{T}{T_O}, Fr \right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

4. EXPERIMENTAL WORK

The experimental investigation has been conducted in an experimental flume at hydraulic laboratory of the faculty of engineering, Al- Azhar University, Cairo, Egypt (photo 1). The flume is 800 cm long, rectangular cross section steel frame of 60x30 cm^2 with visible clear polycarbonate sides to allow visual observation of the water surface. The flume layout is presented in details as shown in fig. 2.
The physical model (pier) is made from Polly carbonate. Four models shaped are suggested as traditional pier for this study. The test program was developed to deal with the pier shape as a mitigation technique against local scour, with a major focus on the time required to achieve an equilibrium scour condition. The test program was done on four different shapes, Elliptical, Hexagonal, Oblong and lenticular, as indicated in table 1. Experiments were conducted under clear-water conditions at different water discharges 13.89, 19.41, 23.77, 28.04 and 30.64 lit/sec and maximum depth of scour was measured. The test conditions for each shape of bridge piers are summarized in Table 1.

Photo: (1) General view of the experimental flume at Al- Azhar University.



Sketch: (1) Experimental flume layout.

Table: (1) Test condition for test series

NO	Shapes	Y(cm)	Velocity in channel cm/s	Q (L/s)	Fr
M_1	Elliptical 	13.5	17.15	13.89	0.15
			23.93	19.41	0.21
			29.34	23.77	0.25
			34.62	28.4	0.3
			37.83	30.64	0.33
M_2	Hexagonal 	13.5	17.15	13.89	0.15
			23.93	19.41	0.21
			29.34	23.77	0.25
			34.62	28.4	0.3
			37.83	30.64	0.33
M_3	Oblong 	13.5	17.15	13.89	0.15
			23.93	19.41	0.21
			29.34	23.77	0.25
			34.62	28.4	0.3
			37.83	30.64	0.33
M_4	Lenticular 	13.5	17.15	13.89	0.15
			23.93	19.41	0.21
			29.34	23.77	0.25
			34.62	28.4	0.3
			37.83	30.64	0.33

The models were placed at b/B=0.5 and at a tangential angle of zero. The bed material (sand) was accurately leveled and the leveling accuracy was checked by means of a water gauge and Ultrasonic meter; photo 2, The model is fitted at the assigned position. During the run, an ultrasonic device measured the water levels, depths and the scour depth.

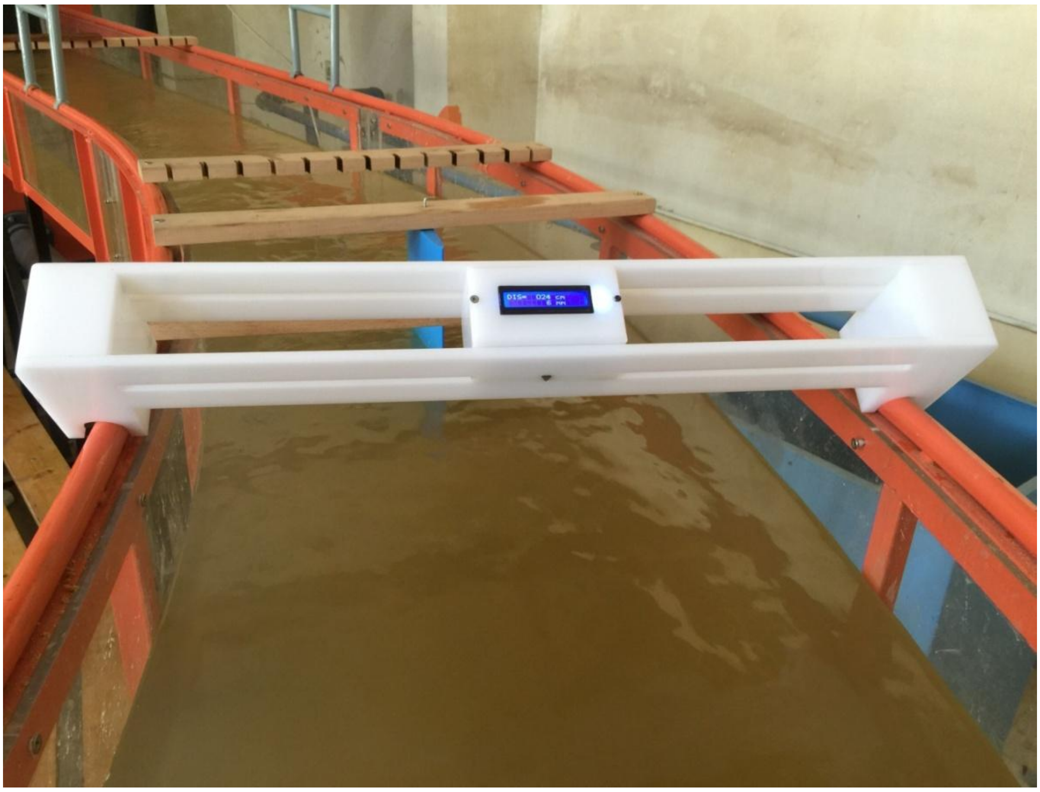


Photo: (2) Measuring device (Ultrasonic device - one spot).

5. ANALYSIS

Twenty (20) experiments were carried out; where angle was used at five (5) different discharges. Measurements were undertaken. Observations were recognized and photos were captured.

These measurements, observations and photos were documented and archived. They were analyzed, comprehended and plotted on graphs. These graphs are presented here. They are discussed with regard to the scour depth and time, as follows:

6.1. SCOUR DEPTH RESULTS

The relation between ds/dsm 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.

Figures (2) to (6) present the relation between the relation between ds/dsm and Fr, from which, the following were observed:

- In general, ds is directly proportional to F_r.
- ds was found to be directly proportional to F_r.
- As for Elliptical pier (M_1), it contributed in the reduction of the scour depth ranged 18%.
- For all the tested cases the appropriate pier shape is the Hexagonal shape (M_2) it contributed in the reduction of the scour depth in the range 34%.
- Concerning the polygon (hexagonal shape (M_3), it contributed in the reduction of the scour depth by 27%.
- Concerning the lenticular pier (M_4) it contributed in the reduction of the scour depth by 27%.
- The concluded aspects are listed on table no (2).

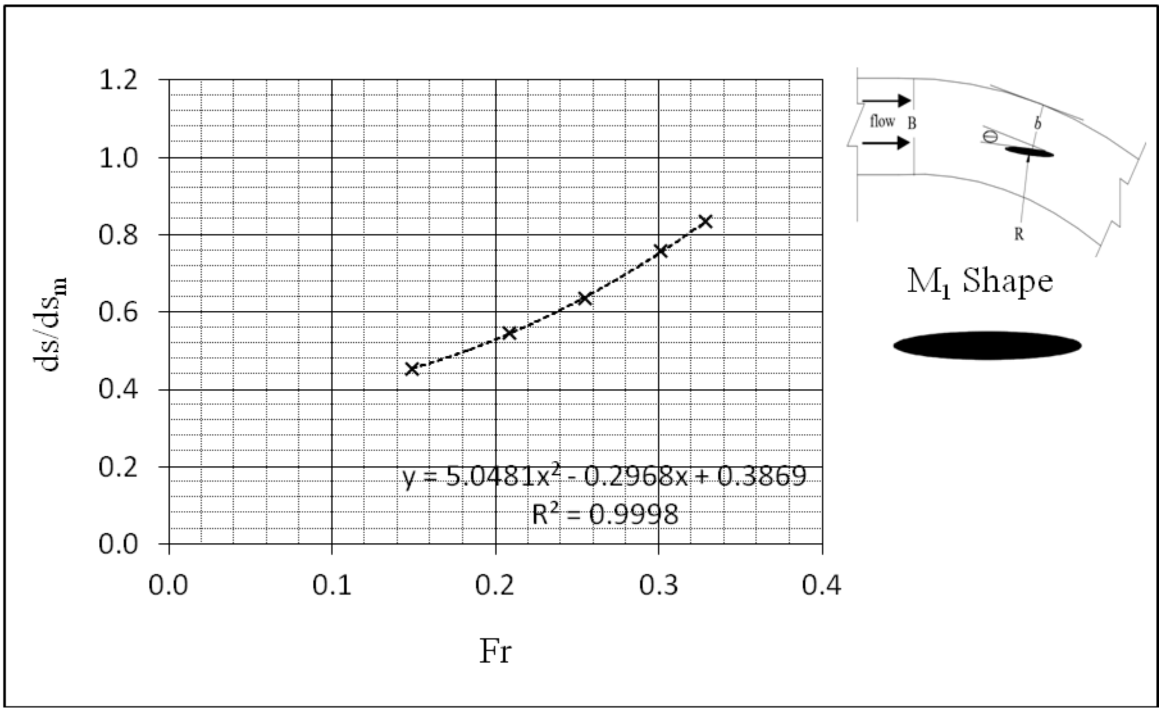


Figure: (2) The relation between (Fr) and (ds/ds_m)

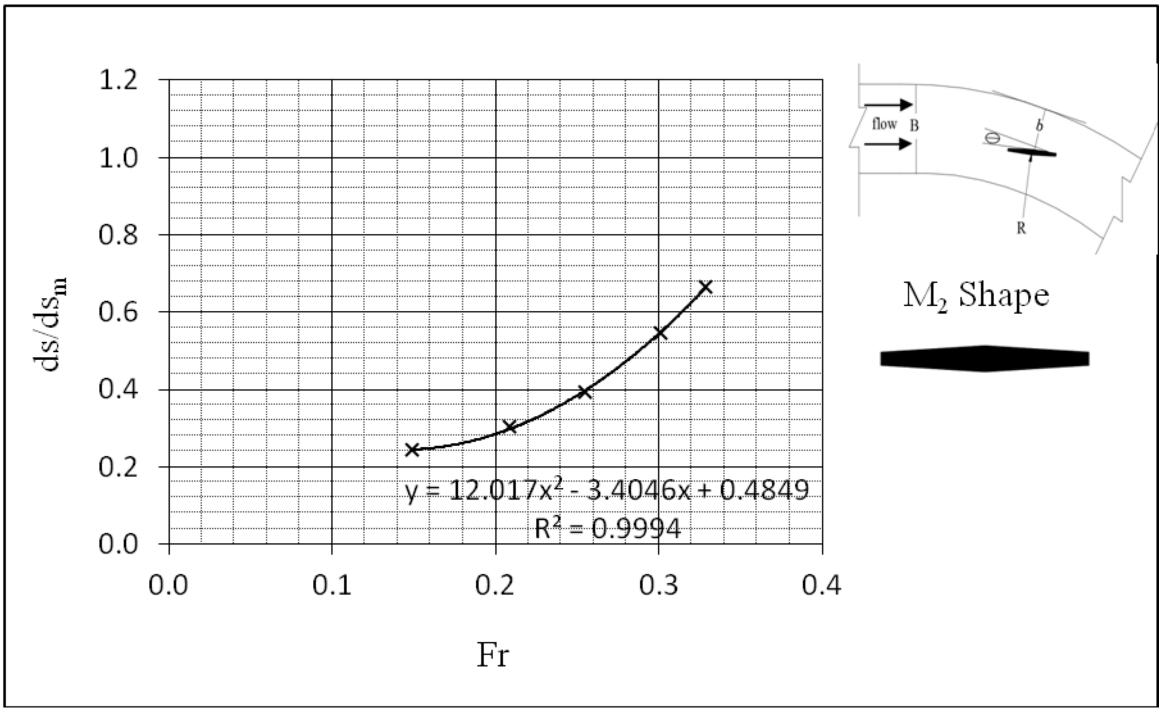


Figure (3): The relation between (Fr) and (ds/ds_m)

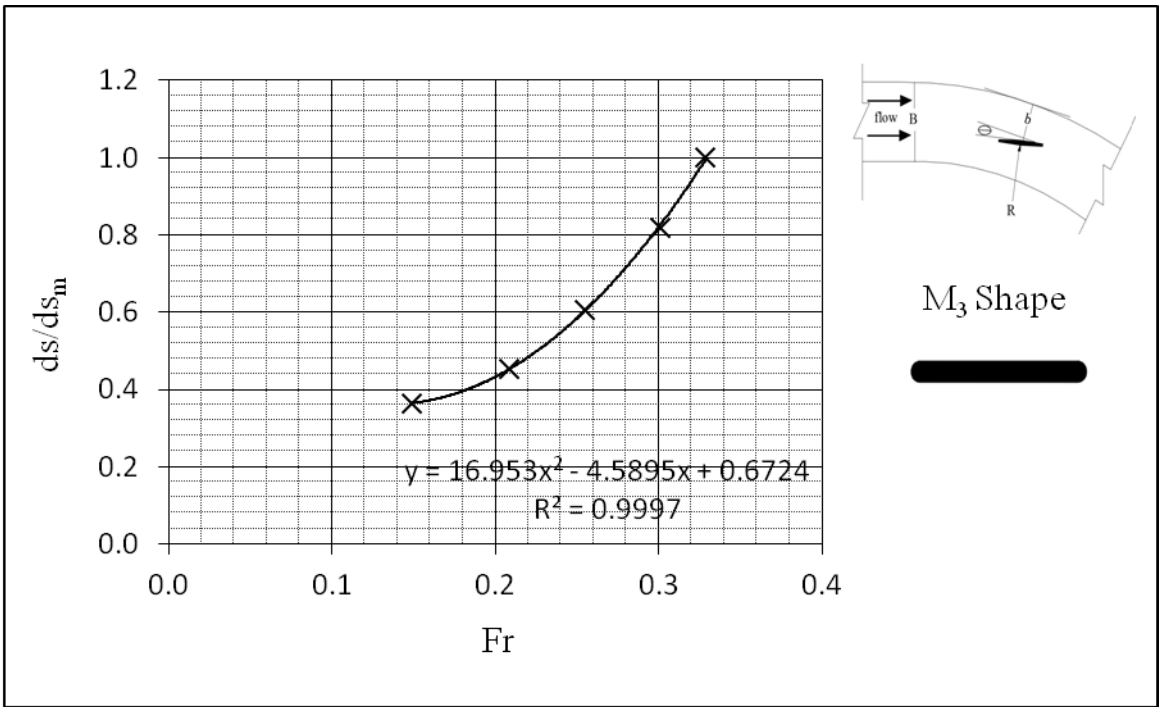


Figure: (4) The relation between (Fr) and (ds/ds_m)

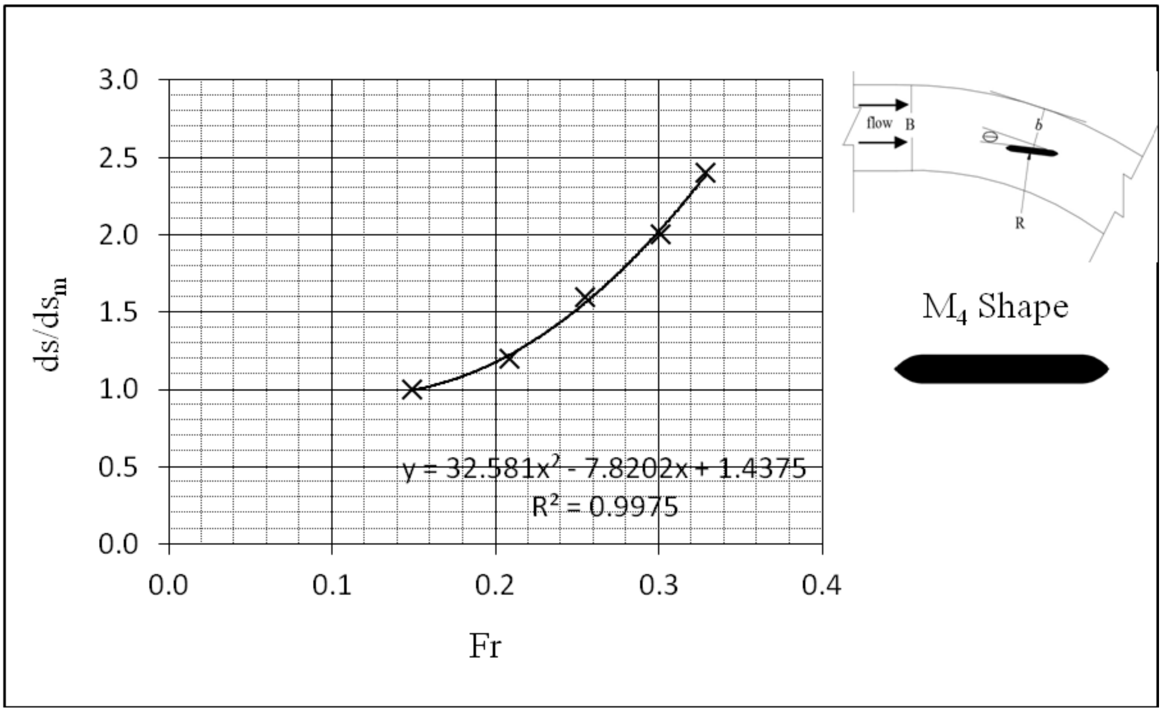


Figure: (5) The relation between (Fr) and (ds/ds_m)

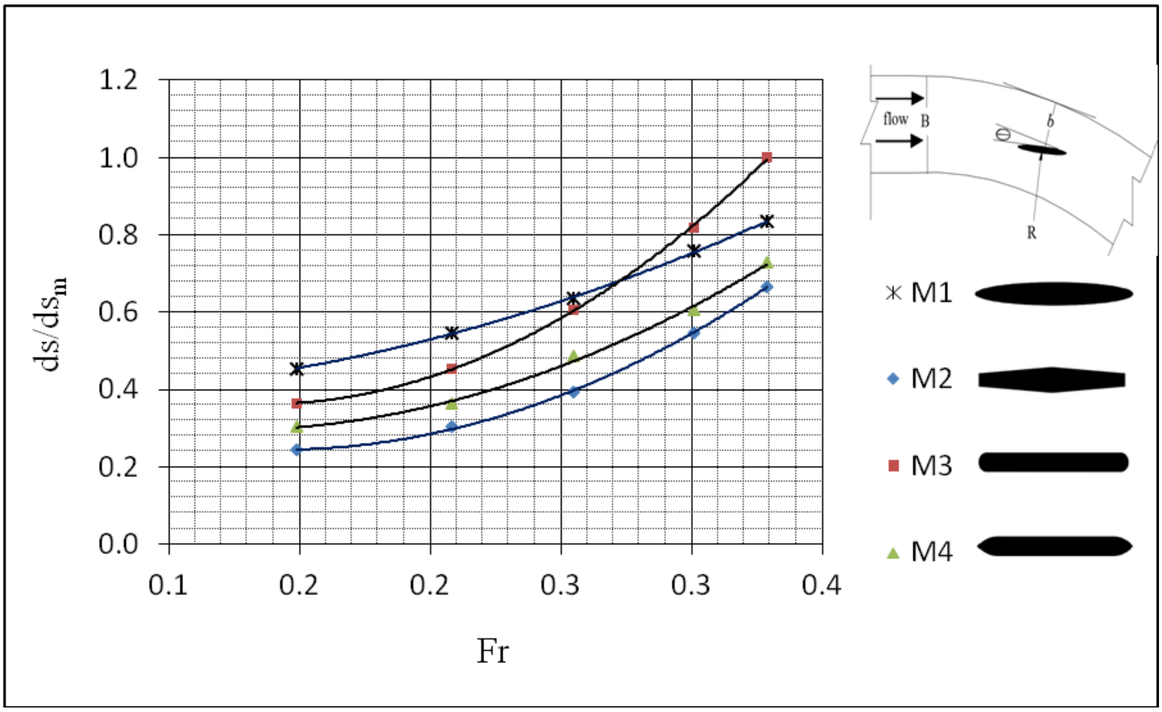


Figure: (6) The relation between (Fr) and (ds/ds_m) for all shapes

Table (2) Pier shape effect

shape	Froude number (-)	ds (cm)	ds/dsm (%)
M_1	0.15	1.5	45
	0.33	2.75	83
M_2	0.15	0.8	24
	0.33	2.2	67
M_3	0.15	1.2	36
	0.33	3.3	100
M_4	0.15	1	30
	0.33	2.4	72

5.2.RATE OF SCOUR DEPTH CHANGES

The rates of scour depth changes were determined. The relations between ds/dsm and T/T_O were correlated. A regression analysis was executed to determine the best fitting curves to which logarithmic functions equations were derived, equations (1) to (4).

$$\frac{ds}{ds_m} = 0.11Ln\left(\frac{T}{To}\right) + 0.85$$ For M_1, Fr = 0.33 .... (4)

$$\frac{ds}{ds_m} = 0.091Ln\left(\frac{T}{To}\right) + 0.668$$ For M_2, Fr = 0.33 .... (5)

$$\frac{ds}{ds_m} = 0.138 Ln\left(\frac{T}{To}\right) + 1.027$$ For M_3, Fr = 0.33 ……………………………… (6)

$$\frac{ds}{ds_m} = 0.07 Ln\left(\frac{T}{To}\right) + 0.721$$ For M_4, Fr= 0.33 …………………………….. (7)

Moreover, figures (7) to (11) were plotted to present the relation between ds/dsm and T/T_O, from which, it was observed that the value of relative scour depth (ds/ds_m) increases by time.

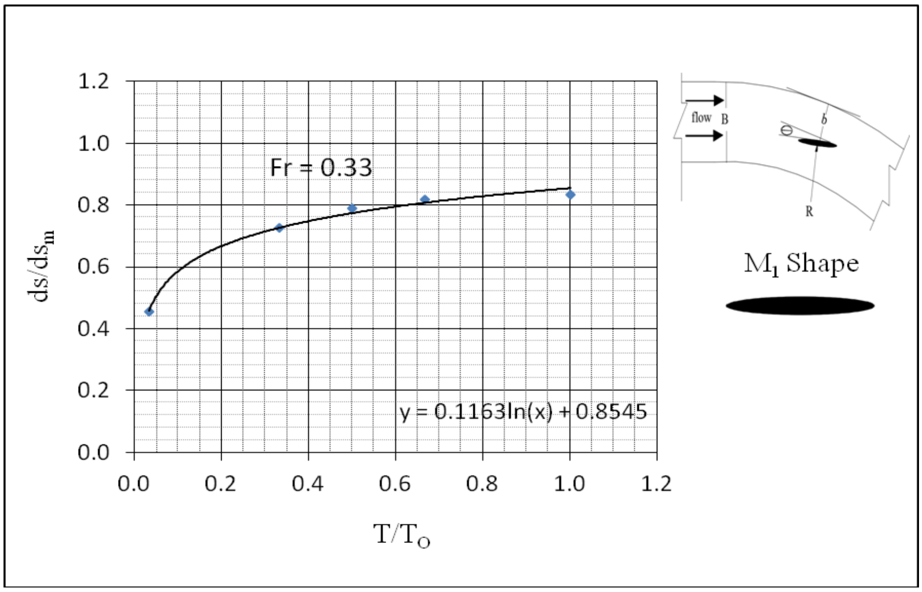


Figure: (7) The relation between (T/T_O) and (ds/ds_m)

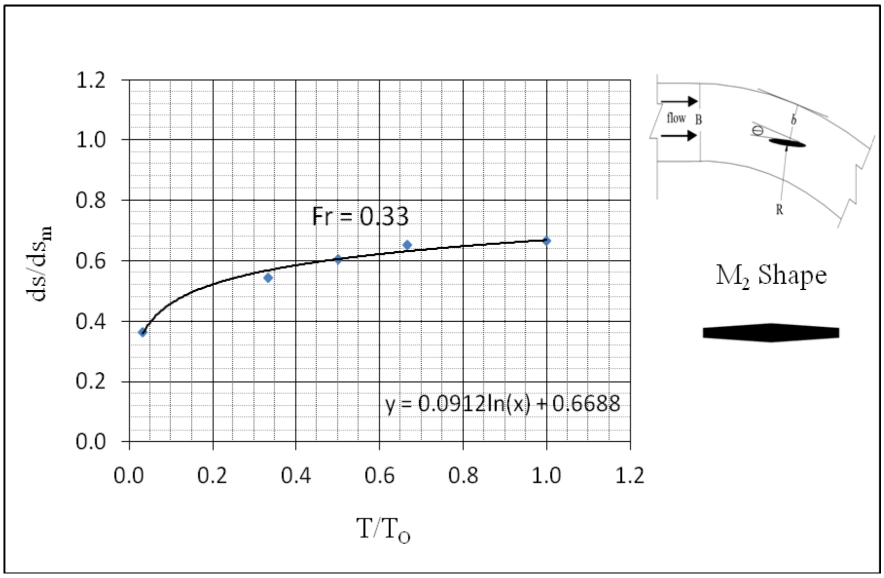


Figure (8): The relation between (T/TO) and (ds/dsm)

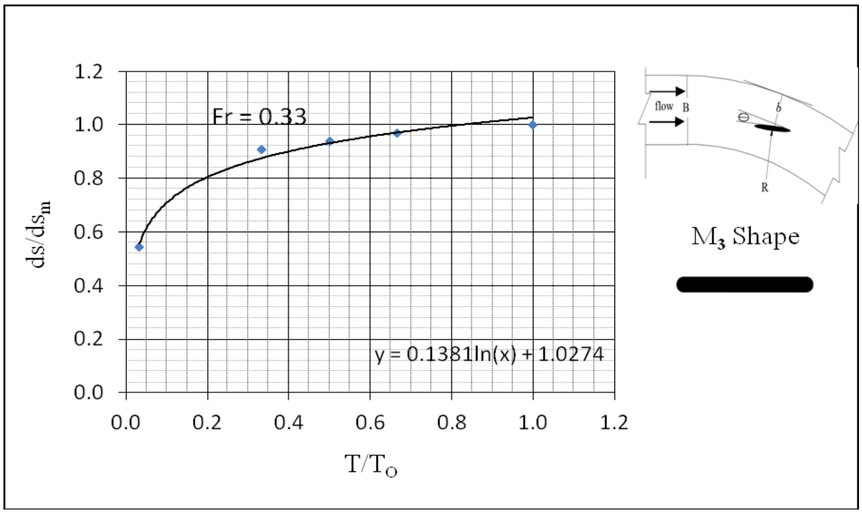


Figure (9): The relation between (T/T_O) and (ds/ds_m)

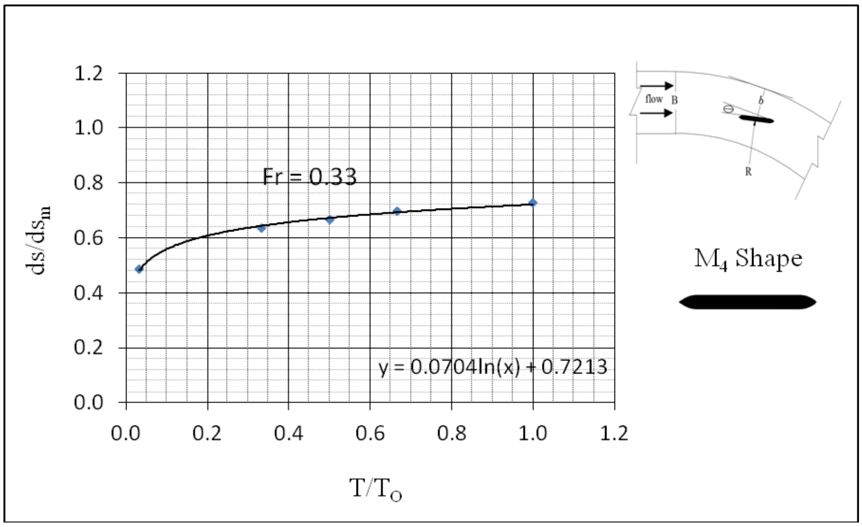


Figure: (10)The relation between (T/T_O) and (ds/dsm)

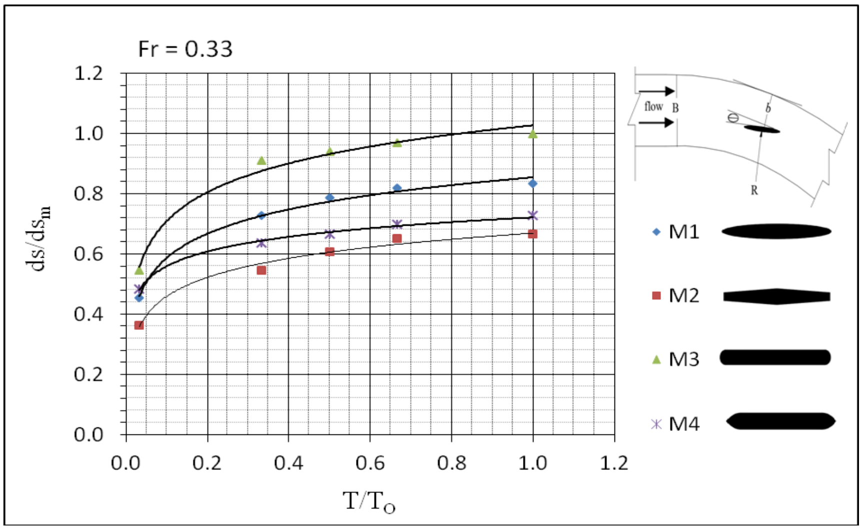


Figure: (11) The relation between (T/T_O) and (ds/ds_m) for all shapes

6. CONCLUSIONS

Based on the above investigations, the conclusions are as follows:

- Piers are to be placed in curved channels with precautions
- The Polygon (hexagonal) piers are capable of reducing the scour depth, reasonably for the inclination angle to the tangent is equal to zero by 34% from maximum depth of scour.
- The elliptical shape was not effective at deceasing the depth of Scour

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