Journal of Kerbala University , Vol. 13 No.4 Scientific . 2015

SCOUR DEPTH MEASUREMENT AROUND PIERS OF AL HINDIYA SECOND BRIDGE

حساب عمق الانجراف حول دعامات جسر الهندية الثاني

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ABSTRACT

Local scour is the erosion of natural bed material around bridge piers by the vortexes action of flowing water. It can result in structural collapse, loss of life and property. Local scour is live-bed if the flow upstream bridge is transporting bed material, otherwise it is clear water. In this paper, the local scour around the piers of al-Hindiya second bridge during the year 2013 was studied. From field surveys at the bridge site it was observed that the cross section area of river upstream bridge is concentrated to the left side as a result of the presence of middle bar. Also there is a scour hole with depth about 4 m around the 4^{th} pier from left bank of the river, while no scour effect was found at the other piers. The field scour depth was compared with depth calculated from the seven empirical equations using bridge geometry, bed materials properties and hydraulic characteristics of the stream flow at approach channel. Laursen's equation was used to find critical velocity of bed materials which showed that there was clear water scour around bridge piers and the scour formula by Sheppard & Melville 2006 had a good agreement with measured scour depth, while other equations were underestimation. Depending on Sheppard and Melville equation a new empirical formula was proposed for al-Hindiya second bridge to predicate the scour depth around the pier corresponding to the hydraulic conditions similar as the study region.

KEYWORDS: Local scour, Pier, Al-Hindiya second bridge, Approach channel, clear water, live bed.

الخلاصة

الانجراف الموقعي هو تآكل تربة قاع النهر المحيطة بدعامات الجسر بفعل تأثير قوة الماء الجاري وقد يؤدي الى انهيار الجسر وإلحاق خسائر بشرية ومادية. يعتبر الانجراف الموقعي live - bed إذا كان هناك انتقال للرسوبيات مع الجريان من مقدم الجسر وإلا يعتبر clear - water. في هذا البحث تم دراسة الانجراف الموقعي حول دعامات جسر الهندية الثاني خلال عام 2013. من المسوحات الحقلية عند موقع الجسر تم ملاحظة وجود تضييق في مقطع النهر مقدم الجسر وتحول مجراه الى اليسار نتيجة وجود جزرة وسطية. أيضا وجود انجراف موقعي بعمق حوالي 4 م حول الدعامة الرابعة للجسر من جهة اليسار بينما لا يوجد انجراف ملحوظ حول بقية الدعامات. تم مقارنة العمق المقاس مع العمق المحسوب من سبعة معادلات وضعية باستخدام معلومات عن شكل الجسر، خصائص مادة القاع و الخصائص الهيدروليكية للجريان مقدم الجسر. تم استخدام معادلة Laursen لحساب السرعة الحرجة لمادة القاع والتي بينت ان نوع الانجراف هو clear- water وان معادلة Sheppard & Melvilleهي الأكثر تطابق مع القيمة الحقلية بينما المعادلات الأخرى اعطت قيم اقل لعمق الانجراف. اعتمادا على معادلة Sheppard and Melville تم التوصل الى صيغة وضعية جديدة لحساب الانجراف الموقعي حول دعامات جسر الهندية الثاني تلائم الظروف الهيدروليكية لمنطقة الدراسة.

1- INTRODUCTION

Local scour at bridge pier is a natural phenomenon and one of the main common cause of highway bridge failures which results in the loss of lives and financial losses. It caused by generation of vortices (horseshoe vortex) as water accelerates around the piers. Vortices, which move downward at the upstream end of the pier leading to move materials from the base, creating a scour hole. As the depth of scour increases, the strength of horseshoe vortex will be reduced and the rate of scour from the base is decreased, over a period of time an equilibrium is occurred [1][2]. It can occur either clear-water scour or live-bed scour. In clear-water scour, bed materials are removed from the scour hole, but not filling by the approach flow, moreover, scouring ceases when the shear stress caused by horseshoe vortex is equal to the critical shear of the sediment particles and the down flow no longer able to remove particles from the bottom of scour hole. In live-bed scour the scour hole is continually supplied with sediment by the approach flow and, equilibrium is obtained when the inflow bed material is equal to the outflow and scouring ceases[3]. In addition to the horseshoe vortex around the base of a pier, there are vertical vortices downstream of the pier called the wake vortex. The wake vortex system is formed by the rolling up of the unstable shear layers generated at the surface of the pier which are detached from either side of the pier at the separation line behind the pier. Both the horseshoe and wake vortices remove material from the pier base region. However, the intensity of wake vortices diminishes rapidly as the distance downstream of the pier increases. Therefore, immediately downstream of a long pier there is often deposition of material fig. (1).

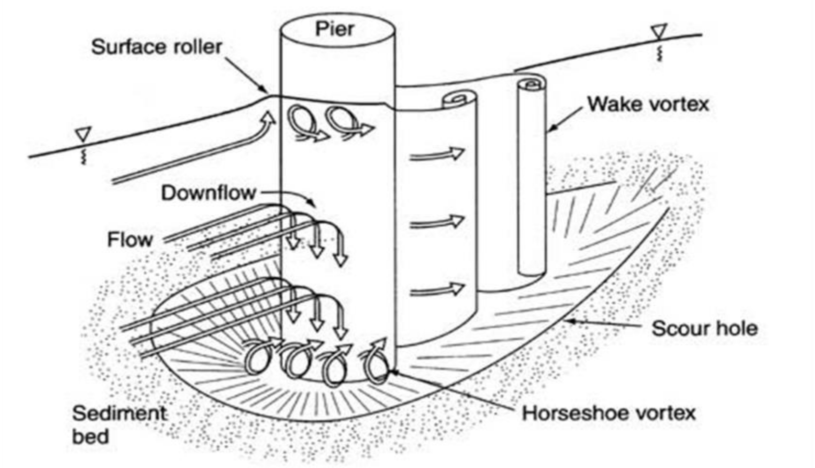

Figure (1): Mechanism of local scour around pier [1]

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A review of previous studies shows that a large number of empirical formulas were proposed to estimate pier scour depth, such as (Laursen and Toch, 1956, Shen et al., 1969; Breusers et al., 1977; Jain and Fischer, 1979, Melville and Sutherland, 1988; Froehlich, 1989 Richardson, 1994; Lim, 1997 and Heza et al., 2007, Haque, 2002, Tafarojnoruz et al. 2011 and many others) [4],[5][6]. Most of these empirical equations were based on laboratory results and field data and they differ from each other with respect to the factors considered in constructing the scour model, parameters used in the equation, laboratory or site conditions, etc.

The main purpose of the present work is to study the local scour depth around Al- Hindiya second bridge in Euphrates river, by using field data with seven empirical pier scour equation and then find the most appropriate formula for the bridge.

2- Dimensional analysis

Scour at piers is influenced by various parameters, The main factors are[7]:

1- Properties of the fluid, such as density and viscosity.

2- Approach channel flow, such as water depth, velocity , critical velocity and gravity.

3- Bed material properties, such as grain size and density .

4- Pier shape and size.

The relationship showing the influence of various parameters on the equilibrium scour depth ds at piers can be given in functional form as follows:

$$ds = f_1 (k_s, k_\theta\ v, y, d_{50}, b, \rho_s, \rho, \mu, g, v_c) \quad \ldots\ldots\ldots\ldots..(1)$$

where:

ds: Scour depth.
K_s : Coefficient for pier shape.
K_θ: Coefficient for pier alignment.
v : Approach velocity.
y : Approach flow depth.
d_{50} : Median sediment diameter.
b : Pier width.
ρ_s: Density of sediment.
ρ : Density of water at a pier.
μ : Dynamic viscosity of water.
g : Acceleration due to gravity.
v_c : Critical velocity of sediment corresponding to initiation of sediment motion.

The dimensional analysis technique using Buckingham π-theorem was applied to obtain dimensionless groups, if the variables ρ, v, b are chosen as repeating variables, the flowing functional relationship illustrates scour depth normalized with pier diameter

$$\frac{ds}{b} = f_2 \left(\frac{v}{v_c}, \frac{y}{b}, \frac{d_{50}}{b}, \frac{\rho_s - \rho}{\rho}, \frac{\rho v b}{\mu}, \frac{gb}{v^2}\right) \quad \ldots\ldots\ldots..(2)$$

The density ratio can be assumed constant for non cohesive sediment, and the pier Reynolds number (ρvb/μ) influences are assumed negligible for the fully turbulent flows [8]. On the other hand, gb/v^2 can be replaced by Froude number .Therefore, the other form which can represent the scour depth as the function of dimensional parameters is

$$\frac{ds}{b} = f_3 \left(\frac{v}{v_c}, \frac{y}{b}, \frac{d_{50}}{b}, Fr\right) \quad \ldots\ldots\ldots..(3)$$

Different field measurements at Al-أHindya second bridge piers were conducted to reduce the effect of parameters on the maximum depth of local scour , and to find a new formula to predict the scour around the piers.

3- Study area

Al- Hindiya second bridge is located across Euphrates river on longitude 44º 13' 45" E and latitude 32º 32' 12" N, it was constructed during the period (2006-2009) at Al- Hindiya city 22 km east Karbala in Iraq fig. (2). It consists of 11openings separated by 10 piers (each pier contains three cylindrical columns) where the diameter of each column is 1.5 m and the space between two adjacent column are 5 m fig. (3). All bridge piers in the main channel are aligned with the flow. The total length of the bridge is 265 m and the width is 15 m , the abutments of the bridge is consist of two piers for each one, and they were built out of the section of the river.

Figure (2): Al- Hindiya second bridge

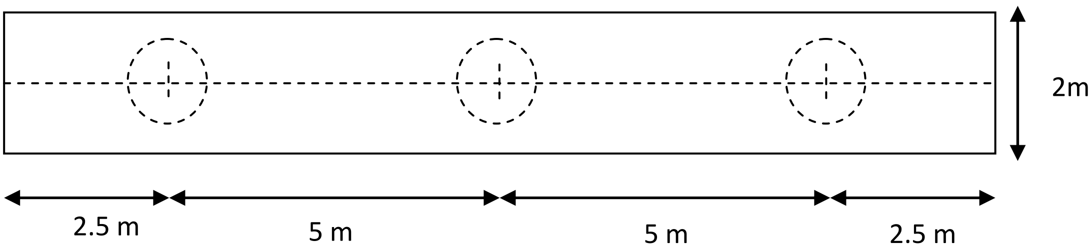


Figure (3): Top view of pier

4- Field investigations

Field investigation at bridge sit showed that there was river bar upstream the bridge forced the river to the lift side. Bars are large natural deposits, generally occurring in meandering or braided rivers, at bridge sites, bar emigration can reduce channel waterways and redirect flows, possibly resulting in increased scour owing to flows concentrating at bridge foundations or in channel confluence[9]. Figure (4) shows the cross section area of river upstream bridge (approach channel) which was obtained from al- Hindiya Water Resources Directorate. As shown in the figure the formation of island concerned the approach river cross section to the left side where the first four piers are existing, also it can see from fig.(4) the position of the first pier is on the left bank, while no scour effect was observed at the second and third piers and there is a deposition around them, that is because, the earth fill which was used during the construction of the bridge didn't left entirely.

Scour depth was clearly shown at the fourth pier from left side which is located nearby the bar. Therefore in this paper the forth pier from the left bank would take into account in the survey of local scour ,while at other piers the scour effect was unobserved due to deposition and bar effect which causes the rise in bed level at piers site.

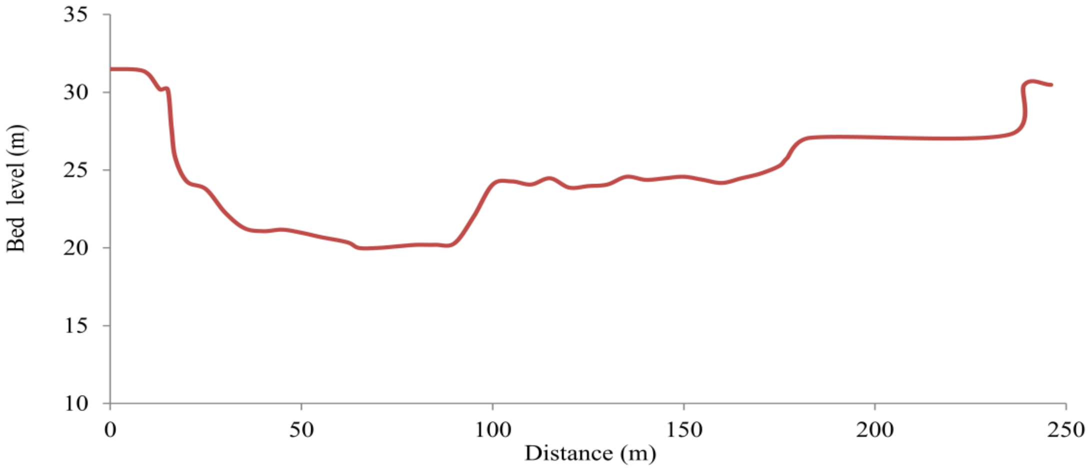
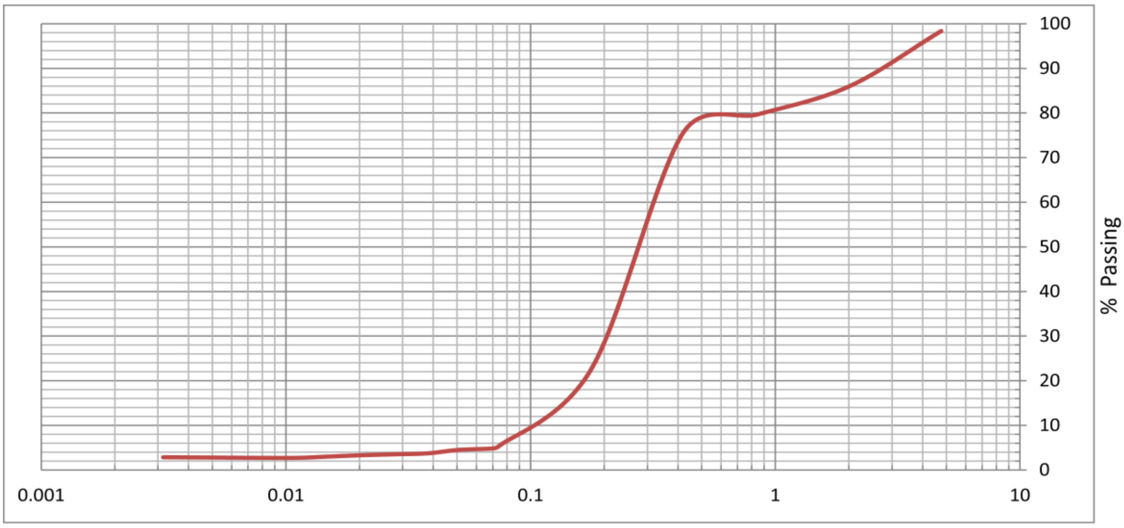


Figure (4): cross section area of river upstream Al- Hindiya second bridge

(Al- Hindiya Water Resources Directorate)

4-1 Bed material sampling

Bed material samples were collected from the approach cross section at the bridge site. The bed materials were sampled at the left, right side and center of the approach cross section. These samples finally mixed well to reduce the error of measurement and get a homogenous sample. Sieve analysis test was conducted in the laboratories Faculty of Engineering at University of Karbala to construct size distribution curve figure (5). The calculations showed that the specific gravity for bed material near bridge is equal to (2.6) and the median size (d_{50}) is about 0.27 mm.



Figure(5) : Grain size distribution curve of bed material

4-2 Hydraulic measurements

Hydraulic measurement had included the depth, velocity, discharge of water at approach channel and scour depth around the piers. As mentioned above the field survey indicated that the scour effect was existent around 4th pier from left bank while the bed level had raised around other piers as result of deposition. Echo- Sounder device which is type of sonar used to determine the depth of water by transmitting pulses into water. Depth of a scour hole was calculated as the difference between the water level at approach channel and water level just upstream the pier. Daily discharge was obtained from Al- Hindiya Water Resources Directorate. Table(1) illustrates Hydraulic measurement for Al- Hindiya second bridge during the year 2013.

Table (1): hydraulic measurement of Al-Hindiya second bridge in year 2013.

Month	Water depth upstream the bridge (m)	Velocity upstream the bridge (m/sec)	Discharge (m^3/sec)	Observed scour depth (m) at 4th pier of bridge.
January	3.9	0.35	180	3.7
February	3	0.25	90	3.9
March	4.1	0.35	200	3.9
April	3.2	0.3	120	3.8
May	3.6	0.32	150	3.9
June	4.9	0.5	350	3.8
July	5.2	0.5	370	3.9
August	4.8	0.4	265	3.8
September	4.6	0.4	250	4
October	4.4	0.4	235	4
November	3.3	0.3	110	4.1
December	3.5	0.3	130	4.2

5- Pier scour formulate

This study will evaluate the performance of the equations proposed by Coleman (1971), Breusers et al. (1977), Jain (1981), Gao et al. (1993), Melville and Sutherland (1997), Richardson and Davis (2001) and Sheppard et.al (2006). These seven models were chosen because they are based on conventional regression techniques and are widely used by researchers and practicing engineers.

1- Coleman 1971 [10]

$$\frac{d_s}{b}=1.49\left(\frac{v^2}{g\,y}\right)^{0.1} \quad \ldots\ldots(4)$$

Where:
ds: Scour depth.
y: Water depth upstream the bridge.
v: Velocity upstream the bridge.
b: Pier width.
g: Acceleration gravity.

2- Breusers et al. 1977 [11]

$$\frac{d_s}{b}=2\;k_s\;k_\theta\;\left(2\,\frac{v}{v_c}-1\right)\;\tanh\;\left(\frac{y}{b}\right) \quad \ldots\ldots\ldots(5)$$

Where:

ds : Scour depth.
k_s: Pier shape coefficient.
k_θ: Pier alignment coefficient.
v/v_c: Flow intensity.
b: Pier width.

3- Jain 1981 [12]

$$\frac{ds}{b}=1.84\left(\frac{y}{b}\right)^{0.3} Fr_c^{\,0.25} \quad \ldots\ldots\ldots(6)$$

Where:

ds: Scour depth.
Fr_c: Critical Froude number.
b: Pier width.
y: Water depth.

5- Gao et al. 1993 [13]

$$ds=0.46\;k_s\;b^{0.6}\;y^{0.15}\;d_{50}^{\,-0.07}\left(\frac{v-v_c'}{v_c-v_c'}\right)^{\eta} \quad \ldots\ldots\ldots(7)$$

$$v_c'=0.645\left(\frac{d_{50}}{b}\right)^{0.053} v_c \quad , \quad \eta=\left(\frac{v_c}{v}\right)^{9.35+2.23\log d_{50}}$$

Where:

ds: Scour depth.
b: Pier width.
ks: Pier shape coefficient.
v_c: Critical velocity.
v_c': Incipient velocity for local scour at pier.
d_{50}: Median sediment diameter.
$\eta = 1$ for clear-water scour
$\eta < 1$ for live-bed scour

4- Melville and Sutherland 1997 [14]

$$ds = k_s \; k_\theta \;\; k_1 \;\; k_d \;\; k_{yd} \;\; b \;\; \ldots\ldots..(8)$$

Where:

ks: Pier shape coefficient.
k_θ: Pier alignment coefficient.
k_1= v/vc for v/vc ≤1, otherwise, k_1=1.
k_d= 0.57 log (2.24b/d_{50}) for b/d_{50}≤ 25, otherwise, k_d=1 .
k_{yd}= 2.4 for b/y ≤ 25, otherwise, k_{yd}=2√y/b .

6 -Colorado State University equation CSU [15]

$$ds=2\; k_s \; k_\theta \; k_3 \;\; k_4 \quad b^{0.65} \; y^{0.35} \;\; Fr^{0.43} \;\; \ldots\ldots\ldots.(9)$$

Where:

k_s: Pier shape coefficient.
k_θ: Pier alignment coefficient.
k_3: Streambed coefficient .
y: Water depth at approach channel.
k_4: Coefficient based on armoring by larger particles in the bed material.
Fr: Approach channel Froude number.

7 – Sheppard et.al 2006 [12]

$$\frac{ds}{b} = 2.5\, f_1 f_2 f_3 \quad \ldots\ldots\ldots..(10)$$

Where:

ds: Scour depth.
b: Pier width.
f_1= tanh $(y/b)^{0.4}$.
f_2= $\{1\text{-}1.75\,(\ln v/vc)^2\}$.
f_3= (b/d_{50}) / $\{0.4(b/d_{50})^{1.2} + 10.6\,(b/d_{50})^{-0.13}\}$.

Eq.(10) is valid for $0.47 < v/v_c < 1$.

To calculate the critical velocity v_c, which bed material of size d_{50} and smaller will be moved, the following equation by Laursen 1963 was used [16]:

$$v_c = 6.19\ \ y^{1/6}\ \ d_{50}{}^{1/3} \quad \ldots\ldots\ldots..(11)$$

For multiple columns spaced less than five pier diameters apart as Al- Hindiya second bridge, the effective pier width (b) is the total projected width of all the columns in a single row, normal to the flow angle of attack [17]. As the piers of Al- Hindiya second bridge are perpendicular to the flow direction ,i.e. θ = zero , therefore the effective pier width is 1.5 m and $K_\theta = 1$. K_s= 1 for circular cylinder pier, K_4 = 1 for sand bed material, K_3 = 1.1for clear water and 1 for live bed [2]. Sheppard And Miller equations are based principally on laboratory data, as well as a few field measurements, the equations include the important observation that normalized local scour depths' dependence on b/d_{50} increases until the value of b/d_{50} equals approximately 50, at which point dependence begins to decrease and it can neglected sediment coarseness effect on scour depth when $b/d_{50} \geq 50$ [12] [18], so f_3 was dropped from equation (10) in this study.

6- Results and discussion

The resultants of application above formulas on study area using field hydraulic measurement are shown in table (2).

Table (2): Calculated scour depth by empirical formulae

Month	Average water depth (m)	Average velocity (m /s)	Critical velocity (m /s)	Scour regime	Calculated scour depth (m)						
					Colman 1971	Breuser 1977	Jain 1981	Melville 1997	Gao. 1993	CSU 2001	Sheppard 2006
Jan.	3.9	0.35	0.50	Clear water	1.26	1.17	1.96	2.51	0.23	1.34	2.60
Feb.	3.0	0.25	0.48	Clear water	1.21	0.12	1.85	1.87	0.44	1.12	0.82
Mar.	4.1	0.35	0.51	Clear water	1.25	1.14	1.98	2.49	0.43	1.35	2.58
Apr.	3.2	0.30	0.49	Clear water	1.24	0.69	1.88	2.22	0.51	1.22	1.95
May	3.6	0.32	0.5	Clear water	1.25	0.86	1.93	2.33	0.63	1.27	2.22
June.	4.9	0.5	0.52	Clear water	1.32	2.75	2.06	3.45	0.62	1.61	3.45
July	5.2	0.5	0.53	Clear water	1.31	2.69	2.09	3.42	0.82	1.62	3.46
Aug.	4.8	0.4	0.52	Clear water	1.27	1.61	2.05	2.77	0.81	1.46	3.04
Sept.	4.6	0.4	0.51	Clear water	1.27	1.65	2.03	2.79	0.81	1.45	3.05
Oct.	4.4	0.4	0.51	Clear water	1.28	1.68	2.01	2.81	1.23	1.44	3.05
Nov.	3.3	0.3	0.49	Clear water	1.24	0.67	1.89	2.21	1.22	1.23	1.93
Dec.	3.5	0.3	0.49	Clear water	1.23	0.64	1.92	2.19	0.43	1.24	1.89

by applying Laursen's equation on hydraulic field data it was concluded that the regime of stream bed is clear water ($v < v_c$), i.e the shear stress at the bottom in the upstream flow is less than the critical value for beginning of sediment motion. From construction of bridge to the time of search, it didn't exposure to a hard hydraulic condition such as a flood event with a high velocity, where the local scour is amplified and quickly reach great depth, therefore it can be said that the measured scour depth in this study was a result of hydraulic condition similar to those measured during the research period. From table (2) it was founded that – Sheppard et al. 2006 equation gave result close to the measured scour around the 4^{th} pier, This result was obtained after neglecting the effect of (b/d_{50}) and dependence on (v/v_c), (y/b) only i.e., ds /b = $f_1(v/v_c)$. f_2(y/b)
By using the results obtained from Sheppard etal 2006 equation after applying hydraulic field data of case study of this research and with the help of statistical program IBM SPSS the best equation for above relation is:

$$\frac{ds}{b} = 0.6 \left(\frac{v}{v_c} \right)^{0.38} \left(\frac{y}{b} \right)^{1.15} \quad \dots\dots\dots.(12)$$

The coefficient of determination of equation (R^2) is 0.9. The modified proposed formula can be used to calculate the max equilibrium scour depth around Al- Hindiya second bridge under clear water condition and with same hydraulic condition of this study.

7- Conclusions

Through this study on Al-Hindiya second bridge, it can be concluded the following:
1- The flow regime upstream bridge is clear water.
2- Bar can change the flow path from its normal channel and increases scouring.
2- There is a obvious scour depth around the 4^{th} pier of bridge.
3- Sheppard and Melville is the most appropriate empirical equation to predict pier scour depth for the bridge or it can be applied the equation that have been proposed during this paper to calculate the scour depth around the pier of Al-Hindiya second bridge with same hydraulic condition of this study.

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