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EVALUATED THE LOCAL SCOUR AT PIERS OF AL - HINDYIA SECOND BRIDGE

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ABSTRACT

In this paper, the local scour around the piers of al-Hindiya second bridge during the period (15/6/2013-16/12/2013) was studied. From field surveys at the bridge site it was observed that there is a scour hole with depth about 4 m around the 4^{th} pier from left bank of the river. The field scour depth was compared with depths calculated from the five empirical equations using hydraulic characteristics of the stream flow (water depths, velocities and critical shear velocity) at approach channel for seven months and with average grain size of the bed material (d_{50}=0.27 mm). Results showed that Melville and Sutherland equation had a good agreement with the field scour depth. The max. scour depth obtained from this equation was about 3.6 m when the $V/Vc \leq 1$. Depending on Melville and Sutherland equation anew formula was proposed for al-Hindiya second bridge to predicate the pier local scour within limitations and conditions similar to that at time of study.

KEYWORDS: Al- Hindiya Second Bridge, Deposition, Empirical Equations, Field Data, Local Scour, Pier

INTRODUCTION

Scour is the result of the erosive action of flowing water removing bed material from around the abutments and piers that support the bridge and erosion of stream bed and bank material which the bridge cross[1]. It 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 for reconstruction and rehabilitation. During the period between 1989 and 2000, 53% of bridge failure in USA were due to flood and resulting scour [2].

Total scour at the bridge site is comprised of three components, namely the aggradation and degradation, contraction scour, and the local scour. Aggradation and degradation are natural scour and have a long-term effect on streambed elevation on which the bridge is located. Aggradation involves the deposition of material eroded from the channel or watershed upstream of the bridge, whereas degradation involves the lowering or scouring of the bed of a stream due to a deficit in sediment supply from upstream long-term streambed elevation changes due to natural or man-induced causes.

The contraction scour results from a reduction of the flow area at the bridge site due to the encroachment into the flood plain or the main channel by the piers, abutments and approach embankments [3]. local scour is the removal of the sediment from around bridge piers or abutments. It can occur as 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 while in live-bed scour the scour hole is continually supplied with sediment by the approach flow.

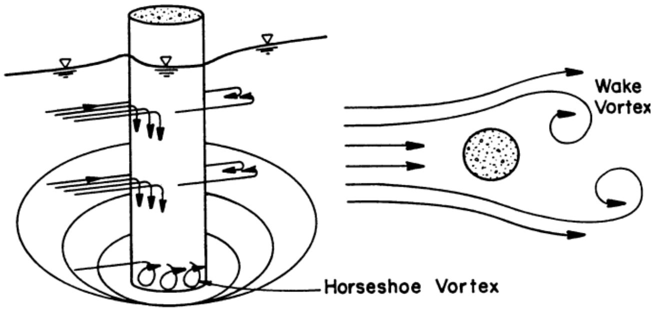

Figure 1: Mechanism of Local Scour around Pier

The many parameters involved in bridge-pier scour may be classified as stream flow characteristics such as velocity and flow depth, bed material characteristics such as the sediment size and distribution, and bridge pier characteristics such as the width, shape, and length of the pier [4].

Many experimental and numerical studies have been carried out throughout the world by researchers to develop equations for predicting the depth of bridge scour and understand the mechanism of this phenomena, 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) [5],[6],[7]. 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 present study aims to performing an extensive field investigation on the local scour at Al- Hindiya second Bridge piers in Kerbela city in Iraq, and compression the field data with five empirical equations to find the most agreeable formula for predicting the scour depth around the piers.

Mechanism of Local Scour around Bridge

Bridge pier scour is one type of local scour which appears as a scour hole around a bridge pier which caused by sediment transport that is driven by the local flow structure induced by a bridge pier. When water is flowing past a pier, the velocity becomes zero on the upstream face of the bridge pier and adverse pressure gradient is developed, as result a horseshoe vortex is formation and forced to move downward the upstream surface of the pier and tends to remove the bed materials from around the base of pier [8]. 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. For live bed local scour, equilibrium is obtained when the inflow bed material is equal to the outflow and scouring ceases. For clear water scour scouring ceases when the shear stress caused by horseshoe vortex is equal to the critical shear of the sediment particles at the bottom of the scour hole [9].

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.

AL- HINDIYA SECOND BRIDGE

Al- Hindiya second bridge crossing Euphrates river was constructed during the period (2006-2009) at Al- Hindiya city 22 km east Kerbela in Iraq figure 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 figure 3. All bridge pier 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

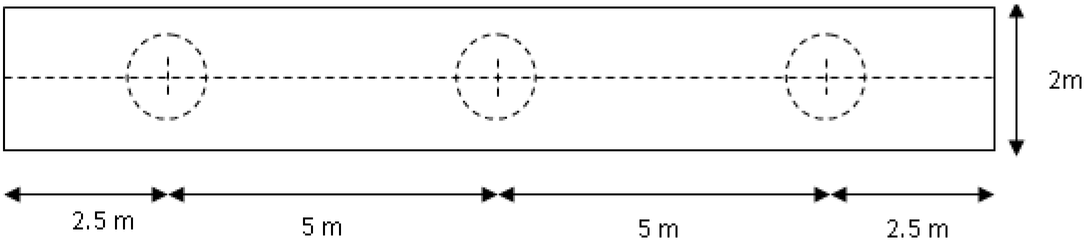

Figure 3: Top View of Pier

FIELD INVESTIGATIONS

Bridge Site

Field investigations at bridge site, which were done at low water level, show that some deposition has raised the bed level and contracted the cross section area of the river, that is because of middle island existence. The island is resultant from entrance of many quantities of loose sediment carried by the water then stay in the channel at the bottom and banks. The river islands have many negative effects such as the narrow and shallow of the channel, The resulting scour shape and geometry are found to be larger than those in the smooth case.[10]

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 the figure 5 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 were 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 island. Therefore in this study 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 island effect which causes the rise in bed level at piers site.

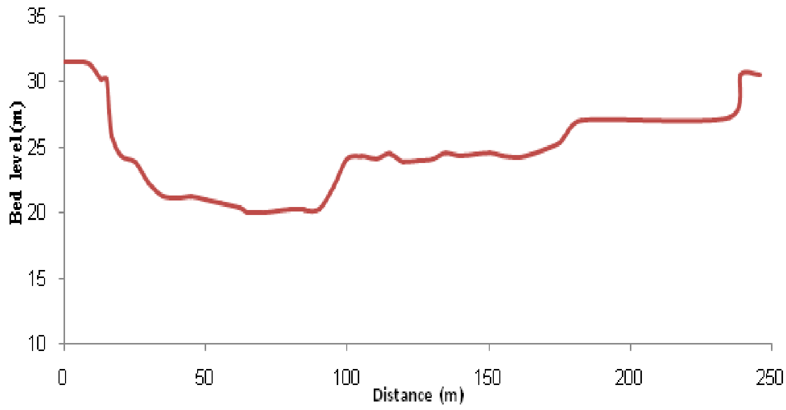

Figure 4: Cross Section Area of River Upstream Al- Hindiya Second Bridge

Figure 5: Deposition Upstream the Bridge

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 Kerbala to construct size distribution curve figure 6. 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.

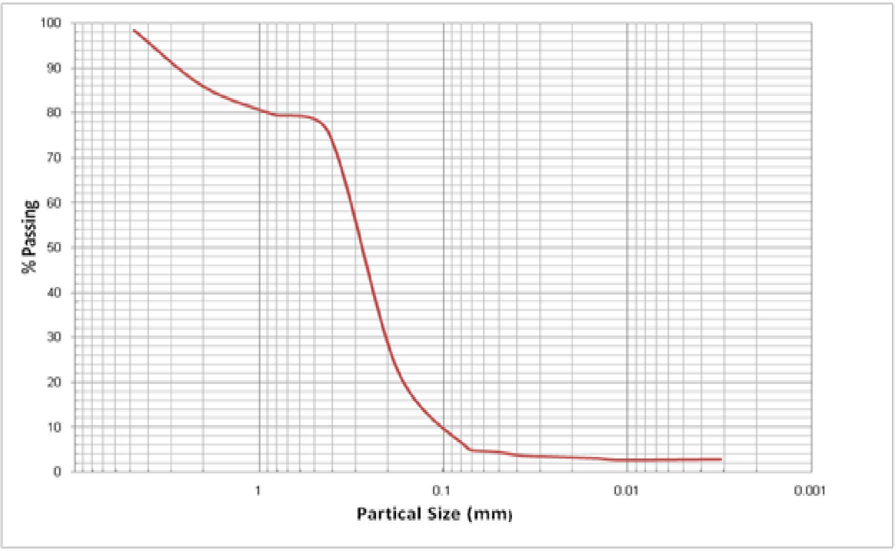

Figure 6: Grain Size Distribution Curve of Bed Material

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 figure 7. 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 period (15 /6/2013- 16/12/2013).

Figure 7: Echo –Sounder Device

Table 1: Hydraulic Measurement of Al-Hindiya Second Bridge

Date	Water Depth (m)	Velocity (m/Sec)	Discharge (m^3/Sec)	Cross Section Area (m^2)	Observed Scour Depth (m)
15-6-2013	4.9	0.5	350	700	3.8
21-7-2013	5.2	0.5	370	740	3.9
26-8-2013	4.8	0.4	265	663	3.8
14-9-2013	4.6	0.4	250	625	3.8
24-10-2013	4.4	0.4	235	588	4
23-11-2013	3.3	0.3	110	367	3.9
16-12-2013	3.5	0.3	130	433	4

Bridge-Pier-Scour Equations

The measured scour depths were Compared with five empirical formulate which were used to estimate the maximum equilibrium scour depth at a circular pier for live bed and clear water conditions. The five formulate are listed below:

Coleman 1971 [11]

$$\frac{ds}{b}=1.49\left(\frac{V^2}{g\,y}\right)^{0.1}$$

Breusers et al. 1977 [12] [13]

$$\frac{ds}{b}=2\,k_s\,k_\theta\left(2\,\frac{V}{V_c}\right)\tanh\left(\frac{y}{b}\right)\qquad Vc=31.08\,\theta s^{1/2}\,y^{1/6}\,d_{50}^{\;1/3}$$

$$\theta_s=0.0019\,d_{50}^{-0.384}\qquad \text{for } d_{50}<0.0009\text{ m}$$

$$\theta_s=0.0942\,d_{50}^{0.175}\qquad \text{for } 0.0009<d_{50}<0.02\text{ m}$$

$\theta_{s} = 0.047$ for $d_{50} > 0.02$ m

Melville and Sutherland 1997 [14]

$$d_{s} = k_s\ k_\theta\ k_1\ k_d\ k_{yd}\ b$$

$$V_c = 5.57\ V_{*c}\ \log \frac{y}{d_{50}}$$

$$k_1 = \frac{V}{V_c} \text{ for } \frac{V}{V_c} \leq 1, \text{otherwise}, k_1 = 1$$

V_{*c} is computed from Shield diagram for $d_{50} < 60$mm

$$k_d = 0.57 \log\left(\frac{2.24\ b}{d_{50}}\right) \text{ for } \frac{b}{d_{50}} \leq 25, \text{ otherwise, } k_d = 1$$

$$k_{yd} = 2.4 \text{ for } \frac{b}{y} \leq 0.7, \text{ otherwise, } k_{yd} = 2\sqrt{y/b}$$

Gao et al. 1993 [8]

$$ds = 0.46\ k_s\ b^{0.6}\ y^{0.15}\ d_{50}^{-0.07} \left(\frac{v - v_c'}{v_c - v_c'}\right)^{\eta} \text{ for live bed scour}$$

$$ds = 0.78\ k_s\ b^{0.6}\ y^{0.15}\ d_{50}^{-0.07} \left(\frac{v - v_c'}{v_c - v_c'}\right) \text{ for clear water scour}$$

$$V_c = \left(\frac{y}{d_{50}}\right)^{0.14} \left[16.7 \left(\frac{\rho_s - \rho}{\rho}\right) d_{50} + 6.05 * 10^{-7} \left(\frac{10 + y}{d_{50}^{0.72}}\right)\right]^{0.5}$$

$$V_c' = 0.645 \left(\frac{d_{50}}{b}\right)^{0.053} V_c, \qquad \eta = (V_c/V)^{9.35 + 2.23 \log d50}$$

Colorado State University Equation [15]

$$d_s = 2\ k_s\ k_\theta\ k_3\ k_4\ b^{0.65}\ y^{0.35}\ Fr^{0.43}$$

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 [16]. 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, $K_3 = 1.1$ for clear water and 1 for live bed, K4 =1 for sand, $V_{*c} = 0.016$ m /sec from Shield diagram.

RESULTS, DISCUSSIONS AND CONCLUSIONS

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

Table 2: Compression of Local Scour Depths Calculated by Empirical Equations

Water Depth (m)	Approach Velocity (m/sec)	Calculated Scour Depth (m)					Observed Scour Depth (m)
		Colman	Breusers	Melville	Gao.eta	CSU	
4.9	0.5	1.32	2.4	3.6	1.7	1.47	3.8
5.2	0.5	1.31	2.36	3.6	1.7	1.48	3.9
4.8	0.4	1.26	1.33	3.14	2.2	1.46	3.8
4.6	0.4	1.27	1.36	3.15	2.22	1.45	3.8
4.4	0.4	1.28	1.39	3.16	2.24	1.44	4
3.3	0.3	1.24	0.45	2.43	1.44	1.23	3.9
3.5	0.3	1.23	0.42	2.42	1.37	1.24	4

The study area since the construction of the bridge till the time of search 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 can be noted among the five empirical formulas, Melville's equation had a good agreement with the field scour depth. Based on limitation in this study $k_s = k_{\theta,} = 1$, $b/d_{50} < 25$, $b/y \leq 0.7$, discharge (110-370) m^3/sec, and $V/Vc \leq 1$ and by application Melville's equation, it can be observed that the relative scour depth (ds/b) in front of the 4th pier is dependent on the ratio of approach flow velocity to critical velocity of sediment figure 8. Based on the shape of the curve in figure 8 it can be proposed formula ($ds/b = 1.96 \ln (V/V_c) + 2.4$) for predicting the depth of scour at al- Hindiya second bridge around the 4^{th} pier bridge with above limitation.

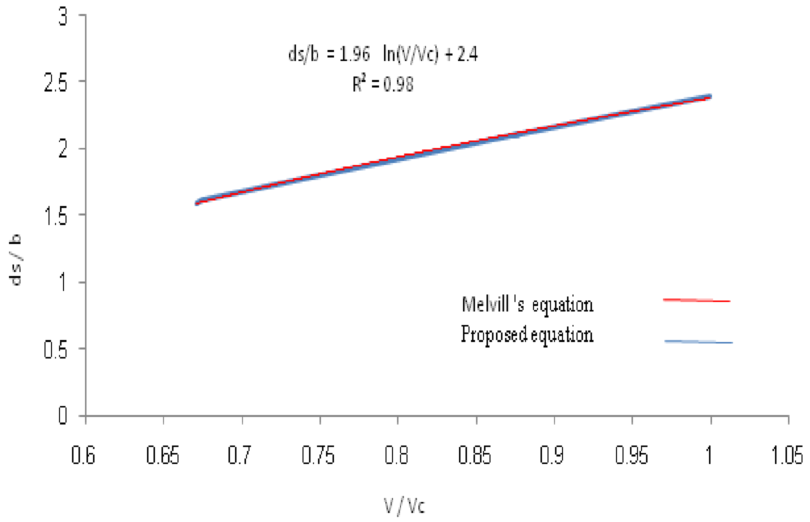

Figure 8: Scour Depth Variation with V/Vc for Al- Hindiya Second Bridge

RECOMMENDATIONS

Recommendations can be included in points below:

- Additional measurements at bridge site with highest velocity would be needed.
- Protection work are needed around the 4^{th} pier to prevent more scour.
- Remove deposition upstream the bridge to prevent the flow from concentration in a certain place.
- Bridges must not be construct at the place where the river island is exist.

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APPENDICES

List of Symbols

ds	Scour depth
d_{50}	Median sediment diameter
b	Pier width.
V	Approach velocity.
y	Approach flow depth.
g	Acceleration due to gravity
Vc	Critical velocity of sediment corresponding to initiation of sediment motion.
θs	Shield mobility parameter
Vc'	Incipient velocity for local scour at a pier.
V*c	Critical shear velocity
K_s	Coefficient for pier shape.
K_θ	Coefficient for pier alignment.
K_I	Coefficient based on flow intensity.
K_d	Coefficient based on the median particle diameter of the bed material.
K_{yd}	Coefficient based on flow depth upstream of a pier.
ρ	Density of water at a pier.
ρs	Density of sediment.
K_3	Coefficient based on the streambed condition.
K_4	Coefficient based on armoring by larger particles in the bed material.
Fr	Approach channel Froude number.