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Estimation of Local Scour and Contraction Scour Around Al-Imam Ali Bridge Piers

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Abstract: The scour phenomena one of most important can be happened to bridge when construction in the stream which can cause the collapse of the bridge. Euphrates River is one of the most important rivers on which many of the bridges are set up. The bridge of Imam Ali, this bridge is situated in Najaf government. In present study, a modeling of the Imam Ali Bridge by using the (HEC-RAS) program was prepared for discharges of 40-1400 m^3/sec. Two types of scouring appeared these are a pier scour and a contraction scour. The first increased with increase discharge while the second decreased with increase discharge. The results give a good indication that the Imam Ali Bridge is safe against the scouring.

Key words: Contraction scour, HEC-RAS program, high discharges, Imam Ali Bridge, local scour, increase discharge

INTRODUCTION

The obstructions in any stream influence its general balance. The construction of any new obstructions like bridges influence the stream conditions and can be viewed as a kind of a stream impediment. Stream impedance may bring about some scour and degradation as well as conceivable variation in the profile of water surface. Piers and abutments of bridges represent one of the major type of steam impedance that caused the phenomenon of scour. This scour can be one of the chief reasons for the failure of bridge.

Scour phenomenon was studied by many researchers, whether laboratory or field studies such as Kothyari *et al.* (1992), Vittal *et al.* (1994), Kumar *et al.* (1999), Kothyaria and Ranga Raju (2001), Coleman *et al.* (2003), Chase and Holnbeck (2004), Dey and Barbhuiya, (2005), Kothyari and Kumar (2010) and Sheppard *et al.*, (2004). The phenomenon of scour occurs by removing soil of streambed because of flowing water in the channel. It is leading to form of a cavity in the bottom of alluvial channels mainly due to water flow. The foundations of a bridge is exposed by the erosive action of flowing water, excavating and carrying away material from around the piers of bridges (Khwairakpam and Mazumdar, 2009).

Local scour including the material removed from around piers, abutments and embankments. Also, it can be calculated by live-bed scour or clear-water. It contains three elements: pier scour, abutment scour and contraction scour. Pier scour is the expulsion supporting soil of the pier leading to being a hole around. Abutment scour is the evacuation the soil around abutment at intersection region between embankment and bridge. Contraction scour is the expulsion of soil from streambed because of the contraction of the stream that is created either naturally or by the construction of bridges.

Scour is depending on flow rates as loose granular soils are less resistant to scour than cohesive soils. However, the maximum scour is deeper in the case of cemented or cohesive soils than scour in sandy waterway (Arneson *et al.*, 2012). In addition, the equations were found that estimated the depths of contraction scour and local scour in laboratory.

Arneson *et al.* (2012) was explained in detailed the process of scour in bridges and prepared by the Federal High Way Administration (FHWA). They summarize the mechanism of scouring effect of vortices those form due to the presence of symptoms (piers) in the waterway. This formation of vortices and the associated flow that occurred from the bottom as a results of the bridge element increases the shear stress and thus, a local increase in the flow of sediment transport capacity (Kothyari, 2007). These vortices work on the surrounding soil around piers. As scour depth increases, the strength of the vortices reduces Which reduces the transfer of sediments from the base of the pier (Lagasse and Richardson, 2001). It will lead to the threat of the bridge to collapse when it exceeds the permissible limits. Moreover, it will be a hole around the pier like horseshoe, so, dubbed a horseshoe (Fig. 1).

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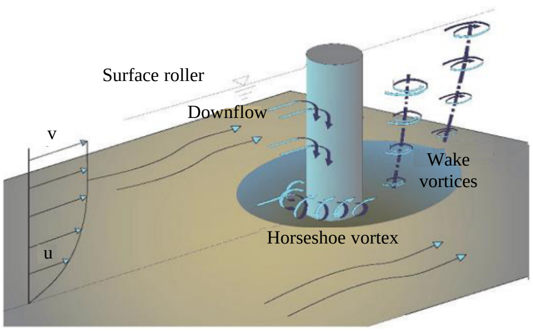

Fig. 1: Flow pattern around bridge piers (Akib *et al*., 2014)

It is well known that the scour mechanism has a complex nature. It is influenced by several factors such as the depth and velocity of the flow in the upstream, the width of the piers and the cohesiveness, size and shape of the sediments. Some of these factors are difficult to identify as cohesiveness, shape of sediment and flow regimes but are possible for others (Ghorbani, 2008). In general, estimations of scour depth can be founded usually on the laboratory research because of the multifaceted nature of assessing stream design around pier and shear powers produced by stream design. A standout amongst the most broadly nearby scour evaluations is the Colorado State University (CSU) equation to predict maximum scour depths, the condition is:

$$\frac{Y_s}{Y_1} = 2K_1K_2K_3K_4\left(\frac{a}{Y_1}\right)^{0.65} Fr^{0.43} \quad (1)$$

For piers rounded nose according to the flow:

$$Y_s \leq 2.4 \text{ times width of pier for } F_r \leq 0.8 \quad (2)$$

$$Y_s \leq 3 \text{ times width of pier for } F_r > 0.8 \quad (3)$$

When the bridges are constructed, the waterway is narrowed to create approaches or bridges or natural narrowing and any narrowing of the waterway causes removal in the soil of the river bed. This type of removal is known in the soil as contraction scour (Zhang *et al*., 2013). In contraction section, the erosion force increases as a result to the narrow area of flow that leads to increase in velocity flow and shear stress. Contraction scour happens until achieving relative equilibrium where the balance is occurred between the amount of transported bed load that leaves the reach with that amount of enters the reach in the same time or there is no bed material be leave the reach due to a decreasing in bed shear stresses under critical values (Arneson *et al*., 2012).

Contraction scour is calculated as live-bed. It is happened when flow area is decreasing but bed shear stress and average velocity is increasing through the contraction reach. Hence, erosive forces is an increase the contraction and the removed bed material from the contracted reach is more than the transported material into the reach. These processing decrease until equilibrium is happened between transported material into the reach and removed from the reach (Zhang *et al*., 2013; Arneson *et al*., 2012):

$$y_2 = y_1\left[\frac{Q_2}{Q_1}\right]^{6/7}\left[\frac{W_1}{W_2}\right]^{K_1} \quad (4)$$

$$Y_s = y_2 - y_0 \quad (5)$$

Alternatively, clear-water, It is happened when either the material bed transport is stopped from the upstream to the downstream reach or the transported material bed in the upstream reach is transported in capacity of the flow less at the downstream reach until either critical velocity or critical shear stress is equal to velocity of the flow or shear stress in the bed material (Zhang *et al*., 2013; Arneson *et al*., 2012):

$$y_2 = y_1\left[\frac{Q_2^2}{CD_m^{2/3}W_2^2}\right]^{3/7} \quad (6)$$

$$Y_S = y_2 - y_0 \quad (7)$$

Clear-water when V_c> means velocity, live-bed when V_c< means velocity (Brunner, 2016; Elsaeed *et al*., 2015). The scour hole depth is usually bigger than resulting of general or contraction scours, often by a factor of 10 as cited by Ghorbani (2008; Arneson *et al*., 2012).

In this study, the hydraulic model buildup to Al-Imam Ali Bridge in Al-Najaf Government in Iraq using by HEC-RAC program. The model was utilizing the one-dimensional US. Armed Force Corps of Engineers Hydrologic Engineering Center River Analysis System, HEC-RAS adaptation (5.0). The model of Al-Imam Ali Bridge was established to estimate the maximum local scour depth around pier and contraction scour in bed stream.

MATERIALS AND METHODS

Description of case study: The case that will study is a single pier for Al-Imam Ali Bridge. It was established for

Fig. 2: Al-Imam Ali Bridge

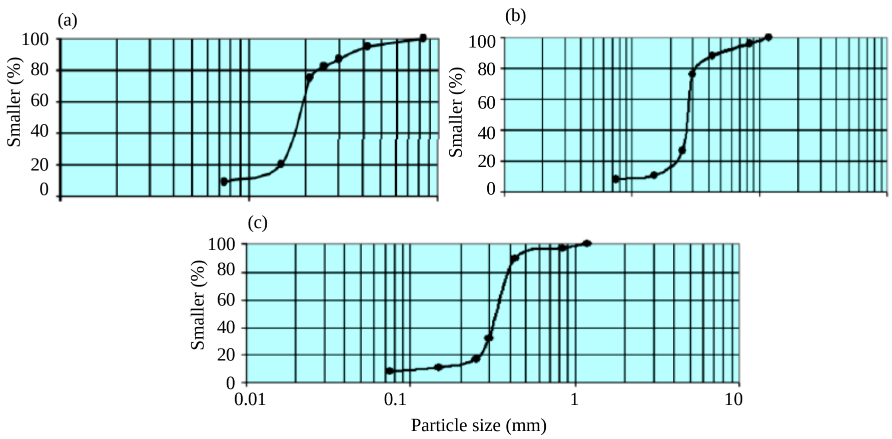

Fig. 3: Sieve analysis of river bed material; a) Main river Section; b) Right bank river Section and c) Left bank river Section

the period (2007-2010). The length of the bridge is 3150 m with single circular piers each width of 1.5 m. The abutment is not within the river section, Fig. 2 shows Al-Imam Ali Bridge.

Data collection: In current study the collection of required data from the site of the Euphrates River and Imam Ali Bridge is accomplished in the first month, January of 2011 included the cross section of the river, Sample of sediments from the bed of river. Figure 3 represents sieve analysis of riverbed. It includes the bottom and sides of the river. The size distribution curve is constructed. The values of D50 and D95 are equal to (0.19) and (0.4), respectively and the Roads and Bridges Directorate provided the bridge data).

Modelling of local and contraction scours in Al-Imam Ali Bridge: As a first step to create, model in in HEC-RAS program, a document of HEC-RAS geometric is used to define the river schematic and locate the sites of cross sections in the river path as Fig. 4 shown it. The model cross sections are represented by (x, y) coordinates (station and elevation points) that describe the geometric boundary of the river and connected cross-sections with each other by input lengths between the reaches as shown in Fig. 5.

To complete the preparing the model, the value of manning coefficients (n) is required. The manning roughness coefficients (n) for (left bank) (right over the bank) was taken as 0.041 and for (main channel) was taken as 0.039.

The information of steady flow is required to complete a calculation of a steady profile of water surface. The steady flow calculation variables in program needs to

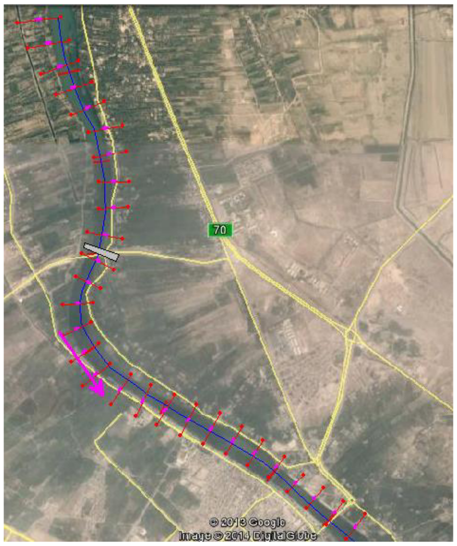

Fig. 4: The river schematic

enter information about the flow regime, discharge data and boundary conditions. The boundary conditions are important to set up the beginning water surface at the upstream and downstream for the river. In this study, the reach slope is a boundary condition for downstream used normal depth calculation. In NWRD, 2013 says equal to (0.00012). The discharge is a boundary condition for upstream used for this calculation from (40-1400 m^3/sec).

To complete the process of representation model, a bridge information was needed. These include the bridge site on the river, length, width and thickness of the bridge which is to enter the station and elevation data by (x, y) forms. In the other hand, piers of the bridge defined by width, height and position of piers according to the distance from the centerline of each to the left. After the calculations, the some results of velocity flow in the river as shown in Fig. 6.

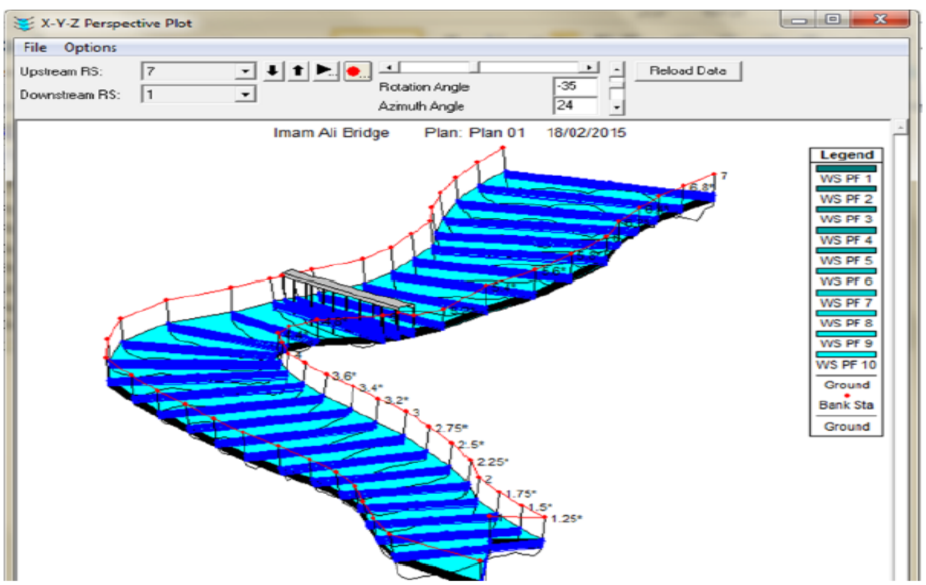

Fig. 5: The bridge with the river

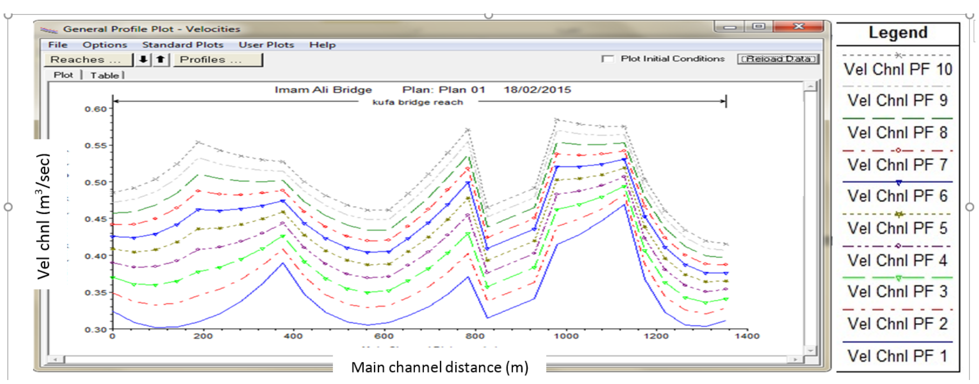

Fig. 6: Some velocity profile

RESULTS AND DISCUSSION

The D_{50} and D_{95} were extracted from sieve analysis which are 0.19 and 0.4, respectively. The (K_1) and (K_2) are parameter to correction factor of shape pier and angle attack. (K_1) is one for round nose, the (K_2) is the correction factor of the attack angle of the run Which is not perpendicular to the piers through the angle of attack. In present study, it is equal to one because the pier is perpendicular on the flow.

The range of discharges is used (40-1400) m^3/sec in this study. The results showed two types of scour. It was the local scour around pier as shown in Fig. 7 and 8 contraction scour in the bed cross section as shown in Fig. 9.

The local scour occurred in all pier expect first and second piers at discharge 50 m^3/sec as shown in Fig. 7. However, at discharge 425 m^3/sec the local scour happened in all piers. The local scour at discharges 60 m^3/sec caused a significant increase in scour value. The scour values in piers No. 3-5 have heigher value then scour values in piers No. 1, 2, 6 and 7. The minimum scour occurred in pier No. 7. The max. scour is in pier No. 4. Figure 8 shows local scour in all piers. The difference in scour values in the bridge piers is due to the difference in velocity values in the river section.

The numerical model is calculated the average approach velocities for all discharges, than calculated the critical velocities and the contraction scour at the cross section area of the bridges by using empirical Eq. 4. The live bed contraction scour happened when the average approach velocities larger the critical velocities. Hence, the contraction scour appears when the discharges are 625-975 m^3/sec as shown in Fig. 9. It reduced by increasing discharges as shown in Fig. 10. This behaver is because of flow area is decreasing as result of found the deck of bridge, hence, erosive forces is an increasing and bed material is removed from the contracted reach more than is transported into the reach. These processing decrease until equilibrium is happened between transported material into the reach and removed from the reach.

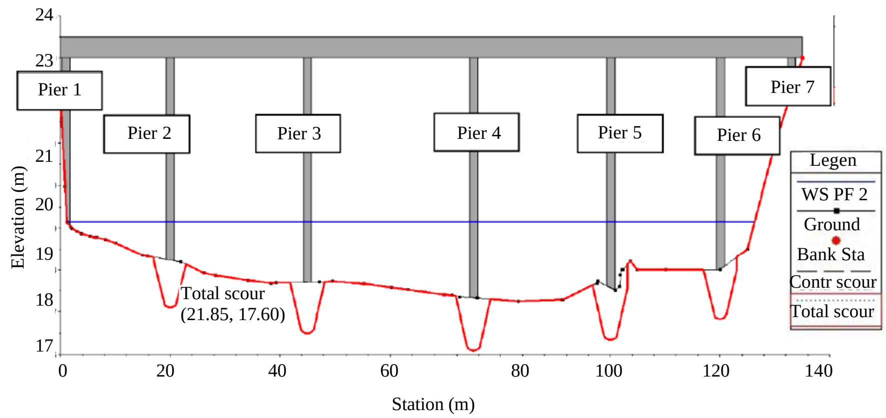

Fig. 7: The local scour in Al-Imam Ali Bridge

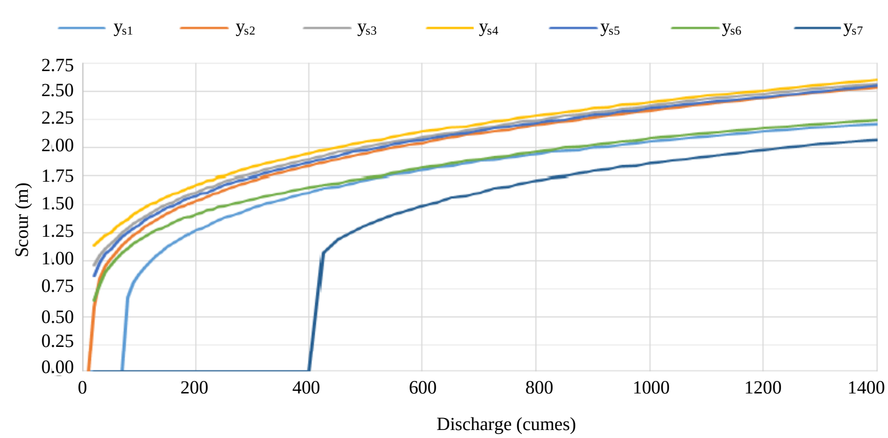

Fig. 8: The value of local scour

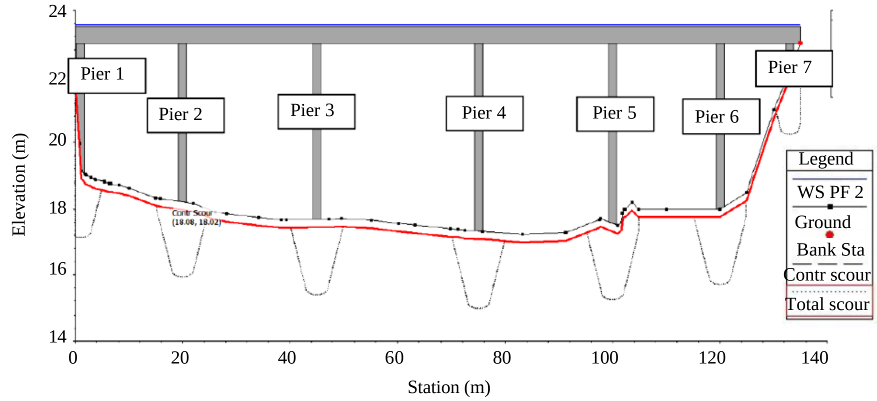

Fig. 9: The contraction scour in Al-Imam Ali Bridge

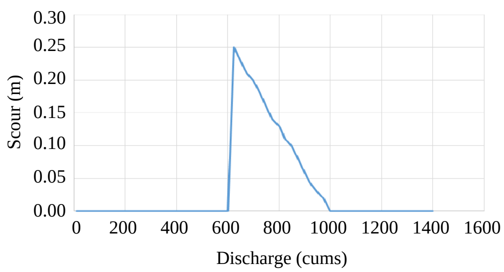

Fig. 10: The value of contraction scour

CONCLUSION

The present review was done to assess the impact of discharging from (40-1400 m^3/day) on the current structures by utilizing HEC-RAS Model and experimental equations to foretelling the scour around piers. The fundamental conclusions might be drawn:

- The contraction scour calculated by live-bed equation
- The local scour depth increased to discharge. While the contraction scour decreased to discharge
- Contraction scour values presented the lowest local scour results
- The maximum scour happened in pier No. 4
- The Imam Ali Bridge is safe because the highest scour value is < 2.4 times the pier width

NOTATIONS

Y_s = The depth of scour (m)
Y_1 = The depth of flow of the upstream pier (m)
K_1 = Correction factors for nose pier
K_2 = The attack angle
K_3 = Bed condition
K_4 = Armoring by bed material size
a = The width of pier (m)
D_{50} = The size of bed material particle which 50% are smaller
Fr_1 = Froude number for upstream of pier
Y_0 = The average depth in channel and overbanks at the contracted section
V = The average velocity of flow in upstream (m/sec)
Q_1 = The flow rate transporting sediment in approach channel (m^3/sec)
Q_2 = The total flow in the contracted (m^3/sce) Q_2 = Q_1×%area open through bridge
W_1 = The Width of bottom the approach channel (m)
W_2 = The Width of bottom the contracted channel (m)
k_1 = 0.59 if $V_*/W<0.5$ mostly contact bed transport to material transport
= 0.69 $V_*/W>2$ mostly suspended bed material transport
(yms) c = The average equilibrium depth in the contracted section after contraction scour, m
y_0 = The average existing depth in contracted section (m)
D_m = Particle diameter of the smallest non-transportable in the bed material (1.25 D_{50}) in the contraction section (m)
C = 40 for metric units
V_c = Critical velocity (m/sec)
n = Manning coefficient
D_{95} = The size of the bed material which 95% is finer
NWRD = Najaf AL-Ashraf Water Resources Department

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