Effect of Bridge Pier Shape on Scour Depth at Uniform Single Bridge Pier

GHULAM MURTAZA*, HASHIM NISAR HASHMI*, USMAN ALI NAEEM*, DAULAT KHAN**, AND NAVEED AHMAD*

ABSTRACT

Bridge pier scouring may lead to the bridge failure and the shape of bridge pier itself is one of the main factor to control scouring around bridge pier. The amount of sediment which is removed from the boundary of bridge pier is called bridge pier scouring and the depth up to which sediment removed is called scour depth. Scouring results, the exposure of foundation, eventually leading to bridge failures. Assessment of the maximum scour that can be faced by pier has a vital role in the design of bridge foundation. Different techniques are used to minimize the scouring effect in order to control the bridge failure. In this study effect of bridge pier shape on scouring was checked on four different shape i.e. circular, oval, square and octagonal. Each pier shape was tested against three different values of flows i.e. 16, 22.50 and 29.50 liter/sec. Uniform bed material of standard deviation ($\sigma_g = 1.21$) and median size ($D_{50} = 0.28$ mm) was used for all tests. Scour is measured with the help of point of gauge and bed is levelled before every experiment. Experimental results show that minimum scour is observed for octagonal bridge pier and maximum for square bridge pier while circular and oval faced intermediate scour depth relative to square and octagonal bridge pier. It is concluded that scour has reduced to 22% when octagonal pier was used compared to circular one.

Key Words: Bridge Pier, Bridge Pier Shape, Octagonal Pier, Scour, Local Scour.

1. INTRODUCTION

Scouring is a process of removal of soil or rocks from the channel by running water. The amount of sediment which is removed from the boundary of bridge pier is called bridge pier scouring and the depth up to which sediment is removed is called scour depth. Scouring results, the exposure of foundation, eventually leading to bridge failures. According to Shirhole and Holt [1], 60% of 283 bridge failure were caused by hydraulic and scouring effects, in United States since 1951. Melville and coleman [2] found that every year, one bridge was failed due to scouring in New Zeeland. Study of 383 river bridge failures by Brice and Blodgett [3] identified the scour as primary reason of the 50% of these failures. 17 bridges were damaged and demolished in 1987 in New York and New England due to scouring.

Authors E-Mail: (gmurtaza18@gmail.com,hashim.nisar@uettaxila.edu.pk,usman.naeem@uettaxila.edu.pk,daulat57@yahoo.com, n.ahmad@uettaxila.edu.pk)
* Department of Civil Engineering, University of Engineering & Technology, Taxila.
** Department of Agriculture Engineering, University of Engineering & Technology, Peshawar.

Recent studies show that the impact of flow originates the formation of horseshoe vortex and separation of flow from bridge pier leads to the rising vortex. These two are the main factors causing bridge scouring [4]. Two main countermeasure for minimizing scour are bed armoring and flow altering. In the former case, the objective is to reduce the scour inducing mechanisms using hard materials or any sort of physical barriers such as rock riprap. In later case, the purpose is to either prevent the formation of the scour inducing mechanisms or to shift the scour away from the vicinity of the pier.

Raudkiviand Ettema [5] recognized that scouring process has three phases i.e. initial phase, principal phase and equilibrium phase.Scouring process is said to be in equilibrium phase when scour depth does not change with time.The concept of equilibrium scour is uncertain and different approaches has been adopted by different authors present to deal with it. Melville [6] reported that equilibrium scour can be achieved in a limited time but Franzetti [7] did not agree with this concept. Critiana and Lanea [8] concluded that scour also depends upon shape and alignment of pier with flow direction.

Lança [9] stated that the scour depth (d_s) around uniform single bridge piers depends on the depth of flow (d), median grain size (D_{50}), pier width (D_p), alignment and shape of the pier, Width of channel(B) and time. Breusers [10] studied the effect of pier shape and alignment on local scour and reported that maximum scour is faced by rectangular pier. He also concluded that length of rectangular pier has no effect on scour depth. Melville [6] found that circular and oval pier behaves in almost same manner with 10%. Some researcher gave the concept of shape factor to relate scour depth of different pier shape. Shape factor of 1.2 is reported by Cristina [8] and 1.11 by Al-Shukur [11] while both researcher used shape factor one for circular pier.

Piers are divided mainly in two categories uniform piers and non-uniform. Pier with a constant section throughout their depth are termed as uniform while non-uniform pier may have a slab footings and pile foundation by Melville [2]. This study was related to check the impact of the uniform bridge pier shapes on local scour.

2. EXPERIMENTAL SETUP

All the tests were performed in laboratory flume in Hydraulic Laboratory, Department of Civil Engineering, University of Engineering & Technology, Taxila, Pakistan. Laboratory flume is (L=20m) long, (B=1m) wide and (Y=0.75m) deep open channel. The whole channel is made of concrete except the walls which are made of glass. Water was delivered to the channel through pipe by a pump that carries water in an overhead tank from an underground storage. Flow was controlled with a valve installed ahead of the channel as shown in Fig. 1.

Water was filled from downstream at very slow rate to avoid to scour in initial stage resulting from slope and then a constant discharge was maintained with the help valve. Flow velocity was measured with the help of velocity sensor while the depth of flow was measured by point gauges as shown in Fig. 2.

The fine sand with $D_{50} = 0.28$ mm, having specific gravity 2.79 and geometric standard deviation (σ_g) = 1.21 was used as bed material. Yanmaz [12] stated that if $\sigma_g < 1.30$ than sand will be uniform. In sand used in this study was uniformly graded. Melville [6] reported that if pier width to grain size ratio is more than twenty-five (25) then sediment size does not affect the scour depth.

Four piers of different shapes (square, circular, oval, octagonal) of equal width were used as pier model as shown in Fig. 3 since it was recommended by Chiew and Melville [13], that the pier diameter should be less than 10% of flume width in order to avoid the influence the walls which leads to contraction scour. Hence the calculated width in each case was 7cm.

Flow was measured by a rectangular notch as per ASTM standard D5242-92 [14]. According to standard

$H/P \leq 0.5$

$H/L \leq 0.5$

$0.25 \, \text{ft} \, (0.08 \, \text{m}) \leq H \leq 2.0 \, \text{ft} \, (0.6 \, \text{m})$

$L \geq 1.0 \, \text{ft} \, (0.3 \, \text{m})$

$P \geq 1.0 \, \text{ft} \, (0.3 \, \text{m})$

$(B \text{``} L)/2 \geq 2H$

Where "H" was measured head above the crest, "P" crest height above the bottom of the channel "L"Crest length and "B" was the channel width as shown in Fig. 4.
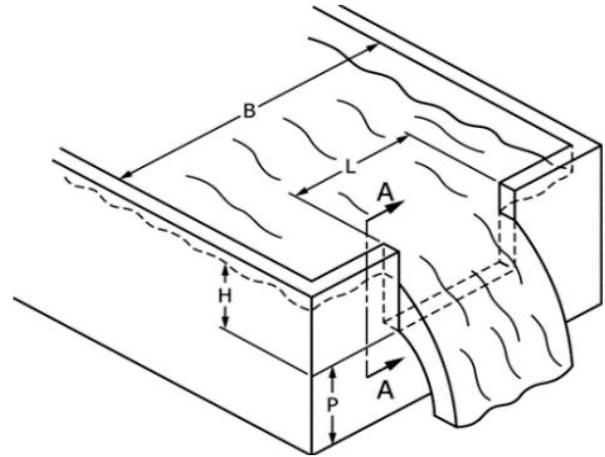

FIG. 4. LABELED DIAGRAM OF RECTANGULAR NOTCH
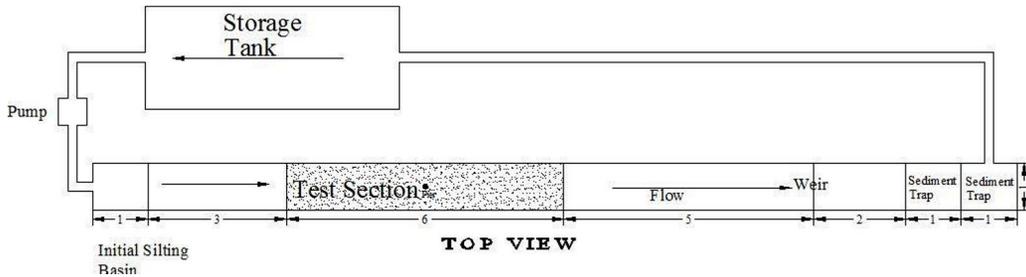
FIG. 1. TOP VIEW OF LABORATORY FLUME

FIG. 2. LABORATORY FLUME

FIG. 3.DIFFERENT PIER SHAPES

Mehran University Research Journal of Engineering & Technology, Volume 37, No. 3, July, 2018 [p-ISSN: 0254-7821, e-ISSN: 2413-7219]

541
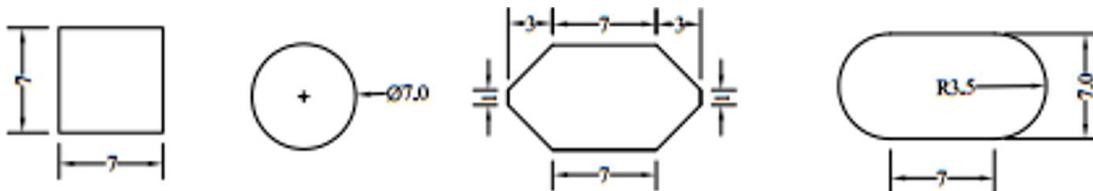
In current study values of P, L and B were calculated to be 40, 40 and 100cm, respectively. The standard equation used for discharge measurement given by ASTM standard D5242-92 [14], is:

$$Q = \frac{2}{3} \times (2g)^{\frac{1}{2}} C_e L_e \left(H_e \right)^{\frac{3}{2}} \qquad (1)$$

Where H_e was Effective head ($H_e = H + \Delta H$) and "H=0.003ft (0.001 m) as mention in ASTM standard D5242-92. L_e was Effective crest length ($L_e = L + \Delta L$) and "L can be calculated from **Fig. 5.** C_e was Discharge coefficient and was calculated from **Fig. 6** as described in ASTM standard D5242-92 [14].

3. RESULTS AND DISCUSSION

Experiments were carried out for three different heads over crest for equal time and discharges were calculated by using Equation (1) as shown in Table1.

Experiments were performed at three different flows i.e. 29.50, 22.50and 16.16 lit/sec to investigate the maximum scour depth.

The result of the experiments performed by using four different bridge pier shapes against three different discharges are shown in Table 2. While their graphical representation is shown in Fig. 7.
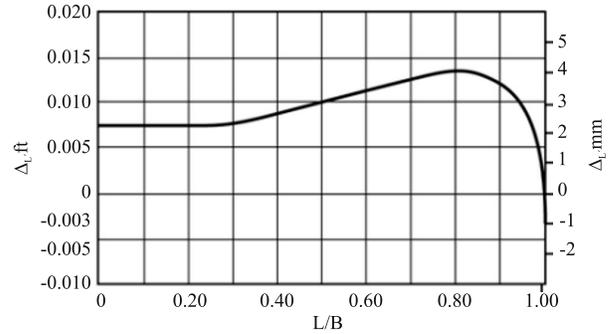

FIG. 5. CREST LENGTH ADJUSTMENT (ASTM STANDARD D5242-92)
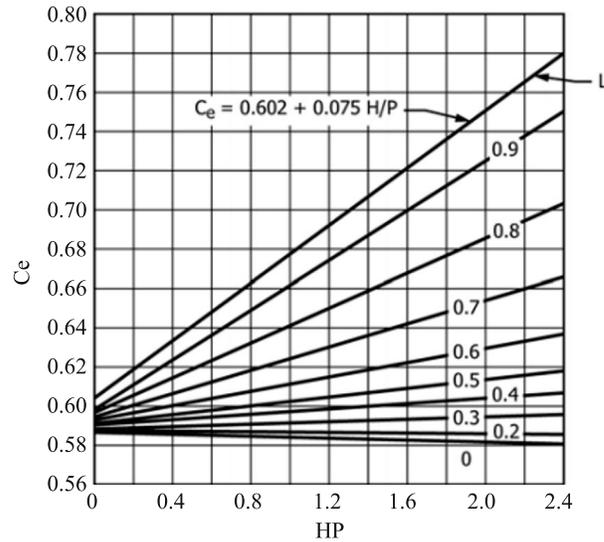
FIG. 6. DISCHARGE COEFFICIENT FOR RECTANGULAR WEIR (ASTM STANDARD D5242-92)

TABLE 1. DISCHARGE CALCULATION TABLE

No.	Crest Length L (m)	Height of Water Above Crest-H (m)	Breadth of Channel-B (m)	Crest Height Above the Bottom P (m)	H/P	L/B	dL	$L_e = L + \delta L$	H	$H_e = H + H$	C_e = from Graph	Discharge =Q Q (m³/s)	Discharge =Q Q (m³/s)
1.	0.4	0.08	1	0.4	0.2	0.4	0.0026	0.4026	0.001	0.081	0.59	0.016	16.00
2.	0.4	0.1	1	0.4	0.25	0.4	0.0026	0.4026	0.001	0.101	0.59	0.02250	22.50
3.	0.4	0.12	1	0.4	0.3	0.4	0.0026	0.4026	0.001	0.121	0.59	0.02950	29.50

TABLE 2. MAXIMUM SCOUR AROUND DIFFERENT BRIDGE PIER SHAPE

No.	Pier Shape	Maxima Scour Depth (cm)		
		Q=16.16 (lit/sec)	(lit/sec) (lit/sec)	Q=22.50 (lit/sec)
1.	Square	8.1	8.4	8.6
2.	Circular	7	7.3	7.8
3.	Oval	6.5	6.8	7.1
4.	Octagonal	5.4	5.7	5.9

From Fig. 7 it has been observed that minimum scour was for octagonal pier and maximum for square bridge pier. While Circular and oval faced intermediate scour depth relative to square and octagonal bridge pier.

Maximum scour was observed for square piers 8.1, 8.4, and 8.6cm for different flows i.e. 16.16, 22.50 and 29.50 lit/sec respectively. Longitudinal profile of scour hole for square pier is shown in Fig. 8.

Scour depth for circular pier was found to be 7, 7.3, and 7.8cm against flows i.e. 16.16, 22.50 and 29.50 lit/sec respectively. Longitudinal scour profile of circular pier is shown in Fig. 9.

Scour around the oval pier was monitored and found to be (5.8, 6.3 and 6.5cm) for flows 16.16, 22.50and 29.50 lit/sec respectively. Longitudinal profile of scour for oval pier is shown on Fig. 10.

Minimum scour was observed when octagonal pier was used. Scour was found to be 5.4, 5.7 and 5.9cm for flows 16.16, 22.50and 29.50 lit/sec respectively. Longitudinal profile of scour for octagonal pier is shown on Fig. 11.

Melville found that circular and oval piers behave in almost same manner with 10% difference and in current study maximum difference that was observed was 8.97%. Some Researchers used shape factor to relate the scour around different type of piers. Shape factor 1.2 was reported by Cristina Fael [8] for square nosed bridge pier shape while shape factor 1.11 was suggested by Al-Shukur [11] in current study it was found to be 1.10-1.15 relative to scour around circular pier.
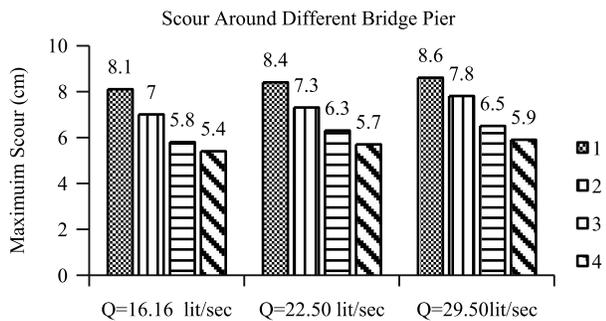

FIG. 7. SCOUR AROUND DIFFERENT BRIDGE PIER SHAPES
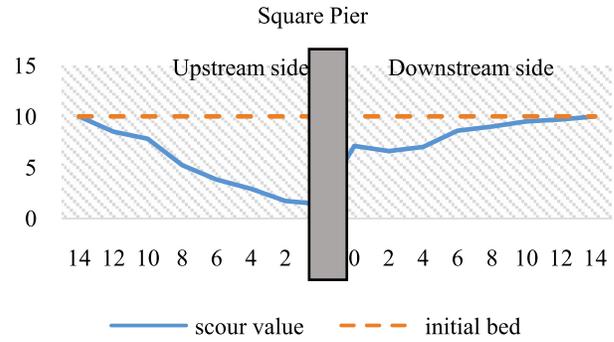
FIG. 8. LONGITUDINAL SCOUR PROFILE OF SQUARE PIER
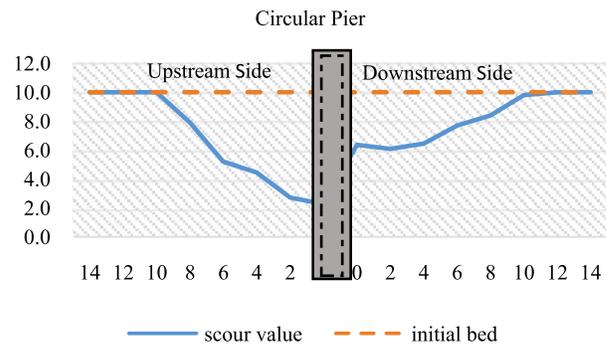
FIG. 9. LONGITUDINAL SCOUR PROFILE OF CIRCULAR PIER
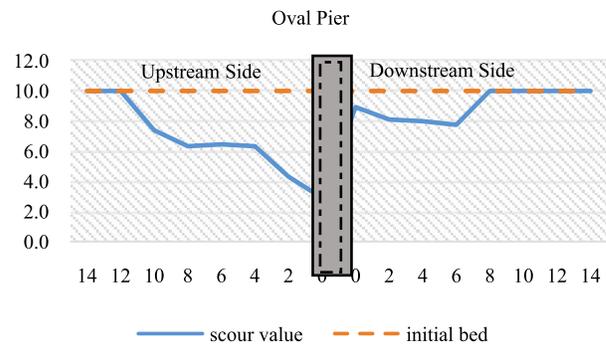
FIG. 10. LONGITUDINAL SCOUR PROFILE OF OVAL PIER
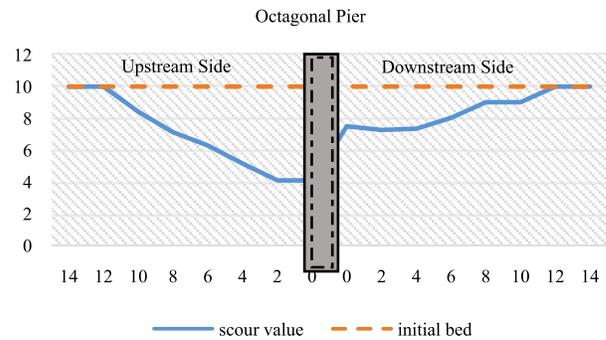
FIG. 11. LONGITUDINAL SCOUR PROFILE OF OCTAGONAL PIER

4. CONCLUSIONS

This study was based on the effect of shape of pier on scour depth. Four different shapes were investigated and it was concluded that:

(i)   Minimum scour was observed in case of octagonal pier.

(ii)   Scour has reduced to 22% when octagonal pier was used compared to circular one.

(iii)   Maximum scour was observed when square pier was used.

5. NOTATION

Following notation are used in this research study.

d	pier diameter
B	Channel width (m)
d	Depth of flow (m)
C_e	Discharge coefficient
d_s	Scour depth (m)
D_p	Bridge pier width (m)
d/D_p	Flow shallowness (-)
D_{50}	Median grain size (m)
F_r	Froude Number (-)
H	Measured head above the crest (m)
H_e	Effective head (m)
L	Crest length (m)
l	Channel length (m)
L_e	Effective crest length (m)
P	Crest height above the bottom of the channel (m)
Q	Discharge ($m^3 s^{-1}$)
S	Energy line slope (-)
Y	Depth of channel (m)
g	Acceleration of gravity (ms^{-2})
ρ	Density of fluid (kgm^{-3})
σ_g	Geometric standard deviation (-)

ACKNOWLEDGMENTS

REFERENCES

[1]   Shirhole, A.M., and Holt, R.C., "Planning for a Comprehensive Bridge Safety Program", Transportation Research Record, pp. 39-50, USA, 1991.

[2]   Melville, B.W., and Stephen, E.C., "Bridge Scour", Water Resources Publication, USA, 2000.

[3]   Brice, J.C., and Blodgett, J.C., "Countermeasures for Hydraulic Problems at Bridges: Analysis and Assessment", Research and Development, Federal Highway Administration, Volume 1, USA, 1978.

[4]   Mohammadnezhad, A.A., and Saneie, M., "Experimental Study on Lozenge Collar Affection in Reduce Amount of Scouring Around Bridge Piers", Journal of River Engineering, Volume 2, pp.7-11, Iran, 2014.

[5]   Raudkivi, A.J., and Robert, E., "Clear-Water Scour at Cylindrical Piers", Journal of Hydraulic Engineering, Volume 109, No .3, pp. 338-350, USA, 1983.

[6]   Melville, B.W., "Pier and Abutment Scour: Integrated Approach", Journal of Hydraulic Engineering, Volume 123, No. 2, pp.125-136, USA, 1997.

[7]   Franzetti, S., Malavasi, S., and Piccinin, C., "Sull'erosione alla Base Delle Pile di Ponte in Acque Chiare", Proceedings of 24th Convegno di Idraulica e Costruzioni Idrauliche, Volume 2, No. 4, pp.13-24, Italy, 1994.

[8]   Fael, C., Rui, L., and António, C., "Effect of Pier Shape and Pier Alignment on the Equilibrium Scour Depth at Single Piers", International Journal of Sediment Research, Volume 31, No. 3, pp. 244-250, China, 2016.

[9]   Lança, R.M., Cristina, S.F., Rodrigo, J.., João, P.P., and António, H.C., "Clear-Water Scour at Comparatively Large Cylindrical Piers", Journal of Hydraulic Engineering, Volume 139, No. 11, pp.1117-1125, USA, 2013.

[10]   Breusers, H.N.C., Nicollet, G., and Shen, H.W., "Local Scour Around Cylindrical Piers", Journal of Hydraulic Research, Volume 15, No. 3, pp. 211-252, Netherlands, 1977.

[11]   Al-Shukur, Abdul-Hassan, K., and Obeid, Z.H., "Experimental Study of Bridge Pier Shape to Minimize Local Scour", International Journal of Civil Engineering & Technology, Volume 7, No. 1, pp. 162-171, India, 2016.

[12]   Yanmaz, A.M., and Omer, K., "Time-Wise Variation of Scouring at Bridge Abutments", Volume 32, No. 3, pp. 199-213, Australia, 2007.

[13]   Chiew, Y.M., and Melville, B.W., "Local Scour Around Bridge Piers", Journal of Hydraulic Research, Volume 25, No. 1, pp. 15-26, Netherlands, 1987.

[14]   ASTM Standard D5242-92, USA, 2013.