# Time develoment of local scour at a bridge pier using square collar in a 180 degree flume bend

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**Abstract:** Local scouring around the bridges pier occurs because of flow separation and developing several vortexes around the bridge pier. In this study, the use of square collars for reducing the effects of local scour at a bridge pier is presented together with the time aspect of the scour development. The study was conducted using in a 180 degree laboratory flume bend with a relative radius of Rc/b=4.67 operated under clear-water conditions. Tests were conducted using one pier with 60 mm diameter in positions of 60 degree under one flow conditions. Investigated was the effect of size and elevation collar on the time development of scour and its efficacy at preventing scour at a bridge pier. The time development of the scour hole around the model pier with and without a square collar installed was compared with similar studies on bridge piers. Several equations for the temporal development of scour depth and those for the prediction of the equilibrium scour depth were tested as part of this study. The depth of the scour hole increases as the duration of the increased flow that initiates the scour increases. It was observed that, as the minimum depth of scour occurs for the square collar at width of 3D placed at elevation of 0.1D below the bed and the size of a collar plate increases, the scour decreases. [Journal of American Science 2010;6(8):188-195]. (ISSN: 1545-1003).

**Keywords:** Square Collar, Time development, Circular pier, 180 degree channel bend, Scour depth

## 1. Introduction

While flood damages typically involve widespread inundation of agricultural land, destruction of homes and businesses, and disruption of economic activity, a less obvious threat is the existence of bridges over waterways that cause flow obstruction and scour around the bridge foundations with possible failure of the bridges. In recent years, flood waters have closed many highways and local roads as well as interstate highways, and caused scour that damaged many bridges and even resulted in loss of life.

For example, one thousand bridges have collapsed over the last 30 years in the United States and the leading cause is hydraulic failure, resulting in large financial losses. In Georgia, the total financial loss from tropical storm Alberto in 1994 was approximately $130 million because more than 100 bridges had to be replaced and repaired due to flooding (Richardson and Davis, 2001).

During the 1993 upper Mississippi River basin flooding, more than 258 million dollars in federal assistance was requested for repair and/or replacement of bridges, embankments, and roadways (Parola et al. 1997). Bridge failures can be also lead to loss of life such as in the 1987 failure of the I-90 bridge over Schoharie Creek near Albany, New York, the US 51 bridge over the Hatchie River in Tennessee in 1989, and the I-5 bridges over Arroyo Pasajero in California in 1995 (Morris and Pagan-Ortiz, 1999).

Breusers et al. (1977) defined scour as a natural phenomenon caused by the flow of water in rivers and streams. It is the consequence of the erosive action of flowing water, which removes and erodes material from the bed and banks of streams and also from the vicinity of bridge piers and abutments.

The mechanism has the potential to threaten the structural integrity of bridges and hydraulic structures, ultimately causing failure when the foundation of the structures is undermined.

The mechanism of bridge foundation failure is due to processes of local scour at the piers caused by flow obstruction, downflow, and formation of a horseshoe vortex that wraps around the obstructions (Fig.1).

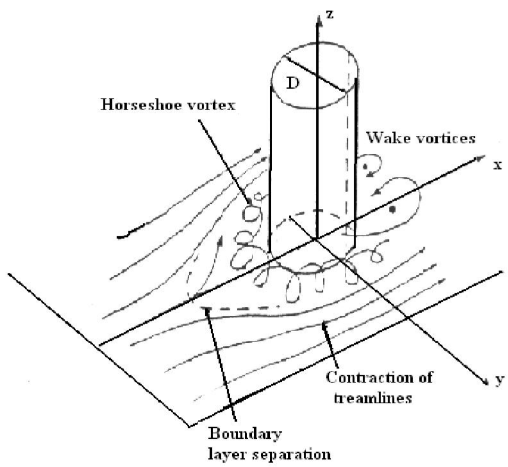


Figure 1. Flow and scour pattern at a circular pier

One way of reducing pier scour is to combat the erosive action of the horseshoe vortex by armoring the riverbed using larger size materials such as stone riprap. Another approach is to weaken the down-flow and thus the formation of the horseshoe vortex using collar.

Chabert and Engeldinger (1956) found that a single circular plate placed 0.4D below the original bed elevation and having a diameter of 3D, where D is the pier diameter, could reduce the depth of scour by 60%.

Ettema (1980) conducted a series of experiments to ascertain the possibility of using a thin collar to mitigate against local scour at a circular bridge pier. Collars were installed on a circular pier at various elevations on, above and below the channel bed. A 0.4 mm thick, circular, brass collar of width two times the pier diameter was installed on the circular pier at four different locations, viz. yc/D = 0.5, 0, -0.5 and -0.1. It was observed that, when a collar of width twice the size of the pier diameter was installed at an elevation of half the diameter (yc/D = 0.5) above the channel bed, the collar was not effective at reducing the scour depth. However, the effectiveness of a collar at reducing scour became noticeable when the collar was installed at the channel bed. No scour developed below the collar when the collar was installed at yc/D = -0.1.

From the study of Singh et al. (2001) it was concluded that the efficacy of a collar in preventing scour is a function of its width and its elevation relative to the bed surface. They found that collar of width of 1.5D, 2D and 2.5D placed on the bed reduced the scour depth by 50%, 68% and 100%, respectively; collar of 2D wide placed at -0.1D resulted a maximum reduction in scour depth.

Mashahir and Zarrati (2002) and Zarrati et al. (2004) worked on the application of a collar to control the scouring around rectangular shape piers having a rounded nose. Their funding also confirmed the previous results. Comparison of the results for rectangular piers aligned with the flow and the previous experiments on circular piers showed that a collar of 3D wide is more effective at reducing the depth of the scour hole for rectangular piers than for circular piers.

The use of collar as a countermeasure at bridge abutment was studied by Kayaturk et al. (2004). The effects of various sizes of collars placed at different elevations on the scour depth at the abutment. Their experimental results showed that not only did the presence of a collar reduce the scour depth; the rate of temporal development of the scour hole was also reduced. According to Kayaturk et al. (2004), a 67% reduction in the scour depth was achieved when the collar was positioned at an elevation of 50 mm below the bed.

Zarrati et al. (2006) studied the use of independent and continuous pier collars in combination with riprap for reducing local scour around bridge pier groups. Their results showed that with two piers in line, a combination of continuous collars and riprap led to a scour reduction of about 50% and 60% for the front and rear piers, respectively. In another experiment with two piers in line, independent collars showed better efficiency than a continuous collar around both the pier. It was also observed that the efficiency of collars is more on a rectangular pier aligned to the flow than two piers in line.

Mashahir et al. (2009) studied the effectiveness of different countermeasures to control scour around bridge piers including application of riprap and installing a collar around piers. Piers aligned with the flow and skewed at 5°, 10° and 20° to the flow were tested. A 3D wide collar installed around the piers at the streambed level has been tested. The size and extent of stable riprap stones for prevention of scouring around the piers was found to decrease when using collar.

The scour geometry around a circular pier in a bend depends on channel geometry (channel width, channel radius and bed slope), pier characteristics (pier diameter and location in bend), collar characteristics (collar size, collar shape and location in bed), flow conditions (approach depth and discharge or velocity), sediment properties (specific gravity, grain size and friction angle), fluid parameters (density and viscosity) and time. Therefore for depth of scour $ds$ can write:

(1)

$$ds = f\left(D, W, H, \theta, Y, b, S_0, V, g, d_{50}, R, \rho_s, \phi, \rho, \mu, t\right)$$

in which D is diameter of pier, W is size of collar, H is location of collar in bed, θ is location of pier in bend, Y is approach flow depth, b is channel width, S0 is bed slope, V is approached flow velocity, g is gravitational acceleration, d50 is median grain size, R is radius of bend, ρs is density of sediment,φ is friction angle of sediment,ρ is density of fluid,μ is viscosity of fluid, and t is time of scour. Using dimensional analysis, Eq. (2) can be written as:

(2)

$$\frac{ds}{D} = f\left(\frac{W}{D}, \frac{Y}{D}, \frac{b}{D}, Fr, \frac{d_{50}}{D}, \frac{R}{\lambda}, \mathrm{Re}, \frac{H}{D}, \frac{\theta}{\lambda}, \frac{\phi}{\lambda}, \frac{\rho_s}{\rho}, S_0, \frac{t}{t_e}\right)$$

in which Fr is approach Froude number, $\lambda$ is angle of bend, te is maximum of time development of scour and Re is Reynolds number. After simplification of above equation and eliminating the parameters with constant values, one can have:

(3)

$$\frac{ds}{D} = f\left(\frac{W}{D}, \frac{H}{D}, \frac{t}{te}\right)$$

Majority of researches on scour at bridge pier are conducted at a straight flume. In this study many examples where the bridges cross the river bends. In this work, results on the effect of square collar on time development of scour at pier in positions of 60 degree in a 180 degree flume bend under a clear water regime are reported.

## 2. Experimentals

Experiments were carried out at the Hydraulic Laboratory of Islamic Azad University, Ahwaz. The main channel consisted of a 9 m long upstream and a 6 m long downstream straight reaches (Fig. 2). A 180 degree channel bend was located between the two straight reaches with a relative radius of Rc/b=4.67. The study conducted at hydraulic laboratory of Islamic Azad university of Ahwaz during March 2009 to October 2009.

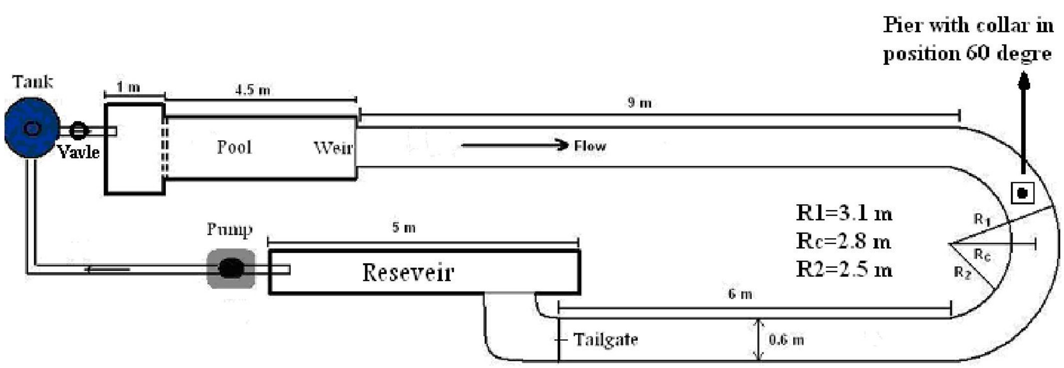


Figure 2. Illustration of the experimental setup (Plan)

The bed of channel was made of Aluminum and sides was made of Plexiglass supported by metal frame. Measurement of discharge was done by a 60 degree triangular weir was used at the upstream section of the flume. Depth of flow and bed profile was measured by a digital point gauge having an accuracy of ± 0.01mm. A sluice gate was located at the end of the main channel to control the flow depth. Uniform sediment with a median size d50 = 2 mm and standard deviation was 1.7 used with a thickness of 20cm and covered the total length of flume. Chiew and Melville (1987) was found that to avoid wall effect on scouring, pier diameter should not be more than 10% of flume width. Therefore in this study a circular pier of diameter 60 mm fabricated from Polyvinyl Chloride (PVC) pipe was used. Collars were made of Plexiglas having a thickness of 5 mm. Figure 3 shows a schematic illustration of a pier fitted with a square. Four different collar widths of 1.5D, 2D, 2.5D and 3D (in which D is the pier diameter) were used. For all of the tests with a collar, the collar was positioned at the bed level,0.1D,0.5D and 1D below the bed in accordance with the recommendations of earlier researchers ( Ettema 1980; Kumar et al. 1999 and Singh et al.2001).

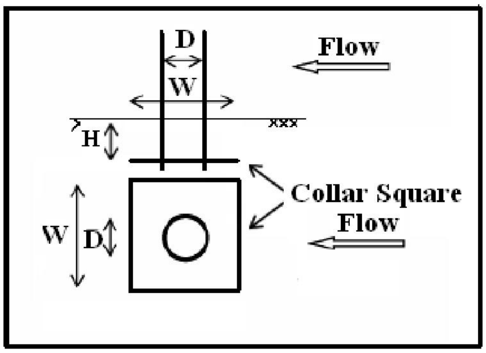


Figure 3. Circular pier fitted with a square collar

The duration of experiments was kept equal to 24 hrs at which equilibrium time condition occurs. Experiment was conducted at Froude number of 0.41 at the position of 60 degree for a pier without collar. The results are shown in Fig.4. As it can be seen approximately 92% of scouring occurs during the first 4 hours. Therefore in all remaining of our experimental tests, duration of 4 hours was selected for each test.

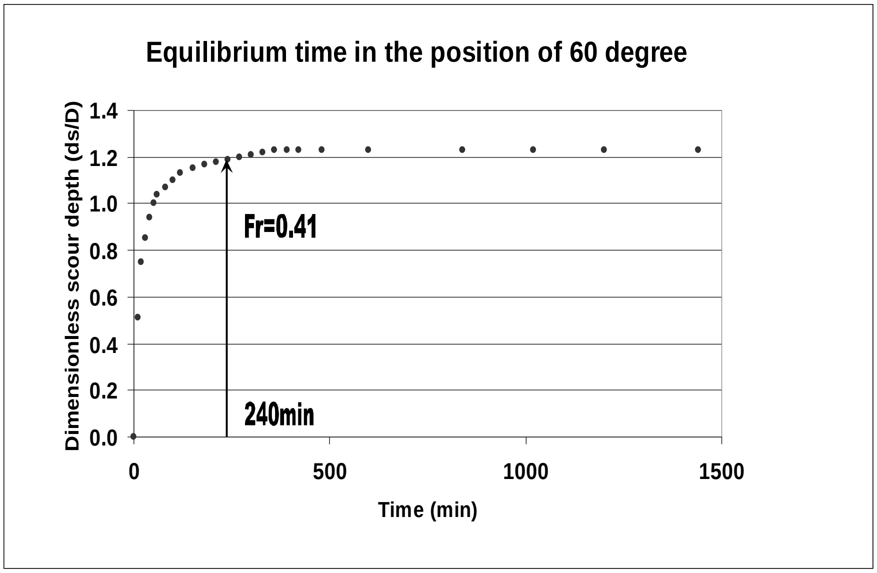


Figure 4. Equilibrium time in the position of 60 degree for a pier without collar

Experiments on scour were performed near threshold condition in straight channel i.e. $0.9<U/U_c<1$ (U is approach velocity and Uc is critical velocity for sediment movement). Initially the bed surface was leveled by a plate attached to the carriage mounted on the channel. Then inlet valve was opened slowly, the discharge increased to a predetermined value so that no scour occurs at the straight reaches of flume. Scour depth in upstream of collar in test time was measured by a digital point gauge having an accuracy of ± 0.01mm (Fig. 5).

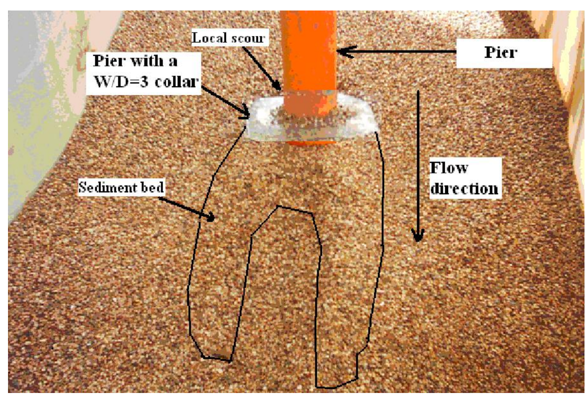


Figure 5. Scour pattern at the end of a test

**3-1. Various sizes of collar fitted at time development of scour**

Figure 6 shows the results obtained time development for four different collar widths, W=1.5D,2D,2.5D and 3D were tested at the bed level. Results shown, the size of a collar plate increases, the scour decreases. Collar plates of size W/D=3 gave a maximum reduction in scour depth.

Figure 7 shows the maximum scour depth with and without collar plates for four different elevations were used at the bed level, 0.1D, 0.5D and 1D below bed with collar sizes of 1.5D, 2D, 2.5D and 3D. As shown by the results in Figure 7, the depth of the scour in square collars reduced increases because of the square collar is sharp-pointed and reduced horseshoe vortex.

As concluded in the study by Mashahir et al. (2004), placing the collar below the channel bed level did not lead to an appreciable increase in the efficacy of the collar. This was so because the depth of the sand sediments above the collar will itself become part of the scour hole as this is swept away very fast by the erosive action of the flow. Comparison of the results for rectangular piers aligned with the flow and the previous experiments on circular piers by Zarrati et al. (2004) and Mashahir et al. (2009) showed that a collar of W/D = 3 is more effective at reducing the depth of the scour hole for rectangular piers than for circular piers.

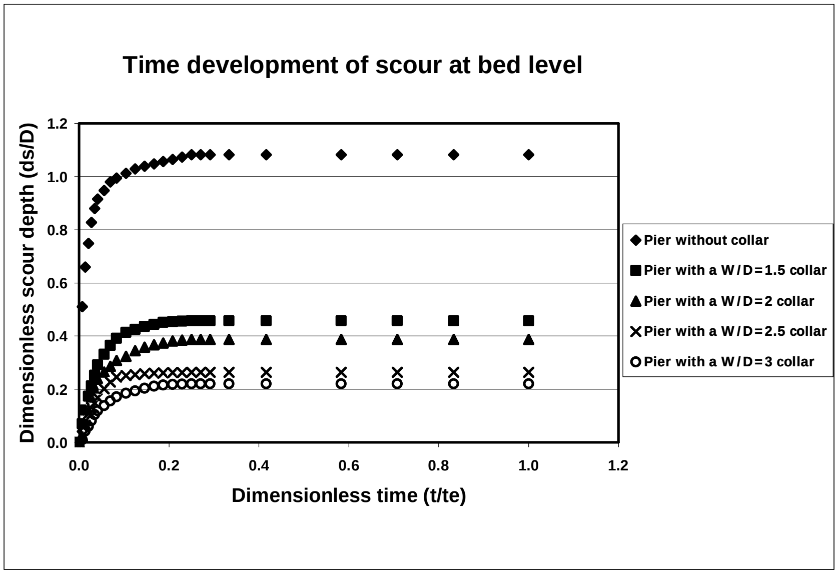


Figure 6. Time development of scour for different collar sizes

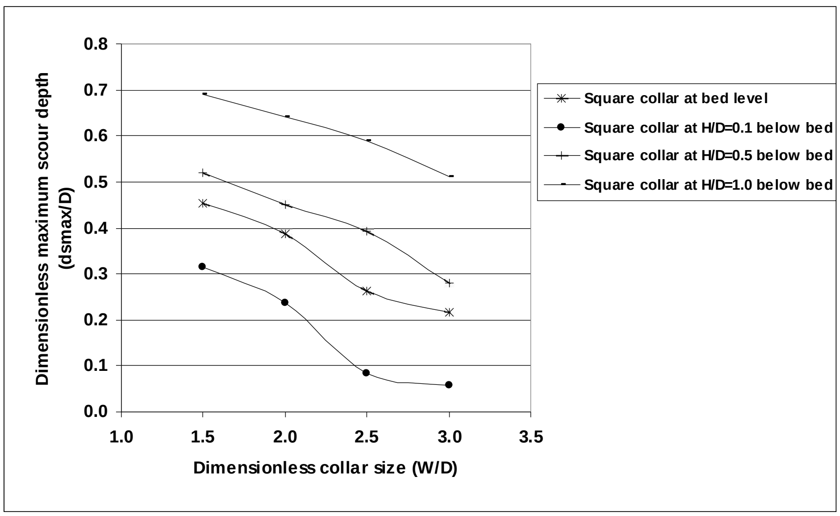


Figure 7. Maximum scour depth for different collar sizes

**3-2. Various elevations of collar fitted at time development of scour**

Figure 8 shows the time development of the local scour around the pier fitted with and without collar plates for four different elevations were used at the bed level, 0.1D, 0.5D and 1D below the bed with collar widths 3D. As shown by the results in Figure 8, the depth of the scour hole reduced because of the collar irrespective of the collar size and vertical position. The experimental results signified that not only did the presence of a collar reduce the scour depth, the rate of temporal development of the scour hole was also reduced.

From Fig.9 it is obvious that, all collar of any width, installed at 0.1D below the bed results maximum reduction in scour depth. The main reason of such finding is that the strength of the downward vortex decreases when the collar placed at 01D below the bed.

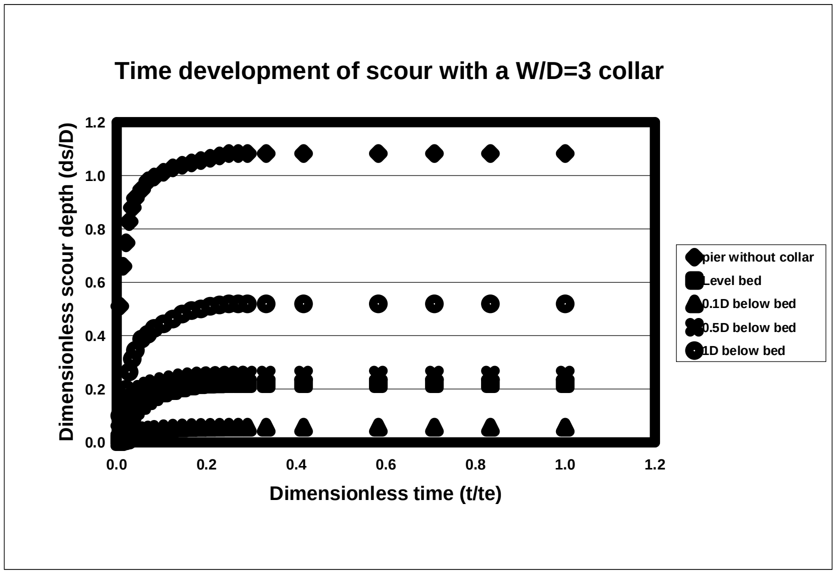


Figure 8. Time development of scour for different elevations

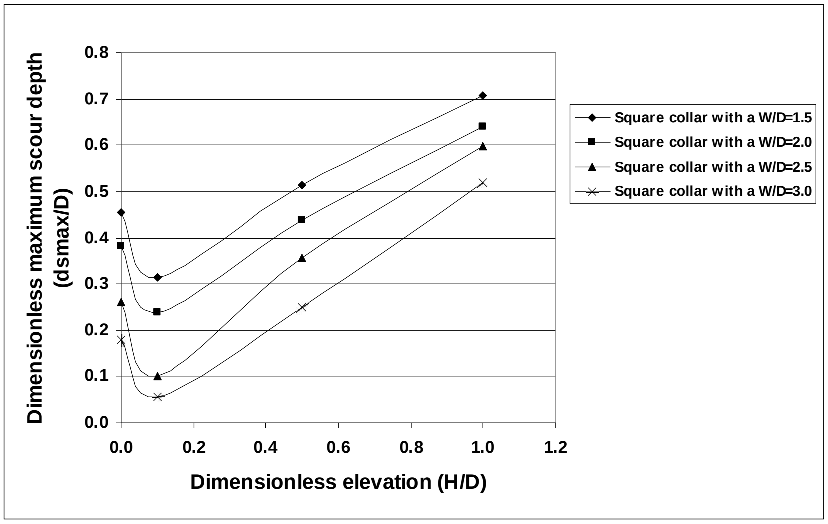


Figure 9. Maximum scour depth for different elevations

Table 1 shows the reduction in the scour depth around the pier fitted with collar plates for four different elevations were used at the bed level,0.1D,0.5D and 1D below the bed with collar widths of 1.5D, 2D, 2.5D and 3D. Table 2 shows collar plates of size W = 3D when placed at 0.1D below the bed surface gives a maximum reduction in scour depth equal to 96% of the scour depth without collar.

Table1. Percent reduction in the scour depth

| Elevations<br>Sizes of collars | Bed level | H/D=0.1 | H/D=0.5 | H/D=1.0 |
|---|---|---|---|---|
| Square collar with a W/D=1.5 | 53 | 71 | 51 | 36 |
| Square collar with a W/D=2.0 | 62 | 78 | 59 | 43 |
| Square collar with a W/D=2.5 | 73 | 90 | 61 | 44 |
| Square collar with a W/D=3.0 | 80 | 96 | 73 | 52 |

**4. Equation for scour depth**

The equation (3) can be written as:

$$\frac{ds}{B} = a\left(\frac{W}{B}\right)^b \left(\frac{H+c}{B}\right)^d Ln\left(\frac{t+e}{t_e}\right)^f \quad (4)$$

in which a, b, c, d, e and f are empirical constants and can be found using experimental data.

By using least squares method for all the data it was found. Therefore, equation (4) can be written as:

$$\frac{ds}{B} = 0.85\left(\frac{W}{B}\right)^{0.8} \left(\frac{H+1}{B}\right)^{1.35} Ln\left(\frac{t+360}{t_e}\right)^{0.185} \quad (5)$$

with regression coefficient of 0.96. Figure 10 shows the comparison of calculated values with use to Eq. (5) and tested values of relative maximum scour depth. It is evident that Eq. (5) predicts the maximum scour depth with acceptable accuracy.

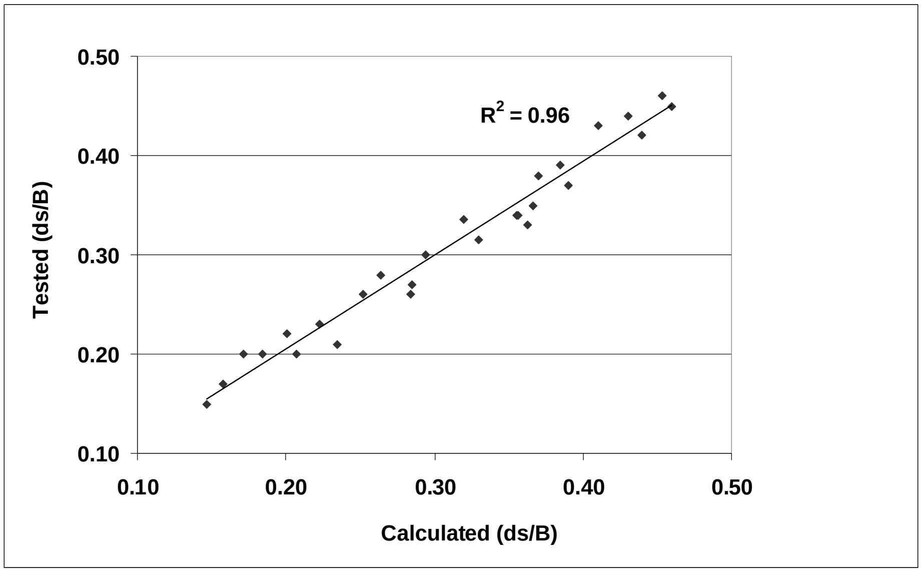


Figure 10. Comparison of calculated and tested scour depth

**4. conclusions**

In this work, presented the results of several long duration scour laboratory experiments around a circular pier located in a 180 degree flume bend. Detailed measurements of the erosion holes allowed the evaluation of scoured volumes. The analysis of the results shows the following.

For a test duration of about 4 hours, the maximum scour depth was observed at the upstream face of the pier for an unprotected pier while the position of the maximum scour depth for a pier protected with a collar of W= 3D.

The pathway to an equilibrium scour depth is different depending on whether the pier is fitted with a collar or not. With a collar in place, the development of the scour hole is considerably delayed.

There was a reduction in the scour depth when a collar of W=3D was used to protect the pier when compared with a W=1.5D, 2D and 2.5D.

All collars of any diameter, at 0.1D below the bed resulted in maximum reduction in scour depth.

Minimum depth of scour occurs for a collar of W=3D placed at 0.1D below the bed. The percent of reduction by 96% compare to without collar.

The equilibrium scour depth in clear water is less than in 25% of total time.

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