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Experimental Study of Local Scour around Circular pier Fitted with Collar

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Abstract:

Scour is defined as the erosion of streambed sediment around an obstruction in a flow field. Bridge pier scouring is a significant problem in the safety estimation of bridges. In this study, the use of rectangular collar for reducing the effect of local scour at a circular pier in a laboratory flume was presented. The study was conducted using 6.6 m laboratory flume in length and 0.4 m in width. Experiments were conducted for various sizes of rectangular collars fitted at the bed elevation on the scour depth at the circular pier with clear-water scour condition. The time development of scour depth at the circular pier with and without a collar of circular installed was conducted. In collars observed that size of a collar plate increases, the scour decreases. Results showed that the maximum reduction in scour depth equal to 100% (no scour hole). Dimensional analysis technique was used, and from the experimental data an empirical formula was derived. It was found that the predicated scour depth from the formula performs well as compared to the observed scour depth.

Keywords: scour depth, collar, dimensional analysis, circular pier

دراسة مختبرية للانجراف الموقعي حول الدعامات الدائرية المزودة بطوق

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المستخلص

اعتمد هذا البحث على تجارب مختبرية لحساب عمق الانجراف الموقعي حول الدعامة المزودة بطوق حيث أخذت الدراسة بنظر الاعتبار تأثير ظروف الجريان و حجم الدعامة و ابعاد الطوق على عمق الانجراف الأعظم و نمط الانجراف حول الدعامة.

أجريت التجارب في قناة مستطيلة بطول 6.6 متر و بعرض 0.4 متر تحت ظرف جريان (subcritical flow) و الخالي من حمل الرسوبيات (clear-water condition) و باستخدام تربة ذات جزيئات منتظمة و غير متماسكة (رمل) كمادة للقاع.

لوحظ ان حجم الطوق له تأثير كبير على تقليل عمق الإنجراف، حيث كانت نسبة التقليل 58%، 67% و 100% لكل من طول الطوق العلوي و السفلي و عرض الطوق بالترتيب.

التحليل البعدي وبرنامج (STATISTICA) أُستخدما لإيجاد معادلة جديدة لحساب عمق الانجراف وبإعتماد التجارب المختبرية، و هي لحساب عمق الإنجراف حول الدعامة مزودة بطوق.

لوحظ من خلال مقارنة القيم المختبرية المسجلة مع قيم التي تم الحصول عليها من المعادلة كانت النتائج متقاربة و كانت قيمة معامل التحديد (Determination Coefficient) 0.954 و التي تعطي توافقا جيداً.

6. NOTATIONS

D	Diameter of Pier
d_{16}	Sediment Size for which 16% of the Particles are Finer
d_{50}	Median Particle Size Which is Taken as the Representative Particle size
d_{84}	Sediment Size for which 84% of the Particles are Finer
d_s	Maximum Equilibrium Scour Depth below the Bed Level
F_p	Pier Froude Number
F_r	Froude Number
L_d	Downstream Length of Collar
L_u	Upstream Length of Collar
R^2	Determination Coefficient
S	Slop of the Channel
t	Scouring Time
V	Mean Velocity of Approach Flow
v/v_c	Flow Intensity
v_c	Mean Velocity at Threshold of Motion of Bed Sediment for Approach Flow
W	Width of Collar
y	Average Upstream Undisturbed Flow Depth
z	Collar Elevation
σ_g	Geometric Standard Deviation of Sediment Size Distribution
μ	Dynamic Viscosity of Water

1. INTRODUCTION:

Flow in an open channel with a mobile bed is usually accompanied by transport of sediments [7]. Scour may occur as a result of natural changes of flow in the channel or as a result of man-made activities, such as construction of structures in the channel or dredging of material from the bed [4].

Bridge failures cost millions of dollars each year in direct expenditure for replacement and restoration in addition to the disruption of transport facilities [9].

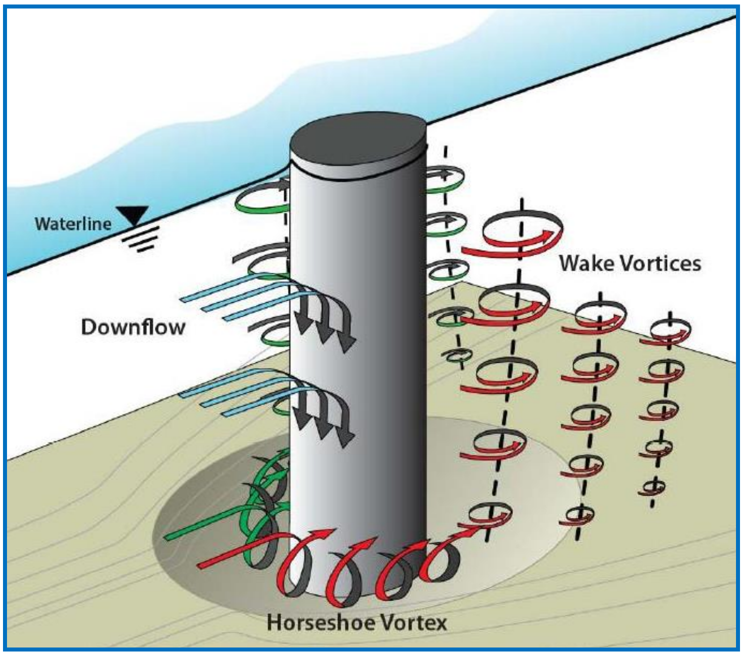
The potential losses accruable from bridge failures and the need to guard against same have prompted for better understanding of the scour process and for better scour prediction methods and equations. Combined effects of turbulent boundary layer , time-dependent flow pattern , and sediment transport mechanism in and around the scour hole make the phenomenon extremely complex [3].

Local scour at bridge pier principally results from the downflow along the upstream face of the pier and the resulting horseshoe vortex which forms at the base of the pier aids the phenomenon [1] (Fig. 1).

Over the past half century, numerous studies had been conducted and numerous equations had been developed to predict bridge pier scour. Most of these equations were developed using laboratory data and sometimes tested using limited field data.

One way of reducing pier scour is to combat erosive action of the horseshoe vortex by armouring the riverbed by using hard engineering materials such as collar [5].

The present study aims to investigate the local scour around circular pier fitted with collar, and using the experimental data to derive a formula to predict a maximum scour depth around the pier.



(Fig.1) Schematic representation of scour around bridge pier [7]

The scour geometry around a circular pier depends on pier characteristics (pier diameter), collar characteristics (collar size, collar shape and location in bed), channel geometry (channel width), 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 (d_s) one can write:

$$(d_s) = f\{L_u, L_d, W, y, d_{50}, v, v_c, \rho_s, \rho, D, S, g, \mu, \sigma_g, t, z, B\} \quad (1)$$

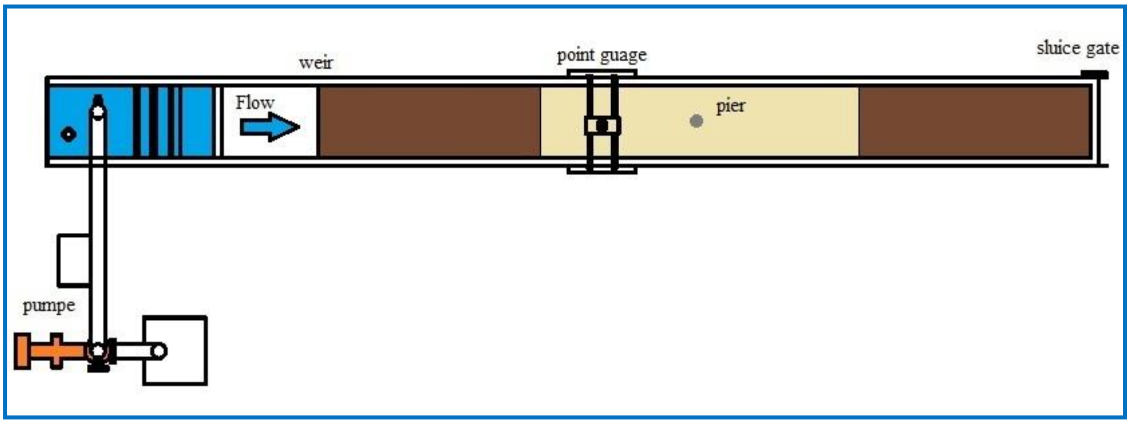
In which L_u=upstream length of collar, L_d= downstream length of collar, W= collar width, y=flow depth, d_{50}=median particle grain size, v= mean approach flow velocity, v_c=critical (threshold) velocity, ρ_s= density of the sediment, ρ= density of the fluid, D=pier diameter, S= slope of the channel, g= gravitational acceleration, μ= dynamic viscosity of fluid, $\sigma_g=(d_{84}/d_{16})^{0.5}$=geometric standard deviation of sediment size distribution, d_{84}=sediment size for which 84% of the sediment is finer, d_{16}= sediment size for which 16% of the sediment is finer, t=scouring time, z=collar elevation from sand bed and B=channel width. Using dimensional analysis, after simplification and eliminating the parameters with constant values, Eq. (2) can be written as:

$$ {d_s}/{D} = f\left({L_u}/{D}, {L_d}/{D}, {W}/{D}, {y}/{D}, {v_c}/{v}, F_p \right) \quad (2) $$

Where, F_p=pier Froude number and v/v_c=flow density.

2. EXPERIMENTAL WORK

Experiments were carried out at the Hydraulic Laboratory of Al-Najaf technical institute-civil techniques department. The main channel consisted of 6.6 m long and 0.4 m width (Fig. 2).



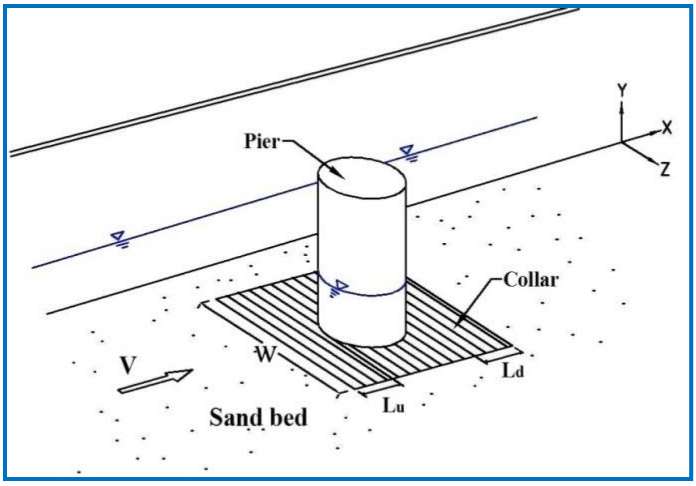
(Fig. 2): the experimental setup

Measurement of discharge was done by a rectangular full width weir used at the upstream section of the flume. Depth of flow and bed profile was measured by a point gauge having an accuracy of ±1 mm.

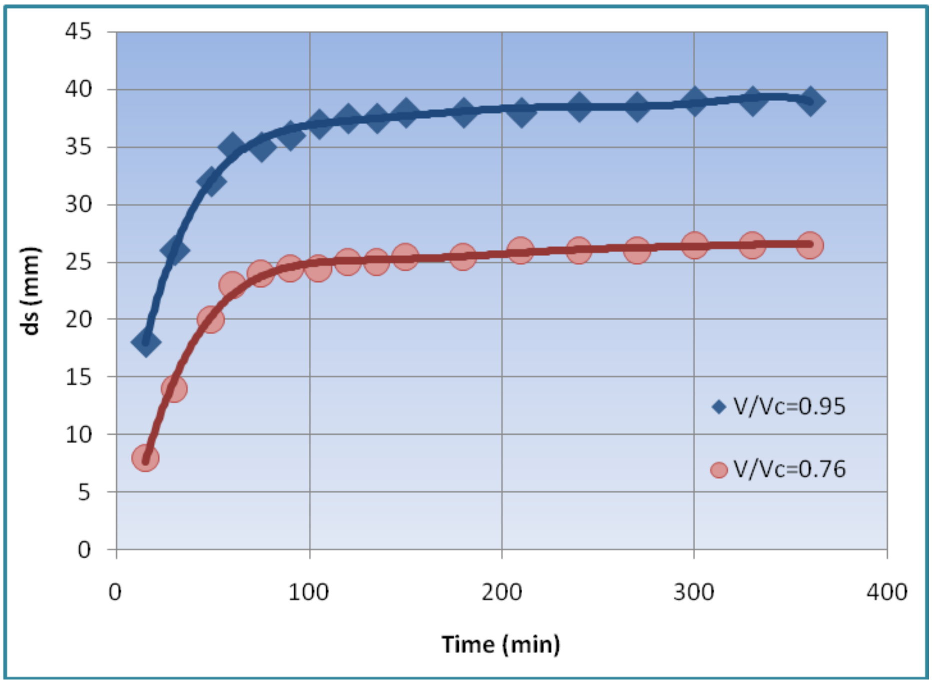
A sluice gate was located at the end of the channel to control the flow depth. Uniform sediment with a mean size diameter d_{50}=0.708 mm and standard deviation was1.15 used with a length of 2 m and thickness of 10 cm. To avoid wall effect on scouring, pier diameter should not be more than 10% of flume width [2]. Therefore in this study three circular piers of diameter 27, 33 and 40 mm fabricated from Polyvinyl Chloride (PVC) pipe was used. Collars were made of Plexiglas having a thickness of 2 mm.

Figure 3 shows a schematic illustration of a pier fitted with a rectangular collar and its dimensions.

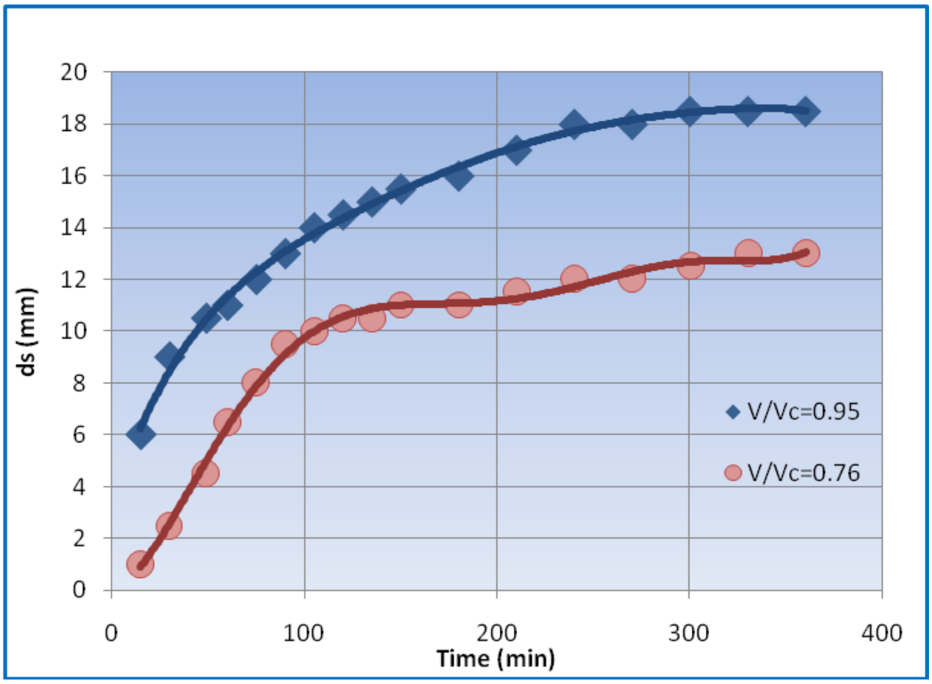
The duration of experiments was kept equal to 4 hrs at which equilibrium time condition occurs. Experiment was conducted at two different flow intensity (velocity) and for two cases with and without collar. The results are shown in Fig. 4 and 5. As it can be seen approximately 95% of scouring [6] occurs during the first 3 hours and half for case with collar. Therefore in all of the experimental tests, duration of 4 hours was selected for each run.



(Fig. 3): A pier fitted with a rectangular collar



(Fig. 4): Scour depth variation with different duration for pier without collar

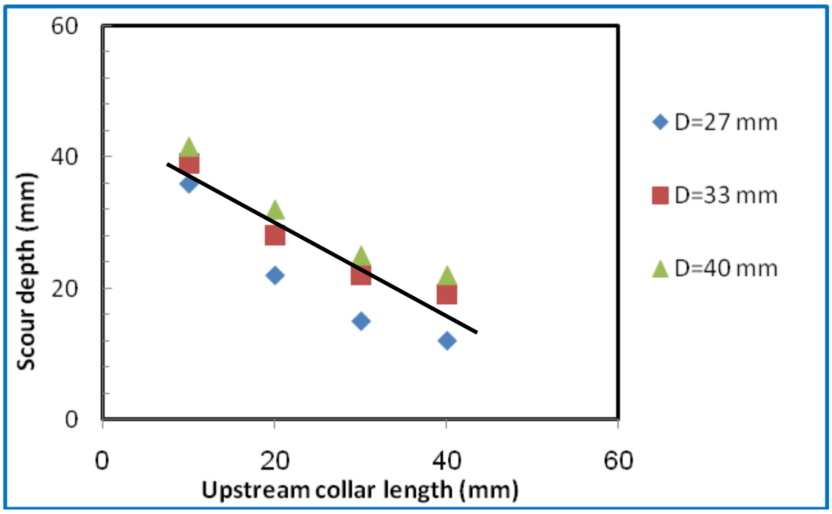


(Fig. 5): Scour depth variation with different duration for pier with collar

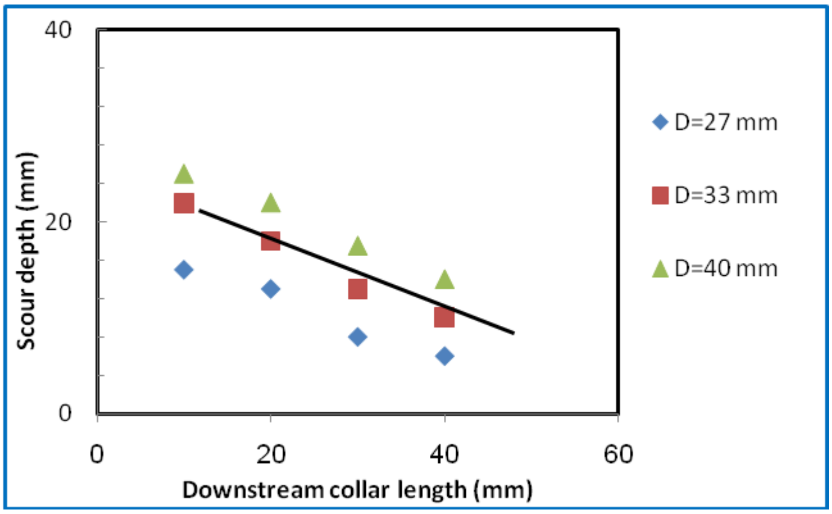
3. RESULTS

Variation of Sizes of Upstream and downstream Length and width of Collar:

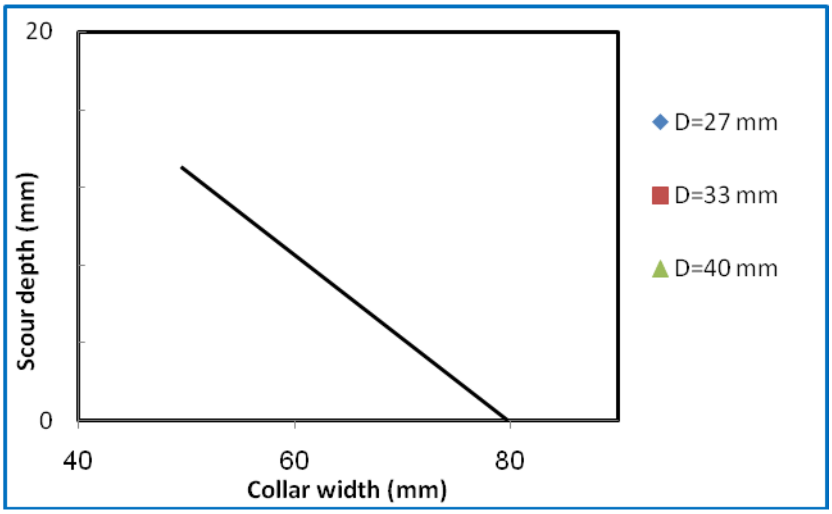
Figures 6, 7 and 8 show the development of the local scour around the circular pier fitted with collars of rectangular plates for four different lengths for upstream and downstream length and width of collar were used with all other parameters kept constant for each one for three sizes of piers at bed level. Results shown that scour depth decreases, with increasing upstream and downstream length and width of collar.



(Fig. 6): Development of scour depth with upstream collar length



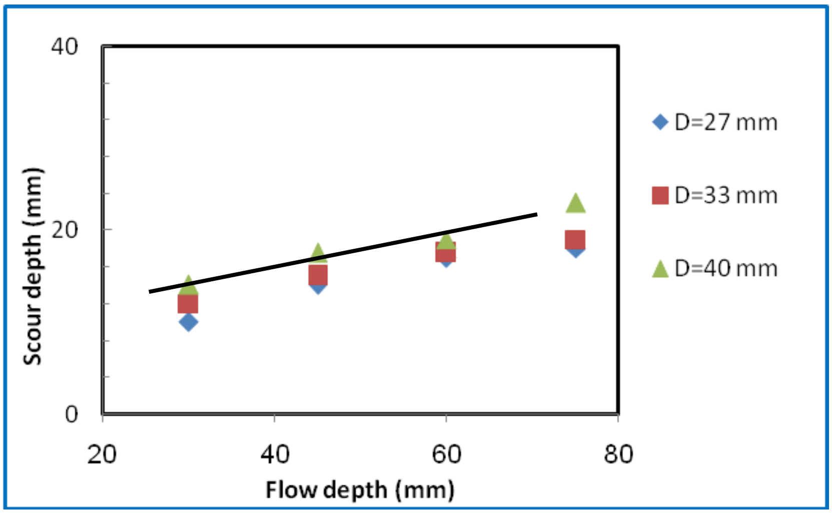
(Fig.7): Development of scour depth with downstream collar length



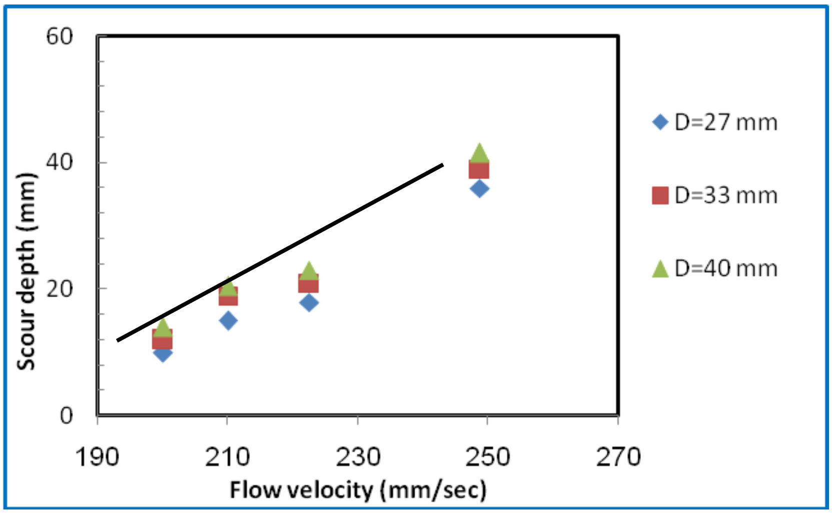
(Fig. 8): Development of scour depth with width of collar

Variation of Flow Depth and Velocity and Pier Froude Number:

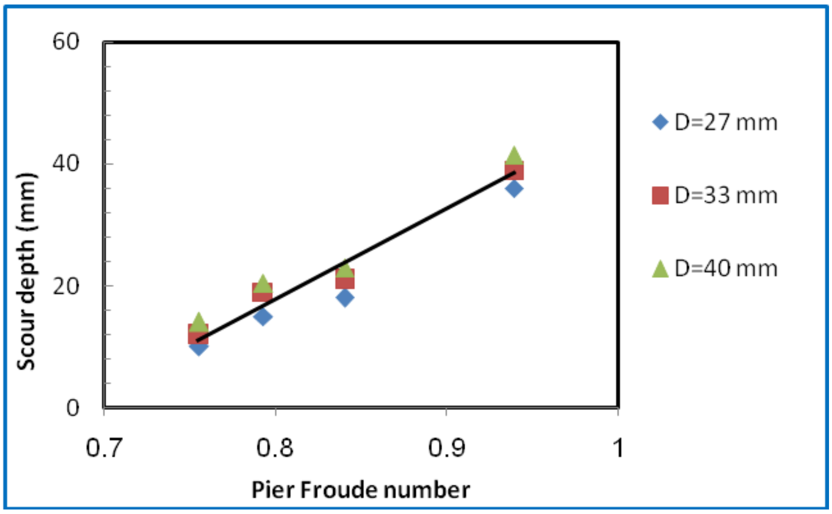
Figures 9, 10 and 11 show the development of the local scour around three different sizes circular piers fitted with constant dimensions of collar at bed level. Results shown that scour depth increases, with increasing flow depth and velocity of flow and pier Froude number.



(Fig. 9): Development of scour depth with flow depth



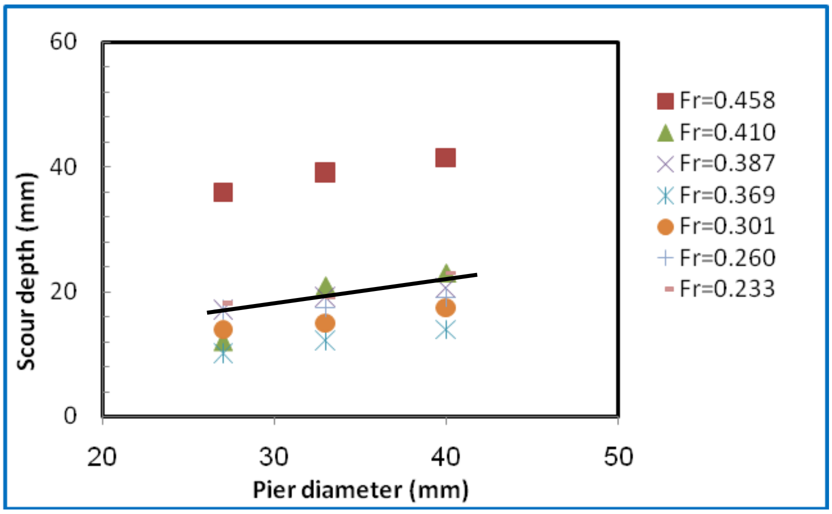
(Fig. 10): Development of scour depth with flow velocity



(Fig. 11): Development of scour depth with pier Froude number

Variation of Pier Sizes:

Figure 12 shows the development of the local scour around three different diameters of circular piers fitted with constant flow conditions (depth and velocity) and dimensions of collar at bed level. Results shown that scour depth increases, with increasing pier size regardless of the influence of other parameters.



(Fig. 12): Development of the scour depth with Pier diameter

The experimental results signified that not only did the presence of collar reduce the scour depth, the rate of temporal development of the scour hole was also reduced.

4. DEVELOPMENT OF NEW FORMULA

In order to generalize the experimental results to some form of a relationship that includes the effects of collar dimensions a limited number of data were concluded from this study.

The computer package (STATISTICA) was used to make analysis for the equation through a non-linear regression analysis.

Model:

$$d_s/D = C_1 \times \left\{ \left(L_u/D \right)^{C_2} \times \left(L_d/D \right)^{C_3} \times \left(W/D \right)^{C_4} \times \left(y/D \right)^{C_5} \times \left(v_c/v \right)^{C_6} \times \left(F_p \right)^{C_7} \right\}$$

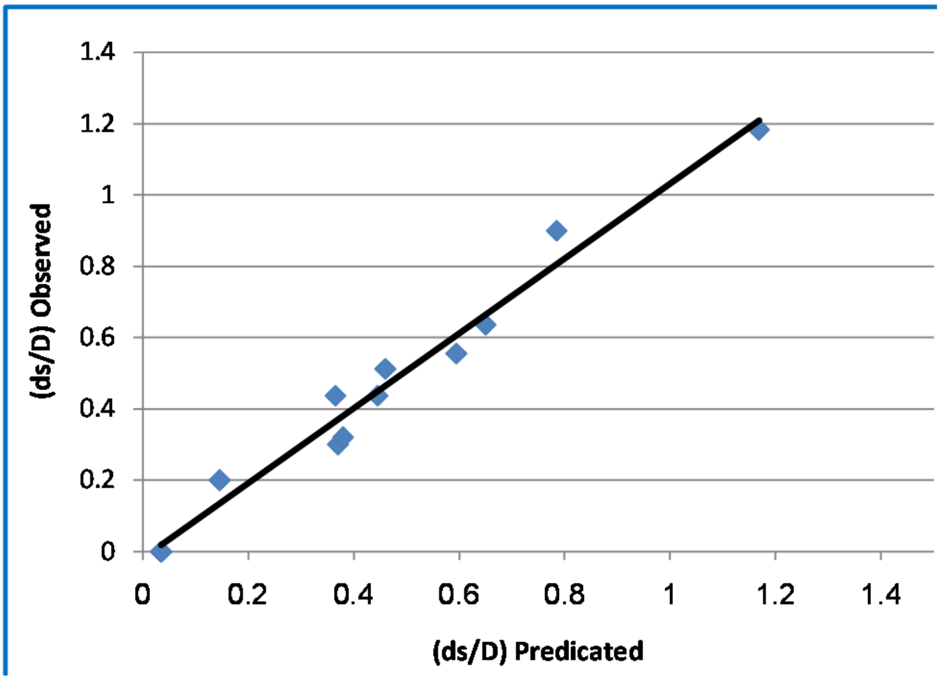
$C_1 = 12.995$ $C_2 = -0.517$ $C_3 = -0.506$ $C_4 = -5.018$ $C_5 = 0.458$ $C_6 = -0.517$ $C_7 = 5.791$

So, the equation becomes:

$$\frac{ds}{D} = 12.995\left\{\left(\frac{L_u}{D}\right)^{-0.517}\left(\frac{L_d}{D}\right)^{-0.506}\left(\frac{W}{D}\right)^{-5.018}\left(\frac{y}{D}\right)^{0.458}\left(\frac{v}{v_c}\right)^{-0.517}{F_p}^{5.791}\right\} \quad (3)$$

The coefficient of determination (R^2) for this formula is (0.954).

Another data is used to testing the equation, a statistical comparison of equation is used to show the convergency [10] of the predicted to the observed records , the value of R^2 are given good agreement for all data as shown in Figure 13.



(Fig. 13): Comparison of Equation (3) to Experimental Data

5. CONCLUSIONS

Under the limitations imposed on this investigation the following conclusions can be drawn.

1. The scour in pier not provided with collar was occurred at the first of equilibrium time, but the pier with collar has different behavior which the occurred scour at first of equilibrium

time represents low percentage from equilibrium scour depth, which can be used in case of floods with short periods.

2. The collar can reduce the scour depth to become nothing and provide complete protection for piers.
3. Increasing in upstream and downstream collar length produced by the percentage of reduction in scour depth of 58% and 67% respectively. This percent in collar width was 100%.
4. The maximum scour depth was observed at the nose of pier at the end of each experiment.
5. The scour depth increased with increasing pier Froude number, depth and velocity of flow.
6. The increasing of pier diameter was given increasing scour depth.
7. The derived formula for the maximum depth of scour Eq. (3) was developed by using the dimensional analysis techniques. These formulas were restricted to the laboratory data. The scour depth was represented as a function of upstream and downstream length of collar, collar width, pier Froude number, flow intensity, flow depth and Pier size. The formula gave a good determination coefficient, and gave an idea to evaluate the maximum scour depth for similar conditions to those covered in this study.

6. REFERENCES

1) Bakar C. J. " Effect of pier spacing on scour around bridge piers" ; Jr . Hydr. Engrg . , ASCE , Vol .111 No .7 (1985).

2) Chiew, Y.M. (1992). ‘Scour protection at bridge piers’. Journal of Hydraulic Engineering, ASCE, 118(9): 1260-1269.

3) Dargahi, B. (1990). ‘Controlling mechanism of local scouring’. Journal of Hydraulic Engineering, ASCE, 116(10): 1197-1214.

4) Duarte, C. A., and Sainz, J. A. (1999). ‘Riprap at Bridge Piers’. J. of Hydr. Research, Vol. 37, No. 3, 291-302.

5) Ernest F. Brater, Horace Williams king, James E. Lindell, C.Y.Wei (1996). Handbook of Hydraulics. Seventh edition, McGraw-Hill Book Company N.Y, ISBN 0-07-007247-7.

6) Ettema, R. (1980). Scour at bridge piers. PhD Thesis, Auckland University, Auckland, New Zealand.

7) Federal Highway Adminisration, (2001). Evaluating Scour At Bridges. National Highway Institute, Publication No. FHWA NHI 01-001, HEC No. 18, U. S.

8) Kumar, V., K. G. Ranga Raju and N. Vittal, 1999. Reduction of local scour around bridge piers using slots and collars. Journal of Hydraulic Engineering, ASCE, 125(12): 1302-1305.

9) Lagasse, P.F. and E.V. Richardson, 2001. ASCE compendium of stream stability and bridge scour papers. J. Hydraulic Engineering, ASCE, 127(7):531-533.

10) Vittal N. , et.al. " Clear Water scour around bridge pier group" ; Jr . Hydr .Engrg . ASCE , Vol .120 No.11 (1994).