Experimental study for bridge pier protection against local scour by using guide panels

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Abstract

Local scour around a bridge pier is the result of the action of a complex vortices system that appears due to the modified of flow patterns caused by obstructed by a bridge pier. Therefore, experimental studies have always been considered to be a powerful utensil in understanding and analyzing the performance of complicated flow conditions and the effect of countermeasures which otherwise cannot be subjected to theoretical analysis. This study was conducted to determine the efficiency of the proposed method in reducing the depth of scour in laboratory conditions. This was done by conducting scour studies for a pier protected by a guide panels with various heights under clear water conditions. Results showed that, as the height of panels decreases the scour depth also decreases, with maximum reduction of scour depth equals to (93%), with neglect side effects on the guide panels scour. The technique of dimensional analysis was used, and based on laboratory results an empirical formula was derived.

Key-Words: - Local scour, Experimental studies, Guide panels, Dimensional analysis.

1- Introduction

Scour process is the result of the erosive action of flowing water, which excavates and carries away materials from the bed, banks of streams, and from around the bridge piers (Fig. 1). Bridge scour is a dynamic phenomenon that affected by many factors such as water depth, flow velocity, pier shape and width, sediment properties, and others. The performance and safety of bridges are affected by three types of scours, namely, general scour, contraction scour, and local scour (Richardson and Davies 1995). General scour is the removal of sediment from the river bottom by the flow of water. General scour develops regardless of the existence of a bridge, it is considered a natural process, but large amounts of sediment may remove over time. Contraction scour refers to the removal of sediment from the bottom and sides of the river. It occurs as a result caused by an increase in flow velocity as the water moves through a bridge opening that is narrower than the river channel. Local scour is defined as the removal of sediment from around bridge piers or abutments, leaving a hole in the sediment, which are known as scour holes (see Fig. 1).

The flow development in the vicinity of a circular pier have been studied by many researchers such as (Hjorth 1975; Melville 1975; Raudkivi 1986; Dargahi 1987; Richardson and Davis 2001) and others, Fig. 2 shows the schematic of flow pattern around a circular pier in a scour hole. It can be seen that; the wake vortices are formed when the separate flow by the pier converges at the downstream of the pier. Also, as the mean flow approaches the pier, a portion of the flow is forced to move down the front surface of the pier formed a horseshoe vortex at the base of the pier, which removes bed materials from around the base of the pier causes local scour at the pier. As the depth of scour increases the strength of horseshoe vortices will be reduced, thereby reducing the transport rate from the base region.

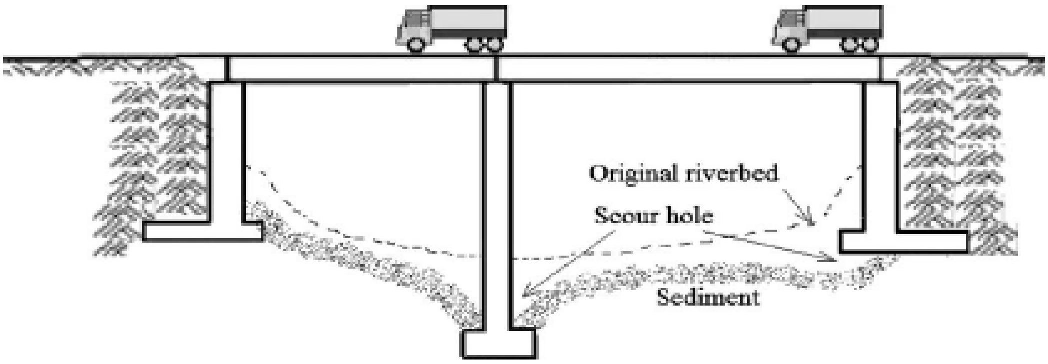

Fig. 1. Bridge scour (Deng and Cai 2010).

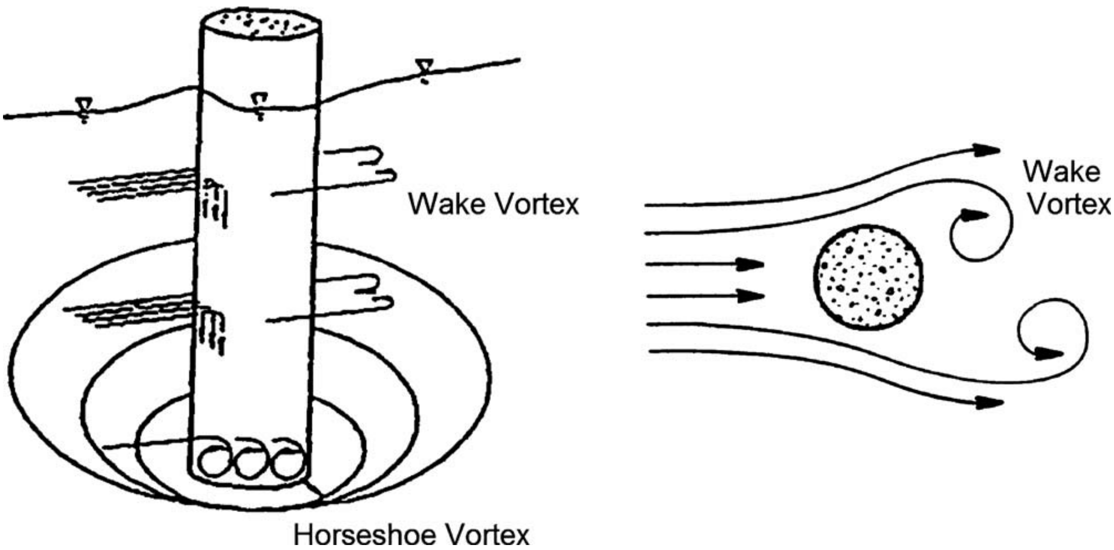

Fig. 2. Flow around a circular pier in a scour hole

(Richardson and Davis 2001).

One of the methods used to reduce the pier scour is to combat the corrosion action of the horseshoe vortex by arming the river bed using solid engineering materials such as a guide panels.

The purpose of the present study is to investigate the local scour around circular pier protected by a guide panels, and the experimental data was used to derive a formula to predict the maximum scour depth around the circular pier.

2- Dimensional analysis

For a smooth circular pier of width D_p located at a rectangular flume with a movable bed in clear water, steady and uniform flow conditions, protected by a guide panels, the maximum scour depth at a pier nose *ds* at time *t* is a function of following parameters:

$$(d_s)=f(y, v, v_c, g, \rho, \ \mu, d_{50}, \rho_s, \ \sigma_g, D_p, \ S, B, t, X_{gp}, W_{gp}, h_{gp}, \alpha_{gp}, T_{gp}, Ol_{gp}) \qquad (1)$$

Where f = unknown function, and the other parameters including in this equation are described as follows:

i) Flow variables; y=flow depth, v=mean approach flow velocity, v_c=critical velocity, g= gravity acceleration.

ii) Fluid variables: ρ= water density; μ= dynamic viscosity.

iii) Bed sediment variables: d_{50}=median particle grain size, ρ_s= sediment density, σ_g=geometric standard deviation, where *dx* = is the grain size for which *x*% by weight of the sediment is finer.

iv) Pier variables: D_p=pier diameter.

v) Channel geometry variables: S=channel slope, B=channel width.

vi) t =scouring time.

vii) guide panels variables: X_{gp}=spacing between pier and guide panels, W_{gp} =width of guide panels, h_{gp} =height of guide panels above the sand bed, α_{gp} = interior angle between panels, T_{gp}=thickness of guide panels, and Ol_{gp}= leading opening between panels.

By using Buckingham π-theorem, and after the simplification of the above equations and eliminating the parameters with negligible and constant values and applying the following considerations to Eq. (1): (1) σ_g < 1.5 for uniform sediment with $D_p/d_{50} > 25$, this ratio can be excluded from the scour formula (Melville and sutherland, 1988), (2) horizontal channel floor without any inclination, (3) for $B/D_p \geq 10$, side-wall (or blockage) effects due to pier presence are negligible (e.g. Chiew and Melville 1987), (4) for constant spacing between pier and guide panels, constant width and thickness of guide panels, and constant interior angle, for both cases (the presence of the leading opening between guide panels or not), (5) and it is independent of dimensionless time at equilibrium conditions.

In accordance with these conditions, the functional relationship which describes depth of scour normalized with pier diameter may be written as:

$$d_s/D_p = F_4(y/D_p \,.\, v_c/v \,.\, D_p\ g/v^2 \,.\, h_{gp}/D_p) \qquad (2)$$

The above equation shown that; the scour depth ratio (d_s/D_p) varies with flow depth ratio (y/D_p), flow intensity (v_c/v), pier Froude number ($D_p\ g/v^2$), and height of guide panels above the sand bed (h_{gp}/D_p).

3- The experimental work and guide panels models:

The experimental work was done at university of Al-Basrah- college of engineering- civil department- at the hydraulic laboratory.

A 5.72 m-long, 0.61 m-wide rectangular flume was used. The longitudinal slope was zero. A uniform sand was used to fill a 1.8 m-long, 0.08 m-deep (Fig. 3).

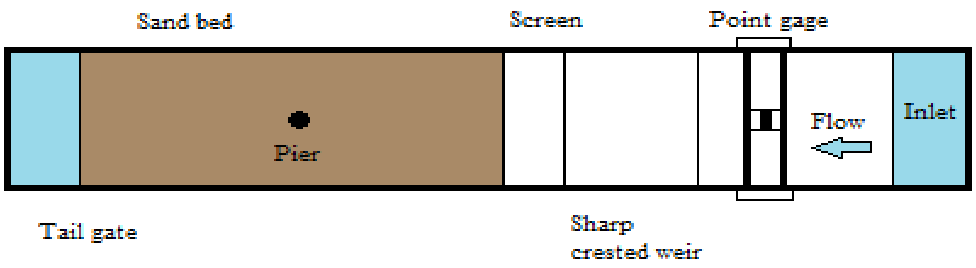

Fig. 3 Illustration of experimental setup.

The flow depth was controlled by a tailgate. A point gauge of ($\pm$ 0.1 mm) accuracy was used to measure the flow depth, the maximum scour depths at the pier front, and the scour at the edge of guide panels.

The guide panels used in the experiments are two vertical panels with an open or closed interior angle, made of plywood and having a constant thickness of 1.8 cm. Experiments include using three different heights of guide panels with constant width and distance from the pier, (see Fig. 4).

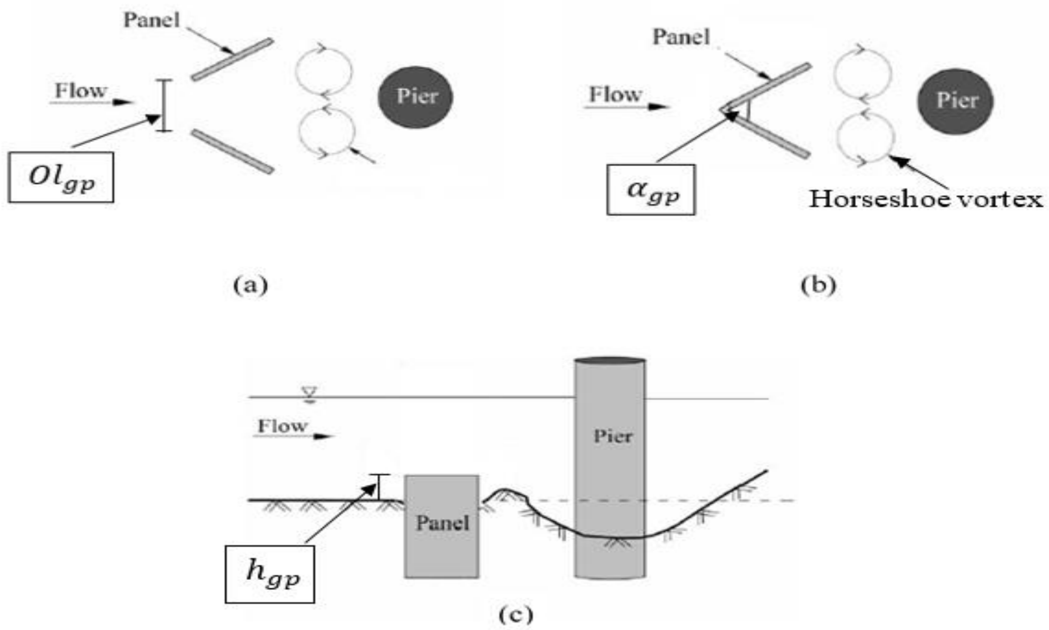

Fig. 4 Schematic Illustration of guide panels; (a) plan view with leading opening, (b) plan view without leading opening (closed interior angle), (c) side view.

4- Results and Discussion:

4-1 Guide panels height

The experiments showed that the height of guide panels has a direct influence on the scouring process. That is, as the height of guide panels increase, the scour depth increases. Three models are used with three different heights (8.5, 9, 10) cm in order to deduce the effect of guide panels height on the scour depth.

A set of experiments are conducting for evaluating the relationship between guide panels heights and scour depth. These experiments are shown in figure (7).

In the experiments, the scour process began at the face of the pier and then extended to its sides. The relationship between the height of the panels and the depth of the scour is that, the lower the height of the panels, the greater the impact on the down flow. Consequently, the horseshoe vortex has less strength leading to a lower scour depth. It must be noticed that in all guide panels tests, there is a scour happened around the guide panels itself.

4-2 interior angle between panels

In this research, it was studied the guide panels with interior angle and without leading opening (closed interior angle) and a guide panels with leading opening (open interior angle). In case without leading opening, it was installed at a distance (1.5 D_p) a head of the pier, the width of panels equals to (1.5 D_p), and three different heights of panels were used (8.5, 9, 10) cm with constant interior angle equal (45°). The efficiency of scour reduction in this case was ringing from 67% to 92%. While in the second case, the guide panels have a leading opening ($Ol_{gp}/D_p = 1.15$) and all other factors were as in the previous case, it was observed that, the efficiency of reducing scour was somewhat convergent, and the scour around the edges of the panels was upper than the first case (see Fig. 7). This is due to the presence of a leading opening which represents sharp edges that reduce the strength of horseshoe vortex and wake vortices, which in turn leads to a higher efficient in reducing depth of scour in front of the pier, but it divides and diverts vortices path around it leading to the highest scouring around, Fig. 6 shows the guide panels tested in both cases.

(a) (b)

Fig. 6 guide panels; (a)closed interior angle, (b) open interior angle (leading opening).

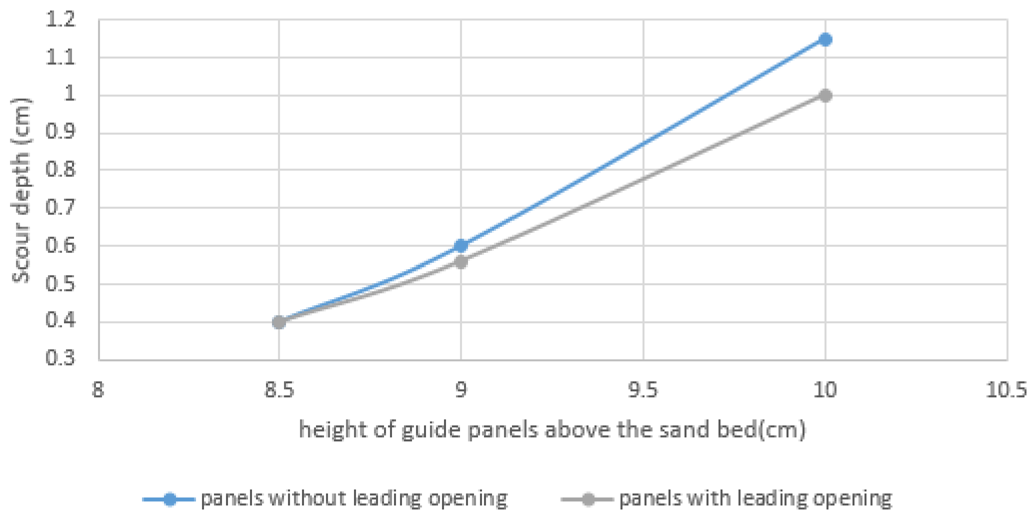

Fig. 7 Variation of scour depth with guide panels height for each cases (with and without leading opening).

4-3 Variation of Flow Depth and Velocity and Pier Froude Number:

Figures 8, 9 and 10 show the development of the local scour around circular pier protected by constant dimensions of guide panels at an elevation (0.5 cm) above the bed level. Results shown that, the scour depth increases with increasing of flow depth, flow velocity, and pier Froude number.

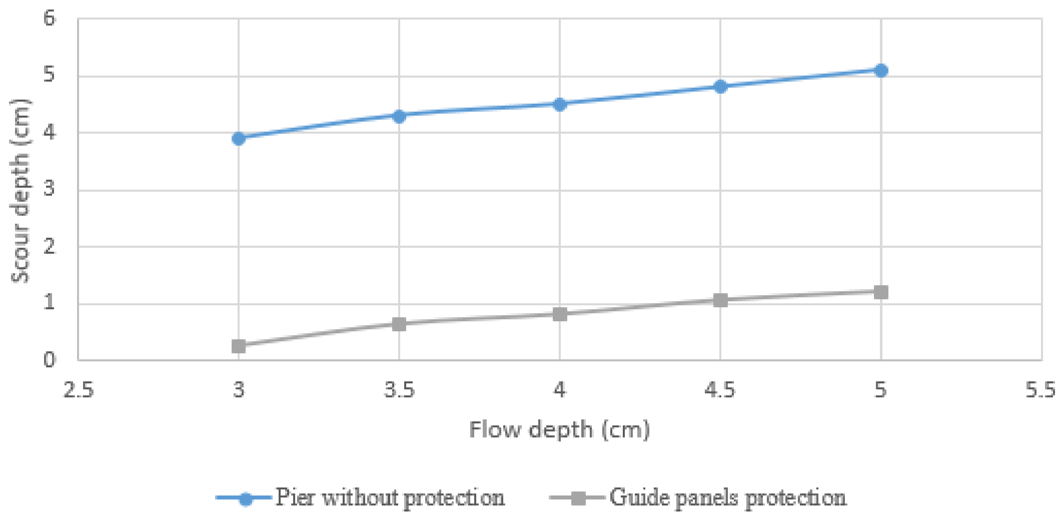

Fig. 8 Variation of scour depth with flow depth.

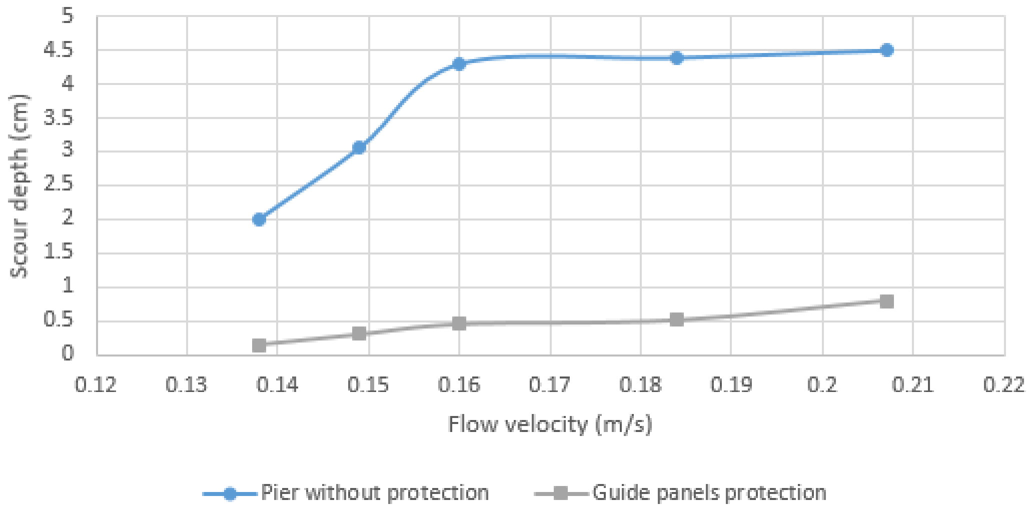

Fig. 9 Variation of scour depth with flow velocity.

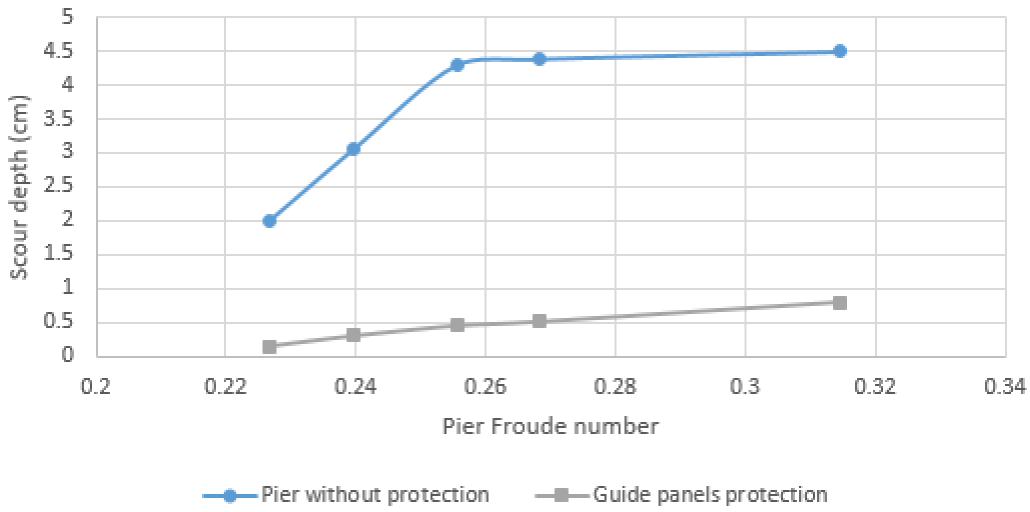

Fig. 10 Variation of scour depth with pier Froude number.

5- DEVELOPMENT OF NEW FORMULA

The computer package IBM SPSS Statistics (Statistical Package for the Social Sciences) was used to make analysis for the guide panels equation derived from dimensional analysis through a non-linear regression analysis. In order to generalize the experimental results to form a relationship that includes the effects of guide panels dimensions, a number of experimental data were used to conduct the analysis.

Model:

$$d_s/D_p = c_0 * \{(y/D_p)^{c_1} * (v/v_c)^{c_2} * \left(F_p\right)^{c_3} * \left(h_{gp}/D_p\right)^{c_4}\}$$

SPSS Nonlinear Regression Analysis gives constants the following values

$c_0 = 0.017 \quad c_1 = -7.436 \quad c_2 = -14.645 \quad c_3 = 5.643 \quad c_4 = 5.694$

So, the equation becomes:

$$d_s/D_p = 0.017 * \{(y/D_p)^{-7.436} * (v/v_c)^{-14.645} * \left(F_p\right)^{5.643} * \left(h_{gp}/D_p\right)^{5.694}\} \tag{3}$$

The determination coefficient for this formula is (R^2 =0.967).

It was used another data to testing the equation, a statistical comparison of equation is used to show the convergence of the predicted to the observed values, as shown in Fig. 11.

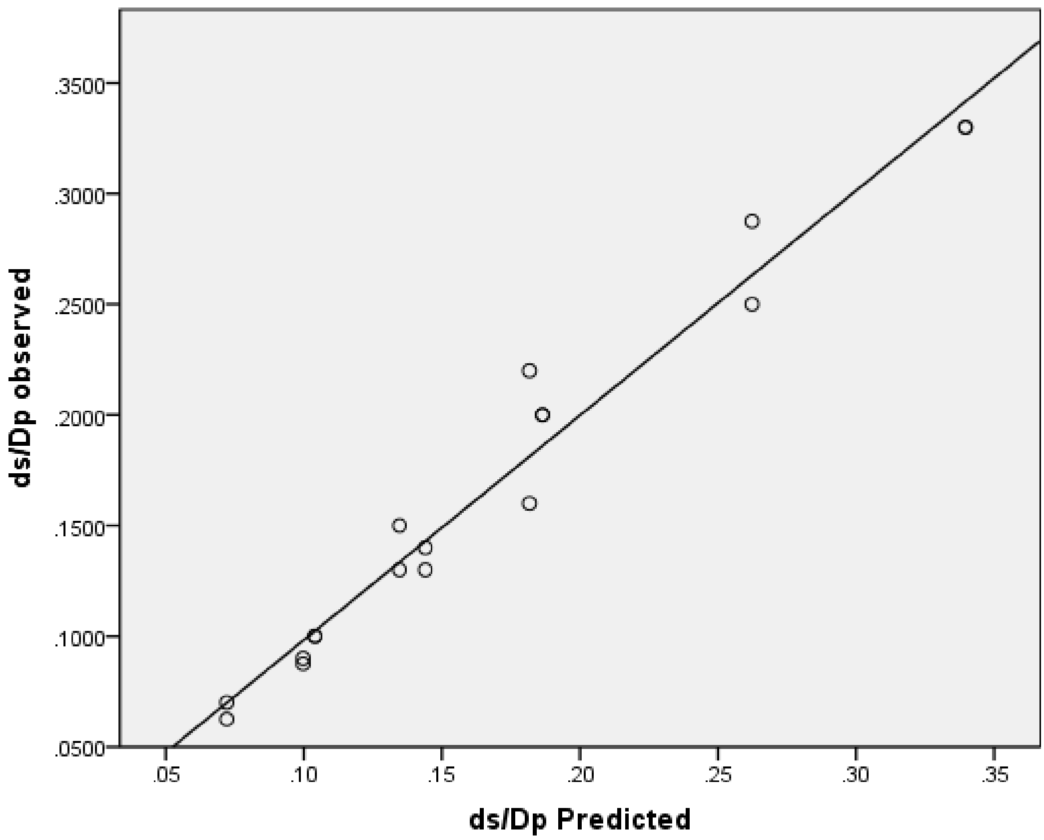

Fig. 11 Comparison of equation (3) from SPSS to experimental data.

6- CONCLUSIONS

In this study, the development of the local scour around circular pier protected by guide panels with and without leading opening were tested. The presence of a leading opening gives, to some extent, more efficiency in reducing depth of scour because of its lead to reduce the strength of horseshoe vortex and wake vortices, which in turn leads to a higher efficient in reducing depth of scour. Also, a different heights of guide panels were tested, the results showed that the lower the panels height, the greater the effect on the down flow that lead to more efficient in reduces scour depth. But, it must be noticed that in all guide panels tests, there is a scour happened around the guide panels itself, especially in the case of a leading opening because of its impact on vortices pattern. As well, from the experimental results of this study, it can be noticed that the scour depth increases with increasing of flow depth, flow velocity, and pier Froude number.

7- REFERENCES

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Notations

D_p	Pier diameter
d_{16}	Sediment size for which 16% of the particles are finer
d_{50}	Median particle size
d_{84}	Sediment Size for which 84% of the Particles are Finer
d_s	Maximum Scour Depth below the Bed Level
F_p	Pier Froude Number
h_{gp}	height of guide panels above the sand bed
Ol_{gp}	leading opening between panels
R^2	Determination Coefficient
S	Slop of the Channel
T_{gp}	thickness of guide panels

t	Scouring Time
v	Mean Velocity of Approach Flow
v/v_c	Flow Intensity
v_c	critical flow velocity for sediment entrainment
W_{gp}	width of guide panels
X_{gp}	spacing between pier and guide panels
y	Flow Depth
α_{gp}	interior angle between panels
σ_g	Geometric Standard Deviation of Sediment Size Distribution
μ	dynamic viscosity of fluid