**JWSR**

# Local scour around rectangular abutment and their countermeasures by using sacrificial piles

Mojtaba Saneie [1*], Faranak Omidi [2], Ramin Fazlola

[1] Assistant Professor, Soil Conservation and Watershed Management Research Institute in Tehran.

[2] M.Sc Candidate Department of Agricultural Engineering, Sari Agricultural Sciences and Natural Resources University.

[3] Assistant Professor, Department of Agricultural Engineering, Sari Agricultural Sciences and Natural Resources University.

**ABSTRACT**

One of the important issues in hydraulic engineering is inspection of local scour depth around bridge pier. Using piles is one of the ways for confronting local scour and erosion. In this study, the experiments were conducted in an 8m long, 0.5m deep and 0.25m wide flume. And the effect of using piles and number of them observed on the amount of scour in three different Frude numbers. The shape of the pier was a rectangle cube with 5cm long and 2.5cm wide. The diameter of the piles was 6mm, and piles were non-submerged. The results of experiments indicated that the use of different number of piles in three different Frude number, (0.214, 0.237, 0.297), reduced volume and depth of scour highly. It is observed that 3 and 4 piles in each three Fr number, (0.214, 0.237, 0.297), had better results in comparing with 2 and 5 piles. And also the lowest amount of scour and the highest efficiency were related to Fr number of 0.214, so the maximum scour depth and volume were reduced by 76% and 92% respectively in comparison with the pier without sacrificial piles. While these amounts in the Fr number of 0.237 were 88% and 66% respectively and in the Fr number of 0.237 were 88% and 52% respectively.

## 1. Introduction

When a structure placed in a river, it causes many changes in the river flow, and usually it causes to increase in capacity of sediment transportation in fluid, so will lead to the scour. In terms of the researches about mechanism of the scour, approach flow to the pier will be stopped by impacting to the pier. A vertical pressure gradient is formed in front of the pier by the vertical profile of velocity, and this vertical pressure gradient creates a downward flow in front of the pier.

This downward flow is the main factor of scour around the pier. Determining of the scour depth is so important, because: a) it states the amount of potential flow ruining around structures and b) may play the main role in designing The structures and foundation dimensions that set in water flow direction. Becoming empty around pier during the flood is the main factor for ruining bridges.

Local scour associated with the structures like spur-dike or abutment is inherent as the

---

[*] Corresponding Author Email: (mojtabasaneie@yahoo.com)

shear distribution are modified locally which leads scouring action until equilibrium is established (Garde et al. 1961). Most of the studies related to the local scour around spur-dike-like (or abutment-like) structures concerned with maximum scour depth ( Melvile 1992, Gill 1972 and Lim 1997), whereas, in some studies (Rajaratnam and Nwachuku 1983; Kuhnle et al. 1997) the geometry and shape of the scour holes are also considered. The designers should be aware of the maximum scour volume to ensure the integrity of the structure and safety against failure. So reduction of local scour around this kind of structures is important from the engineering point of view. Countermeasures for preventing from local scour around abutment can be categorized in two groups: 1) deviation flow equipment like sacrificial piles and submerged vanes are placed on upstream of the pier. 2) Protection equipment like Rip Rap (Melvile, Hadfied 1999).

Tomas (1967), Tanaka and Yano (1967), Nil (1973) and Etama (1980) showed that installing a vane or collar in front of the pier can reduce scour depth by diverting and reducing the downward flow (Chiew 1992). Chio (1987), Kumar (1992), Heidarpour et al. (2003) had a research about the control and reduction of local scour at unique pier using slots. And also Bairam and Larson (2000), Saterland (1987) and Heidarpour et al. (2003) had researches about the control and reduction of local scour at group of piers using slots (Samimi et al. 2006). Saadatnia et al. (2010) had an experimental study about the control and reduction of local scour using spur-dike (Saadatnia et al. 2010). In 1998 Munsur Rahman had an inspection about local scour around pier and control of local scour using piles (Rahman et al. 1998). In 1999 Bruce W. Melville and Anna C. Hadfield had a research about using piles to the reduction of scour around pier (Melvile, Had

field 1999).

Sacrificial piles as a tool to reduce local scour around bridge piers have long been recognized. Some of these methods include inserting multiple piles or a single sill or sacrificial pile in front of the pier. The basic idea is to divert the flow around the pier and to reduce the flow intensity and the local scour. Guided by the sacrificial pile approach in the case of scour reduction around bridge pier, it can be hypothesized that for reduction of local scour around spur-dike or abutment like structures, the sacrificial piles may play some positive roles.

In the present study there was no general movement of bed particles in the upstream straight channel, and the local scour discussed here is classed as the clear water scour. The focused points in the experimental results are summarized as below:

a) Influence of Fr number on the maximum depth on the volume of the scour hole.
b) Influence of pile number on the maximum depth on the volume of the scour hole.

## 2. Experiments

Experiments were conducted in an 8m long, 0.25m wide and 0.2m deep transparence wall flume, having longitudinal slope of 0.001. The test reach was selected in the middle section with 2m length and 25cm width. The plan form of the approach channel was straight with fixed side bank. The sediment used on the bed had a mean diameter of 0.88mm and a standard deviation of 1.24.

The plan view of the abutment and sacrificial piles are shown in Fig.1. The model of the abutment was made of flexi glass, whereas sacrificial piles were made of metal. The length and width of the abutment were 5cm

and 2.5cm respectively. The diameter of the piles was 6mm, and one among at the upstream of the pier, so the first pier was contacting the side bank of the flume. All experiments were conducted in a discharge of 3 lit/sec, and in three different Fr numbers (0.214-0.237-0.297). The discharge was adjusted by a triangle weir, and then the depth of the water was reduced gradually by a sharp weir at the end of flume. In all the experiments the model abutment was installed at right side and in X=300cm from the beginning of the flume.

In all experiments with the piles, the pile groups were installed at a distance of 2L (10cm) upstream of the abutment ( L is the length of abutment). Flow level was always below the abutment (The piles were always non-submerged). In total fifteen experiments were conducted having different initial arrangements. The initial hydraulic and other boundary conditions are summarized in table 1. Experiments were conducted in 3 different depths of 6.85cm, 6.4cm and 5.5cm, and for each Fr number piles the number of 2, 3, 4, 5 were inspected.
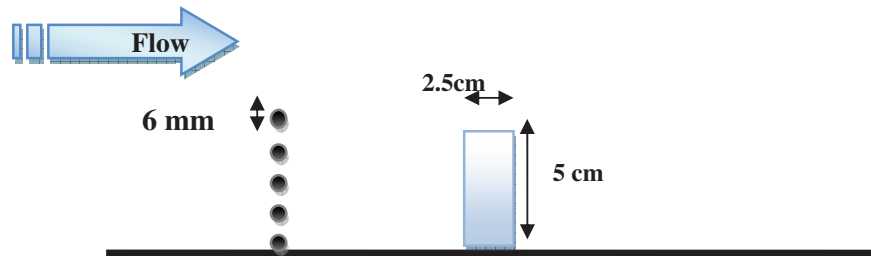


Fig.1: The plan view of model abutment and sacrificial piles

Table 1. Experimental condition

| Run. No | y (cm) | Fr | No. of pile | L |
|---------|--------|-------|-------------|-----|
| 1 | 6.85 | 0.214 | 0 | 2L |
| 2 | 6.85 | 0.214 | 2 | 2L |
| 3 | 6.85 | 0.214 | 3 | 2L |
| 4 | 6.85 | 0.214 | 4 | 2L |
| 5 | 6.85 | 0.214 | 5 | 2L |
| 6 | 6.4 | 0.237 | 0 | 2L |
| 7 | 6.4 | 0.237 | 2 | 2L |
| 8 | 6.4 | 0.237 | 3 | 2L |
| 9 | 6.4 | 0.237 | 4 | 2L |
| 10 | 6.4 | 0.237 | 5 | 2L |
| 11 | 5.5 | 0.297 | 0 | 2L |
| 12 | 5.5 | 0.297 | 2 | 2L |
| 13 | 5.5 | 0.297 | 3 | 2L |
| 14 | 5.5 | 0.297 | 4 | 2L |
| 15 | 5.5 | 0.297 | 5 | 2L |

During the experiment without piles, maximum scour depth was measured at different times. It was clear that maximum scour depth was changing very slowly after 60 minutes and hence equilibrium time was considered 60 minutes from the beginning of the tests Fig. 2.

At the equilibrium state the detailed bed level data were recorded by bed profiler set. Using the collected data, the bed contours were plotted by surfer. In run1~5, the piles were installed at X=289, and the effect of pile number of 2, 3, 4, 5 in Fr number of 0.214 were inspected. During run 6~10 and 11~15 the effect of piles 2, 3, 4, 5 in the Fr number of 0.237 and 0.297 respectively were inspected. (At the distance of 2L from the abutment)

## 3. Dimensional Analysis

Dimensional analysis begins with the basic independent variables that characterized a system and arranges them into a parsimonious functional relationship with coefficients that are then determined by statistical analysis of the experimental data.

$$d_s = f(V, X, \rho, L, b, B, n, g, d_{50}, y, d_p, \nu) \qquad (1)$$

Where $d_s$ is the maximum of scour depth, V is the velocity of flow, X is the distance of piles from abutment, $\rho$ is the fluid density, L is length of the abutment, b is width of abutment, B is the width of flume, n is the number of piles, $\nu$ is the fluid kinematic viscosity, g is the acceleration of gravity, $d_{50}$ is the mean diameter of sediment, y is depth of water and $d_p$ is the diameter of piles. Using statistical analysis and combining some of the dimensionless groups, leads to the following equation:

$$\frac{d_s}{y} = 2.057 \left( \frac{y}{nd_p} \right)^{0.136} (Fr)^{1.535}$$

$$Fr = \frac{V}{\sqrt{gy}} \qquad (2)$$

In this statistical analysis: determine coefficient, $R^2 = 0.948$ and mean error respectively, MER = 12%.

Fig. 3 shows the relation between calculated and observed depth scouring.
And

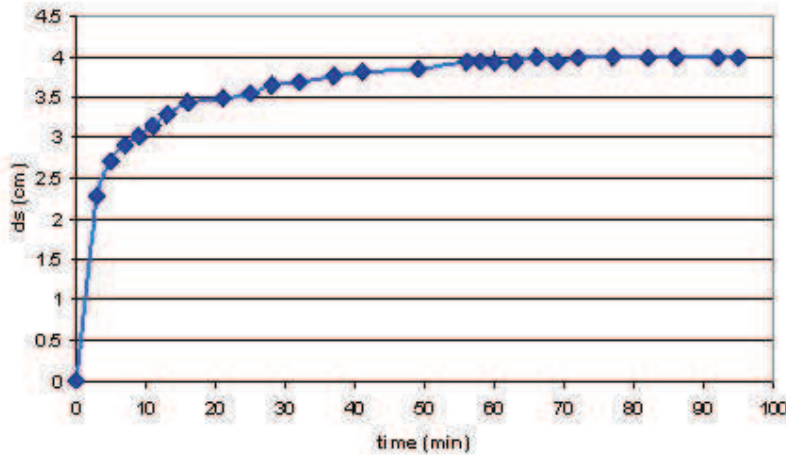$$V_s = f(V, X, \rho, L, b, B, n, g, d_{50}, y, d_p, \nu) \qquad (3)$$



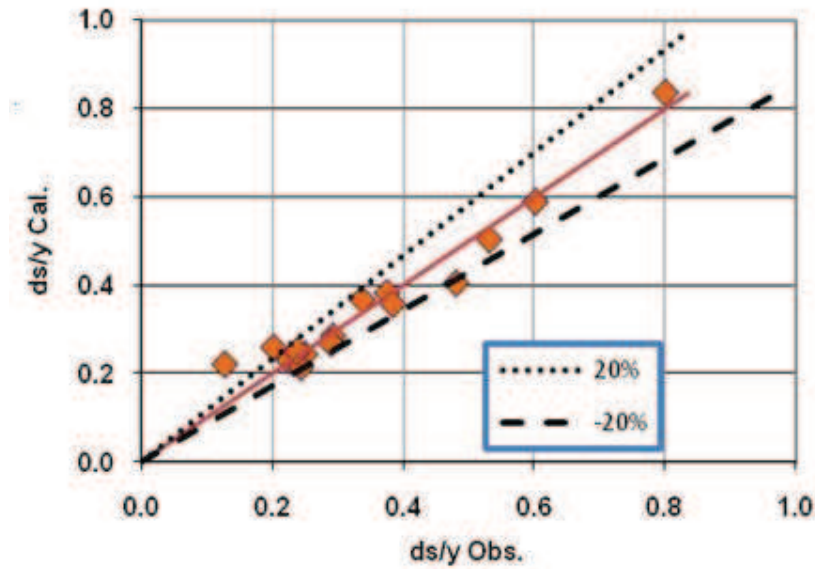Fig.2: Maximum scour depth with time (Run1)
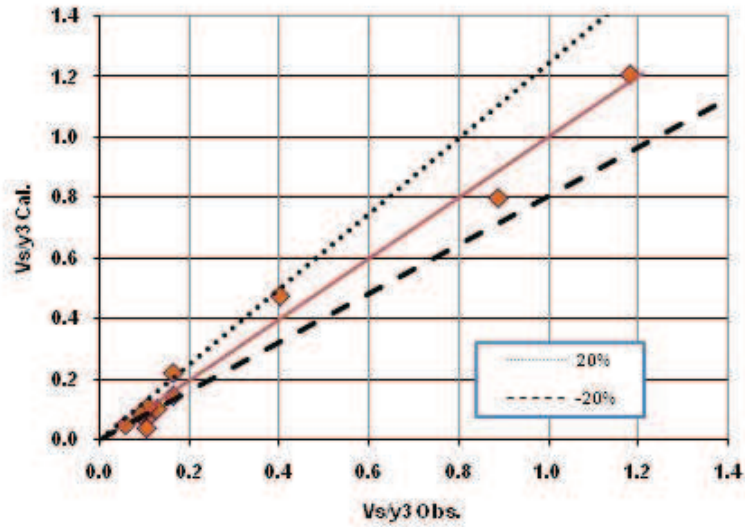
Fig.3: Calculated and observed depth scouring



Fig.4: Calculated and observed volume scouring

That $V_s$ is the volume of the scour hole. Using dimensional analysis and combining some of the dimensionless groups, leads to the following equation:

$$\frac{V_s}{y^3} = 5.390 \left(\frac{L}{y}\right)^{9.533} \left(\frac{y}{nd_p}\right)^{1.013} (Fr)^{1.753} \qquad (4)$$

In this statistical analysis: determine coefficient, $R^2$ =0.984 and mean error respectively, MER = 19%. Fig. 4 shows the relation between calculated and observed volume scouring.

## 4. Results and Discussions

In this study, the effect of pile number was inspected at three different Fr numbers. In all the experiments, maximum scour depth was located in the vicinity of the abutment nose. There was no sediment transport except around the abutment, and the scoured volume of local scour hole and the volume of the sand deposition downstream were in good balance with some little discrepancy. The result of the local scour in Run 2~5, Run 7~10 and Run 12~15 were compared with the results of Run 1, 6 and 11 respectively. It was found that the piles may have some positive effects to reduce local scour around abutment, if they are placed properly. The detailed results and their comparison would be explored in the final sub-section. The final state geometry of scour holes in Run6~10, along longitudinal direction were shown in Fig.5. The upstream and downstream part of the scour holes from maximum scoured point had different slopes. The upstream was very steep and short, whereas, the downstream was relatively mild and longer.
During Run6, the bed profile was recorded by bed profiler set, and the changing process

of scour hole was inspected. The location of maximum scour depth is changing in front of abutment to the top corner upstream during the time.

The basic objective of the experiments with sacrificial piles was to test their effectiveness to reduce the local scour. And hence provide countermeasure against failure. The results of experiment with piles (Run 2~5, Run 7~1, Run 12~15) were compared to the results of Run1, 6 and 11 respectively, where the piles were not used but the discharge and runtime were the same. It was found that local scour could be reduced by the use of pile groups but the number of them and depth of water (Fr number) was very important to optimize the benefit. In this study the effect of pile number in three different water depths (three different Fr numbers) at the same location from abutment were inspected. It can be observed from Fig.7 and Fig.8 that 4 piles have the best operation in each three Fr numbers, and also the water level had an important role in piles operation.

Percentage of reduction on maximum scour depth and the volume in different water levels and pile numbers are shown in Fig.9 and Fig. 10.
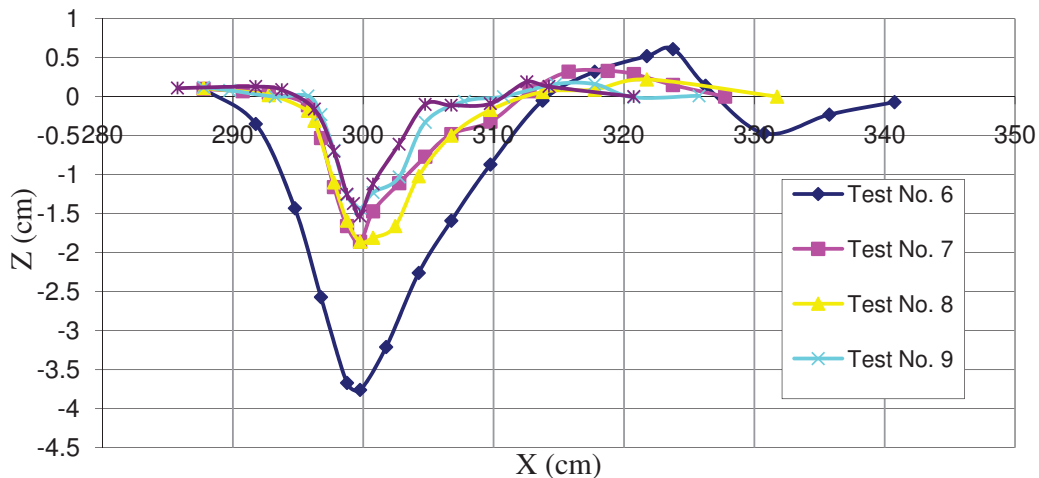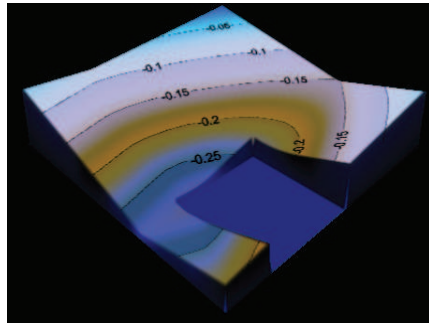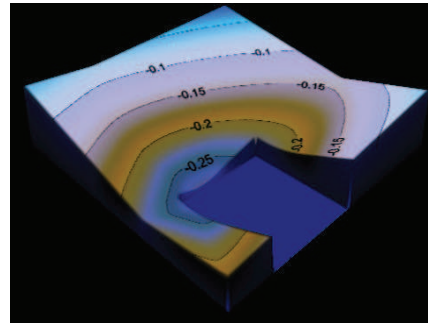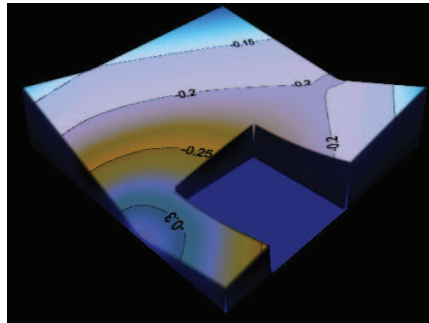


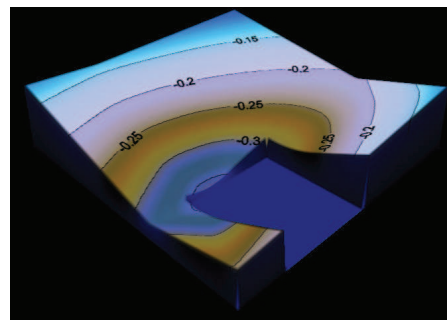Fig.5: Longitudinal profiles of the scour holes at the final state (Run6~10)

18 Minutes after beginning the test



5 Minutes after beginning the test



58 Minutes after beginning the test



47 Minutes after beginning the test

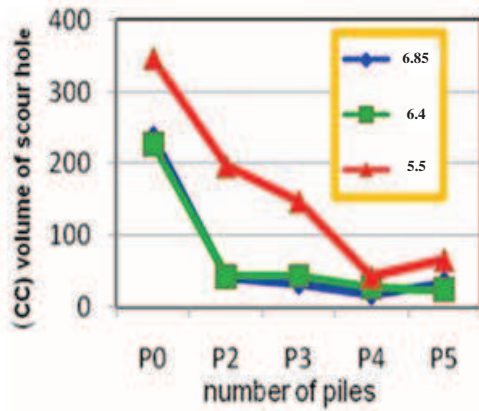Fig.6: Time pattern of scour in Fr number of 0.237



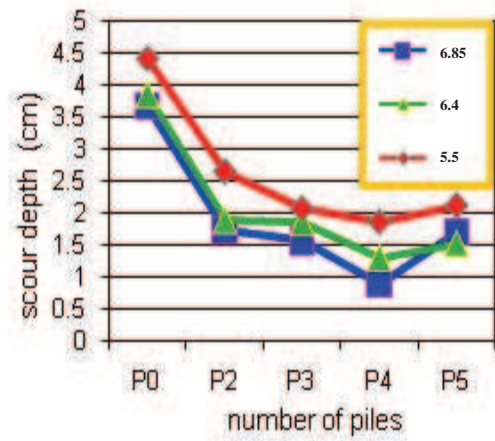Fig.7: The volume of scour hole in three different water levels



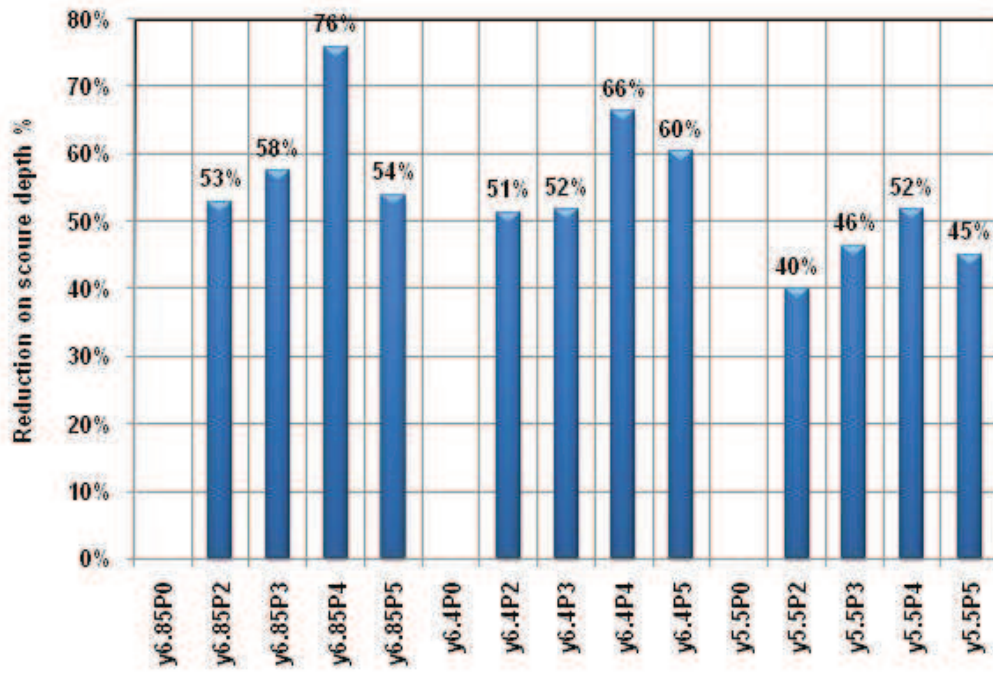Fig.8: Maximum scour depth in three different water levels

Fig.9: Percentage of reduction on maximum scour depth in different water levels and pile numbers
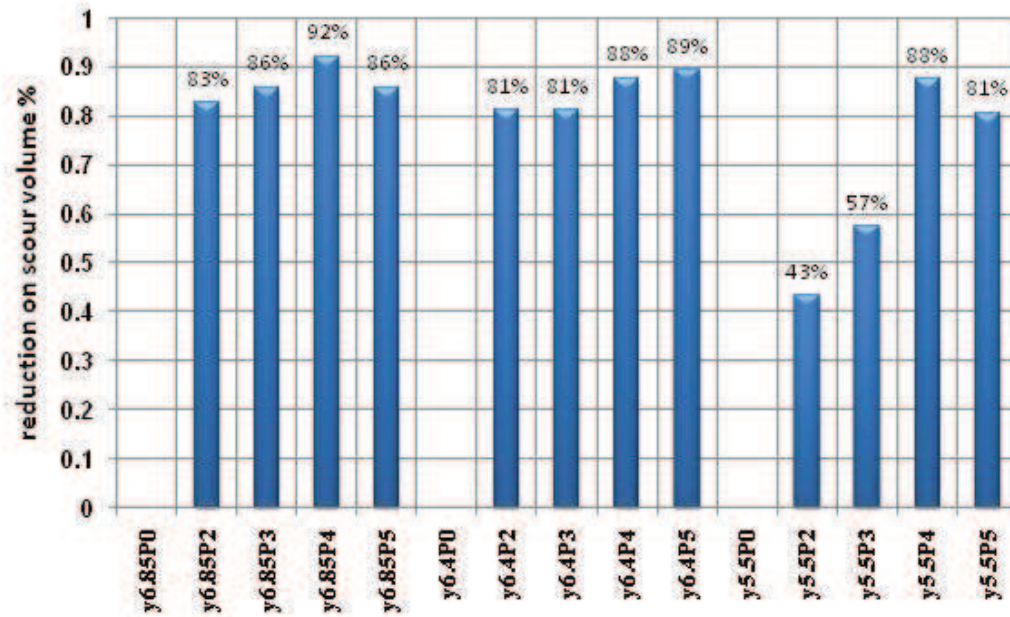


Fig.10: Percentage of reduction on scour volume in different water levels and pile numbers

## 5. Conclusion

From the present study the following conclusions can be drawn:

a) Local scour around abutment can be reduced using sacrificial piles

b) Generally, 3 and 4 piles in each three water depths had better results in comparing with 2 and 5 piles, (Length of abutment).

c) Minimum amount of scour and maximum amount of efficiency was in the Fr number of 0.214

d) The maximum scour depth and volume in Run 4 were reduced by 76% and 92% respectively in comparing with Run1

e) The maximum scour depth and volume in Fr number of 0.237 and 0.297 were (66% , 88%) and ( 52% , 88%) respectively

## Refrences

Chiew Y M (1992) Scour protection at bridge piers. Journal of Hydraulic Engineering. ASCE. 126(1):43-55

Garde r J, Sbramanyta K and Nambudripad KD (1961) Study of scour around spur dikes. Journal of the Hydraulic Division, ASCE, Vol.87, Hy6, PP. 23-37

Gill M K (1972) Erosion of sand beds around spur dikes. Journal of the Hydraulic Division. ASCE, Vol. 98, HY 9, PP. 1587-1602

Kuhnle R A, Alonso C V And Shields F D (1997) Geometry of scour holes around spur dikes, an experimental study. Proceeding of the conference on management of landscapes, distributed by channel incision, pp. 283-287

Lim S (1997) Equilibrium clear-water scour around an abutment, J. of Hydraulic Engineering, ASCE, Vol.123, No.3, PP.237-243

Melvile B W, Hadfield A C (1999) Use of sacrificial piles as pier scour countermeasures. Journal of Hydraulic Engineering November pp. 1221-1224

Melville W B (1992) Local scour at bridge abutments. Journal of Hydraulic Engineering, ASCE, Vol.118, PP. 615-631

Rahman M, Murata H, Nagata N and Muramoto Y (1998) Local scour around spur-dike-like structures and their countermeasures using sacrificial piles, Annual Journal of Hydraulic Engineering, JSCE, VOL. 42

Rajratnam N, Nwachuku B A (1983) Erosion near groin-like structures. Journal of Hydraulic Research, IAHR, Vol. 21, PP. 277-287

Saadatnia M, Khodashenas S R and esmaeili K (2010) Experimental study of groin on reducing depth and volume scouring of pier noise. 5th national conference civil engineering Mashhad Iran (In Persian)

Samimi B T, Barani Gh A, Khanli M and Khanjani M J (2006) Experimental effect of submerge vanes on bridge pier scouring . national conference on irrigation and drainage management Ahvaz Iran (In Persian)