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The Effect of Geometric Parameters and Foundation Depth on Scour Pattern around Bridge Pier

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ORIGINAL ARTICLE

ABSTRACT: Scour around bridge foundations is one of the major causes of serious damage to the bridge. In this study, the effect of shape, level and position angle of foundation on scour pattern was investigated experimentally. The experiments were conducted for 4 foundation shapes including; square, cylinder, aerodynamic along and across the channel, 5 foundation depths and 7 foundation alignments. The results show that the scour depth depends on the foundation depth, shape and foundation alignment to the approach flow. The best foundation shape which leads to minimum scour, was aerodynamic shape along the channel, square, aerodynamic across the channel and cylindrical shape, respectively. The results also show that positioning of foundation below the initial channel bed, leads to less values of scour depth around bridge pier. Also the best angle for positioning of foundation is zero, i.e. parallel to flow direction. Analyses of results also show that the appropriate level for positioning the foundation is 25 to 50 % pier diameter below the channel bed.

Keywords: Local Scour, Non-Uniform Bridge Pier, Foundation Shape, Foundation Depth, Position Angle of Foundation

INTRODUCTION

Scour around the foundations of bridge piers is one of the major causes of serious damage to bridges (e.g. Tsujimoto et al., 1987). Local scour at a bridge pier principally results from the down flow along the upstream face of the pier and the resulting horseshoe vortex which forms at the base of the pier aids the phenomenon (Kumar et al., 1999) (see Figure. 1). Most of the scour investigators mainly focused on the scour around piers with uniform horizontal cross-section geometry and did not consider the effects of foundation geometry. The foundations of bridge pier usually are used for transferring the loads on bridge to safe place like earth. However, in reality many bridge piers behave as non-uniform depending on the exposure of their foundation into the flow field. In the present study, a cylindrical pier with a foundation is considered as non-uniform pier.

Several investigations are available those describe the scour around piers of non-uniform geometry in consideration of the foundation. Reading to non-uniform bridge pier Chabert and Engeldinger (1956) conducted some experiments on pier with cylinder foundation. The results show that the reduction of scour occurs when the foundation placed on or below the of bed level. The study of Jones and et al. (1992) on rectangular pier shows that when a foundation place on or below the certain level of bed, significant reduction of in scour is obtained. Melville and Raudkivi (1996) conducted experiment on pier and cylinder foundation. They found the optimum value of the ratio of pier diameter to foundation depth in order to obtain less scour. Parola and et al. (1996) conducted some experiments on pier and rectangular foundation and found that when foundation placed below the bed, increases its ability to protect on scour around piers with rectangular foundation. Their result also showed that as the extending of foundation in upstream increased the depth of upstream scour decreases. Umeda and et al. (2010) conducted experimental studies on cylinder bridge pier with cylindrical foundation. They found that when foundation placed blew the bed, leads to less scour. Ataie-Ashtiani and et al. (2010) evaluated scour of clear-water around the complex bridge pier with the different values of pile. Lu and et al. (2011) suggested an empirical model for temporal development of scour depth of cylinder bridge pier with foundation. Aarabi (2011) studied local scour in single pier with continuous foundation. The width of foundation along the flow is 1 to 4 times of pier diameter. He concluded that by using the continues foundation the scour depth is reduced up to 52%.

A review of literature shows the lack of information exist on the effect of foundation shape on scour depth. Thus the aim of this study is study the effect of foundation shape, depth and position angle of foundation on scour around the non–uniform bridge pier.

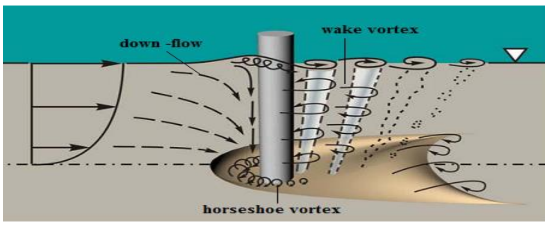

Figure 1. Flow and scour pattern at a circular pier.

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MATERIALS AND METHODS

Experiments were carried out in a 60 cm wide, 60 cm deep and 10 m long rectangular straight at the Hydraulic Laboratory, of Gorgan University of Agriculture Science of Natural Resource. Uniform sediment with a mean size diameter d_{50}=0.9 mm and standard deviation was 1.35 was used with a thickness of 25cm.

All the experiments were conducted under steady flow, and clear-water conditions (U/Uc<1, where U=average approaching flow velocity and Uc=critical velocity). Initially the bed level was leveled by a plate attached to the carriage mounted on the channel. Then inlet valve was opened slowly, in order of increasing discharge to given value and presently the sediment movement in upstream reach.

Figure 2 shows four different foundation shapes, including square, cylinder, aerodynamic along the channel and aerodynamic across the channel. The pier was simply modeled with a cylinder (D = 40 mm) positioned on foundation (D* =80 mm).

The foundation top elevation Z is measured from the initial bed level and is positive if the top of the foundation is below the initial bed level and vice versa. For all of foundation shapes five different levels of Z/D= 0, +0.25, +0.5, +1.5, -0.25 were used. For aerodynamic foundation along the channel the experiments were carried out at seven position angles of foundation which is shown in Figure 3.

The duration of experiments was kept equal to 50 hrs at which equilibrium time condition is achieved. The results are shown in Figure 4. As it can be seen approximately 95% of scouring occurs during the first 30 hours. The bed levels during and after finishing the run were measured using point gauge and 3D bed profiler instrument.

Table 1. Flow conditions.

Parameter	Value
Fr	0.23
H (m)	0.15
U (m/s)	0.284
Q (m^3/s)	0.0255

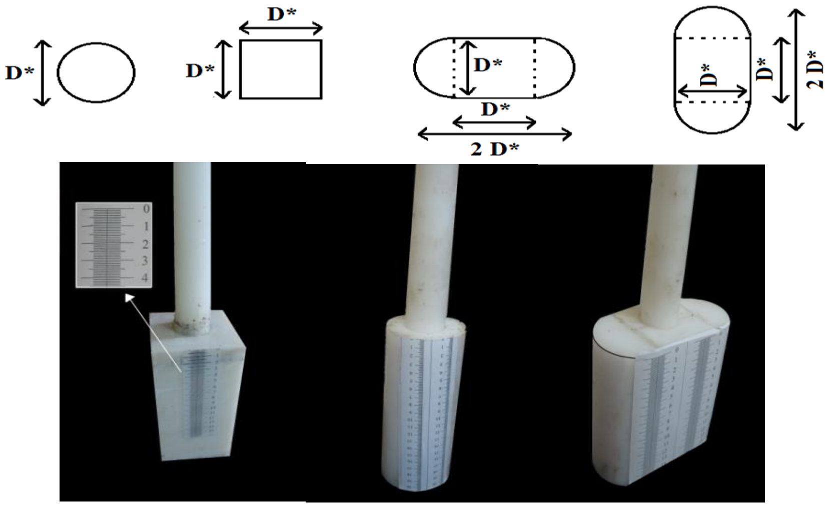

Figure 2. Foundation shapes used along the flow (non-uniform piers).

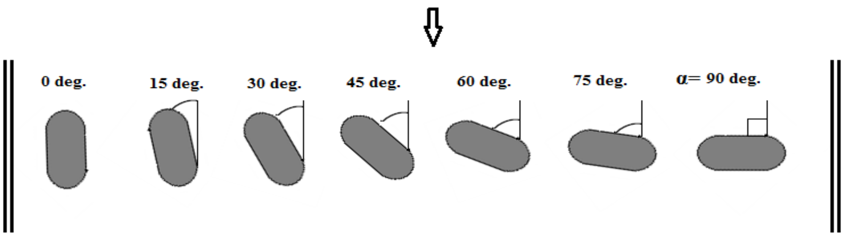

Figure 3. Various foundation alignments (α) to the approach flow

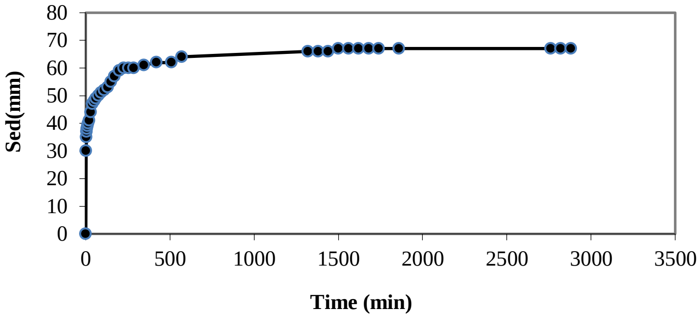

Figure 4. Time variation of scour depth at the upstream face of the pier

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RESULTS AND DISCUSSION

In the following the effect of level, shape and position angle of foundation on scour depth is considered separately.

Level of foundation position

Experimental observation indicates the difference between scour mechanism of non-uniform pier and uniform pier. When foundation is placed on bed (Z/D=0) the level of foundation acts as a collar and prevent the scour. Scour begins from the sides of foundation and dimension of scour hole increases in upstream, rapidly. At the beginning of experiment the maximum of scour depth is along the edge of foundation, but by increasing the time the extension of scour hole dimension in upstream of pier, and the position of maximum scour depth are moved to front of foundation. Increasing the foundation level in front of pier, provide more down flow and intense the scour. When foundation is placed above the bed level (Z/D=-0.25) the scour from the front of foundation extended to the back of foundation. When the foundation is placed below the bed (Z/D=+0.5) the foundation scour around the non-uniform bridge pier is as the same as uniform bridge pier, until not exposed the level of foundation, but when it appears, the upper surface of foundation inhibited the scouring in front side of pier. After few hours maximum depth of scour comes to the front of pier, slowly and the scour depth increased again. The samples of temporal development of scour depth for different foundation shape in different foundation level are present in Figure 5 and 6, respectively.

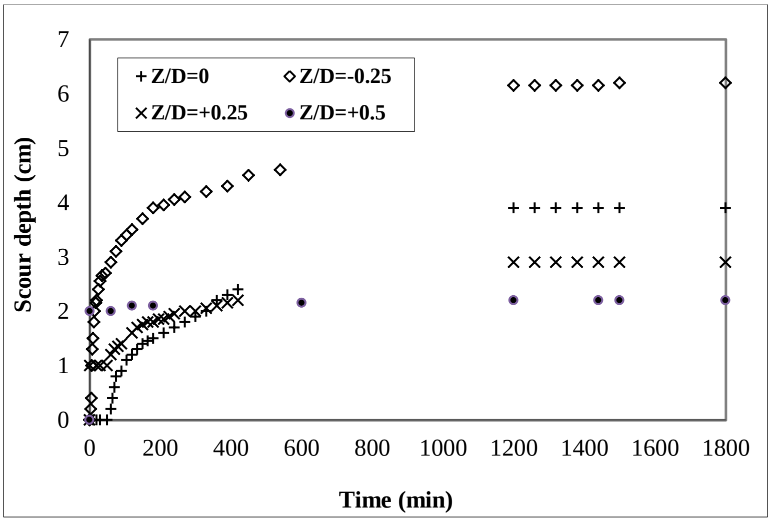

Figure 5. Time variation of scour depth at the upstream face of the circular pier with square foundation at different depth foundation

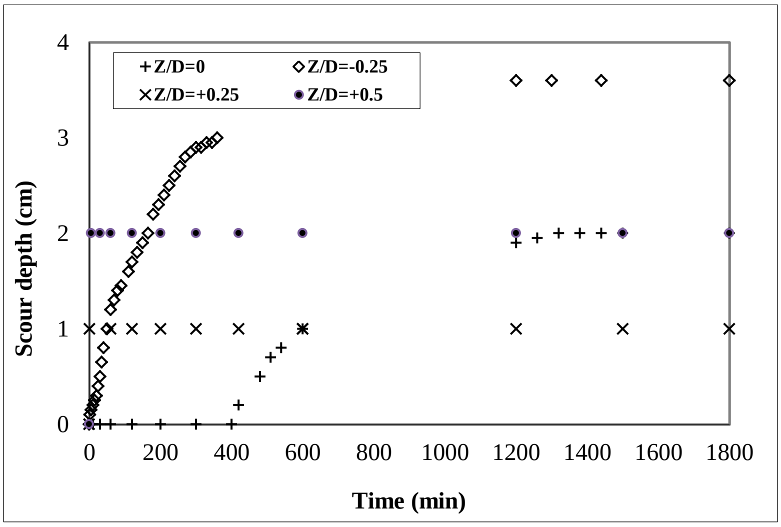

Figure 6. Time variation of scour depth at the upstream face of the circular pier with aerodynamic foundation along the channel at different depth foundation

Foundation shape

In Figure 8 and 9 the samples of temporal development diagram of scour depth with Z/D= -0.25 and Z/D= +0.25 are presented for 4 foundation shapes. The scour in aerodynamic foundation along the channel is less and using the foundation on the level of Z/D= +0.25 decreases the scour of front of pier to uniform pier up to 85%. The maximum scour occurs in the bridge pier with cylinder foundation, square foundation, aerodynamic foundation across the channel and aerodynamic foundation along the channel, respectively.

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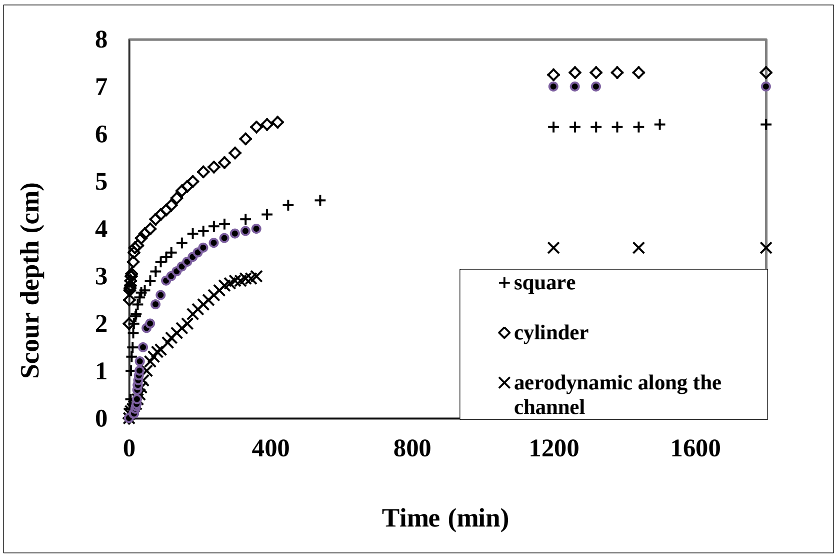

Figure 7. Time development for all foundation shapes at Z/D= -0.25

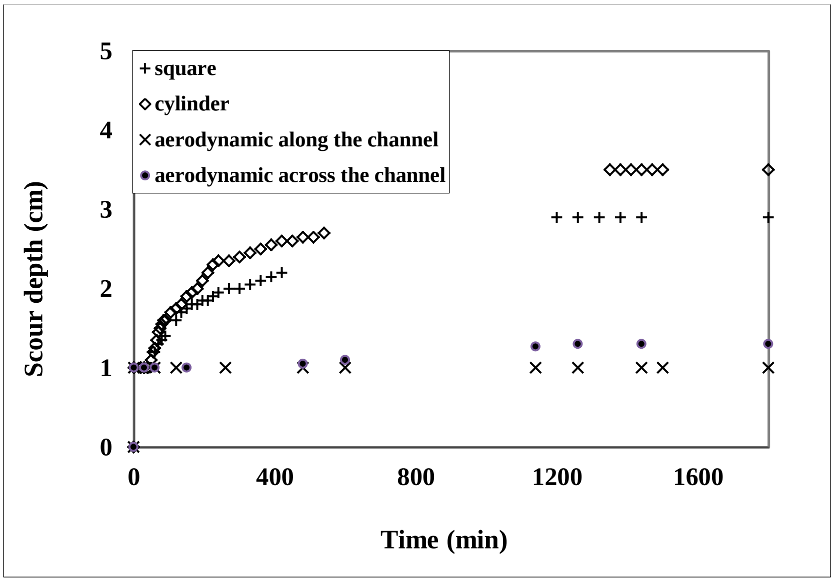

Figure 8. Time development for all foundation shapes at Z/D= +0.25

Foundation alignment, α

The scour pattern of inclined foundation is differing from the foundation which is position along and across the channel. There are low pressure and high pressure area in inclined foundation that low pressure area is part of foundation that is not exposed in direct path of channel and high pressure area is part of foundation which contact with flow directly (see Figure. 9). When the angle of foundation along the channel is zero, the scour is began from the vertical sides of foundation and after a while come to the front of foundation (see Figure. 9, a). By increasing alignment of attack up to 45 degree, when 0<α< 45 scour occurs on two vertical sides of foundation with the exception that the scour hole is more in the low pressure side of foundation, than the other sides and the scour hole extended to the front side of foundation. This ratio increases with increasing the alignment of attack (see Figure. 9, b). Where 45<α<90, there is no evidence of scour on high pressure vertical sides of foundation, scour begins from the low pressure sides of foundation (see Figure. 9, c). In alignment of attack 90^0 that foundation is across the channel scour begin from the back of foundation with two symmetrical arc and after certain time, scour hole extended from the vertical sides foundation to front side of foundation (see Figure. 9, d).

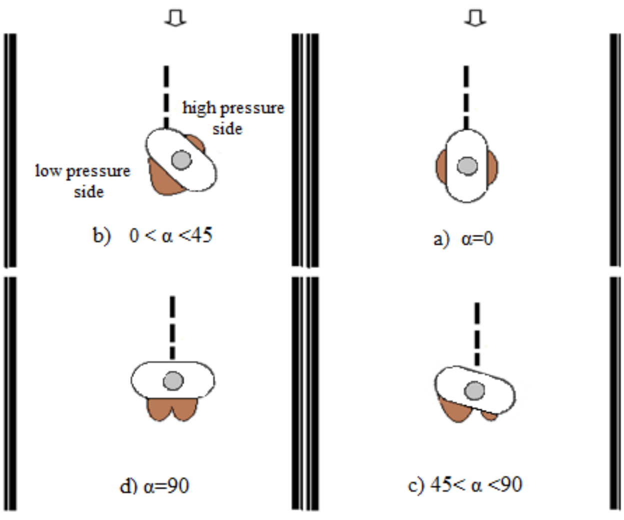

Figure 9. Scour pattern at bridge pier with aerodynamic foundation

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By increasing angle of foundation with channel the effective width of foundation increased. Turbulence around the foundation increased and scour around it increased. The Figure 10 shows the flow pattern around the non-uniform bridge pier in inclined and vertical position. By increasing angle of foundation, sediment washing in low pressure side of foundation and sediment accumulation in the high pressure side of foundation is more.

The contour map and of the scour hole at the end of the test are as shown in the Figures 11-17 in the non-uniform pier with the various position angle of foundation. As shown, increasing angle of foundation scour around the foundation increased. Increasing scour depth in low pressure side is added to the vortex strength and the sediments moved from the sides of foundation and accumulation on the back of foundation. The sediments accumulation values, conversely on the other side is low in the high pressure side the accumulation is high and cause the sediments level be higher than the bed level. This phenomena cause the scour hole in inclined foundation is asymmetric, but when the foundation is zero or 90 degree the scours hole is symmetric.

By increasing angle of foundation, scour increased, but at 90 degrees maximum scour depth is less than the inclined position, because in this position the rejection of water is more the approaching speed is less than the other position thus scour is low.

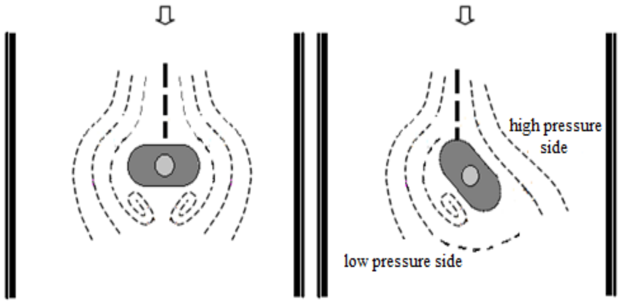

Figure 10. Flow paths around bridge pier with aerodynamic foundation

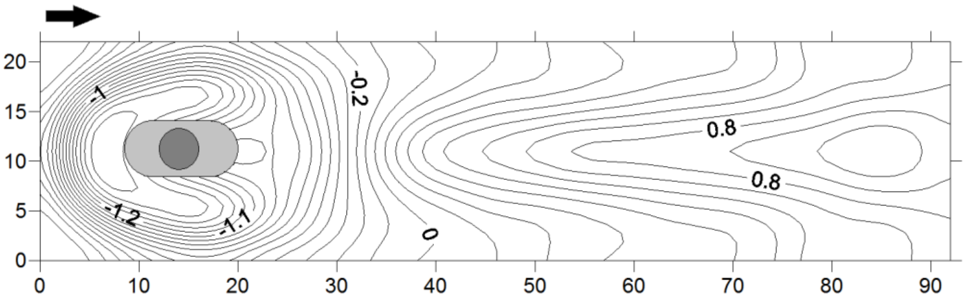

Figure 11. Contour map of the scour for alignment of attack α=0

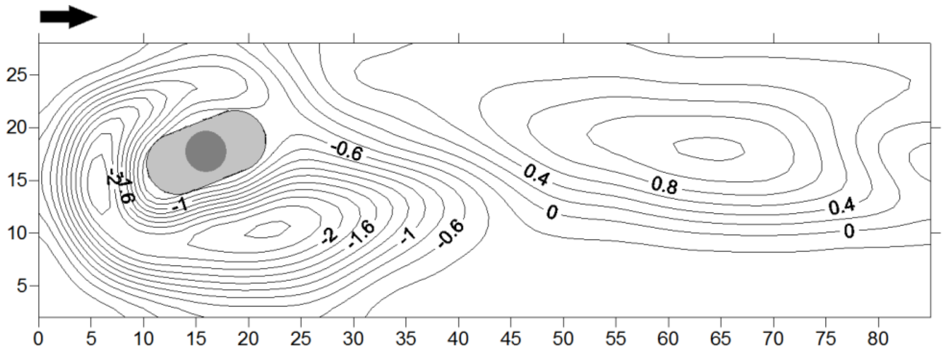

Figure 12. Contour map of the scour for alignment of attack $\alpha=15^0$

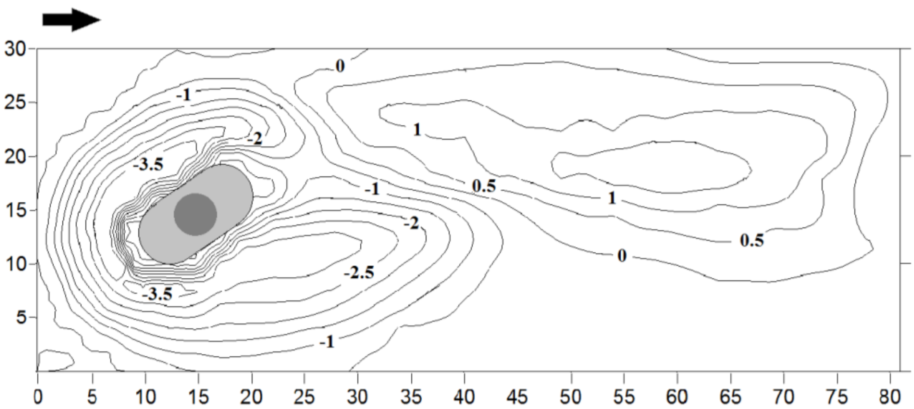

Figure 13. Contour map of the scour for alignment of attack $\alpha=30^0$

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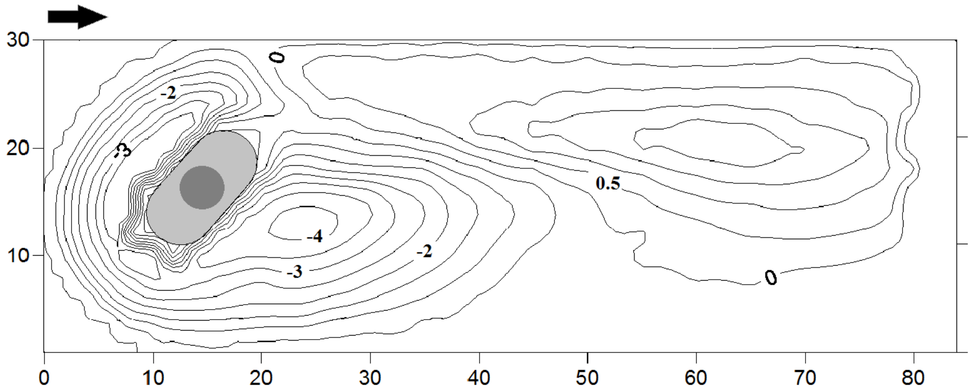

Figure 14. Contour map of the scour for alignment of attack α=45^0

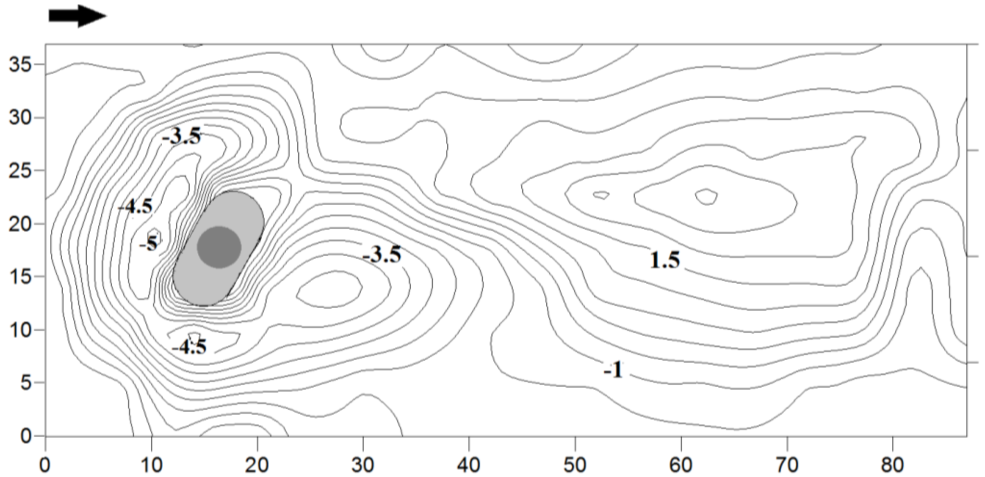

Figure 15. Contour map of the scour for alignment of attack α=60^0

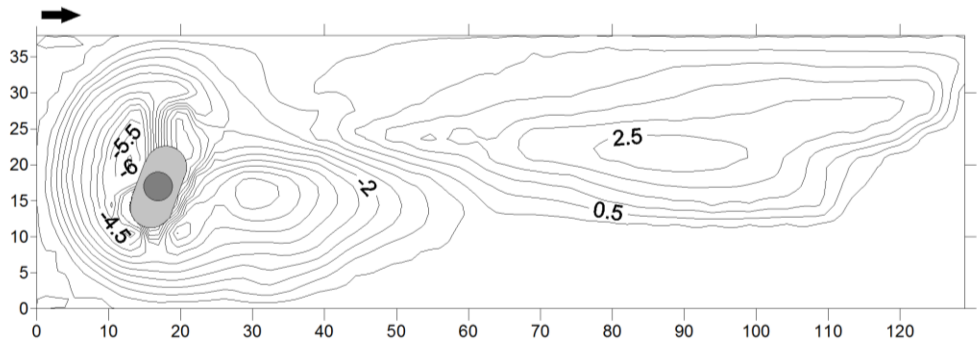

Figure 16. Contour map of the scour for alignment of attack α=75^0

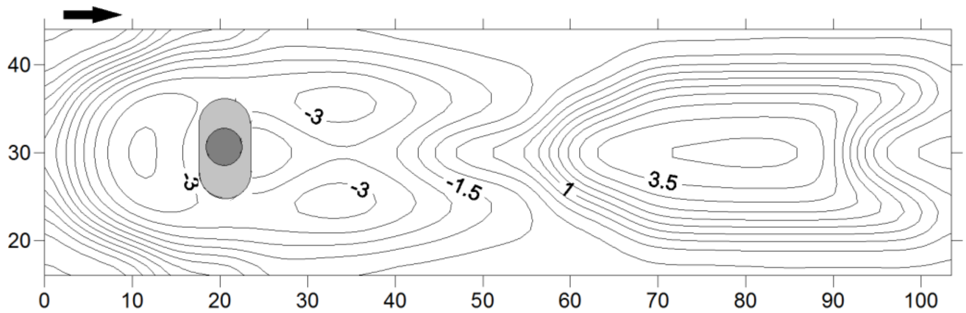

Figure 17. Contour map of the scour for alignment of attack α=90^0

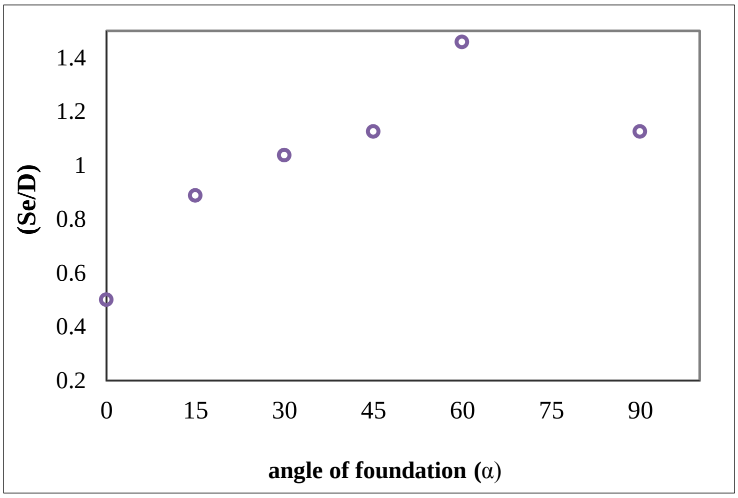

Figure 18. Relative between foundation alignment to the approach flow and maximum scour depth

CONCLUSIONS

The following conclusions are based on this experiment on the process of the scour development and sediment transport around a pier with foundation of varying depth from an initial bed level, shape and angle of foundation.

1. The retarding and limiting the scour due to the foundation occur when it is placed below the bed (Z/D= 0.25-0.5). The scour depth increases with foundation level when the foundation placed above the initial bed level.

2. The best level of foundation for various foundation shapes is different. The result shows square and cylinder foundation when placed at Z/D= +0.5 below the bed level gives a maximum reduction in scour depth equal to 70% of the scour depth without foundation and for both aerodynamic foundation maximum reduction in scour depth equal to 90% of the scour depth without foundation when placed at Z/D=+0.25.

3. The best foundation shape which leads to minimum scour around it, was aerodynamic shape along the channel, square, aerodynamic across the channel and cylindrical shape, respectively.

4. Inclined foundation creates two low pressure and high pressure area around the foundation. The accumulation of sediments in high pressure area and washing the sediment in low pressure is high so scour hole around the non-uniform pier is asymmetric.

5. By increasing the angle of flow to foundation increasing the effective width of foundation which allows increasing the depth of scour. In 90 degree angle, the maximum of scour depth in relation to inclined position is less, because in this position water rejection is more and approaching speed in company with the other position is less so its scour is low.

NOTATION

The following symbols are used in this paper:

D = pier diameter (L);
D^* = foundation diameter (L);
U = average approaching flow velocity ($L^2 T^{-1}$);
Uc = critical velocity (LT^{-1});
d_{50} = median size of sand (L);
h = approaching flow depth (L);
Z = foundation height (L);
α = position angle of foundation;
t = time (T);
S_{ed} = scour depth in uniform pier (L);
S_e = scour depth in non-uniform pier (L);

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