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Experimental Study on the Effect of Single Spur-dike with Slope Sides on Local Scour Pattern

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ABSTRACT

Constructing the spur-dikes is one of the most efficient methods for protecting river banks. The spur-dike in the flow path leads to local scour around this structure. Scour around the spur-dike is one of the major problems that might endanger the stability of the structure. Therefore, estimating the scour around this structure based on the flow condition and geometry of the spur-dike is highly important. The experiment was conducted in laboratory flume 6m long, 0.45 m width and 0.45 m deep and with median diameter of particle size 1.48 mm and the maximum local scour around the direct upright and trapezoidal spur-dike (with slope side) and the effect of Froude number and spur-dike side slope on geometry of local scour are investigated. According to the results, by increasing the Froude number and spur-dike side slope, the maximum scour depth and hole dimension of scour is increased, also sedimentation length is increased but its height is decreased and the amount of bed changes toward downstream is increased.

Key words: Spur-dike, Slope side, Scour, Froude number.

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1. INTRODUCTION

The spur-dikes are deflector structure that are developed from the river banks towards the flow center and leads to deviation and directs the flow from the banks towards the river centerline. This flow deviation creates rotating area with severe turbulence around the spur-dike. Hydraulic process of this matter expands the scour hole around the spur-dike and bed material sedimentation in downstream and the river bank. While the scour is considered as a serious hazard for the spur-dike and consequently for the river, sedimentation in downstream river banks is a natural solution for protecting the river banks. The spur-dike in flow path causes local scour around this structure. The spur-dike increases the local flow velocity and its turbulence and creates vortices that impose extra erosion forces around the structure bed. Many researches have investigated the scour around the spur-dike. Kuhnle et al. (1999) via their studies on the maximum depth of the scour hole concluded that in shallow flow, the maximum scour depth occurs in spur-

dike nose and by increasing the flow it moves towards the center of the channel (1). Ghodsian and Tehrani (2001) conducted a research on investigation of position and length of the spur-dike on its scour in 90° bend. The results showed that the maximum scour depth of the first half of the bed is less than that of the second half bend. Opposite of the maximum scour depth, dimensions of the scour hole increases by moving the spur-dike from the first half of the bed to its second half (2). Nagy (2004, 2005) by studying the spur-dike angle with the bank and Froude number for submerged and non-submerged spur-dike in direct channel, reached to the conclusion that the scour increases by raising the Froude number and also the scour for 90° is more than other angles. On the other hand, the maximum scour depth, width and volume of the hole for non-submerged spur-dike is more than that of submerged (3, 4). Ardeshtir et al. (2005) conducted a research in a laboratory flume on spur-dike series and reported that the most appropriate length for subsidiary spur-dike is 0.66 to 0.77 of the first spur-dike length. Also as the first spur-dike

diverts the flow towards the other side bank, the maximum scour occurs in the second spur-dike (5). Also Nasrollahi et al. (2008) studied the effect of flow depth on where the maximum scour depth occurs. They concluded that by increasing the flow depth, the maximum scour depth location moves towards the center of the spur-dike (6). Fazli et al. (2008) also investigated the laboratory changes of scour and how the scour hole is formed around the direct spur-dike in diverse position of 90° bend and concluded that as the spur-dike approaches to the end of the bend the scour increases (7). Zhang and Nakagava (2009) investigated an experimental and numerical study to simulate the flow pattern and bed alternation in presence of permeable and impermeable spur-dike. These experiments have been conducted in direct flume 8 m long, 0.4 m wide and 0.4 m deep in clear water condition. This research showed that permeability has an important effect on flow pattern and bed changes. Results showed that in a permeable spur-dike due to the flow separation and formation of vortexes, the scour occurs between the shafts while in impermeable scour due to flow separation and formation of horseshoe vortexes, scour occurs behind the spur-dike (8). Masjedi et al, (2011) conducted a laboratory research on a scour around L-shaped spur-dike in 180° bend in clear water condition. They performed their tests by $Fr=0.23, 0.25$ and 0.35 . The spur-dike with the length of 10, 15, 20 and 25 percent of channel width were settled in 30°, 45°, 60° and 90° in bend. The obtained results showed that the depth of scour increases by passage of time. The scour depth increases by raising Froude number. Increasing the length of spur-dike raises the maximum depth of the scour (9). Teraguchi et al, (2011) used a laboratory model for investigation of turbulent flow and bed changes around permeable and impermeable spur-dikes. Results of the tests showed that the maximum scour depth in impermeable spur-dike nose is more than that of permeable spur-dike (10). Osman and Negmaldin (2012)

investigated the effect of constriction on permeable and impermeable spur-dikes series via laboratory model. Results of these tests showed that the scour depth around the impermeable spur-dike with 60% is 2.6 times more than the scour depth around spur-dike with 80% constriction and this ratio is 3 times more for the permeable spur-dike in the same condition (11). Van Den Heever (2013) by conducting a laboratory research investigated the erosion and sedimentation and hydraulic flow of a laboratory model of rivers in South Africa. In this study, the variables were: length, distance and angle of locating spur-dikes. Their research showed a slow velocity area between the spur-dikes in which the sedimentation occurs. By increasing the distance between the spur-dikes, the flow velocity between them increases and this matter lead to changes the sedimentation pattern between the spur-dikes (12). By considering the studies of the previous researches, it is found that few number of researches have been done on the shape and geometry of the structure, scour hole expansion and scour pattern around spur-dikes. One practical and economical method is to construct spur-dike by using Rip Rap and therefor the spur-dikes are often built in trapezoidal shaped. In this research, the maximum of local scour in erodible bed around direct upright and trapezoidal (with slope sides) spur-dike were studied. By doing this research for different side slopes and also diverse hydraulic condition, besides comparing the result of upright spur-dike, the effect of side slopes on the erosion around the spur-dike can be found out.

2. MATERIALS AND METHODS

The experiments were conducted in a laboratory flume 6 m long, 0.45 m wide and 0.45 m deep in the hydraulic laboratory of Tarbiat Modares University. The walls and the bottom of the channel are made of glass which is 10 mm thick. The bed material is sand with $d_{50}=1.48$ mm. The Channel's characteristics have been shown in Figure 1.

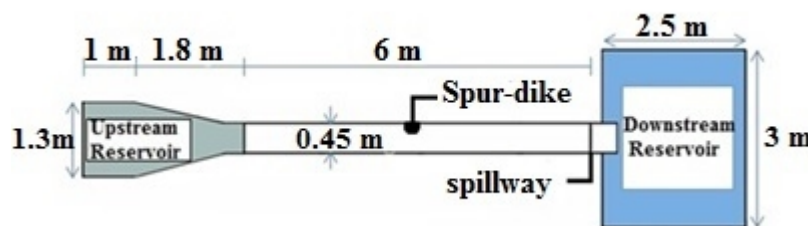


Figure 1. Laboratory equipment and channels

The utilized spur-dikes in the experiments are impermeable and made of Plexiglas. In this research four spur-dikes have been used which are 10 cm length, 5 cm width, 42

cm deep and the side slope are 90°, 85°, 80 and 75°. Utilized spur-dikes are shown in Figure 2.

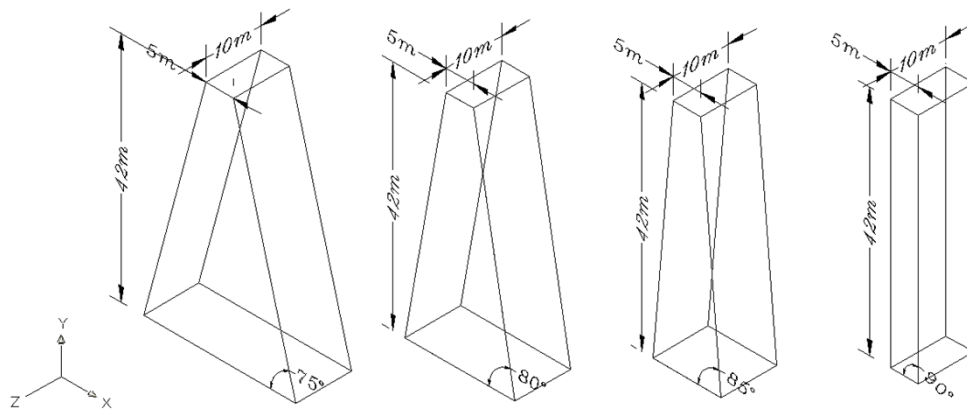


Figure 2. A schematic view of the utilized spur-dike in the experiments

In order to find a relationship between the effective factors on the scour around the spur-dikes, a dimensional analysis was conducted on the influential parameters. The independent and effective variables are: Channel width (B), channel longitudinal slope (s_0), spur-dike length (L), the angle of spur-dike with wall (β), the spur-dike height (H), the spur-dike width (b), the side slope of the spur-dike (z), the average flow velocity before the spur-dike (U), the flow depth in upstream (h), the average diameter of the bed material (d_{50}), the standard deviation in distribution of the particle size (σ_g), submerged density of the bed material (γ_s), water mass density (ρ), sediments mass density (ρ_s), acceleration of gravity (g), kinematic viscosity (ν). By selection of maximum scour depth (d_{se}) as the dependent variable, the following relation is obtained:

$$d_{se} = f(B, S_0, L, \beta, H, b, Z, U, h, d_{50}, \rho_s, \sigma_g, \nu, \gamma_s, \rho, g) \tag{1}$$

The general form of the above mentioned relation by using Π -Buckingham Method could be written as follow:

$$\frac{d_{se}}{h} = f\left(\frac{B}{h}, S_0, \frac{L}{h}, \theta, \frac{H}{h}, \frac{b}{h}, Z, \frac{U}{\sqrt{gh}}, \frac{h}{d_{50}}, \frac{\rho}{\rho_s}, \sigma_g, \frac{U h}{\nu}, \frac{\rho U^2}{\Delta \gamma_s d_{50}}\right) \tag{2}$$

Due to the channel slope, the angle of spur-dike with the wall, Fluid, length and depth of spur-dike are constant, the

dimensional parameters of $S_0, \theta, \frac{H}{L}, \frac{\rho}{\rho_s}, \sigma_g$, are removed. Consequently by combining, the following dimensionless parameters are considered as follow for investigation of the variable effect on the scour around the spur-dike with slope side:

$$\frac{d_{se}}{h} = f(Fr, Re, Z) \tag{3}$$

Due to the turbulence of the flow, the effect of Reynolds number can be ignored and ultimately the following equation is obtained:

$$\frac{d_{se}}{h} = f(Fr, Z) \tag{4}$$

Discharge is constant for all the experiments in 15 l/s, and once the channel width and the flow depth is known, U can be calculated. In this way U/U_c is determined. Three flow depths were considered for the experiments and consequently the ratio of U/U_c was obtained. Table 1 shows the flow condition in the experiments. By considering the three Froude number and four slope sides for the spur-dike, twelve experiments were conducted.

Table 1. Froude number and flow depths in the experiments

h (m)	U (m/s)	Uc (m/s)	U/Uc	Fr
0.11	0.303	0.355	0.85	0.29
0.12	0.278	0.367	0.76	0.26
0.13	0.256	0.377	0.68	0.23

At the beginning of the experiments, large amount of scour could be seen around the spur-dikes and gradually by passage of time the erosion process slowed and finally after a while it was balanced. In this research Ettema criteria was used. Ettema (1980) considered the relative

balance time for the scour hole in experiments equal to the time that the scour depth changes in each 4 hours be less than 1 mm (13). In Figure 3, the balance time of one of the test can be seen. Based on the figure and the calculation, 24 hours has been considered as the balance time.

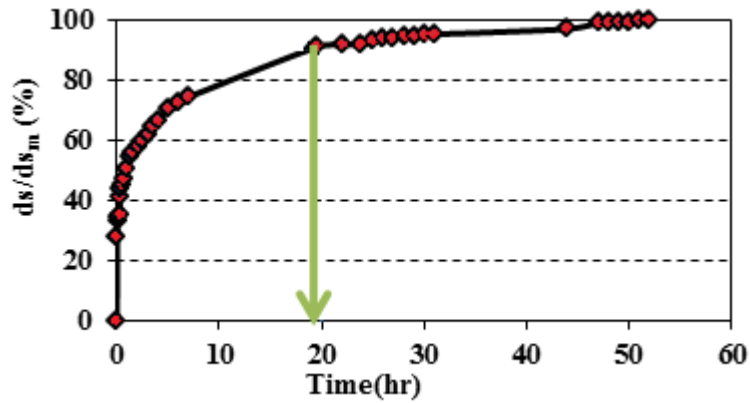


Figure 3. The balance time of scour

In these experiments, after the channel drainage, changes in the bed around the spur-dikes after the scour and sedimentation were measured by a laser meter. Longitudinal grids for measuring have been irregular in a way that in the areas with more bed changes, smaller gridding is selected and in the areas where the topography was flatter, bigger gridding was used. The minimum and maximum distance between the longitudinal grids along the channel were respectively 2 cm and 10 cm. The

distance between measured points in latitudinal grids was 1.5 cm.

3. RESULTS AND DISCUSSION

In this research, different parameters of scour geometry were studied. The defined parameters are: upstream length of scour hole (a), downstream length of the scour hole (b), scour hole width (c), maximum scour depth (ds) (Figure 4).

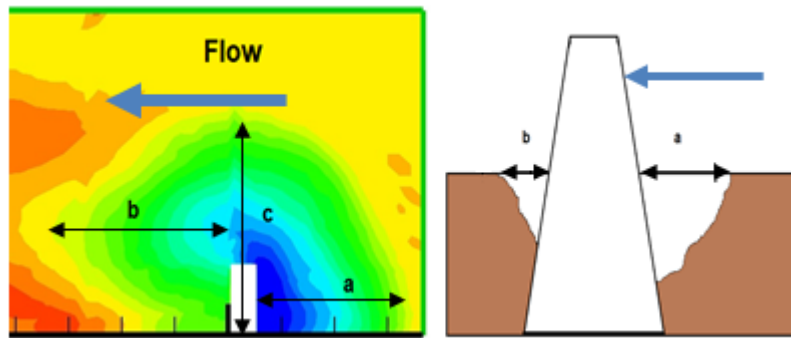


Figure 4. The scour hole dimension

In order to investigate the effect of the spur-dike slope sides on the maximum scour depth, the scour hole width and the scour hole upstream and downstream length, above mentioned experiments were conducted in $U/U_c=0.68, 0.78$ and 0.85 . In Figure 5 the effect of slope on these parameters can be seen. According to Figure 5 (a), by increasing the spur-dike side slope from 75° to 90° , the maximum scour depth increases. Since by increasing the spur-dike side slope, vortex power in upstream of spur-dike increases and this increase eases the material erosion of the spur-dike upstream and also the capacity of sediment transport inside the scour hole increases. In addition, the maximum scour depth occurs in upstream of spur-dike nose. In Figure 5 (b), changes of the downstream length of scour hole have been shown. By decreasing the spur-dike side slope, the downstream length of the spur-dike hole is

also decreased because by reducing the spur-dike side slope, the spur-dike width is increased and the vortex is formed and moved from the upstream of spur-dike nose, should pass a long distance for sediment transport from spur-dike to downstream and this matter leads to reduction of sediment transport power to downstream and consequently decrease the downstream length of scour hole. Figure 5 (c), by increasing the spur-dike sides slope in all conditions, upstream length of the scour hole increases because by increasing the scour hole depth, material collapse from the hole side increases and this matter leads to growth of scour hole length in upstream. In Figure 5 (d) by increasing the spur-dike side slope, the scour hole width increases and this is caused by the scour depth growth due to the slope increase.

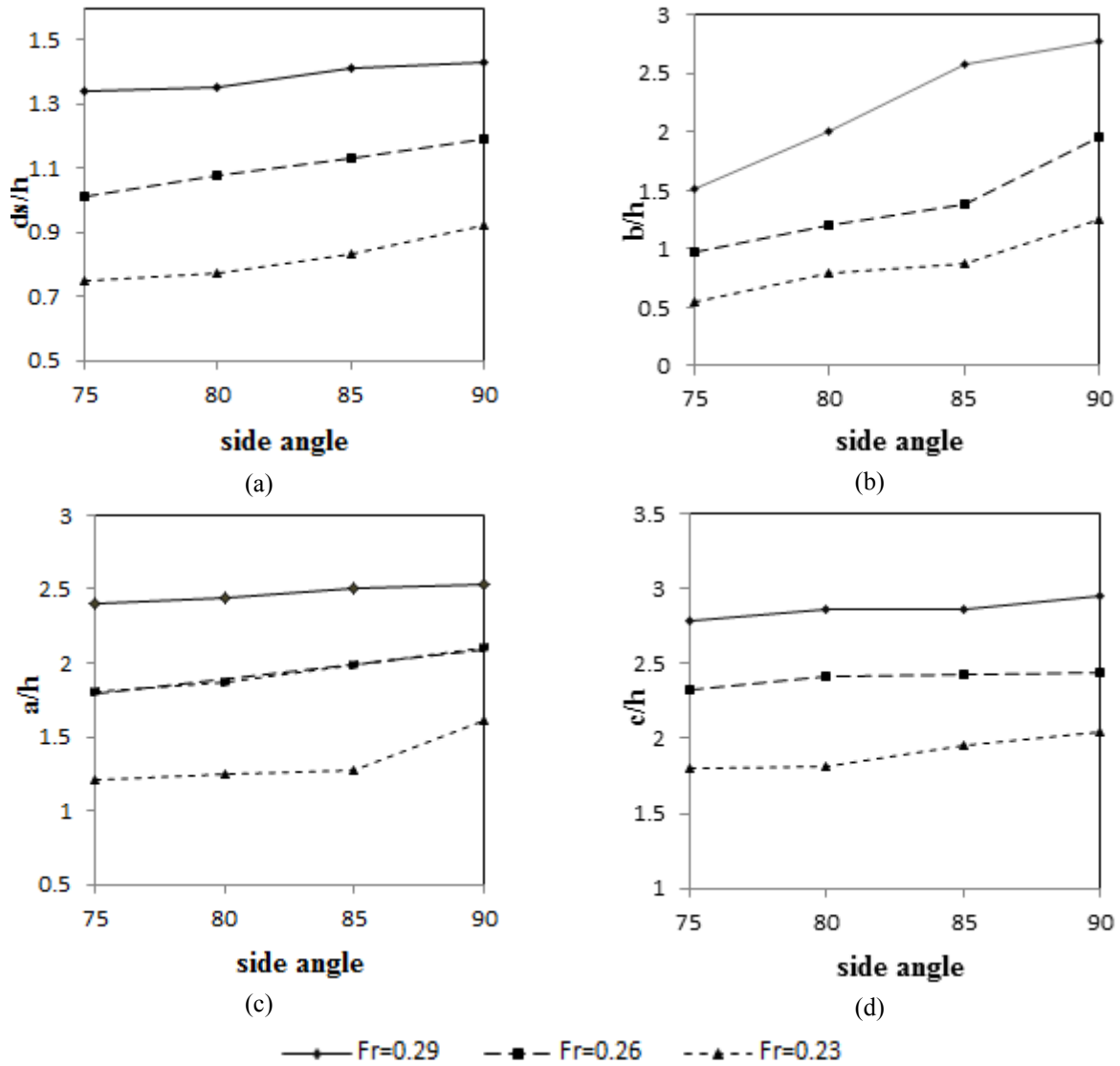


Figure 5. The scour hole parameters change in diverse spur-dike sides slope: a) the maximum scour depth, b) the scour hole downstream length, c) the scour hole upstream length, d) the scour hole width

In Figure 6, longitudinal profile in 10% of the channel width for $Fr=0.26$ has been shown. As it is seen, by increasing the spur-dike side slope, the scour depth in

upstream and downstream of the spur-dike is increased. Also by increasing the spur-dike sides' slope, bed change and migration towards downstream becomes more.

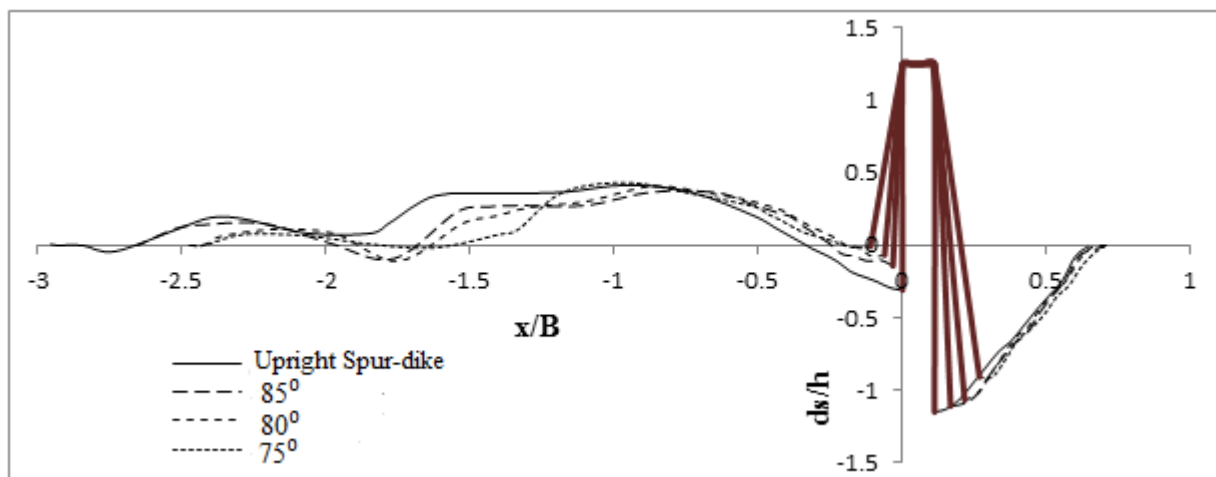


Figure 6. Longitudinal profile in 10% of the channel width for $Fr=0.26$

In Figure 7, the bed topography for $Fr=0.26$ has been

shown. According to the results, the maximum scour

occurs in the upstream of spur-dike nose. Also after the scour hole around the spur-dike, sedimentation is formed and after that, a scour hole is shaped as well while the extracted material from this hole formed sedimentation in downstream. Regarding the hole dimensions the first scour hole (around the spur-dike) is bigger than the second one and also the first sedimentation is bigger than that of the second one in every respect. According to the figure, the first sedimentation is formed near the spur-dike wall and

the highest part of this sedimentation is close to the spur-dike adjacent wall. By increasing the spur-dike side slope, dimension of the scour hole around spur-dike also increases. Consequently, dimension of the sedimentation is increased and it is divided into two parts. By decreasing spur-dike side slope from 90° towards 75° migration and alternation of the bed towards the downstream of spur-dike is decreased.

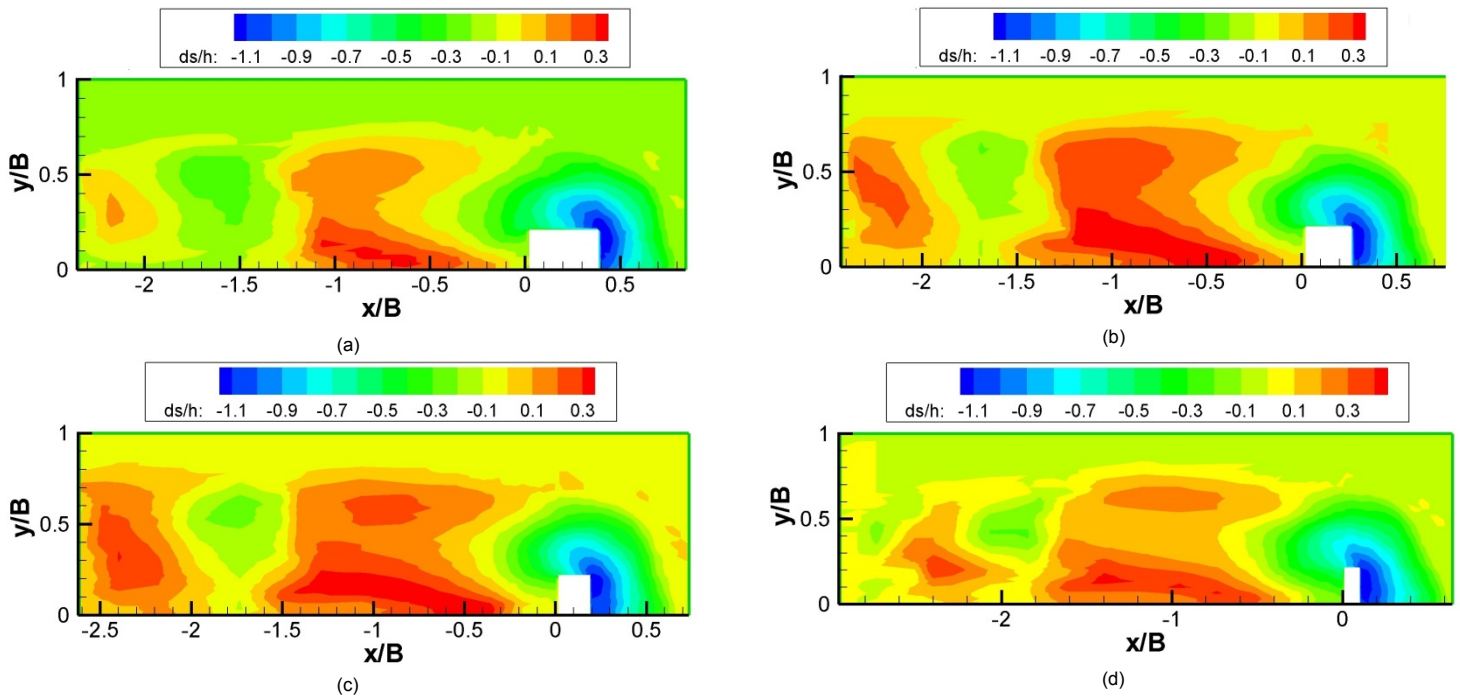


Figure 7. Bed topography changes for $Fr=0.26$ a) spur-dike with 75° side slope, b) spur-dike with 80° side slope, c) spur-dike with 85° side slope, d) spur-dike with 90° side slope (flow is from right to left)

In Fig.8 The effect of the Froude number on downstream length of the scour hole, maximum scour hole width and upstream length of the scour hole are seen. These experiments were conducted in four modes of spur-dike sides' slope. As it is shown in Figure 8 (a), by increasing Froude number, the maximum scour depth in scour with different slope always increases and it is caused by increase of the flow velocity. By increasing the Froude number in a constant side slope, downward flow and horseshoe vortex work more appropriately in order to increase the maximum scour depth. In Figure 8 (b), the upstream length changes of scour hole in diverse slopes and three Froude number are seen. According to this figure, for all slopes of the spur-dike by increasing the Froude number, upstream length of scour hole is increased. When the Froude number of the flow in constant discharge increases, by increasing the flow velocity and decreasing the flow depth and increasing the downstream flow power, before the spur-dike bigger vortex formed. Therefore, the flow effect on the spur-dike upstream bed expands to farther areas. On the other hand, the upstream hole length

depends on the scour in the hole center so that the materials collapsed from the hole wall and transferred to the downstream with the channel main flow due to the vortex caused by pressure difference. Therefore, it brings about many changes of the scour hole upstream length compared to the Froude number. In Figure 8 (c) the effect of Froude number on alternations of the scour hole downstream length in different slopes of the spur-dike has been shown. By increasing the Froude number, the downstream length of the scour hole is increased, because by increasing the Froude number, sediment transport power is increased. In the spur-dikes with steeper slopes, this parameter alternation is more than Froude number. In Figure 8 (d), in lower Froude numbers, due to the low speed of the flow in the spur-dike upstream, the local effect of the flow on the width of the scour hole is little. By increasing the Froude number, the flow speed is increased and its depth is decreased and this matter increases the effects of velocity on the width of the scour hole and consequently by increasing the Froude number of the flow, the width of the scour hole is increased.

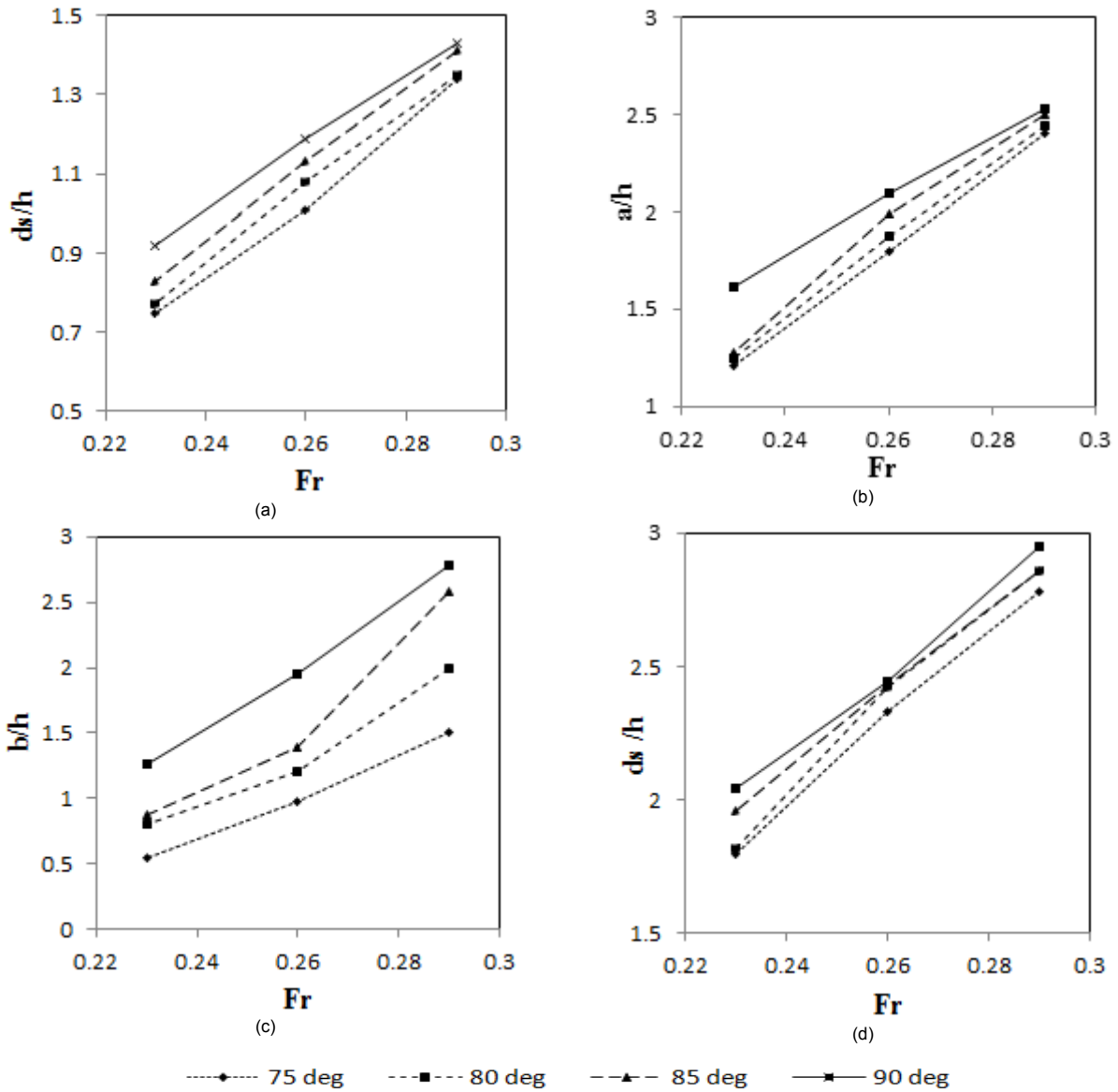


Figure 8. The scour hole parameters changes with different Froude number a) maximum scour depth, b) the scour hole downstream length, c) the scour hole upstream length, d) the scour hole width

In Figure 9 and Figure 10, longitudinal profile in 10% of the channel width for the spur-dike with 80 and 90 slopes has been shown. As it is seen, by increasing Froude

number, the scour depth flow in upstream and downstream of the spur-dike is increased and by increasing the Froude number length of the first sedimentation is increased.

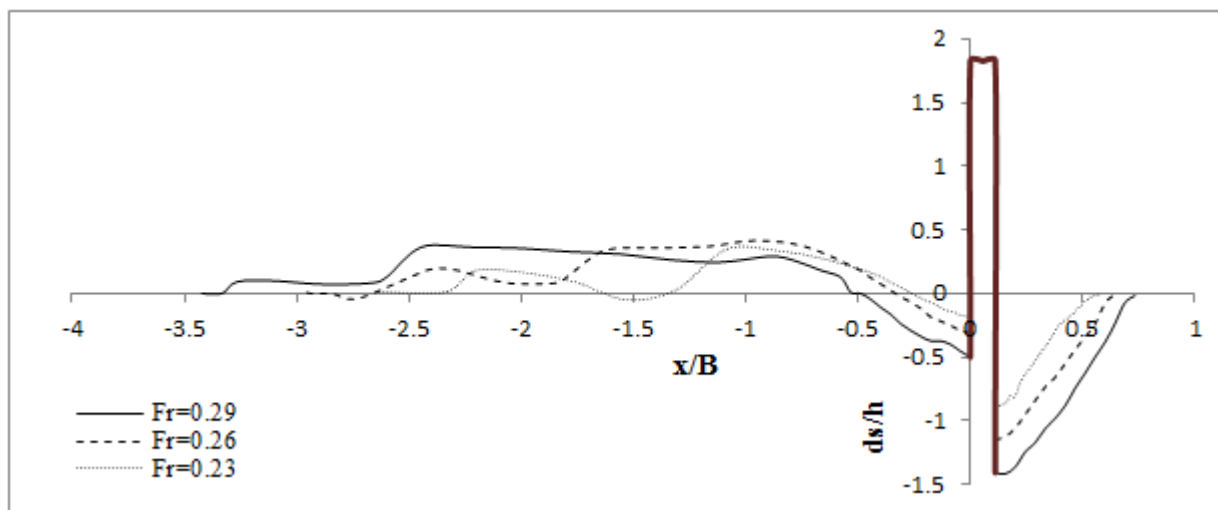


Figure 9. Longitudinal profile in 10% of the channel width for the spur-dike with 90 side slope

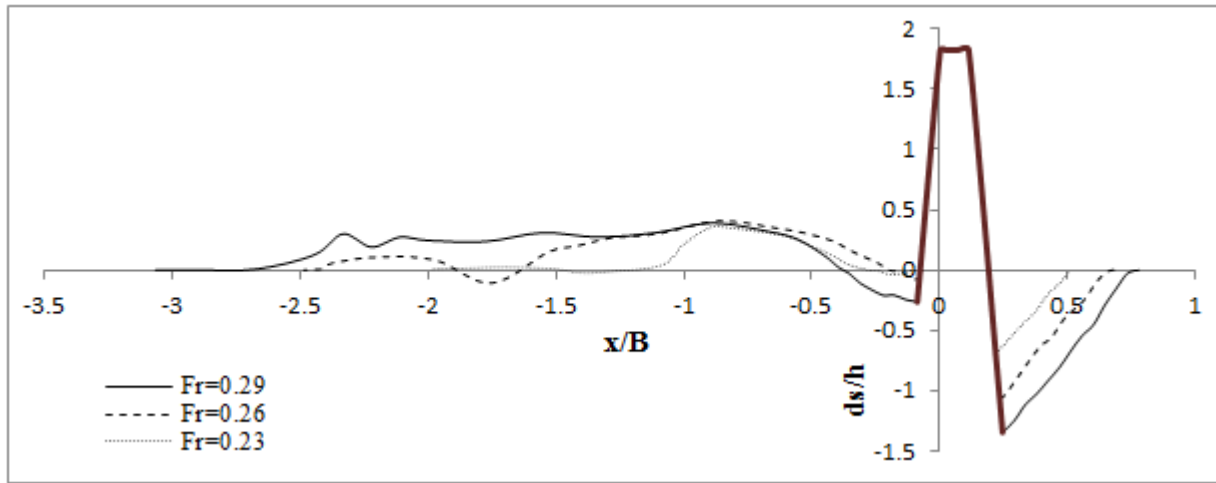


Figure 10. Longitudinal profile in 10% of the channel width for the spur-dike with 80 side slope

In Figure 11 and Figure 12 the bed topography for two spur-dikes with 75 and 90 side slope has been shown. According to the figure it can be concluded that by increasing the Froude number, the maximum scour depth and dimensions of the scour hole is increased. In addition,

length of the sedimentation after the spur-dike is increased. By increasing the Froude number, expansion of the bed surface changes towards downstream increases and the height of the sedimentary hill decreases.

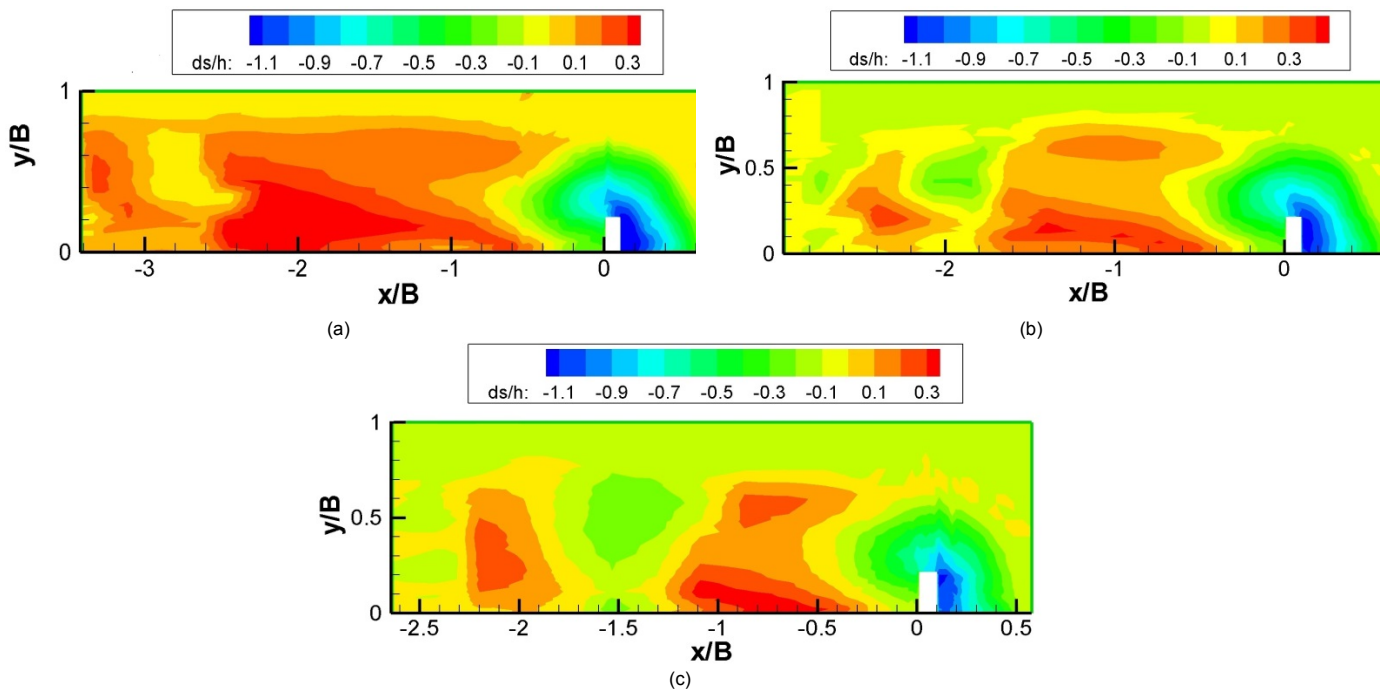


Figure 11. Bed topography changes for 90 spur-dike, a) Fr = 0.29, b) Fr=0.26, c) Fr=0.23

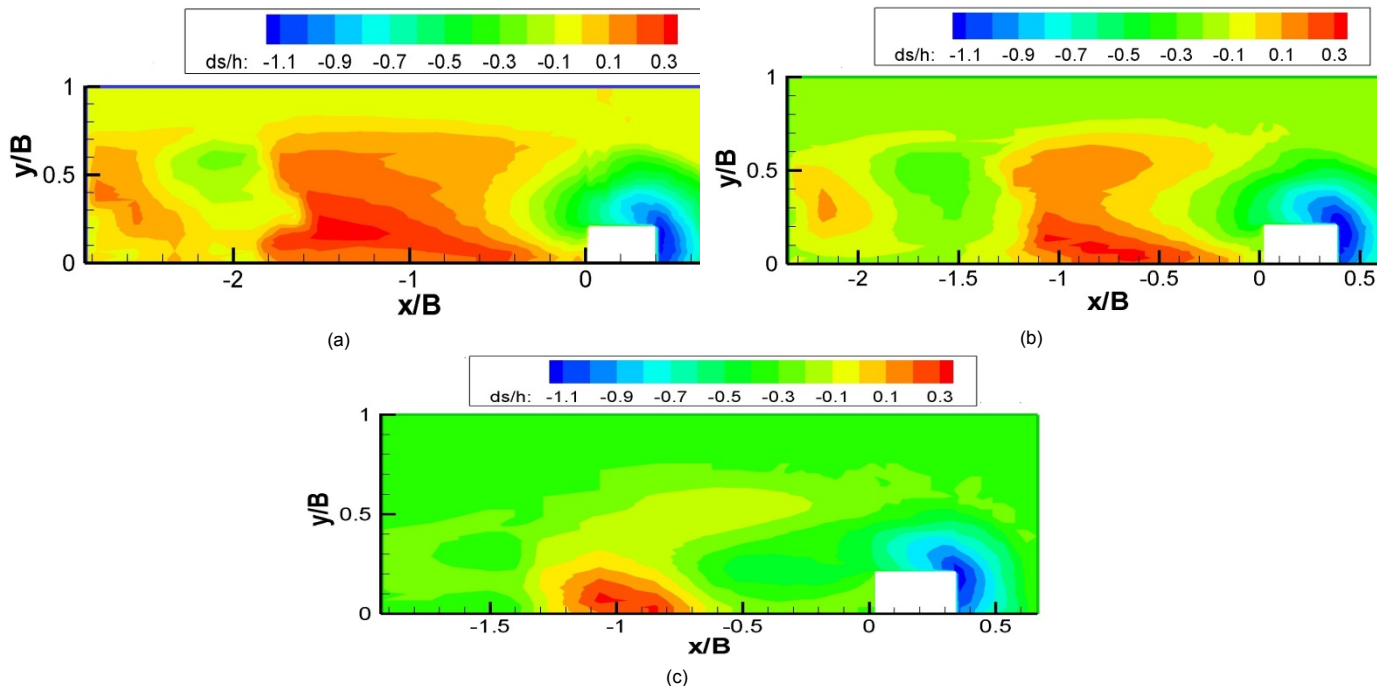


Figure 12. Bed topography changes for 75 spur-dike, a) $Fr = 0.29$, b) $Fr=0.26$, c) $Fr=0.23$

On the whole it can be concluded that in direct spur-dikes with the slope sides in different Froude numbers, by increasing the Froude number and when the spur-dikes side slope gets steeper, the maximum scour depth and dimension of scour hole is increased. Also by increasing Froude number and the spur-dike sides slope, the sedimentation length is increased but its height decreases and expansion of bed changes towards downstream increases.

4. CONCLUSION

In this study, the maximum of local scour around the direct upright spur-dikes and trapezoidal spur-dike (with slope sides) have been studied and the effect of Froude number and the spur-dike side slope on the scour geometry provided. Results show:

1. By increasing the spur-dike side slope from 75 to 90 degree, the maximum scour is increased because by increasing the spur-dike slope, the vortex power in spur-dike upstream is increased and the sediment transport power in the scour hole is increased.
2. By decreasing the spur-dike sides' slope, also the scour hole downstream length decreases because by decreasing the spur-dike side slope, its width increases and it leads to the vortex energy reduction and it caused the reduction of the sediment transport power to downstream.
3. By increasing the spur-dike sides slope in all forms, the upstream length of the scour hole increases, because by increasing the scour hole depth, the material collapse from the hole wall is increased.
4. By increasing the scour side slope, the scour hole width increases and it leads to the scour depth increase due to slope increased.
5. By increasing Froude number the maximum scour depth in spur-dike with different slopes continuously increases

and its main reason is increase of the flow velocity.

6. For all the spur-dike sides slope, by increasing the Froude number the scour hole upstream length increases because by increasing the flow velocity the downward flow power and the vortexes close to the spur-dike increases.
7. By increasing the Froude number, the downstream length of the scour hole is increased because by increasing the Froude number, the sediment transport power is increased. In the spur-dike with steeper slope, this parameter changes is more than that of Froude number.
8. In lower Froude numbers due to low velocity of the flow in upstream of spur-dike, the local effects of the flow on the scour width is little. By increasing the Froude number, the flow velocity increases and it leads to the scour hole width increase.

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AUTHORS CONTRIBUTION

This work was carried out in collaboration among all authors.

CONFLICT OF INTEREST

The author (s) declared no potential conflicts of interests with respect to the authorship and/or publication of this paper.

REFERENCES

1. Kuhnle RA, Alonso CV, Shields FD. Geometry of scour holes associated with 90 spur dikes. *Journal of Hydraulic Engineering*. 1999;125(9):972-8.
2. Ghodsian M, Tehrani S. Scour around groins. *International Journal of Sediment Research*. 2001;16(1):60-8.
3. Nagy HM. Maximum depth of local scour near emerged vertical wall spur dike. *Alexandria Engineering Journal*. 2004;43(6):819-29.

4. Nagy HM. Hydraulic evaluation of emerged and submerged spur-dikes: temporal bed evolution and equilibrium state characteristics. *Alexandria Eng J.* 2005;44(2):279-90.
5. Ardeshir A, Karami H, Saneie M, editors. Experimental study on the effect of secondary groyne on local scouring around first groyne. 7th International Civil Engineering Conference, Tarbiat Modarres University, Tehran, Iran; 2005.
6. Nasrollahi A, Ghodsian M, Neyshabouri S. Local scour at permeable spur dikes. *J Appl Sci.* 2008;8(19).
7. Fazli M, Ghodsian M, Neyshabouri SAAS. Scour and flow field around a spur dike in a 90 bend. *International Journal of Sediment Research.* 2008;23(1):56-68.
8. Zhang H, Nakagawa H. Characteristics of local flow and bed deformation at impermeable and permeable spur dykes. *Annual Journal of Hydraulic Engineering, JSCE.* 2009;53:145-50.
9. Masjedi A, Akbari I, Abyar H. Evaluating scour at L-shape spur dike in a 180 degree bend. *World Applied Sciences Journal.* 2011;15(12):1740-5.
10. Teraguchi H, Nakagawa H, Kawaike K, Yasuyuki B, Zhang H. Effects of hydraulic structures on river morphological processes. *International Journal of Sediment Research.* 2011;26(3):283-303.
11. Osman MA, Saeed HN. Local Scour Depth at the Nose of Permeable and Impermeable Spur Dykes. *University Of Khartoum Engineering Journal.* 2012;2(1).
12. Van Den Heever ADD. An investigation of the use of groyne as a means of riverbank erosion protection: Stellenbosch: Stellenbosch University; 2013.
13. Ettema R. Scour at bridge piers. 1980.