Evaluation Of Local Scour Development Around Curved Non-Submerged Impermeable Groynes

Dr. Hasan Mahdi M. Al-Khateeb, Dr. Hayder Abdulameer K. AL-Thamiry, Huda Hadi Hassan

Abstract: Groynes are man-made hydraulic structures constructed for a variety of purposes. They extend outside the bank in the depth of streams. Local scour usually occurs around groynes resulting in problems of interest to hydraulic engineers. In this study, laboratory experiments were conducted to evaluate the local scour around different number of groynes distributed on different spacing with different shapes. Physical models have been developed for groynes installed in a straight hydraulic channel grounded with uniform cohesionless (soil) as bed material with medium grain size (d50 = 0.69 mm). The experiments were conducted under subcritical flow and Clear- water conditions. Three different numbers of groynes (single, double and triple) were used to indicate the impact of the numbers on the local scour; such impact have been observed to be as reverse relationship, specially, for the intermediate groynes. Different spacing between groynes as (1, 1.5, and 2) times the length of groynes were used in this study. For the range tested, it has been observed that for each spacing decrease by (0.5 Lg) there was a decrease in scour depth about (20%). Also, several lengths of groynes (13, 10, and 7) cm were used, and it has been observed that scour depth is decreased about (20 - 53)% by decreasing the ratio of groyne length to main flow width (Lg/B) by (7.5%). Two different shapes of curved groynes, namely as, quadrant (quarter of a cylinder) and semi-parabolic shaped groynes were used to indicate the effect of groyne shape on the local scour. Generally, scour is decreased about (75) % in quadrant shape groynes as compared with that of semi-parabolic shape groynes.

Index Terms: Curved Groynes, Dimensional Analysis, Impermeable, Local Scour, Non-Submerged, Parabolic, Quadrant.

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1 INTRODUCTION

Hydraulic engineers face a considerable problem related to the local scour occurring around various types of obstructions placed in an alluvial channel. In practice, a channel is often obstructed by a means or another, such as groynes, piers, abutment, and so on. Groynes are typical man-made hydraulic structures that extend outside the bank of the stream to deflect the current away from the bank in order to protect the bank against erosion. Groynes are used to enhance the aquatic habitat by creating stable pools in unstable streams. It is also widely used to redirect the flow in channels of a river to improve the navigation hydraulic conditions. In addition, the groyne is considered a water-friendly structure to improve the surrounding scenery and the accessibility to the river [1].

2 LITERATURE REVIEW

Groynes may be classified upon different basis, such as effect on the stream flow (attracting, deflecting or repelling), shape or appearance in plan (straight, T-head, L-head, hockey, inverted hockey, straight with pier head, wing or tail), submergence (submerged or non-submerged), methods and materials of construction (permeable or impermeable).

No considerable literature are available about scour developed near curved groynes. The following available literature covered none curved groynes. Khasaf [2] carried out a laboratory study for scour pattern around diverse cases of impermeable groynes changing geometry and the angle of inclination of groyne with respect to the flow direction. He found that the scour depth increases with increasing the degrees of the opening ratio, Froude Number, and the degrees of angle of inclination of groyne with respect to the flow direction. Kuhnle et al. [3] tested various cases of straight impermeable groynes changing angles with respect to the flow direction and groynes lengths under clear-water overtopping flows. He found that the least bed erosion occurred in the region of the closest bank and associated with groynes of (90°) angles, while the groyne with angle (45°) leads to increase in the bank erosion. The greatest width of the scour hole was corresponding with the (135°) groynes, but they provide improved aquatic habitats and minimize the possible erosion of the channel bank. Kurzke et al. [4] performed a laboratory study to calculate the exchange of water quantities between the main flow and field of groynes. They, also used straight impermeable groynes. It was found from experiments that fields of groynes mostly make two vortices; one is large in the center of the field of groyne and other, secondary, in the top corner of the field of groynes. Attia and El saied [5] presented a study using a two-dimensional hydrodynamic model (mathematical model) to simulate and predict the flow pattern around non-submerged single groyne in a straight channel. They found patterns between the longitudinal velocity for repelling and attracting type groynes with more or less slight increase in the maximum velocities, and they found the straight groyne type can be designed for sediment removal and evacuation in front of critical hydraulic zones and infrastructures. Ezzeldin et al. [6] studied the local scour around a single straight impermeable submerged groyne installed in a straight channel according to different angles of inclination with respect to flow direction. Their experiments showed that the main reason for the drift is a vortex which takes the form of a horseshoe around the groyne, but its impact disappears when it reaches Froude number that lessens the intensity of the flow around the groyne, hence, the vortex causing erosion becomes weaker

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and slower, so, water ability to carry sediment decreases. Alauddin [7] conducted studies to comprehend the flow dynamics against various orientations and configurations of impermeable non-submerged groynes in a straight channel with sand-bed alluvial river. One of these configurations was curved (parabolic as (x= c yn), where, (c=0.01), exponent (n=1.78)), and other configurations were downstream aligned last-half portion. Those configurations were considered to promote the flow to be concentrated for deeper channel at low flow and minimize scour near groynes at high flow. Uddin and Hossain [8] made an estimation for maximum local scour depth around bell mouth groyne constructed along the bank of a straight channel to locally change of river conditions. It was observed that scour depth varied proportionally (directly) with the variation flow velocity and Froude number. Kang, J. et al. [9] worked a laboratory study for a series of impermeable straight groynes in a straight channel to analyze the impact of the flow along the space of the groynes, and to derive data so the space of the groynes through an irrigating model test can be suggested. They showed that the mean flow velocity at the center of the groyne area was reduced by (40)% when compared with the flow velocity of the inlet. Focusing was on flow configuration through the groyne field and the flow range at the center of the groyne field against the space of the groyne. Decreasing influence of groyne erosion was suggested using the analysis of the shelter effect of aquatics and the countercurrent in the bank line. Dawood [10] conducted laboratory experiments using three different numbers of impermeable non-submerged groynes (single, double, and triple) with different shapes (straight, T-head, and L-head) in a straight channel. She found indirect relationship relating the effect of groynes' number and shape on scour maximum depth. She, also, used different spacing as (1, 1.5, and 2) times the length of groynes, and noted that increasing the spacing by 0.5 times groyne length caused increasing the scour depth about (20)%.

3 OBJECTIVE

The major goal of the present study is to investigate the effect of groyne's shape, length and spacing on local scour, which formed around impermeable non-submerged groyne located in a straight channel with subcritical flow conditions. To achieve this objective, the study consisted of laboratory work and statistical handling for the results obtained with formulation based on dimensional analysis.

4 MATERIALS AND METHODS

4.1 Dimensional Analysis

For clear water approach flow conditions, the maximum scour depth (ds max) at a groyne nose may be a function of the following parameters as shown in (1):

$(ds)=f \{y, v, v_c, L_g, \rho, \rho_s, g, n, b, d_{50}, \mu, \sigma_g, B, S_0\}$ …................... (1)

Where y=flow depth, v=mean approach flow velocity, vc=critical velocity, Lg=length of groyne, ρ=density of fluid, $\rho_{\square}$=density of the sediment, g=gravitational acceleration, n=number of groynes, b=spacing between the groynes, d_{50}=median particle grain size, μ=dynamic viscosity of fluid, σ_g=geometric standard deviation, B=the width of the channel, and S_0=slope of the channel. Using dimensional analysis, equation (2) can be written as:

$ds/y = f(v/vc, Re, L_g/y, Fr, \rho_s/\rho, b/y, d_{50}/y, n, \sigma_g, B/y, S_0)$ ..………. (2)

As channel width is constant (40 cm) for all runs, the term (B/y) can be can disregarded. Effect of changing channel width is implicitly considered in (v/v_c). Simplifying the equations above and eliminating the parameters with constant and negligible values, and applying the assumption (single sediment size, constant viscosity and relative density), equation (3) can be written as:

$ds/y = f(v/v_c, L_g/y, Fr, b/y, n)$ ……………….. (3)

4.2 Laboratory Work

Investigation experiments were performed in an open channel at the Hydraulic Laboratory in Al-Najaf Technical Institute, Department of Civil Techniques. Fig. (1) shows the laboratory flume used in this study. The main structure is a glass fiber. It is molded in steel stiffeners which has a net inner dimensions of (6.6) m in length, (0.4) m in width and (0.4) m in depth. The flume includes two parts: an upstream inlet section of (1.0) m length connected to water tank, and a working section of (5.6) m in length. This section is divided into three parts. The middle part has a layer of sand (erodible uniform sediments) with a depth of (0.1) m and length of (2) m. Upstream and downstream sections has (1.25) m length with bed surface level matching the middle (sand) level to obtain the same channel ground surface level. The bed material consists of cohesionless sand with a median particle size (d_{50}) equal to 0.69mm. The geometric standard deviation of the sand size equal to 1.23, which implies that the sand used is of a uniform size.

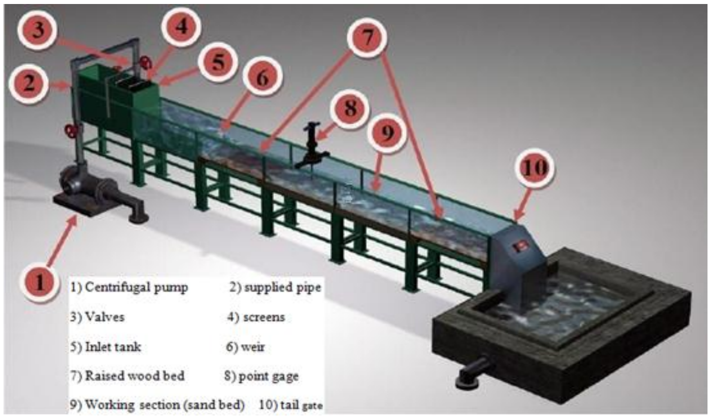
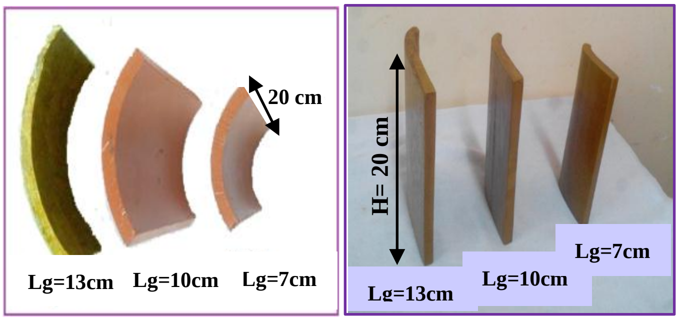


Fig. (1): *Sketch to the laboratory flume and its accessories*

The flow depth is controlled by an adjustable tail gate which lies at the downstream of the trap basin. There is also a sharp crested rectangular weir to measure flow discharge. This weir is mounted at the upstream section of flume, and it is (0.4) m in width, and (0.25) m in height. All depth measurements were carried out using a point gauge with accuracy (±1) mm. It was mounted on a carriage. This carriage can move above the working area transversely and longitudinally. The groyne models used in the experiments were made of plywood. Those models were (10) mm thick, (20) cm high and (7, 10, and 13) cm long. They were installed at different spacing of (L_g, $1.5L_g$, and $2L_g$). the groynes were fabricated with two different shape functions for the plan section to represent curved groynes. They were quadrant and semi-parabolic plan section shapes, as shown in Fig. (2). In order to determine the time required to reach (equilibrium) conditions of scour to be adopted in all runs for the purpose of eliminating the time effect, different velocities of flow were used. The scour was recorded at different time intervals using a point gauge to measure the maximum scour at the nose of upstream groyne. To reach maximum (final) scour depth, the test run conducted for 360 min (6 hrs) in order to reach stable situation of no more scour to occur with more time.



a b

Fig. (2): *The groyne group.* ***(a)*** *quadrant;* ***(b)*** *semi-parabolic*

The scour depth has sharply increased during the first half of test run duration, while it became approximately constant during the second half. Values of scour depth at various test durations as a percentage of final scour depth have been calculated. It has been observed that (94 - 97) % of the local scour can be achieved in (3.5) hours. For more accuracy, time duration (4) hours has been adopted in this study for all runs to eliminate the time effect. The scour depth has sharply increased during the first half of test run duration, while it became approximately constant during the second half. Values of scour depth at various test durations as a percentage of final scour depth have been calculated. It has been observed that (94 - 97) % of the local scour can be achieved in (3.5) hours. For more accuracy, time duration (4) hours has been adopted in this study for all runs to eliminate the time effect. Steady subcritical flow was maintained for performing all the experiments at a clear water conditions with plain bed. The groyne models were fixed to the side wall of the working section of the flume. Starting the runs was beginning with raising up the tail gate and the working area is genteelly filled with water in order to allow any air bubble to peculate out of the bed to avoid any apparent settlement around the groynes, and prevent any abrupt high local velocity which may cause a disturbance in the sand bed to occur with starting water pumping in the flume for the run. After water pumping starts, the tail gate is gradually lowered until the required water depth to be established in the flume. This depth is checked by the point gauge. After achieving the equilibrium time, the flow is stopped, the flume is drained slowly to avoid any change in the scour hole, and the sand is allowed to dry. Then, the required measurements of sand bed surface level are recorded by using the point gauge at several points around the groyne, upstream and downstream, longitudinally and transversely. The scour depth at the downstream nose of the first groyne is, accurately, recorded at which the expected higher scour usually occurs, see Fig. (3).

Fig. (3): *Scour pattern at the end of a test*

A total of 90 runs with total time of 360 hours have been carried out throughout the laboratory work over three months. Those runs included the seven parameters studied influencing scour depth. Some of those parameters are related to the groyne as length, spacing, number and shape. Others are related to flow conditions like depth, velocity and Froude number.

5 RESULTS AND DISCUSSION

The following four subsections discuss the results obtained from the laboratory work according to the seven parameters tested. The fifth subsection illustrates the statistical determination for constants proposed by the dimensional analysis for the scour depth formula.

5.1 Effect of flow velocity and depth (Froude Number) on the Scour Depth

The dimensional analysis has shown that the Froude Number ($Fr = v/\sqrt{gy}$) is a significant parameter for scour around groynes. The experiments were conducted with Froude numbers of 0.526, 0.470, 0.415 and 0.359 to cover the desired range for subcritical flow. To investigate the effect of Froude Number on scour depth, it may be worth to discuss effect of each of its components; flow velocity and depth, separately. Fig. (4) elucidate the influence of flow velocity on scour keeping water depth constant as well as other parameters (Lg, b, shape and n) are also constants. Generally, It can be found that the scour increases with increasing Froude number. This may be attributed to the increase in separation zone by increasing flow velocity, which will produce more eddies causing more scour.

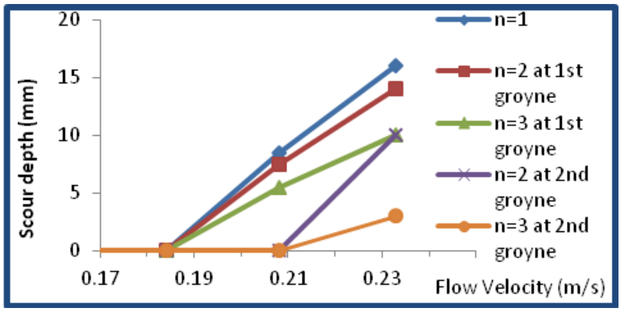


Fig. (4): *Effect of flow velocity on the scour depth for quadrant groynes with (Lg= 130 mm, b=260mm, y=20mm)*

Fig. (5) illustrates the effect of flow depth on scour depth. It is clear that scour depth is directly proportioned with flow depth. As the flow depth decreases, the surface roller becomes relatively more dominant and cause the horseshoe vortex to be less capable to entraining sediments. Therefore, for shallower flows, the local scour depth is reduced until it becomes with no clear effect. Increasing flow velocity and/or decreasing flow depth will increase Froude Number. On the basis of the above discussion, decreasing flow depth leads to decrease scour depth when flow velocity kept constant, on the other hand, at constant flow depth when flow velocity increases scour depth increases, too.

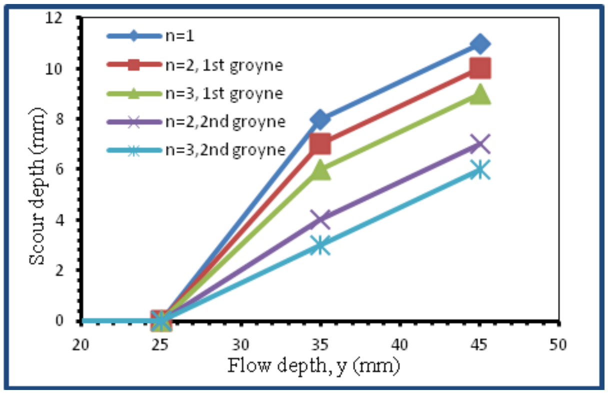


Fig. (5): *Effect of flow depth on the scour depth for quadrant groynes with (Lg= 130 mm, b=260mm, v=0.192 m/s)*

In all cases, when Froude Number increases (due to velocity increase or depth decrease, or even increasing velocity relatively more than increasing depth) will cause scour depth to increase. This is belong to that scour is more sensitive to flow velocity and the vortices than flow depth. In order to deduce the effect of Froude Number on the scour depth, the results may be plotted as dimensionless values relating between Froude Number and the fraction [scour depth, (ds)/water depth, (y)] as in Fig.(6).

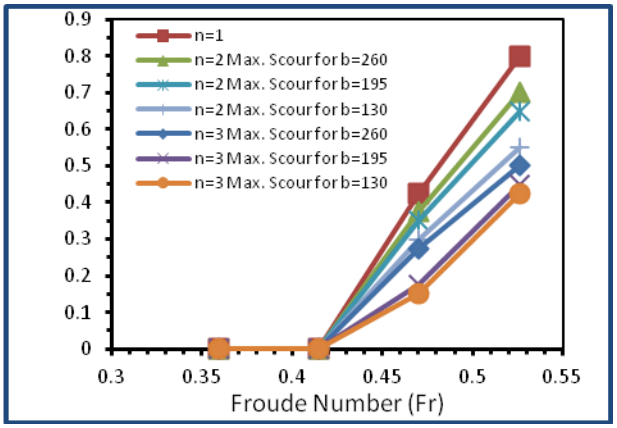


Fig. (6): *Development of scour depth with Froude Number for different number of groynes and spacing (b) with length of groynes (Lg= 130 mm)*

5.2 Effect of Groynes' Number and Spacing on the Scour Depth

The effect of number of groynes would be, clearly, significant when the effectiveness of other parameters is held constant as shown in Fig. (7). Each curve of the six curves in this figure represents a set of experiments for a certain Froude Number with different number of groynes, but all curves are for experiments with the same b, Lg and y. The number of groynes has a direct influence on the scouring process, that is, one (single) groyne has a deeper scour when compared with group of groynes, compare Fig. (8) with Fig. (9). This may due to the interference between successive vortices caused by successive groynes leading to weakening each other of the horseshoe vortices.

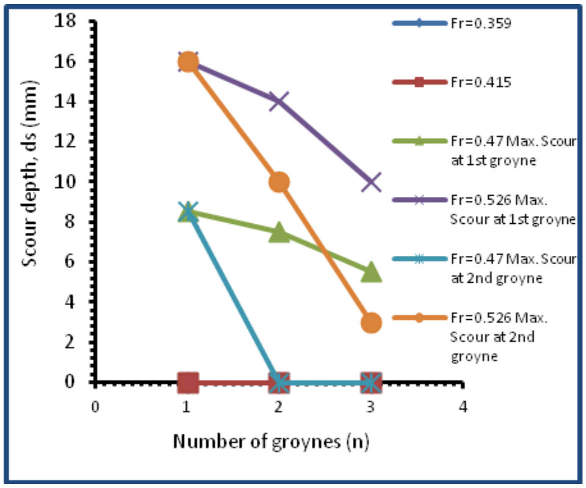


Figure (7): *Development of the scour depth with the number of groynes (b=260mm, y=20mm and Lg= 130 mm)*

No considerable scour occurs at upstream side of groynes, especially the intermediate groynes. Such elucidation is shown in contour maps of Figures (8) (9), (11) and (12). It can be seen from these figures; the scour regions have less elevation and wider area for one (single) groyne as compared with that of the two groynes and three groynes. The scour of one groyne is located just downstream of the groyne nose and deposition at the far downstream, whereas those of groyne group are distributed over scattered locations within group area. For one (single) groyne, the deposition region starts at a far distance toward the downstream from the groyne, and the hump is relatively high and scatters at longer and wider space when compared with that of the group. This phenomenon is observed visually in all experiments which harmonize with this situation. On the other hand, these figures indicate that more (major) scour occurs at first groyne, while less (minor) scour happens at the second groyne. In some cases, there is no considerable scour to happen at the second one. In any case, sedimentation happens behind the first groyne, and may continue to the second one depending on the distance between the two groynes. Scour is found, usually, to concentrate at a region just downstream (beyond) the groyne. This observation can be explained physically by the fact that, scouring is due to the horseshoe vortex system whose dimensions may be a function controlled, strongly, by the number and spacing of successive groynes. For all cases of quadrant groynes tested, The depth of scour is decreased by (20)% when decreasing the spacing between the groynes by (0.5 Lg) (half of groyne length). Fig. (10) shows effect of the spacing between the groynes that has a direct influence on the scouring process. That is, the scour depth increases with increasing the spacing between the groynes. Two and three of the groynes were used with different spacing in order to investigate the effect of spacing on the scour depth. For more elucidation to the influence of spacing between the groynes, compare Figures (9), (11), and (12).

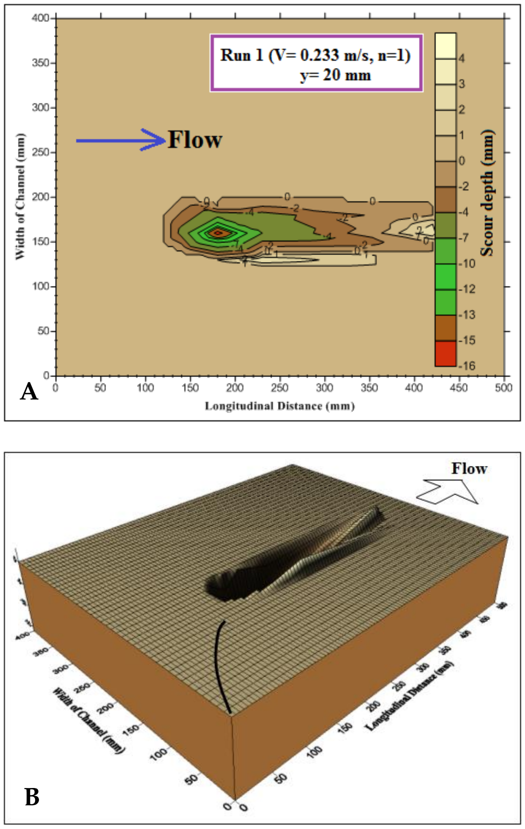


Figure (8): *Distribution of the scour depth with single groyne (y=20mm and Lg= 130 mm), A) bed level contour , B) 3D sketch of bed level*

It can be seen from these figures that the scouring process is greater (regarding the max. scour depth) when the spacing increases, while the other influencing parameters (groyne length, flow depth and velocity) are kept constant. On the contrast, the scour decreases when decreasing the spacing between the groynes. This may due to the interference between horseshoe vortices of the groynes. The interference between horseshoe vortices cause filling sediment particle near groynes.

5.3 Effect of Length of Groyne on the Scour

The length of groyne has direct influence on scour depth. That is, the scour depth and area of scour increases with increasing the groyne length, Fig. (13). When the length of groyne increases the velocity at the groyne location increases, too. This is because of decreasing main flow cross section. Therefore, the depth of scour in the case of the long groyne is greater than the short one keeping other influencing parameters constants. Using the available data above, it can be seen that the scour depth is decreased about (20 - 53)% by decreasing the ratio of groyne length to main flow width (Lg/B) by (0.075) for quadrant groynes.

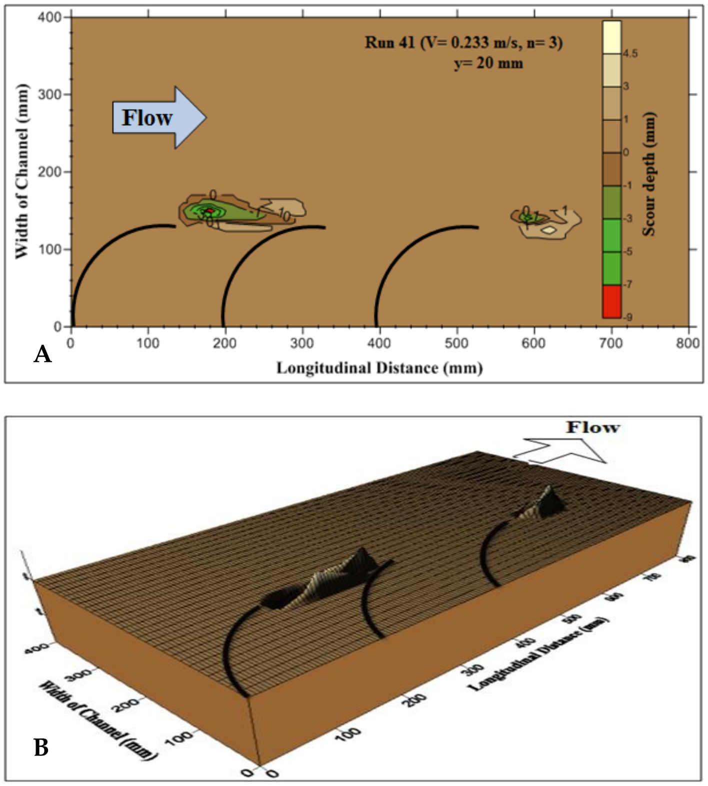


Figure (9): *Distribution of the scour depth with triple groynes (y=20mm, b=195mm and Lg= 130 mm), A) bed level contour , B) 3D sketch of bed level*

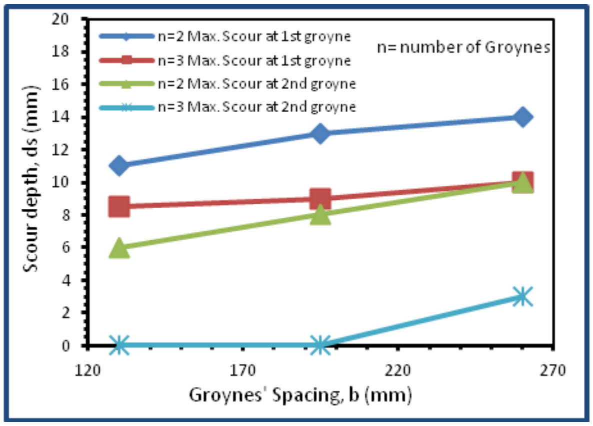


Figure (10): *Development of scour depth with groynes' spacing for length of groyne (Lg= 130 mm, v=0.233m/s, y=20mm)*

5.4 Effect of Groyne's Shape on the Scour

The two categories of different models (quadrant and semi-parabolic) were used to investigate shape's effect of groyne on the scour depth. Fig. (14) is obtained from experiments conducted to evaluate the relationship between scour depth and shapes of groyne. This figure show, clearly, that quadrant groynes result in scour depth less than that caused by corresponding semi-parabolic groynes. This may due to better roundness of quadrant groynes that lead to less vortices of locations where flow streamlines change in three dimensions.

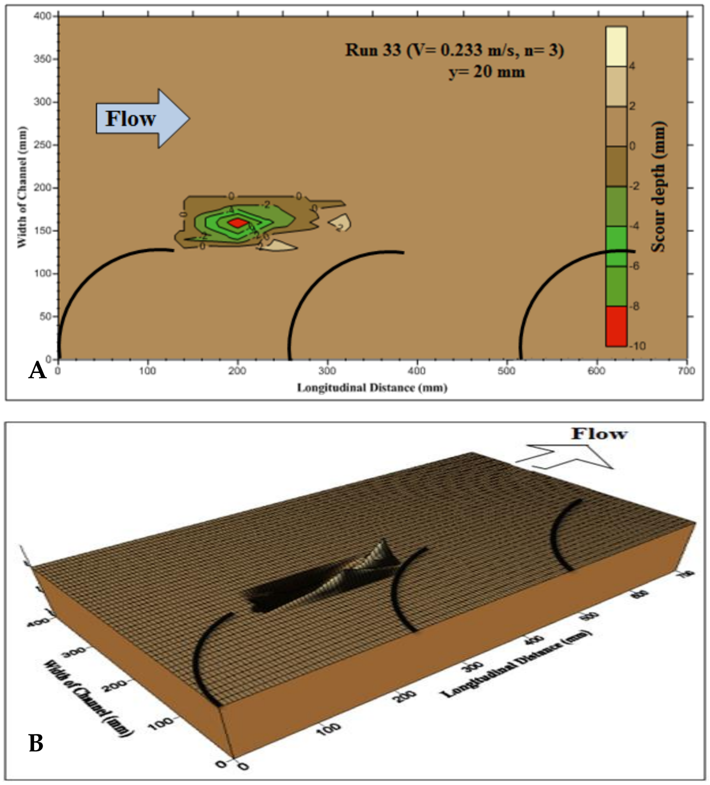


Figure (11): *Distribution of the scour depth with triple groynes (y=20mm, b=260mm and Lg= 130 mm), A) bed level contour, B) 3D sketch of bed level*

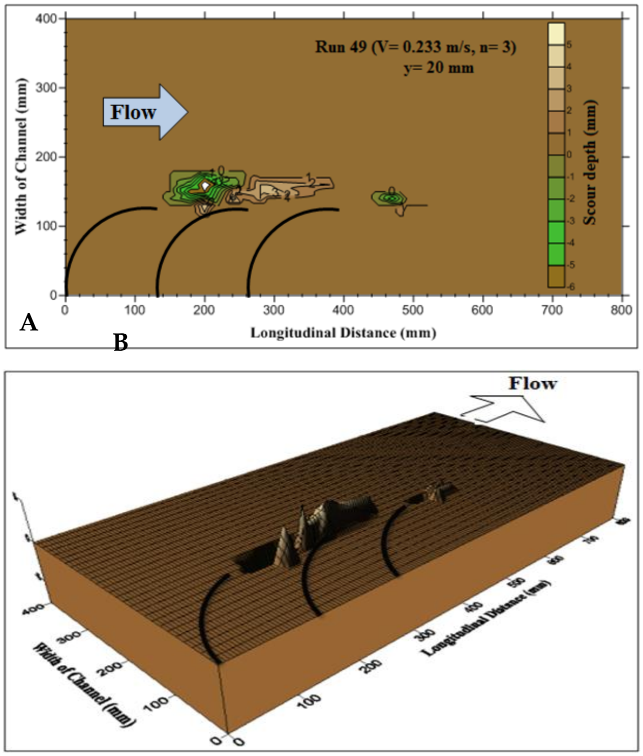


Figure (12): *Distribution of the scour depth with triple groynes (y=20mm, b=130mm and Lg= 130 mm), A) bed level contour, B) 3D sketch of bed level*

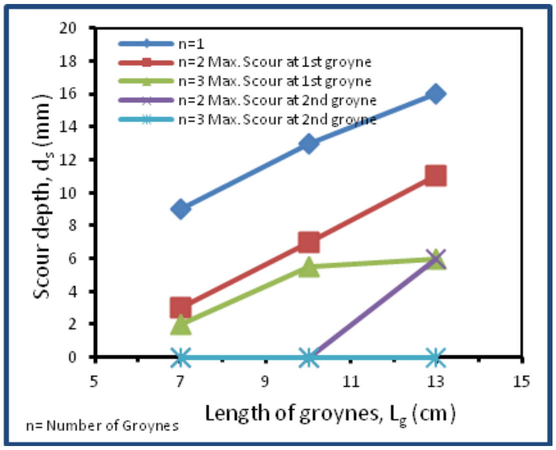


Figure (13): *Development of scour depth with different lengths of groyne*

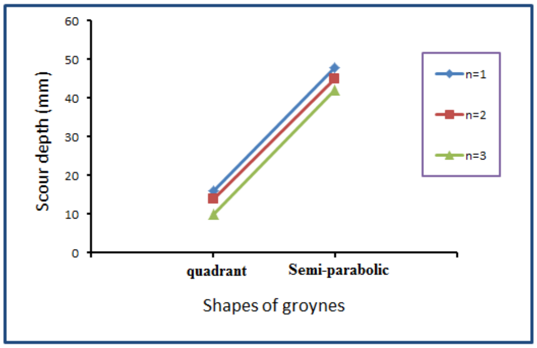


Figure (14): *Development of scour depth as affected by groyne shape.*

Generally, scour is decreased by about (75)% using quadrant shape groynes as compared with that of semi-parabolic shape groynes.

5.5 Developed Equation for Scour Depth

The equation (3) can be written as:

$$ds/y = (C_1 \times b/y - C_2 \times Fr^{C_3}) + C_4 \times (v/v_c)^{C_5} \times n^{C_6} \times L_g/y^{C_7} + C_8 \quad \ldots(4)$$

In which C1, C2, C3, C4, C5, C6, C7, and C8 are empirical constants and can be found using the experimental data obtained. By using SPSS V16.0 program the constants can be found. Accordingly, Eq.(4) can be written as:

$$ds/y = (0.009 \times b/y - 5.858 \times Fr^{1.567}) + 1.435 \times (v/v_c)^{4.198} \times n^{-0.174} \times (L_g/y)^{0.324} + 0.648 \quad \ldots\ldots\ldots(5)$$

Values of (ds/y) were calculated from the Eq(5) and presented with the laboratory-measured values as shown in Fig. (13), which shows the extent of correlation between the measured and calculated values. The coefficient of determination (R2) for this formula is (0.904).

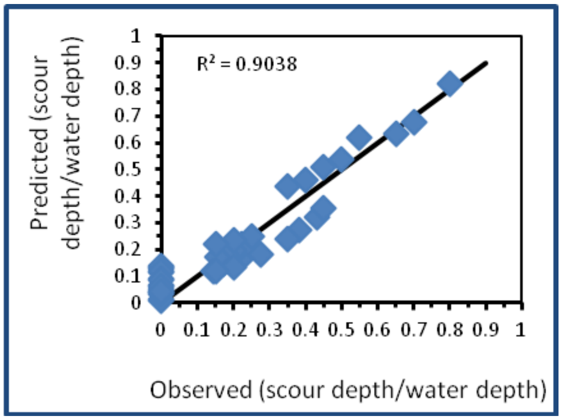


Figure (15): *Comparison between experimentally measured ds/y and corresponding ds/y calculated by Eq.(5).*

6 CONCLUSIONS

1. The depth of scour is decreased by (20)% when decreasing the spacing between the groynes by (0.5 Lg) (half of groyne length) for quadrant shape groynes.
2. The scour depth is decreased about (20 - 53)% by decreasing the ratio of groyne length to main flow width (Lg/B) by (0.075) for quadrant groynes.
3. Generally, scour is decreased by about (75)% using quadrant shape groynes as compared with that of semi-parabolic shape groynes.
4. On the basis of experimental data obtained, the derived formula for the maximum depth of scour gives a good determination coefficient (%90.4) and can be used to evaluate the maximum scour depth for similar conditions.

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Symbols Used

SYMBOL	DEFINITION	DIMENSIONS
B	Width of the flume	L
b	Spacing between the groynes	L
L_g	Length of groyne	L
d_{16}	Sediment size for which 16% of the particles are finer	L
d_{50}	Median particle size which is taken as the representative particle size	L
d_{84}	Sediment size for which 84% of the particles are finer	L
d_s	Maximum equilibrium scour depth below the mean bed level	L
Fr	Froude number	-
g	Gravitational acceleration	L/T2
G_s	Specific gravity of grains	-
n	Number of groynes	-
R^2	Determination coefficient	-
S_0	Slope of the channel	-
T	Scouring time	T
v	Mean velocity of approach flow	L/T
v_c	Mean velocity at threshold of motion of bed sediment for approach flow	L/T
y	Flow depth	L
υ	Kinematic viscosity of water	L2/T
σg	Geometric standard deviation of sediment size distribution	-
μ	Dynamic viscosity of water	M. T/L
ρ	Mass density of water	M/L3
ρ_s	Mass density of sediment	M/L3