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Research paper

Study of the Local Scour Around L-Shape Groynes in Clear Water Conditions

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Abstract

River training structures; such as groynes; are efficient engineered methods utilized to protect eroding river banks. But during groynes design stage; the designers faces one of the most significant issues which is the evaluation of the maximum depth of local scour around groynes. This is due to the flow area constriction in the groyne location itself; which in turn cause increasing in local velocity that consequently causes the scour. In the present study, the maximum scour depth around L-shape groyne was computed based on laboratory experiments where different number of groynes and distances between them were used as sort of countermeasures to reduce the scour around the groynes foundations. The results showed clear decreasing in scour depth at increasing number of groynes and also distance between them in the limitation of this study. A new formula based on experimental data was derived to calculate the local scour depth. This formula gave R^2 =0.903 which reflecting good agreement to the results.

Keywords: *Clear water conditions, L-shape groynes, local scour, river training structures, sediment transport.*

1. Introduction

The human kind existence is highly related to rivers, which they need to be controlled and trained to get the human life requirements and the optimum use of them. The controlling process usually done by constructing river training structures. Groynes are the most popular and useful transverse river training structures [1] that are defined as a manmade hydraulic structures protruding from the river bank for many purposes such as: bank protection from erosion, maintaining a desired cross section and alignment of rivers by stabilizing them, providing a sufficient flow depth for navigation, enhancement riverine aquatic habitats, modulation the surrounding scenery and facilitating the river accessibility [6].
In spite of the many advantages of groynes; but their existence (or any obstruction placed in alluvial river) lead to development of dangerous scour holes around them, so the groynes will suffer from instability that causing, with time, a failure in the groyne structure. With regard to the local scour, it is important to state that the presence of groynes will trigger a complex system of vortices at the base of the groynes themselves which consider along with the downflow at the upstream face the primal reasons of scour [4], see Fig. 1 where it also shows how the horse-shoe vortex hits the sand bed instantly in front of the groyne and then kicking up the eroded material which subsequently transported downstream by the main flow. The scour holes develop until reaching to its final shape through four sequent phases that are: the initiation phase, the development phase, the stabilization phase and at the last the equilibrium phase. This drifting from phase to another with time depends on the conditions of the flow.

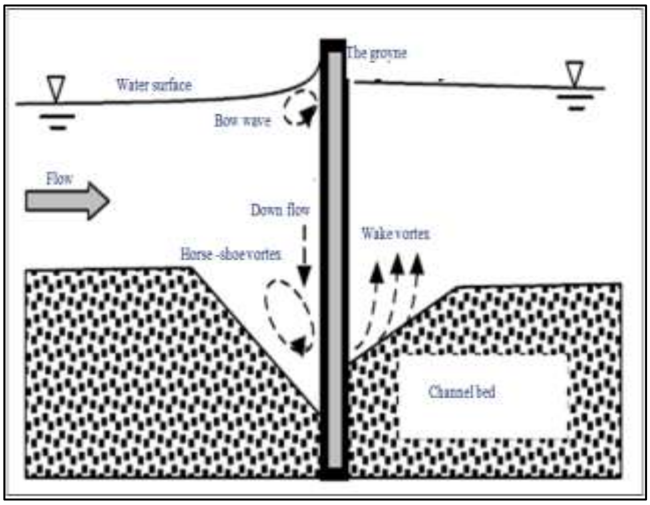

Fig. 1: Flow and local scour at the longitudinal section passing the groyne head [10]

If the flow velocity less than the critical velocity (V<Vc) (clear water condition), the scour develops first rapidly and then continue until the scour hole dimensions no longer increase and the scour depth reaches a distinctive value that is the maximum depth of scour [9], whereas the scour of live bed takes place if there is general transition of material of bed by the flow and the approach flow velocity becomes greater than the threshold of motion (V>Vc) [8]. Then the scour hole depth is reached much quickly but oscillates with time since the sediments enters from upstream, then leaves the scour hole, see Fig. 2.

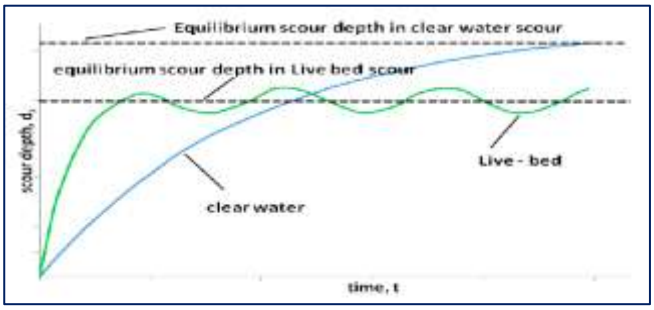

Fig. 2: Conditions of live-bed and clear-water scour [3]

The goal of the present study is to introduce the number of groynes and the distance between them as a two effective countermeasures in order to reduce the local scour around L-shape groyne that is located at a stipulated location.

2. Scour parameters

The scour around groynes is a complex 3D phenomenon that is influenced by several parameters. These parameters are categorized in four main heading as reported by [2], [7]:

1- Approaching flow parameters: flow depth & intensity, mean & shear velocity, distribution of velocity and the roughness of the bed.
2- Bed sediment parameters: distribution of the particle size, mass density, soil coherence, repose angle and shape of the particle.
3- Groyne parameters: shape plain view, length, spacing, number and direction of the groyne with respect to the main flow direction.
4- Fluid parameters: kinematic viscosity, gravitational acceleration and the mass density.

3. The laboratory flumes

The flume used in this work is illustrated in Fig. 3 and Photo 1. It is made of metal frame with tempered (8 mm) glass sides and having a length of 7.225 m with inner section of 0.4*0.4 m. The flume has three parts; the first part is the inlet tank of 1 m length with cross section of 0.4*0.6 m and contains two screens to avoid the entering of debris into the flume working section. The second part is the working section which has a length of 5.025 m and consists of three sections; the first section of length 1 m consists of sharp crested rectangular weir used to measure flow discharge, the middle section was filled with erodible sand to a depth of 0.1 m and extends over 3 m. The remaining of first and third section of the working section have a bed surface level of 0.1 m to match the middle level and this bed made from non-swelling and compressed wood. The last part of the flume is a metal reservoir located at the end of the flume with dimensions of 1.2*1*0.625 m for length, width and height, respectively.

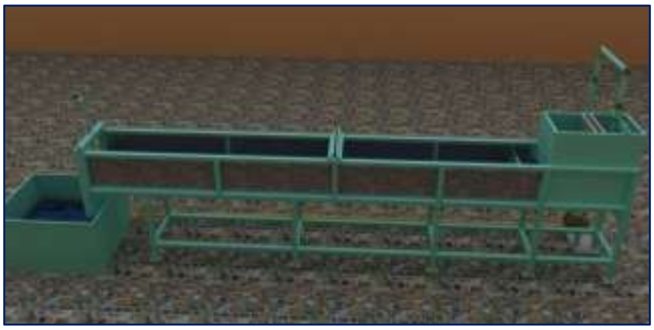

Fig. 3: The laboratory flume (sketched by 3D max program)

Photo 1: The laboratory flume

The flume has a closed water system where the water is supplied from the reservoir by a pump having specifications of discharge and head equal to 0.833-4.67 l/sec and 10.5-20.5 m respectively which located at the flume upstream. The flow depth in the flume is controlled by a tail gate that manually adjustable by means of a hand wheel.

At the end of each test session, the flume is drained carefully and then setting the sand bed to be in a straight level using scraper. To facilitate getting a uniform thickness of the sand layer, two opposite thin wood plates are used where they mounted on the both sides of the flume walls. The scour hole depth measurements are taken using a point gauge consists of a metal bar of 0.4 m height with a needle its end.

4. The groyne model

The model that used in all experiments was L-shape groyne made from 10 mm thick polystyrene foam material with a net height of 15 cm and 13 cm long, see Fig. 4.

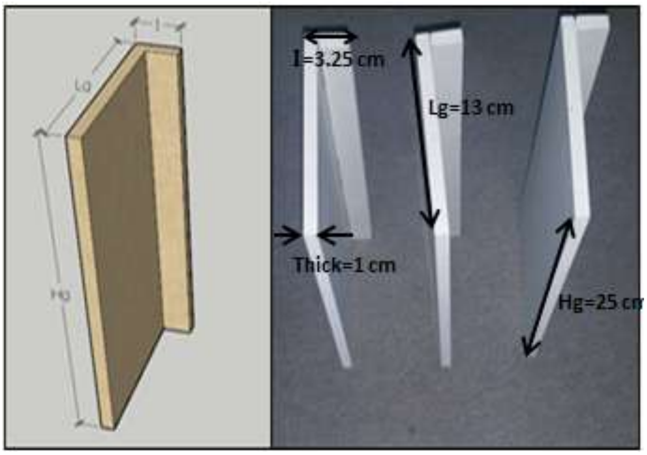

Fig. 4: The L-shape groyne model

The groyne was tested with three different configurations (single, double, triple) and the distances between them were changed three times (1L, 1.5L, 2L) to simulate different practical situations and to cover the aim of the present study. The models were fixed vertically in the sand layer and in the middle of the flume working section to achieve a well established flow. A silicon adhesive was used to stick promptly the groynes to the internal side of the flume.
The models material was selected because it does not swell when immersed in water for a long period. A play doh was used to seal the space between the end of the groyne and the flume wall. Photo 2 shows L-shape groyne placed in the flume before beginning the experiments.

Photo 2: The L-shape groyne placed in the flume

5. The bed material

In this study, uniform sand was utilized as the material of flume bed where its characteristics were obtained by a mechanical sieve analysis conducted in the Kufa University at the quality control laboratory.
The result of the grain size distribution showed that the bed material composed of cohesion-less sand with a main diameter d_{50} equal to 0.7 mm. So the ripple will not be formed since it is only formed if d_{50} larger than 0.7 mm. Also the geometric standard deviation of the sand size $\sigma_g=\sqrt{(d_{84}/d_{16})}$ was equal to 1.31, so the sand is of uniform size and the results can preclude the sediment non-uniformity effect [5]. Fig. 5 shows the grain size distribution.

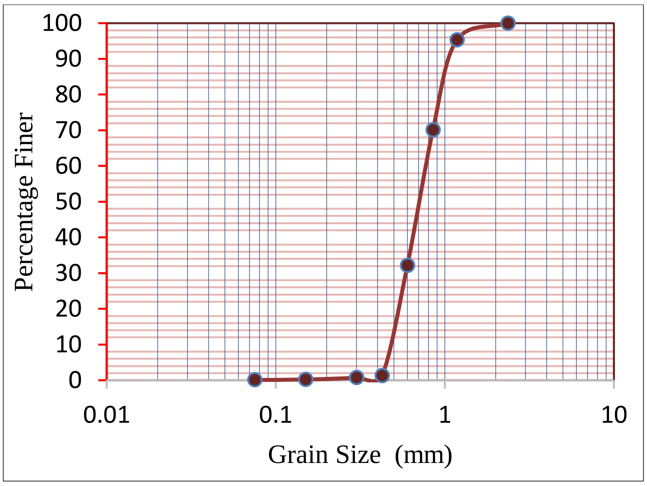

Fig. 5: Grain size distribution for the bed material (d_{50} =0.7 mm)

6. The equilibrium time

For the purpose of eliminating the time effect; it is required knowing the time to reach the equilibrium conditions of scour. Thus, four different velocities were used and the scour was registered at different time durations using a point gauge to measure the maximum scour at the groyne upstream nose.
The experiments were conducted for 6 hours in order to let the stable conditions to be reached where no more scour will occur with increasing time.

Fig. 6 shows that the scour depth has rapidly increased during the first half of the run period, then it becomes almost constant through the second half. In another meaning, it has been observed that 95-97% of local scour can be accomplished in 3.5 hours. For more accuracy, a time period of 4 hours has accordingly been used in this study for all experiments.

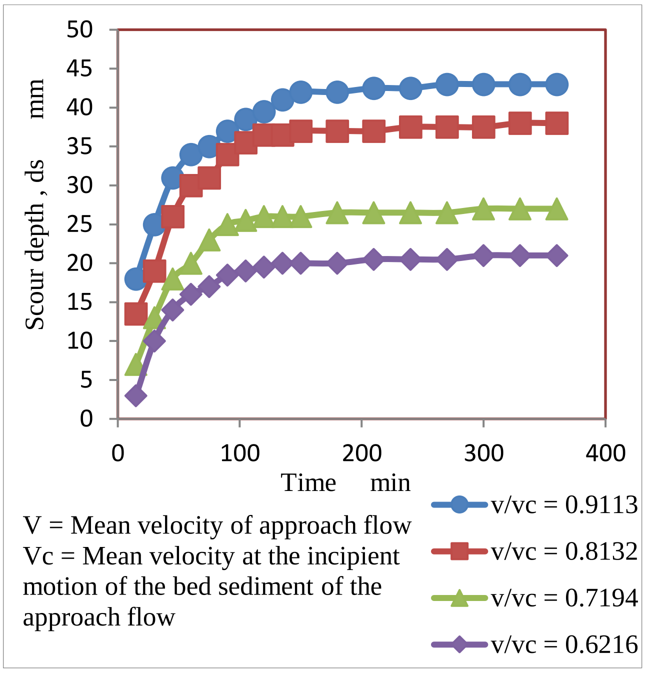

Fig. 6: Scour depth development with the time for L-shape groyne

7. The experimental work purposes

A steady subcritical flow and clear water conditions, with zero slope for the flume bed, were the conditions that applied for all the experiments in this study. Table 1 shows the experiments classification according to their purpose.
Fifty six different experiments were conducted to see how the scour depth was affected by the most important parameters which they are: flow depth (y), flow velocity (V), Froude number (Fr), number of groynes (n) and distances between the groynes (b). Table 2 listed all the experimental data.

Table 1: The experiments and their purpose

Runs	Description
1-4	They made for determining the equilibrium time at which the scour will not increase.
1-8	Tested the water depth and the flow velocity using one L-shape groyne of 13 cm length.
9-32	Tested the effect of changing the space between two L-shape groynes having a length of 13 cm for three times (L, 1.5L, 2L).
33-56	Tested the effect of changing the space between three L-shape groynes having a length of 13 cm for three times (L, 1.5L, 2L).

8. Analysis and discussion of results

The most important step in designing the groynes foundations is evaluating the scour depth formed around them. Therefore, to inspect the scour phenomenon, different sets are carried out using the L-shape groynes.

8.1. Flow depth (y)

The effect of flow depth (y) on the scour depth (ds) with different number of groynes is shown in Fig. 7. From this figure, it is very clear that the scour occurrence is directly proportional to the flow depth, where increasing the flow depth will also increase the scour depth while the other influencing parameters are remain constant.

Table 2: The experimental data

Run number	Y (mm)	V (m/s)	Vc (m/s)	b (mm)	n	Fr	V/Vc	b/y	ds (mm)	ds/y
1	21	0.222	0.243	0	1	0.49	0.911	0	43	2.047
2	21	0.198	0.243	0	1	0.436	0.813	0	38	1.809
3	21	0.175	0.243	0	1	0.386	0.719	0	27	1.286
4	21	0.151	0.243	0	1	0.333	0.621	0	21	1
5	46	0.18	0.281	0	1	0.268	0.640	0	62	1.347
6	36	0.18	0.27	0	1	0.303	0.668	0	48	1.333
7	26	0.18	0.254	0	1	0.356	0.709	0	34	1.307
8	16	0.18	0.230	0	1	0.454	0.780	0	9	0.562
9	21	0.222	0.243	260	2	0.49	0.911	12.38	30	1.428
10	21	0.198	0.243	260	2	0.436	0.813	12.38	26	1.238
11	21	0.175	0.243	260	2	0.386	0.719	12.38	18	0.857
12	21	0.151	0.243	260	2	0.333	0.621	12.38	0	0
13	46	0.18	0.281	260	2	0.268	0.640	5.65	53	1.152
14	36	0.18	0.27	260	2	0.303	0.668	7.22	37	1.027
15	26	0.18	0.254	260	2	0.356	0.709	10	25	0.961
16	16	0.18	0.230	260	2	0.454	0.780	16.25	0	0
17	21	0.222	0.243	195	2	0.49	0.911	9.29	36	1.714
18	21	0.198	0.243	195	2	0.436	0.813	9.29	30	1.428
19	21	0.175	0.243	195	2	0.386	0.719	9.29	20	0.952
20	21	0.151	0.243	195	2	0.333	0.621	9.29	2	0.095
21	46	0.18	0.281	195	2	0.268	0.640	4.24	54	1.173
22	36	0.18	0.27	195	2	0.303	0.668	5.42	42	1.166
23	26	0.18	0.254	195	2	0.356	0.709	7.5	30	1.153
24	16	0.18	0.230	195	2	0.454	0.780	12.19	2	0.125
25	21	0.222	0.243	130	2	0.49	0.911	6.19	38	1.809
26	21	0.198	0.243	130	2	0.436	0.813	6.19	32	1.523
27	21	0.175	0.243	130	2	0.386	0.719	6.19	25	1.19
28	21	0.151	0.243	130	2	0.333	0.621	6.19	5	0.238
29	46	0.18	0.281	130	2	0.268	0.640	2.83	55	1.195
30	36	0.18	0.27	130	2	0.303	0.668	3.61	43	1.194
31	26	0.18	0.254	130	2	0.356	0.709	5	30	1.153
32	16	0.18	0.230	130	2	0.454	0.780	8.13	7	0.437
33	21	0.222	0.243	260	3	0.49	0.911	12.38	29	1.381
34	21	0.198	0.243	260	3	0.436	0.813	12.38	25	1.190
35	21	0.175	0.243	260	3	0.386	0.719	12.38	13	0.619
36	21	0.151	0.243	260	3	0.333	0.621	12.38	0	0
37	46	0.18	0.281	260	3	0.268	0.64	5.65	52	1.130
38	36	0.18	0.27	260	3	0.303	0.668	7.22	32	0.888
39	26	0.18	0.254	260	3	0.356	0.709	10	23	0.884
40	16	0.18	0.230	260	3	0.454	0.780	16.25	0	0
41	21	0.222	0.243	195	3	0.49	0.911	9.29	31	1.476
42	21	0.198	0.243	195	3	0.436	0.813	9.29	26	1.238
43	21	0.175	0.243	195	3	0.386	0.719	9.29	15	0.714
44	21	0.151	0.243	195	3	0.333	0.621	9.29	0	0
45	46	0.18	0.281	195	3	0.268	0.640	4.24	53	1.152
46	36	0.18	0.27	195	3	0.303	0.668	5.42	34	0.944
47	26	0.18	0.254	195	3	0.356	0.709	7.5	24	0.923
48	16	0.18	0.230	195	3	0.454	0.780	12.19	0	0
49	21	0.222	0.243	130	3	0.49	0.911	6.19	32	1.523
50	21	0.198	0.243	130	3	0.436	0.813	6.19	27	1.286
51	21	0.175	0.243	130	3	0.386	0.719	6.19	18	0.857
52	21	0.151	0.243	130	3	0.333	0.621	6.19	0	0
53	46	0.18	0.281	130	3	0.268	0.640	2.83	54	1.173
54	36	0.18	0.27	130	3	0.303	0.668	3.61	37	1.027
55	26	0.18	0.254	130	3	0.356	0.709	5	26	1
56	16	0.18	0.230	130	3	0.454	0.780	8.13	0	0

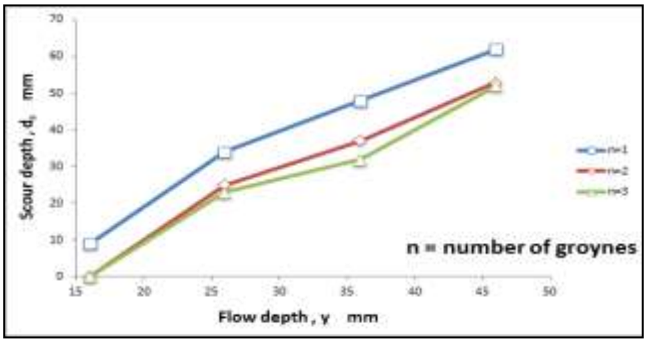

Fig. 7: Effect of flow depth on scour depth development

8.2. Flow velocity (V)

A linear increase to the scour depth as the velocity increase was observed for the velocities less than the threshold value, regardless the other parameters. Fig. 8 and photo 3 show the above result which is in agreement with the previous investigations for clear water conditions [1],[3].

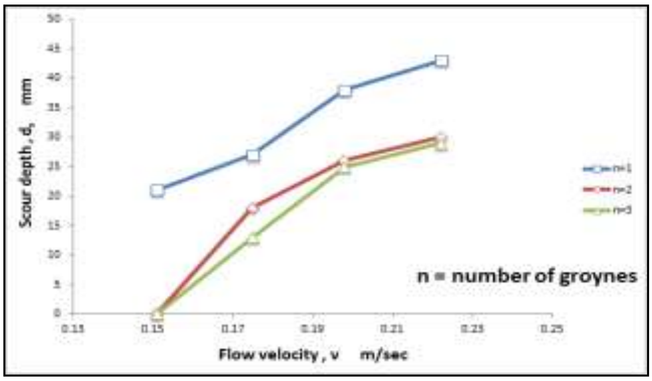

Fig. 8: Effect of flow velocity on scour depth development

Photo 3: Effect of (V) on (ds) development

8.3. Froude number (Fr)

The result of the L-shape groyne has been drawn in Fig. 9 to relate Fr with the dimensionless fraction (ds/y). It is clearly evident that any increase in Fr will increase the scour depth at surely constant value for the other parameters.

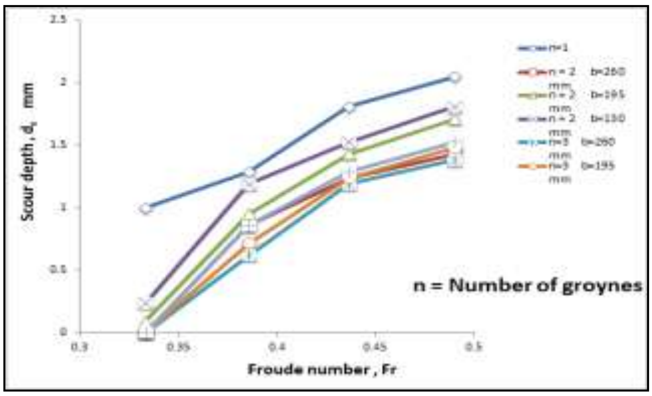

Fig. 9: Effect of Froude number on scour depth development

8.4. Number of groynes (n)

The number of groynes has a pivotal impact on the scour process. Fig. 10 shows the decreasing in the scour depth at increasing number of groynes (within the limitation of this study) when the efficiency of the remaining parameters are kept constant. Increasing number of groynes by one will decreasing the scour depth by about 3.33-30.2%. From the experimental observations, the scour area has wider range and much deeper elevation for one groyne as compared with that of double or triple groynes.

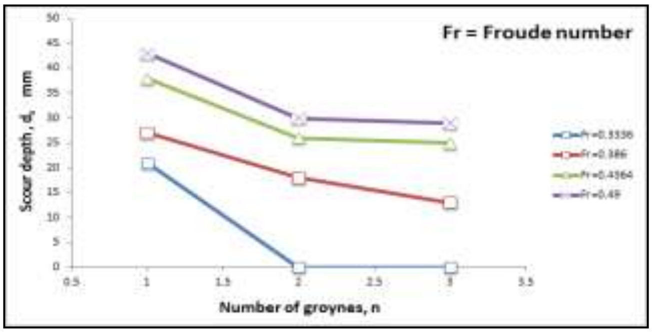

Fig. 10: Effect of groyne number on scour depth development

8.5. Distances between groynes

Double and triple groynes configurations were utilized along with three various distances between them to show their effectiveness on the scour depth. The relationship between the distances and the scour depth has been drawn in Fig. 11 and illustrated in Photo 4.

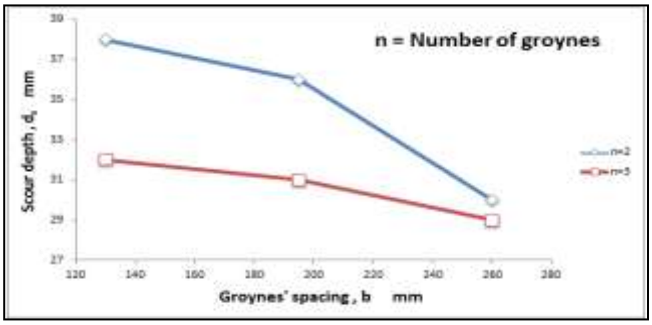

Fig. 11: Effect of groynes′ distances on scour depth development

Photo 4: Effect of groynes′ distances on scour depth development

Both the figure and the plate show clearly the decrease of scour depth that takes place when the distance between the groynes increased (within the limitation of this study). Increasing spacing by half of groyne length (0.5 L) will decrease the scour depth by about 3.13-17%.

9. Development of new formula

Using the dimensional analysis technique, the scour depth is related to some variables in non-dimensional formula:

$$ds/y = F(V/Vc, Fr, n, b/y) \quad (1)$$

The critical velocity found through semi-logarithmic average velocity equation which based on the velocity profile:

$$V/V*c=5.75 \log(5.53(y/d_{50})) \quad (2)$$

The following equations are used to find the critical shear velocity V_{*c} where these equations consider modification to Shields diagram:

$$V_{*c} = 0.0115 + 0.0125(d_{50})^{1.4} \qquad 0.1\ \text{mm} < d_{50} < 1\ \text{mm} \quad (3)$$

$$V_{*c} = 0.0305(d_{50})^{0.5} + 0.0065 d_{50}^{-1} \qquad 1\ \text{mm} < d_{50} < 100\ \text{mm} \quad (4)$$

The results of the experimental work used as input data in the computer package (IBM Statistics SPSS 16.0) to develop equation utilized to calculate the relative scour depth (ds/y), through a non-linear regression analysis.

$$ds/y=C_1+\{C_2*(b/y)\}-\{C_3*(Fr^{C_4})\}+\{C_5*(V/Vc^{C_6})*(n^{C_7})\} \quad (5)$$

C_1= -1.293 C_2= -0.035 C_3= 99.281 C_4= 4.452
C_5= 9.821 C_6= 2.753 C_7= -0.043

The above formula has a coefficient of determination (R^2) equal to (0.941). After the simplification and arrangement, the formula becomes:

$$ds/y = -1.3 - \{0.035*(b/y)\} - \{99.3*(Fr^{4.45})\} + \{9.8*(V/Vc^{2.75})*(n^{-0.04})\} \quad (6)$$

To test the accuracy of the above formula, 20% from the original data (that were not used in deriving the above formula) have been substituted in the formula itself, and a statistical comparison between the predicted values of ds/y and the observed values of ds/y were made. The coefficient of determination value (R^2 =0.903), reflecting a good agreement for all data, as illustrated in Fig. 12.

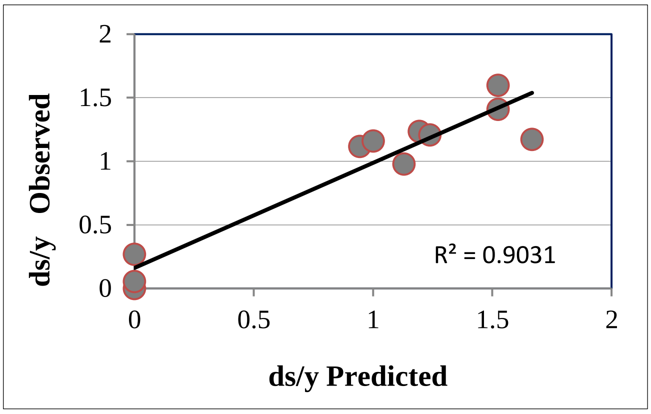

Fig. 12: The formula 3 comparison with the experimental data

10. Conclusions

Based on the previous analysis of the experimental work, the following conclusions are drawn:
1- For constant number of groynes and distances between them, the scour depth increased with increasing the flow depth, flow velocity and Froude number.
2- For constant hydraulic conditions, the scour depth decreased with increasing the number of groynes by about 3.33-30.2% for each increasing in number of groynes equal to one, and the distances between them by about 3.13-17% for each half of groyne length (0.5 L) increase in these distances (within the limitation of this work).
3- The ultimate depth of scour was occurred at the groyne nose from the upstream side.
4- Maximum scour has been observed to occur at the first groyne due to its location, as the first one that the water to collide with.

11. The list of notations

b: The distance between groynes (L).
ds: The local scour around groynes (L).
d_{50}: The main diameter of the sediment particle (L).
Fr: Froude number (Fr= $V/\sqrt{g\, y}$) (-).
g:The gravitational acceleration (LT^{-2}).

L: The length of groyne (L).
n: The number of groynes (-).
V: The mean velocity of the flow (LT^{-1}).
Vc: The critical velocity (LT^{-1}).
V_*c: The critical shear velocity (LT^{-1})
y: The flow depth (L).

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