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LOCAL SCOUR EVALUATION AROUND NON-SUBMERGED CURVED GROYNES

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ABSTRACT

This study presents a laboratory experiments for evaluating the local scour depth around S-shape solid non- submerged groynes using different number of these groynes and also different distances between them as two countermeasures to reduce the scour. The study was conducted in non- curved laboratory flume where uniform cohesion-less sand of median size (d50) equal to (0.7 mm) was used as the bed material. The physical hydraulic model of the groynes was made of polystyrene foam with fixed dimensions to operate under steady subcritical flow and clear water conditions. The studied parameters in this study were the number of groynes changed three times (single, double, triple), the distances between them altered also three times (1L, 1.5 L, 2L) and finally the hydraulic conditions (depth and velocity of the mean flow) also changed four times for each parameter. A new empirical equation was derived where its coefficient of determination indicates good agreement between the predicted results and the observed ones experimentally.

Keywords: Clear Water Conditions, Curved Groynes, Local Scour, River Training Structures, Sediment Transport.

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1. INTRODUCTION

In general; scour can be defined as a natural phenomenon induced by the flow in streams or rivers. It is the outcome for the severe erosion action of flowing water that erodes and removes material from the rivers banks and beds and also around structures such as weirs, gates, abutments, piers and groynes. This is long-term mechanism having the possibility to endanger the structural stability and firmness of hydraulic structures to cause ultimately in undermining their foundations [1]. Groynes are river training structures; starting with a root at the riverbank and ending with a head at the river flow; constructed for purpose of diverging the flow away from the banks to protect them from erosion, controlling the flood situations, improving the navigation and also decreasing rivers dredging costs since their presence will regulate and increase the sediment transport rate through the river reach at the groynes location. Different materials are used to make the groynes such as earth, gravel, piles, rock and stone where they can be designed according to the hydraulic conditions to be either submerged or non- submerged. Since the flow over the apex of solid groynes can cause rigorous erosion; then they usually designed to be non- submerged ones. A discrimination based on how they look in plan view is made for groynes like T-shape, I-shape, L-shape, J & inverted J shape and curved groynes [2][3]. When the groynes placed through the river reach; they will restrict a specific part of cross section of the river, due to that; the local velocity and discharge increase to cause; as a consequence; a complex vortices system composed of horse shoe and wake vortices. These vortices along with down flow cause unique interactions between the flow and the bed material which lead after all to form scour in the vicinity of groynes [4], see Fig. 1.

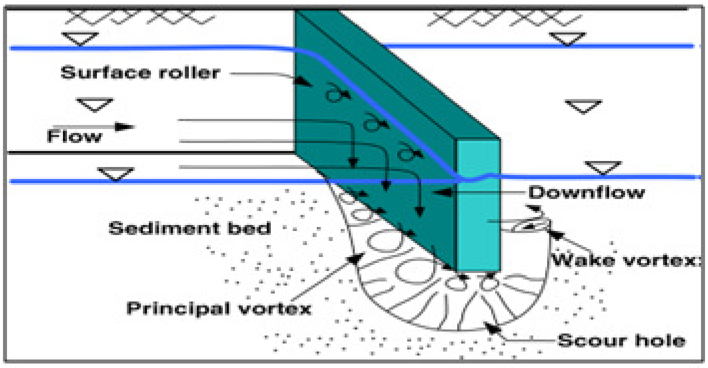

Figure 1 The vortices system, down flow and scour phenomenon around an isolated groyne [5]

The scour around groynes is sorted to live bed scour and clear water scour depending on the approach flow conditions if it clear water or sediment laden. The scour of clear water takes place in the sediment transport absence by approaching flow into the scour holes while developing of scour of live bed is done due to the continuous feeding with bed sediments by the flow, see Fig. 2.

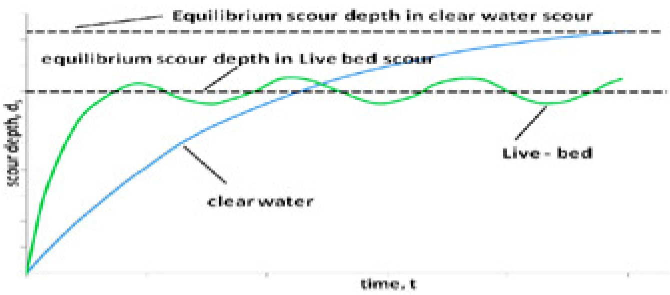

Figure 2 Clear-water and live-bed scour conditions [6]

Over the years; knowledge the design scour depth has been the main concern of engineers where it is required for economical and safe design of groynes foundations. In the current study; the design scour depth is close to be the maximum equilibrium scour depth that occurred at the threshold motion of sediment [7].

There is numerous of studies that have been performed with a purpose of finding the equilibrium scour depth in clear water conditions. Zhang and Nakagawa [8] made a systematic review includes the most influenced and earliest works such as Ahmad [9], Gill [10], Michiue et al. [11], Kothyari and Ranga Raju [12], Coleman et al. [13] and many others. More recent studies are made. Ezzeldin et al. [14,15] investigated local scour around groyne that was single, submerged, impermeable, have straight shape, placed in non curved channel and have different inclination with respect to direction of flow. From experiments; they assured that horse shoe vortices around groyne is the main cause of scour. Kadota and Suzuki [16] studied experimentally the trends and characters of local scour and bed configuration downstream of some types of groynes like L-shape, T-shape, and their results showed larger scour depth becomes for L-shape in the downstream from the groyne head while deposition takes place at some distance from the groyne. Dawood [17] performed experimental investigation utilizing three different shapes (I-, T- & L-head) of solid non- submerged groynes with three different configurations (single, double, triple) in non- curved channel, the results showed increasing number of groynes will decrease the scour depth. also she made empirical formula to relate the local scour with the most influential design parameters such as flow depth and velocity, number and length of groynes.

It can be seen from the literature that past studies focused on scouring around the traditional shapes such as I- , L- and T-shapes which proved to cause large scour around them. Therefore; a study about the non-traditional shapes of groynes and how they will effect on minimizing the local scour around the groynes themselves is much necessary and vital. In the current study; an experimental investigation has been made on single non-submerged solid groyne model having S-shape in the plan view and how well good the effectiveness of using the number and distances between the groynes as two countermeasures to reduce the local scour formed around them.

2. SCOUR PARAMETERS

There are four sequential phases that the scour holes have to pass in each one to get at the end its final shape. The first phase is the initiation phase; also known drilling or carving phase; usually have short duration and in it the flow transport ability dominating the sediment transfer over the bed, then a gradual scour around the groyne takes place. The development phase is the second one that usually have much longer time where the flow separation begins due to the scour hole expansion. At the end of this phase; the top scour hole gradient is reached to stability state. The third phase is the stabilization and it includes deepen the scour hole a lot more. The last phase is the equilibrium phase that obtained at equalization the bed velocity with the critical worth in clear water scour case. This phase can be distinguished through the disability of flow of local scour to pick up the sediment from the scour hole.

3. THE LABORATORY FLUME

The flume used in this study is illustrated Plate 1. It is made by the researcher of metal frame with tempered (8 mm) glass sides, having length of (7.225 m) with cross section (0.4*0.4 m). The flume composed of three parts; an inlet tank positioned in the flume upstream with dimensions of (1*0.6*0.4 m) for length, depth and width respectively. To avoid the entering of debris or any unwanted particles into the flume working section; two screens have been used where they placed inside the inlet tank.

Plate 1 The laboratory flume

The working section represents the second part of the flume having a length of (5.025 m) and partitioned to three sections. The first section have a length of (1 m) containing sharp crested rectangular weir utilized to measure flow discharge with cross section of (0.4*0.25 m) for the width and height respectively.

The uniform erodible sediments were placed in the second section of the working section with a length of (3 m) and depth of (0.1 m). There is a non-swelling compressed wood plates placed in the remaining of the second part of the flume with bed surface level of (0.1 m) to match the level of the rest of the flume. A metal reservoir placed above the ground at the end of the flume is considered the last part where it has dimensions of (1.2*1*0.625 m).

The flume is supplied with a tail gate to control the flow depth where it is adjustable by means of hand wheel. Also the flume has a closed water system for supplying it with water from the reservoir by a pump placed besides the flume upstream. After ending each run; the flume is drained carefully and then set the sand bed level to be straight again using scraper.

All the measurements of scour hole were taken using manually made point gauge of metal bar having a (40 cm) length with needle at its end.

4. THE GROYNE MODEL

The shape of the groyne that used in all the experiments is the S-shape model; see Fig. 3; where it made of (10 mm) thick polystyrene foam material with net height of (15 cm) above the sand bed level and (13 cm) long.

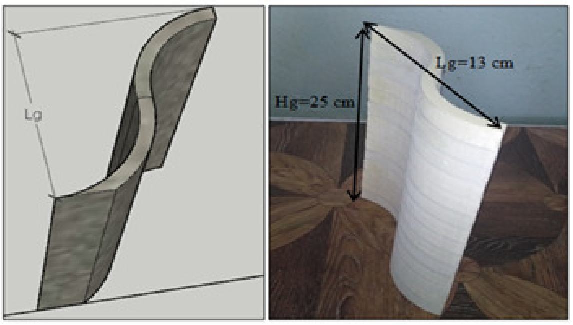

Figure 3 The S-shape groyne model

Three different configurations (single, double, triple) and also three different distances between groynes (1L, 1.5L, 2L) were tested to cover the goals of the present study for simulating different practical situations. A silicon adhesive was utilized to stick firmly the groynes to the internal side of the flume; these groynes were fixed vertically in the sand layer and located in the middle of the working section for achieving a well established flow. The space between the flume wall and the groyne end was secured using a play doh, plate 2 shows a groyne with S-shape placed in the flume before the run starting.

Plate 2 The S-shape groyne placed in the flume

5. THE BED MATERIAL

Sand with specific characteristics was used as the bed flume material where it tested by a mechanical sieve analysis performed in Kufa University at the quality control laboratory. The grain size distribution results illustrated that the used sand composed of cohesion-less particles with a main diameter (d_{50}) equal to (0.7 mm). Since the ripple will formed at particles mean diameter larger than (0.7 mm); so with the above value of tested sand; there will be no ripple to formulate.

Also this size of sand has a geometric standard deviation ($\sigma_g=\sqrt{(d_{84}/d_{16})}$ of (1.31), so the sediment size will not affect the depth of scour that will be expected to happen due to armoring effect in non uniform sand. Fig. 4 shows the curve of grain size distribution.

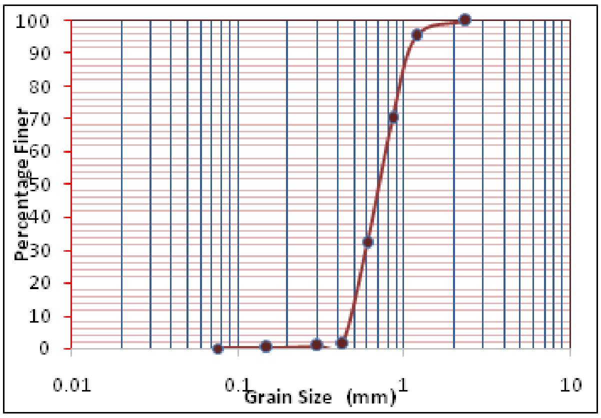

Figure 4 Grain size distribution for the bed material (d_{50} =0.7 mm)

6. THE EXPERIMENTAL WORK PURPOSE

The experimental work that has been performed in this study was consisted of (56) runs where they classified in Table 1 according to there purpose.

Table 1 The experiments and their purpose

Runs	Description
1-8	Tested the water depth and the flow velocity using one S-shape groyne of (13 cm) length.
9-32	Tested the effect of changing the space between two S-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 S-shape groynes having a length of (13 cm) for three times (L, 1.5L, 2L).

All the experiments were performed in conditions of clear water and steady subcritical flow with no slope for the flume bed. As regard the time requested to obtain the scour depth at equilibrium conditions where this time will be used in all the experiments to eliminate the effect of time; four flow velocities are used where the scour is recorded using point gauge at several time intervals and the runs last for (6 hours) until reach the situation where no more scour will occur with increasing time. The results showed that (95-97%) of the local scour are achieved in (3.5 hours), but for more accuracy time period of (4 hours) has been utilized in this study for all the experiments.

7. DIMENSIONAL ANALYSIS

The dimensional analysis is a mathematical technique that hired in research works for design and performing models experiments.

By utilizing this technique; the maximum depth of scour (ds_{max}) at S-shape groyne nose and for clear water conditions can be written in functional form:

$ds_{max} = f\{y, v, v_c, L, \rho, \rho_s, g, n, b, d_{50}, \mu, \sigma_g, B, S_o\}$. (1)

where; y:depth of flow, v:velocity of main flow, v_c:critical velocity, L:length of groyne, ρ:density of fluid, ρ_s:density of bed sediments, g:gravitional acceleration, n:number of groynes, b:distance between groynes, d_{50}:mean grain size, μ:dynamic viscosity of fluid, σ_g:geometric standard deviation, B:width of flume, S_o: slope of flume.

By applying the Buckingham′s π theorem; also after many simplifications and arrangements; equation (1) can be written as:

$ds_{max}/y = f(v/v_c, Fr, n, b/y)$… (2)

Table 2 listed all the data regarding the tested parameters with the final results.

8. ANALYSIS AND DISCUSSION OF RESULTS

Discussing and analyzing the results obtained from the laboratory work are showed in the following sections:

1- Flow depth (y)

The experiments were conducted with four different values of flow depth (16, 26, 36 & 46 mm) to cover the goal of this study. From these experiments; it was found that the scour depth is directly proportional with flow depth while all other parameters are held constant; see Fig 5 and plate 3. When the flow depth decreasing; then the surface roller flow becomes comparatively more dominate, consequently; it will decrease the ability of horse shoe vortices to pick up and entrain sediments.

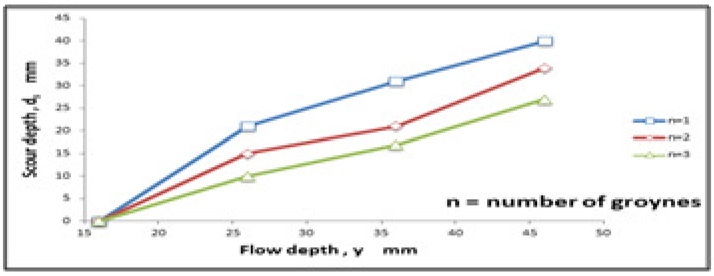

Figure 5 Effect of flow depth on scour depth development

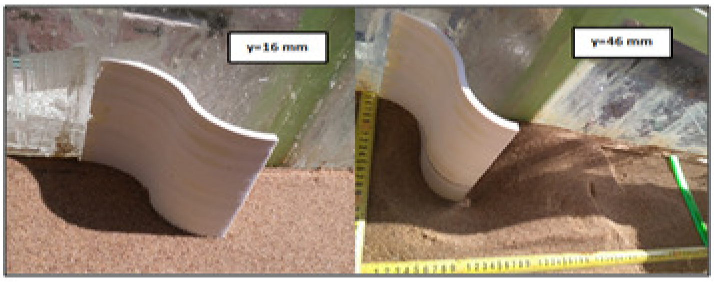

Plate 3 Effect of flow depth on scour depth development

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	29	1.381
2	21	0.198	0.243	0	1	0.436	0.813	0	24	1.143
3	21	0.175	0.243	0	1	0.386	0.719	0	12	0.571
4	21	0.151	0.243	0	1	0.333	0.621	0	0	0
5	46	0.18	0.281	0	1	0.268	0.640	0	40	0.869
6	36	0.18	0.27	0	1	0.303	0.668	0	31	0.861
7	26	0.18	0.254	0	1	0.356	0.709	0	21	0.807
8	16	0.18	0.230	0	1	0.454	0.780	0	0	0
9	21	0.222	0.243	260	2	0.49	0.911	12.38	21	1
10	21	0.198	0.243	260	2	0.436	0.813	12.38	18	0.857
11	21	0.175	0.243	260	2	0.386	0.719	12.38	8	0.381
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	34	0.739
14	36	0.18	0.27	260	2	0.303	0.668	7.22	21	0.583
15	26	0.18	0.254	260	2	0.356	0.709	10	15	0.576
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	24	1.143
18	21	0.198	0.243	195	2	0.436	0.813	9.29	20	0.952
19	21	0.175	0.243	195	2	0.386	0.719	9.29	8	0.381
20	21	0.151	0.243	195	2	0.333	0.621	9.29	0	0
21	46	0.18	0.281	195	2	0.268	0.640	4.24	35	0.760
22	36	0.18	0.27	195	2	0.303	0.668	5.42	24	0.666
23	26	0.18	0.254	195	2	0.356	0.709	7.5	17	0.653
24	16	0.18	0.230	195	2	0.454	0.780	12.19	0	0
25	21	0.222	0.243	130	2	0.49	0.911	6.19	25	1.19
26	21	0.198	0.243	130	2	0.436	0.813	6.19	21	1
27	21	0.175	0.243	130	2	0.386	0.719	6.19	10	0.476
28	21	0.151	0.243	130	2	0.333	0.621	6.19	0	0
29	46	0.18	0.281	130	2	0.268	0.640	2.83	38	0.826
30	36	0.18	0.27	130	2	0.303	0.668	3.61	29	0.805
31	26	0.18	0.254	130	2	0.356	0.709	5	20	0.769
32	16	0.18	0.230	130	2	0.454	0.780	8.13	0	0
33	21	0.222	0.243	260	3	0.49	0.911	12.38	14	0.666
34	21	0.198	0.243	260	3	0.436	0.813	12.38	12	0.571
35	21	0.175	0.243	260	3	0.386	0.719	12.38	3	0.142
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	27	0.586
38	36	0.18	0.27	260	3	0.303	0.668	7.22	17	0.472
39	26	0.18	0.254	260	3	0.356	0.709	10	10	0.384
40	16	0.18	0.230	260	3	0.454	0.780	16.25	0	0

2- Flow velocity (V)

It is a significant parameter that affect on the scour around groynes. Four different velocities were used range from (0.151 to 0.222 m/sec). the investigation illustrates that the scour increased with flow velocity increasing at constant values for all the remaining parameters. Increasing the velocity will increase the separation zone which located downstream the groyne, see Fig 6 and Plate 4, so more eddies will be produced that in turn causing more scour to occur.

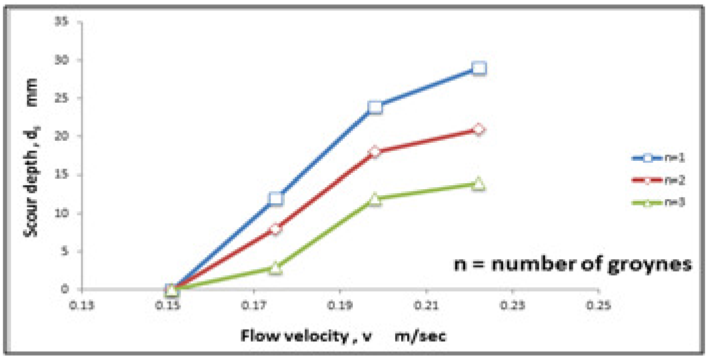

Figure 6 Effect of flow velocity on scour depth development

Plate 4 Effect of flow velocity on scour depth development

3- Froude number (Fr)

As shown from the dimensional analysis technique; Froude number (Fr=√(v/gy)) proved to have major effect on the scour process around S-shape groynes. The experiments were performed with Froude number range from (0.33 to 0.49) and the results were plotted with the dimensionless fraction (ds/y) (scour depth/flow depth) in Fig. 7. From this figure it evident that increasing Froude number will increase the scour depth. This can be explained from the Froude number law where any increase in flow velocity and/or decrease the flow depth (and hence increasing Froude number) will increase the scour depth.

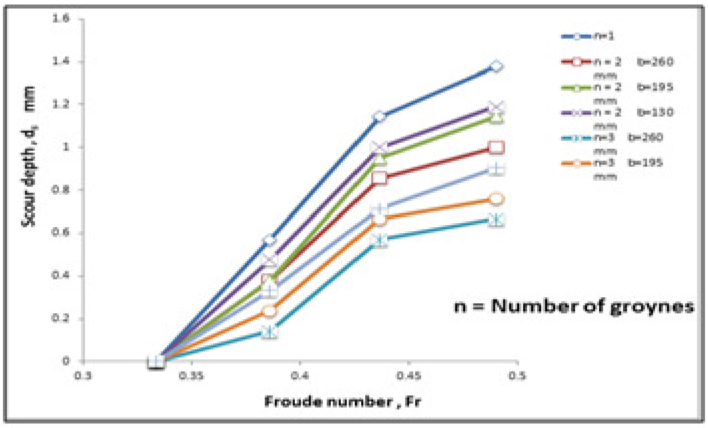

Figure 7 Effect of Froude number on scour depth development

4- Number of groynes (n)

Fig. 8 shows the important effect of groynes number on the local scour where all the other studied parameters are kept constant. This effect was showed using three configurations (single, double & triple). From the figure it is clear that increasing number of groynes will decrease the scour depth. This situation happened due to the overlapping of the successive vortices as a result for the successive groynes where this lead to weakening the strength each one of the horse shoe vortices to make more scour.

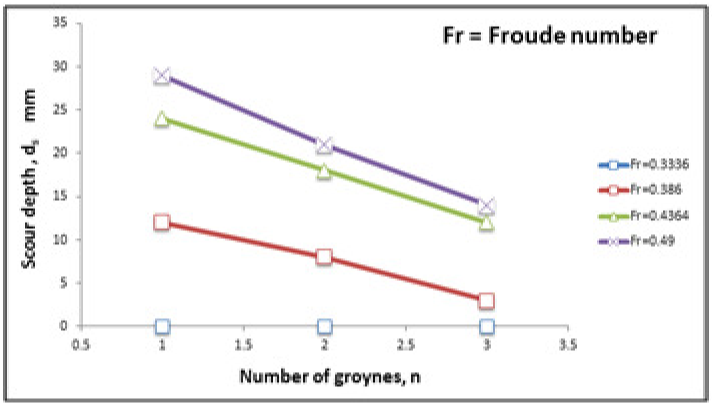

Figure 8 Effect of groyne number on scour depth development

5- Distances between groynes

A set of experiments are conducted using three different distances between the groynes (1L, 1.5L, 2L) to evaluate the relationship between them and the scour depth. Fig. 9 shows the decline in scour depth when the distance between groynes increased at constant values of other influencing parameters (and in the limitation of this study). This situation occurs as a result of scattering the horse shoe vortices system over the increased distance in a way so they will be arranged one after another, and each one of them will scour the sediments and carry it to deposit in the next hole of scour caused by the next vortex. Plate 5 shows decline the scour depth with increasing the distance between groynes.

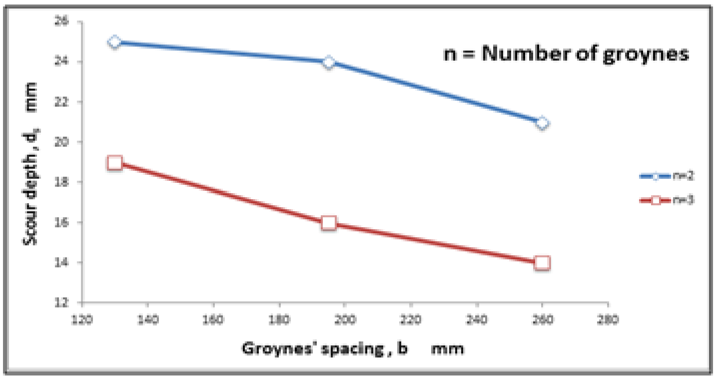

Figure 9 Effect of groynes′ distances on scour depth development

Plate 5 Effect of groynes′ distances on scour depth development

DEVELOPMENT OF NEW FORMULA

To develop equation used to calculate the relative scour depth (ds_{max}/y); then the outcomes of the experimental work were utilized as input data in the computer package (IBM Statistics SPSS 16.0) with a non-linear regression analysis.

$$ds_{max}/y = C_1 + \{C_2*(b/y)\} - \{C_3*(Fr^{C4})\} + \{C_5*(V/V_C{}^{C6})*(n^{C7})\}\ldots \tag{3}$$

C_1= -2.741 C_2= -0.005 C_3= 29.307 C_4= 3.006 C_5= 7.751 C_6= 1.996 C_7= -0.287

A coefficient of determination (R^2) equal to (0.917) has been found for the above formula. When it is rearranged; becomes:

$$ds_{max}/y = -2.741 - \{0.005*(b/y)\} - \{29.307*(Fr^{3.006})\} + \{7.751*(V/V_C{}^{1.996})*(n^{-0.287})\} \tag{4}$$

There is a part of the original experimental data (about 20%) did not use in developing equation (4), these data are substituted in the equation and there results were compared with the experimental results to see the convergence between them.

The value of coefficient of determination (R^2=0.9331) is reflected good agreement for all data as illustrated in Fig. 10.

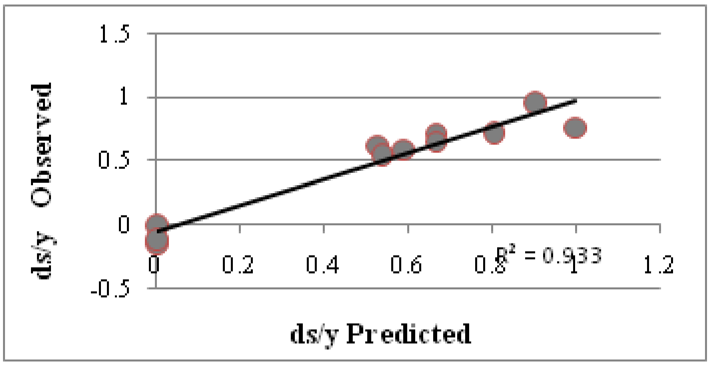

Figure 10 The formula 4 comparison with the experimental data

CONCLUSIONS

The following points are concluded from the present study:

- At the upstream of the groyne nose; the maximum scour depth was observed.
- The scour depth increased with increase flow depth, flow velocity, Froude number (within the limitation of this study).
- The scour depth decreased with increasing the number and the distances between groynes (within the limitation of this study).
- In the head of first groyne; the deepest scour occurs due to objection of this groyne to the flow.
- Based on the obtained experimental results; the developed formula for the maximum scour depth reflects well coefficient of determination and can be used to predict the maximum local scour depth in similar conditions.

THE LIST OF NOTATIONS

B: The width of flume (L).

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).

μ: Dynamic viscosity of water (MTL^{-1}).

n: The number of groynes (-).

ρ: The water mass density (ML^{-3}).

ρ_s: The sediment mass density (ML^{-3}).

S_o: The slope of flume (-).

V: The mean velocity of the flow (LT^{-1}).

Vc: The critical velocity (LT^{-1}).

y: The flow depth (L).

σ_g: The geometric standard deviation of sand bed (-).

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