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## Laboratory evaluation of Scour rate and energy dissipation in Gabion Stepped Weirs with considering the effect of Discharge and tail water depth

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### ABSTRACT

The problem of erosion and scouring the floor is one of the significant issues in the rivers. Prediction of development dimensions of scour and energy dissipation and also methods of their controlling and reduction is the component items that must be considered in design of hydraulic structures. Gabion stepped-Weir is one of the structures that dissipating energy and playing an important role to reduce the amount of scour in downstream. Appropriate design of these structures can prevent intensifying damages. In this article with attention to the mentioned important issue, Gabion Stepped-Weirs is analyzed, evaluated and designed by considering physical characteristics of Weirs and hydraulically characteristics of flow. The effects of these parameters include slope (1: 1, 1: 1.5 and 1: 2), Aggregate size of the stepped-weirs (25 and 50 mm), Discharge (8, 10 and 15 lit/s) and tail water depth (5, 6, 7, 9, 12, 15, 18, 21 cm) is conducted in laboratory to determine amount of scour and energy dissipation. After evaluation and analysis the results observed that the changes in the amount of discharge and slope of stairs contrasted with scour have direct relationship and is inversed in relationship with energy dissipation and also aggregate size and tail water depth is inversed in relationship with scour value, and directly in related with energy dissipation.

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## INTRODUCTION

Due to high performance, stability and economics, gabion structures are widely used for protecting the hydraulic structures. Gabion stepped weirs are usually used in river beds and catchments. These structures are attractive for designers because they can be used for dissipating of energy. The erosion issue of rivers, particularly in floor with high slope and downstream of bridge is caused to damage considerably to protective structures and technical facilities of river. Generally has been presented different methods in order to stabilize the Bed Rivers and its retrofitting against of erosion.

These methods include use of staircase systems nappe flow and skimming flow, variety consumption of structures for energy dissipation, using of resistant materials against of water erosion and using the composition structural such as drop, spillway, Weir, Stilling basin and etc.

Weirs and drops are most important and most common dissipation structures for energy on irrigation and eroding waterway. Stepped drop spillway or stairs is used to reduce the destructive force of water on the slope, especially at the time of occurrence of gigantic floods in the river that created the serious threat for established facilities and downstream and adjacent areas, In the field of energy distribution on stepped-weirs conducted various studies that can be reference to studies of Sorensen in 1985 and Chanson in 2000 and provided estimation for wasted energy on this type of weirs in skimming flow (Chanson, H., 2000 and Sorensen, R.M. 1985). Also Stephenson is used stepped-weirs in the direction of water flow, to eliminate water energy and reduce the erosion power in order to reduce energy of flow and trapping some of suspended sediments in upstream (Stephenson, D. 1979). Peyras *et al.* are researched about energy dissipation in this type of weirs and indicated that gabion stepped-weirs will be able to tolerance discharge up to 3 cubic meters per second in unit wide. Also Reversing of the Slope stairs and pouring a concrete layer on stairs increased energy dissipation (Peyras, L. 1992). Based on Stephenson testing, increasing the number of stairs up to 3 is caused to increase energy dissipation and energy downfall reduced with increasing the number of stairs Because of the increasing the number of stairs will change the flow regime (Stephenson, D. 1993).

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Ebrahimi and *et al.* spillway is showed reducing in downstream view of the slope, by studying about hydraulic properties of flow on the model of gabion-stepped due to increasing the turbulence of flow caused to waste more energy in all cases. (Ebrahimi, N., *et al.* 2005). Halaghi and Bayat by implement experiments, about the effects of upstream and downstream slope of spillway on energy dissipation indicated that gabion-stepped Weirs with upstream vertical slope and downstream slope of 1: 4, have the most amount of energy drop, But in terms of stability structures recommended upstream slope of 1: 1. (Meftah Halaghi, M., *et al.* 2009). Also Helghi and *et al.* have been showed that by increasing the depth of upstream flow in fact, increasing the overpass flow will be increased energy dissipation based on tests conducted, (Meftah Halaghi, M., *et al.* 2006).

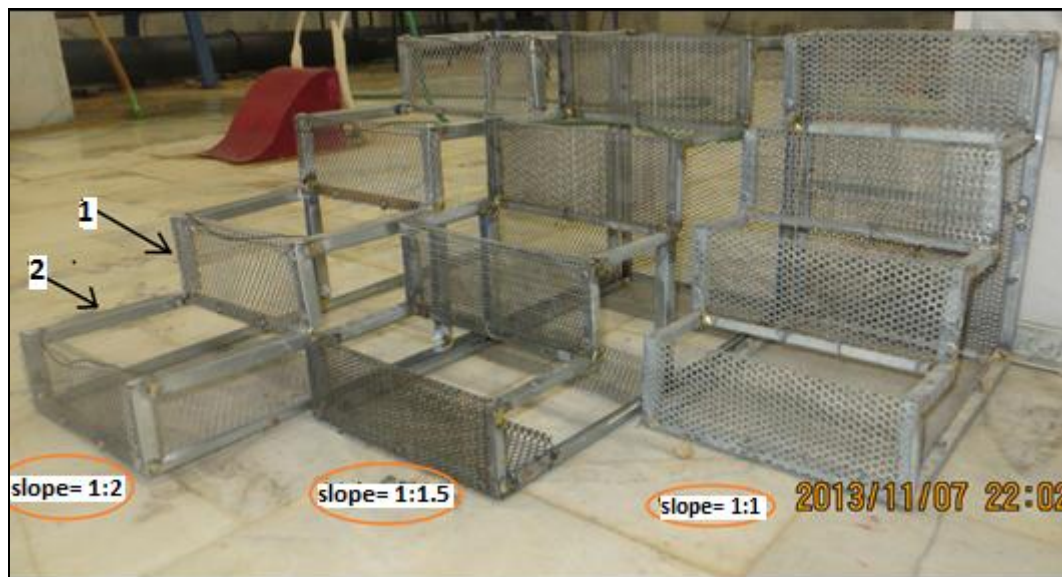
In this study, by using gabion stepped weirs in the form of stepped spillway slope (stone basket) consists of soft galvanized mesh and rounded corner pebble of river on flow upstream, is tried to comprise and determine the rate of energy dissipation and scour on different discharge and tail water depth. In these experiments to demonstrate the effect of different parameters is used 4 different steps and aggregated with different size ( $D_{50} = 2, 5$  and  $5$  cm).

## 2- Preparation of equipment and devices for testing:

For evaluating of considered parameters need some tools and equipment is sometimes required new equipment and replacing some of the equipment. In the following section, described briefly some of them how to prepare. tools and equipment have been replaced by the author are consisted of related stairs to determine the slope of weirs, sand of bed Flume, stone seeds  $D_{50}$ , sealing curtain, water pump, casing of discharge set, trowel and etc.

### 2-1- stairs:

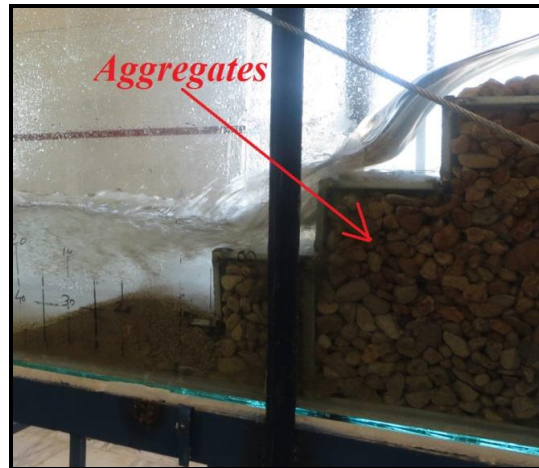
At the workshop instructed stairs that height of each Stair is 10 cm and the size of stairs floor of 10, 15 and 20 cm in 3 different forms with the slope of 1: 1, 1: 1.5 and 1: 2 (following figure).



**Fig. 1:** stairs with different slope

### 2-2- stone seeds (with $D_{50}$ to the size of 25 and 50 mm):

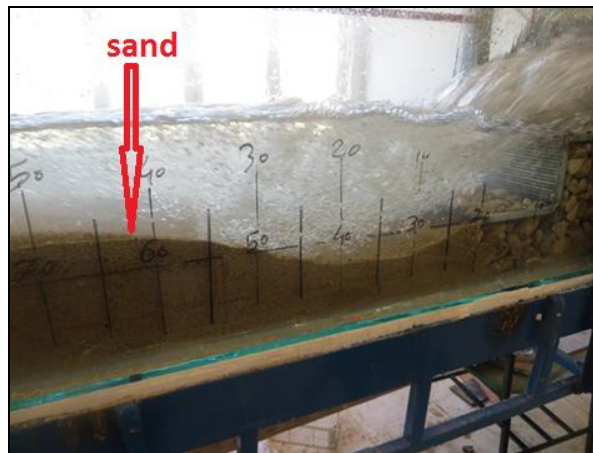
By considering that in this experiment is tried to use rubble. Therefore we picked up stone seeds from river bed located in Millas village, Lordegan city, sieved (sieve score: 1" and 2"); and segregated them based on their size ( $D_{50} = 50$  and  $25$ ) and then transferred them to lab, every stone seeds are completely washed and then used.



**Fig. 2:** location of stone seeds

**2-3- sand:**

Sand with size of 0.08 mm has been used to assess and review for scouring. Sands are distributed and smoothed in the floor of Flume laboratory with thickness of 10 cm before doing any testing.



**Fig. 3:** expanded sand with 10 cm thickness on floor of Flume

**2-4- Flume:**

A closed compartment with width of 30 cm, length of 8 meters and height of 40 cm located on the metal framework and tightened and sealed by the cable, glass and glue respectively. Water flows from the Flume and the path of the water curtain overflows is about height of 80 cm.



**Fig. 4:** the part of laboratory Flume

#### Description of test process:

In these tests, the influence physical and hydraulic parameters on energy dissipation and scouring of flow is analyzed and evaluated. Physical variables or parameters are included stairs slope and grain size ( $D_{50}$ ), which in these tests is used three kinds of different slopes 1 to 1, 1 to 1.5 and 1 to 2 and various  $D_{50}$  in size of 25 mm and 50 mm in different conditions of test. Hydraulic parameters are included tail water depth and amount of water discharge input which in these tests is used different discharging of 8, 10 and 15 liters per second and different tail water depth 5, 9, 15 and 18 cm. however, each parameter individually in different situation have been tested and evaluated.

To the order in which the above-mentioned 4-variable, slope of stairs, size grains ( $D_{50}$ ), Discharging and tail water depth is considered that each variable also is several different situations. For example for slope of 1:1, different Discharge was tested individually and in each discharge is tested different  $D_{50}$  and different tail water depth. Generally it can be mentioned that in this kind of testing with three different forms has been implemented based on the stairs slope (three forms) and in any form of stairs is used two different  $D_{50}$  and after that in each test is used three types of Discharges and has been considered in each Discharge three different tail water depth and finally is implemented 54 different tests with various variables.

#### 4- Effect of discharge on the amount of scouring:

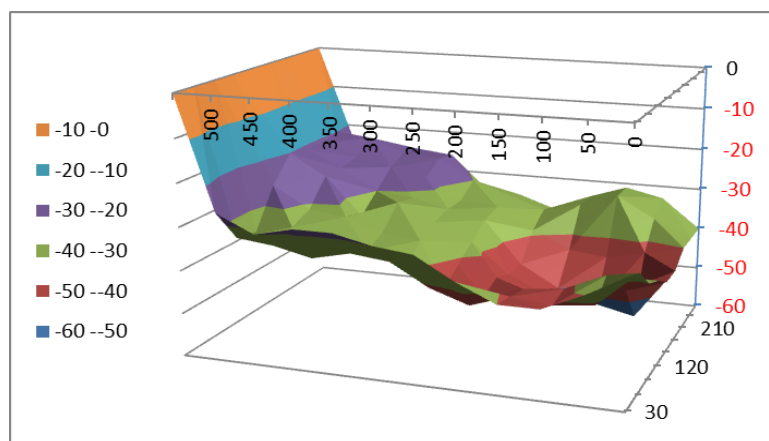
In this section, for evaluating of Discharges value and how to influence amount of Discharge in order to determine the scour depth and energy dissipation value has been used of 3 different tests (8, 10 and 15 lit/s). With attention to huge number of conducted tests, in order to prevent bringing high volume of content and figures, have been tried the results are shown in table and related figures of some results. Discharge of 8, 10 and 15 lit/s on three types of different steps slope have been tested and with different tail water depth and various  $D_{50}$ , which is presented in the following section. It should be noted here due to the different depth of tail water for each test is intended lowest depth of any tests and may be in a different discharge this tail water depth, are changed to comparison of Discharging effects.

##### 4-1- Effect of discharge with aggregate size of 25( $D_{50}$ ) mm, slope of 1: 1 and lowest tail water depth:

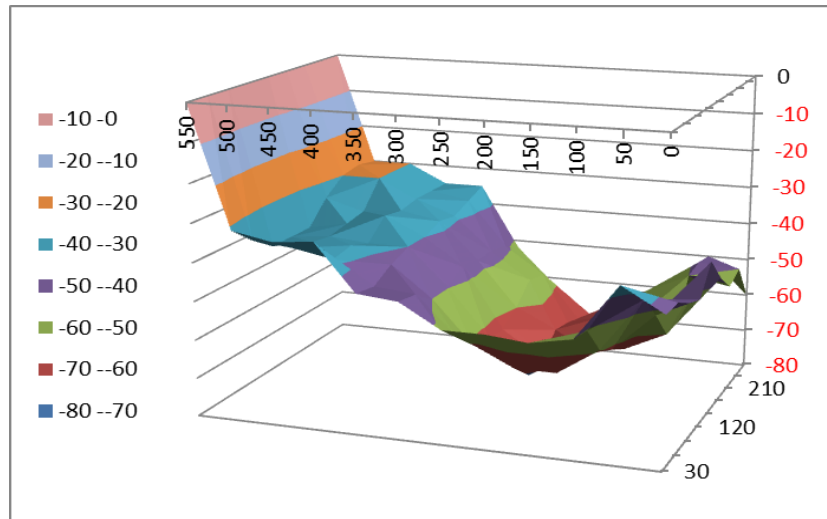
In the obtained results by increasing the amount of discharge in a fixed slope and specified  $D_{50}$  with lowest tail water depth is increased the minimum of scour depth. It means clay sediments will be moved at more depth of created hole. This condition is visible in following figures. Based on three-dimensional graph, value of depth scour hole will be boosted by increasing of discharge.

**Table 1:** effects of discharge on amount of scour in the slope of 1: 1

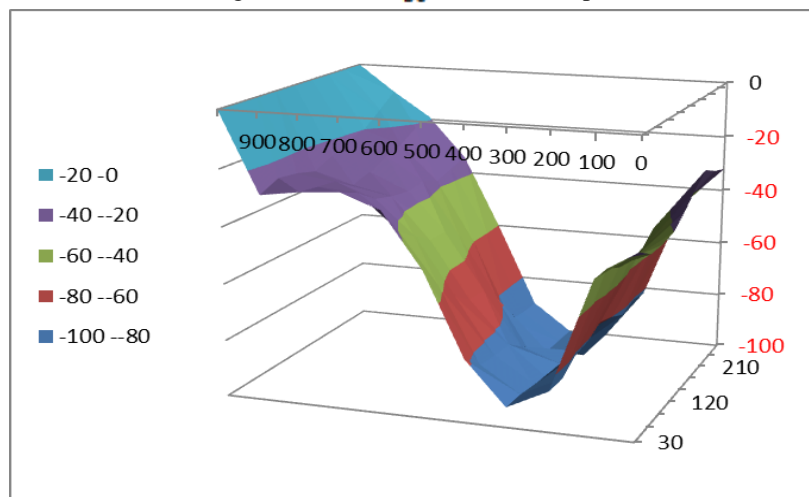
Scour depth (y) in mm			Tail water depth(cm)	Aggregate size( $D_{50}$ )	Stairs slope	Disgorge(lit/s)
maximum	minimum	average				
-20	-55	-37.5	5	25	1:1	8
-29	-71	-50	6	25	1:1	10
-10	-100	-55	9	25	1:1	15



**Fig. 5:** created scour hole with Discharge of 8 lit/s,  $D_{50}$  of 25 mm, slope of 1: 1 and 5 cm tail water depth



**Fig. 6:** created scour hole with Discharge of 10 lit/s,  $D_{50}$  of 25 mm, slope of 1: 1 and 6 cm tail water depth



**Fig. 7:** created scour hole with Discharge of 15 lit/s,  $D_{50}$  of 25 mm, slope of 1: 1 and 9 cm tail water depth

4-2- Effect of discharge with aggregate size of 25 mm ( $D_{50}$ ), slope of 1: 2 and lowest tail water depth:

In the following achieved results by increasing the amount of discharge in a fixed slope and the specified  $D_{50}$  are enhanced by the lowest tail water depth, the minimum of scour depth and based on three-dimensional graph with reducing discharge, the depth of scour hole will be increased.

**Table 2:** effects of discharge on scour depth value in the slope of 1: 2 1:1.5

Scour depth (y) in mm			Tail water depth(cm)	Aggregate size( $D_{50}$ )	Stairs slope	Disgorge(lit/s)
maximum	minimum	average				
-9	-41	-25	5	25	01:01.5	8
-4	-47	-25.5	9	25	01:01.5	10
15	-99	-42	15	25	01:01.5	15
-10	-34	-22	5	25	01:02	8
-14	-76	-45	6	25	01:02	10
20	-86	-33	12	25	01:02	15

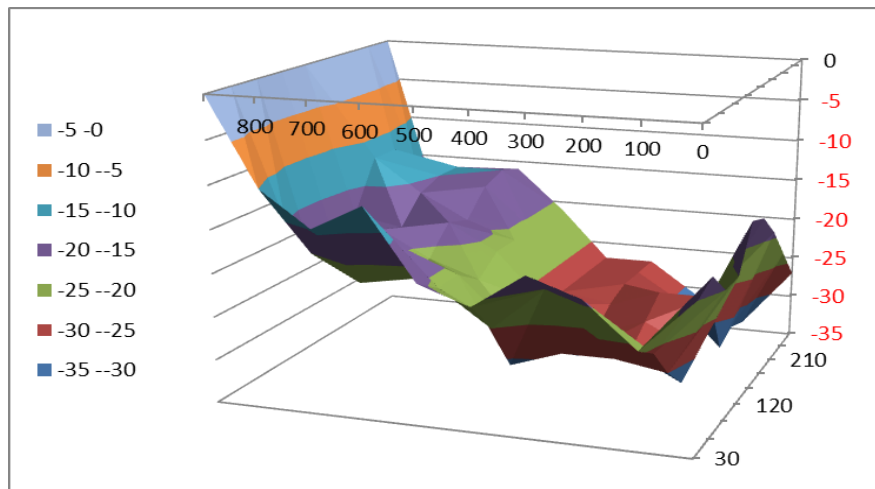


Fig. 8: created scour hole with Discharge 8 on  $D_{50}$  about 25 mm with slope of 1: 2 and tail water depth is 6

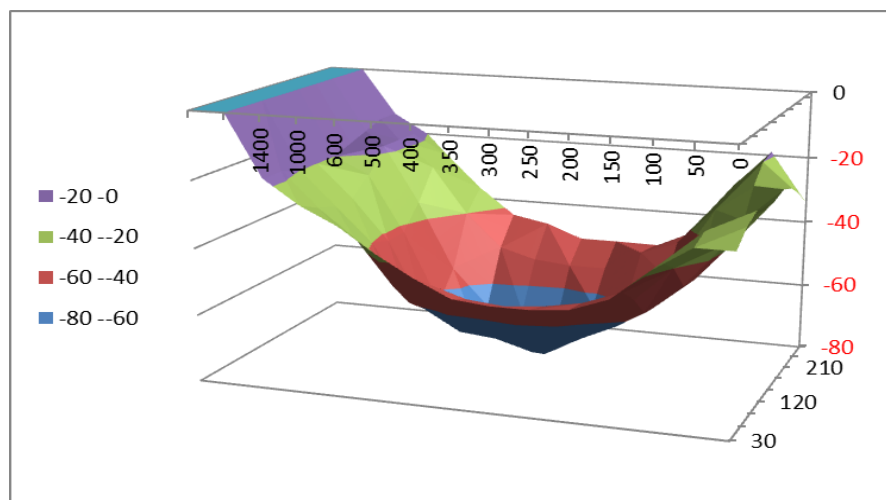


Fig. 9: created scour hole with Discharge 10 on  $D_{50}$  about 25 mm with slope of 1: 2 and tail water depth is 6

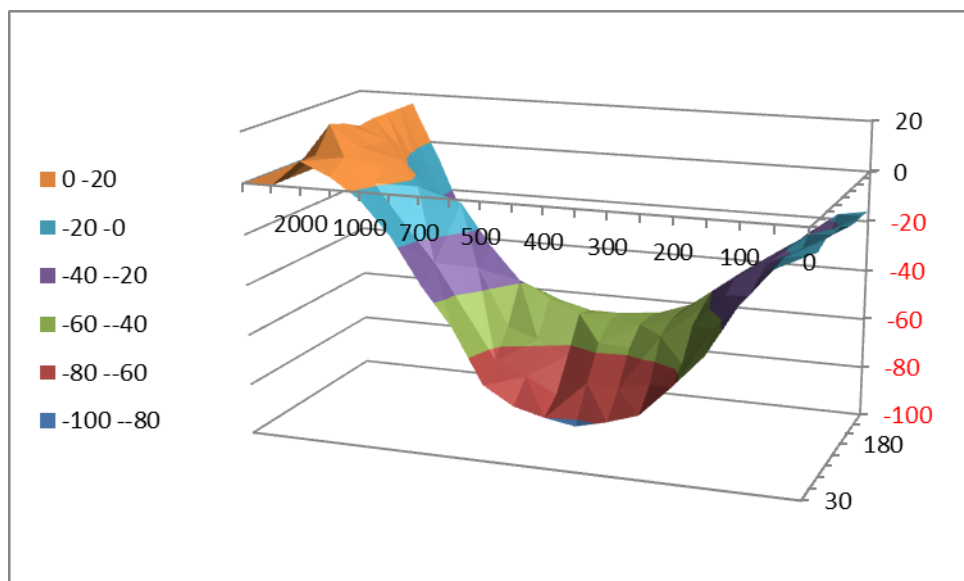
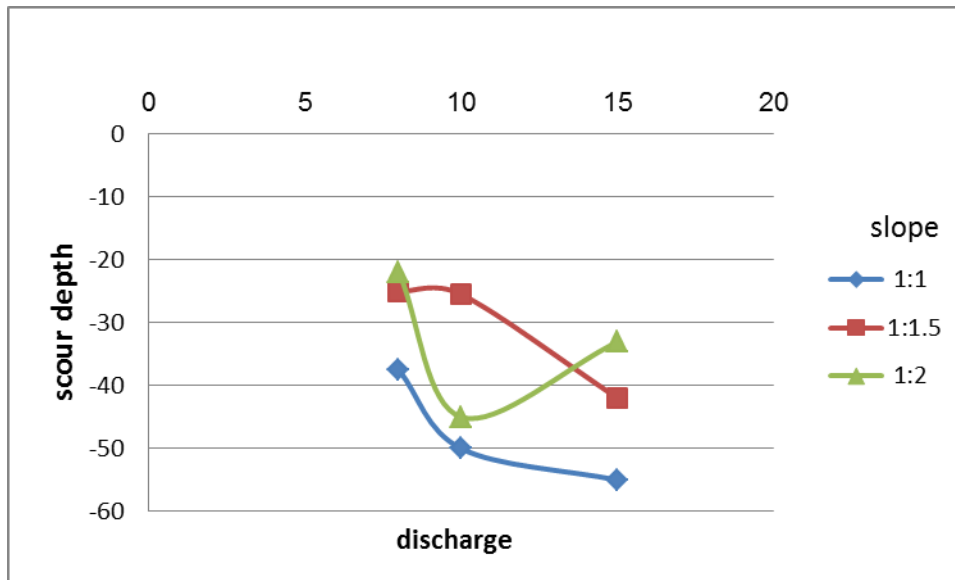


Fig. 10: created scour hole with Discharge 15 on  $D_{50}$  about 25 mm with slope of 1: 2 and tail water depth is 12

#### 4-2-1- comparison of scour depth at different slope due to Discharge changes:

In the following graph is shown the influence of discharge on scour depth related to average for 3 discharges and 3 different slopes are boosted by using of 25 mm size  $D_{50}$  as summary of above achieved results. Observed that on different slope boosted with an increasing on the rate of discharge from 8 to 15 lit/s the scour depth. Another result that is visible is the slope of 1: 1 has the most scour depth and with reduction of slope the scour depth is reduced. The amount of variation that can be seen in slope of 1: 1.5 caused by unequal depth of tail water in comparisons tests towards each other.



**Fig. 11:** effect of Discharge in the amount of scour (on different slope and same tail water depth and same size of  $D_{50}$ )

#### Effect discharge on energy dissipation with the $D_{50}$ size of 25 mm:

Gabion stepped weirs due to inflow and over flow of water is caused dissipation of energy. The energy of Inflow when passed through the Porous media of coarse aggregation is eliminated due to the effect of aggregation friction, and over flow are losing their energy due to pass on stairs. The affecting parameters on energy dissipation can be expressed as follows:

Discharge, number of stairs, stair height and length, height of spillway, acceleration of gravity, height of the page, porosity and water depths of upstream and downstream. Therefore, the affecting factors on energy dissipation are considered as follows:

$$\Delta E = F(q, n, l, b, H, g, h, y_1, y_2) \quad (1)$$

By using dimensional analysis (method of Buckingham  $\pi$ ) and becoming simple the Dimensionless parameters, and also with attention to conducted tests that the height of Weir, upstream slope and porosity in order to effect of page height, have been considered fix, the dissipation of energy can be write in the form of a function form Dimensionless factors as following:

$$\frac{\Delta E}{E_1} = f\left(n, Fr, \frac{l}{b}, \frac{y_1}{y_2}, \frac{h}{H}, \frac{y_c}{y_1}\right) \quad (2)$$

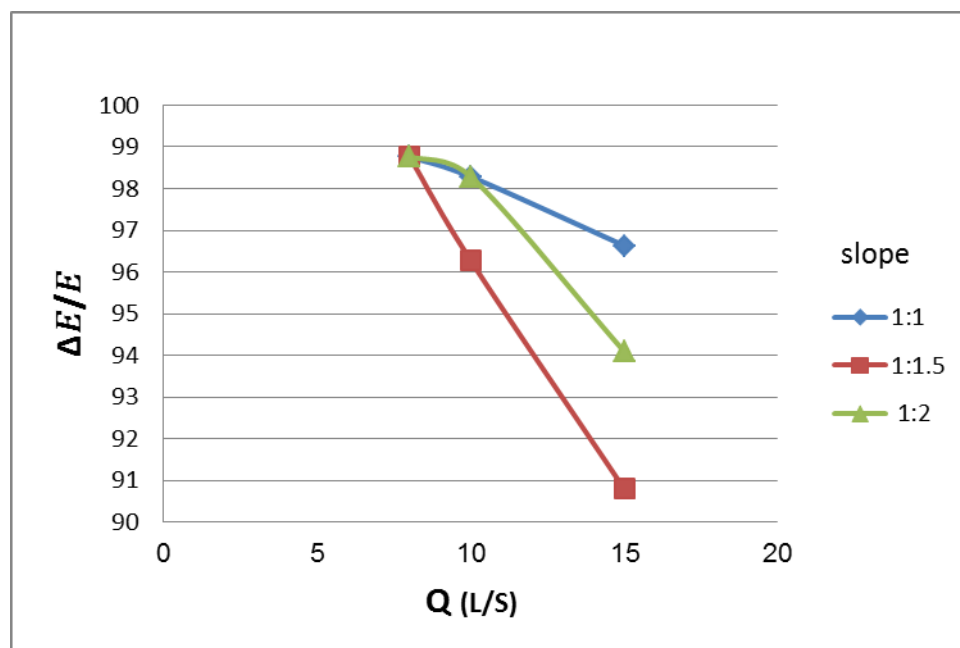
Where  $y_c = \sqrt[3]{\frac{q^2}{g}}$  (critical depth),  $E_1 = y_1 + \frac{q^2}{2gy_1^2}$  (Weir water energy in upstream),  $n$  is porosity of aggregation  $y_1$  is upstream water depth,  $y_2$  is tail water depth,  $\frac{l}{b}$  is downstream slope of weir,  $Fr = \frac{q}{\sqrt{gy_1^3}}$

(Froude number of flow),  $E_2 = y_2 + \frac{q^2}{2gy_2^2}$  (energy of water in tail water weir). And finally, the percentage of energy dissipation is calculated from  $\frac{E_1 - E_2}{E_1} \times 100$ .

By using above achieved equation and results presented in the below table and graphs can be said that with the increase rate of Discharge from 8 to 15 lit/s, the rate of relative energy

**Table 3:** effect of discharge on energy dissipation

energy dissipation			Tail water depth(cm)	Upstream water depth	Aggregate size( $D_{50}$ )	Stairs slope	Disgorge(lit/s)
$\Delta E/E$	E2	E1					
98.7661	26.4512 5	2143.70 7	5	46.3	25	01:01	8
98.2844 7	37.5747	2190.26 6	6	46.8	25	01:01	10
96.6300 2	82.5747	2450.30 2	9	49.5	25	01:01	15
98.7661	26.4512 5	2143.70 7	5	46.3	25	01:01.5	8
96.2698 7	81.6998 7	2190.26 6	9	46.8	25	01:01.5	10
90.7943 2	225.566 9	2450.30 2	15	49.5	25	01:01.5	15
98.7661	26.4512 5	2143.70 7	5	46.3	25	01:02	8
98.2844 7	37.5747	2190.26 6	6	46.8	25	01:02	10
94.0870 2	144.885 8	2450.30 2	12	49.5	25	01:02	15



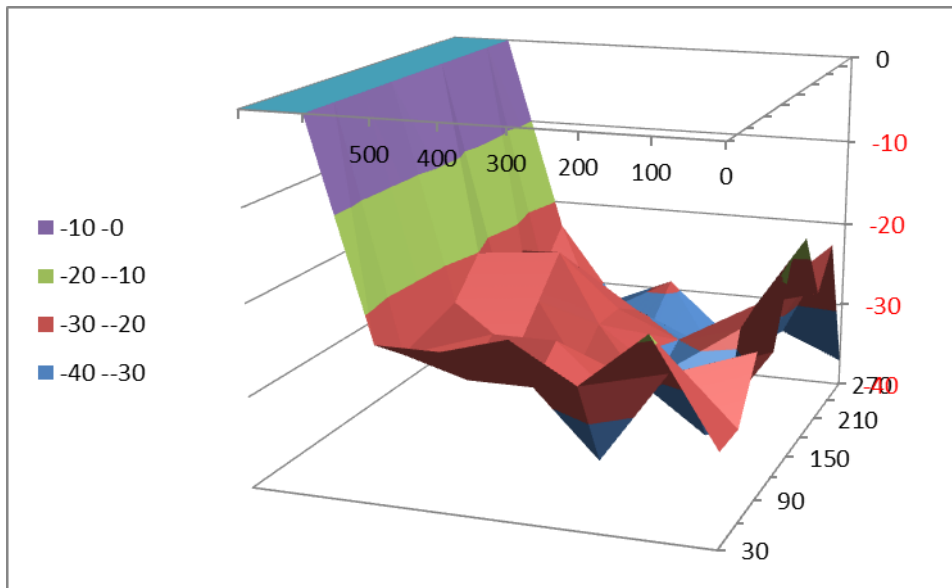
**Fig. 12:** relative changes in energy dissipation versus changes of Discharge with a size of 25 mm ( $D_{50}$ ) in different slope

#### 4-4- effect of discharge with aggregate size of 50 mm ( $D_{50}$ ), different slope and lowest tail water depth:

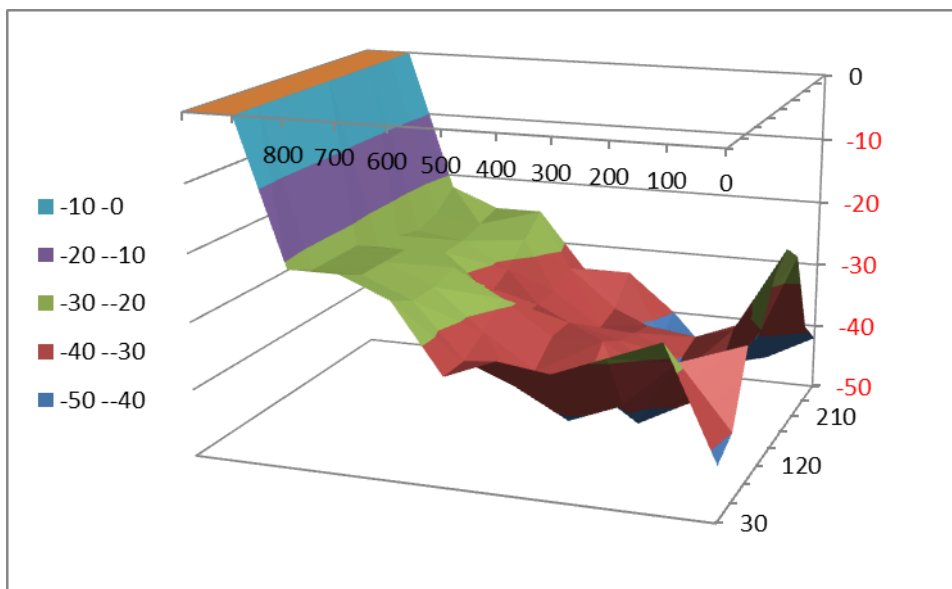
Following results and figures are shown due to increase in the amount of discharge have been removed more sediments in more depth in different slopes,  $D_{50}$  and the tail water depth. Based on the minimum table the minimum depth of scour has increased with an increase in Discharge.

**Table 4:** effects of discharge on amount of scour in different slope

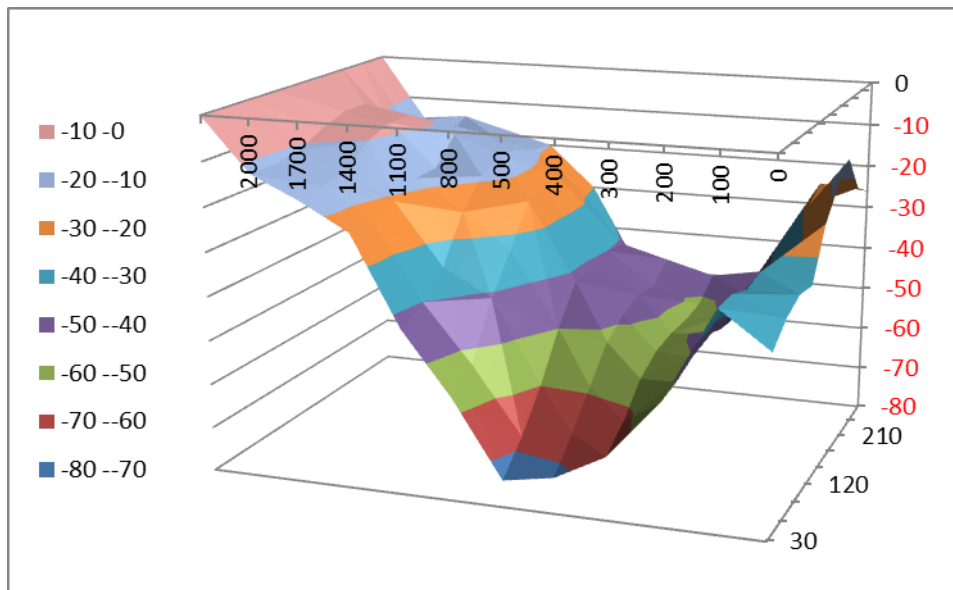
Scour depth (y) in mm			Tail water depth(cm)	Aggregate size( $D_{50}$ )	Stairs slope	Disgorge(lit/s)
maximum	minimum	average				
-21	-60	-40.5	5	50	01:01	8
-21	-67	-44	6	50	01:01	10
-33	-75	-54	9	50	01:01	15
-17	-38	-27.5	5	50	01:01.5	8
-16	-54	-35	6	50	01:01.5	10
-26	-67	-46.5	9	50	01:01.5	15
-7	-34	-20.5	5	50	01:02	8
-21	-48	-34.5	6	50	01:02	10
-6	-74	-40	9	50	01:02	15



**Fig. 13:** created scour hole with Discharge of 8 lit/s,  $D_{50}$  of 50 mm, slope of 1: 2 and 5 cm tail water depth



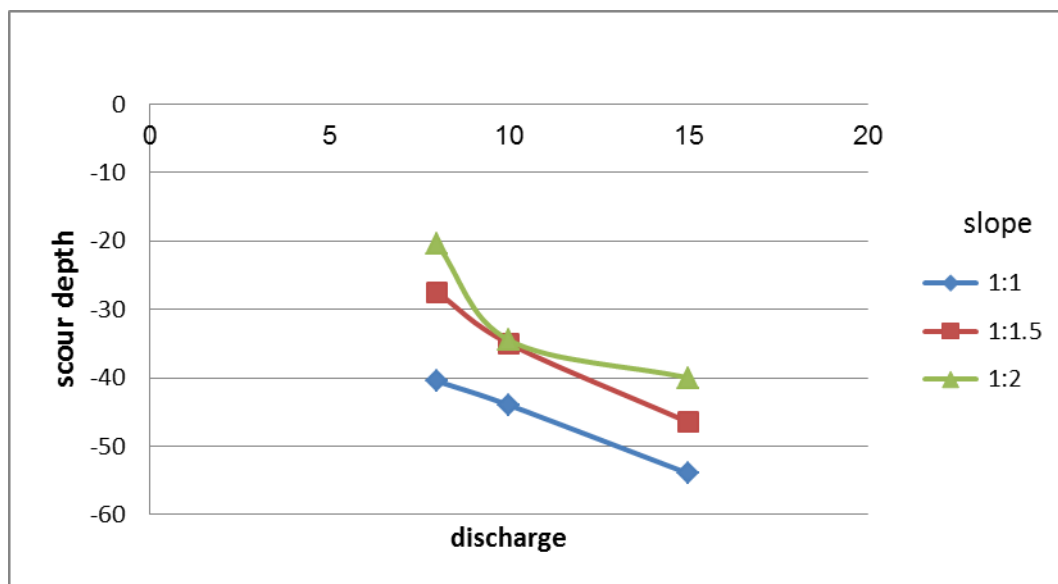
**Fig. 14:** created scour hole with Discharge of 10 lit/s,  $D_{50}$  of 50 mm, slope of 1: 2 and 6 cm tail water depth



**Fig. 15:** created scour hole with Discharge of 15 lit/s,  $D_{50}$  of 50 mm, slope of 1: 2 and 9 cm tail water depth

4-1-1- the comparison of the scour depth at different slope due to Discharge changes:

In the following graph as summary of above achieved results, Observed that on different slope with an increase in rate of discharge from 8 to 15 lit/s is increased the scour depth. Another result that is visible is the slope of 1: 1 has the most scour depth and with reduction of slope the scour depth is reduced.



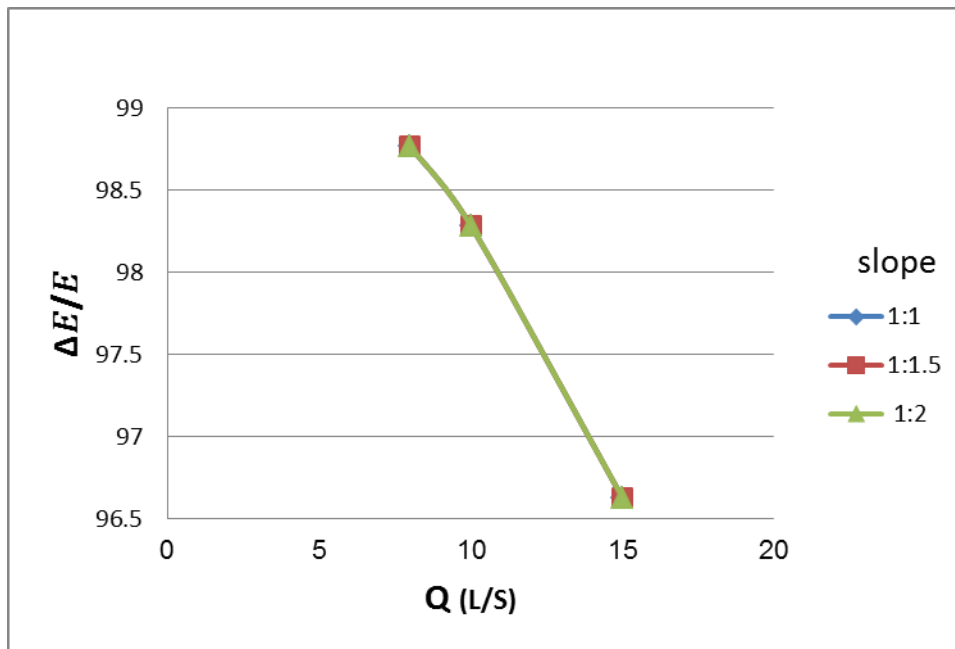
**Fig. 16:** effect of Discharge in the amount of scour (on different slope and same tail water depth and same size of  $D_{50}$ )

4-5- effect of discharge on energy dissipation with the  $D_{50}$  size of 25 mm:

In the below table and graphs is cleared that with the increasing rate of Discharge from 8 to 15 lit/s, the rate of relative energy dissipation is reduced.

**Table 5:** effect of discharge on energy dissipation

energy dissipation			Tail water depth(cm)	Upstream water depth	Aggregate size( $D_{50}$ )	Stairs slope	Disgorge(lit/s)
$\Delta E/E$	E2	E1					
98.766	26.451	2143.7	5	46.3	50	01:01	8
98.284	37.575	2190.3	6	46.8	50	01:01	10
96.63	82.575	2450.3	9	49.5	50	01:01	15
98.766	26.451	2143.7	5	46.3	50	01:01.5	8
98.284	37.575	2190.3	6	46.8	50	01:01.5	10
96.63	82.575	2450.3	9	49.5	50	01:01.5	15
98.766	26.451	2143.7	5	46.3	50	01:02	8
98.284	37.575	2190.3	6	46.8	50	01:02	10
96.63	82.575	2450.3	9	49.5	50	01:02	15

**Fig. 17:** relative changes in energy dissipation versus changes of Discharge with a size of 25 mm ( $D_{50}$ ) in different slope

##### 5- Effect of tail water depth on scour in different Discharges, slopes and $D_{50}$ :

In this section is investigated and analyzed the achieved results related to the effect of tail water depth in different Discharge (with constant slope and  $D_{50}$ ), in different slope (with constant Discharge and  $D_{50}$ ) and various  $D_{50}$  (with constant slope and Discharge).

##### 5-1- Effect of tail water depth on scour in different Discharges, in slopes of 1:1 and aggregate size of 25 mm:

In this section, the effect of tail water depth is tested in different Discharge 8, 10 and 15 lit/s in slope of 1: 1 and  $D_{50}$  of 25 mm. obtained results by considering three different tail water depth for each discharge accordance with the following table observed that whatever the amount of tail water depth is reduced the maximum and minimum of scour depth in scour hole are increased.

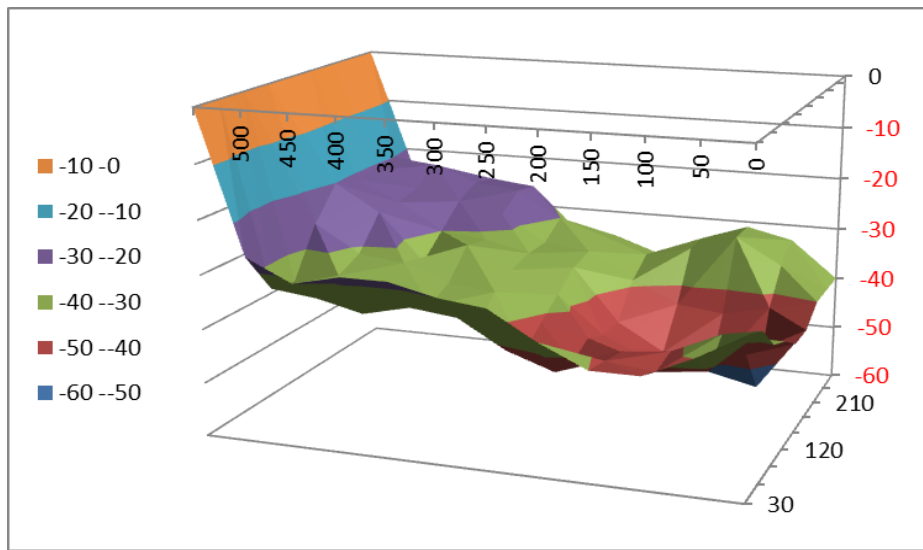
3-dimensional shapes and holes caused by the impact to the depth of the tail water depth in Discharge 8 liters per second with a 1: 1 gradient and the  $D_{50}$  are shown to 25.

Following three-dimensional shape of scour hole that caused by the effects of tail water depth in discharge of 8 lit/s with slope of 1:1 and aggregate size of 25 mm are indicated.

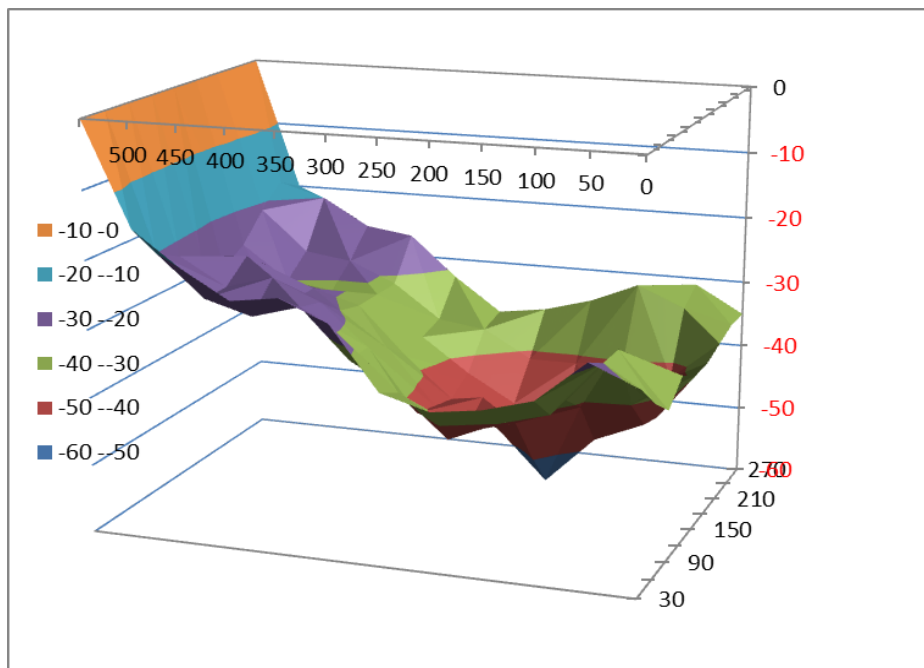
**Table 6:** effect of tail water on scour depth

Scour depth (y) in mm			Aggregate size(D <sub>50</sub> )	Stairs slope	Disgorge(lit/s)	Tail water depth(cm)
maximum	minimum	average				
-20	-55	-37.5	25	1:1	8	5
-15	-55	-35	25	1:1	8	7
-5	-48	-26.5	25	1:1	8	9
-29	-71	-50	25	1:1	10	6
-1	-66	-33.5	25	1:1	10	9
0	-50	-25	25	1:1	10	12
-10	-100	-55	25	1:1	15	9
-7	-85	-46	25	1:1	15	12
25	-80	-27.5	25	1:1	15	15

The following figures is shown the amount and shape of scouring hole for Discharge 8 lit/s with different tail water depth (slope of 1: 1 and  $D_{50}$ : 25 mm) that the rate of scouring is more in fewer depth of tail water.



**Fig. 18:** created scour hole in 5 cm depth of tail water



**Fig. 19:** created scour hole in 7 cm depth of tail water

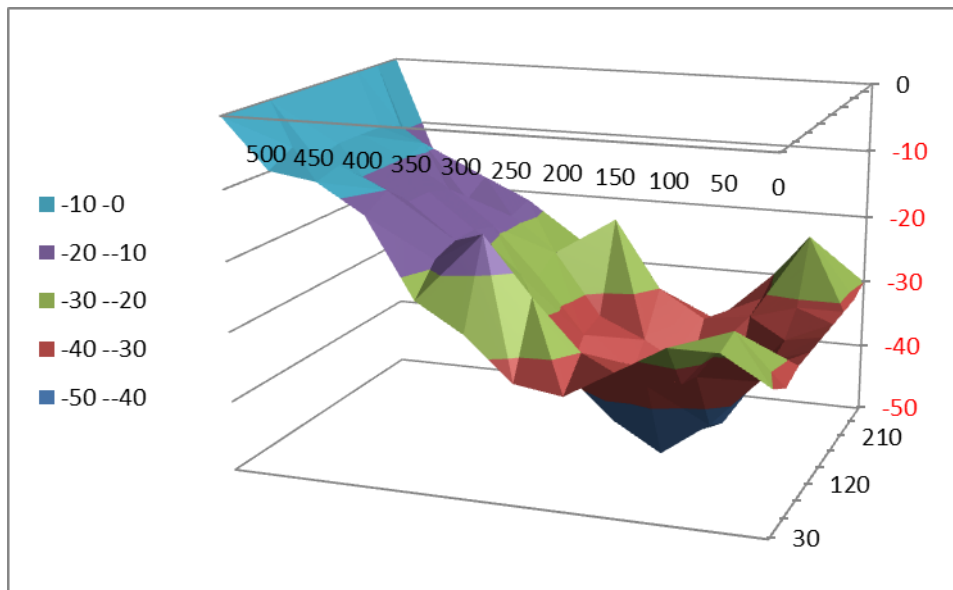


Fig. 20: created scour hole in 9 cm depth of tail water

5-1-1- comparison of scour depth at different slope due to changing depth of tail water:

In the following chart the effects of tail water depth on scour depth for every independent discharge is shown and the results suggest that by increasing the tail water depth, the amount of scour depth is reduced and also in the bigger discharge this effects and change is become more.

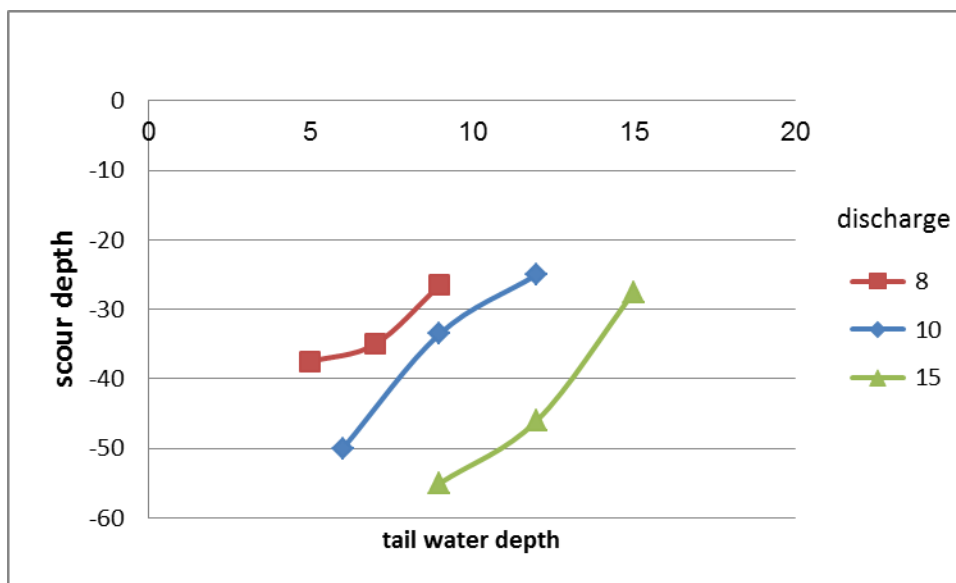


Fig. 21: the effects of tail water depth on scour depth in slope of 1:1 and  $D_{50}$  of 25 mm

5-2- effect of tail water depth in different Discharge in slope of 1: 2 and size  $D_{50}$  of 25 mm:

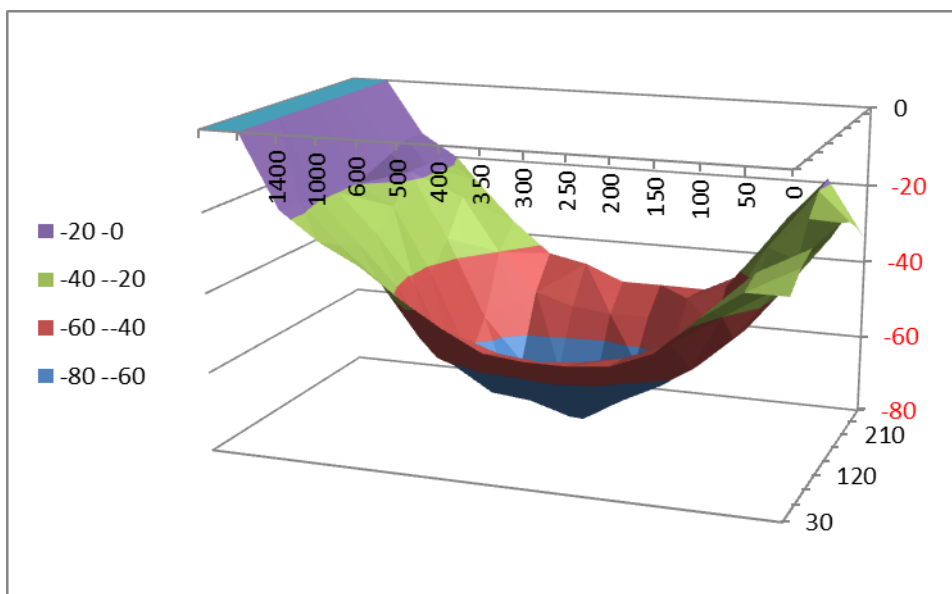
Obtained results by considering three different tail water depths for each discharge according to the following table observed that whatever the amount of tail water depth is reduced the maximum and minimum of scour depth in hole of scour are increased.

Following three-dimensional shape of scour hole that caused by the effects of tail water depth in discharge of 10 lit/s with slope of 1:2 and aggregate size of 25 mm are indicated.

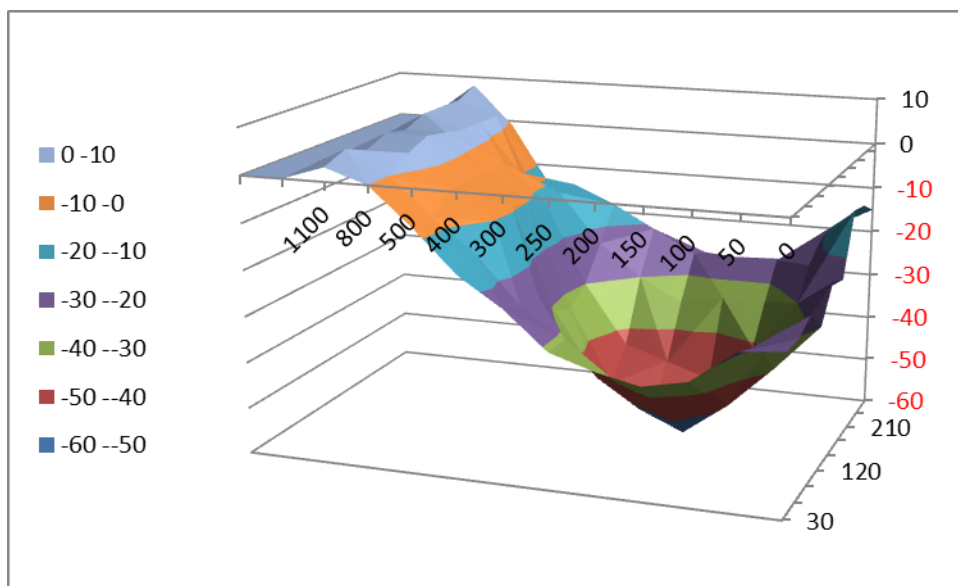
**Table 7:** effect of tail water on scour depth

Scour depth (y) in mm			Aggregate size( $D_{50}$ )	Stairs slope	Disgorge(lit/s)	Tail water depth(cm)
maximum	minimum	average				
-10	-34	-22	25	1:2	8	5
-10	-25	-17.5	25	1:2	8	7
-5	-30	-17.5	25	1:2	8	9
-14	-76	-45	25	1:2	10	9
8	-56	-24	25	1:2	10	12
1	-38	-18.5	25	1:2	10	15
20	-86	-33	25	1:2	15	15
9	-58	-24.5	25	1:2	15	18
33	-29	2	25	1:2	15	21

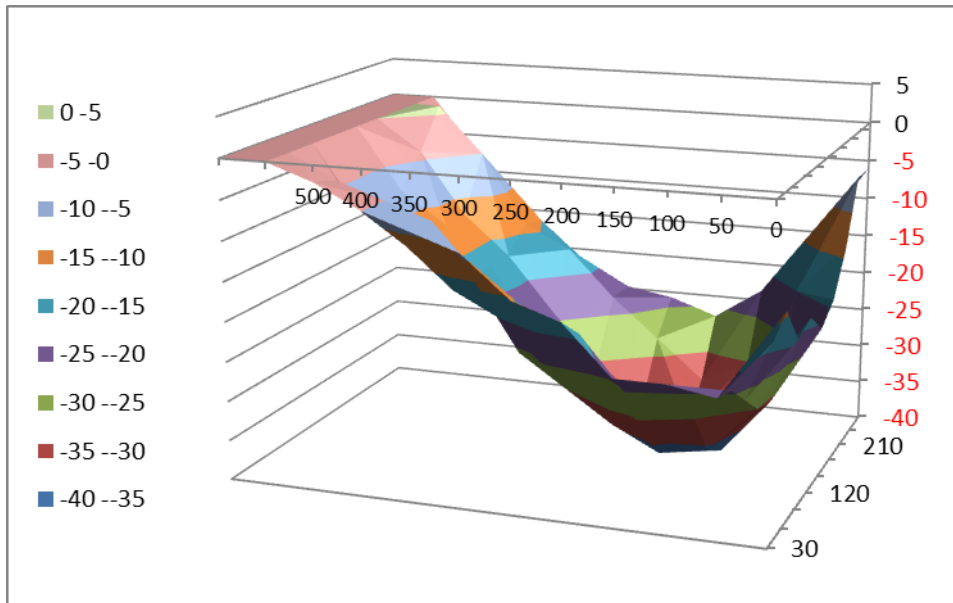
The following figures is shown the amount and shape of scouring hole for Discharge 10 lit/s with different tail water depth (slope of 1: 2 and  $D_{50}$ : 25 mm) that the rate of scouring is more in fewer depth of tail water.



**Fig. 22:** created scour hole in 6 cm depth of tail water



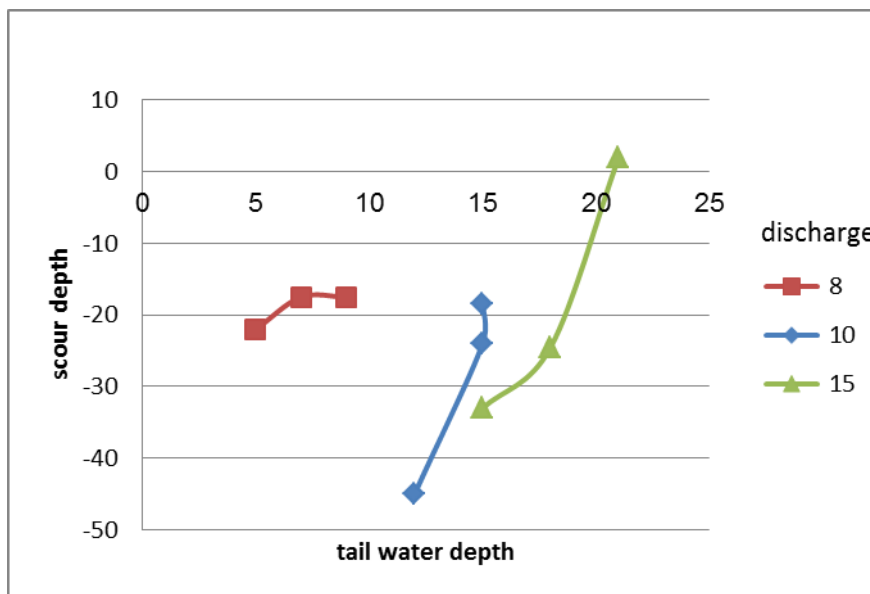
**Fig. 23:** created scour hole in 9 cm depth of tail water



**Fig. 24:** created scour hole in 12 cm depth of tail water

5-2-2- comparison of scour depth at different slope due to changing depth of tail water:

In the following chart the effects of tail water depth on scour depth for every independent discharge is shown and the results suggest that by increasing the tail water depth, the amount of scour depth is reduced and also in the bigger discharge this effects and change is become more.



**Fig. 25:** the effects of tail water depth on scour depth in slope of 1:2 and  $D_{50}$  of 25 mm

5-2-2- comparison of energy dissipation versus scour depth at different tail water depth with  $D_{50}$  of 25 mm

Observed that by increasing tail water depth or in more accurate way, by increasing the ratio of  $y_2/y_1$ , is reduced the relative percentage of energy dissipation. This reduction impact in higher Discharge is appearing more.

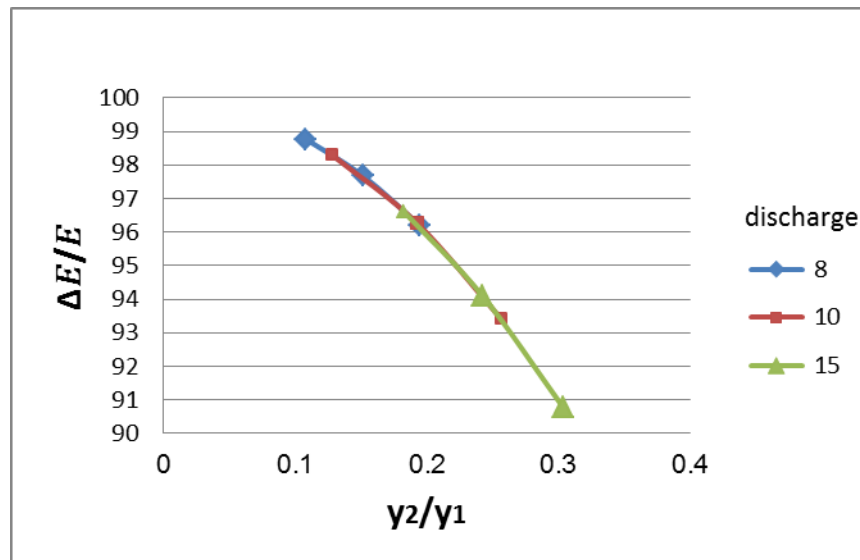


Fig. 26: dissipation of energy versus  $y_2/y_1$

#### Conclusion:

In this Laboratory research the scour value and energy dissipation are considered and analyzed under changes of four effective parameter such as discharge of flow, tail water depth of gabion stepped weir, stairs slope and aggregate size used for gabion stairs ( $D_{50}$ ). Those summarizes of obtained results of the tests can be express in the following sentences:

- Increase the amount of scour and create a deeper scour hole have a direct relationship with an increase of Discharge.
- Increase the amount of scour and create a deeper scour hole have an inverse relationship with increasing tail water depth. So reducing in tail water depth is follow by scour increasing, and tail water increasing is one of the important factors for inhibition of scour.
- As with increasing in tail water depth, is reduced the amount of scour depth and in larger amount of discharge the effect of tail water depth is become more.
- Increase the amount of energy dissipation has an inverse relationship with increases of discharge. Means in fewer discharge has been seen more energy dissipation.
- Increase the amount of energy dissipation has a direct relationship with increases tail water depth. And observed that increasing the tail water depth, is followed by increase the amount of energy dissipation and tail water increasing is one of the important factors for dissipation of energy.

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